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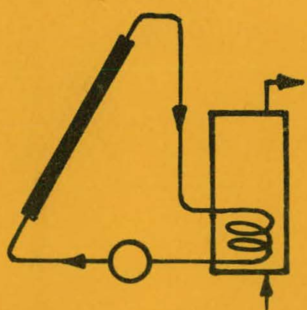
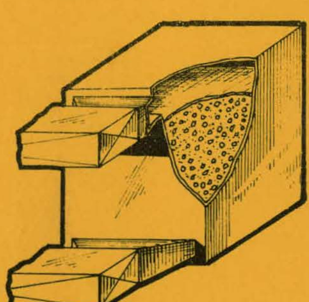
DESIGN AND INSTALLATION MANUAL FOR THERMAL ENERGY STORAGE



Solar Energy Group



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DESIGN AND INSTALLATION MANUAL FOR THERMAL ENERGY STORAGE

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February 1979

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Kenneth J. Nield, Contributing Editor
Raymond R. Rohde, Contributing Editor
Ronald M. Wolosewicz, Contributing Editor

DESIGN AND INSTALLATION MANUAL
FOR THERMAL ENERGY STORAGE

ABSTRACT

The purpose for this manual is to provide information on the design and installation of thermal energy storage in solar heating systems. It is intended for contractors, installers, solar system designers, engineers, architects, and manufacturers who intend to enter the solar energy business. The reader should have general knowledge of how solar heating systems operate and knowledge of construction methods and building codes. Knowledge of solar analysis methods such as f-chart, SOLCOST, DOE-1, or TRNSYS would be helpful.

The information contained in the manual includes sizing storage, choosing a location for the storage device, and insulation requirements. Both air-based and liquid-based systems are covered with topics on designing rock beds, tank types, pump and fan selection, installation, costs, and operation and maintenance. Topics relevant to heating domestic water include safety, single- and dual-tank systems, domestic water heating with air- and liquid-based space heating systems, and stand-alone domestic hot water systems. Several appendices present common problems with storage systems and their solutions, heat transfer fluid properties, heat exchanger sizing, and sample specifications for heat exchangers, wooden rock bins, steel tanks, concrete tanks, and fiberglass-reinforced plastic tanks.

INTRODUCTION

PURPOSE

The purpose of this manual is to provide the practical information you will need to select the type of thermal energy storage system that best fits your needs and to design and install the system. We hope this manual will help you ensure that your thermal energy storage system operates as intended throughout its lifetime and will enable you to avoid the pitfalls that have plagued some earlier systems.

Although do-it-yourselfers will find this manual useful, it is written primarily for professional design and installation personnel in the solar energy industry. These include contractors, installers, solar system designers, engineers, architects, and manufacturers.

We have assumed that the reader has a general knowledge of how solar systems work, as well as knowledge of construction techniques and local building codes. If you lack this background, the books about solar systems listed in the bibliography near the end of this manual should be helpful to you.

The installation methods and sample specifications presented here will be especially useful to contractors and installers of solar systems. Designers, engineers, and architects are expected to have more detailed knowledge of solar system design methods such as f-Chart, SOLCOST, DOE-1, and TRNSYS. Some of the appendices require a relatively high level of technical expertise and are aimed primarily at these readers. The appendices on heat transfer fluids (B) and heat exchangers (D and E) fall into this category. If you need the information in these appendices, but cannot understand it, consult an engineer or an architect.

SCOPE AND ORGANIZATION

In this manual we have tried to provide a comprehensive treatment of the types of thermal energy storage systems in common use today, namely systems built around rock beds or tanks of water. The main text contains general information about storage systems, while the appendices contain details on specific subjects. A glossary and a bibliography are included.

Chapter 1 discusses general characteristics of thermal energy storage systems, including characteristics of storage media; size, location, and insulation of storage devices;

and heat exchangers. Read Chapter 1 thoroughly before continuing, because the information it contains provides a background for the rest of the manual.

Rock beds for thermal energy storage are discussed in Chapter 2. Special characteristics of rock beds and rock bed performance and construction are a few of the topics covered, along with a design example. Chapter 3 discusses liquid-based storage systems. Some topics covered in this chapter are tank types and costs, pumps and other system components, and tank installation. Domestic hot water thermal energy storage systems, either stand-alone or as part of space heating systems, are discussed in Chapter 4, along with methods of safeguarding the drinkable water in the systems.

Although modern engineering practice specifies the use of the metric (SI) systems, the construction industry has not yet adopted these units. Therefore, to enhance the usefulness of the manual we have used English engineering units throughout.

FUTURE EDITIONS

Beginning in 1979 new model building codes and product standards for solar systems and components will become available. They are being prepared by several organizations, including the American Society of Mechanical Engineers, the American Society for Testing and Materials, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, the American National Standards Institute, and others, with the help of numerous government, industry, and consumer organizations. The codes and standards will cover safety, performance, durability, and reliability of solar systems and components. Codes relating to storage systems will be covered in a future edition of this manual.

Later editions will also include the following, if and when they become commercially available:

- Phase change materials
- Annual or seasonal storage
- Ice storage
- New systems for basement retrofit
- Low-cost storage
- Improved liners for tanks
- Direct contact heat exchangers.

One of the functions of solar energy research is to simplify design methods and procedures. If significant improvements in design methodology become available, they will also be included.

INTRODUCTION

We would like to draw upon your experiences in order to make future editions more useful to you. At the end of this manual you will find a page that contains space for your comments, criticisms, and experiences. The back of the page is preaddressed so that you can tear it out and mail it to us. We welcome your replies.

You can find sources of additional information about many aspects of solar energy systems in the bibliography. Specific questions about almost any topic relating to solar energy may be addressed to the National Solar Heating and Cooling Information Center, P.O. Box 1607, Rockville, Maryland 20850. You can call them by dialing toll-free 800-523-2929 or, if you are in Pennsylvania, 800-462-4983.

THERMAL ENERGY STORAGE

CHAPTER 1.
GENERAL INFORMATION ABOUT THERMAL ENERGY STORAGE SYSTEMS

Solar heating systems must be able to provide heat even when the sun is not shining. Fortunately, on good days solar systems can collect more energy than is needed to meet the daytime heating load. This excess energy can be stored for later use. This manual will describe how the energy can be stored in two common types of sensible heat storage systems.

Sensible heat, as it flows into the storage system, raises the temperature of the storage material. When space heating is needed, heat is removed from storage and the temperature of the storage material drops. The most common sensible heat storage systems are built around rock beds or water tanks, and these are the types of storage systems we will consider in detail.

Figure 1-1 represents a typical air-based system, which uses a rock bed for storage; Figure 1-2 represents a typical liquid-based system, which uses water for storage. Many variations of these space heating systems are possible, but the storage systems will always need (1) a heat storage material, (2) a well-insulated container, and (3) provisions for efficiently adding and removing heat.

We will begin by discussing some characteristics of storage materials--heat capacity and daily operating range, which affect the sizing of the storage device, and temperature stratification, which affects its performance. We will then discuss finding a location for and insulating the storage container and moving heat into and out of storage.

HEAT CAPACITY

Heat, or thermal, capacity is a material's ability to store sensible heat. In the English system of units it is measured in terms of the number of British thermal units (Btu) required to raise the temperature of one pound of the material by 1 degree Fahrenheit. Water has a heat capacity of 1 Btu per pound per degree Fahrenheit (Btu/lb/°F). Most other materials have a lower heat capacity than water; rock, for example, has a heat capacity of 0.21 Btu/lb/°F.

The total amount of heat materials can store is not the only basis by which storage materials' thermal capacities are compared. Engineers frequently work with a derived quantity known as the volumetric heat capacity, which is found by multiplying the material's heat capacity by its density.

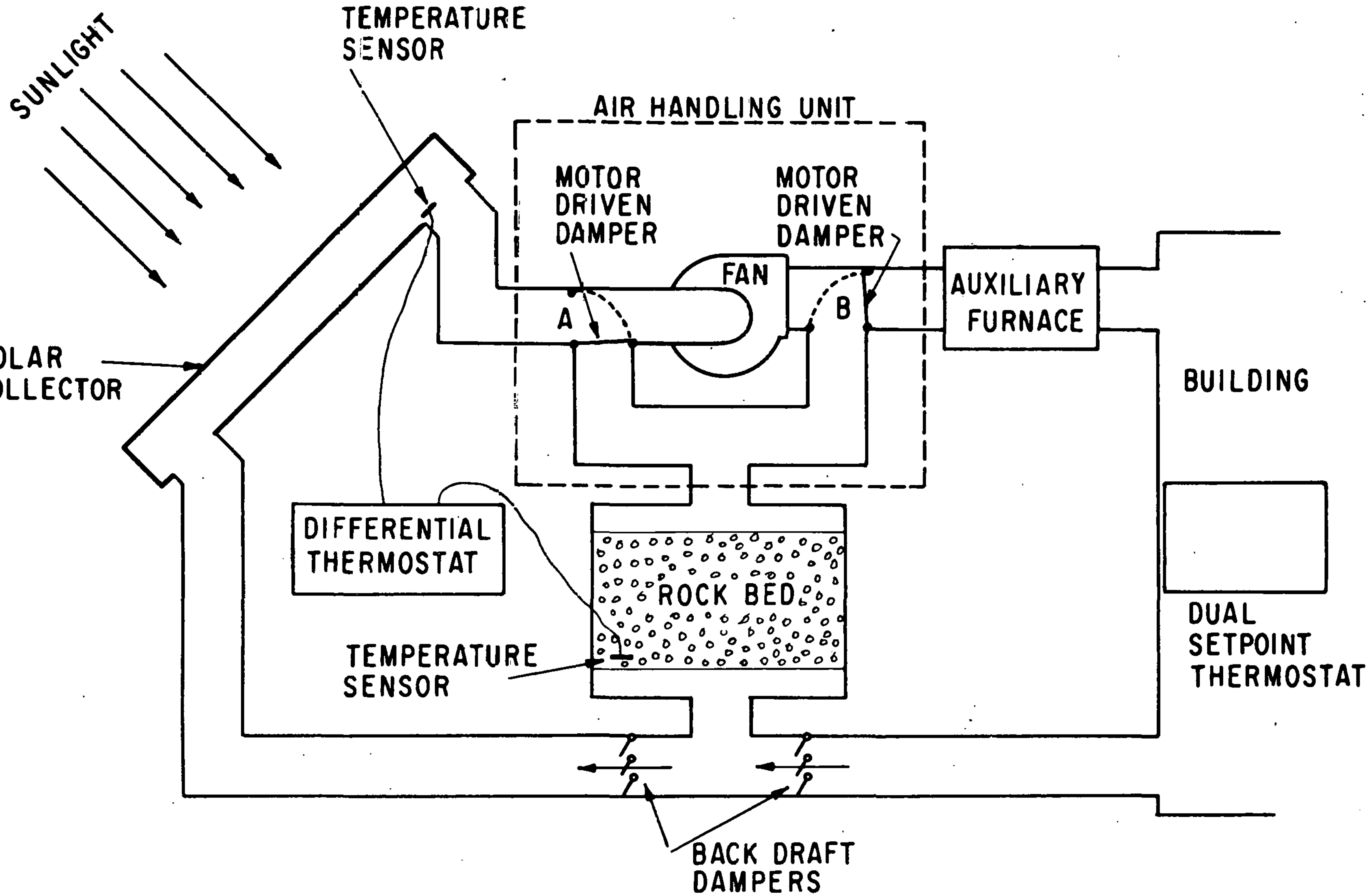

Figure 1-1. Typical Air-based System

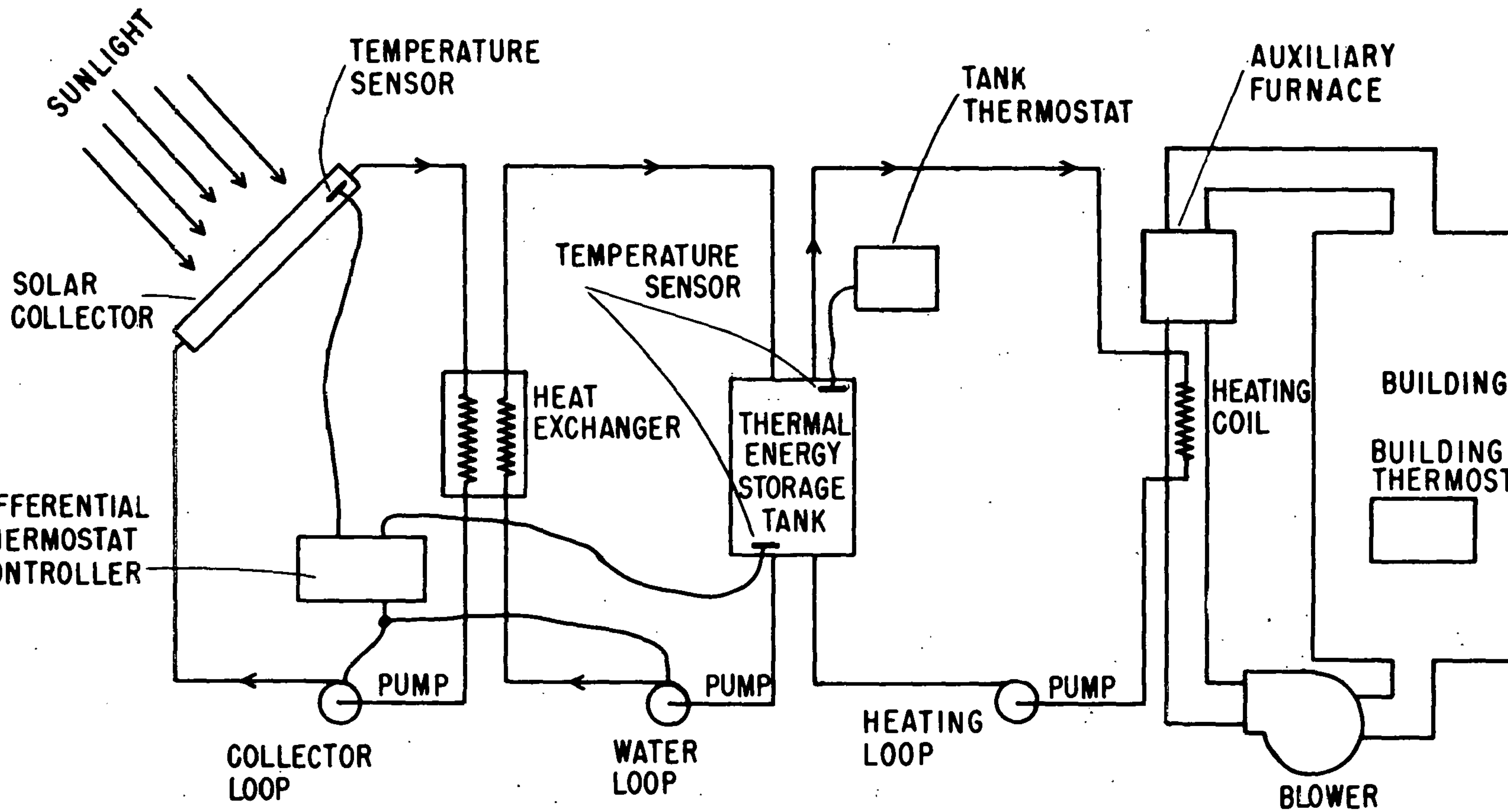

Figure 1-2. Typical Liquid-based System

The volumetric heat capacity describes the quantity of heat the material can store per cubic foot for every degree of temperature change.

Table 1-1 gives the heat capacities and volumetric heat capacities of some some common storage materials. The voids referred to in the table are the spaces that exist between individual pieces of piled up rock or other loose material. The proportion of these spaces to the total volume of the rock bed is called the void fraction. Numerous experiments have shown that loose materials pack with a void fraction of from 20 to 30 percent. These loose materials behave as if their thermal capacity were reduced by this same percentage.

As you can see in Table 1-1, 1 cubic foot of water can store 62.4 Btu for every degree of temperature rise. A cubic foot of rock packed to a 30-percent void fraction can store only 24.3 Btu per degree of temperature rise. Therefore, to store the same quantity of heat over the same temperature range the rock bed's volume would have to be 2.6 times greater than that of the water tank.

Table 1-1. Sensible Heat Storage Materials

Material	Density, lbs/ft^3	Heat Capacity, $Btu/lb \cdot {}^{\circ}F$	Volumetric Heat Capacity, $Btu/ft^3 \cdot {}^{\circ}F$	
			No Voids	30% Voids
Water	62.4	1.00	62.4	-
Scrap Iron	489	0.11	53.8	37.7
Scrap Aluminum	168	0.22	36.96	25.9
Scrap Concrete	140	0.27	27.8	26.5
Rock	167	0.21	34.7	24.3
Brick	140	0.21	29.4	20.6

DAILY TEMPERATURE RANGE

The storage system's daily temperature range is also closely related to the size of the storage device. Both air- and liquid-based systems typically operate over a daily temperature range of under 60°F on a sunny winter day. The exact range is highly variable from system to system, season to season, and day to day. Factors that influence the daily temperature range include the amount of sunshine available, the size of the storage device, the heat capacity of the storage material, the demand for heat, the type of system, the way the system is connected to the load, and the temperature limitations of materials in the system.

The daily temperature range (T - T) is related to the amount of usable heat (Q, measured in Btu) stored in the device by the following equation.

$$Q = m\, C_p (T_{max} - T_{min}) \qquad (1\text{-}1)$$

Here m is the mass of the storage material in pounds and C is the heat capacity in Btu per pound per degree Fahrenheit of the storage medium.

Example: Suppose you must store 400,000 Btu from the solar collectors on a sunny winter day, and you want to limit the daily temperature range on that day to 40°F. How much water is required for storage?

Solving Equation 1-1 for m after substituting in the values for stored heat, daily temperature range, and heat capacity yields the required mass of water.

$$m = \frac{Q}{C_p (T_{max} - T_{min})} \qquad (1\text{-}2)$$

$$= \frac{400{,}000 \text{ Btu}}{1 \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}} \times 40^\circ\text{F}}$$

$$= 10{,}000 \text{ lb. of water}$$

Since one gallon of water weighs 8.34 pounds, this amount of water is equal to 1200 gallons.

SIZING

For residential space heating or domestic hot water heating systems, storage capacity should be about 10 to 15 Btu per degree Fahrenheit per square foot of collector (Btu/°F-sq ft). Dividing this amount by the heat capacity from Table 1-1 yields the mass of storage material required. For rock the required mass is about 50 to 75 pounds per square foot of collector; for water the required mass is 10 to 15 pounds per square foot of collector. Alternatively, dividing the 10 to 15 Btu/°F-sq ft by the volumetric heat capacity yields the required volume of storage material. Since a rock bed usually has a void fraction of about 30 percent, the required storage volume is about 0.41 to 0.62 cubic feet of rock per square foot of collector. For convenience, these numbers are usually rounded upward to 0.50 to 0.75 cubic feet of rock per square foot of collector. About 0.16 to 0.24 cubic feet of water per square foot of collector is required. If these numbers are converted to gallons and rounded upward the result is 1.25 to 2.0 gallons of water per square foot of collector.

This rule of thumb is compatible with the f-Chart and Pacific Regional Handbook methods for determining the collector size, since both methods assume the approximate storage capacity specified by the rule of thumb. With a daily temperature range of 40°F for a larger storage unit or 60°F for a smaller storage unit, the unit can store about 15 x 40 = 600 Btu per square foot of collector. This is very roughly comparable to the amount of heat a solar collector can provide for space heating or domestic hot water on a sunny winter day.

TRNSYS and DOE-1, the computer methods for analyzing the system, will provide more accurate sizing, and you should use one of them if you have access to a computer. The computer methods should also be used for solar-assisted heat pump and industrial systems. The rule of thumb does not apply to these types of systems, where the hour-by-hour heating demands differ greatly from residential heating demands, but it provides a good first guess that should then be refined by computer analysis.

It may not always be possible to install the optimum-sized storage device because of limitations of space or, in liquid-based systems, tank availability. Figure 1-3 shows what happens when storage capacity is varied. (We assume here that other factors, such as heating load and collector area, remain the same.) As you can see, if the storage capacity is less than about 10 Btu/°F-sq ft, the fraction of the heating load supplied by solar energy is less than it should be--that is, some of the heat collected is wasted.

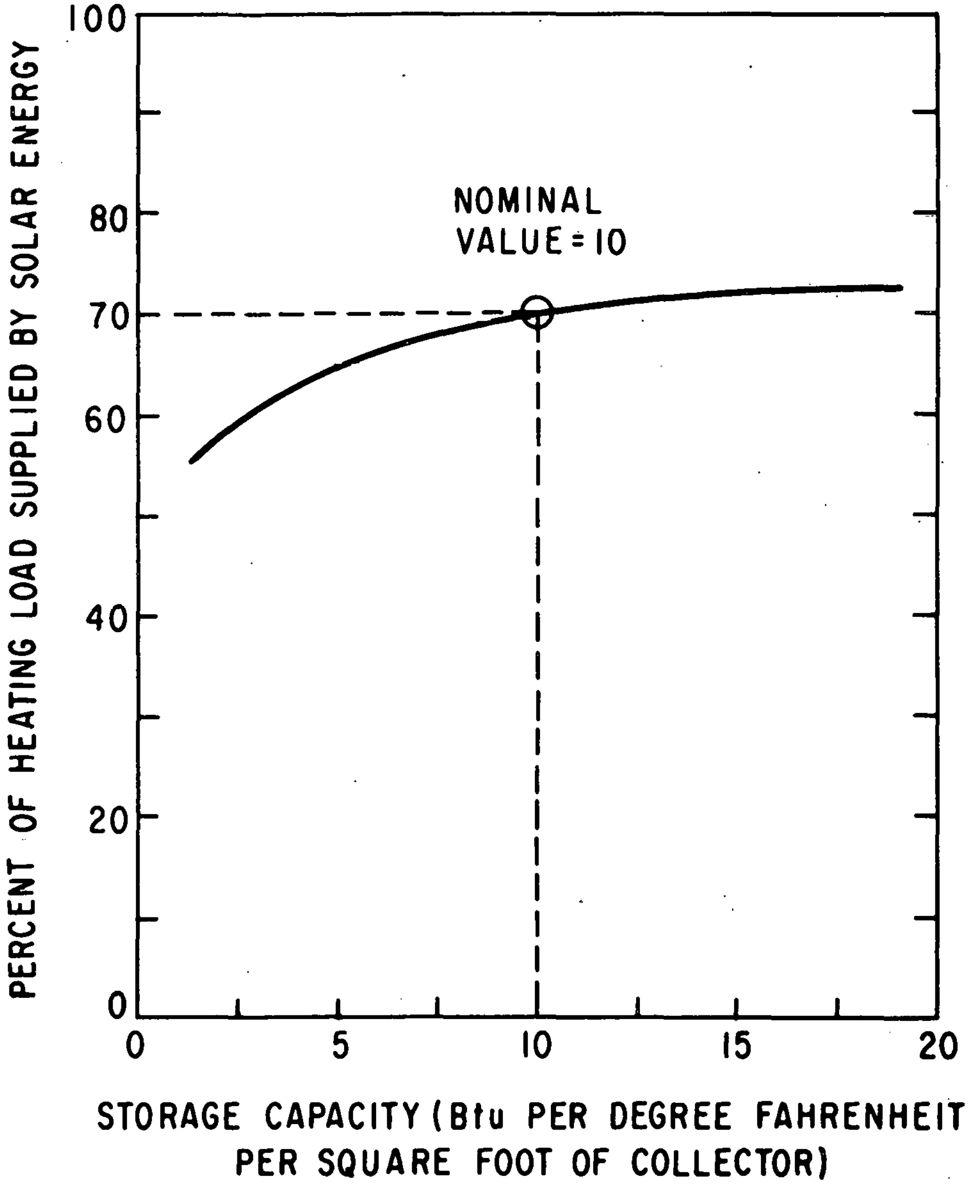

Figure 1-3. Effect of Varying Storage Capacity Upon Percentage of Heating Load Supplied by Solar Energy

Heating load and collector area remain constant.

Source: D. Balcomb et al. Solar Heating Handbook for Los Alamos. Los Alamos Scientific Laboratory Report UC-5967/CONF-75027-1, May 1975.

If the storage capacity is greater than about 15 Btu/°F-sq ft, the greater storage capacity will not significantly increase the percentage of the heating load supplied by solar energy. If the storage unit is grossly oversized, heat losses will be excessive. However, a slightly oversized storage unit will have only slightly higher heat losses than a properly sized one and will cost only slightly more. These penalties are minor compared with the penalty for making the storage unit too small. Therefore, if a standard-sized storage unit does not fall within the rule of thumb for your system, choose the next larger rather than the next smaller size.

TEMPERATURE STRATIFICATION

When heat is delivered to storage, temperature stratification can occur. That is, some parts of the storage material can become hotter than other parts. In theory, a perfectly stratified system can perform 5 to 10 percent more efficiently than a thermally mixed system if the system is designed to take advantage of stratification. Whether temperature stratification can be maintained in practice depends on the type of system used.

Stratification is relatively easy to achieve in rock beds. The solar-heated air enters at the top of the rock bed and flows downward through many labyrinthine paths, losing most of its heat by the time it leaves the bottom of the rock bed. Thus, the rock bed is hot at the top but relatively cool at the bottom. Since rocks can't move around, this temperature differential is easily maintained, and the collector operates at a lower average temperature than it would if there were no stratification. Temperature stratification from top to bottom of a rock bed compensates for the lower efficiency of air-type collectors compared with liquid-type collectors.

Temperature stratification can also occur in water tanks, but pumping the water to the collector or the heat exchanger tends to cause the hotter and cooler water to mix, destroying stratification. Even natural convection from a coil-in-tank heat exchanger can upset the stratification process. Thus, if you plan to use a water tank for thermal energy storage you should not count on gaining the small performance advantage stratification offers.

LOCATION

In principle, for collector-to-storage losses to be minimized the storage device should be as close as possible to the solar collectors. Since solar collectors are usually mounted on the roof, the attic might seem a logical site for the storage container. However, an attic would require extensive structural modifications to support the storage container's weight. In practice, storage containers are usually located in basements, crawl spaces, garages, or outdoors, and the following sections describe the advantages and disadvantages of these various locations. Tables 1-2 and 1-3 summarize this information.

Basement

Basements or other heated indoor areas are good locations for thermal storage devices. Tanks or rock beds in heated areas generally require less insulation than in outdoor installations, and the building protects the storage device from weathering. Any heat lost from storage escapes into heated areas, so during the heating season these losses are not considered losses to the solar system.

The main disadvantage of indoor storage devices is that they take up valuable space. In addition, heat lost from storage into the living area is uncontrollable. In summer, the losses from a hot storage device can increase the air conditioning load unless the storage area is well ventilated or the system is shut down for the summer.

Although a basement will generally provide enough room for a water tank to be installed, getting a large tank into the building is a major problem. Cast-in-place concrete tanks and plastic-lined wooden tanks can be assembled inside existing buildings. Although steel and fiberglass tanks can be installed in basements of new construction, repair or replacement of these tanks would be expensive. For this reason, we do not recommend installing a large one-piece tank in a basement.

If you plan to install a rock bed in a basement, you must consider the floor-to-ceiling space available. Most basements have seven feet of clearance between the floor and the ceiling. By careful design, you can keep a rock bed within this size limit; but in some cases you will have to remove part of the basement floor slab to gain more clearance.

Appropriate foundations must be developed for all storage devices, since they are extremely heavy. A structural engineer should determine whether the floor slab needs reinforcement to support the storage unit's weight.

Table 1-2. Advantages and Disadvantages of Storage Locations

Advantages		
Utility Room or Basement	**Unheated Garage**	**Crawl Space**
. Insulation requirement is minimal.	. Insulation is protected from weather.	. Insulation is protected from weather.
. Insulation is protected from weather.	. Leaks are easily detected.	. Thermal losses may contribute to building heat in winter.
. Thermal losses contribute to building heat in winter.	. Access for repairs is easy.	
. Leaks are easily detected.	. Steel or FRP tanks can be installed in an existing garage.	
. Access for repairs is relatively easy.		

Disadvantages		
Utility Room or Basement	**Unheated Garage**	**Crawl Space**
. Living space is reduced.	. Garage space is reduced.	. Thermal losses may add to air conditioning load in summer.
. Thermal losses add to air conditioning load in summer.	. Extra insulation is required.	. Access is difficult for retrofit or repairs.
. Leaks may damage building interior.	. Freeze protection is required in most of the U.S.	. The shape of the tank may require extra insulation.
. Steel or FRP tanks are difficult to install in an existing building.	. Leaks may damage the garage.	
	. Thermal losses cannot be recovered.	

Table 1-2. (Continued)

Advantages	
Outdoors, Above Grade	**Outdoors, Below Grade**
. Access is easy. . Thermal losses do not add to air conditioning load. . Storage unit does not reduce living space.	. Thermal losses do not add to air conditioning load. . Storage unit does not reduce living space.

Disadvantages	
Outdoors, Above Grade	**Outdoors, Below Grade**
. Extra insulation is required. . Weather protection is required. . Thermal losses cannot be recovered. . Freeze protection is required in most of the U.S. . Vermin may burrow into the insulation.	. Access for repairs is difficult. . Groundwater may cause several types of problems. . Thermal losses cannot be recovered. . Vermin may burrow into the insulation. . Careful design is required to ensure sufficient net positive suction head for the pump.

Table 1-3. Storage Location, Applicability, and Special Requirements

Storage Location	Applicability: New Building	Applicability: Retrofit	Special Requirements: Weather-proof Insulation	Special Requirements: Extra Insulation	Special Requirements: Freeze Protection	Special Requirements: Protection from Groundwater	Special Requirements: Long-Lifetime Components
Utility Room or Basement	yes	X[a]	no	no	no	no	yes
Unheated Garage	yes	yes	no	yes	yes	no	no
Crawl Space	yes	X	no	yes	no	no	yes
Outdoors--Above Grade	yes	yes	yes	yes	yes	no	no
Outdoors--Below Grade	yes	yes	yes	yes	X	yes	yes

[a] Items marked "X" must be determined by the individual situation.

Crawl Space

Heat losses from storage devices in unheated locations such as the crawl space are irrecoverable. This is a disadvantage during the heating season, but a potential advantage during the air conditioning season. If the crawl space is well ventilated and insulated from the air conditioned rooms, heat escaping from the storage device will not add to the air conditioning load.

Most crawl spaces do not have enough vertical clearance for a rock bed with vertical air flow to be installed. Although rock beds with horizontal air flow have been built, maintaining uniform air flow and thermal stratification in them is more difficult than in rock beds with vertical air flow. Therefore, we do not recommend installing a rock bed in a crawl space that does not have an unusually large amount of vertical clearance.

To install a storage device in a crawl space, follow the recommendations for below grade installations. Considering the difficulties of installing a storage device in an existing crawl space, this location should be considered primarily for new construction. Even in this case, the cramped working quarters could make repair costly.

Garage

The garage is an excellent location for steel or fiberglass water tanks, since they can be easily removed and replaced through the large door. Other types of water tanks, as well as rock beds, can also be used here. The garage protects the storage device from the weather.

Tanks in unheated garages must be protected from freezing. Heat losses from storage devices in this location are irrecoverable, and the storage device reduces the space available for cars.

Outdoors

The storage device can be located outside the building either above or below grade. In either case, the storage container must be well insulated and built on a good foundation. The ducts or pipes to and from the storage unit must be insulated, weatherproofed, and possibly waterproofed. Vermin are occasionally a problem in outdoor tanks. Use vermin-proof insulation or surround the insulation with half-inch mesh wire cloth. Heat losses from outdoor storage devices are irrecoverable.

__Above Grade__: In an aboveground installation, the storage device should be placed inside a shelter or covered with roofing and siding. This protection must be designed in compliance with local codes for wind resistance and for snow loads.

Water tanks in unheated shelters must be protected from freezing. In moderate climates, an electric immersion heater will do this satisfactorily.

__Below Grade__: The main problem with buried storage devices is that groundwater can soak the insulation (even if it is closed-cell foam). In several instances, the resulting high losses have forced owners to abandon underground storage devices.

The following guidelines should be followed if you choose to install the storage device underground.

- If possible, avoid burying the storage device so deep that the highest level of groundwater (usually in Spring) rises above the bottom of the insulation.
- Use pea gravel beneath the foundation to allow water to drain.
- Use waterproof insulation, such as closed-cell foam, even in dry areas. We recommend that for an underground storage device you use twice the insulation thickness specified in the following section, because groundwater can degrade the performance of even a closed-cell foam.
- Do not rely upon dry earth for insulation.
- If possible, direct rainwater away from the storage unit. Avoid situations where undisturbed soil (especially clay) surrounding the hole where the storage unit is installed forms a catch-basin for rainwater.
- Position the tank vents so that neither rainwater nor groundwater can enter the tank. If the lid is separate from the body of the storage device, the joint __must__ be above the highest groundwater or floodwater level. A waterproof barrier __must__ be installed to direct rainwater away from the joint.

If a substantial portion of the tank is buried below the freeze line, no freeze protection will be required.

MINIMIZING HEAT LOSS

Insulating the Storage Device

The storage device must be well insulated so that heat loss will be minimized. The HUD Intermediate Minimum Property Standards specify that the storage device should be insulated so that losses during a 24-hour period do not exceed 10 percent of the storage capacity. However, minimum standards do not necessarily produce the most cost-effective system. Because the energy-saving benefits of insulation are so great, we recommend that storage devices be insulated to comply with the SMACNA (Sheet Metal and Air Conditioning Contractors' National Association) standard of a 2-percent loss in 12 hours and that the HUD standard be used only if all the following conditions are met.

- All the heat that escapes from storage heats the building.
- The solar system is shut down in the summer or the area around the storage device can be ventilated so that heat losses do not add to the air conditioning load.
- The storage device is used only to supply space heating.
- You can tolerate uncontrolled heat losses from storage overheating the building occasionally.

A simple calculation can be used to determine how much insulation will limit a storage device's heat loss to 2 percent in 12 hours. First find the entry in Tables 1-4 through 1-7 that corresponds most closely to the shape and size of your storage device. The number you find is a multiplier that can be used in the following equation.

$$\text{R-value} = \text{table value} \times (\text{storage temperature} - \text{ambient temperature}) \quad (1\text{-}3)$$

For "storage temperature," use the average maximum temperature, in degrees Fahrenheit, that you expect the storage device to reach on an average January day.

For "ambient temperature," use the average temperature, in degrees Fahrenheit, of the storage device's surroundings on an average January day.[1] The R-value obtained will have the units of °F-sq ft-hr/Btu commonly used by insulation manufacturers in the United States.

<u>Example</u>: Suppose you want to calculate the amount of insulation needed on a 1500-gallon water tank that will be installed in a basement. The tank is horizontal and cylindrical, is 10 feet long, and has a diameter of 5 feet. Table 1-5 contains the multipliers for horizontal, cylindrical water tanks; the appropriate multiplier for a water tank of this size and shape is 0.16. If the maximum temperature of the tank on an average January day will be 160°F, and if the ambient temperature in the basement in January will be 65°F, the insulation R-value that will limit the tank's losses to 2 percent in 12 hours will be:

$$\text{R-value} = 0.16 \times (160-65)$$

$$= 0.16 \times 95$$

$$= 15$$

The total insulation around the tank should have an R-value of 15 °F-sq ft-hr/Btu.

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[1] Assume an ambient temperature of about 65°F for storage devices in heated areas. For unheated locations, find out the average January outdoor temperature from the nearest weather bureau office. For underground ambient temperature, assume that the ground temperature rises linearly from the average January outdoor temperature at the surface to the average annual outdoor temperature at a point 20 feet underground. This is a rough approximation to the ground temperature, but it is sufficiently accurate for our purposes here.

To calculate a heat loss rate different from 2 percent in 12 hours, multiply the table value by 2 and then divide the result by the percent loss that you want. If, in the preceding example, you had wanted to allow a 5-percent loss in 12 hours, you would have calculated the multiplier to use as follows:

$$\frac{2 \times 0.16}{5} = 0.064$$

and the R-value would have been:

$$\text{R-value} = 0.064 \times 95 = 6\ {}^{\circ}\text{F}\cdot\text{ft}^2\cdot\text{hr/Btu}.$$

Table 1-8 gives R-values per inch of thickness of typical insulators. Most storage units have several insulation layers, including the walls. The R-value of multilayered insulation is the sum of R-values for each layer, as shown in Figure 1-4.

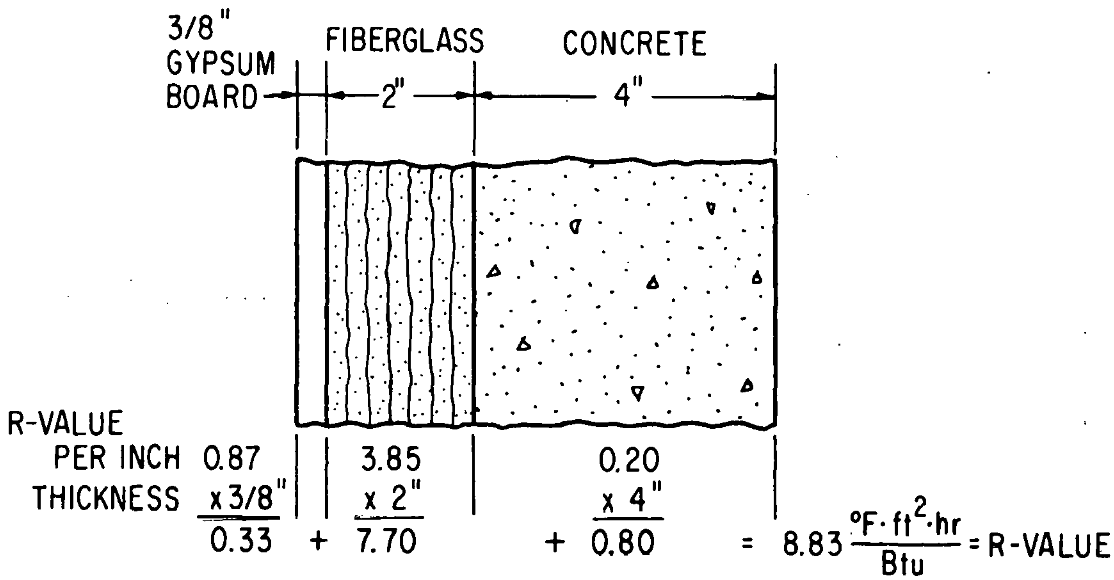
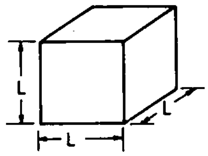
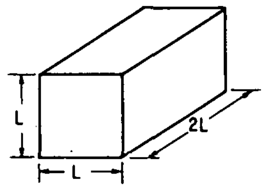
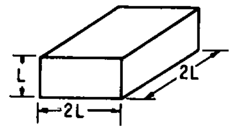
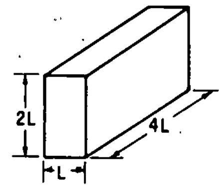


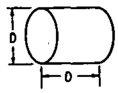
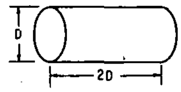
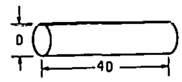
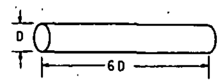
Figure 1-4. R-value of Multilayered Insulation

Table 1-4. Insulation Multipliers for Rectangular Water Tanks[a]

Size Gallons	Shape			
				
250	0.35	0.38	0.42	0.40
500	0.28	0.30	0.33	0.32
750	0.24	0.26	0.29	0.28
1000	0.22	0.24	0.27	0.25
1500	0.19	0.21	0.23	0.22
2000	0.17	0.19	0.21	0.20
3000	0.15	0.16	0.18	0.17
4000	0.14	0.15	0.17	0.16
5000	0.13	0.14	0.16	0.15

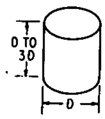
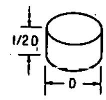
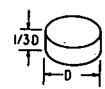
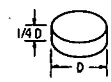
[a] Table values are for a 2% loss in 12 hours with an assumed daily temperature range of 60°F. Table units are $ft^2 \cdot hr/Btu$. To obtain the required R-value for the side and top insulation, multiply the table value by the difference (°F) between the storage temperature and the ambient temperature. The R-value for the bottom insulation is assumed to be half that on the top and sides.

Table 1-5. Insulation Multiplier for Horizontal Cylindrical Water Tanks[a]

Size Gallons	Shape			
				
250	0.28	0.29	0.33	0.36
500	0.22	0.23	0.26	0.29
750	0.19	0.20	0.23	0.25
1000	0.17	0.18	0.21	0.23
1500	0.15	0.16	0.18	0.20
2000	0.14	0.14	0.16	0.18
3000	0.12	0.13	0.14	0.16
4000	0.11	0.11	0.13	0.14
5000	0.10	0.11	0.12	0.13

[a] Table values are for a 2% loss in 12 hours with an assumed daily temperature range of 60°F. Table units are $ft^2 \cdot hr/Btu$. To obtain the correct R-value for the insulation, multiply the table value by the difference (°F) between the storage temperature and the ambient temperature.

Table 1-6. Insulation Multipliers for Vertical Cylindrical Water Tanks[a]

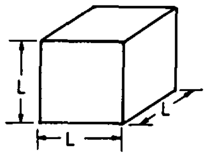
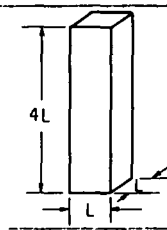
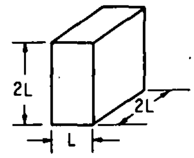
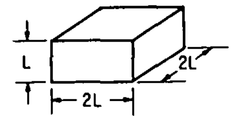
Size Gallons	Shape			
				
80	0.47[b, c]	0.53[b]	0.47	0.51
120	0.41	0.47	0.41	0.44
250	0.32	0.36	0.32	0.35
500	0.26	0.29	0.25	0.28
750	0.22	0.25	0.22	0.24
1000	0.20	0.23	0.20	0.22
1500	0.18	0.20	0.18	0.19
2000	0.16	0.18	0.16	0.17
3000	0.14	0.16	0.14	0.15
4000	0.13	0.14	0.13	0.14
5000	0.12	0.13	0.12	0.13

[a] Table values are for a 2% loss in 12 hours with an assumed daily temperature range of 60°F. Table units are ft^2·hr/Btu. To obtain the required R-value of insulation, multiply the table value by the difference (°F) between the storage temperature and the ambient temperature

[b] The R-value of the bottom insulation is assumed to be half that on the top and sides for tanks specified by the first two columns.

[c] The first column is applicable to all tanks with height of 1 to 6 times the diameter. Insulation multipliers for most domestic hot water tanks can be found in the first column.

Table 1-7. Insulation Multipliers for Rock Beds[a]

Volume of Rock,[b] (cubic ft.)	Shape of Rock Bed[b]			
				
100	0.82	0.83	0.80	0.97
150	0.72	0.72	0.70	0.85
200	0.65	0.66	0.64	0.76
300	0.57	0.57	0.56	0.67
400	0.52	0.52	0.51	0.61
500	0.48	0.48	0.47	0.56
600	0.45	0.46	0.44	0.53
800	0.41	0.41	0.40	0.48
1000	0.38	0.38	0.37	0.45

[a] Table values are for a 2% loss in 12 hours with an assumed daily temperature range of 60°F. Table units are in $ft^2 \cdot hr/Btu$. obtain the required R-value for the side and top insulation, multiply the table value by the difference (°F) between the storage temperature and the ambient temperature. The R-value for the bottom insulation is assumed to be half that on the top and sides.

[b] The insulation is assumed to cover both plena, but the volume and shapes given are for the rocks only.

Table 1-8. R-values and Densities of Common Building and Insulating Materials[a]

Material	Density, lb/ft^3	R-value, °F·ft^2·hr/Btu per inch thickness
Acoustic Tile	18.0	2.53
Asbestos-Cement Board	120.0	0.22
Brick: Common	120.0	0.20
Face	130.0	0.11
Cellulose Fill	-	3.70
Cement (Mortar or Plaster with Sand)	116.0	0.20
Concrete, Heavy Weight	140.0	
Dried Aggregate		0.11
Undried Aggregate		0.08
Concrete, Heavy Weight	80.0	0.40
Concrete, Light Weight	30.0	1.11
Concrete Block-Heavy Weight		
4-inch	101.0	0.18
6-inch	85.0	0.15
8-inch	69.0	0.13
12-inch	76.0	0.11
Concrete Block-Medium Weight		
4-inch	76.0	0.28
6-inch	65.0	0.23
8-inch	53.0	0.18
12-inch	58.0	0.18
Concrete Block-Light Weight		
4-inch	65.0	0.33
6-inch	55.0	0.30
8-inch	45.0	0.25
12-inch	49.0	0.19
Fiberglass		3.85

[a] Source: R.M. Graven and P.R. Hirsch. DOE-1 Users' Manual. Argonne National Laboratory Report ANL/ENG-77-04, November 1977.

Table 1-8. (Continued)

Material	Density, lb/ft^3	R-value, °F·ft^2·hr/Btu per inch thickness
Gypsum or Plaster Board	50.0	0.90
Gypsum Plaster		
Light Weight Aggregate	45.0	0.63
Sand Aggregate	105.0	0.18
Hard Board		
Medium Density Siding	40.0	1.53
Medium Density Other	50.0	1.37
High Density Standard Tempered	55.0	1.22
High Density Service Tempered	63.0	1.00
Insulation Board		
Sheathing	18.0	2.63
Shingle Backer	18.0	2.52
Nail Base Sheathing	25.0	2.28
Mineral Board, Preformed	-	3.47
Mineral Wool/Fiber		
Batt	-	3.33
Fill	-	3.09
Particle Board		
Low Density		1.85
Medium Density		0.11
High Density		0.08
Underlayment		0.46
Polystyrene, Expanded		4.17
Polyurethane, Expanded	1.0	6.26
Urea Formaldehyde	0.7	4.17
Roof Insulation, Preformed	16.0	2.78
Wood, Soft (Fir, Pine, etc.)	32.0	1.25
Wood, Hard (Maple, Oak, etc.)	45.0	0.91

Insulation also limits the exposed surface temperature to prevent burns. The R-values given by Tables 1-4 through 1-7 will limit the temperature on the outer surface of the insulation to 140°F or less.

Insulating Pipes and Ducts

Heat can be lost, not only from the storage device, but also as it is moved into and out of storage. These losses include:

- Losses between the collector and the storage unit (charging losses)
- Losses between the storage unit and the heating load (discharge losses).

To minimize these losses, (1) the piping system from collector to storage must be well insulated and have weather protection, and (2) the piping or ductwork from storage to load must be kept as short as possible and be well insulated.

The Polytechnic Institute of New York recommends using R-4 insulation for pipes less than 1 inch in diameter and R-6 insulation for pipes 1 to 4 inches in diameter. A method of calculating the most economical insulation thickness for pipes is given in the ASHRAE Handbook of Fundamentals, Chapter 17, "Thermal Insulation and Water Vapor Barriers."

HEAT EXCHANGERS

Heat exchangers are devices that transfer heat from one fluid to another while preventing mixing of the two fluids. Hot fluid flows on one side of a metal barrier and heats a cold fluid flowing on the other side. In order for heat to be transferred the hot fluid must be hotter than the cold fluid directly across the barrier. This necessary temperature difference leads to a loss of overall system efficiency each time a heat exchanger is used. Heat exchangers typically used in solar energy systems are shown in Figures 1-5 through 1-11.

Heat Exchangers in Liquid-based Systems

The collectors must be protected against freezeup in the winter. If antifreeze is used for protection, a liquid-to-liquid heat exchanger must be installed as shown in Figure 1-2 to separate the heat transfer fluid from the water in storage, since antifreeze is too expensive to use as a storage medium. Because there must be a temperature difference from the collector side to the storage side of the heat

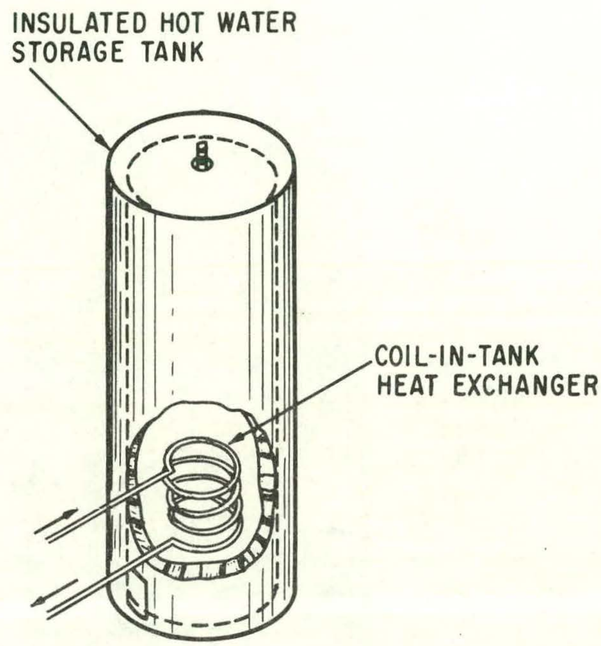


Figure 1-5. Typical Coil-in-Tank Heat Exchanger

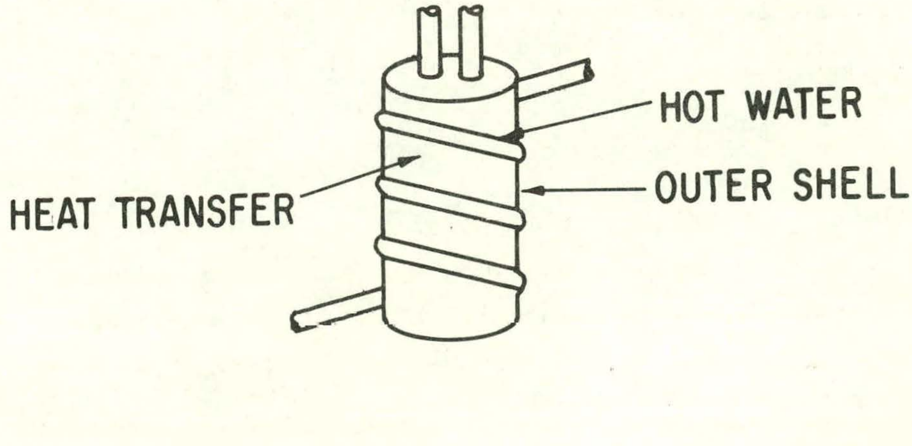


Figure 1-6. Schematic Drawing of Wraparound (Traced Tank) Heat Exchanger

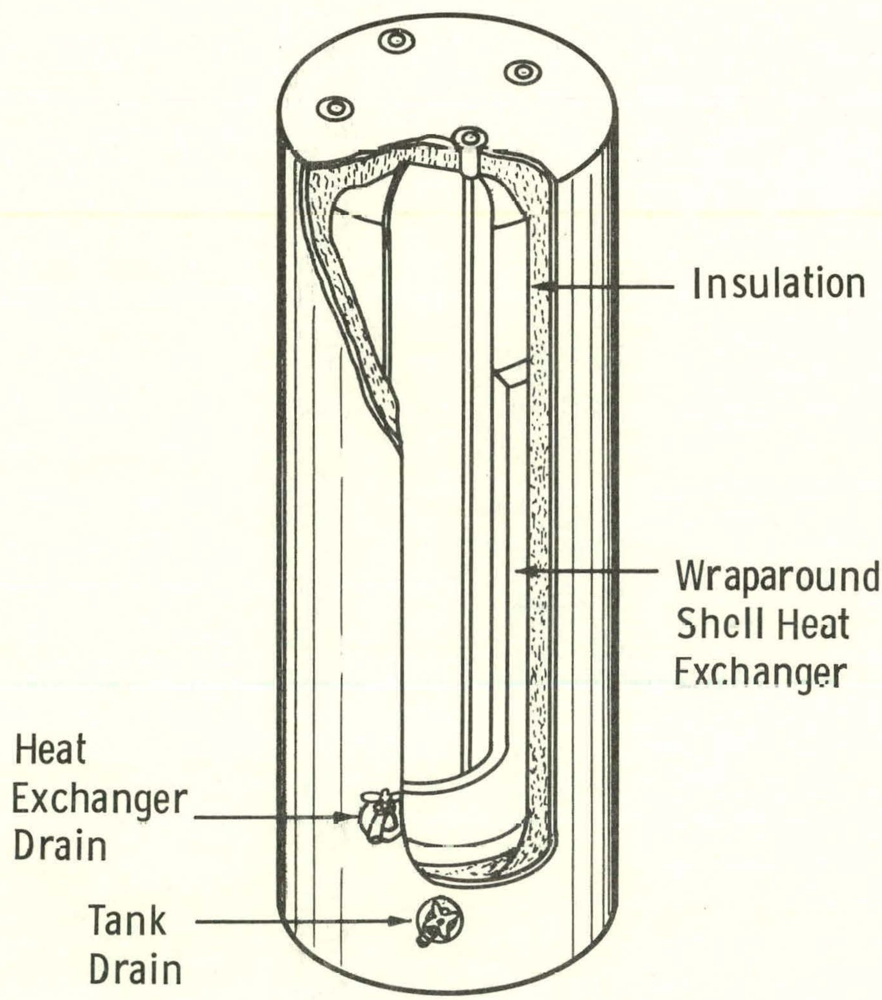


Figure 1-7. Wraparound Heat Exchanger

A pressure-bonded metal plate with integral fluid passageways is clamped around the outside of the storage tank.

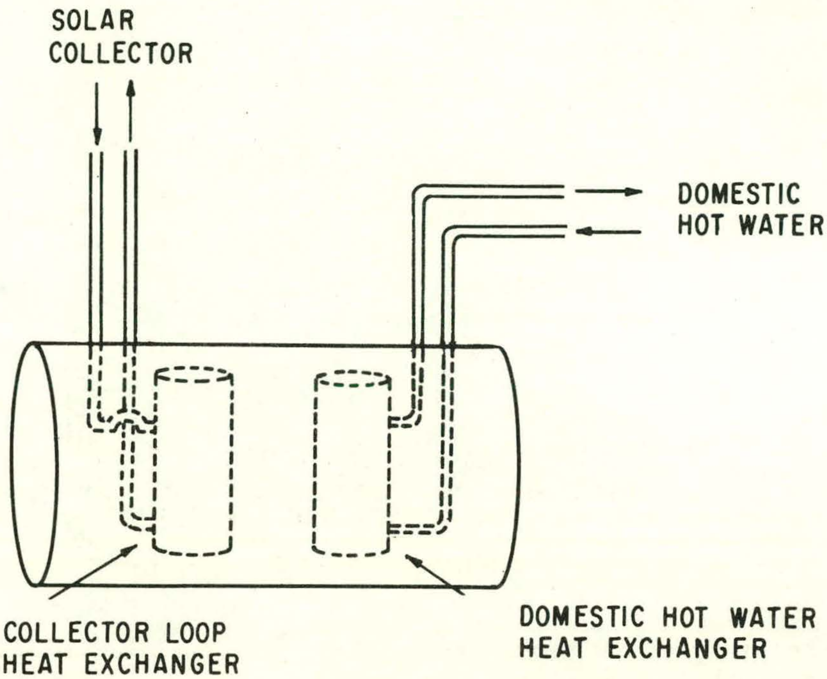


Figure 1-8. Two Tank-in-Tank Heat Exchangers

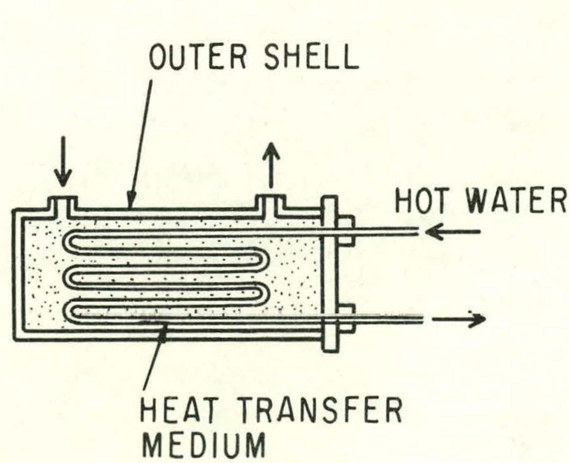


Figure 1-9. Shell-and-Tube Heat Exchanger

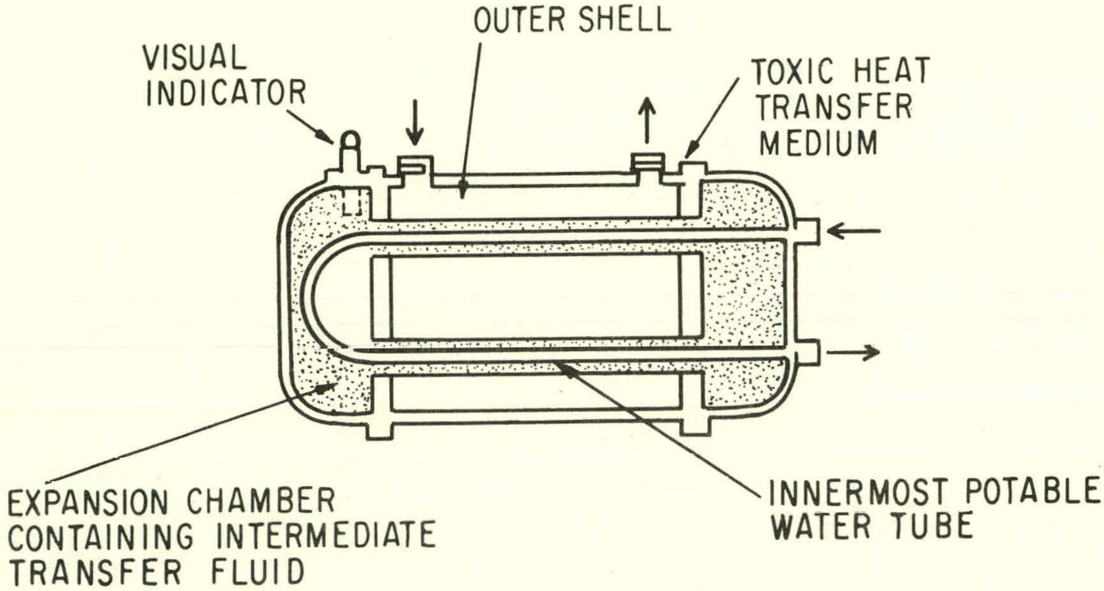


Figure 1-10. Shell-and-Double-Tube Heat Exchanger

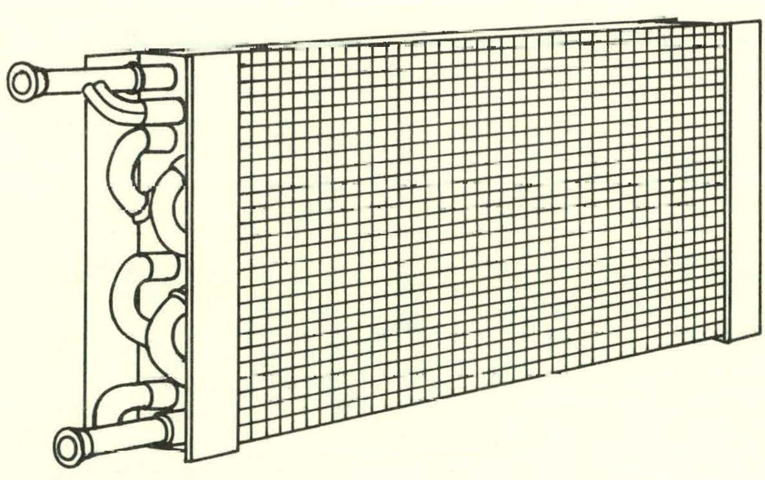


Figure 1-11. Typical Liquid-to-Air or Air-to-Liquid Heat Exchanger

Drawing courtesy of Bohn Heat Transfer Division, Gulf-Western Manufacturing Company, Danville, Illinois.

exchanger, the collector must operate at a higher, less efficient temperature than in a system without a heat exchanger between collector and storage. Thus, the heat exchanger imposes a performance penalty on the system.[2]

The collector-to-storage heat exchanger can be as simple as a coiled tube immersed in the storage tank (Figure 1-5) or wrapped around the outside of the tank (Figure 1-6). Figure 1-7 shows a wraparound shell heat exchanger. Figure 1-8 shows two tank-in-tank heat exchangers.

The types of heat exchangers represented in Figures 1-5 through 1-8 rely on natural convection to move the water inside the tank past the heat exchange surface. If the tank is large, say several hundred gallons, natural convection is an inefficient means of transferring heat. Shell-and-tube heat exchangers (Figures 1-9 and 1-10) are often used in this case, and a pump circulates the water between the tank and the heat exchanger.

In the simple heating system shown in Figure 1-2, one heat exchanger (liquid-to-air) is needed to transfer heat to the building. This heat exchanger is often a finned-tube unit (Figure 1-11) inserted in an air duct. Less frequently used alternatives are baseboard convectors, radiant heating coils, and individual fancoil units.

Solar-heated domestic hot water requires a heat exchanger to separate the potable, or drinkable, hot water from either the nonpotable storage fluid or the collector fluid. Heat exchangers for use with potable water are subject to special safety requirements discussed in Chapter 4.

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[2]Another method of protecting the collectors is to drain them whenever there is danger of freezing weather. This method, known as the draindown system, is one of the most efficient solar collection systems available. Details of the draindown system and its many variations are available in systems design manuals such as ITT's <u>Solar Systems Design Manual</u>.

A draindown system must be totally foolproof. Pipes must be carefully pitched and collectors carefully selected to ensure that all of the water will drain when it should. A single failure can ruin the collectors. Many designers prefer to use antifreeze in the collectors rather than risk this loss. The designer must decide whether to pay the penalties of lower performance and higher first cost for an antifreeze system in return for less risk of an expensive failure.

Heat Exchangers in Air-based Systems

In contrast with the liquid-based system, the air-based system (Figure 1-1) does not need separate heat exchangers between the collectors and the heating load. The rock bed is both the storage device and the collector-to-load heat exchanger.

Air-based collector systems used to heat domestic hot water must use an air-to-liquid heat exchanger. Such a heat exchanger usually consists of finned water tubing in the air-handling duct (Figure 1-11) similar to the finned tube heat exchanger used in air ducts of liquid-based systems.

Heat Exchanger Effectiveness

As we said earlier, using heat exchangers imposes a penalty on the solar space heating system. A collector-to-storage heat exchanger forces the collector to operate at a higher temperature than in a system without the heat exchanger. Similarly, the storage-to-load heat exchanger forces the storage system to operate at a higher temperature than would be required if that heat exchanger could be eliminated.

In order to calculate how efficiently a system with heat exchangers will perform, you must be able to determine the penalty imposed on the system by the heat exchangers. This penalty, called heat exchanger effectiveness, is defined as the actual rate of heat exchange divided by the rate of heat exchange of a perfect, infinitely large heat exchanger.

Since there is no perfect, infinitely large heat exchanger, the designer's task is to choose the size of heat exchanger that will minimize the overall cost of the system. This relatively complex task is described in Appendix D. Alternatively, most heat exchanger manufacturers can select the properly sized heat exchanger given the following information about the system:

- The physical characteristics of the two fluids in the heat exchanger (See Appendix B.)
- The amount of heat to be transferred (Btu per hour)
- The flow rates (gallons per minute) on both sides of the heat exchanger
- The approach temperature difference (degrees Fahrenheit), defined as the difference between the temperatures of the hot fluid entering the heat exchanger and the heated fluid leaving the heat exchanger.

Appendix E gives sample specifications for heat exchangers that are not integral parts of a storage tank. Appendix G, Part 2, gives sample specifications for domestic hot water tanks with integral heat exchangers.

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CHAPTER 2. THERMAL ENERGY STORAGE IN AIR-BASED SYSTEMS

GENERAL CHARACTERISTICS OF ROCK BEDS

When rocks are used as the heat storage medium in a solar space heating system, a container must be built for them. The container can be wood or concrete and is usually rectangular. In addition to providing enough room to contain the loose rock, it must have air spaces at the top and bottom.

When solar-heated air is forced into the top of the container, the air space (or plenum) allows the air to spread out and pass evenly down through the rock bed, heating the rocks. Cool air is drawn off the bottom and returned to the collectors. When space heating is required, the air flow is reversed, and warm air is delivered from the top of the rock bed into the building. Thus, the rock bed functions as both storage medium and heat exchanger between the solar collectors and the heating load.

Uniform distribution of air in the rock bed is important, for nonuniform distribution allows air to bypass part of the rocks. The designer can allow for uniform air distribution in three ways.

- By designing the rock bed for a vertical air flow through the rocks
- By designing sufficiently large plenum chambers
- By designing the rock bed so that it has a pressure drop of at least 0.15 inches of water.

The rock bed should be designed for a vertical air flow because the rocks tend to settle. If the flow were horizontal, air would tend to flow through the gap between the top of the rocks and the top of the bin instead of through the rocks. In addition, vertical air flow takes advantage of air's natural tendency to stratify.

The function of the plena is to distribute the air uniformly over the top and bottom of the rocks. To do this the resistance to air flow through the plena must be much less than the resistance to air flow through the rocks. We recommend that the cross-sectional area of each plenum be at least 10 percent of the cross-sectional area of the rock bin. That is, the plenum height times the plenum width should be at least 10 percent of the rock bin's width times its length.

Designing the rock bed so that it has a pressure drop of at least 0.15 inches of water will ensure that the air-flow resistance of a properly designed plenum is much less than the air-flow resistance of the rocks. A method of designing the rock bed for the desired pressure drop is explained later in this chapter.

The ideal rocks to use in a rock bed are the rounded ones typically found in river beds. The rocks should be screened to assure uniform size. Angular rocks and rocks of varying size pack tighter in the bin than uniformly sized rounded rocks and cause higher pressure drops than allowed for. Before filling the bin, carefully wash and dry the rocks to remove any dust or dirt that could cause trouble after startup. Rocks conforming to ASTM C 33, "Standard Specifications for Concrete Aggregates," have been washed and generally are satisfactory for use in rock beds.

Rocks that react with components of the air or rocks that crumble are not suitable for use in thermal energy storage systems. Limestone, dolomite, and marble react with water and carbon dioxide; as they react they may settle and increase the pressure drop in the rock bed. (This problem is most severe if the rock bed is used for nighttime cooling in the summer.) Sandstone tends to crumble and make dust.

The rock bin itself must be strong enough to withstand the outward pressure of the rocks. The pressure, already great when the bin is first filled, increases as the rocks expand, contract, and settle with the heating and cooling of the bin. A flimsy box can split at the seams. Construction details for a wooden bin are shown in Appendix F. Construction of a poured-concrete bin is similar to that of the cast-in-place water tank described in Appendix H, except that no lining is needed.

Leaks frequently present a problem in air-based systems. Although leaks in air-based systems are not as serious as leaks in liquid-based systems, they can degrade performance to the point where the system becomes uneconomical to operate. Moreover, leaks in air-based systems are more difficult to detect than leaks in liquid-based systems. Places to look for leaks include seams in the corners of the rock bin, joints between ductwork and the rock bin or other equipment, and dampers that do not seal properly.

PERFORMANCE CHARACTERISTICS OF ROCK BEDS

The performance of the rock bed depends on several inter-related characteristics: the rock bed face velocity, the size of the rocks, the heat-transfer relaxation length, and the pressure drop across the rock bed.

Face Velocity

The face velocity describes the quantity of air moving through the rock bed. To compute it divide the total air flow rate by the rock bed's cross-sectional area (length x width). Rock bed storage systems are usually designed so that face velocities range from 10 to 60 feet per minute. Increasing the face velocity increases the pressure drop across the rock bed.

Rock Size

Rocks are usually sorted into specific sizes by being passed through a screen mesh. So long as the rocks are clean, approximately round, and of uniform size they can be specified by their average diameters. If the rocks are angular or of mixed sizes, use the diameter of the smallest rocks to calculate the pressure drop. The rock size affects primarily the relationship between the heat-transfer relaxation length and the pressure drop. For a given face velocity smaller rocks give shorter heat-transfer relaxation lengths but larger pressure drops. For larger rocks the reverse is true.

Heat-Transfer Relaxation Length

The heat-transfer relaxation length is the ratio of the input heat to the heat that can be absorbed per foot of depth of the rock bed. For design purposes, the heat-transfer relaxation length specifies the minimum rock bed depth needed for effective temperature stratification.

Rock bed depths can vary from installation to installation, depending on the available space. The effect of the rock bed's depth on the system's performance is illustrated in Figure 2-1. In this figure, the horizontal axis represents the rock bed depth expressed as a multiple of the heat-transfer relaxation length. The vertical axis represents the percentage of the heating load supplied by solar energy. In Figure 2-1 the volume of rock and the size of the solar collector were held constant. Study of a large number of cases yielded results typified by Figure 2-1 and led to the conclusion that <u>temperature stratification and adequate heat transfer will occur as long as the rock bed depth is greater than five times the heat-transfer relaxation length</u>. Most rock bed designs easily exceed this depth, but it is necessary to check every design for this requirement to ensure stratification and adequate heat transfer.

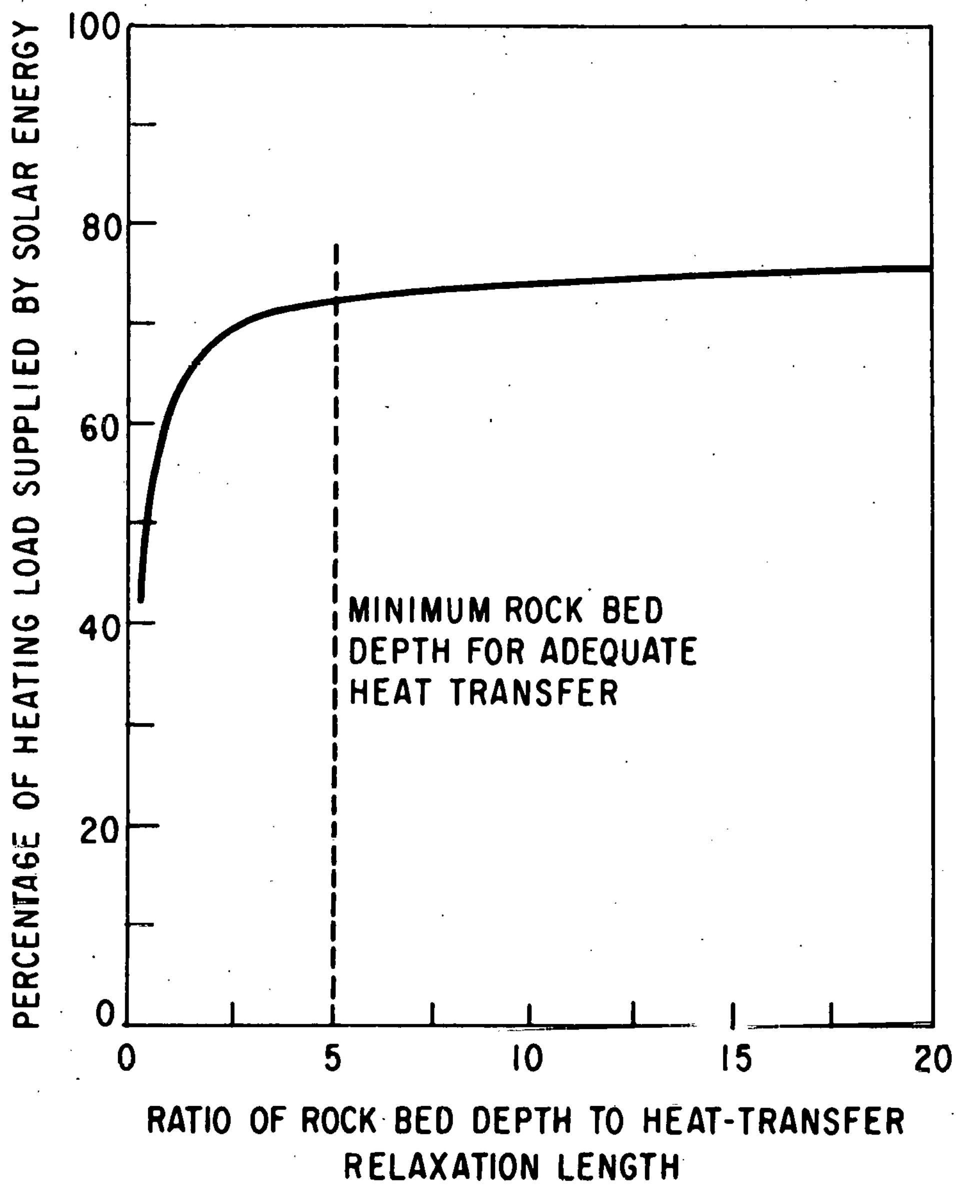

Figure 2-1. Effect of Rock Bed Depth on System Performance

Pressure Drop

Since the rock bed is porous and heat must be transferred from the air to the rocks, the rock bed flow path should be long. But, as the flow path increases, the resistance to the flow also increases. As we stated earlier, a pressure drop of at least 0.15 inches of water is necessary to ensure uniform air flow in the rock bed. However, because the electric power required to pump the air increases as the pressure drop increases, the pressure drop should be less than 0.30 inches of water. The pressure gradient, which we will use in later calculations, is the pressure drop divided by the rock bed depth.

Performance Map[3]

The relationship among the face velocity, the rock size, the relaxation length, and the pressure gradient is shown in the rock bed performance map in Figure 2-2.

The vertical axis in Figure 2-2 represents the pressure gradient across the rock bed expressed in inches of water column per foot of bed depth. The horizontal axis represents the heat-transfer relaxation length corresponding to a given rock diameter and face velocity.

The designer's task is to design an adequate rock bed subject to the constraints of the system. Typical constraints include:

- Rock volume of 0.50 to 0.75 cubic feet per square foot of collector
- Air flow of 1 to 2 cubic feet per minute per square foot of collector
- Rock bed pressure drop of more than 0.15 but less than 0.30 inches of water
- Rock bed depth restriction (for example, the ceiling height in a basement)
- Availability of rocks limited to certain sizes.

You can use the rock bed performance map to adjust either the face velocity or the rock diameter to achieve a suitable pressure drop in the space available for the storage unit.

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[3]The information used to make this performance map was derived from R. V. Dunkle and W. M. Ellul, "Randomly-Packed Particulate Bed Regenerators and Evaporative Cooling," Mechanical and Chemical Engineering Transactions of the Institution of Engineers, Australia, MC8(2):117-121, 1972.

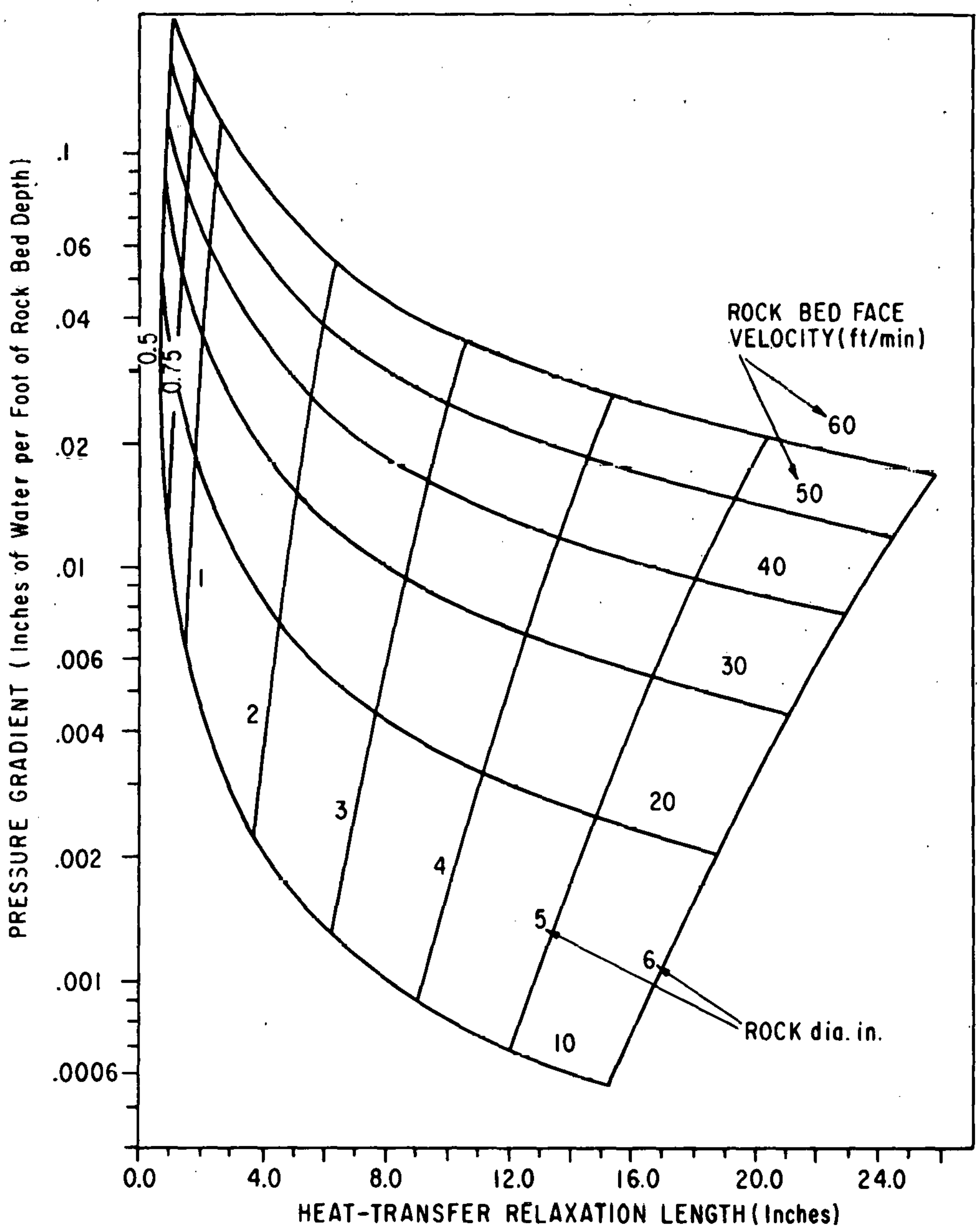

Figure 2-2. Rock Bed Performance Map

A sample problem illustrating the use of the performance map in designing a rock bed follows.

Design Example

In this example we will assume that the designer, using f-Chart, SOLCOST, or some other method, has determined that he should install 500 square feet of collector on a residence. The design will be subject to several constraints.

- The collector manufacturer specifies an air flow rate of 2 cubic feet per minute per square foot of collector, or 1000 cubic feet per minute, for this example.
- The rule of thumb for sizing storage given in Chapter 1 specifies 0.50 to 0.75 cubic feet of rock per square foot of collector, or 250 to 375 cubic feet of rock, for this example.
- The pressure drop across the rock bed should be 0.15 to 0.30 inches of water, as specified earlier in this chapter.
- The rock bed depth should be at least five times the heat-transfer relaxation length to ensure stratification and adequate heat transfer.
- The designer plans to build the rock bed in a basement that has a 7-foot floor-to-ceiling height, so the rock bed's depth will be limited. Allowing 8 inches for insulation and 6 inches for each plenum leaves 5 feet 4 inches for the rocks.

Using these constraints we can calculate maximum and minimum values for the rock bed's cross-sectional area, face velocity, and pressure gradient, and the maximum value of the heat-transfer relaxation length. These maximum and minimum values, when plotted on the rock bed performance map, help the designer configure the system.

The rock bed's cross-sectional area is its volume divided by its depth.

- minimum cross-sectional area $= \frac{250 \text{ cu. ft.}}{5.33 \text{ ft.}} = 46.9$ sq. ft.

- maximum cross-sectional area $= \frac{375 \text{ cu. ft.}}{5.33 \text{ ft.}} = 70.3$ sq. ft.

The face velocity is the air flow rate divided by the rock bed's cross-sectional area.

- minimum face velocity $\frac{1000 \text{ cu. ft./min.}}{70.3 \text{ sq. ft.}} = 14.2 \text{ ft./min.}$

- maximum face velocity $\frac{1000 \text{ cu. ft./min.}}{46.9 \text{ sq. ft.}} = 21.3 \text{ ft./min.}$

The pressure gradient is calculated as follows:

- minimum pressure gradient $= \frac{0.15 \text{ in. of water}}{5.33 \text{ ft.}}$

  $= 0.028 \text{ in. of water/ft.}$

- maximum pressure gradient $= \frac{0.30 \text{ in. of water}}{5.33 \text{ ft.}}$

  $= 0.056 \text{ in of water/ft.}$

Finally, the maximum heat-transfer relaxation length is the rock bed's depth divided by 5.

$$\frac{64 \text{ in.}}{5} = 12.8 \text{ in.}$$

Figure 2-3 shows the maximum and minimum face velocities and pressure gradients and the maximum heat-transfer relaxation length plotted on the rock bed performance map. The lines drawn on the performance map define the acceptable design region for this example. The designer is free to base his design on any point within the acceptable design region.

Either 1/2-inch or 3/4-inch rock can be used in the final design. For the final design in this example we will arbitrarily choose 3/4-inch rock and a 20-feet-per-minute face velocity. This choice will give a pressure drop equal to the minimum, which requires the minimum amount of electricity to pump the air. If the rocks settle, the increased pressure drop will not have a serious effect on the rock bed's performance. Since the heat-transfer relaxation length for this design is 1.25 inches, the rock bed depth of 64 inches will assure good stratification and adequate heat transfer.

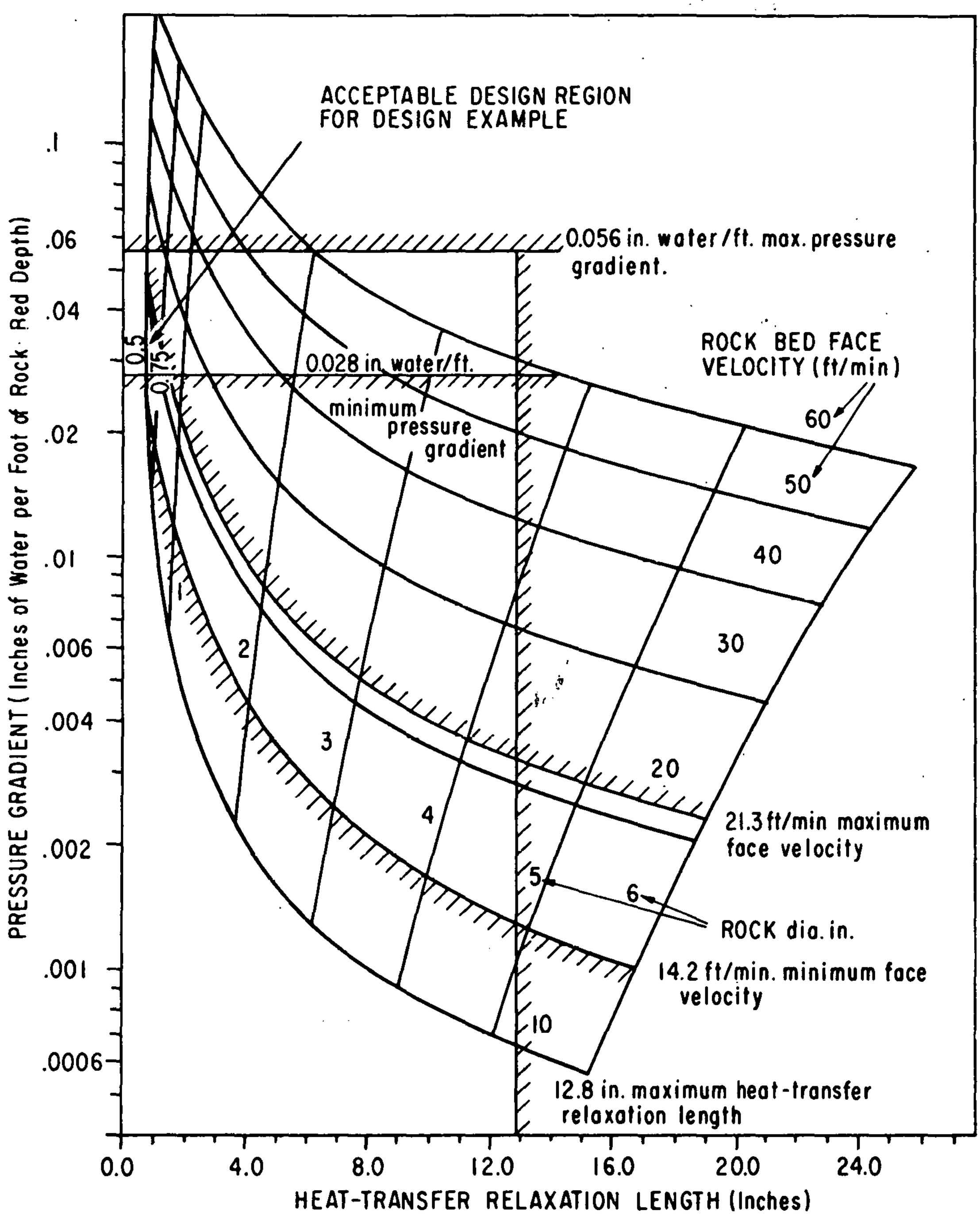

Figure 2-3. Rock Bed Performance Map for Design Example

The 20-feet-per-minute face velocity divided into the air flow rate determines the cross-sectional area of the rock bed.

$$\frac{1000 \text{ cu. ft./min.}}{20 \text{ ft./min.}} = 50 \text{ sq. ft.}$$

Fifty square feet of cross-sectional area can be easily obtained by making the box 8 feet long by 6 feet 3 inches wide on the inside.

The volume of rock will be 8 feet x 6 feet 3 inches x 5 feet 4 inches = 267 cubic feet. This amounts to 0.53 cubic feet of rock per square foot of collector. Recalling that the density of rock is about 167 pounds per cubic foot, and allowing for a 30-percent void fraction, we determine that the weight of the rock is

$$267 \text{ cu ft.} \times 167 \text{ lb./cu. ft.} \times 0.70 = 31{,}212 \text{ lb.} = 15.6 \text{ tons}$$

We can also look at the weight of the rock bed in terms of its floor loading.

$$\frac{31{,}212 \text{ lb.}}{50 \text{ sq. ft.}} = 624 \text{ lb./sq. ft.}$$

Since most basement floors can support only 150 to 400 pounds per square foot, we must ask a structural engineer to determine the load capacity of the floor and to design reinforcements if necessary. Otherwise the structure of the house could be damaged.

The last item to check is the cross-sectional area of the plena. If we make each plenum 8 feet wide by 6 inches high, its cross-sectional area will be 4 square feet, or 8 percent of the rock bed's cross-sectional area. Since this is less than the 10 percent suggested minimum, we must choose among several alternative methods of dealing with the problem.

- We can keep the design as it is and accept the possibility that the undersized plena will degrade the performance of the rock bed. This alternative will be unattractive to the designer who must guarantee the system's performance to a buyer.
- We can modify the floor above the rock bed so that the rock bed can be made 4 or more inches taller. If the rock bed can be located under a closet, this is a reasonable alternative.

- If the structural engineer recommends reinforcing the basement floor, we can make the top of the reinforced floor 4 inches deeper than the original floor. In this case we must provide some means of draining water from the rock bed so mildew and molds cannot grow inside. The drain must flow by gravity to another drain connected to the sewer and located outside the rock bed. If the drain inside the rock bed were connected directly to the sewer, the water trap would eventually dry out and admit sewer gas directly into the ventilation system.
- We can redesign the rock bed for a shallower rock depth. If we do this, the acceptable design region becomes much smaller or disappears entirely.

In this design example, we used a rock bed depth near the minimum practical depth to illustrate several of the tradeoffs that you may have to make when designing a rock bed. If you are designing a rock bed to fit in a basement, the most severe constraint is likely to be the depth. In locations where the rock bed can be deeper, you will have more freedom of design, but the floor loading will be higher.

FAN SELECTION

When you select a fan for the system your main concern will be matching the fan's pumping characteristics to the system's pressure drop characteristics. The fan's diameter, type (axial flow or centrifugal), blade angles, and operating speed (RPM) all affect its pumping characteristics. Fan manufacturers publish data giving flow rate versus static pressure for their products. If the fan can operate at more than one speed, data for several speeds will be published. Typical curves for three different fan speeds are shown in Figure 2-4.

The designer must calculate the system's pressure drop at the operating flow rate and select a fan and operating speed that will give a static pressure equal to the system's pressure drop at the operating flow rate. Figure 2-4 shows the operating flow rate. For the fan data shown in the figure, the fan should operate at 1100 RPM to provide the operating flow rate required by the system.

To illustrate what will happen if the designer makes the wrong choice of fan or fan speed, a curve labelled "system pressure drop" has been drawn on Figure 2-4. If the fan is too large or the fan speed too fast, the system will operate at Point A. Both the air flow rate and the system pressure drop will be greater than planned for, and the fan will consume more electric power than a properly sized fan.

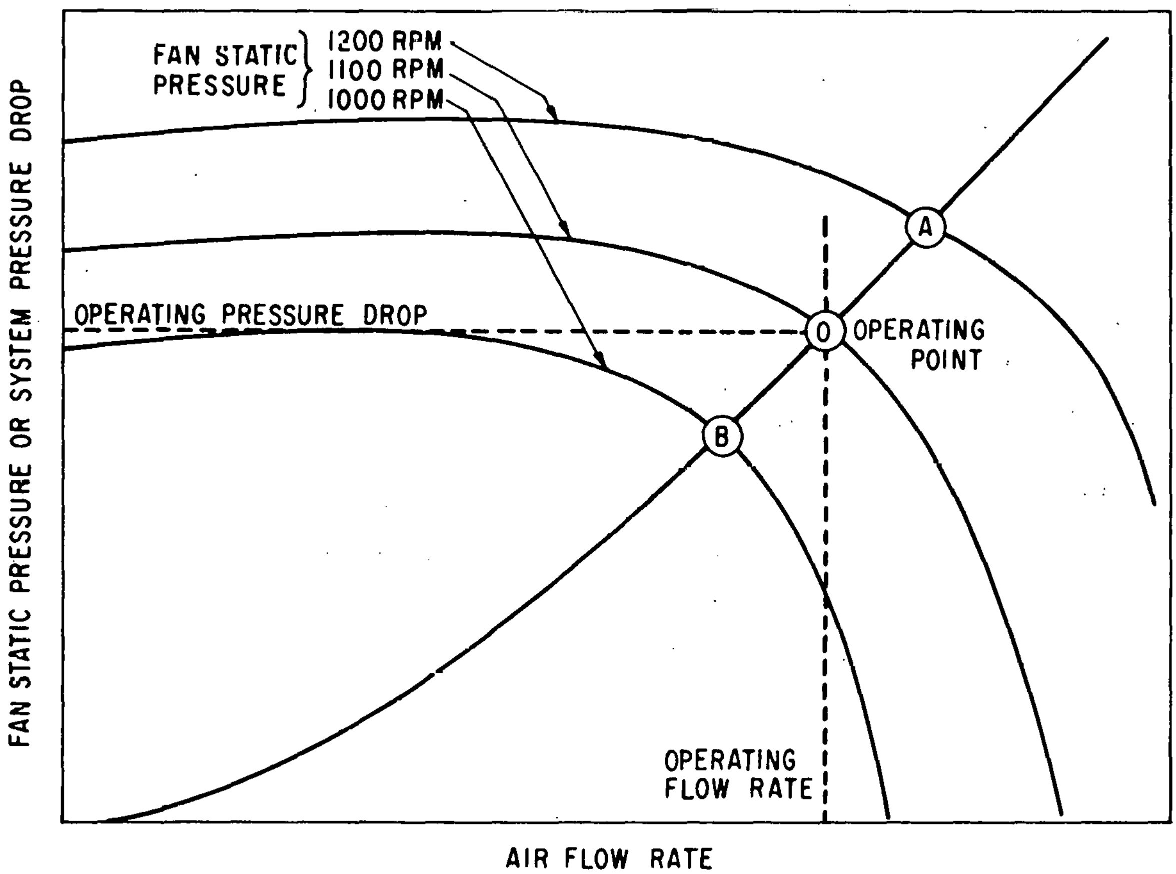

Figure 2-4. Typical Fan and System Characteristics

If the fan is too small or the fan speed too slow, the system will operate at Point B. The system pressure drop will be lower than it should be for normal operation; but, more importantly, the air flow rate will be lower than it should be. The low air flow rate will degrade the system's performance.

System Pressure Drops

The system pressure drop is the sum of several component pressure drops:

- Rock bed pressure drop
- Collector pressure drop
- Filter and damper pressure drops
- Duct losses, including allowance for bends, branch ducts, and expansions or contractions.

We have already discussed rock bed pressure drop. Information about collector, filter, and damper pressure drops should be obtained from the various manufacturers. Detailed procedures for calculating duct losses can be found in the ASHRAE Handbook of Fundamentals, Chapter 25, "Air Duct Design Methods". The pressure drops caused by expansion from the air duct into the plenum of the rock bed and the corresponding contraction at the opposite end of the rock bed should not be overlooked. The method for calculating these pressure drops is also given in the ASHRAE Handbook of Fundamentals.

Power Requirements

Having selected the fan, the designer must choose a motor to power it. If the motor is too small, the fan will not be able to pump the necessary amount of air, and frequent motor burnouts will be likely. An oversized motor will draw only slightly more power than a motor of exactly the proper size (unless the motor is grossly oversized). Thus, it is better to select a slightly oversized motor than an undersized one. Belt drives must be rated for one and a half times the motor power and should include an adjustable sheave on the motor.

Many fan manufacturers publish the motor requirements with the fan performance curves, as shown in Figure 2-5a. If the manufacturer's data is presented in this way, select the larger of the two motors indicated by the dashed lines on either side of the operating point. For example, in Figure 2-5a dashed lines corresponding to 3/4 and 1 horsepower lie on either side of the operating point (Point O). Choose the 1 horsepower motor.

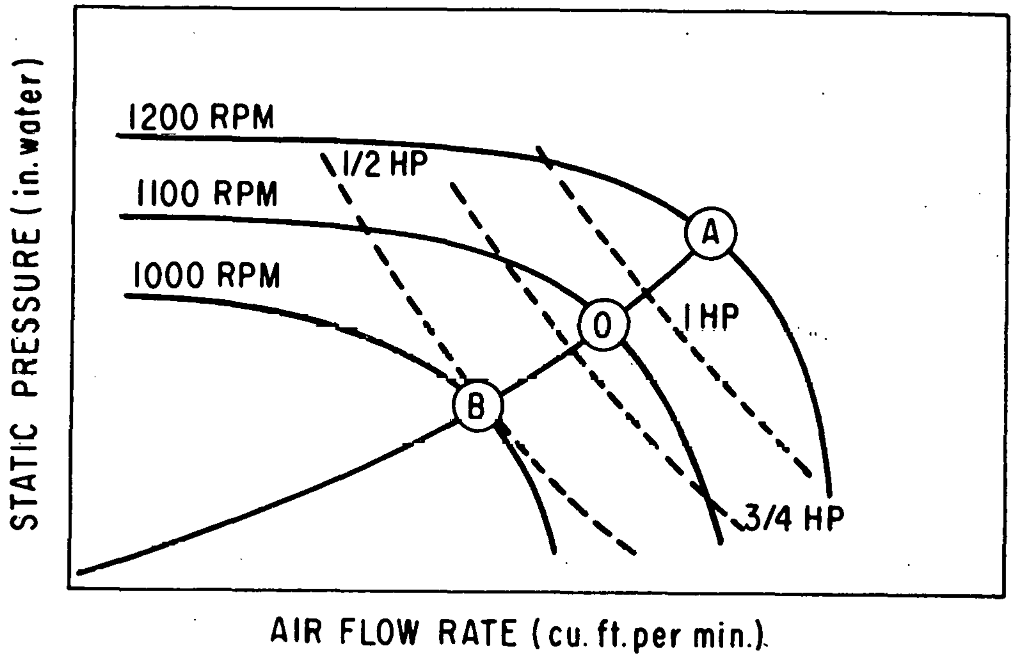

Figure 2-5a. Typical Fan Performance Curves Showing Motor Power Requirements

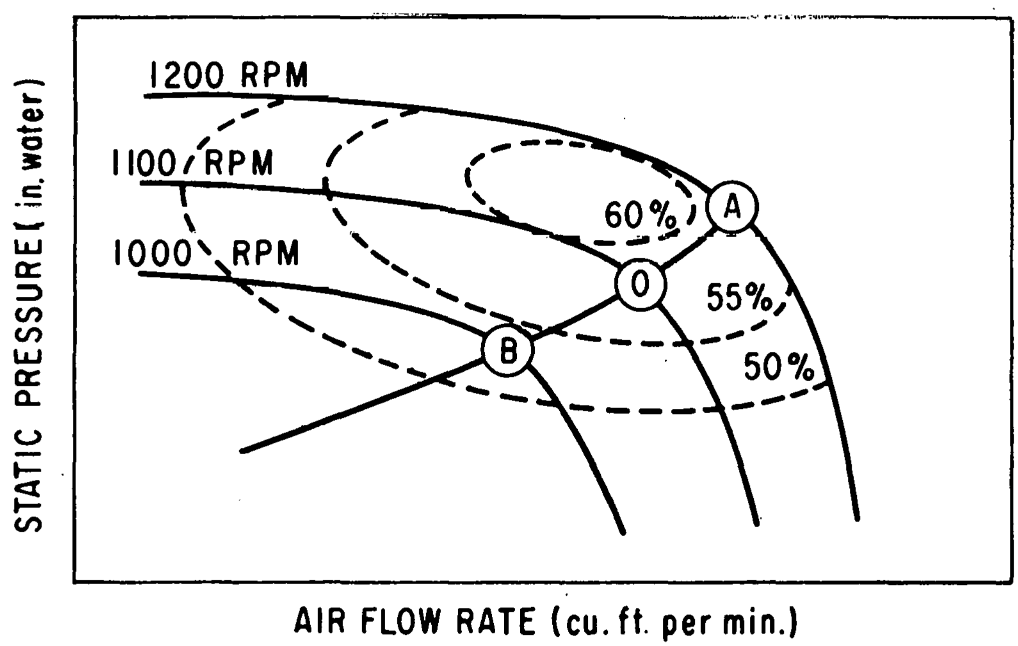

Figure 2-5b. Typical Fan Performance Curves Showing Fan Efficiency

Sometimes the manufacturer presents fan efficiency, as shown in Figure 2-5b, instead of motor horsepower. A short calculation is required to determine the minimum motor power.

Minimum motor power (H.P.) =

$$\frac{\text{air flow rate (cu.ft./min.)} \times \text{system pressure drop (in. of water)} \times 1.25}{\text{fan efficiency (percent)} \times 63.46}$$

The constant 63.46 converts the units of cubic feet per minute, inches of water, and percent into horsepower. The constant 1.25 gives a safety factor to ensure that the motor will not be undersized.

Fan Installation

The temperature of the air a fan must handle in a solar system can sometimes present a problem that is not often encountered in conventional heating systems. Study your system carefully and determine the maximum air temperature the fan will encounter. If that temperature exceeds 100°F, the fan must meet the following specifications.

- The fan bearings must be able to operate continuously at the maximum air temperature. Special bearings may be required. Alternatively, the bearings can be located outside the stream of hot air and shaft seals specified to minimize leakage.
- The motor and drive belts must be outside the stream of heated air.
- The fan should be selected on the basis of a modified operating point (Point M in Figure 2-6) instead of the previously defined operating point (Point O). To find the modified operating point multiply both the air flow rate and the fan static pressure at the operating point by the factor

$$\frac{\text{air temperature (°F)} + 460}{530}$$

The modified operating point applies only to fan selection and should not be used for other calculations.

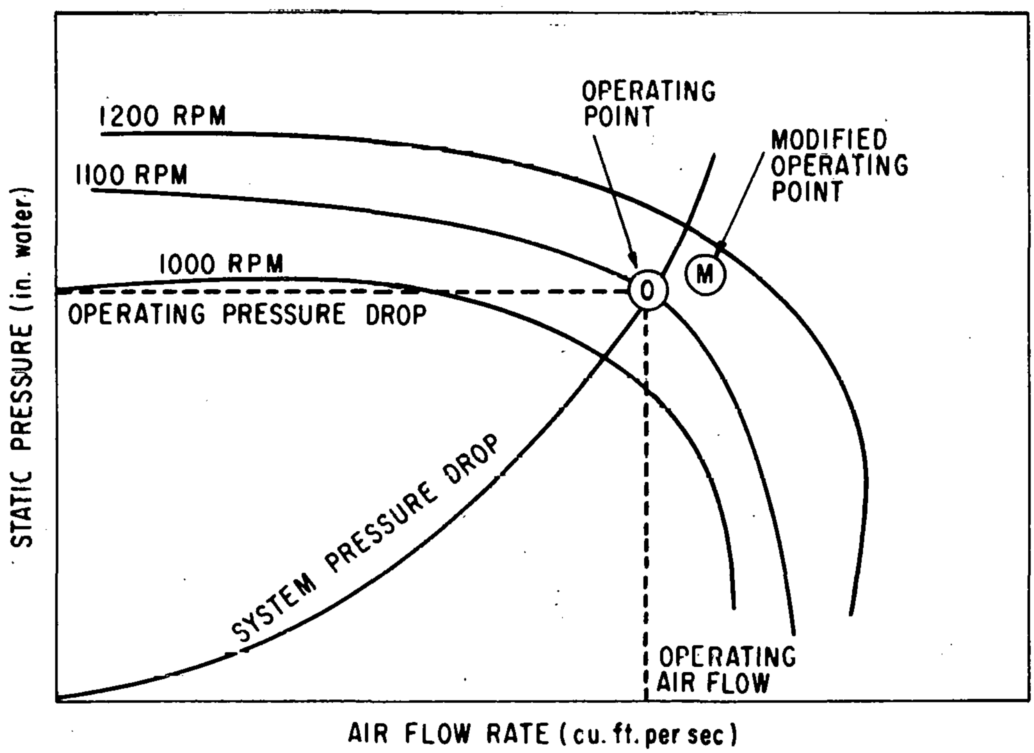

Figure 2-6. Modified Operating Point

Since the major operating expense of an air-based system is the cost of electricity, it is important to install the fan so that it will operate at its highest efficiency. We recommend connecting the inlet of the fan to the ductwork with a straight section of duct at least five duct diameters long. The duct should match the diameter of the fan inlet so that there will not be a sudden contraction or expansion as the air enters the fan. If a transition from a rectangular duct to a round fan inlet must be made, the transition slope should not exceed 4 in 12 inches (15°). It is especially important to avoid using bends or elbows near the fan inlet. Use similar care in designing the outlet ductwork.

OTHER COMPONENTS

Filters

Filters for the air-based solar system should be located:

- In the space-conditioning return air system, as required in nonsolar systems
- At the rock bin inlet
- At the rock bin outlet
- In the collector supply system.

The filters must be easily accessible for service or replacement. Filter mounts must minimize the amount of leakage bypassing the filter and leakage escaping the duct.

The face velocity of the filter (air flow rate divided by filter area) should not exceed 300 feet per minute. If the filter is larger than the cross-section of the duct, a transition to the full filter size, with a slope not exceeding 4 in 12 inches (15°), must be made.

Install a filter replacement indicating gauge at each filter. The gauge can be self-indicating or remote-indicating, but in either case the indicating part of the gauge must be located where it will be easy to see.

Dampers

Automatically controlled dampers are essential in the air-based solar system to control the direction of air flow through the rock bed and to control the collector and space heating loops. Dampers should be installed in the ducts between the collectors and the rock bed to prevent thermosyphoning at night. Thermosyphoning is a frequent cause of excessive heat loss from storage. Since the most serious problem with dampers in solar systems is excessive leakage, you should choose dampers with a leakage rate not exceeding 1/2 percent. Resilient damper seals are helpful here.

Air Handlers

Air handlers, including a fan and as many as four motorized dampers in one package, are available. The main advantages of an air handling unit are:

- Air handlers require less installation labor than separate components.
- Air handlers specifically designed for solar applications can be purchased.

We recommend choosing an air handler in preference to individual components if an air handler that meets your system's flow rate and control requirements is available.

Temperature Sensors

Two temperature sensors should be located in the rock bed, one 6 inches below the top of the rocks and the other 6 inches above the bottom of the rocks. Low temperature readings by both sensors indicate that little heat remains in the rock bed, and the auxiliary heater must supply space heat. High temperature readings by both sensors indicate that the rock bed is fully charged. A high temperature reading at the top and a low temperature reading at the bottom indicate that the rock bed is partially charged.

Be extremely careful to avoid damaging the temperature sensors while you are filling the rock bin. It is a good idea to install a spare temperature sensor, especially at the bottom of the rock bed where the temperature sensor would be difficult to replace.

Air-to-Water Heat Exchanger

If the solar system is to provide domestic hot water, an air-to-water heat exchanger is usually installed in the collector return duct. Although it is possible to bury a water tank in the rock bed, using an air-to-water heat exchanger in the duct offers the advantages of (1) good heat transfer characteristics, and (2) the ability to bypass the rock bed during the summer while providing solar-heated water. (Bypassing the rock bed in summer will reduce the air conditioning load if the rock bin is located in an air conditioned part of the building.)

Install a low-leakage automatic damper between the heat exchanger and the collector to protect the heat exchanger from freezing. The damper should close automatically when the collector is not collecting. In several instances heat exchangers have frozen when cold air from the collector settled around the heat exchanger where there was no damper to separate them, or where the damper leaked. The preferred type of actuator uses a 24-volt motor to open the damper and a spring to close it, so that the heat exchanger will be protected even during a power failure.

Auxiliary Heating System

Every solar-heated building must have an auxiliary heating unit to furnish heat when the sun is not shining or the thermal storage device is depleted. The auxiliary heater must be able to supply 100 percent of the heating load without any assistance from the solar system. Such a unit should be located as close as possible to the storage device to minimize the length and cost of the connecting ducts. Almost all air-based solar systems use forced-air auxiliary heaters, which can be placed in the duct following the rock bed, as shown in Figure 2-7a, or in parallel with the rock bed, as shown in Figure 2-7b.

The configuration shown in Figure 2-7a has a minimum rock bed operating temperature of about 65 to 70°F. Studies have shown that people find circulating air at 70°F chilling. To ensure that the air will circulate at a comfortable temperature, the auxiliary heater is turned on whenever solar energy is unable to maintain a duct temperature of about 95°F or more. While the auxiliary heater is operating, solar energy preheats the air entering the auxiliary heater. This system is usually used with an electric heater. Because the solar-heated air must pass through the auxiliary furnace's heat exchanger, some solar heat may be lost up the flue of a gas or oil furnace. If the auxiliary furnace has an automatic flue damper to prevent this loss, the solar preheat arrangement is feasible with a gas or oil furnace.

The configuration shown in Figure 2-7b is usually used with gas or oil auxiliary heaters without flue dampers or for situations where there is not room to install the rock bed between the blower and the auxiliary heater. The auxiliary heater is turned on whenever solar energy cannot maintain a duct temperature of about 95°F or more. If the rock bed cannot maintain a 95°F outlet temperature, a motorized damper switches the air flow to the auxiliary heater, and the auxiliary heater is turned on. Thus, if the rock bed and auxiliary heater are installed in parallel, the minimum usable rock bed temperature is 95°F.

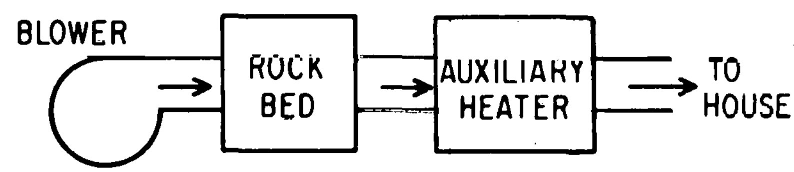

Figure 2-7a. Rock Bed in Series with Auxiliary Heater

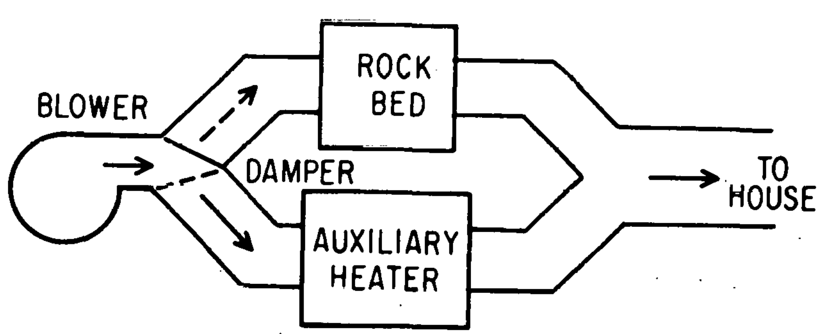

Figure 2-7b. Rock Bed in Parallel with Auxiliary Heater

In some solar heating installations the design air flow rate through the collectors does not match the residential space air flow requirements. For example, if the building is to be cooled as well as heated, the air flow requirements will normally be based on the cooling load and will be higher than the air flow required for heating. In areas where the design temperatures and the amount of available sunshine are low, it is possible that the solar collector's flow rate requirements will exceed the conventional heating system's flow specifications.

In those systems where the collector and the conventional heating system air flows are essentially balanced, the solar system blower can provide the total air movement. A second blower is necessary when an air imbalance exists or when constant air circulation through the building is required for ventilation or filtration. This second blower may be a component of a standard furnace, a roof-top unit, or an air handling system. When air movement requirements of the conventional system exceed those of the solar system, a duct must be installed to bypass the rock bed, and air balance between the two systems must be adjusted with a damper.

ROCK BED COSTS

The costs of rock beds will vary widely from region to region. The cost of rocks at the quarry typically range from three to ten dollars per ton, although "ornamental rock" may cost as much as sixty dollars per ton. You will need to carefully specify the type of rocks you want, and you may want to inspect them before they are delivered. In locations distant from suitable quarries delivery is a major expense.

The cost of the rock container will, of course, depend upon the type of container that you build. Wooden containers are the least expensive, followed by cinder block and concrete. Figure 2-8 shows the relative cost per cubic foot of these three types of containers. The cost per cubic foot for larger containers is less than for smaller ones, because the volume goes up faster than the surface area, and it is the surface area that determines the amount of material and labor involved in constructing the container.

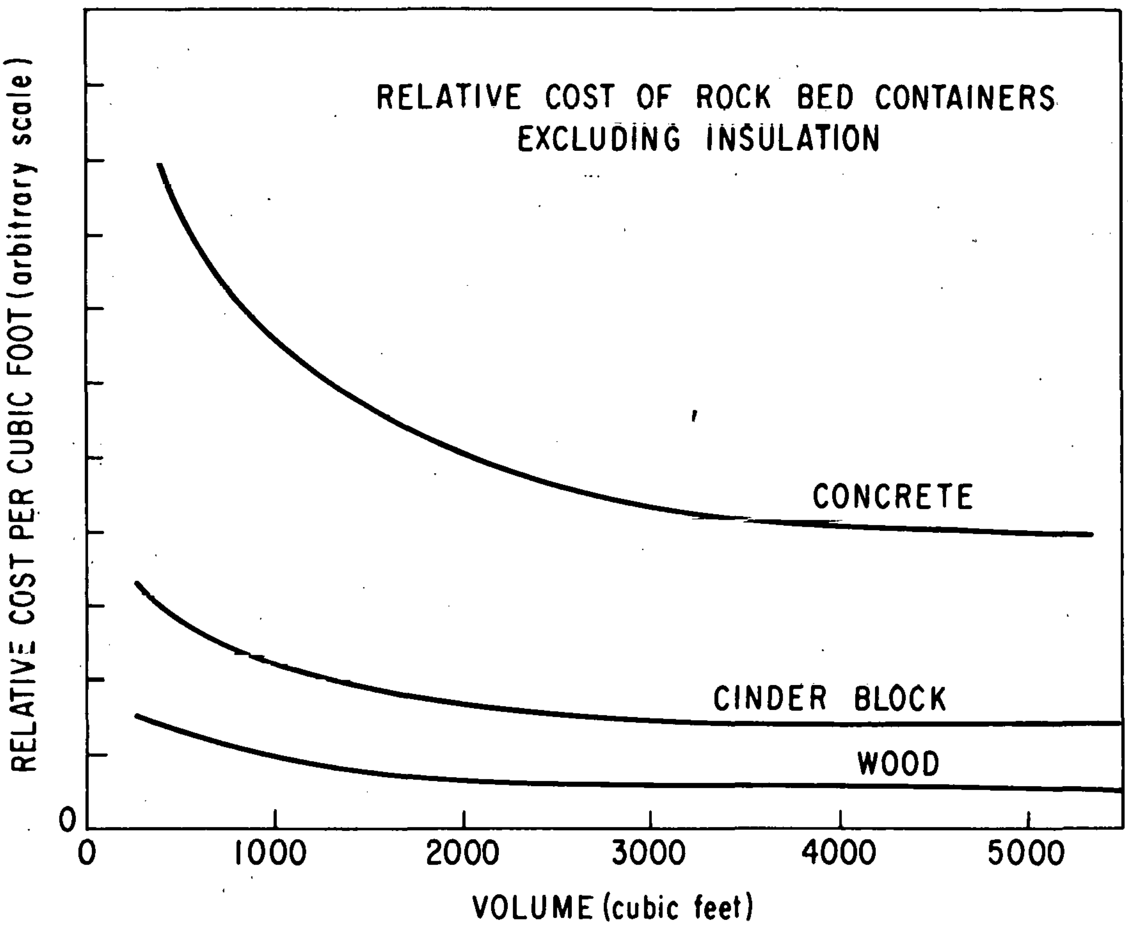

Figure 2-8. Relative Cost of Rock Bed Containers

Source: United States Energy Research and Development Administration, Division of Solar Energy. Inter-Technology Corporation Technology Summary, Solar Heating and Cooling. ERDA Report no. COO/2688-76-10, 1976.

OPERATION AND MAINTENANCE

Design for Maintainability

Maintenance must be considered as the system is being designed. Many solar systems fail or perform poorly because they cannot be properly maintained. For example, a component that cannot be easily replaced should last the lifetime of the system. Even better, the system should be redesigned so that the component can be repaired or replaced. Before installing any components the designer should consider how each component will be repaired or replaced and provide for working room around the components.

Simple systems are usually easier to maintain than complicated systems. The relative advantages of simple systems are:

- Initial cost is lower.
- Installation errors are less likely.
- There are fewer components to fail.
- Controls and operation are easier to understand.
- Defective components can be more easily found and replaced.

Answering three questions will help you decide whether the system is too complicated or too simple.

- If a feature were deleted from the system, how much energy collection would be lost?
- If a feature were deleted from the system, would a mode of failure be introduced?
- If a feature were deleted from the system, would human safety be degraded?

A system analysis method (such as f-Chart, SOLCOST, DOE-1, or TRNSYS) is required to estimate the extra amount of energy collection attributable to a particular feature. If the value of the extra energy collected over the life of the system is less than the cost of the feature, the feature cannot be justified economically. If, in addition, the answers to the second and third questions are "no," the feature should be deleted from the system.

Startup

Before applying insulation to the ducts and the rock bin, carefully inspect and test the system. Begin by checking all ducts, dampers, and wiring against the system drawings. Typical problems that might be encountered include:

- Inlet and outlet connections to rock bed, fans, heat exchanger, or collector reversed
- Normally open automatic dampers installed in place of normally closed automatic dampers
- Fan rotation reversed.

Leak detection is more difficult in air-based systems than in liquid-based systems, but in most cases leaks can be felt by hand while the fan is operating. Sometimes you can detect leaks more easily if you introduce a non-toxic odor such as air freshener into the duct. (Smoke is not recommended for use here.) Test the collector ducts when the sun is not shining, or put an opaque cover over the collectors before testing. Dampers may be closed manually as required to test various sections of the system.

If you find a leak, try to repair it permanently before applying duct tape. Leaks are most likely to occur at the seams of the rock bin, at joints between duct sections, and at connections between ducts and other equipment.

This is a good time to test the system in all operating modes to ensure that it functions as intended. Since systems vary greatly in their operating modes, only general guidelines can be given here. Most controller manufacturers make testing devices and publish data on how to use the testers. You may need a set of jumper wires to operate the system in its various modes. CAUTION, DANGEROUS VOLTAGE MAY BE PRESENT AT CONTROLLER TERMINALS. Flows in ducts can usually be determined by feeling a temperature change, and by observing temperature changes with the temperature sensors installed in the ducts, rock bed, and collectors.

Install the insulation on the ducts, rock bed, and other components. As you install the insulation you should label the ducts according to air flow direction. Tag the dampers, fans, filters, and so on to correspond with the numbers on the system drawings. Automatically controlled two-way dampers should be labelled "normally open" or "normally closed" and the legs of automatically controlled three-way dampers should be labelled "common," "normally open," and "normally closed".

Operate the system in its heating, noncollecting mode to fully discharge the rock bed. With the rock bed discharged its temperature sensors should indicate low temperatures. Change to the collecting, nonheating mode to charge the rock bed. As it charges, its top temperature sensor should indicate a high temperature, its bottom temperature sensor a low temperature. When the rock bed is fully charged, both temperature sensors should indicate high temperatures. Replace defective sensors.

Inspect the air filters. If they are excessively dirty, find the cause and repair it before you install clean air filters. The system is now ready for operation.

Periodic Inspection and Maintenance

The following tasks should be performed monthly during the heating season or at intervals specified by component manufacturers.

- Replace air filters.
- Inspect fan belts.
- Lubricate motor and fan bearings.

Before each heating season, inspect the system for leaks and check fans, dampers, sensors, and controllers for proper function.

Owner's Manual

The contractor should provide the owner with a manual that includes the following:

- A summary description of how to operate the controls
- Instructions on how to do periodic maintenance
- A detailed description of how the system operates
- Schematics of ducting and wiring with labels that correspond to the labels attached to the hardware
- Component and system warranties.

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THERMAL ENERGY STORAGE

CHAPTER 3. THERMAL ENERGY STORAGE IN LIQUID-BASED SYSTEMS

INTRODUCTION

Before selecting a particular type of storage tank, you must consider a number of variables:

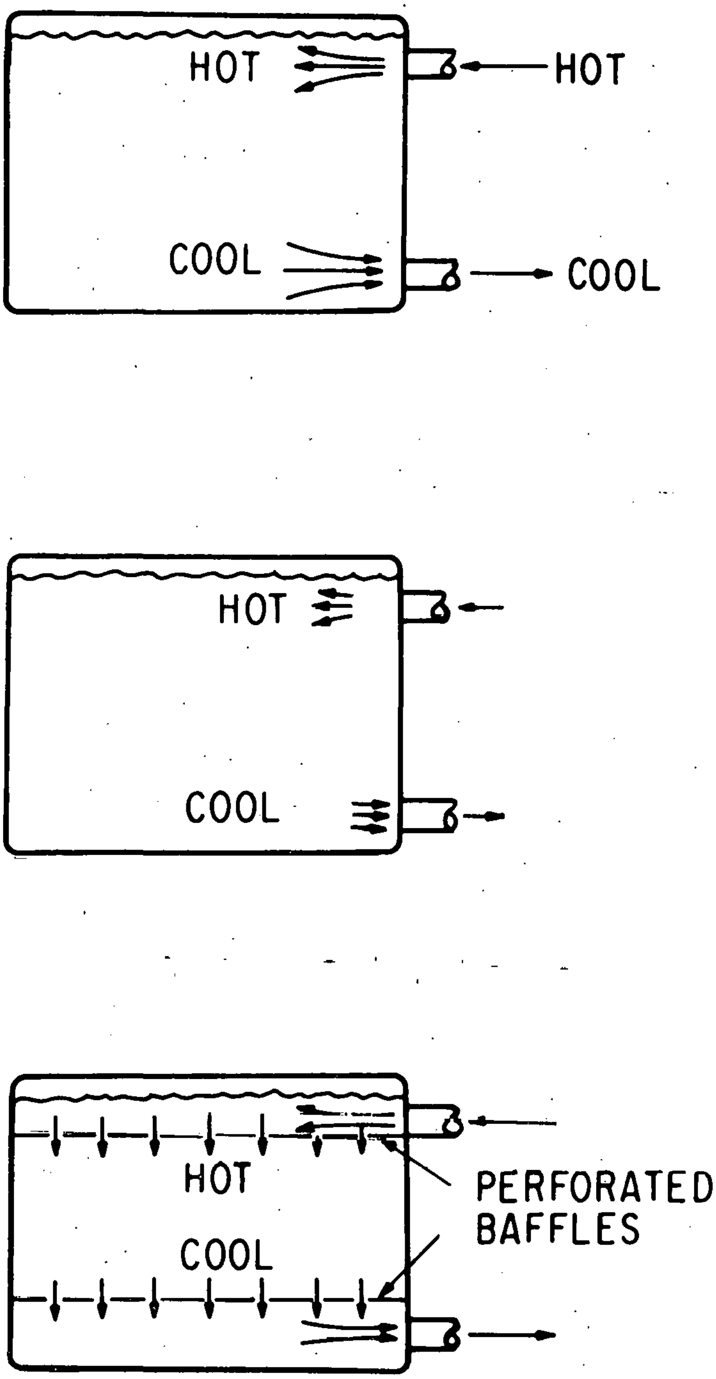
- Size and shape
- Material
- Location
- Insulation
- Corrosion
- Cost
- Leak protection
- Protective coating
- Installation
- Pressure and temperature limits

Our discussion of these considerations is based on experience with early residential solar heating systems. The designer should use tested materials, such as steel, fiberglass, concrete, or wood with plastic lining, to avoid the risks inherent in using materials that have not been proven. Advantages and disadvantages of each type of tank are shown in Table 3-1. All types of tanks can be purchased or constructed in any size likely to be used in storage systems.

Normally, only one tank is used for storage in space heating systems. Where the properly sized tank is unavailable, or where space restrictions dictate the use of smaller tanks in place of a larger one, two or more storage tanks can be used. Two small tanks cost more than a large one, however, and a multiple tank system requires more insulation because multiple tanks expose a larger surface area than a single tank.

In Chapter 1 we said that a storage system with perfect thermal stratification can perform 5 to 10 percent better than a thermally mixed system. Although perfect stratification cannot be achieved in a liquid-based system, partial stratification can be encouraged by the methods shown in Figures 3-1a, b, and c. Using a horizontal inlet and outlet and low-velocity flows (Figures 3-1a and b) is so easy to do that it should be standard practice in liquid-based systems. Baffles (Figure 3-1c) are most easily installed by the manufacturer. Avoid the design mistakes illustrated in Figures 3-2a, b, and c.

Connecting two or more tanks in series is sometimes promoted as a means of providing temperature stratification. In theory, only water from the coldest tank enters the collector, and the collector discharges water only to the hottest tank. In practice, the small gain from imperfect stratification is usually lost because of the higher heat losses suffered by multi-tank systems.



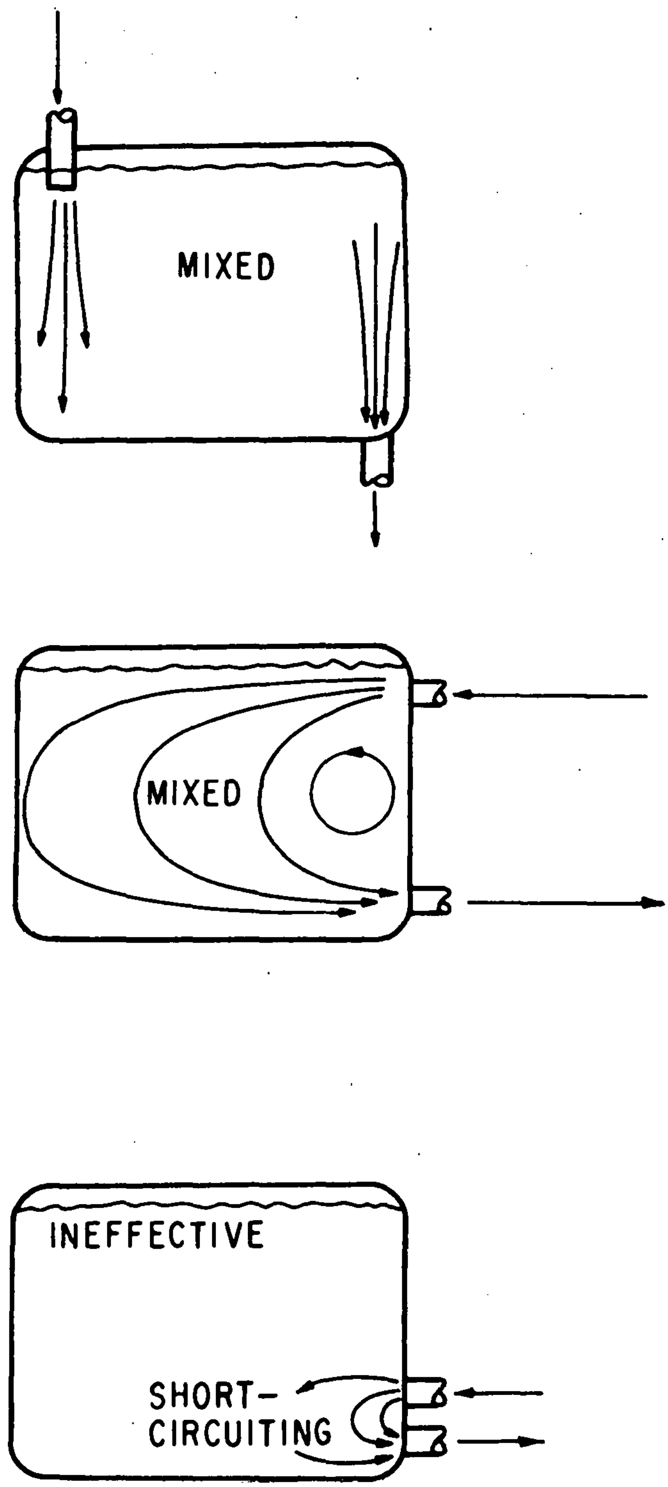
a. Horizontal Flow

Hot water should enter or leave at the top; cold water should enter or leave at the bottom.

b. Low-Velocity Flow

c. Baffles to Direct Flow

Figure 3-1. Methods of Promoting Thermal Stratification in Water Tanks



a. Vertical flow disrupts thermal stratification.

b. High-velocity flow causes turbulence, mixing, and short-circuiting.

c. Inlet and outlet close together causes short-circuiting. Parts of storage medium far from inlet and outlet may be ineffective.

Figure 3-2. Water Tank Design Mistakes

Table 3-1. Advantages and Disadvantages of Tank Types

ADVANTAGES

Steel Tank	Fiberglass Tank	Concrete Tank	Wooden Tank with Liner
Cost is moderate.	Factory-insulated tanks are available.	Cost is low.	Cost is moderate.
Steel tanks can be designed to withstand pressure.	Considerable field experience is available.	Concrete tanks may be cast in place or may be precast.	Indoor installation is easy.
Much field experience is available.	Some tanks are designed specifically for solar energy storage.		
Connections to plumbing are easy.	Fiberglass does not rust or corrode.		
Some steel tanks are designed specifically for solar energy storage.			

DISADVANTAGES

Steel Tank	Fiberglass Tank	Concrete Tank	Wooden Tank with Liner
Complete tanks are difficult to install indoors.	Maximum temperature is limited even with special resins.	Careful design is required to avoid cracks and leaks.	Maximum temperature is limited.
Steel tanks are subject to rust and corrosion.	Fiberglass tanks are relatively expensive.	Concrete tanks must not be pressurized.	Wooden tanks must not be pressurized.
	Complete tanks are difficult to install indoors.	Connections to plumbing are difficult to make leaktight.	Wooden tanks are not suitable for underground installation.
	Fiberglass tanks must not be pressurized.		

TANK TYPES

Steel Tanks

The principal advantages of steel tanks are their moderate cost, the relative ease of fabricating them to ASME Pressure Vessel Code requirements, the ease of attaching pipes and fittings, and the amount of experience available with steel tanks.

Steel tanks are subject to rust and corrosion. Six basic approaches to protecting the tank from corrosion are:

- Use a protective inner coating or lining.
- Increase the steel thickness.
- Use a chemical inhibitor.
- Use cathodic protection.
- Exclude oxygen by sealing the system.
- Use stainless steel alloys.

Protective Coatings: Glass and stone linings will protect steel from corrosion but are prohibitively expensive and not readily available in tanks larger than 120-gallon capacity. A large number of alternative coatings are available. Typical of these coatings are phenolic, epoxy, butyl rubber, and coal tar. How well the coatings adhere to the tank wall depends largely on the skill of the people who apply them. An interior coating that detaches from the walls can cause severe clogging problems, even when a flow strainer is used. Ask the tank or coating manufacturer for information on temperature limits, length of time the coating will protect the tank, and warranties.

Increased Thickness: Extra wall thickness in steel tanks may be worth the extra expense and can be easily combined with other methods of protection.

Chemical Corrosion Inhibitors: Chemical corrosion inhibitors protect the tank either by forming chemical complexes on the surface of the metal or by adjusting the acidity of the solution to a range where corrosion takes place very slowly. In systems protected by chemical corrosion inhibitors, the solutions must be tested periodically, typically every six to twenty-four months, in order to maintain the effectiveness of the inhibitor. Corrosion inhibitors are available as separate components to be added to plain water in a tank or mixed with antifreeze solution to protect the collector loop and heat exchangers.

Since all corrosion inhibitors are toxic to some degree, their use in solar systems should be considered carefully, particularly when potable water is to be heated. Chromate-type inhibitors should not be used in systems involving potable water because the chromates are both carcinogenic and highly toxic. Moreover, proper disposal of used chromate solutions is exceedingly difficult. Because sewage treatment plants cannot effectively treat them, chromates should not be flushed into sewers. Ask the inhibitor manufacturer about the toxicity of his product, what metals it protects, and how often it must be tested.

Cathodic Protection: A bar of highly reactive metal, such as zinc, aluminum, or magnesium, can be attached inside the tank to provide cathodic protection against galvanic corrosion. The bar must make electric contact with the tank and must be submerged in the water. The metal chosen for the protective bar should be more reactive than the most reactive metal in the solar system. This method of protection works well in combination with tank coatings. Since protection of the solar system ends when the metal bar is completely dissolved, the bar must be replaceable.

Sealing System Against Oxygen: If the system is completely sealed so that no air or water can enter it, the only oxygen available for the rusting process is the oxygen trapped inside the system. When the oxygen in the system is used up, no further rusting can occur. Sealed systems must be designed to ASME Pressure Vessel Codes, and an expansion tank may be required to limit the pressure created as the liquid in the system expands. This method of preventing rust does not protect against galvanic corrosion or acid attack.

Stainless Steel: Stainless steel tanks are rarely used in solar systems because of their high initial cost. However, stainless steel tanks do not require interior or exterior coatings or other methods of protection. When the cost of maintaining corrosion inhibitors is considered, a stainless steel tank may cost less than a carbon steel tank over the lifetime of some systems. Because there has not been much experience with stainless steel tanks in solar systems, we recommend that you investigate the costs of several alternative tank materials before you decide on a stainless steel tank.

These techniques of corrosion inhibition may be used singly or may be combined in various ways.

A sample specification for steel tanks is given in Appendix G.

Concrete Tanks

Concrete tanks for solar energy storage may be divided into two categories: cast-in-place tanks and precast tanks, including tanks designed primarily to be used as septic tanks and utility vaults. The problems of design and selection of concrete storage systems can be addressed by good specification and installation practices. The following discussion is based on actual experience with the use of concrete tanks in solar systems and on the requirements of applicable codes and standards to storage systems.

Major advantages of concrete tanks are that they are relatively inexpensive as long as their shape is kept simple, the mass of concrete becomes part of the storage system, and concrete is a readily available construction material. Concrete also has considerable resistance to underground loads. Because concrete can be cast in almost any shape, it is ideal for retrofit installations. Concrete is also fireproof and corrosion resistant.

Concrete does have several disadvantages, however. It is subject to capillary action, so water can seep through cracks and joints unless the tank is lined. Concrete requires sophisticated design and workmanship and, being very heavy, often requires special foundations. Leakproof connections through the tank walls are often difficult to make, and substances leaching from unlined concrete tanks can cause corrosion of metals (especially aluminum) in the system.

Detailed specifications for concrete tanks are given in Appendix H.

Fiberglass-Reinforced Plastic Tanks

Both factory-insulated and on-site-insulated fiberglass-reinforced plastic (FRP) tanks are available and have been successfully used in solar energy installations. The main advantage of FRP tanks is that they do not corrode.

We recommend that you use factory-insulated FRP tanks, which are designed specifically for solar energy storage and are available in convenient sizes and shapes. A typical factory-insulated FRP tank consists of an inner FRP shell covered with 2 to 4 inches of urethane insulation. An outer FRP shell protects the insulation. Factory-insulated FRP tanks can be used outdoors above or below grade or in a garage. In new houses, they can be installed in a basement or utility room. Because these tanks are usually too large to fit through the doors of existing houses, retrofit applications are not practical.

Installation of on-site-insulated FRP tanks requires much more care than that of factory-insulated FRP tanks. The extra labor required to insulate and install an on-site-insulated tank may make a factory-insulated tank less expensive. Some installations, however, can benefit from the greater variety of sizes and shapes that are available in on-site-insulated tanks.

Nearly all FRP tanks have two limitations.

- FRP tanks must not be pressurized or subjected to a vacuum inside the tank unless they are specifically designed for it. A vent will ensure that the tank is not subjected to these conditions.

- Tank temperatures must never exceed the limit specified by the manufacturer. Exceeding the limit will void the warranty and damage the tank. Since the temperature limit is nearly always below the boiling point, THE SYSTEM CONTROLLER MUST STOP HEAT ADDITION TO THE TANK BEFORE THE MANUFACTURER'S TEMPERATURE LIMIT IS REACHED. Adjust the cutoff point on the controller to 5°F below the temperature limitation on the tank. Since many controllers do not have a provision for limiting the tank temperature, you must select the controller carefully.

The temperature limitation is determined by the type of resin used to make the tank. Ordinary polyester resins have a limitation of 160°F -- suitable only for low-temperature tanks. With premium quality resins, the temperature limitation can be raised to 180-200°F. Consult the tank manufacturer for details.

A sample specification for FRP tanks is shown in Appendix I.

Wooden Tanks with Plastic Liners

A vinyl-lined, 2000-gallon cylindrical tank is available in kit form.* According to the manufacturer's instructions, the tank, made of 3/8-inch CDX plywood and reinforced with steel bands, can be installed with simple hand tools. The kit includes insulation for the bottom, sides, and cover, as well as a 1-inch PVC compression fitting. The maximum allowable temperature inside the tank is 160°F.

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*Acorn Structures, Inc., Concord, Massachusetts 01742.

You can make a small plastic-lined wooden tank by using the type of vinyl bag made to line a pickup-truck bed as a liner and adapting the wooden box described in Appendix F to suit the dimensions of the bag. The dimensions of this type of tank make it suitable for installation in a crawl space. Since the bag will have only one opening, you will have to add another one. Put it as far from the first opening as possible to minimize short-circuiting from the inlet to the outlet. As in other tanks with vinyl liners, the temperature within the tank should be strictly limited to 160°F or less.

TANK COSTS

Factors that affect tank installation costs include the tank's size, whether it is being installed in a new building or has to be built into an existing one, its location, its temperature requirements, its insulation requirements, and the materials used.

Size

Tank size is the most important factor affecting cost. Generally, the cost per gallon decreases as the size of the tank increases, as shown in Figure 3-3. Because system performance is not extremely sensitive to tank size (unless the tank is considerably undersized) the best approach is to select a standard size close to the optimum size as determined in Chapter 1.

New Building or Existing Building

Whether the tank is to be installed in a new or an existing building limits the choice of tank materials and location. A steel or fiberglass tank can be installed in the basement of a new building before the floor joists are put in, but such an installation is not ordinarily possible in an existing building. For an existing building you must choose either a different location or a different tank material.

Reinforcements to the foundation can be specified before a new building is built, but in an existing building part of the basement floor may have to be removed before a reinforced section of floor can be installed. The greater flexibility in choosing tank materials, tank location, and foundation reinforcement generally gives a solar system in a new building a cost advantage over a solar system in an existing building.

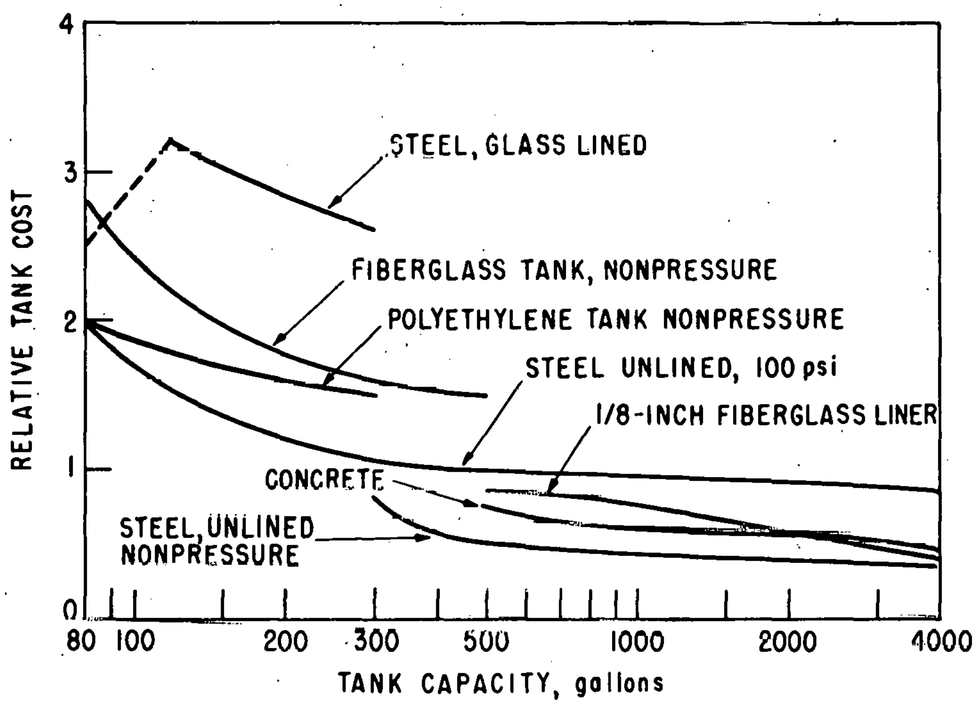

Figure 3-3. Relative Cost of Tanks in the Los Angeles Area, June 1975

Cost of steel tanks includes supports and fittings. Add 0.1 unit to the cost of unlined steel tank for phenolic lining.

Source: E. J. Beck, Jr. and R. L. Field. Solar Heating of Buildings and Domestic Hot Water. Civil Engineering Laboratory Technical Report R835, Naval Construction Battalion Center, Port Hueneme, California, April 1976.

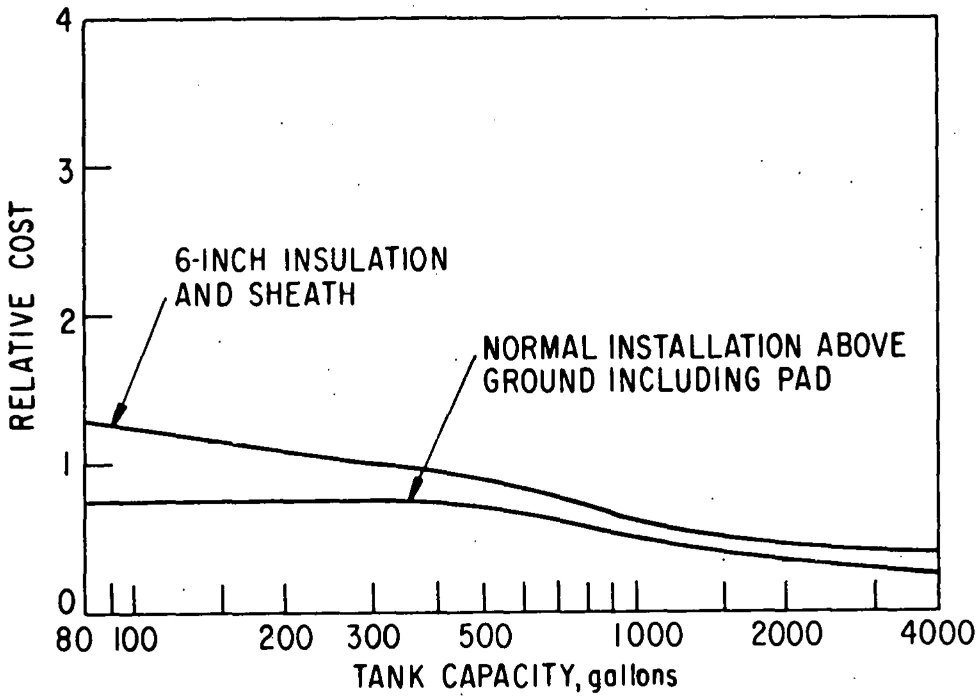

Figure 3-4. Relative Cost of Insulation and Installation for Tanks in the Los Angeles Area, June 1975

Relative cost scale is the same as in Figure 3-3.

Source: E. J. Beck, Jr. and R. L. Field. Solar Heating of Buildings and Domestic Hot Water. Civil Engineering Laboratory Technical Report R835, Naval Construction Battalion Center, Port Hueneme, California, April 1976.

Location

Tank location affects the special requirements for tanks shown in Tables 1-2 and 1-3. These requirements include waterproof insulation, extra-thick insulation, freeze protection, protection from groundwater (tie-down straps, exterior corrosion protection, provisions for drainage of groundwater, etc.), long-lifetime components, and limitations on materials that can be used. Each special requirement adds to the system's cost.

Underground tanks generally use the most special requirements. The insulation should be waterproof and should have extra thickness because of the possible presence of groundwater, which reduces its insulating value. Tie-down straps are required to prevent flotation of a partly filled tank. Provisions for draining groundwater and rainwater away from the tank and exterior corrosion protection for steel tanks should also be included. Because access to them is difficult, underground tanks should be designed for a long lifetime. Steel, fiberglass, and concrete can be used for underground tanks, but wood is not recommended because of its short lifetime when in contact with earth.

Basement locations generally impose few special requirements on the storage tank. Weatherproof and extra-thick insulation, freeze protection, and protection from groundwater are not needed when the tank is indoors. Steel and fiberglass tanks cannot be installed in existing buildings because they ordinarily will not fit through the doors. If a steel or fiberglass tank is to be installed in a new building it should last the lifetime of the building. Both wooden and cast-in-place concrete tanks are suitable for basement installation.

The requirements for tanks in basements also apply to tanks in crawl spaces. In addition, since most crawl spaces are unheated, extra insulation and a means of protecting the tank from freezing are needed.

A garage is an excellent location for steel or fiberglass tanks. The large door allows for easy installation or replacement of the complete tank. Since most garages are unheated, extra insulation and a means of protecting the tank from freezing are needed.

The requirements for outdoor, aboveground storage tanks are the same as for those in garages, except that the tank must also be protected from the weather. Some factory-insulated fiberglass tanks are adequately protected against weathering and do not need additional protection.

Temperature Requirements

High storage temperatures are undesirable for the following reasons.

- High temperatures decrease collector efficiency.
- High temperatures increase insulation requirements.
- High temperatures require better quality lining and material for all types of tanks.
- High temperatures increase corrosion rates.

Each of these effects of high storage temperature tends to increase costs.

Insulation Requirements

Insulation requirements are primarily determined by the tank's location. Indoor tanks in heated areas require the least insulation, and protection of the insulation can consist of a simple cover. Typical insulation costs for indoor tanks are shown in Figure 3-4. Tanks in unheated indoor locations need extra insulation thickness, but a simple cover is sufficient protection for the insulation. Outdoor tanks have the most severe insulation requirements. Aboveground tanks require extra insulation thickness and protection from weather. Underground tanks require waterproof insulation and extra thickness to compensate for the presence of groundwater. The cost of insulating an outdoor tank is about two to four times the cost of insulating an indoor tank. The costs of materials and labor frequently make a factory-insulated tank less expensive than an on-site-insulated tank.

Materials

In the 500- to 4000-gallon-capacity sizes used in space heating systems, the least expensive storage tanks are unlined, unpressurized steel tanks, plastic-lined wooden tanks, and concrete tanks. Steel and concrete tanks are roughly comparable in cost, as shown in Figure 3-3. Local availability, shipping costs, and installation costs tend to determine which type of tank is least expensive for a particular installation. The cost of the lining necessary for steel tanks does not change this conclusion. The cost of insulation makes plastic-lined wooden tanks (not shown in Figure 3-3) slightly less expensive than steel tanks.

Steel tanks with a 100 psi ASME rating generally cost approximately twice as much as non-pressure-rated tanks, but if you have a local source of ASME-rated tanks the difference in cost can be much less. A sealed system using a pressure-rated tank, a phenolic lining, and cathodic protection has a potentially long lifetime.

Fiberglass is the most expensive material for tanks, but it does not corrode. If the maximum tank temperature is limited by the system controller, a fiberglass tank can have the long lifetime required for some installations.

PUMPS

Pumps are used to circulate heat transfer fluids in all liquid-based solar systems except thermosyphon systems. This section will discuss the types of pumps available and how to select a pump for a specific application.

Two types of pumps are readily available on the market. One is the positive displacement pump, characterized by a low flow rate and high head. ("Head," a term used throughout this section, is another word for pressure, which can be measured in the number of feet of liquid that the pressure can support in a vertical pipe.) The positive displacement pump is rarely used in solar systems, which do not need a high head. If you use a positive displacement pump you will need a relief valve on the output side to prevent excessive pressure from mounting if a pipe becomes plugged.

Centrifugal pumps, characterized by a low head and high flow rate, are used in most solar systems and are available with a wide variety of flow rates. These pumps can be sealed against leaks in three ways: with adjustable packing, with a mechanical seal, or with a magnetic coupling.

The adjustable-packing seal, shown in Figure 3-5, is the least desirable sealing system because it requires frequent inspection and adjustment. This type of seal uses a packing gland to squeeze the packing between the pump housing and the pump shaft. If the packing-gland adjustment is too tight, the packing will bind the pump shaft, but if the packing-gland adjustment is too loose, the seal will leak. As the packing wears, the packing gland must be tightened. Adjustable-packing seals should not be used where access to the pump is difficult, where leakage from the seal could cause system failure, where leakage could create a hazard to people, or where antifreeze fluids are used. Antifreeze solutions, especially silicon oils and, to a lesser extent, glycol solutions, have an affinity for leaks.

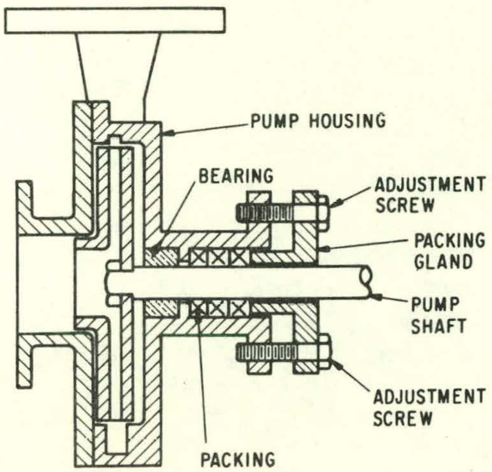

Figure 3-5. Cross-section through an Adjustable-packing Seal

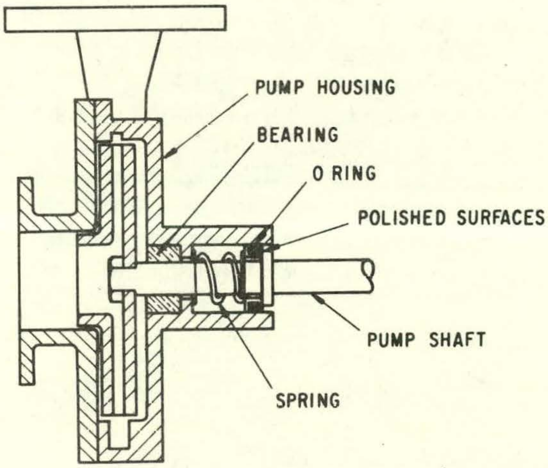

Figure 3-6. Cross-section through a Mechanical Seal

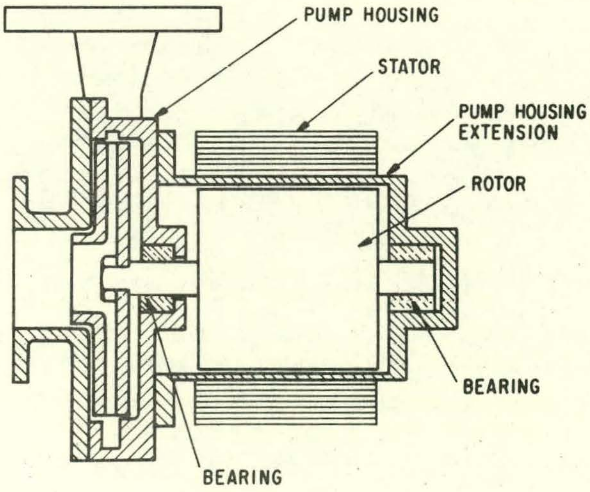

Figure 3-7. Cross-section through a Magnetically Coupled Pump

The mechanical seal, shown in Figure 3-6, consists of two carefully polished surfaces pressed together by a spring. One of the surfaces is part of the pump shaft, and the other surface is sealed against the pump housing with an O ring. A minute amount of leakage lubricates the polished surfaces. The amount of leakage is so small that it evaporates before becoming visible.

Considerable experience with hydronic heating systems has shown that mechanical seals can last the lifetime of the system without requiring adjustments. The system must be kept clean, for grit in the water can easily scratch the polished surfaces. Chromate-type corrosion inhibitors have caused failures when the leakage evaporated and deposited hard chromate crystals between the polished surfaces. High temperatures and pressures also cause premature failure. Some antifreeze fluids, such as silicon oils, tend to leak excessively with mechanical seals.

A pump that uses a magnetic coupling, shown in Figure 3-7, has no troublesome rotating seals. Instead, the rotor of the electric motor and its bearings are placed entirely inside an extension of the pump housing. The stator of the electric motor fits outside the pump housing and drives the rotor with a rotating magnetic field. In some designs a set of rotating magnets replaces the stator, and an external electric motor turns a shaft that rotates the magnets. Magnetically coupled pumps can be expected to last the lifetime of the system.

Pump Performance

Figure 3-8 shows a typical pump performance curve, which includes three different sets of curves. (These curves can be obtained from pump manufacturers and distributors.) The designer must first consider the upper set of curves, which gives the head versus flow. Figure 3-8 shows six head-versus-flow-rate curves corresponding to six impeller diameters. Manufacturers supply several impeller sizes to fit each pump model in order to closely match the pump characteristics to the system characteristics. Also shown on the upper set of curves are the pump efficiency and the required motor horsepower.

To use the upper set of curves in selecting a pump, you must know the flow rate at which the system must operate. This flow rate is determined from manufacturers' or distributors' data on collectors or heat exchangers. Data on head loss through collectors and heat exchangers is also available from manufacturers or distributors. The ASHRAE Handbook of Fundamentals, Chapter 26, "Pipe Sizing," gives a method for calculating head loss caused by friction in pipes. The sum of head losses for individual components equals the head loss for the system. We have plotted on Figure 3-9 a typical head-loss-versus-flow-rate curve for a system, shown as Curve A. Although we have shown a complete curve, you will need to calculate only two or three points close to the flow rate at which your system must operate.

Curve B, a pump-head-versus-flow-rate curve, is also shown in Figure 3-9. For clarity, we include only one pump curve. A system having the characteristics of Curve A and using a pump with the characteristics of Curve B will operate at the intersection of the two curves. For such a system the flow rate will be Q and the head will be H. The designer must select a pump that will give a flow rate Q that is within 5 percent of the flow rate required by the collector or heat exchanger. In situations where more than one pump and impeller diameter combination will give acceptable flow rates, curves similar to those in Figure 3-8 will help you choose the pump with the highest efficiency.

Pump Power

The lower set of curves in Figure 3-8 gives the power consumed by the pump versus flow rate and impeller diameter. After selecting a pump, an impeller diameter, and a flow rate, you can use the lower set of curves to determine the size of the motor required by the pump. In a well designed system the total pumping power for the system should not exceed 1 1/2 percent of the solar power being collected. (1 HP = 2546 Btu per hour; 1 watt = 3.41 Btu per hour.)

Net Positive Suction Head

The middle curve in Figure 3-8 gives the pump's net positive suction head (N.P.S.H.) requirement. Net positive suction head is the absolute head at the pump inlet minus the vapor head of the liquid being pumped. If the N.P.S.H. does not exceed the pump's N.P.S.H. requirement, cavitation can occur and can destroy the pump in a short time. Most systems have sufficient N.P.S.H., but all systems must be checked for this requirement.

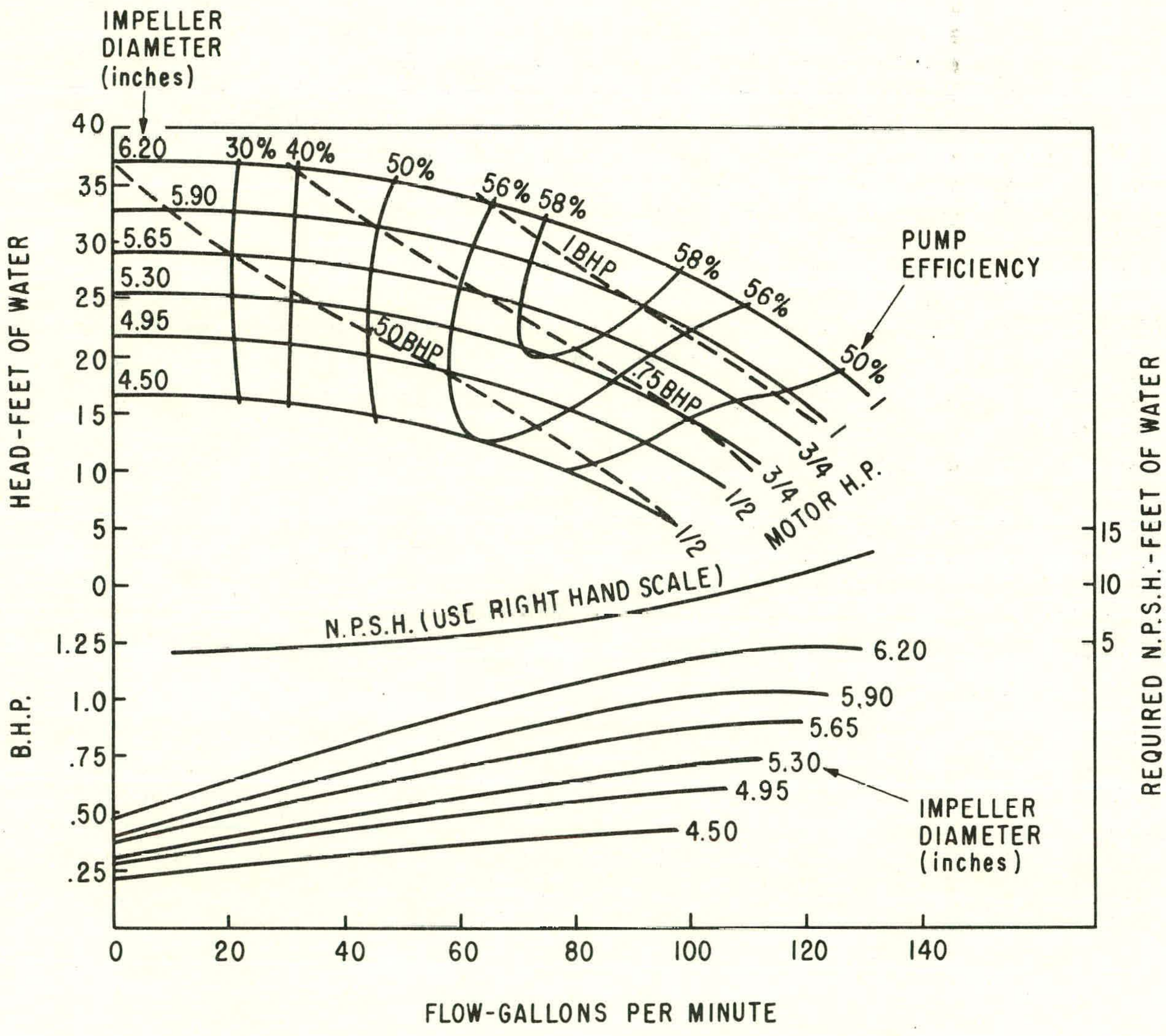

Figure 3-8. Typical Pump Performance Curve

Based on a drawing supplied by Taco, Inc., Cranston, Rhode Island.

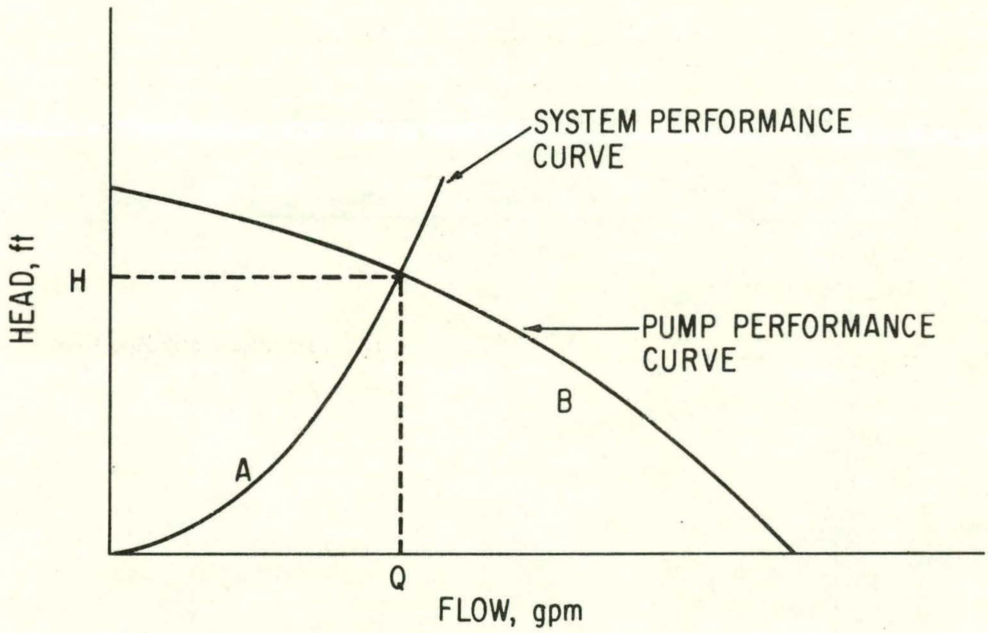

Figure 3-9. Pump and System Performance Curves

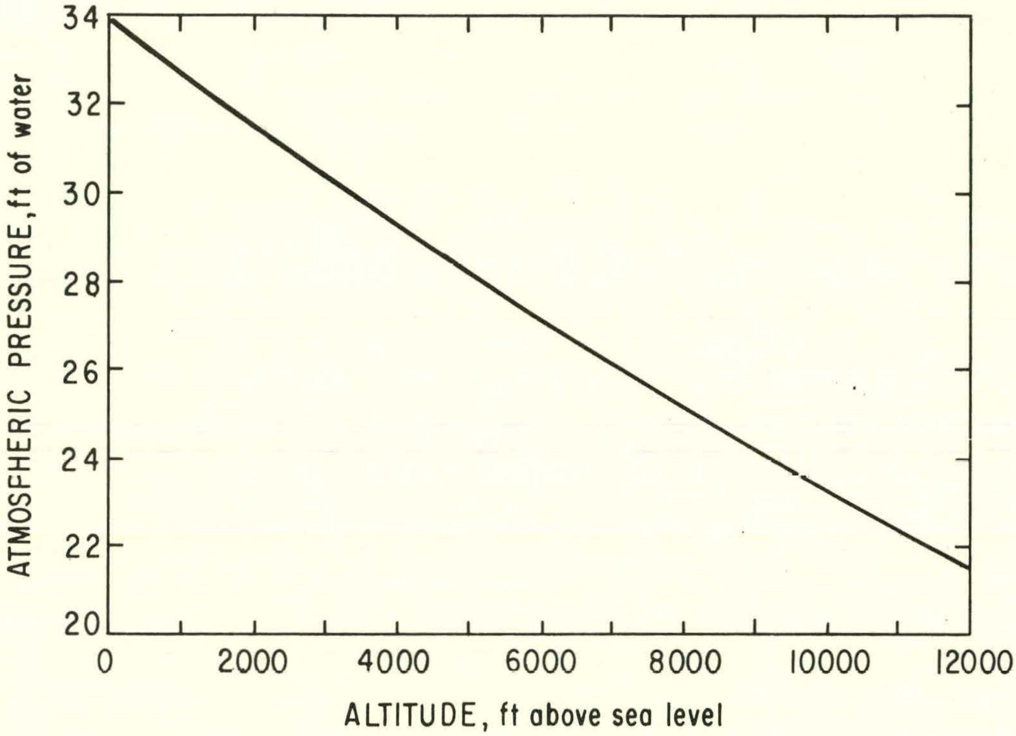

Figure 3-10. Atmospheric Pressure Versus Altitude

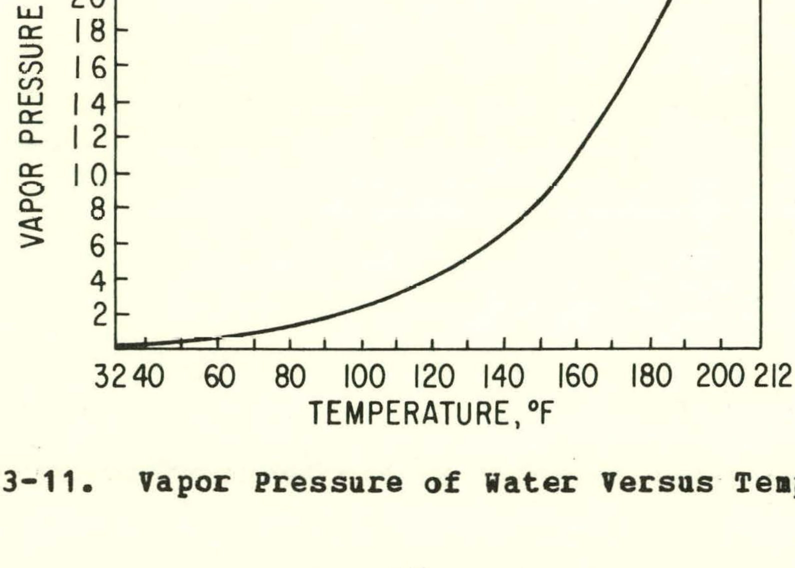

Figure 3-11. Vapor Pressure of Water Versus Temperature

The N.P.S.H. at the pump inlet can be calculated in the following manner.

- Find the atmospheric pressure measured in feet of water. Figure 3-10 gives atmospheric pressure versus altitude.
- Measure the difference in height (in feet) between the pump inlet and the surface of the water in the tank. If the pump is located below the water surface, add this difference. If the pump is located above the water surface, subtract this difference.
- Subtract the head loss caused by friction in the pipe connecting the pump inlet to the storage tank. Refer to the ASHRAE Handbook of Fundamentals, Chapter 26, for the method of calculating this head loss.
- If the system is pressurized, add the tank gauge pressure measured in feet of water. (Multiply psig by 0.43 to get feet of water.)
- Subtract the vapor pressure, measured in feet of water, at the highest temperature the system will reach. Figure 3-11 gives the vapor pressure of water versus its temperature.

The result is the N.P.S.H.

Pump Materials

Pumps are usually made from iron, bronze, or stainless steel. Iron will quickly rust in an open system, but it can be used in a closed system with corrosion inhibitors. Both bronze and stainless steel pumps can give long service life.

OTHER COMPONENTS

Hand-Operated Valves

Solar systems generally use the same types of hand-operated valves commonly found in residential water systems. There are two types of valves, the globe valve and the gate valve. The globe valve (Figure 3-12) controls the amount of flow. Globe valves do not permit complete draining of lines when they are placed in a horizontal position, and they offer more resistance to flow than do gate valves. Gate valves (Figure 3-13) are not suitable for controlling the amount of flow but are used to open or close a line. When open, gate valves have only small resistance to flow. They can be used as isolation valves. Most valves used in solar systems are of this type.

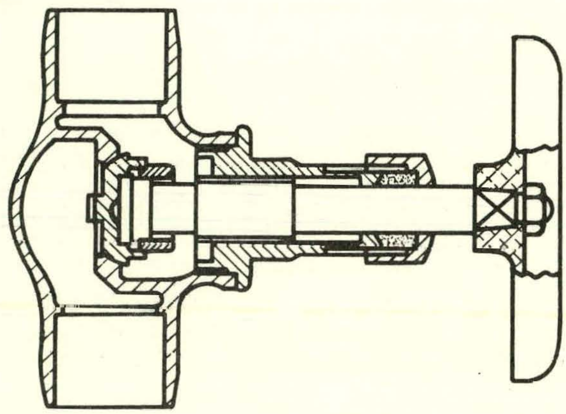

Figure 3-12. Typcial Section through a Globe Valve

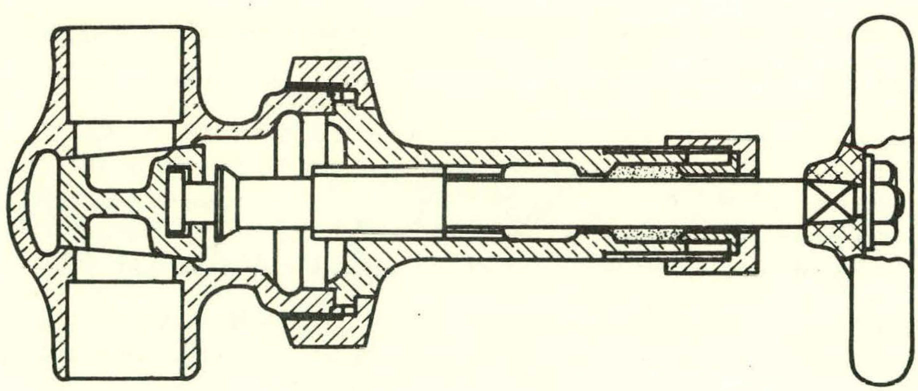

Figure 3-13. Typical Section through a Gate Valve

Temperature and Pressure Relief Valves

Any closed subsystem must contain a temperature and pressure (T&P) relief valve to prevent damage to the system from excessive temperature or pressure. T&P valves for domestic hot water tanks usually have 210°F temperature and 150 psi pressure settings. Temperature and pressure settings for other types of tanks will differ from settings for domestic hot water tanks. All T&P valves must meet ASME Boiler and Pressure Vessel Code requirements.

Expansion Tanks

The liquids in a solar system expand when they are heated. The pipes and other components also expand, but not enough to contain the increased volume of the liquid in a closed system. To allow room for this excess volume in closed systems, an air space must be provided. The air space may be provided as part of the main tank in the system or as a separate expansion tank.

Incorrect sizing of expansion tanks has been a frequent cause of trouble in solar systems. A method of determining expansion tank size is given in the ASHRAE Handbook and Product Directory, 1976 Systems, Chapter 15, "Basic Water System Design." Since the volumetric expansion of antifreeze solutions is greater than the volumetric expansion of water, systems using antifreeze require a larger expansion tank than do systems using water. The method of calculating expansion tank size given in the ASHRAE Handbook and Product Directory must be modified as follows.

- From the distributor or manufacturer of the fluid, obtain data on how the fluid's density changes with changes in temperature. (This information for water and some other heat transfer fluids can be found in Figure B-4, Appendix B of this manual.)
- Multiply the volume of fluid in the system by the fluid's density at the lowest temperature that you expect and divide the result by the fluid's density at the highest temperature that you expect. The result will be the total expansion of the fluid in the system (Part E in Equation 7 of the ASHRAE handbook mentioned above). All other parts of the ASHRAE method of sizing expansion tanks can be used without modification.

Two types of expansion tanks are available. One is a simple tank with an air space; the other uses a flexible diaphragm to separate the water from the air in the tank, thus preventing the water from absorbing the air. Both are effective, but the diaphragmless tank requires periodic replacement of the air absorbed by the water in the tank.

Vacuum Relief Valves

As a solar system cools, the volume of the liquid in the system decreases. Vacuum relief valves must be installed in closed systems to prevent vacuum damage to tanks. For example, if a tank with a 4-foot horizontal diameter cools until the pressure in the tank is 1 pound per square inch below atmospheric pressure, the force on the top of the tank will be more than 1800 pounds.

Temperature Sensors

Temperature sensors in storage tanks serve three purposes:

- To tell the controller when to turn the collector pump on. This temperature sensor should be installed in the tank near the bottom connection to the tank. When the collector temperature is warmer than the temperature at the bottom of the tank, the system controller turns on the collector pump.
- To tell the controller when heat is available for heating. This temperature sensor should be installed in the tank near the top connection to the tank. When the tank is warm enough to supply heat to the load, the controller will take heat from storage to satisfy the load. Otherwise, the controller will turn on the auxiliary heater.
- To limit the temperature in the tank to a safe maximum. Some controllers use the same temperature sensor to indicate when heat is available for the load and to limit the tank temperature, while other controllers use separate temperature sensors for these functions. Unfortunately, many of the controllers that are commercially available do not have provisions for limiting tank temperatures. Limiting the tank temperature is essential if the tank has a rubber or plastic liner or if the tank is made of fiberglass-reinforced plastic. Even metal tanks can benefit from a temperature limit, for corrosion rates approximately double with each 10-degree increase in tank temperature.

In addition to the temperature sensors, thermometers should be installed to measure the water temperature at the upper and lower connections to the tank. These thermometers will help the installers start up and adjust the system. After the system is in operation, the thermometers can help detect malfunctions. For example, a failure of the collector circuit would be indicated by an abnormally low tank temperature in the afternoon of a sunny day.

Auxiliary Heating System

As we stated in the preceding chapter, solar space heating systems must have auxiliary heaters that are able to supply 100 percent of the heating load. Liquid-based systems are often combined with forced air heating systems, requiring a liquid-to-air heat exchanger in a forced-air duct to transfer heat to the building air. The heat exchanger can be installed either upstream of the auxiliary heater as shown in Figure 3-14a or downstream of the auxiliary heater as shown in Figure 3-14b.

The configuration shown in Figure 3-14a has a minimum operating temperature of about 70 to 75°F. The minimum operating temperature is a few degrees above the return air temperature because of the temperature drop caused by the heat exchanger. Studies have shown that people find 70°F circulating air chilling. To ensure that the air will circulate at a comfortable temperature, the auxiliary heater is turned on whenever solar energy is unable to maintain a duct temperature of about 95°F or more. While the auxiliary heater is operating, solar energy preheats the air entering the auxiliary heater. This system is usually used with an electric heater. Because the solar-heated air must pass through the auxiliary furnace's heat exchanger, some solar heat may be lost up the flue of a gas or oil furnace. If the auxiliary furnace has an automatic flue damper to prevent this loss, the solar preheat arrangement is feasible with a gas or oil furnace.

The configuration shown in Figure 3-14b is usually used with gas or oil auxiliary heaters without flue dampers or for situations where there is not room to install the heat exchanger between the blower and the heater. As in the previous configuration, the auxiliary heater is turned on whenever solar energy cannot maintain a duct temperature of about 95°F or more. In this configuration the pump that circulates water from storage to the heat exchanger must be turned off when the auxiliary heater is turned on so that the auxiliary energy heats the building instead of recharging the storage unit.

The solar space heating system can also be combined with hydronic heating systems (Figure 3-14c) using baseboard heaters, fancoil units, ceiling panels, or floor panels. Each type of hydronic system has a minimum operating temperature that varies with the outdoor temperature. If the temperature in storage is less than the minimum operating temperature of the system, the automatic valves must shut off the storage loop, and the boiler must be turned on.

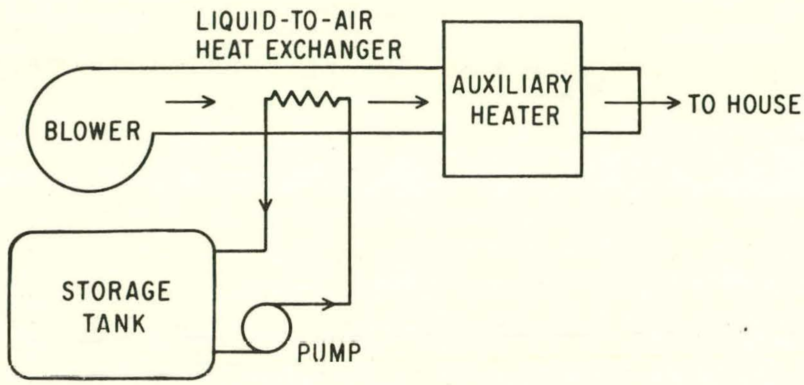

Figure 3-14a. Liquid-to-Air Heat Exchanger Installed Upstream of Auxiliary Heater

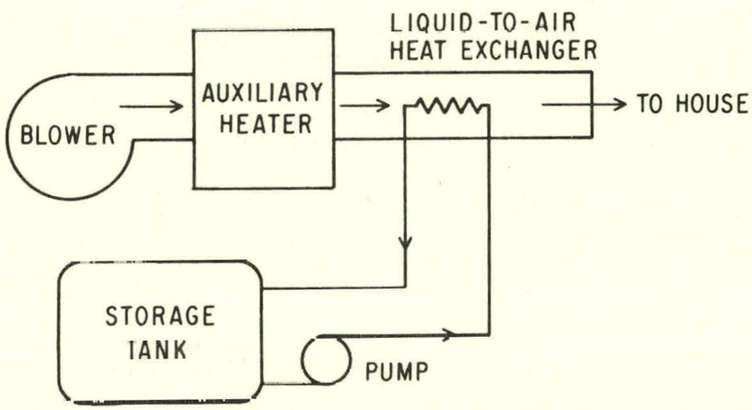

Figure 3-14b. Liquid-to-Air Heat Exchanger Installed Downstream of Auxiliary Heater

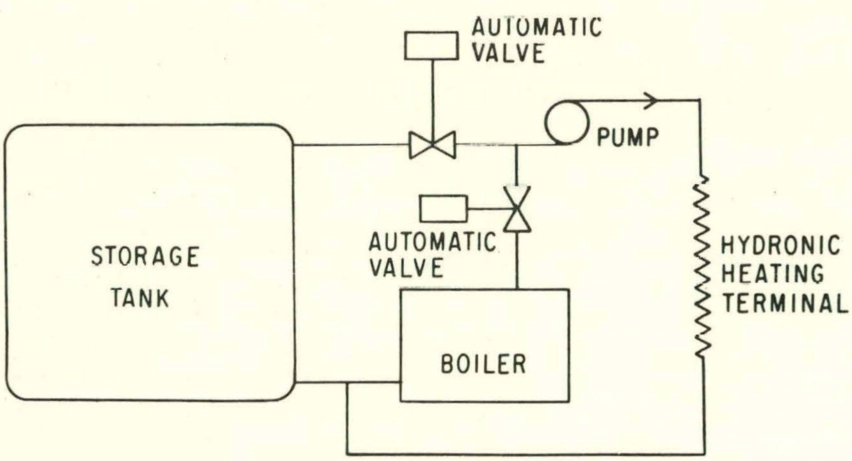

Figure 3-14c. Combined Solar and Hydronic Heating Systems

TANK INSTALLATION

Proper installation of storage tanks is essential. The foundations under the tank must be strong enough to support the weight of the tank and the water that the tank will hold. Water weighs about 8.3 pounds per gallon, so the water in a 1000-gallon tank will weigh 8300 pounds -- more than four tons. If the foundation is not built to hold this weight, the tank may settle and cause leaks in the connected piping or in the tank itself. We recommend that you have a structural engineer review the foundation design for any storage tank. Local building codes will specify the type of footings required.

Vertical steel tanks that are not buried need a concrete ring-wall foundation. Horizontal steel tanks above ground should be supported on concrete saddles with appropriate foundations. The tank manufacturer will tell you the tank's weight to help you determine how much support it needs.

Fiberglass tanks are designed to be installed with full bottom support. If an aboveground tank is mounted on a concrete pad, the concrete must be smooth and have enough reinforcement to support the weight of the full tank.

For tanks installed underground, anchorage must be provided to prevent bouyant uplift when the tank is empty. The tank should be anchored to a concrete pad at least 6 inches thick and weighing at least as much as the water the tank can hold. The concrete should be covered with a layer of fine pea gravel, sand, or number 8 crushed stone at least 6 inches deep and spread evenly over the concrete to separate it from the tank. Fiberglass or steel hold-down straps should be anchored a foot beyond the sides of the tank. The hold-down straps should pass over the top of the tank and should be tightened with turnbuckles to give a snug fit. Use at least a 5 to 1 safety factor when you calculate the strength of the hold-down straps and turnbuckles.

Backfill with pea gravel, sand, or number 8 crushed rock at least 2 inches all around the tank. The remainder of the backfill may be clean tamped earth or sand to a depth of 24 to 36 inches above the tank. Provide concrete pads for nozzles and manholes extending to grade. See Figure 3-15 and Appendices G and I for additional details.

In areas with a high water table, the tank insulation must be impervious to water or the tank must be installed in a vault provided with a sump pump.

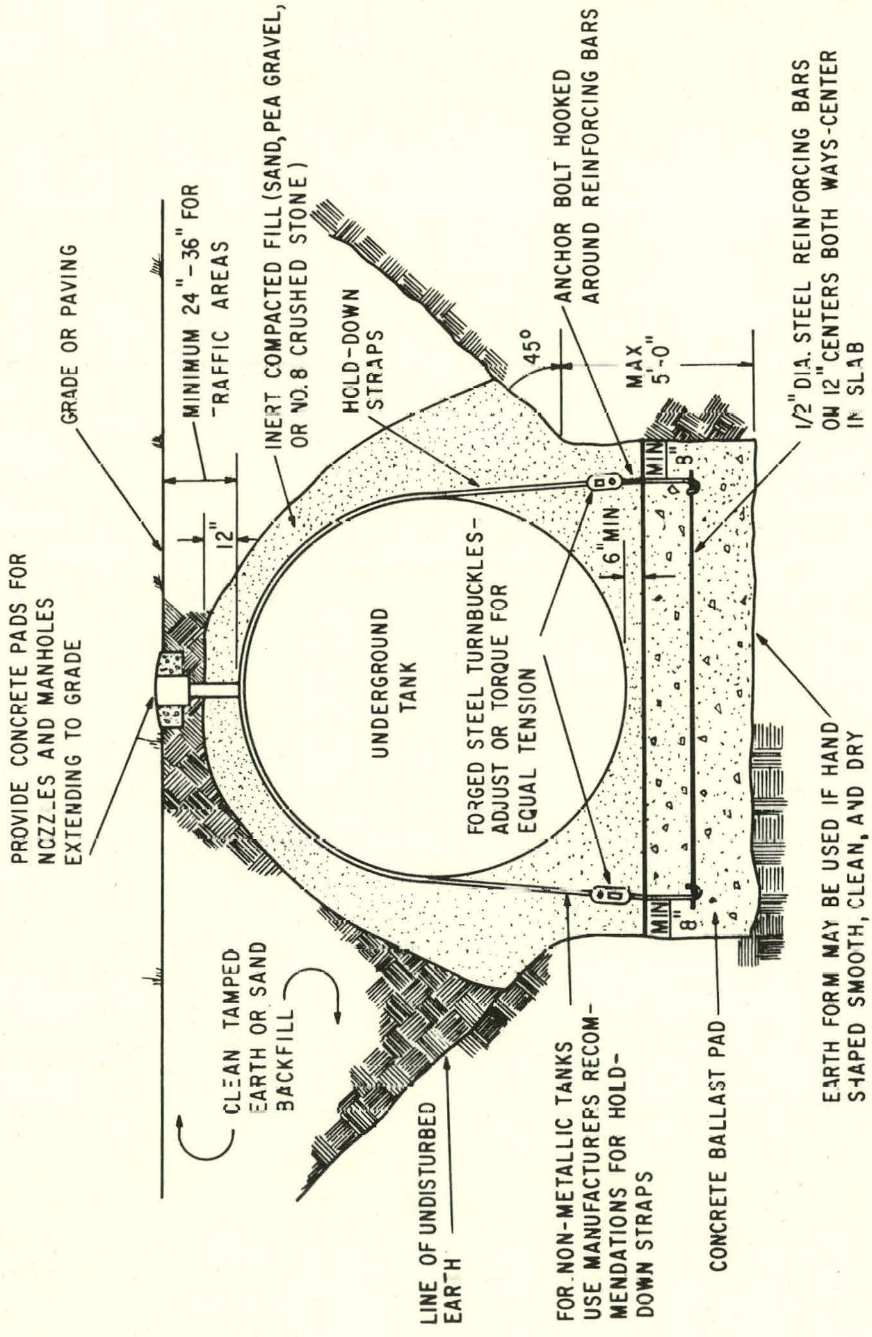

Figure 3-15. Installation of an Underground Tank

OPERATION AND MAINTENANCE

Design for Maintainability

Maintenance must be considered as the system is being designed. Many solar systems fail or perform poorly because they cannot be properly maintained. If a storage tank cannot be easily replaced, it should last the lifetime of the building. Before installing any components the designer should consider how each component will be repaired or replaced and provide for working room around the components. All tanks and heat exchangers must have a means of being drained for inspection and repairs.

Simple systems are usually easier to maintain than complicated systems. The advantages of a simple system are:

- Initial cost is lower.
- Installation errors are less likely.
- There are fewer components to fail.
- Controls and operation are easier to understand.
- Defective components can be more easily found and replaced.

Answering three questions will help you decide whether the system is too complicated or too simple.

- If a feature were deleted from the system, how much energy collection would be lost?
- If a feature were deleted from the system, would a mode of failure be introduced?
- If a feature were deleted from the system, would human safety be degraded?

You can use a system analysis method (such as f-Chart, SOLCOST, DOE-1, or TRNSYS) to estimate the extra amount of energy collection attributable to a particular feature. If the value of the extra energy collected over the life of the system is less than the cost of the feature, the feature cannot be justified economically. If, in addition, the answers to the second and third questions are "no," the feature should be deleted from the system.

Startup

Before insulation is applied to the pipes, the system must be carefully inspected and tested. Begin by checking all piping, valving, and wiring against the system drawings. Typical problems that might be encountered include:

- Pumps or valves reversed
- Inlet and outlet connections to tanks, heat exchangers, or collectors reversed
- Normally open valves installed in place of normally closed valves, or vice versa
- Lines in drain-down systems improperly sloped.

This is a good time to begin labeling the piping, although some parts must be labeled after the insulation is installed. The contents (air, water, ethylene glycol, etc.) should be tagged on each major line, along with the notation for liquids "potable," "nonpotable," or "toxic". Potable water is fit for human consumption. Toxic substances, such as ethylene glycol and many corrosion inhibitors, are, of course, nonpotable; however, a substance need not be toxic to be nonpotable. Water that resides in a storage tank for several weeks is nonpotable, even if it has no toxic additives. A color code can be used for labeling (see the <u>ASHRAE Handbook of Fundamentals</u>). Safe fluids should be labeled with green, white, gray, black, or aluminum; dangerous fluids with orange or yellow. Pipes should be labeled with flow direction.

Valves, pumps, heat exchangers, and so on should be tagged to correspond to the identification numbers on the system drawings, and flow directions should be marked on the parts. Automatically controlled two-way valves should be labeled "normally open" or "normally closed". The legs of three-way valves should be labeled "common," "normally open," and "normally closed".

Before installing insulation and before backfilling a below ground storage tank, test the entire system for leaks. If the system can be pressurized, the best way to test for leaks is:

> Close the vent valves if necessary. Attach an air compressor to the system through a valve and fill the system to the normal operating pressure of the weakest component. Turn off the air compressor and close the valve. If the air pressure drops more than 20 percent in twenty-four hours, the system leaks. Test all pipe joints and packings with soapy water. Bubbles will appear at the leak. Do not forget to open the vent valves if you have had to close them before testing.
>
> THIS TEST IS ONLY FOR FINDING LEAKS IN THE SYSTEM; IT IS NOT A REPLACEMENT FOR THE ASME PRESSURE VESSEL CERTIFICATION TEST. PERFORM ASME PRESSURE VESSEL CERTIFICATION TESTS OF COMPONENTS BEFORE YOU PERFORM THIS LEAK TEST TO BE CERTAIN THAT ALL COMPONENTS CAN WITHSTAND THE TEST PRESSURE.

If the system is not designed for pressure or if the system has already been leak-tested with compressed air, fill the system to the proper levels with the appropriate fluids. Inspect all pipe joints and packings for leaks and remove any trapped air pockets.

Trapped air pockets can be removed in several ways.

- Fill the system to its highest point.
- If the system is designed for pressure, pressurize the system and open the air bleed valves at the high points, or
- Turn the pumps on and allow the liquid to sweep the air from the system.

Check and refill the system to the proper levels.

Test the system in all operating modes to ensure that it functions as intended. Since systems vary greatly in their operating modes, only general guidelines can be given here. Most controller manufacturers make testing devices and publish data on how to use the testers. You may need a set of jumper wires to operate the system in its various modes. DANGEROUS VOLTAGE MAY BE PRESENT AT CONTROLLER TERMINALS. Flows in pipes usually can be determined by feeling a temperature change and by observing temperature changes with the thermometers installed in the tank and collectors.

A special additional test is required for drain-down systems. After operating the system in the collecting mode and then in the drain-down mode, shut off the system and temporarily disconnect the piping, as shown in Figure 3-16a. Apply compressed air as shown in Figure 3-16b to blow the trapped water into buckets. If more than a few drops of water fall into the buckets, the system does not drain properly and could be damaged by freezing. Do not operate the system until the cause of faulty draining has been corrected and the system has been retested. If the system passes the drain-down test, reconnect the pipes.

Several final operations should be performed before the system is put into operation. Inspect the filters. If you find dirt or grit, or if the fluid is discolored, do not start the system until the cause has been found and corrected. Test the fluid pH and measure the antifreeze or corrosion inhibitor concentration. If test results are not within the manufacturer's specifications, do not continue until the cause has been found and corrected. Inspect and repair leaks, if any. Finally, install the insulation on piping and complete the labeling of components. The system is now ready for operation.

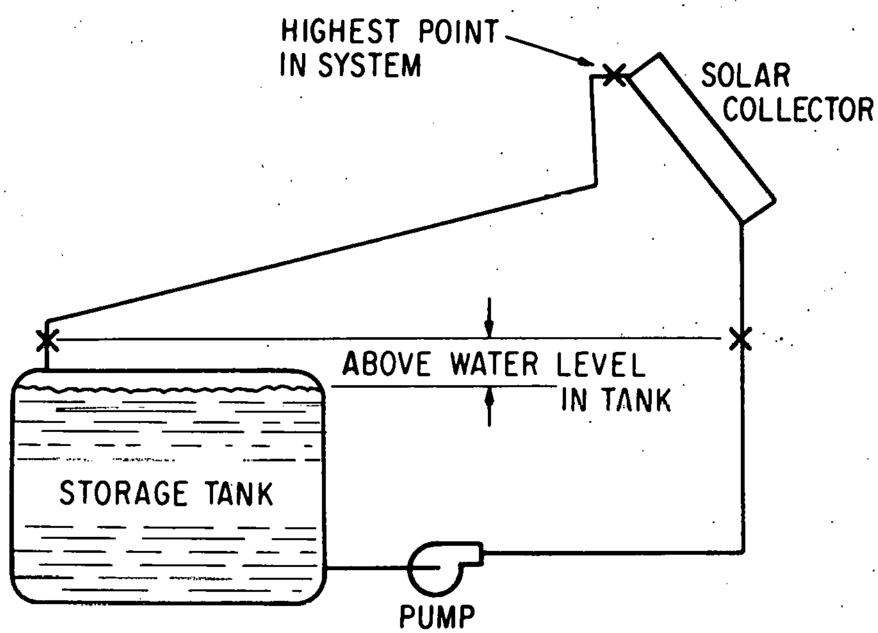

Figure 3-16a. Temporarily disconnect piping at points marked "X" for drain-down test.

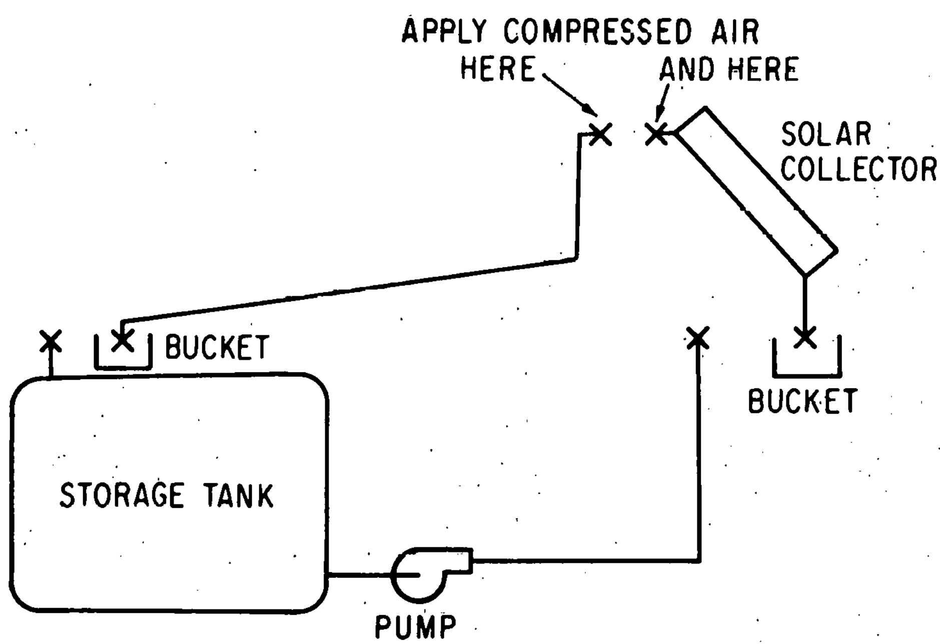

Figure 3-16b. Drain-down Test

Periodic Inspection and Maintenance

The following tasks should be performed twice each year, when the system is switched between winter and summer modes.

- Inspect for leaks.
- Check fluid levels in tanks.
- Clean or replace fluid filters.
- Examine fluid samples for grit, sludge, dirt, or discoloration.
- Test the fluid pH.
- Measure the concentration of antifreeze or corrosion inhibitors.
- Check pumps, valves, sensors, and controllers for proper function.

At an interval (usually two to five years) specified by the tank manufacturer, the collector manufacturer, the antifreeze manufacturer, or the corrosion-inhibitor manufacturer, drain and replace the fluids in the system. (For some systems this is unnecessary.)

Owner's Manual

The contractor should provide the owner with a manual that includes the following information:

- A summary description of how to operate the controls
- Instructions on how to do periodic maintenance
- A detailed description of how the system operates
- Schematics of plumbing and wiring with labels that correspond to the labels attached to the hardware
- Component and system warranties.

REFERENCES

- American Society of Heating, Refrigerating and Air-Conditioning Engineers, 345 East 47th Street, New York, New York 10017.
  ASHRAE Handbook of Fundamentals, 1972.
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- American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York 10017.
  ASME Boiler and Pressure Vessel Code, 1977.

- E. J. Beck, Jr. and R. L. Field.
  Solar Heating of Buildings and Domestic Hot Water.
  Civil Engineering Laboratory Technical Report R835, Naval Construction Battalion Center, Port Hueneme, California 93043. 1976.

- International Telephone and Telegraph Corporation, Fluid Handling Division, Training and Education Department, 8200 North Austin Avenue, Morton Grove, Illinois 60053.
  Solar Heating Systems Design Manual.
  Bulletin TESE-576, 1976.

- United States Department of Housing and Urban Development.
  Intermediate Minimum Property Standards Supplement: Solar Heating and Domestic Hot Water Systems.
  Number 4930.2. Government Printing Office, 1977.

CHAPTER 4.
THERMAL ENERGY STORAGE IN DOMESTIC HOT WATER SYSTEMS

The most common and economical use of solar energy in the United States is heating hot water in homes and other buildings. Building codes strictly regulate systems containing potable (drinkable) hot water, so check local codes before installing a solar domestic hot water heating system.

SAFETY CONSIDERATIONS

Solar hot water heating systems differ from conventional hot water heating systems mainly in two areas, both related to safety. First, the potable water must be separated from nonpotable water and from the toxic substances used in many solar systems. Second, overheating of the system must be guarded against.

Separation of Potable and Nonpotable Water

The Department of Housing and Urban Development has published standards for property receiving federal financing in their Solar Initiative programs. The HUD Intermediate Minimum Property Standards lists the following requirements:

"S-615-10 PLUMBING

"S-615-10.1 Handling of Nonpotable Substances

Potable water supply shall be protected against contamination in accordance with the prevailing model plumbing code having jurisdiction in the area, as well as the requirements which follow.

"S-615-10.1.1 Separation of Circulation Loops

Circulation loops of subsystems utilizing nonpotable heat transfer fluids shall either be separated from the potable water system in such a manner that a minimum of two walls or interfaces is maintained between the nonpotable liquid and the potable water supply or otherwise protected in such a manner that equivalent safety is provided.

"Commentary: Double wall heat exchanger designs are one way of meeting the intent of this criterion. When double wall heat exchanger designs consisting of two single wall heat exchangers in combination with an intermediary potable heat transfer liquid are used, leakage through one of the walls would result in a single wall configuration. Although this design is considered to meet the intent of this criterion, there are several other designs that avoid this problem.

"The use of single wall configurations which solely rely upon potable water pressure to prevent contamination is not considered to be an acceptable solution. Similarly, extra thick single walls are not considered to meet the intent of this criterion.

"For approval of other than double wall designs, the procedures described in S-101 should be utilized.[5]

"S-615-10.1.2 Identification of Nonpotable and Potable Water

In buildings where dual fluid systems, one potable water and the other nonpotable fluid, are installed each system may be identified either by color marking or metal tags as required in ANSI A13.1-1956 [Scheme for the Identification of Piping Systems, American National Standards Institute] or other appropriate method as may be approved by the local administrative code authority. Such identification may not be required in all cases.

"S-615-10.1.3 Backflow Prevention

Backflow of nonpotable heat transfer fluids into the potable water

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[5]S-101, "Variations to Standards," is an earlier section of the HUD Intermediate Minimum Property Standards. It lists some general goals and refers to Section 101-4 of MPS 4900.1, Minimum Property Standards for One- and Two-Family Dwellings, which contains details for approval of one-time-only and multiple-occurrence variations.

system shall be prevented in a manner approved by the local administrative code authority.

"Commentary: The use of air gaps and/or mechanical backflow preventers are two possible solutions to this problem."

Of these standards, only the double-walled heat exchanger requirement is rarely encountered in conventional plumbing practice. Some types of double-walled heat exchangers are:

(a) Wraparound shell (Figure 1-7)
(b) Two single-walled heat exchangers with an intermediate loop (Figure 1-8)
(c) Shell-and-double-tube (Figure 1-10)
(d) Coil soldered to tank--also called traced tank (Figure 1-6)
(e) Two tubes swaged together.

Two tubes swaged together means that one tube is inside another in such a way that the outside of the inner tube is firmly pressed against the inside of the outer tube. This type of double tube is often used in heat exchangers and is sometimes called double-walled, but for separating potable water from toxic substances it should be considered as having an extra-thick single wall.

A heat exchanger of Type b can use the water in the main storage tank as an intermediate loop if the storage water contains no toxic additives, or the intermediate loop may be an independent loop with its own pump between two single-walled heat exchangers .

The HUD standards have been interpreted in various ways. The strictest interpretation would require that a Type a, b, or c double-walled heat exchanger be used whenever any heat transfer fluid other than potable water is used to heat potable water. Types d and e would be considered single-walled heat exchangers with extra-thick walls and would not be allowed. However, Types d and e have been allowed by local building code authorities where a heat transfer fluid with low toxicity, such as food-grade (U.S.P.) propylene glycol or the silicon oils, has been used.

The current state of uncertainty is expected to be cleared up in 1979 when the American National Standards Institute, which is working with many professional, trade, consumer, and government groups, publishes a model building code for solar heating and cooling equipment. Until the new standards are available, the HUD standards as interpreted by local building code officials should be used as guidelines.

Overheating

Overheating is the second area of concern in domestic hot water heating by solar energy. Conventional hot water heaters are regulated by thermostats that do not allow water temperatures to exceed the thermostat setting (usually 140°F). It is quite possible, especially in summer, for solar-heated water to reach scalding temperatures that can cause serious burns. For this reason all the hot water should pass through a tempering (mixing) valve that adds enough cold water to keep the temperature of water delivered to the taps below 140°F. Figure 4-1 shows a typical tempering valve installation. If the tempering valve is soldered in place, the temperature-sensing element must be removed during soldering to prevent its being damaged.

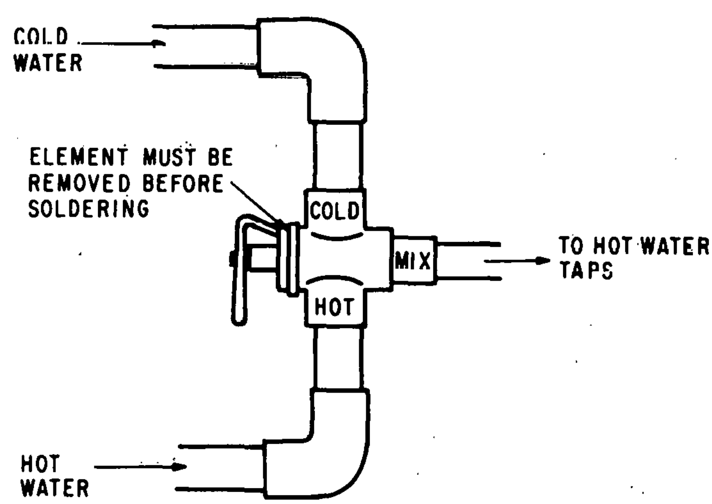

Figure 4-1. Typical Tempering Valve

All domestic hot water tanks must be equipped with temperature and pressure relief valves as specified in local building codes. In addition, the tank must comply with the ASME Boiler and Pressure Vessel Code if any of the following conditions are exceeded:

- 120-gallon-capacity tank
- 200,000-Btu-per-hour heating rate
- 210°F water temperature in tank.

Since most single-family residential domestic hot water tanks do not exceed these conditions, they are exempt from ASME Boiler and Pressure Code requirements.

SIZING DOMESTIC HOT WATER STORAGE SYSTEMS

The storage system should be large enough to supply approximately 100 percent of the daily hot water load from storage. The HUD Intermediate Minimum Property Standards recommend the following guidelines for determining the load:

- For one- and two-family residences and apartments up to twenty units, each unit requires 20 gallons each for the first two persons plus 15 gallons for each additional person.
- For apartments of 20 to 200 units, each unit requires 40 gallons.
- For apartments of more than 200 units, each unit requires 35 gallons.

In most cases there is no conflict between these storage sizes and the rule of thumb of 1.25 to 2 gallons per square foot of collector given in Chapter 1.

If there is a small conflict between the rule of thumb and the HUD recommendations, choose 1.25 gallons per square foot of collector or the HUD recommendation, whichever is larger. In the rare instance that the conflict between the two methods is substantial, only computer methods such as TRNSYS or DOE-1 can resolve the conflict.

AUXILIARY HEATING SYSTEMS

To provide hot water on cloudy days you will need auxiliary heat, which can be provided by gas, oil, or electricity. There is considerable controversy about whether the auxiliary heat should be added to the solar-heated tank (a one-tank system, shown in Figure 4-2) or the auxiliary-heated tank should be separate from the solar-heated tank (a two-tank system, shown in Figure 4-3).

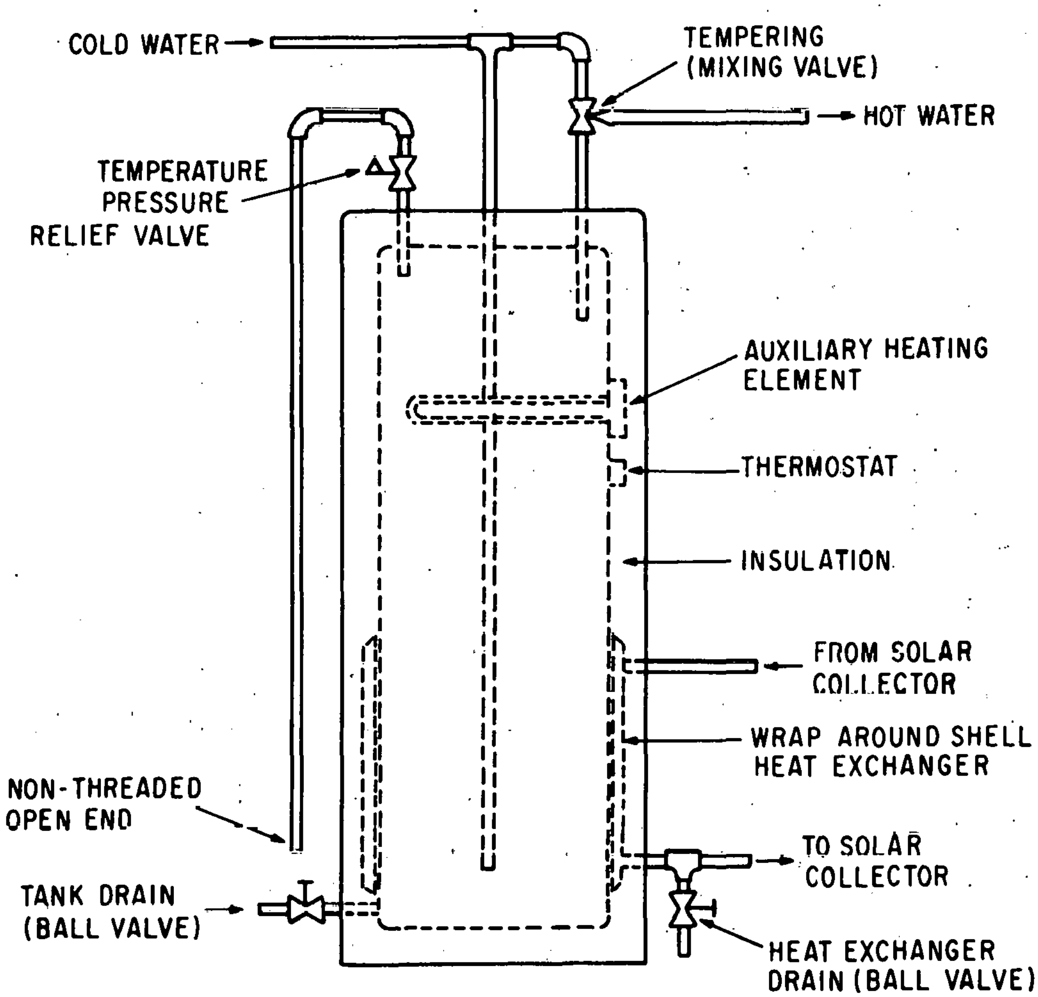

Figure 4-2. Typical One-Tank Installation

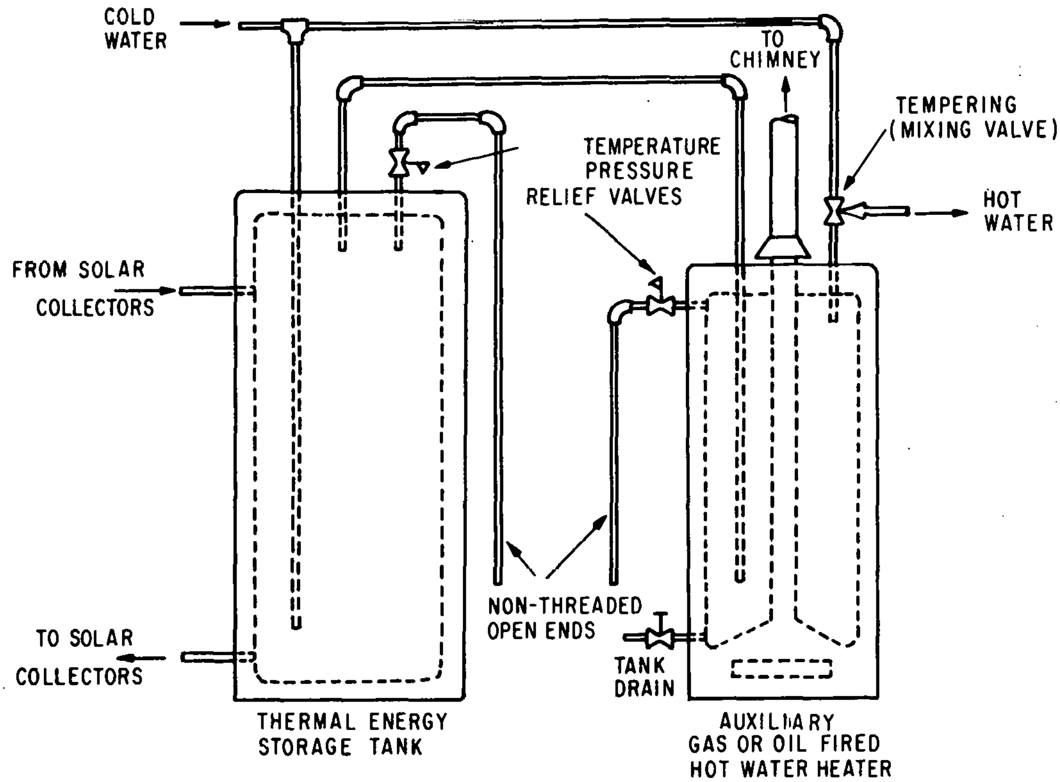

Figure 4-3. Typical Two-Tank Installation

With gas or oil auxiliary heat the flue is a major source of heat loss. This heat loss can be minimized in two ways, which can be used separately or in combination: (1) by using a small auxiliary heating tank which has relatively small flue loss, or (2) by installing an automatic flue damper. The use of a small auxiliary heating tank implies a two-tank system. The small heater does not provide enough hot water for heavy demand by itself, but preheating the water from the solar storage tank allows the auxiliary heater to recover quickly. Retrofit solar systems can use an existing gas or oil water heater as the auxiliary unit, although the tank and its corresponding flue losses will be larger than necessary. Automatic flue dampers are recommended for gas and oil auxiliary heaters, but they may be prohibited or very strictly regulated by local building codes. If you want to use an automatic flue damper, be sure it is approved by the American Gas Association (AGA), Underwriters Laboratories (UL), and your local building codes.

With electric auxiliary heat there are no flue losses, and one-tank systems are usually specified, since the cost of providing an electric heater in the tank is very low compared with the overall cost of another tank. Electric heaters are usually installed in the upper part of the tank to take advantage of temperature stratification. In retrofit applications, storage tanks with electric heaters are frequently ordered where the source of auxiliary heat is an existing gas or oil water heater. The electric element is left unconnected until the gas or oil water heater fails, at which time the electric element is connected and the system is converted to one-tank operation.

TANK INSULATION

Typical domestic hot water tanks have insulation values of R-10 or less. By comparison, following the method described in Chapter 1 of this manual would yield an insulation requirement of R-29 to R-33 to limit heat loss to 2 percent in 12 hours (assuming a tank temperature of 140°F and an ambient temperature of 70°F). Even if the insulation requirements were lowered to limit losses to 10 percent in 24 hours as specified in the <u>HUD Intermediate Minimum Property Standards</u>, R-11.5 to R-13 insulation would be required. Clearly, then, most domestic hot water tanks can benefit from added insulation, and insulation kits are available. The added insulation is very effective on electric- and solar-heated storage tanks, but it cannot reduce the flue losses in gas- or oil-fired tanks. If you install additional insulation, be careful not to obstruct air vents on gas- or oil-fired tanks, pressure and temperature safety valves, or water temperature tempering valves.

DOMESTIC HOT WATER WITH LIQUID-BASED SPACE HEATING

A domestic hot water heating system can be used with a liquid-based space heating system in several ways. A separate stand-alone hot water system that can operate throughout the year independent of the space heating system can be used. This type of installation allows the space heating system to be shut down in the summer with no effect on the hot water system.

Two variations of a system in which domestic hot water is preheated by a heat exchanger in the storage tank are shown in Figure 4-4. The main advantage of this type of system is that it does not require a separate tank for storing preheated domestic hot water. However, the space heating storage tank must be heated in the summer to provide year-round solar-heated domestic hot water. Furthermore, most corrosion inhibitors could not be used in the storage tank without violating the HUD Intermediate Minimum Property Standards for double-walled heat exchangers.

A system in which hot water from the main storage tank is pumped through the domestic hot water heat exchanger is shown in Figure 4-5. The spring-check valve prevents thermosyphoning when the domestic hot water tank is warmer than the main storage tank. The chief advantage of this system is that corrosion inhibitors can be used in the main storage tank, since domestic hot water tanks with double-walled heat exchangers are available. Disadvantages include the system's mechanical complexity and the necessity of heating the main storage tank in summer.

DOMESTIC HOT WATER WITH AIR-BASED SPACE HEATING

An air-to-liquid heat exchanger (Figure 1-11) installed in the return (hot) air duct between the collectors and the damper that directs air to the rock bed or building is commonly used to heat domestic hot water in air-based systems. The heat exchanger must be capable of withstanding water-main pressure, since it will contain potable water. A pump circulates water from the domestic hot water tank to the air-to-liquid heat exchanger.

A back-draft damper is required to prevent thermosyphoning of the air in cold weather. Failure to install the back-draft damper can cause the air-to-liquid heat exchanger to freeze. A two-way damper can be installed so the air can bypass the rock bed in the summer.

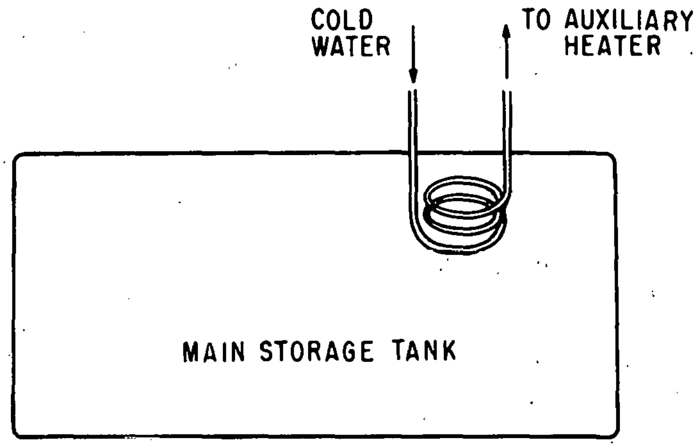

Figure 4-4a. Coil Immersed in Main Storage Tank to Heat Domestic Hot Water

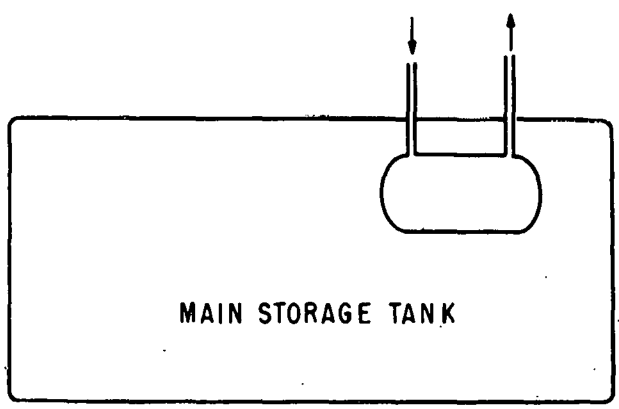

Figure 4-4b. Tank Immersed in Main Storage Tank to Heat Domestic Hot Water

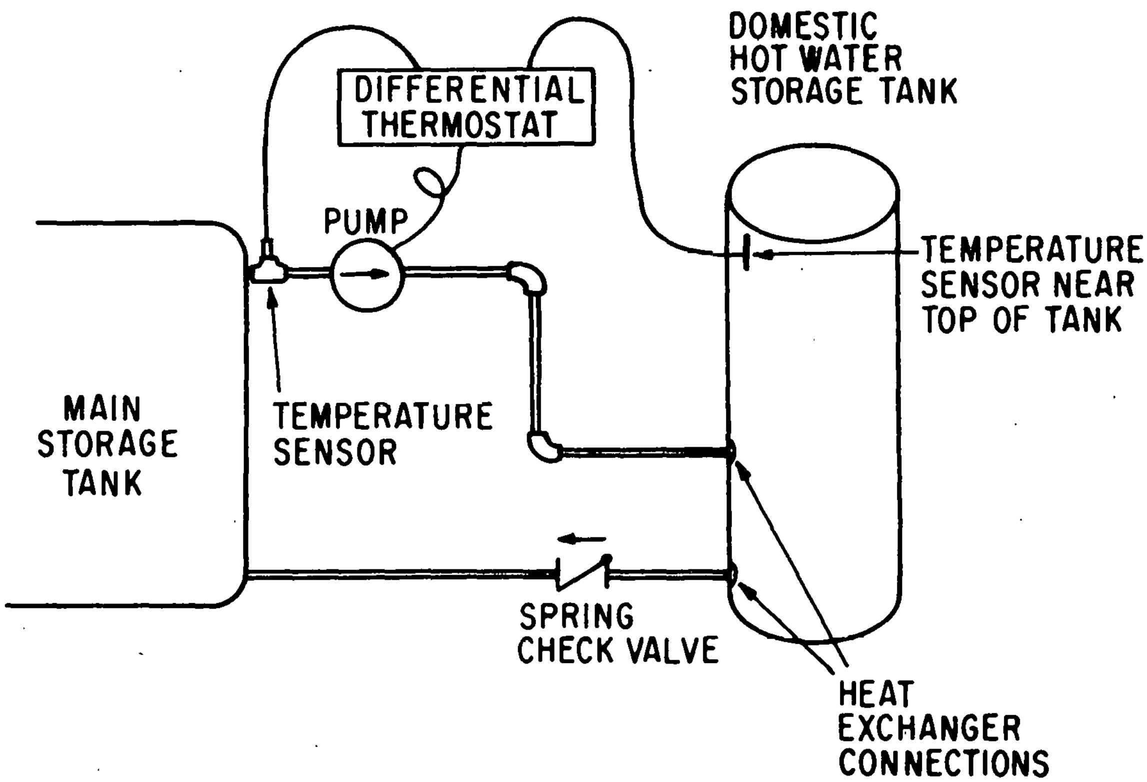

Figure 4-5. Water Pumped from Main Storage Tank to Heat Domestic Hot Water

STAND-ALONE DOMESTIC HOT WATER SYSTEMS

The most common type of solar system being installed today is the stand-alone domestic hot water system. Since the purpose of these systems is to heat water, most are liquid-based, although a few are air-based.

For single-family residential systems, many companies sell kits that include specialized solar system components such as collectors, storage tanks, heat exchangers, controllers, pumps, valves, and temperature sensors, as well as installation instructions. The installer must supply standard hardware such as electrical wire, pipe and fittings, and nuts and bolts. We recommend using such a kit in preference to individual components because the kit manufacturers have selected components and controls that work together and have tested and modified the systems to eliminate problems.

If you use a kit there are several things you should do before beginning to install it. Read the manufacturer's instructions carefully so that you will know what order the steps of the installation must follow, what specialized skills are necessary, and whether any steps require special care or precautions. Determine exactly what materials you must supply--this requirement varies from one manufacturer to another. Also, determine what type of heat exchanger is supplied in the kit, whether the heat exchanger fluid to be used is toxic, and whether local building officials will approve the installation.

Systems larger than 120-gallon capacity are not available as kits. If you choose to design a domestic hot water system using components from different sources, your design team should be thoroughly familiar with the material in Chapters 1, 3, and 4 of this manual and the appendices referred to in these chapters. We also recommend that a professional engineer be a member of the design team. An important difference between large and small systems is that domestic hot water tanks larger than 120-gallon capacity must have an ASME Pressure Vessel Certification. A sample specification for a large domestic hot water tank is given in Appendix G.

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APPENDIX A. COMMON PROBLEMS OF STORAGE SYSTEMS

The following table presents some examples of problems actually experienced with solar energy storage systems, what caused the problems, and how they were dealt with.[1]

PROBLEM	DESCRIPTION	RESOLUTION
Stratification in Liquid Tank Not Accomplished.	High velocity input prevented stratification and reduced efficiency.	Diffusers were installed to minimize velocity.
High Thermal Loss in Buried Tank	Water getting into insulation of buried tank increased heat loss.	Provide ground drainage, provide waterproof insulation, or locate above ground.
Heat Loss	High heat loss at night was thought to be caused by heat escaping through the tank insulation because of high ground water. Further investigation showed a faulty thermocouple that allowed pump to run all night, rejecting tank heat to atmosphere.	Thermocouple was replaced and replacement also failed. It was then found that the thermocouples used were not suitable for the temperatures experienced. They were replaced with high temperature thermocouples.
Heat Loss	Ground water around tank caused high heat loss.	Additional insulation and stones were placed under and around tank to improve drainage.

[1] United States Department of Commerce, National Technical Information Service. Hardware Problems Encountered in Solar Heating and Cooling Systems, prepared by Mitchell Cash, George C. Marshall Space Flight Center. N78-25539, May 1978.

PROBLEM	DESCRIPTION	RESOLUTION
Bypass of Rock Bed	A rock bed designed for horizontal flow had an air space at the top, which permitted the air to bypass the rocks.	Redesign to use vertical flow through the rock bed. (Horizontal flow also reduces the desired stratification effect.)
Leakage	Leakage existed at joints of fiberglass tank after tank was assembled on site from two halves.	Carefully assemble following the manufacturer's recommendations and using the recommended sealing materials.
Leakage	Fiberglass tanks leaked through wicking action in some fiberglass threads that extended through the tank.	Seal all exposed fiberglass threads.
Sewer Gas in the House	A sewer drain was installed under a rock bin to remove any water. The heat in the bin evaporated the water in the drain trap, letting sewer gas into the house.	Changed drain to a location outside rock bin.
Heat Loss through Insulation	Buried concrete tank leaked water through the tar seal, soaking the insulation and increasing the heat loss.	Changed to aboveground storage tank.
Heat Loss	Heat loss from domestic hot water tanks exceeded manufacturer's specifications. Investigation showed the added solar piping and instrumentation provided an increased heat leak path.	Adequately insulated all exposed piping and instrumentation connected to the storage tank.

PROBLEM	DESCRIPTION	RESOLUTION
Oversized Storage Tank	Tank was too large for collector area and tank temperature never exceeded 57°C (135°F).	Replaced tank with one that provided 7.6 liters (2 gallons) of storage for each square foot of collector.
Contaminated Heat Exchangers	Heat exchangers supposedly of refrigeration quality were contaminated with machine oil and metal filings.	Units were returned to vendor for cleaning.
Heat Transfer Losses	Heat transfer from collector loop through the heat exchanger into the storage tank was not as good as assumed.	A parallel heat exchanger was added. (This was considered less expensive than replacing with a more desirable larger single heat exchanger.)
Corrosion	Investigation indicated that the corrosive condition of the ground itself might create problems with the underground storage tank.	Installed cathodic protection for the tank (sacrificial magnesium anodes) and coated tank with a rubberized vapor barrier.
Heat Loss	Steel legs supporting storage tank conducted heat away from tank.	Thermally isolated supporting legs.
Heat Loss	Underground tank insulation was damaged by lack of proper support in rocky soil. Maintaining water-tight insulation on underground storage tanks is difficult. Water in insulation increased heat transfer.	Check waterproofing prior to installing, provide proper support, install carefully, patch any bad spots in insulation, and backfill carefully.

PROBLEM	DESCRIPTION	RESOLUTION
Incorrect Inlet and Outlet	Flow from collector to tank entered at bottom of tank. Flow back to collector was also from bottom of tank, causing short circuit in flow path and eliminating benefit of stratification.	Flow from collector to tank should enter tank at top where water is hottest. Flow back to collector should be from bottom of tank (on opposite end from inlet if no distribution manifold is used).
Materials	Material planned for inside coating of storage tank melted at 82°C (180°F).	Changed to a compound stable at 145°C (250°F).
Saturation of Insulation	An open-cell foam was applied to the tank. This acted as a sponge, collected water, and increased heat loss.	Use closed-cell foam.
Too Many Tank Penetrations	The fiberglass storage tank had all feed and return pipes for the solar collector loop, house loop, and domestic hot water loop through the tank below the water level. This resulted in leaks that were difficult to seal.	Two of the three loops were pressurized with positive pressure to the pump suction. Only suction line to the unpressurized loop needed to be below the water level to provide positive suction to the pump. All others could be brought into the tank above the waterline, and even the one suction line tank penetration could be above the water level if a foot valve was added.

PROBLEM	DESCRIPTION	RESOLUTION
High Pressure Drop in Heat Exchanger	Heat exchanger tubes extended completely through manifold to far side of manifold and restricted flow.	Reworked manifold header to provide internal clearance.
Loss of Heat from Storage	A heat exchanger for collector-to-storage heat transfer was installed too high in the storage tank. Under some conditions (particularly when solar radiation was low), the collector pump would start when collector temperatures were below storage tank top temperatures, resulting in transfer of heat from storage to collector.	Ensure proper location of heat exchangers and proper location and setting of controls.
Trash in Tank	Tank covers were difficult to remove to check water level, and loose tank insulation was dislodged and dropped into tank.	Covered source of loose insulation and used care in opening.

APPENDIX B. HEAT TRANSFER FLUIDS

Heat transfer fluids are used in solar systems to transfer heat from the solar collector to the storage medium and from the storage medium to the building. They are sometimes called "collector coolants" because they cool the collector as they absorb its heat.

The fact that some heat transfer fluids and manufacturers are mentioned by name in this appendix as examples in no way constitutes endorsement or recommendation.

COMPARISON OF HEAT TRANSFER FLUIDS BY GENERAL CHARACTERISTICS

Air

Air is one of the most commonly used heat transfer fluids in solar systems. It is free and will operate at any temperature the solar system will reach. Moreover, a leak in an air-based system will cause no damage, although it will degrade system performance. Since air has a low volumetric heat capacity, its flow rate through the system must be high. The power used to transfer a given amount of energy is higher for air than for most liquids. The major disadvantage of air is that it requires large duct size, which makes retrofitting difficult and provides more area for thermal losses. Air handling systems are also generally noisier than liquid-based systems.

Water

Water is a readily available fluid with good heat transfer properties (i.e., high heat capacity, high thermal conductivity, and low viscosity). Its major drawbacks are its high freezing temperature, its expansion upon freezing, and its corrosive effect on common engineering materials (except copper). Also, its low boiling point can cause large pressures within the collector system under zero flow conditions. Water has no adverse biological or environmental effects.

Ethylene Glycol

Other than water, the most commonly used heat transfer liquids in flat plate collectors are water/ethylene glycol solutions. These common, colorless, odorless antifreeze solutions are also used in many other applications. Ethylene glycol is relatively inexpensive and available from many manufacturers. (See listings in the Thomas Register.) With corrosion inhibitors, aqueous ethylene glycol solutions can reduce the corrosive action and freezing temperature of water. These solutions are usually available in a wide range of concentrations and inhibitor levels. The thermal properties of the solutions (heat capacity, thermal conductivity, and viscosity) are poorer than those of water.

The boiling and flash points of aqueous ethylene glycol mixtures are low and can be easily reached under zero flow conditions. Glycols can oxidize to organic acids (such as glycolic acids) when exposed to air near boiling temperatures. The inhibitors used are designed to neutralize these extremely corrosive acids. Periodic maintenance and addition of inhibitors must be done if these fluids are used. Another major drawback to the use of ethylene glycol is its high toxicity.[1] Most plumbing codes require that ethylene glycol solutions be separated from potable water by double-walled heat exchangers.

Propylene Glycol

Propylene glycol has properties similar to those of ethylene glycol, except that propylene glycol has higher viscosity and is less toxic. With inhibitors, propylene glycol can be used with most common engineering materials. Periodic maintenance and inhibitor addition must be performed to limit corrosion. Propylene glycol will also form acids at high temperatures in oxygen-rich atmospheres. Because of its lower toxicity, propylene glycol has been widely used in the food industry. Most manufacturers who produce ethylene glycol also market propylene glycol. The higher viscosity of propylene glycol makes the heat transfer properties of aqueous proplyene glycol mixtures poorer than those of ethylene glycol.

Other Glycols

Other glycol solutions have been used as heat transfer fluids in industry applications. These include diethylene and triethylene glycol. With inhibitors, both of these fluids can be used with higher boiling points than ethylene glycol. The thermal properties of these aqueous solutions are similar to those of ethylene glycol at similar concentrations. The vapor pressure of each is slightly higher than that of ethylene glycol. The toxicity of these fluids is between that of ethylene and propylene glycol; their cost is slightly higher than that of ethylene and propylene glycol.

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[1] The U.S. Federal Food, Drug and Cosmetic Act of 1938, a big step in the formation of the U.S. Food and Drug Administration (FDA), was prompted mainly by a poisoning episode in 1937 involving at least 73 deaths and perhaps as many as 107 deaths caused by diethylene glycol contained in a drug known as "Elixir Sulfanilamide" (Campbell). Diethylene glycol is somewhat less toxic than ethylene glycol.

Other glycol heat transfer compounds include polyalkylene glycols such as Ucon[2] brand fluids and Jeffox[3] brand fluids. With inhibitors, the corrosive action of these compounds upon common engineering materials can be reduced. They are low in toxicity and are available in a wide range of viscosities. Fluids of this type that are applicable to heat transfer purposes cost more than the other glycol compounds.

Petroleum (Mineral) Oils

Petroleum oils are also used as heat transfer fluids in industry applications. They generally are fluids designed to operate at high temperatures, although some are able to offer lower temperature operation. As a group, they have poorer heat transfer properties than water, with lower heat capacity and thermal conductivity and higher viscosity. The flash point and boiling point lie below possible zero flow temperatures of a collector. Upon exposure to air at high temperatures, these fluids are subject to oxidation and cracking, forming tars and other by-products that will reduce collector performance and increase corrosion. The toxicity of these fluids is generally low and their prices are relatively low. Mobiltherm[4] Light brand fluid was chosen in this study as a good representative of this class of fluids for low temperature applications.

Silicone Fluids

Some flat plate collector installations have used silicone fluids as the heat transfer fluids. They are produced by Dow Corning and General Electric, among others. These fluids have low freezing and pour points, low vapor pressure, low general corrosion, good long term stability, and low toxicity. Their major drawbacks are high viscosity, causing poor heat transfer and requiring higher flow rates, and high cost. Also, leakage through fittings can create problems because silicone fluids have lower surface tension than aqueous solutions. Joints and fittings must be adequate to insure minimal leakage.

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[2] Ucon is a trademark of Union Carbide Corporation.
[3] Jeffox is a trademark of Jefferson Chemical Company, Inc.
[4] Mobiltherm is a trademark of Mobil Oil Corporation.

Other Fluids

Another possible fluid for use in flat plate collectors is Dowtherm[5] J brand fluid. It is an alkylated aromatic compound with low viscosity, low heat capacity, and low thermal conductivity. It is relatively inexpensive but has low flash and fire points. Oxidation of Dowtherm J at high temperatures upon exposure to air can lead to formation of insoluble materials and increased fluid viscosity. When the fluid is overheated, the flash point can be lowered and vapor pressure increased. If it is contaminated by other fluids (such as water), corrosion can be enhanced (in the case of water, steel). The toxicity of Dowtherm J is high. As with aqueous ethylene glycol solutions, double walls would most likely have to separate the potable water from the Dowtherm J.

Some other possible heat transfer fluids include Therminol[6] 44 brand ester-based fluid, Therminol 55 brand alkylated benzene fluid, and Therminol 60 brand hydrogenated aromatic fluid. They have low heat capacities, low thermal conductivity, high viscosity, and low freezing temperatures. The flash points of these fluids are at the upper range of possible zero flow temperatures. The costs of Therminol 44 and 60 are relatively high, while Therminol 55 is much less costly.

Sun-Temp[7] brand fluid, a saturated hydrocarbon, is another possible heat transfer fluid available to flat plate collector users. It has low heat capacity, low thermal conductivity, high viscosity, a low freezing temperature, a high boiling temperature, low toxicity, low corrosivity with aluminum, and low vapor pressure. It is relatively inexpensive. Because of its high viscosity, larger flow rates are required to produce turbulent flow and to increase heat transfer.

Recently, inorganic aqueous salt solutions have been proposed as possible heat transfer fluids. According to Kauffman, 23-percent sodium acetate and 38-percent sodium nitrate aqueous solutions with suitable additives can be used as heat transfer fluids. These solutions have low toxicity. Their cost is comparable to that of ethylene glycol, and their heat transfer properties are similar to those of the glycols. Pumping costs for these fluids would be low. Like other aqueous solutions, they are subject to boiling at lower temperatures with large vapor pressures. These fluids are still being investigated for solar energy applications.

COMPARISON OF HEAT TRANSFER FLUIDS BY PHYSICAL PROPERTIES

In the preceding discussion of heat transfer fluids, general characteristics of each fluid studied were discussed. In the following sections, the following physical properties will be considered.

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[5] Dowtherm is a trademark of Dow Chemical Company.

[6] Therminol is a trademark of Monsanto Company.

[7] Sun-Temp is a trademark of Research Technology Corporation.

- Thermophysical properties
- Flow rate
- Cost
- Toxicity
- Flammability
- Corrosiveness
- Vapor pressure
- Freeze protection

The heat transfer fluids discussed earlier will be compared to offer a quantitative description of probable performance in double-loop heat exchanger collector systems. In some sections, representative fluids were chosen for the comparison. For ethylene glycol a 50-percent aqueous solution with inhibitors was used. Because most properties of the glycols are not drastically different from manufacturer to manufacturer, we did not always compare each available ethylene or propylene glycol product. A 50-percent solution for both ethylene and propylene glycols was used, since this allows adequate freeze protection for most cases. For some applications, lower concentrations might be plausible; in such cases, the results found here will be slightly conservative for heat transfer and flow rate properties. Also, since the properties of diethylene and triethylene glycol are close to those of ethylene glycol, we did not consider it necessary to compare these fluids in every section.

Thermophysical Properties

The thermophysical properties of the fluids were found from the manufacturers' specifications over the operating temperature range of flat plate collectors. For heat transfer, water is the best fluid. It has a high heat capacity, high thermal conductivity, and low viscosity. Water and the other heat transfer fluids are compared in Figures B-1 through B-4 for the following thermophysical properties.

- Viscosity
- Heat capacity
- Thermal conductivity
- Density

Generally, aqueous solutions (such as ethylene and propylene glycol) have better thermophysical properties than do the rest of the heat transfer fluids except Dowtherm J. Dowtherm J has a lower viscosity than glycol solutions but also has lower heat capacity and thermal conductivity. Other simple comparisons of the heat transfer fluids can be made from Figures B-1 through B-4.

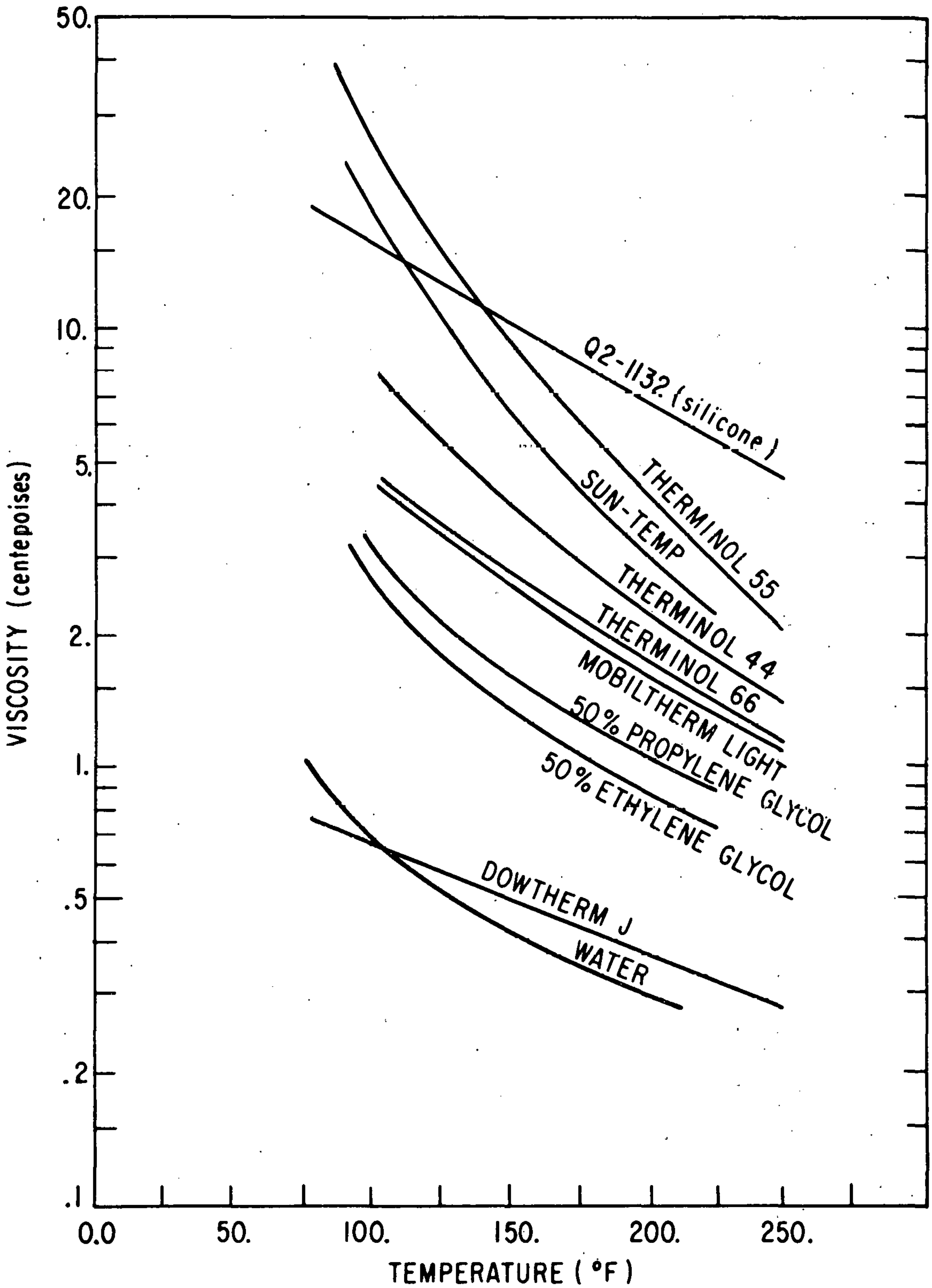

Figure B-1. Viscosity of Heat Transfer Fluids Versus Temperature (Multiply centipoises by 2.419×10^{-4} to get lb/ft·hr.)

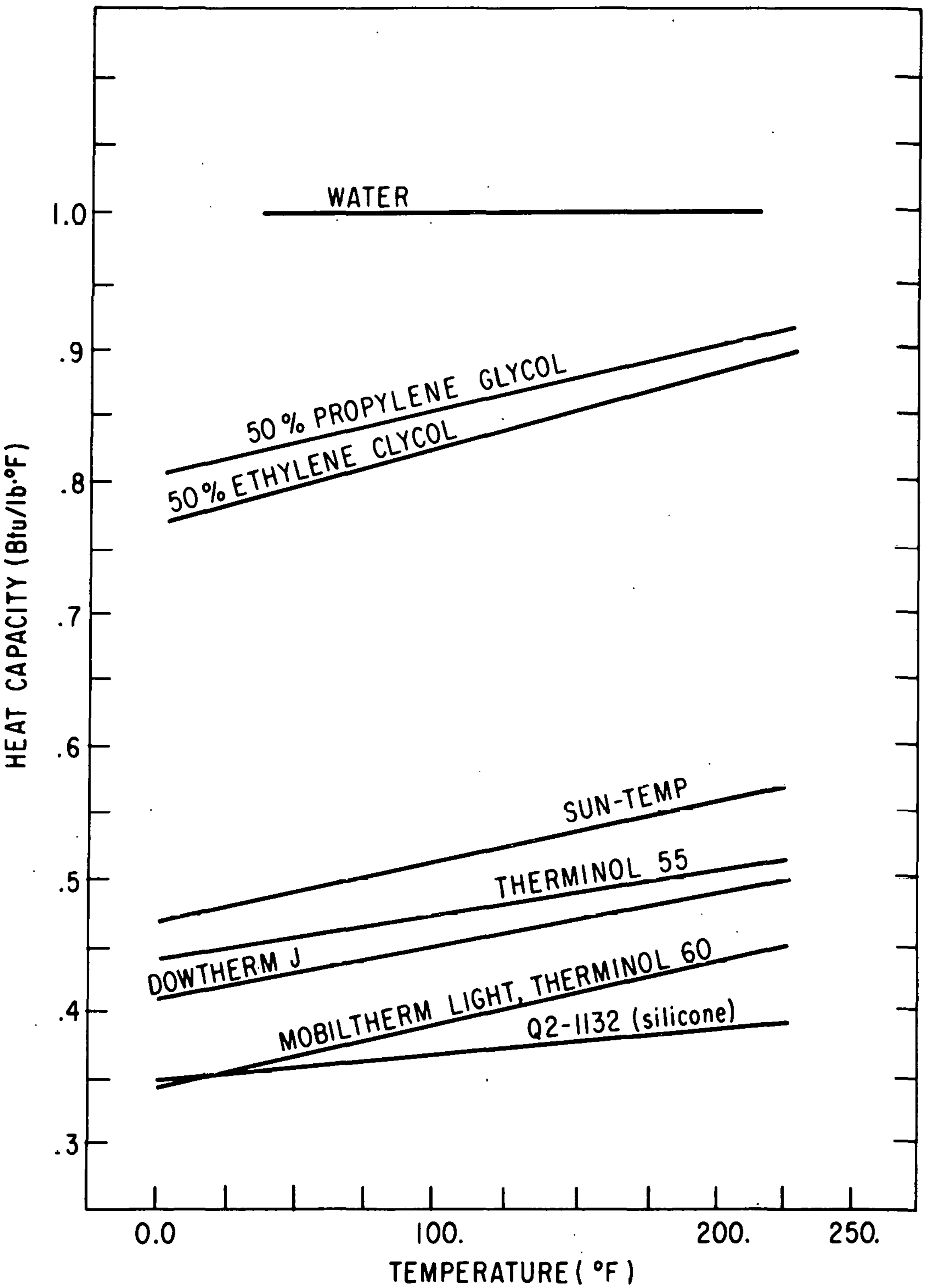

Figure B-2. Heat Capacity of Heat Transfer Fluids Versus Temperature

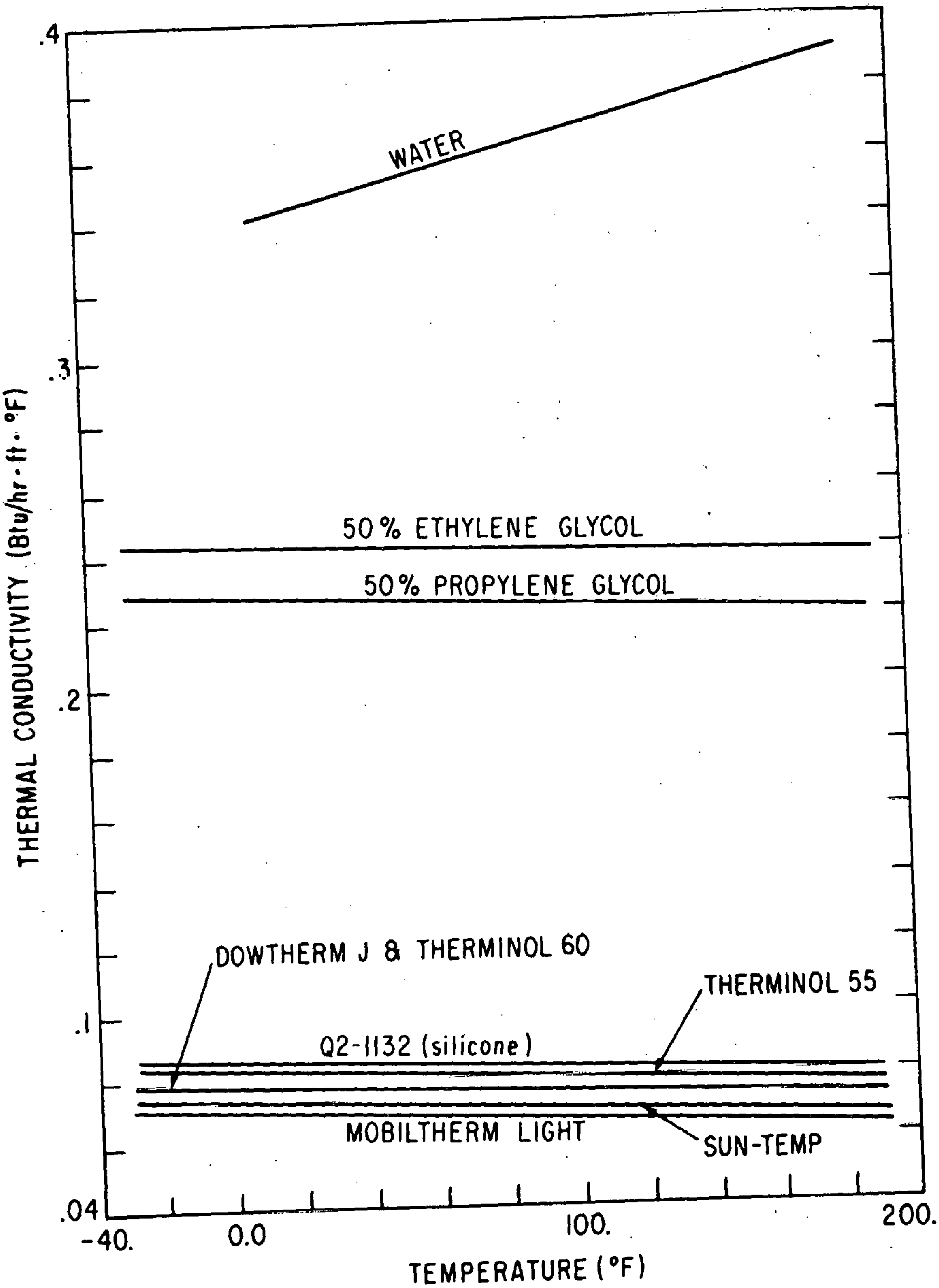

Figure B-3. Thermal Conductivity of Heat Transfer Fluids Versus Temperature

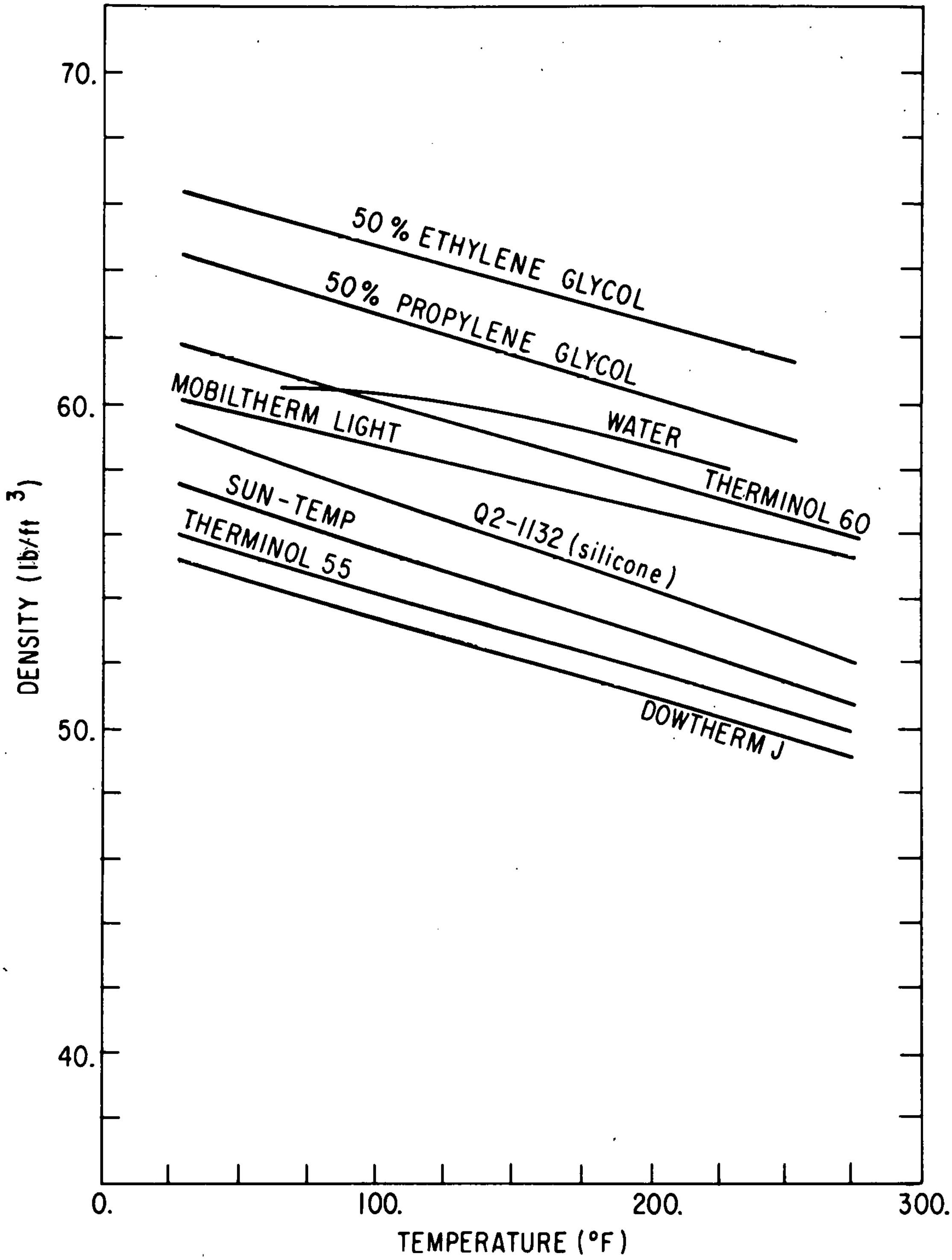

Figure B-4. Density of Heat Transfer Fluids Versus Temperature

Flow Rate

One of the important parameters to be considered in selecting a heat transfer fluid is the operating pressure drop caused by friction within the fluid channel. The pressure drop of the fluids was investigated for various flow rates and fluid channel sizes. McAdams found the pressure drop per tube length within tubes to be:

$$\frac{\Delta P}{L} = \frac{f\ G''^2}{2\ D_i g\rho\ 144} \qquad \text{(psi/ft)} \qquad \text{B-1}$$

This neglects entrance and exit effects. Equation B-1 is applicable for collector, heat exchanger, and traced tank tubes where:

f = friction factor

= $16/Re$, for $Re < 2500$ (laminar flow)

= $0.0014 + 0.125/Re^{0.32}$, for $Re > 2500$ (turbulent flow in smooth-walled tubes)

Re = Reynolds number

= $G''\ D_i/\mu$

μ = fluid viscosity (lb/ft·hr)

G'' = mass flow rate through tube (lb/hr·ft^2)

D_i = tube inside diameter (ft)

g = acceleration of gravity

= 4.18×10^8 ft/hr^2

ρ = density of fluid (lb/ft^3)

Equation B-1 can be reduced to the Darcy equation in the form:

$$\frac{\Delta P}{L} = \frac{0.0216 f\ Q^2}{d^5} \qquad \text{B-2}$$

where:

Q = flow rate (gal/min)

d = tube inside diameter (in)

Equation B-1 shows that the tube size greatly affects the pressure drop within the tube. Some fluids, because of their higher pressure drops, require larger tube sizes than water.

The shell-side pressure drop can be found by using the following equation from D. Q. Kern.

$$\Delta P = \frac{f\, G^2_{max}\, D_s\, (N_{baf} + 1)}{2\, g\rho\, D_o\, 144} \qquad \text{(psi)} \qquad \text{B-3}$$

where:

G_{max} = maximum flow rate through shell side (lb/hr·ft^2)

D_s = shell diameter (ft)

N_{baf} = number of baffles within heat exchanger

D_o = tube outside diameter (ft)

f = friction factor

= $0.0014 + 0.125/Re'^{0.32}$

Re' = $G_{max}D_o/\rho$

Cost

In some applications, more expensive fluids can be competitive with less costly ones. In order to determine the relative cost of a heat transfer fluid, the volume of fluid required for a particular application must be known. For some applications (such as domestic hot water heating) the amount of heat transfer fluid required will be small since the collector area needed is small. In traced tank systems more costly fluids can be used if their other properties are desirable.

Table B-1 shows the 1978 costs of many heat transfer fluids in single 55-gallon drum quantities. Note for the glycol solutions that the final costs will generally be lower, since a 100-percent solution of the glycols is not necessary. Thus Mobiltherm light and the glycols are the least expensive heat transfer fluids for initial installation, while the silicone fluids are the most expensive.

There are other costs besides those of the initial fillup. Periodic maintenance and inhibitor addition, if needed, can add to the total cost of the fluid over a specific time period. Where inadequate corrosion and freeze protection might lead to collector failure, this additional cost must be considered. Also, more viscous fluids will require higher flow rates and increased pumping costs. Thus the total investment in fluid over a given time period is equal to the sum of the initial cost of the fluid plus any additional costs of added fluid or inhibitor, increased pumping costs, maintenance, cost of replaced parts needed because of inadequate freeze or corrosion protection, or cost of reserve draindown or expansion tanks needed for some fluids.

Table B-1. Initial Fillup Cost of Heat Transfer Fluids

Fluid	Cost per Gallon (Single 55-gallon drum quantities)	Manufacturer
Water	--	--
100% Ethylene Glycol	2.56	Union Carbide
100% Propylene Glycol	2.45	Union Carbide
100% Diethylene Glycol	2.82	Union Carbide
100% Triethylene Glycol	3.70	Union Carbide
100% Ucar[a] Thermofluid (Ethylene glycol & inhibitors)	3.81	Union Carbide
100% Ucar Foodfreeze (Propylene Glycol & inhibitors)	3.63	Union Carbide
100% Dowtherm[b] SR-1 (Ethylene Glycol & inhibitors)	3.65	Dow Chemical
100% Dowfrost[b] (Propylene Glycol & inhibitors)	3.45	Dow Chemical
Mobiltherm[c] Light	1.29	Mobil Oil
SF-96(50) (Silicone)	14.00	General Electric
Q2-1132 (Silicone)	23.00	Dow Corning
Dowtherm J	4.50	Dow Chemical
Therminol[d] 44	7.65	Monsanto
55	2.80	Monsanto
60	6.80	Monsanto
Sun-Temp[e]	3.50	Resource Technology Corporation

[a] Ucar is a trademark of Union Carbide Corporation.
[b] Dowtherm and Dowfrost are trademarks of Dow-Chemical Corporation.
[c] Mobiltherm is a trademark of Mobil Oil Corporation.
[d] Therminol is a trademark of Monsanto Company.
[e] Sun-Temp is a trademark of Resource Technology Corporation.

Toxicity

The toxicity of a heat transfer fluid can greatly affect the design and operation of a double-loop flat plate collector system. Most plumbing codes require that double walls or vented surfaces separate a toxic fluid from potable water supplies. The possibility of poisonous fumes escaping from the heat transfer fluid must also be considered. These problems require the use of different heat exchangers, which transfer heat less optimally than those that operate without a toxic fluid. The following discussion describes the toxicity of the heat transfer fluids studied. The information was obtained from the manufacturers.

In a discussion of toxicity the following definitions (from United States Codes Annotated, 1974) are useful.

A hazardous substance is any substance or mixture of substances which:

- Is toxic
- Is corrosive (will cause destruction of living tissue by chemical action)
- Is an irritant
- Is a strong sensitizer
- Is flammable or combustible
- Generates pressure through decomposition, heat, or other means.

A toxic substance is any substance that has the capacity to produce injury or illness to man through ingestion, inhalation, or absorption through any body surface.

A highly toxic substance is any substance that produces death within 14 days in half or more than half of a group of ten or more laboratory white rats, each weighing between 200 and 300 grams, at a single dose of 50 milligrams or less per kilogram of body weight when orally administered, or when inhaled continuously for a period of 1 hour or less at an atmospheric concentration of 200 parts per million by volume or less of gas or vapor, or 2 milligrams per liter by volume or less of dust or mist.

LD_{50} refers to the quantity of chemical substance that kills 50 percent of dosed animals within 14 days. Dosage is expressed in grams or milliliters per kilogram of body weight.

Single dose (acute) oral LD_{50} refers to the quantity of substance which kills 50 percent of dosed animals within 14 days when administered orally in a single dose.

Because the primary hazard in using heat transfer fluids is the possibility that the heat transfer fluid may leak into a potable water supply and be ingested, acute oral toxicity is the primary concern in this section. Table B-2 lists the LD_{50} values for selected fluids for

Table B-2. Acute Oral Toxicities of Heat Transfer Fluids

Fluid	LD_{50}
Water	--
100% Ethylene Glycol (No inhibitors)	8.0
100% Propylene Glycol (No inhibitors)	34.6
100% Diethylene Glycol (No inhibitors)	30.
100% Triethylene Glycol (No inhibitors)	30.
100% Dowtherm SR-1	4.
Mobiltherm Light	20.
SF-96(50) (Silicone)	50
Q2-1132 (Silicone)	50
Dowtherm J	1.1
Therminol 44	13.5
Therminol 55	15.8
Therminol 60	13.0
Sun-Temp	No test information available

acute oral toxicity. No substance listed is highly toxic according to the preceding definition, but several are quite toxic. Dowtherm J is the most toxic fluid listed in Table B-2, with the ethylene glycol mixture second. The least toxic fluids are silicone fluids, Sun-Temp, and propylene glycol. (Propylene glycol is routinely used in the food industry.)

Flammability

The possibility of the heat transfer fluid being a fire hazard was considered. In a discussion of the flammability of a heat transfer fluid the following definitions are useful.

Boiling point -- the temperature at which the vapor pressure of a liquid equals the absolute external pressure at the liquid vapor interface.

Flash point -- the lowest temperature at which a combustible vapor above a liquid ignites and burns when ignited momentarily in air.

Fire point -- the lowest temperature at which a combustible vapor flashes and burns continuously.

Self-ignition point -- the temperature at which self-sustained ignition and combustion in ordinary air take place independent of a heating source.

Extremely flammable -- any substance that has a flash point at or below 20°F as determined by the TOCT (Togliabue Open Cup Tester).

Flammable -- any substance that has a flash point between 20°F and 80°F as determined by the TOCT.

Combustible -- any substance that has a flash point between 80°F and 150°F as determined by the TOCT.

Table B-3 lists the fluids studied and their boiling or flash points, whichever were supplied by the manufacturers. None of the fluids listed are extremely flammable or flammable. Only Dowtherm J is combustible, with a flash point of 145°F. With the exception of the silicone fluids, Sun-Temp, and Therminol 44, most of the fluids have flash points below possible staganation temperatures.

The HUD Minimum Property Standards for FHA eligibility, according to Kauffman, preclude the use of fluids whose flash points are not at least 100°F higher than the highest temperature to which they might be exposed. Thus the use of fluids with low flash points is limited unless adequate safeguards limit the exposure of these fluids to high temperatures and exposure to the atmosphere.

Table B-3. Flammability of Heat Transfer Fluids

Fluid	Boiling Point °F	Flash Point, °F (Cleveland Open Cup)
Water	212	--
100% Ethylene Glycol	388	240
50% Ethylene Glycol	225	
100% Propylene Glycol	370	225
100% Diethylene Glycol	475	290
100% Triethylene Glycol	550	330
100% Dowtherm SR-1	325	240
50% Dowtherm SR-1	230	
100% Dowfrost	--	214
Mobiltherm Light	250	
SF-96(50)		600
Q2-1132		450
Dowtherm J		145
Therminol 44	425	405
Therminol 55	600	355
Therminol 60	650	310
Sun-Temp	500	310

Corrosion

Butt and Popplewell state that general corrosion is usually slow in most systems but that localized corrosion is the prime cause for corrosion problems in flat plate collector systems. According to Popplewell, the four basic types of localized internal corrosion that can be affected by the heat transfer fluid are: (1) galvanic, (2) pitting, (3) crevice, and (4) erosion.

Galvanic corrosion occurs when two dissimilar metals are joined together in an electrolyte (a fluid that conducts electricity, such as an aqueous solution). Depending on the type of metals in contact, corrosion can occur quite rapidly at the interface. This problem can be avoided by separating any dissimilar metals in an electrolytic solution with insulating couplings.

Pitting corrosion is characterized by rapid localized metal loss which leads to perforation of metals in uninhibited aqueous solutions. For aluminum, the presence of chloride ions in the heat transfer fluid will aggravate this type of corrosion. Metal ions (copper and iron) will cause pitting to begin on aluminum surfaces. Steel is also susceptible to pitting corrosion in aqueous heat transfer fluids with chloride ions.

Crevice corrosion is similar to pitting corrosion in that rapid metal loss occurs in localized areas (inside crevices). Crevices can occur in blockages within internal channels or gaskets through which the heat transfer fluid passes. Aluminum and carbon steel are more susceptible to this form of corrosion in aqueous environments. This problem can be reduced by eliminating possible crevices by proper design.

Erosion Corrosion is caused by the joint action of corrosion coupled with mechanical removal of the protective product film. It occurs under high velocity or turbulent liquid flow conditions. Partial obstructions within the fluid channel can cause localized high velocities and enhanced corrosion. Aluminum, copper, and steel are all subject to this form of corrosion. According to Popplewell, a maximum velocity of 2 feet per second is considered relatively safe if the system is relatively free of abrasions.

General Wastage

Most of the fluid manufacturers show that the general wastage of common engineering materials by their fluids is small. Table B-4 shows several examples of general wastage of metallic surfaces by different fluids. Little is known at present of the possibilities of localized corrosion by the non-aqueous solutions.

Table B-4. General Corrosion of Various Metals by Heat Transfer Fluids

Metal	Silicone (Q2-1132), mg/cm^2	50% Propylene Glycol, mg/cm^2 per day
Aluminum	0.01 Bright	0.25
Cast Iron	0.01 Bright	--
Steel	0.01 Bright	0.002
Copper	0.02 Medium Stain	0.124

Silicone humidified fluid corrosion test results obtained as per SAE xj 1705 (from Dow Corning Form No. 22-380A-76).

Vapor Pressure

Under zero flow conditions within the collectors, temperatures in excess of 300°F are possible. For aqueous solutions the vapor pressure under stagnation conditions can reach several atmospheres. Some collectors cannot withstand these pressures. Figure B-5 shows the absolute vapor pressure versus temperature for several of the fluids. The vapor pressures of the fluids are quite low, even under zero flow conditions, except for the aqueous solutions and Dowtherm J.

Freeze Protection

One of the major drawbacks of using water as a heat transfer fluid is its high freezing temperature. In the continental United States, few locations have had no recorded below-freezing temperatures.

Antifreeze solutions have been commonly added to water to lower its freezing temperature. In some cases these solutions can retard the expansivity of the water and create a slush that will not rupture the fluid vessel. Most nonaqueous fluids do not expand upon freezing and thus will reduce the risk of damaged piping.

Because some fluids become so viscous that their freezing temperatures are not easily measured, the pour point temperatures of the fluids are used as their lower operating limits. The pour point temperature is the temperature of the fluid at which it fails to flow when the container is tilted to horizontal and held for 5 seconds.

Freeze protection temperatures can best be obtained from the manufacturer for the particular fluid in question.

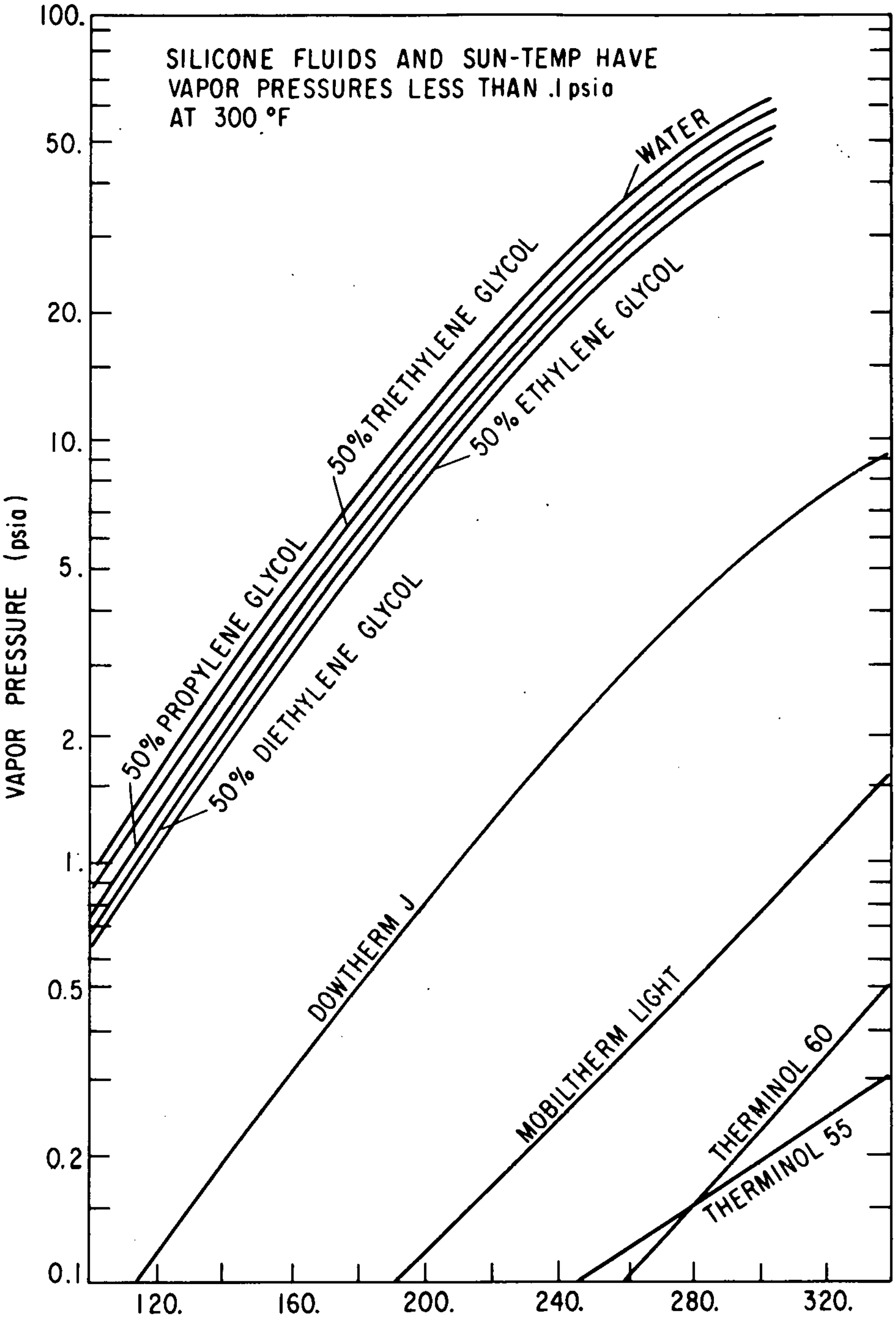

Figure B-5. Vapor Pressure of Heat Transfer Fluids Versus Temperature

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APPENDIX C. CALCULATING INSULATION REQUIREMENTS FOR STORAGE DEVICES

This appendix explains how the multipliers in Tables 1-4 through 1-7 in Chapter 1 were derived. In addition, the more detailed description of insulation calculations in this appendix will be helpful in cases where Tables 1-4 through 1-7 are not applicable (for example, in calculating insulation for an odd-shaped storage device).

The first step in calculating the amount of insulation needed around the storage device is deciding how much heat loss per hour can be tolerated. Generally the amount of heat loss is stated as some percentage of the system's storage capacity in a given time period. The storage capacity is given by:

$$S = C_p \cdot V \cdot \Delta T_{storage} \qquad \text{C-1}$$

where:

- C_p is the volumetric heat capacity of the storage medium (Btu/°F·ft^3).
- V is its volume (ft^3).
- $\Delta T_{storage}$ is its daily temperature range (°F).

The volume is stated in cubic feet. If you are working with volume stated in gallons, multiply the number of gallons by 0.1337 to get cubic feet.

Example 1: From Table 1-1 we find C_p for water to be 62.4 Btu/°F·ft^3. A 750-gallon water tank whose operating temperature will normally reach 160°F when charged and 100°F when discharged will have a storage capacity of:

$$S = 62.4 \frac{\text{Btu}}{\text{°F}\cdot\text{ft}^3} \times 750 \text{ gal} \times 0.1337 \frac{\text{ft}^3}{\text{gal}} \times (160\text{°F}-100\text{°F})$$

$$= 6257.16 \frac{\text{Btu}}{\text{°F}} \times (60\text{°F})$$

$$= 375,400 \text{ Btu}$$

If we insulate the storage device so that it will lose p percent of its energy in h hours, then the heat loss per hour will be:

$$\dot{Q} = S \times \frac{p}{100} \times \frac{1}{h} \qquad \text{C-2}$$

Example 2: If we insulate the 750-gallon tank in Example 1 so that it will lose 2 percent of its stored energy in 12 hours, its heat loss per hour will be:

$$\dot{Q} = (375{,}400 \text{ Btu}) \times \frac{2}{100} \times \frac{1}{12} \text{ hours}$$

$$\dot{Q} = 626 \frac{\text{Btu}}{\text{hour}}$$

Once you know how much heat loss you will allow from the storage device per hour, you can determine how much insulation is needed. The amount of heat escaping from the storage device is the sum of the amounts that escape through each of its walls. These heat losses depend on the area of the walls, on the total R-value of the insulation on each wall (see Figure 1-4), and on the temperature difference across the walls. For rectangular tanks the amount of heat that escapes per hour will be:

$$\dot{Q} = \left(\frac{A_{top}}{R_{top}} + \frac{A_{sides}}{R_{sides}} + \frac{A_{bottom}}{R_{bottom}}\right) \Delta T_{wall} \qquad \text{C-3}$$

where:

A is the area (ft^2).

R is the R-value ($ft^2 \cdot °F \cdot hour/Btu$). These are the units commonly used by U.S. insulation manufacturers.

ΔT_{wall} is the difference between the normal maximum storage temperature and the ambient temperature (°F). ΔT_{wall} is not the same as $\Delta T_{storage}$ in Equation C-1.

For cylindrical tanks the heat loss per hour will be:

$$\dot{Q} = \left(\frac{\pi D^2}{4R_{end}} + \frac{\pi DL}{R_{sides}} + \frac{\pi D^2}{4R_{end}}\right) \Delta T_{wall} \qquad \text{C-4}$$

where:

π = 3.14

D = tank diameter (ft)

L = tank length (ft)

R = R-value of the insulation ($ft^2 \cdot {}^\circ F \cdot hour/Btu$)

Assuming that the R-value of the insulation on the top and sides of a rectangular tank is R and that the insulation on the bottom is some fraction, f, times R, Equation C-3 can be rewritten as follows:

$$\dot{Q} = \left[LW + 2LH + 2WH + \frac{LW}{f}\right] \frac{\Delta T_{wall}}{R} \qquad \text{C-5}$$

where L, W, and H are the length, width, and height of the container. Rearranging this equation gives:

$$R = \left[LW\left(\frac{1+f}{f}\right) + 2H(L+W)\right] \frac{\Delta T_{wall}}{\dot{Q}} \qquad \text{C-6}$$

Example 3: Suppose that the 750-gallon tank in the previous examples is rectangular and has a length of 5 feet, a width of 4 feet, and a height of 5 feet. It has half as much insulation on the bottom (f = 0.5) as it has on the top and sides and is located in a basement whose normal temperature is 65°F so that ΔT_{wall} is (160°F - 65°F) = 95°F. In Example 2 we calculated the desired heat loss rate to be 626 Btu/hour. The R-value of the insulation needed to allow this heat loss rate will be (from Equation C-6):

$$R = \left[(5\text{ft.} \times 4\text{ft.}) \left(\frac{1 + 0.5}{0.5}\right) + 2 \times 5\text{ft.} \times (5\text{ft.} + 4\text{ft.})\right] \times \frac{95°F}{626 \text{ Btu/hour}}$$

$$= 20 \text{ ft}^2 \times (3) + 10 \text{ ft.} \times (9 \text{ ft.}) \times \frac{95°F}{626 \text{ Btu/hour}}$$

$$= \frac{150 \text{ ft}^2 \times 95°F}{626 \text{ Btu/hour}}$$

$$= 22.8 \frac{\text{ft}^2 \cdot °F \cdot \text{hour}}{\text{Btu}}$$

For a cylindrical tank, assume that one end of the tank has some fraction, f, as much insulation as the other end and the sides. Then Equation C-4 can be rewritten as follows:

$$\dot{Q} = \left(D^2 + 4DL + \frac{D^2}{f}\right) \frac{\pi \Delta T_{wall}}{4R} \qquad \text{C-7}$$

where D is the tank diameter and L the lenth. Rearranging this equation gives:

$$R = \left[D^2 \left(\frac{1 + f}{f}\right) + 4DL\right] \frac{\pi \Delta T_{wall}}{4\dot{Q}} \qquad \text{C-8}$$

Example 4: Suppose that the 750-gallon tank in Examples 1 and 2 is cylindrical and has a diameter of 4 feet and a length of 8 feet. It is located aboveground outside where the average January temperature is 30°F so that ΔT_{wall} is (160°F - 30°F) = 130°F. The insulation is the same all around, so f = 1. Again, we want $\dot{Q}$ to be limited to 626 Btu/hour as calculated in Example 2. With Equation C-8, we can calculate the desired amount of insulation as follows:

$$R = \left[(4 \text{ ft.} \times 4 \text{ ft.}) \frac{(1+1)}{1} + 4 \times 4 \text{ ft.} \times 8 \text{ ft.}\right] \frac{3.14 \times 130°F}{4 \times 626 \text{ Btu/hour}}$$

$$= \left[(16 \text{ ft}^2)\ (2) + 128 \text{ ft}^2\right] \frac{3.14 \times 130°F}{4 \times 626 \text{ Btu/hour}}$$

$$= \frac{160 \text{ ft}^2 \times 3.14 \times 130°F}{4 \times 626 \text{ Btu/hour}}$$

$$= 26.1 \frac{\text{ft}^2 \cdot °F \cdot \text{hour}}{\text{Btu}}$$

Calculating the proper amount of insulation for rock beds is a little more complicated because the insulated surface includes the plena as well as the walls around the rocks. Because of the added heat loss area for the plena and because rock beds have a larger volume, the amount of insulation required will be greater for a rock bed than for a water tank of equal thermal capacity.

Equation C-1 can be used to calculate the storage capacity of rock beds if the value of C_p that is used includes the voids around the rocks. Table 1-1 gives values of C_p for a 30-percent void fraction. If your rock bed has a different void fraction, then the value of C_p without voids (also in Table 1-1) must be multiplied by 1 minus the void fraction to get the correct C_p to use in Equation C-1.

Equations C-2, C-3, and C-6 can also be used if the height, H, in Equation C-6 includes the plena. The volume, however, does not include the plena. The rule of thumb is that the vertical area of each plenum should be one tenth of the horizontal area of the rocks. Using this rule of thumb and assuming that the plenum opening is along the length of the rock bed container, the total height of rock bed plus both plena will be:

$$H_{total} = H_{rocks} + 0.2 \times \text{width} \qquad \text{C-9}$$

The values given in Tables 1-4 through 1-7 were calculated from the formulas given above.

In calculating the multipliers for water tanks (Tables 1-4 through 1-6) the following assumptions were made.

- The daily temperature range, $\Delta T_{storage}$, in Equation C-1 is 60°F.
- The heat loss rate in Equation C-2 is 2 percent (P = 2) in 12 hours (h = 12).

Including the conversion from gallons to cubic feet in Equation C-1, the first assumption gives the storage capacity:

$$S = 62.4 \frac{Btu}{°F \cdot ft^3} \times 0.1337 \frac{ft^3}{gallon} \times 60°F \times G$$

(where G is the capacity of the tank in gallons) or

$$S = 500.57 \frac{Btu}{gallon} \times G$$

Using this value and the second assumption in Equation C-2 gives:

$$\dot{Q} = 500.57 \frac{Btu}{gallon} \times G \times \frac{2}{100} \times \frac{1}{12\ hours}$$

or

$$\dot{Q} = 0.834 \frac{Btu}{hour \cdot gallon} \times G$$

For rectangular water tanks it is assumed that the insulation at the bottom of the tank is half that on the sides and top (f = 0.5). Using this value of f and the value for $\dot{Q}$ obtained above, Equation C-6 becomes:

$$R = \left[LW \frac{(1.5)}{0.5} + 2H(L-W)\right] \frac{\Delta T_{wall}}{0.834 \frac{Btu}{hour \cdot gallon} \times G}$$

or

$$R = \left[\frac{3LW + 2H(L+W)}{0.834\ G}\right] \Delta T_{wall}$$

The values given in Table 1-4 are then:

$$M = \left[\frac{3LW + 2H(L+W)}{0.834\ G}\right] \qquad \text{C-10}$$

where the appropriate tank dimensions and capacity have been inserted.

It is assumed in the calculations for Table 1-5 that the tank is uniformly insulated all around (f = 1). Using the value of $\dot{Q}$ given above, Equation C-8 becomes:

$$R = (2D^2 + 4DL)\ \frac{3.14}{4 \times 0.834\ G}\ \Delta T_{wall}$$

or

$$R = \left[\frac{D^2 + 2DL}{0.531\ G}\right] \Delta T_{wall}$$

The values given in Table 1-5 are then:

$$M = \left[\frac{D^2 + 2DL}{0.531\ G}\right] \qquad \text{C-11}$$

where the appropriate dimensions and tank capacity have been used. The last two columns of Table 1-6 also use the multiplier given by Equation C-11.

In the first two columns of Table 1-6 it is assumed that the tank has only half as much insulation on the bottom as it has on the sides and top. This changes the multiplier in these columns to:

$$M = \frac{3D^2 + 4L}{1.062\ G} \qquad \text{C-12}$$

because in this case f = 0.5 in Equation C-8.

The assumptions used in deriving the multipliers for rock bed insulation in Table 1-7 are:

- The daily temperature range, $\Delta T_{storage}$, in Equation C-1 is 50°F.

- The heat loss rate in Equation C-2 is 2 percent ($p = 2$) in 12 hours ($h = 12$).
- The R-value of the insulation on the bottom is half that on the top and sides.
- The void fraction is 30 percent.

Using the value of C_p for rocks with a 30-percent void fraction and the first assumption given in Equation C-1 gives the storage capacity of the rock bed:

$$S = 24.5 \frac{\text{Btu}}{\text{ft}^2\,{}^\circ\text{F}} \times 50^\circ\text{F} \times V$$

or

$$S = 1225 \frac{\text{Btu}}{\text{ft}^2} \times V$$

where V is the volume of the rocks, including voids.

The second assumption and Equation C-2 then give:

$$\dot{Q} = 1225 \frac{\text{Btu}}{\text{ft}^2} \times V \times \frac{2}{100} \times \frac{1}{12\ \text{hours}}$$

or

$$\dot{Q} = 2.04 \frac{\text{Btu}}{\text{ft}^2\cdot\text{hour}} \times V$$

Inserting this value and the height as given in Equation C-9 into Equation C-6 with $f = 0.5$ gives a multiplier of:

$$M = \frac{3LW + 2(H+0.2W)(L+W)}{2.04\ V} \qquad \text{C-13}$$

The values in Table 1-7 were calculated by inserting the appropriate dimensions and volume into Equation C-13.

APPENDIX D. DETERMINING HEAT EXCHANGER SIZE

Using a heat exchanger either as a means of separating antifreeze solution from the storage water or as a means of separating potable water from nonpotable water requires choosing a heat exchanger of the proper size. For purposes of calculating heat exchanger size there are two main types of heat exchanger systems, double-loop and single-loop. A double-loop system, illustrated in Figure D-1, requires two pumps (forced convection) to maintain positive control of the flow on both sides of the heat exchanger. A single-loop system has only one pump and typically features either a coil inside the tank or a coil fastened to the outside of the tank. Single-loop systems rely on bouyancy of the heated water to maintain flow on the tank side of the heat exchanger (natural convection). Forced convection is maintained on the other side of a single-loop system by a pump.

The use of a heat exchanger leads to a collection penalty, as shown in Figure D-1. The efficiency of collection decreases with increasing collection temperature, as shown in the curve in the lower part of the figure. The presence of the heat exchanger increases the collection temperature and hence produces the collection penalty.

DOUBLE-LOOP HEAT EXCHANGER SYSTEMS

De Winter first analyzed the case of a double-loop heat exchanger system and found that if capacity rates were used in the two loop so that:

$$(WC_p)_{coll} \leq (WC_p)_{sto} \qquad \text{D-1}$$

where:

W is the mass flow rate,

C_p is the heat capacity,

coll is the loop through the collector, and

sto is the loop through the storage tank, as shown in Figure D-1, then the heat collected by the collector-heat exchanger combination was simply reduced by the factor:

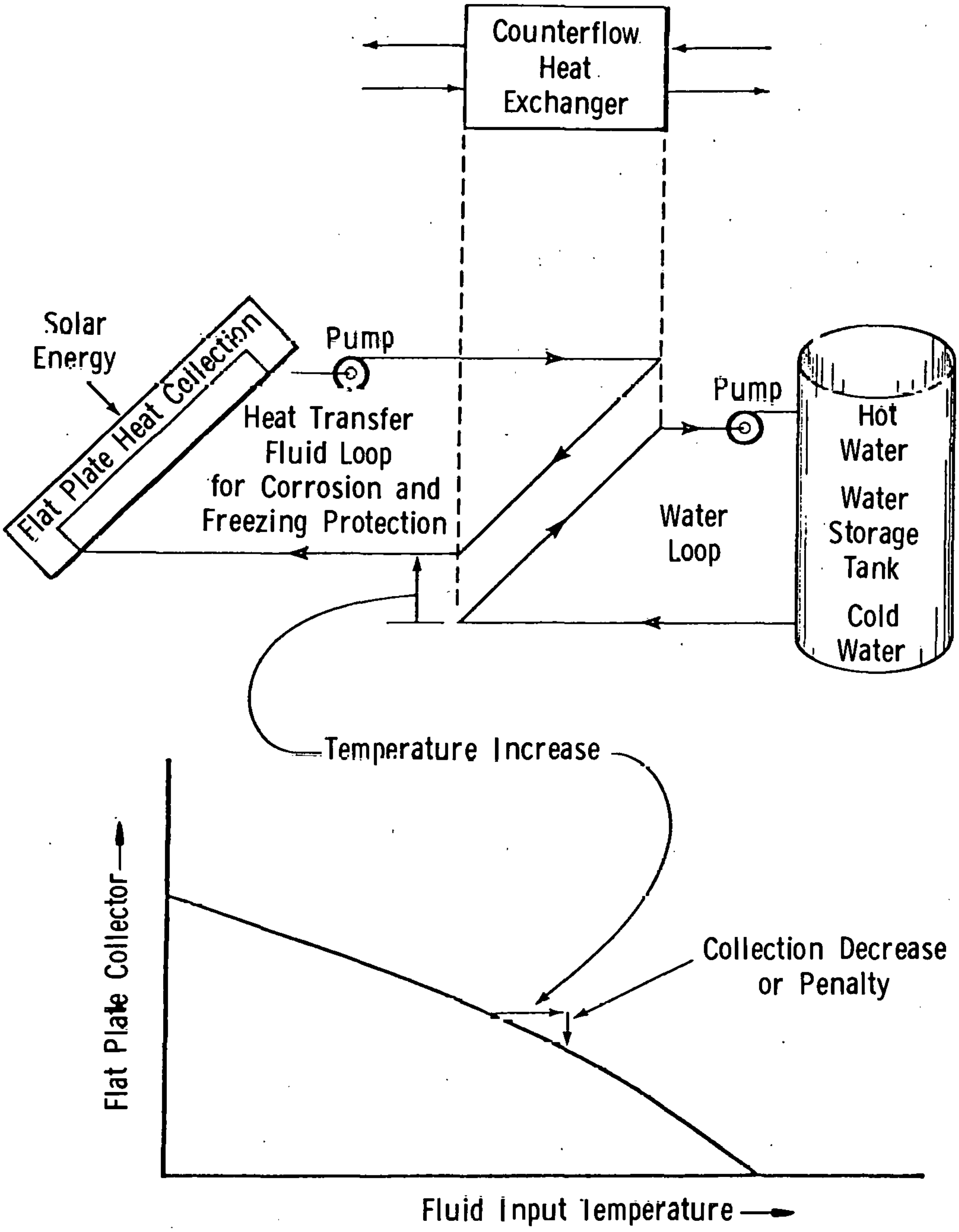


Figure D-1. Heat Collection Decrease Caused by a Double-Loop Heat Exchanger

$$\frac{F_R'}{F_R} = \frac{1}{1 + \frac{F_R U_c A_c}{(WC_p)_{coll}} \left[\frac{1}{\varepsilon} - 1\right]} \qquad \text{D-2}$$

where:

- F_R is the standard collector efficiency factor of the Hottel-Whillier flat plate collector model.
- F_R' is the same factor modified by the heat exchanger effect.
- A_c is the area of the collector.
- U_c is the collector heat loss coefficient.
- ε is the heat exchanger effectiveness.

Klein, Beckman, and Duffie extended this to systems in which Equation D-1 does not hold and determined that for this more general case:

$$\frac{F_R'}{F_R} = \frac{1}{1 + \frac{F_R U_c A_c}{(WC_p)_{coll}} \left[\frac{(WC_p)_{coll}}{\varepsilon \ (WC_p)_{min}} - 1\right]} \qquad \text{D-3}$$

Equation D-3, which is completely general, is shown in Figure D-2. In the general case, the heat exchanger effectiveness is an exponential function of the parameters NTU = $(U_x A_x)/(WC_p)_{min}$ and of $(WC_p)_{max}$ as shown in Equations D-4a and D-4b. (A_x is the heat exchanger heat transfer area and U_x the associated overall heat transfer coefficient.)

$$\varepsilon = \frac{1 - e^{-N}}{\left[1 - (WC_p)_{min}/(WC_p)_{max} e^{-N}\right]} \qquad \text{D-4a}$$

with

$$N = NTU \left[1 - (WC_p)_{min}/(WC_p)_{max}\right] \qquad \text{D-4b}$$

The effectiveness increases as the heat exchanger heat transfer area increases. This reduces the collection penalty--it increases F_R'/F_R, bringing it closer to 1--so that heat collection is increased. However, increasing the heat exchanger size increases the system cost. By doing

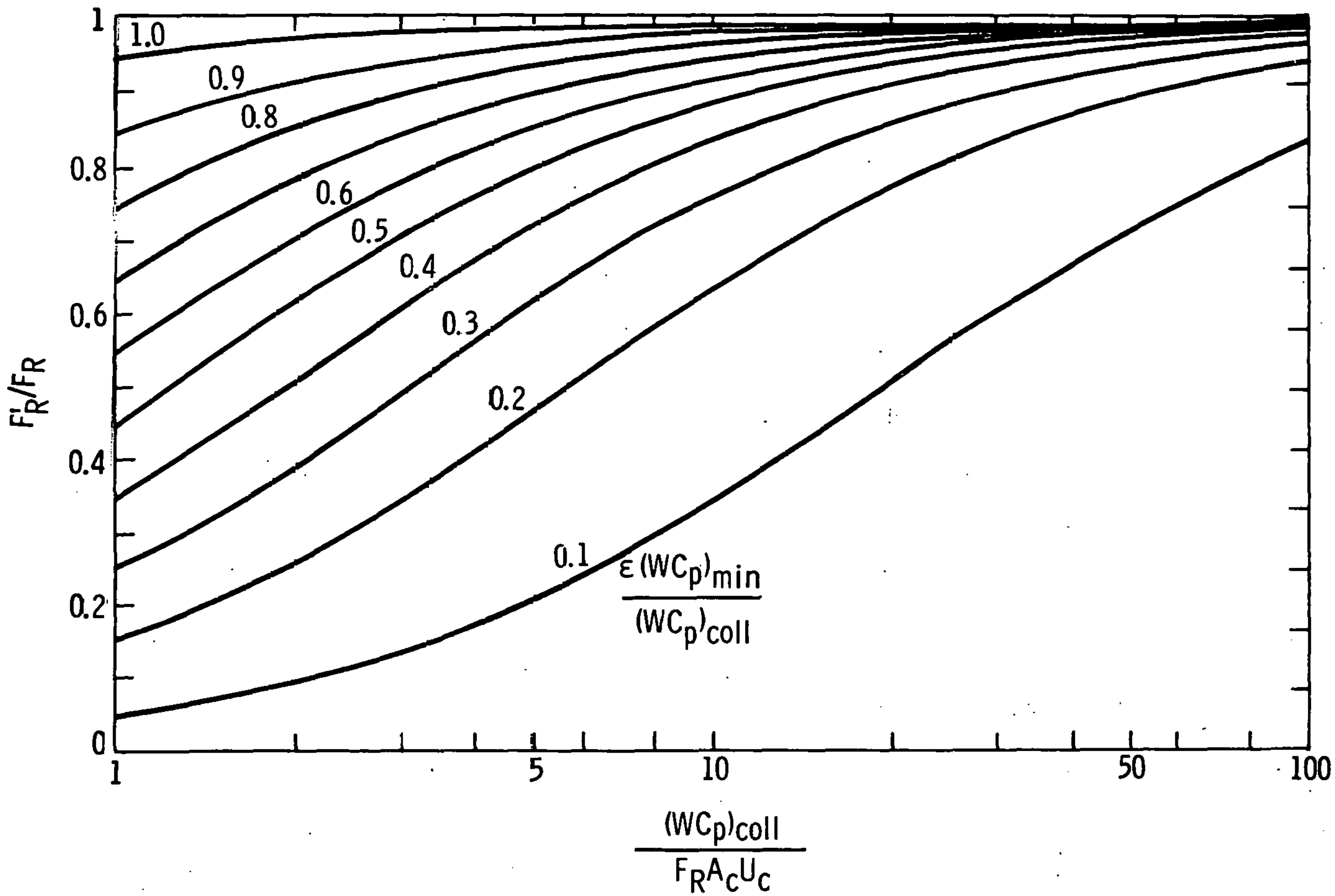


Figure D-2. Collector Heat Exchanger Factor F'_R/F_R

a computer simulation the designer can find an optimum heat exchanger size as illustrated in Figure D-3.

For the specific case in which:

$$(WC_p)_{coll} = (WC_p)_{sto} \qquad \text{D-5}$$

de Winter found that:

$$\frac{F_R'}{F_R} = \frac{1}{1 + \frac{F_R U_c A_c}{U_x A_x}} \qquad \text{D-6}$$

since:

$$\varepsilon = \frac{1}{1 + \frac{(WC_p)_{coll}}{U_x A_x}} \qquad \text{D-7}$$

When the cost per unit area of the collector (C_c) and the cost per unit area of the heat exchanger (C_x) are constant, de Winter further found that if the heat transfer coefficient U_x did not vary with the area A_x the optimum heat exchanger area A_x could be calculated from the equation:

$$A_x = A_c \left[\frac{F_R U_c C_c}{U_x C_x}\right]^{1/2} \qquad \text{D-8}$$

According to Horel and de Winter, with a given <u>average</u> WC_p product, the optimum heat exchanger invariably had a storage capacity rate $(WC_p)_{sto}$ higher than its collector capacity rate $(WC_p)_{coll}$, so that Equation D-1 was invariably satisfied and Equation D-2 applied. For typical values of the collector capacity rate $(WC_p)_{coll}$, they found that the value of $C' = (WC_p)_{coll}/(WC_p)_{sto}$ ranged from 0.5 to 0.6 and that, for all practical purposes, Equation D-8 could still be used to find the optimum heat exchanger area, since this was only about 1 percent different from that found for the optimum (unmatched capacity rate) case.

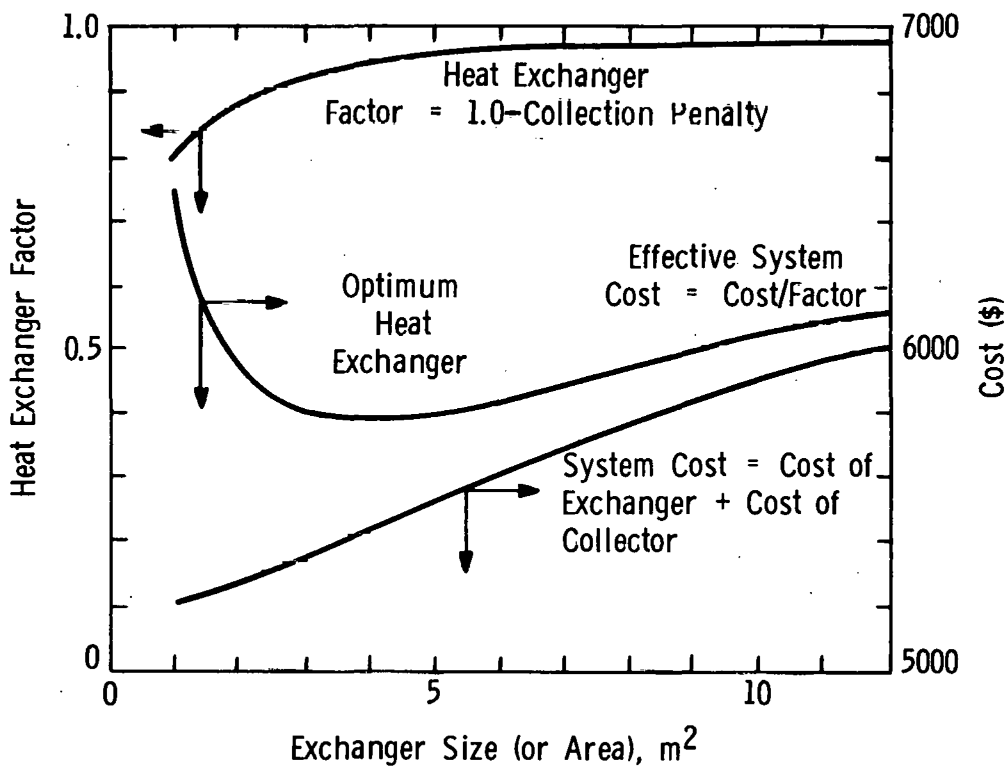


Figure D-3. Typical Heat Exchanger Optimization Plot, Showing the Heat Exchanger Factor, Total System Cost, and Effective System Cost as a Function of Heat Exchanger Size or Area

SINGLE-LOOP HEAT EXCHANGER SYSTEMS

An analysis for a single-loop system, using a traced tank or a coil in a tank, was performed by Horel and de Winter. They found that the same heat exchanger factor determined for a double-loop system in Equation D-2 could be used for the single-loop system. Again the designer can determine an optimum heat exchanger area using the methodology shown in Figure D-3. The main difficulty in this case lies in the fact that the heat transfer coefficients used to determine U_x are no longer straightforward forced convection coefficients, since on the water (storage) side there is a natural convection coefficient that is harder to determine. This area is addressed in the next section.

FORCED CONVECTION IN HEAT EXCHANGERS

Using heat transfer coefficients will enable the designer to optimize the heat transfer of a collector-to-storage system. They also allow easy comparison of heat transfer fluids. Heat transfer coefficients within the tubes and outside the tubes (i.e., shell-side heat transfer coefficients) as well as overall heat transfer coefficients must be used. In the following sections, each of these coefficients is discussed.

Inside Tube Heat Transfer Coefficients

For a double-loop heat exchanger system, inside tube heat transfer coefficients must be specified for the collector tubes and the exchanger tubes. For a traced tank, the inside tube heat transfer coefficients must also be determined for the helical coil.

The inside tube heat transfer coefficient is dependent upon:

- Flow rate through the tube
- Cross-sectional area of the tube
- Temperature of operation
- Properties of the fluid at the operating temperature.

Depending on the state of the fluid (i.e., laminar, transitional, or turbulent) different correlations must be used to determine the inside tube heat transfer coefficients (h_i). For the laminar region (Reynolds number < 2500) the following correlation from McAdams can be used:

$$h_i = \frac{KC_2}{D_i} \qquad \text{D-9}$$

where:

$$C_2 = 1.75 \left(\frac{G'C_p}{KL} \right)^{1/3} \quad \text{for } 1.75 \left(\frac{G'C_p}{KL} \right)^{1/3} > 3.66$$

$$C_2 = 3.66 \quad \text{for } 1.75 \left(\frac{C'C_p}{KL} \right)^{1/3} < 3.66$$

h_i = inside tube heat transfer coefficients (Btu/hr·°F·ft^2)

K = thermal conductivity of fluid (Btu/hr·°F·ft)

D_i = inside tube diameter (ft)

G' = flow rate (lb/hr)

C_p = heat capacity of fluid (Btu/lb·°F)

L = tube length (ft)

Thus, in the upper laminar region, the inside tube heat transfer coefficient also depends upon the tube length.

For the transitional region (2500 < Reynolds number < 7100), h_i becomes:

$$h_i = (C_p \ \mu/K \qquad \text{D-10}$$

where:

$$J' = 0.116\ (Re^{2/3} - 125)/Re$$

and

Re = Reynolds number

= $G''D_i/\mu$

μ = viscosity of fluid (lb/ft·hr)

G'' = flow rate per tube (lb/ft^2·hr)

For the turbulent region (Re > 7100), the inside tube heat transfer coefficient from McAdams is for values of L/D greater than 60.

$$h_i = \frac{0.023\ K\ Re^{0.8}}{D_i} (C_p\ \mu/K)^{0.4} \qquad \text{D-11}$$

Since, in general, the transitional region should be avoided, it was included only to provide continuity from the laminar to the turbulent regimes. Also note that, at the interface between transitional and turbulent (Re = 7100) and the interface between laminar and transitional (Re = 2500), the equations do not predict similar inside tube heat transfer coefficients. For Re = 7100 there is a 10-percent difference between the two equations, whereas around Re = 2500 the error is larger. The selection of the transitional region between Reynolds numbers 2500 and 7100 was completely arbitrary. It was chosen to minimize the errors at the two boundaries and to allow reasonable heat transfer in the lower turbulent region.

For the traced tank system, the effect of the fluids operating in the laminar regime is greater, since the heat transfer coefficients can affect the helical coil efficiency. Heat exchangers operating in laminar flow have much lower effectiveness than those operating in the turbulent regime.

Some simple relationships between the flow rate in gallons/(minute·per tube) and the other flow rates follow.

$$Q = Q_n N$$

$$Q_n = \frac{0.1247\ G'}{\rho N}$$

$$G'' = \frac{4G'}{D_i^2 N \pi}$$

where:

Q = total system flow rate (gallons/minute)

N = total number of tubes

Q_n = flow rate per tube (gallons/minute)

ρ = density of the fluid (lb/ft^3)

Shell-Side Heat Transfer Coefficient

The shell-side heat transfer coefficient within the heat exchanger (h_o) was determined for those fluids studied. h_o is a function of:

- Shell entrance flow rate
- Temperature of operation
- Fluid properties at the operating temperature
- Characteristics of the heat exchanger
  - (1) Tube pitch
  - (2) Baffle spacing
  - (3) Outer tube diameter
  - (4) Number of tube rows.

A correlation was found from Kreider and Kreith.

$$h_o = 0.33\ Re'^{\ 0.6}\ (C_p\ \mu/K)^{0.33}\ K/D_o$$

Re' = Reynolds number through minimum cross-sectional area of heat exchanger

G_{max} = flow rate through the minimum cross-sectional area of the heat exchanger ($lb/ft^2 \cdot hr$)

$$= \frac{G_s}{A_{min}\ (N_{row} + 1)}$$

G_s = total shell flow rate (lb/hr)

Q_s = total shell flow rate (gal/min)

$= 0.1247\ G_s/\rho$

A_{min} = minimum cross-sectional area (ft^2)

$= S_{baf} S_{min}$

S_{baf} = baffle spacing (ft)

S_{min} = tube spacing (ft)
= (pitch -1) D_o

Pitch = equilateral triangular pitch
= 1.25

N_{row} = number of tube rows across diameter of shell. This is a conservative estimate of the number of tube openings available for the fluid to flow through.

Figure D-4 shows the exchanger characteristics more clearly.

Overall Heat Transfer Coefficient

The overall heat transfer coefficient of a heat exchanger (U_x) can be determined from the following equation by Kays and London.

$$U_x = \frac{1}{\frac{1}{h_o} + \frac{1}{h_{so}} + \frac{D_o}{D_i h_i} + \frac{D_o}{D_i h_{is}} + R_{wall}} \qquad \text{D-13}$$

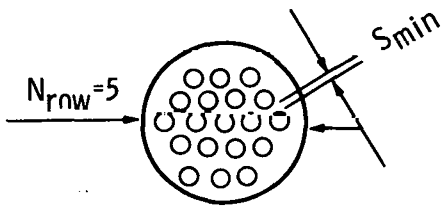
where:

h_{so} = shell side scaling coefficient ($Btu/hr \cdot ft^2 \cdot °F$)
h_{is} = inside tube scaling coefficient ($Btu/hr \cdot ft^2 \cdot °F$)
R_{wall} = tube wall heat transfer resistance ($hr \cdot ft^2 \cdot °F/Btu$)

$$= \frac{D_o}{2\, K_{tex}} \ln \frac{D_o}{D_i}$$

K_{tex} = thermal conductivity of the tube wall ($Btu/hr \cdot ft \cdot °F$)

The scaling coefficients can be assumed constant for nearly all fluids and tube sizes and equal to 100 $Btu/hr \cdot ft^2 \cdot °F$. If the water is very hard (over 15 grains/gallon), a scaling coefficient of 330 $Btu/hr \cdot ft^2 \cdot °F$ can be specified. The reciprocal of the scaling coefficient, known as the fouling factor, is frequently specified instead of the scaling coefficient. Normally, scaling coefficients decrease with time if maintenance is not periodically performed because of increased scaling deposits on the inner and outer tube walls. This can reduce the performance of the heat exchanger and increase the possibility of corrosion.



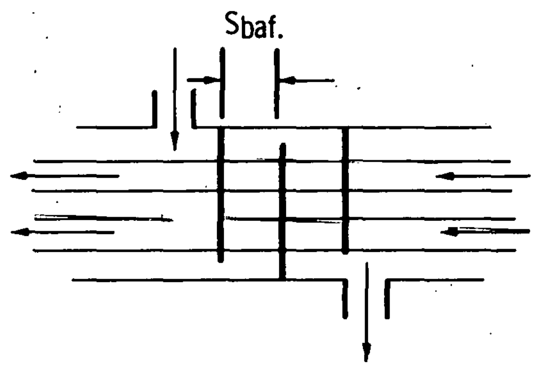


Figure D-4. Shell-Side Heat Exchanger Dimensions

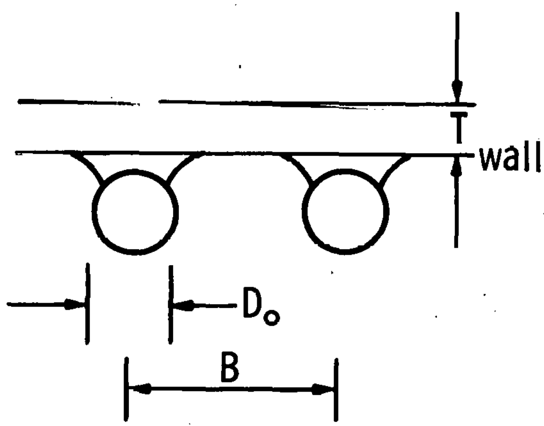


Figure D-5. Traced-Tank Heat Exchanger Dimensions

Since the wall resistance for copper tubing within the heat exchanger is generally negligible, the equation for the overall heat transfer coefficient cannot be reduced further.

NATURAL CONVECTION IN TANKS WITH INTERNAL COILS OR IN TRACED TANKS

One difficulty with coils in tanks or with traced tanks involves the natural convection heat transfer coefficient on the tank side. Forced convection heat transfer coefficients are normally determined entirely by the flow conditions. Natural convection coefficients, however, are determined by the geometry of the heating (or cooling) surface, by the temperature difference between the surface and the fluid, and by the fluid properties.

Natural Convection Equations

The conduction problem between the inside tank wall and the fluid in the tubes is analogous to that obtained in a flat plate collector with the tubes bonded below the plate. The heat transfer rate is given by the product of inside water film coefficient h_t, inside tank heat transfer area A_t, F_t, and fluid to water temperature difference. According to Duffie and Beckman:

$$F_t = \frac{1}{\frac{Bh_t}{\pi D_o h_i} + \frac{Bh_t}{C_{bond}} + \frac{B}{D_o + (B - D_o)F}} \qquad \text{D-14}$$

where:

B = spacing between tubes (ft)

D_o = outside diameter of the coil tube (ft)

h_i = heat transfer coefficient of fluid circulating through the coil (Btu/hr·ft^2·°F)

C_{bond} = conductance of tank to coil bond $\approx \frac{4T_{wall}k_{wall}}{D_o}$ (Btu/hr·ft·°F)

This value of the bond conductance was determined by de Winter.

T_{wall} = thickness of tank wall (ft)

k_{wall} = conductivity of tank wall (Btu/hr·ft·°F)

F = fin efficiency of tank wall between the tubes, for heat losses to the water.

Figure D-5 shows the relationship among the parameters of the traced tank.

The natural convection coefficients are given by McAdams. Equations 7-4a and 7-4b in his book pertaining to vertical plates are reproduced here as Equations D-17 and D-20. Equation 7-6a in his book pertaining to horizontal cylinders can be replaced with Equation D-20 if the tube diameter is replaced by a "flow length" L equal to half the tube perimeter:

$$L = \pi \frac{D_o}{2} \qquad \text{D-15}$$

For the turbulent regime, defined by

$$10^9 < (KL^3\Delta T) < 10^{12}, \qquad \text{D-16}$$

the heat transfer coefficient is given by McAdams's Equation 7-4a for vertical plates:

$$\frac{h_t L}{k} = 0.13(KL^3\Delta T)^{1/3} \qquad \text{D-17}$$

or, in a simplified form,

$$h_t = 0.13kK^{1/3}\Delta T^{1/3} = A_i\Delta T^{1/3}. \qquad \text{D-18}$$

For the laminar regime, defined by

$$10^4 < (KL^3\Delta T) < 10^9, \qquad \text{D-19}$$

the heat transfer coefficient for both vertical plates and horizontal tubes is given by

$$\frac{h_t L}{k} = 0.59(KL^3 \Delta T)^{1/4} \qquad \text{D-20}$$

or, in simplified form,

$$h_t = 0.59kK^{1/4}(\frac{\Delta T}{L})^{1/4} = A_1(\frac{\Delta T}{L})^{1/4}. \qquad \text{D-21}$$

It should be noted that tubes are almost certain to stay in the laminar natural convection regime in solar applications unless the tank is stirred up.

In the above equations:

- L is the natural convection flow length along the surface (ft) for vertical plates and vertical tubes, and L must be calculated from Equation D-15 for horizontal tubes.
- D_o is the outside diameter of the tube (ft)
- $K = \frac{\rho^2 g}{\mu^2} \beta (\frac{C_p \mu}{k})$ See Table D-1.
- β is the fluid thermal expansion coefficient ($ft^3/ft^3 \cdot °F$).
- ΔT is the temperature difference between the wall and the fluid (°F).
- h_t is the natural convection heat transfer coefficient ($Btu/hr \cdot ft^2 \cdot °F$).
- ρ is the fluid density (lb/ft^3).
- g is the acceleration of gravity = 4.17×10^8 ft/hr^2.
- C_p is the heat capacity ($Btu/lb \cdot °F$).
- μ is the viscosity of the fluid ($lb/hr \cdot ft$).
- k is the thermal conductivity of the fluid ($Btu/hr \cdot ft \cdot °F$).

The values of K, of k, and of A_i and A_1 used in Equations D-18 and D-21 are given in Table D-1 for water as a function of temperature T in degrees Fahrenheit.

Table D-1. Convection Factors for Water

T	K	k	A_i	A_1
60	$.337 \times 10^9$	0.338	30.58	27.02
80	$.557 \times 10^9$	0.351	37.54	31.81
100	$.959 \times 10^9$	0.363	46.54	37.69
120	1.453×10^9	0.372	54.77	42.85
140	2.189×10^9	0.379	63.97	48.37
160	2.785×10^9	0.385	70.42	52.18
180	3.660×10^9	0.390	78.13	56.60

Recommended Iteration Procedure

Since the natural convection heat transfer coefficient is a function of the temperature difference, it is necessary to iterate to determine the final heat transfer situation. The recommended scheme below will lead to convergence to within about 1 percent within 4 or 5 iterations.

(1) Calculate the heat transfer coefficient h_i on the forced convection side (usually Equation D-11, but possibly Equation D-9 or D-10).

(2) Assume a natural convection heat transfer coefficient h_t of 100 Btu/hr·ft^2·°F to start the calculation process.

(3) Calculate $U_x = h_t F_t$, based on h_i, h_t, and the conduction geometry.

(4) Calculate NTU = $\frac{U_x A_t}{W C_p}$.

(5) Calculate the effectiveness for the coil or traced tank from $\varepsilon = 1 - e^{-NTU}$.

(6) Calculate F_R' / F_R. (Use Equation D-2, D-3, or D-6.)

(7) Calculate the collected heat Q from the collector performance map.

(8) With Q and h_t and the natural convection area, calculate $\Delta T_{avg} = \frac{Q}{h_t A}$.

(9) Calculate the natural convection heat transfer coefficient h_t obtained with this temperature difference. (Use Equation D-20 or D-21.)

(10) Go back to Step 3 and go through the calculations until the numbers in successive iterations no longer change appreciably.

It should be noted that this calculation applies to two types of systems:

- The case in which an antifreeze loop heats a traced storage tank or a storage tank with a coil. This involves water being heated by natural convection.
- The case in which a domestic water line is being heated by a storage tank with a coil or by a traced storage tank. This involves water being cooled by natural convection.

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APPENDIX E. SAMPLE SPECIFICATIONS FOR HEAT EXCHANGERS

In this appendix, comments and other material that is not a part of the sample specifications are written in italics.

1.0 WORK INCLUDED (Provide)

1.1 All materials, parts, and work related to heat exchangers as indicated on drawings or specified herein.

1.2 Heat exchanger accessories such as bleed valves, supports, pressure-relief valves, etc.

1.3a Heat exchangers used to heat water for thermal energy storage.

1.3b Heat exchangers used to heat potable water.

Choose item 1.3a or 1.3b as appropriate to your system. In some cases both 1.3a and 1.3b will be required.

1.4 Heat exchangers designed to operate at temperatures between 35°F and 300°F.

2.0 RELATED WORK

2.1 Cast-in-place concrete.

2.2 Anchor bolts.

2.3 Piping and pipe connections.

2.4 Tanks.

2.5 Pumps.

3.0 DETAILS

3.1 All details shall be in accordance with the ASME Code, American Water Works Association, TEMA Standards, etc., as applicable to heat exchangers.

3.2 Contractor shall be responsible for all dimensions and shall check structural drawings in relation with other work and existing field conditions. Contractor shall be responsible for proper arrangement and fit of the work; and, if discrepancies are noted between the various drawings and work, the Contractor shall notify the Owner immediately in writing and shall not proceed until so directed.

3.3 The omission of any material shown on the drawings or called for by these specifications shall not relieve the Contractor of the responsibility for furnishing and installing such materials, even though such drawings may have been approved.

4.0 APPLICABLE CODES AND STANDARDS

4.1 HUD Intermediate Minimum Property Standards, Solar Heating and Domestic Hot Water Systems, 1977 edition.

4.2 ASME Code.

4.3 TEMA Standards.

5.0 CONSTRUCTION

Choose section 5.1a, 5.1b, or 5.1c as applicable to your particular installation.

5.1a Type

The heat exchanger should be a 4-pass shell-and-tube type with a removable U-tube bundle constructed to meet ASME Code and TEMA Standards.

This is a general purpose heat exchanger. Since it separates the two fluids by only a single wall, this type of heat exchanger should not be used to separate toxic fluids from potable water. Consult the heat-exchanger manufacturer regarding the number of passes vs. performance of heat exchangers.

5.1b Type

The heat exchanger shall be a U-tube bundle for installation in a storage tank. The heat exchanger shall be constructed to meet ASME Code and TEMA Standards.

This type of heat exchanger requires a flange on the tank to mate with the flange on the heat exchanger. Since this type of heat exchanger separates the two fluids by only a single wall, it should not be used to separate toxic fluids from potable water. This type of heat exchanger relies on natural rather than forced convection to transfer heat to or from the water in the tank.

5.1c Type

The heat exchanger shall be a double-walled type constructed to meet ASME Code and TEMA Standards and shall meet HUD Intermediate Minimum Property Standards for separation of toxic fluids from potable water and applicable local building codes.

Specify this type of heat exchanger if your system requires heating potable water with a toxic fluid.

5.2 Materials

Other less easily corroded materials can be specified at extra cost. Consult the heat exchanger manufacturer for availability.

5.2.1 Shell --Seamless steel.

U-Tube bundle heat exchangers do not include a shell.

5.2.2 Baffles --Steel.

5.2.3 Heads --Steel.

5.2.4 Tube Sheets --Steel.

5.2.5 Tubes --3/4-inch O.D. copper.

5.3 Pressure and Proof Test

Shell and tubes shall be designed for 150 psi operating pressure and shall be tested at 225 psi per ASME Code requirements.

Do not specify a shell pressure if you specified a U-tube bundle in section 5.1.

6.0 <u>ACCESSORIES (Optional)</u>

6.1 The heat exchanger shall have mounting saddles welded to the shell as shown on the drawings.

6.2 The heat exchanger shall be equipped with a replaceable zinc plug in the head to resist corrosion.

6.3 An automatic air-bleed valve shall be installed on the shell.

7.0 INSULATION

7.1 After the system has been installed and pipes and equipment have been tested and proven tight, install 2 inches of fiberglass insulation all over the heat exchanger except at flanges and valves.

7.2 Adjacent pieces of insulation shall be closely and tightly fitted to eliminate voids. Cut and miter insulation to fit the shape and contour of surfaces to be insulated. Band insulation with straps on 9-inch centers on round surfaces and wire or strap in place as required at heads of other flat or irregularly shaped surfaces, using galvanized steel wire and strapping.

7.3 Apply a 1/2-inch-thick coat of mineral fiber cement smoothly troweled over insulation. Finish with field-applied 8-ounce canvas jacket neatly pasted on.

8.0 CAPACITY AND DIMENSIONAL REQUIREMENTS

8.1a Capacity

The following specification is applicable to shell-and-tube and double-walled heat exchangers. Fill in the flow rates and temperatures with numbers that you calculated in designing your system. (Refer to sections on heat exchangers in Chapters 1 and 4 and Appendix D, "Determining Heat Exchanger Size.")

You must also specify the fluids to be used in the heat exchanger. In this example, water and propylene glycol solution have been specified, but you may require different fluids. You must also specify fouling factors appropriate to the fluids used. For the water found in most solar energy systems a fouling factor of 0.001 hr.-square ft.-°F per Btu is adequate. For hard water (over 15 grains per gallon) use a fouling factor of 0.003 hr.-square ft.-°F per Btu.

The heat exchanger shall have the capacity to heat ______ gpm of water (in the tubes) from ____°F when supplied with _____ gpm of propylene solution (50 percent) at ____°F (at the inlet end of the shell). Fouling factors shall be 0.001 hr.-square ft.-°F per Btu for both tube side and shell side.

8.1b Heat Exchanger Area

The following type of specification should be used in place of 8.1a if you specified a U-tube bundle heat exchanger in Section 5.1. Since the U-tube bundle uses natural *convection, you cannot specify the flow rate on the exterior of the tubes. Instead you must calculate and specify the required heat exchange area. Refer to Appendix D for a method of calculating heat exchange area.*

The heat exchanger shall have a minimum heat exchange area of ____ square feet. The heat exchanger will be supplied with ____ gpm of propylene glycol solution (50 percent) at ____°F and will be used to heat water.

8.2 Pressure Drops and Velocities

For most systems maximum pressure drops should be specified to ensure that your pumps will be able to maintain the required flow rates and that the cost of energy for the pumps does not become excessive.

8.2.1 The maximum pressure drop on the shell side shall be ____ psi with the fluid, flow rate, and temperature specified in section 8.1.

8.2.2 The maximum pressure drop on the tube side shall be ____ psi with the fluid, flow rate, and temperature specified in section 8.1.

The maximum velocity is often specified to limit erosion of the tubes. Erosion can be severe at velocities greater than about 8 feet per second.

8.2.3 The maximum tube velocity shall be ____ feet per second.

8.3 Dimensions

If you have special dimensional requirements, such as maximum heat exchanger length, heat exchanger diameter, or location of inlet and outlet, state your requirements in this section.

9.0 DRAWINGS

Include drawings appropriate to your system. Sample drawings of a shell-and-tube heat exchanger and a U-tube bundle are shown in Figures E-1 and E-2, respectively. A sample mounting detail is shown in Figure E-3.

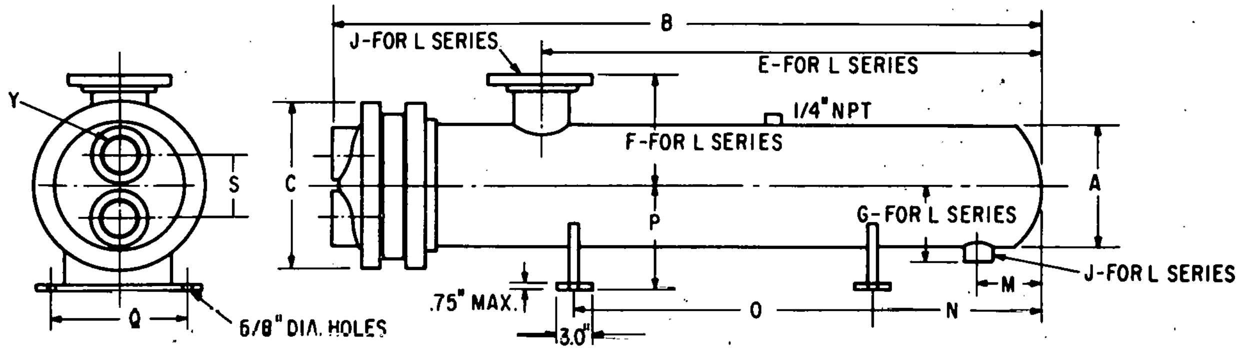


Figure E-1. Typical Shell-and-Tube Heat Exchanger (Based on drawings supplied by Taco, Inc., Cranston, R.I.)

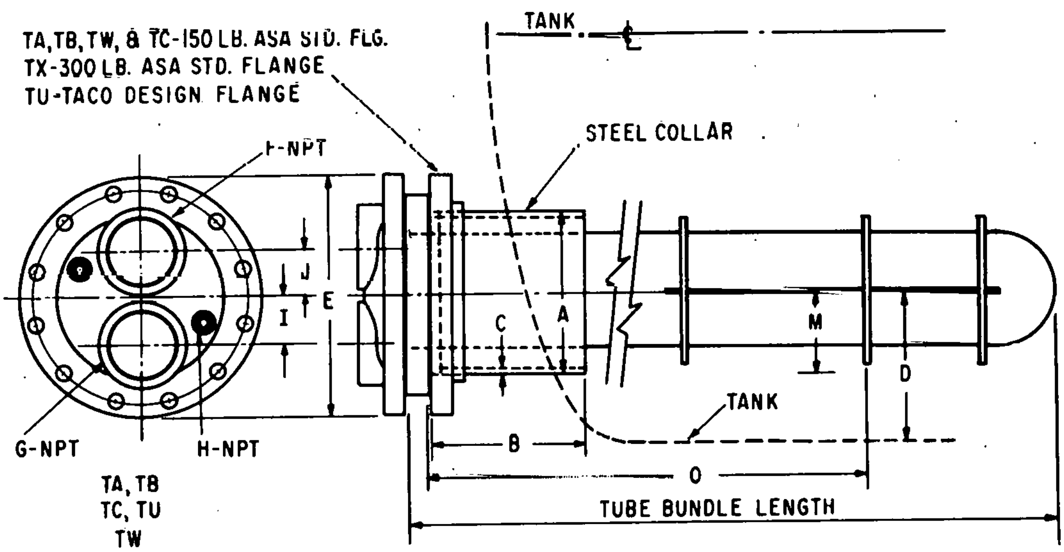


Figure E-2. Typical U-Tube Heat Exchanger (Based on Drawings supplied by Taco, Inc., Cranston, R.I.)

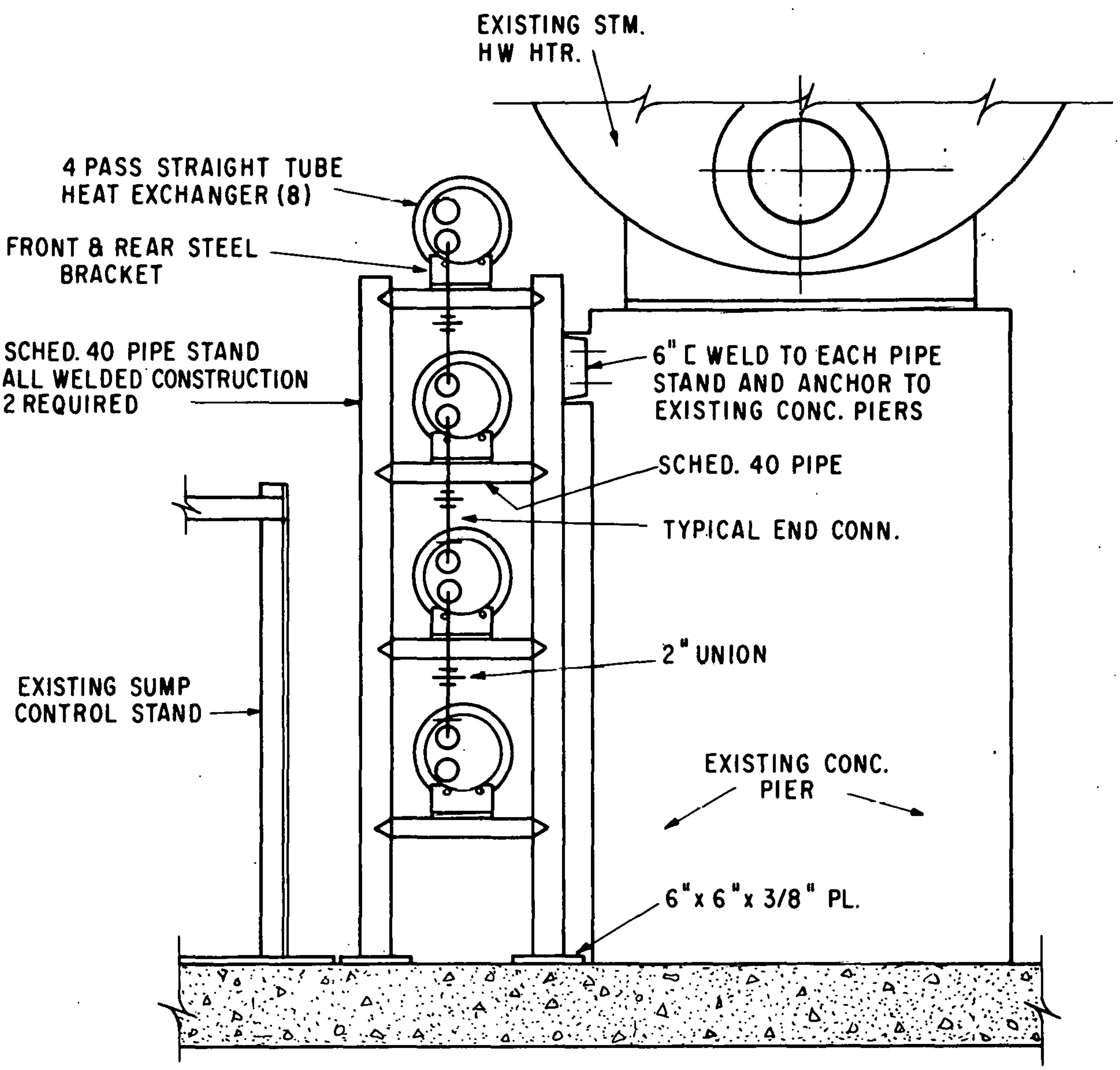


Figure E-3. Mounting Detail for Multiple Shell-and-Tube Heat Exchangers in a Large System

APPENDIX F. CONSTRUCTION DETAILS FOR A WOODEN ROCK BIN

The wooden rock bin described in this appendix is similar to the one developed in the design example in Chapter 2. The rock depth shown in Figures F-1 through F-7 is slightly less than the rock depth given in the design example to allow clearance for installing the top cover, and the rock volume is less than the rock volume of the design example.

Figures F-1 through F-7 are intended only as a general guide to rock bin design. Both the length and width can be altered as needed to suit the rock volume requirements for a storage system in a single-family residence. The depth of the bin can be made up to 20 percent deeper than the depth shown in Figures F-1 through F-7 provided that you maintain the same or closer centers for the 2 by 6 ribs.

If you wish to make the bin more than 20 percent deeper than the depth shown in Figures F-1 through F-7, ask a structural engineer to examine the design. Potential problem areas for a deep bin are (1) strength of the bond-beam and metal-lath supports for the bottom of the rock bed, (2) heavy loading of the floor and foundation, and (3) high outward pressure of rocks against the walls. The outward pressure increases with the rock depth. For this reason we have specified thicker plywood for the bottom half of the bin than for the top half. (See Figure F-1.) In a deep bin, thicker plywood and closer rib spacing may be required.

The rock bin shown in Figures F-1 through F-7 is intended for installation in a basement, but it could be adapted to outdoor, aboveground service by providing thicker insulation, weatherproof siding, and a roof. Wooden rock bins should not be used for underground storage. If you must have an underground rock bin, one of the concrete tanks described in Appendix H can be modified for use as a rock bin. (Concrete can also be used for aboveground or basement rock bins.)

FOUNDATION

Since the rock bed is heavy, it must be built on an adequate foundation. Most basement floors are inadequate to support the rock bed; ask a structural engineer to design a proper foundation. We recommend a 2-1/2-foot clearance between the rock bin and any load-bearing wall to avoid overloading the wall foundation. The 2-1/2-foot clearance also provides access for maintenance. Do not place the rock bed over sewer lines, drain lines, or water lines because the weight of the rock bed can disrupt these lines and block access to them.

If the floor slab must be modified (to provide a stronger foundation or to provide clearance for a deep bin, for example), use the following procedure:

(1) Remove the required area of the existing concrete slab, remove all poor-quality soil, check the soil-loading capacity, and excavate to the proper depth.
(2) Smooth out the supporting soil and cover with pea gravel or coarse sand. To prevent water seepage, cover the gravel or sand with a tough plastic film.
(3) Provide supports for the slab reinforcing bars.
(4) Use pre-mixed concrete and trowel the surface smooth.
(5) Install 1/2-inch anchor bolts in the unhardened concrete or install self-drilling tubular expansion shield anchors after the concrete has hardened. The storage container's base frame can be used as an anchor template.

ROCK BIN

The air inlet and outlet openings have not been shown in Figures F-1 through F-7 because the details will vary with the duct size and shape, the shape of the rock bin, and the space available for the ductwork. These openings should be developed for each application. Because the metal-lath and supporting block restrict air flow, we recommend that you design the bottom duct opening with up to twice the cross-sectional area of the top duct opening.

The following material and construction specifications should be used:

(1) All reinforcing ribs shall be dense, Number 1 Douglas Fir or Southern Yellow Pine.
(2) Exterior grade plywood with the bonding glue capable of continuously withstanding a temperature of 140°F for a 20-year period shall be used.
(3) All vertical and all horizontal structural support members shall be nailed and glued to the exterior grade plywood. All bonding glues shall meet the temperature specification in Item 2.
(4) Timber Engineering Company (TECO)[1] connectors or equivalent shall be used to join all vertical ribs to the bottom connecting members.
(5) All timber in contact with concrete shall be coated with asphalt paint.
(6) To provide a finished appearance, the plywood storage container's outer cover shall be attached to the reinforcing ribs with screws. This exterior surface should be painted.
(7) All joints, all timber-concrete contacts, and all cracks shall be caulked with a silicone caulk. A 3/8-inch caulk bead is recommended.

---

[1] 5530 Wisconsin Avenue, Washington, D.C. 20015

FILLING THE BIN

Select the rocks carefully. The requirements detailed in Chapter 2 are summarized as follows:

- Rounded river rocks are preferred, but rocks that conform to ASTM C 33 "Standard Specification for Concrete Aggregates" are generally acceptable.
- Rocks must be washed as specified in ASTM C 33 to remove all dirt, sand, dust, and foreign material.
- Rocks that react with components of the air, such as limestone, marble, and dolomite, are undesirable.
- Rocks that crumble or make dust are unacceptable.
- The range of rock sizes must be no smaller than 75 percent and no larger than 150 percent of the size you calculated according to the design procedure in Chapter 2.

You should reject any load of rock that does not conform to all these requirements.

Fill the bin carefully in 6-inch layers. Spread the rocks evenly in each layer before adding the next layer. Use a chute to distribute and to break the fall of the rocks or place the rocks by hand. Do not simply dump the rocks from a truck or allow the falling rocks to strike the walls of the bin. After spreading the first layer of rock, install a temperature sensor in position, connect it to the control system, and carefully cover it by hand with rocks. Add the next layer carefully to avoid damaging the temperature sensor. (Not all control systems require a temperature sensor at the bottom of the bin.) Before adding the last layer of rocks, install the upper temperature sensor with the same care you used to install the lower temperature sensor.

Lay the top cover on the rock bin. Using wedges to temporarily raise the top cover, run a bead of caulking around the top closing rib. (See Figure F-5, Detail F.) Remove the wedges and allow the top cover to seal against the top closing rib. Run a bead of caulking around the joint between the rock bin and the top cover and cover the joint with duct tape as shown in Figure F-5, Detail F. Secure the top cover to the rock bin with 1/8-inch x 3/4-inch x 6-inch steel straps and four Number 10 x 1-inch wood screws per strap (not shown on the drawings). Space the straps approximately 2 feet apart around the joint.

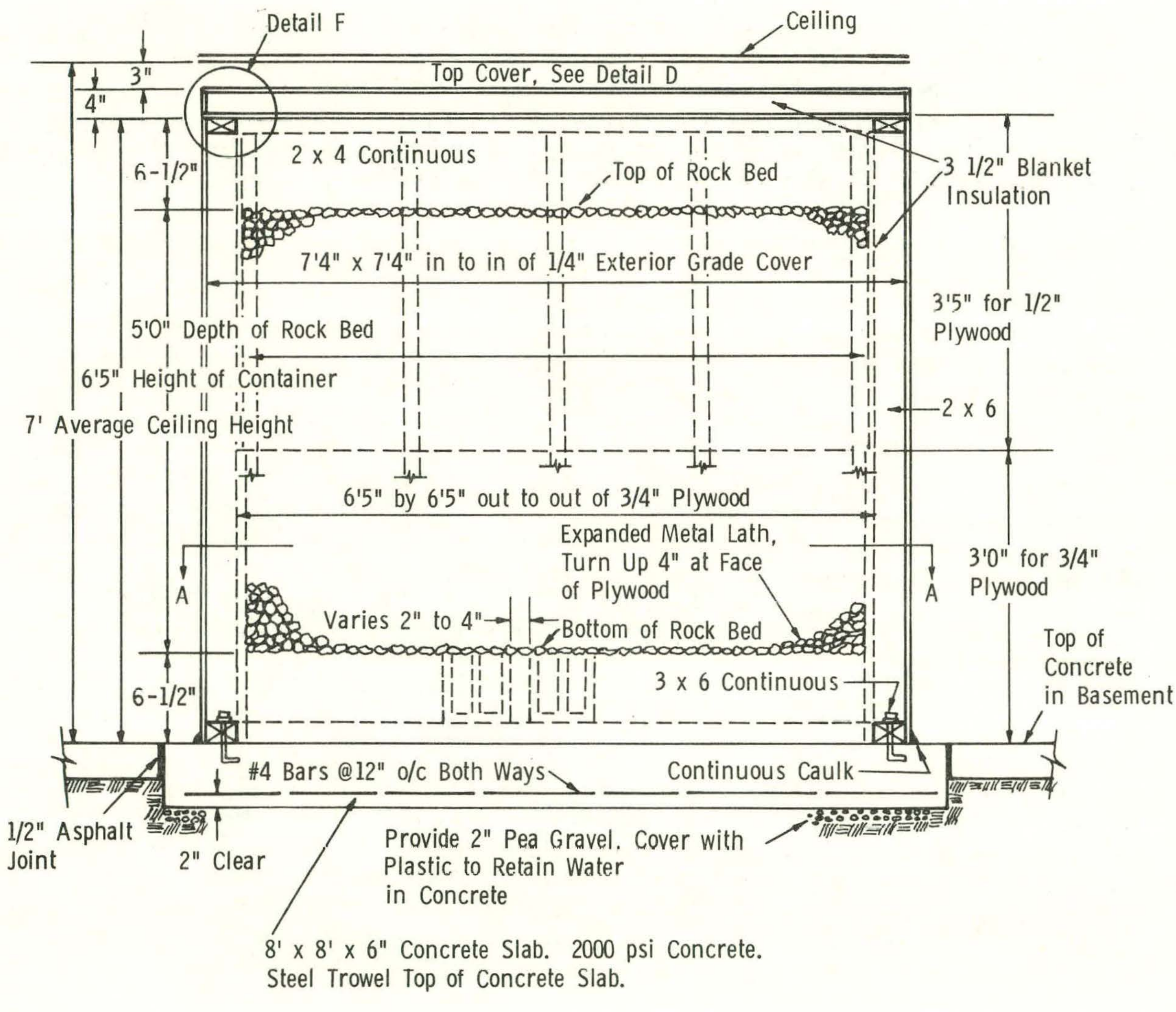


Figure F-1. Elevation of Wooden Rock Bin

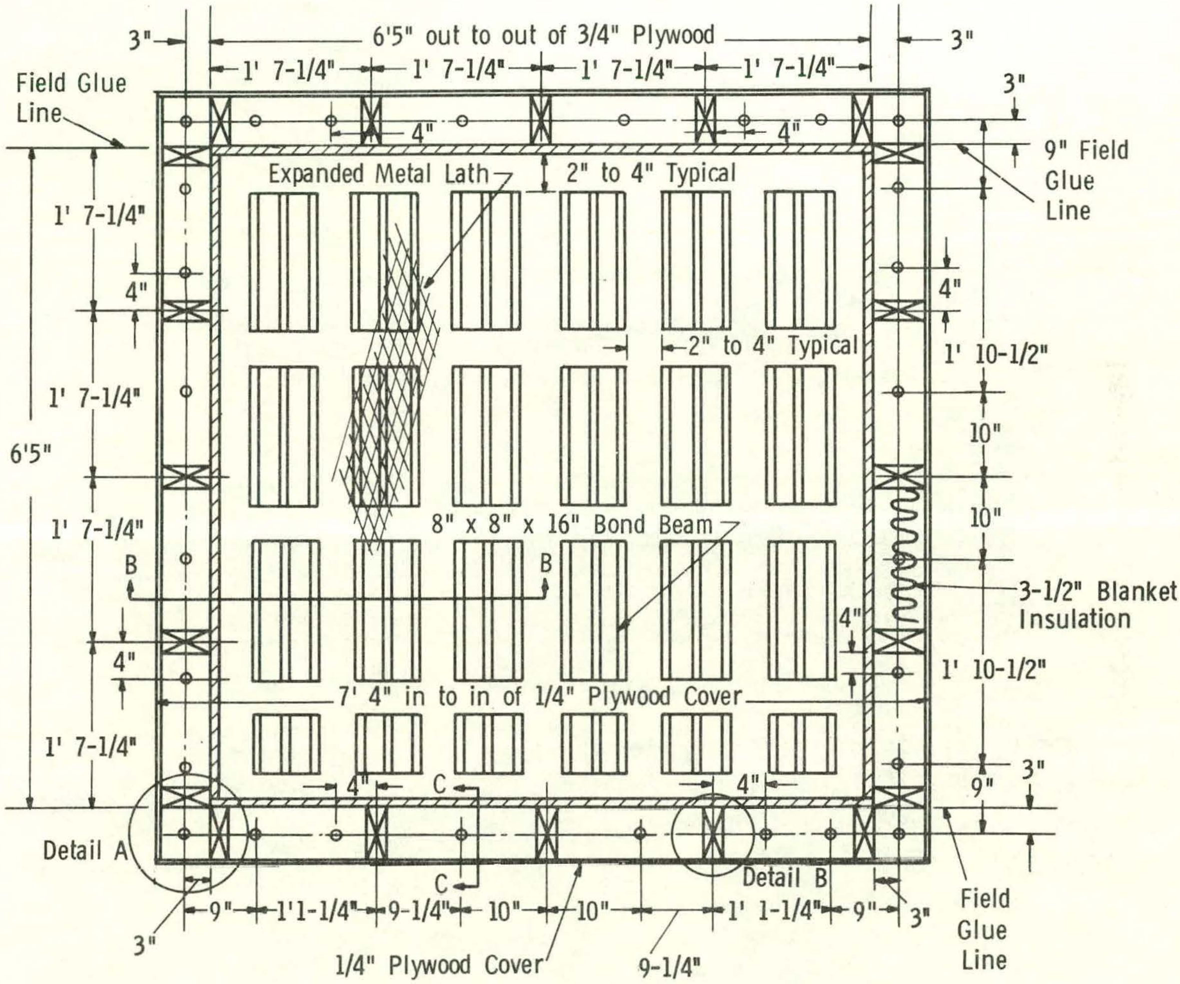


Figure F-2. Section A-A of Wooden Rock Bin

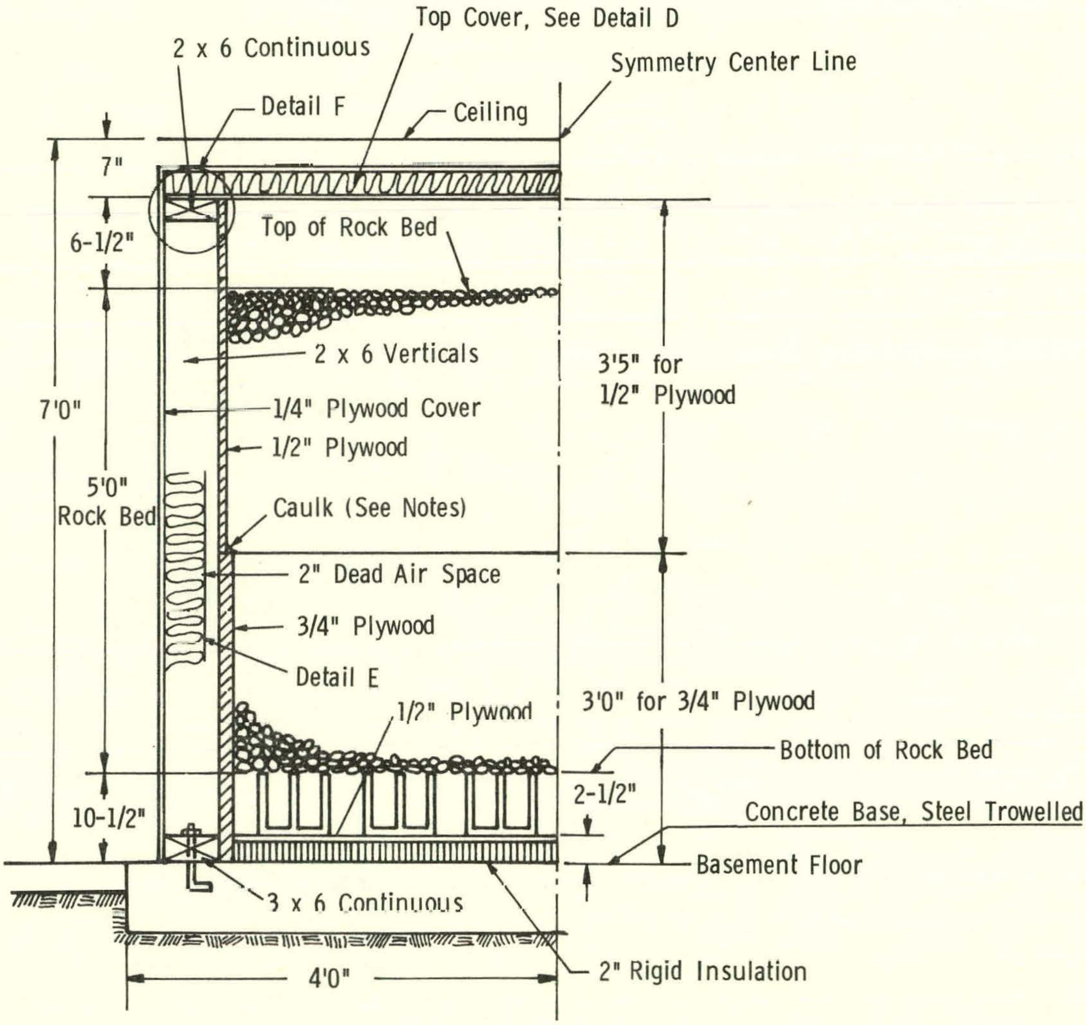


Figure F-3. Section B-B of Wooden Rock Bin

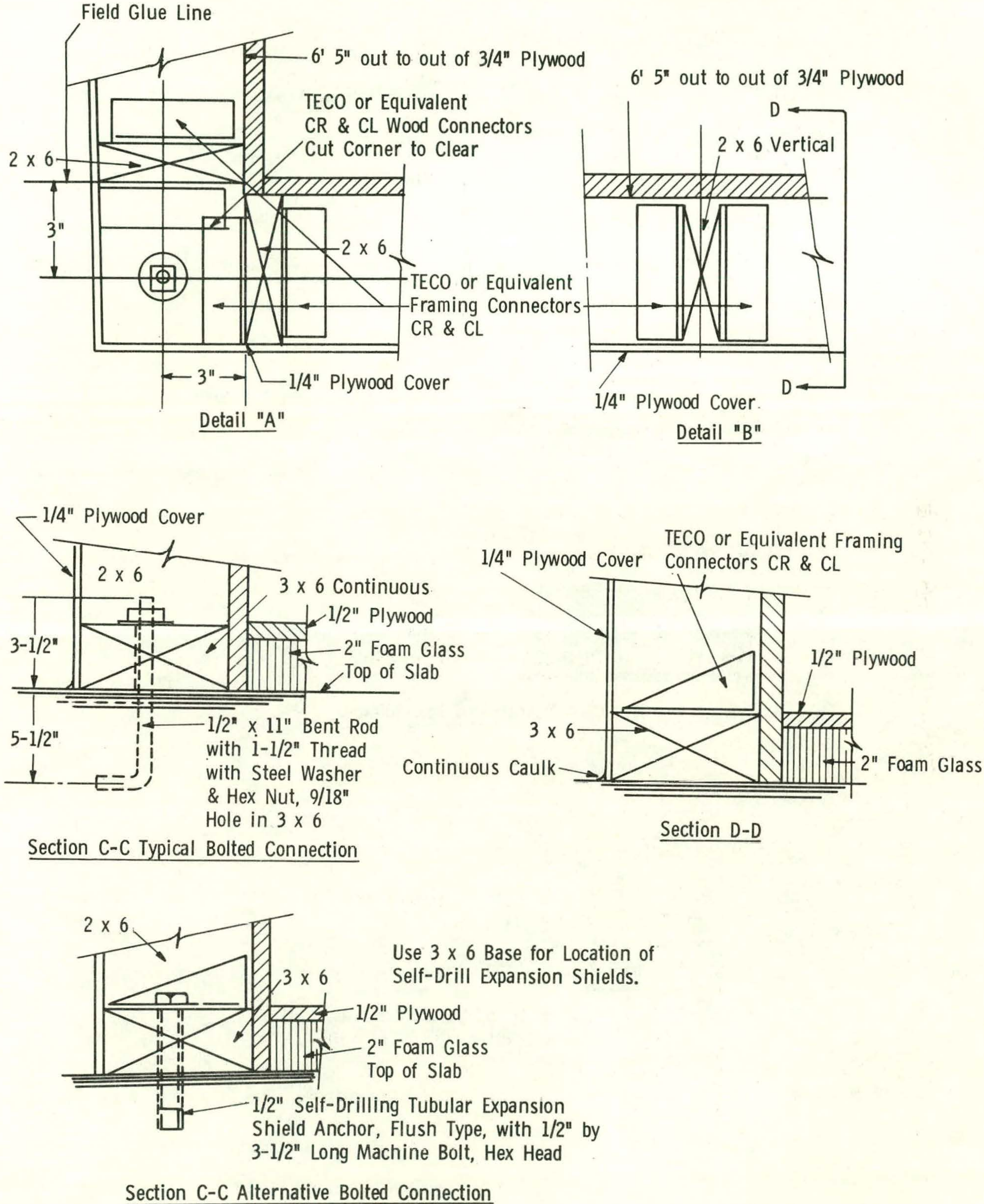
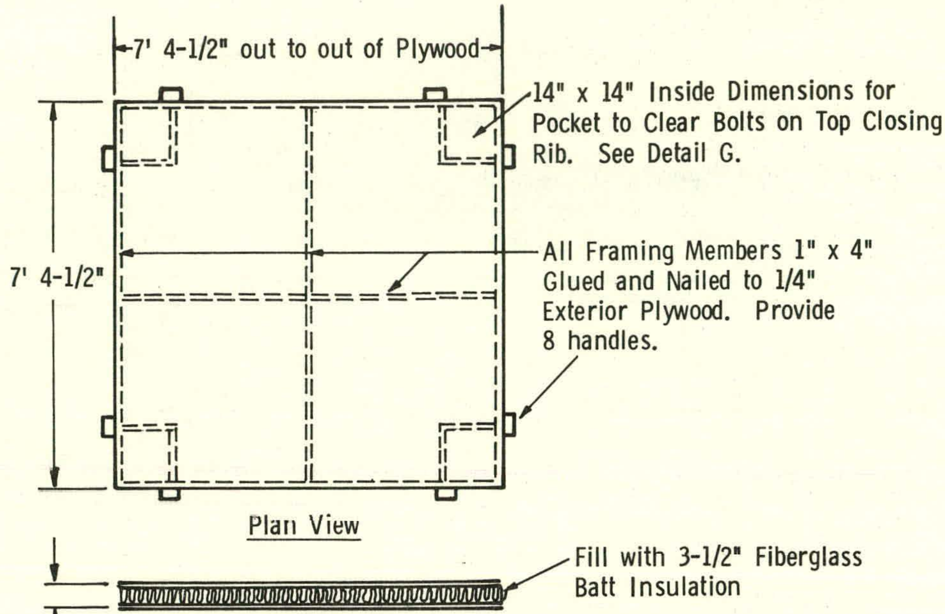
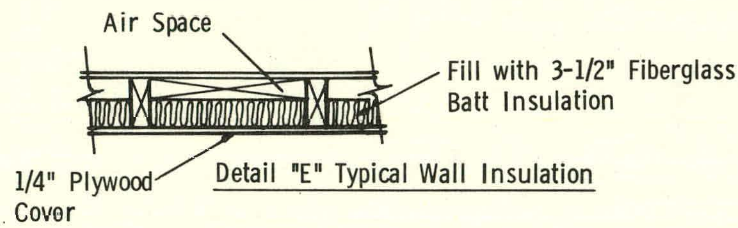


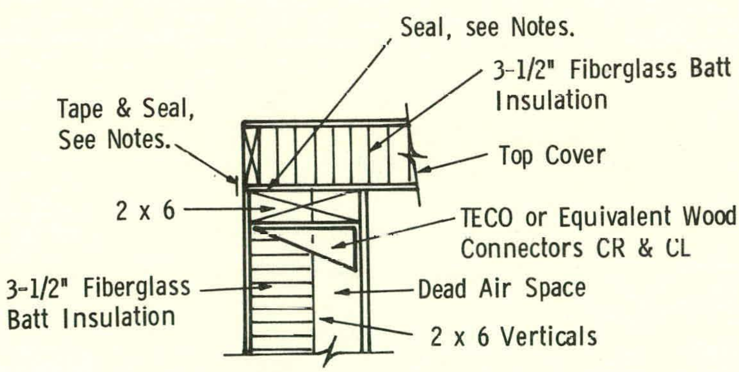
Figure F-4. Corner and Base Details for Wooden Rock Bin



Detail "D" Top

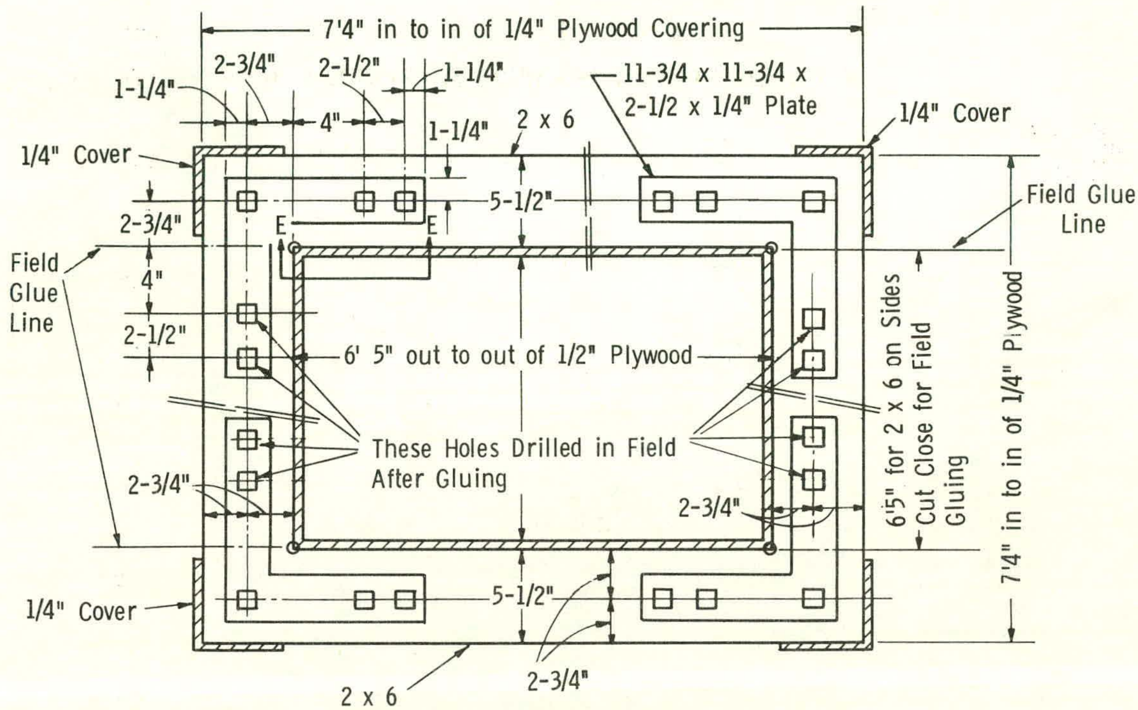


Detail "E" Typical Wall Insulation

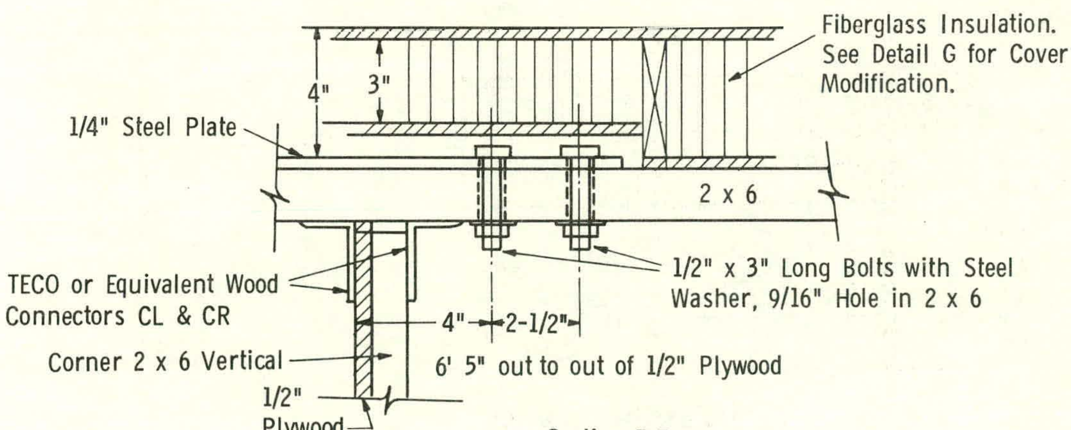


Detail "F"

Figure F-5. Top Details of Wooden Rock Bin



Plan View of Top Closing Rib



Section E-E

Figure F-6. Top Closing Rib of Wooden Rock Bin

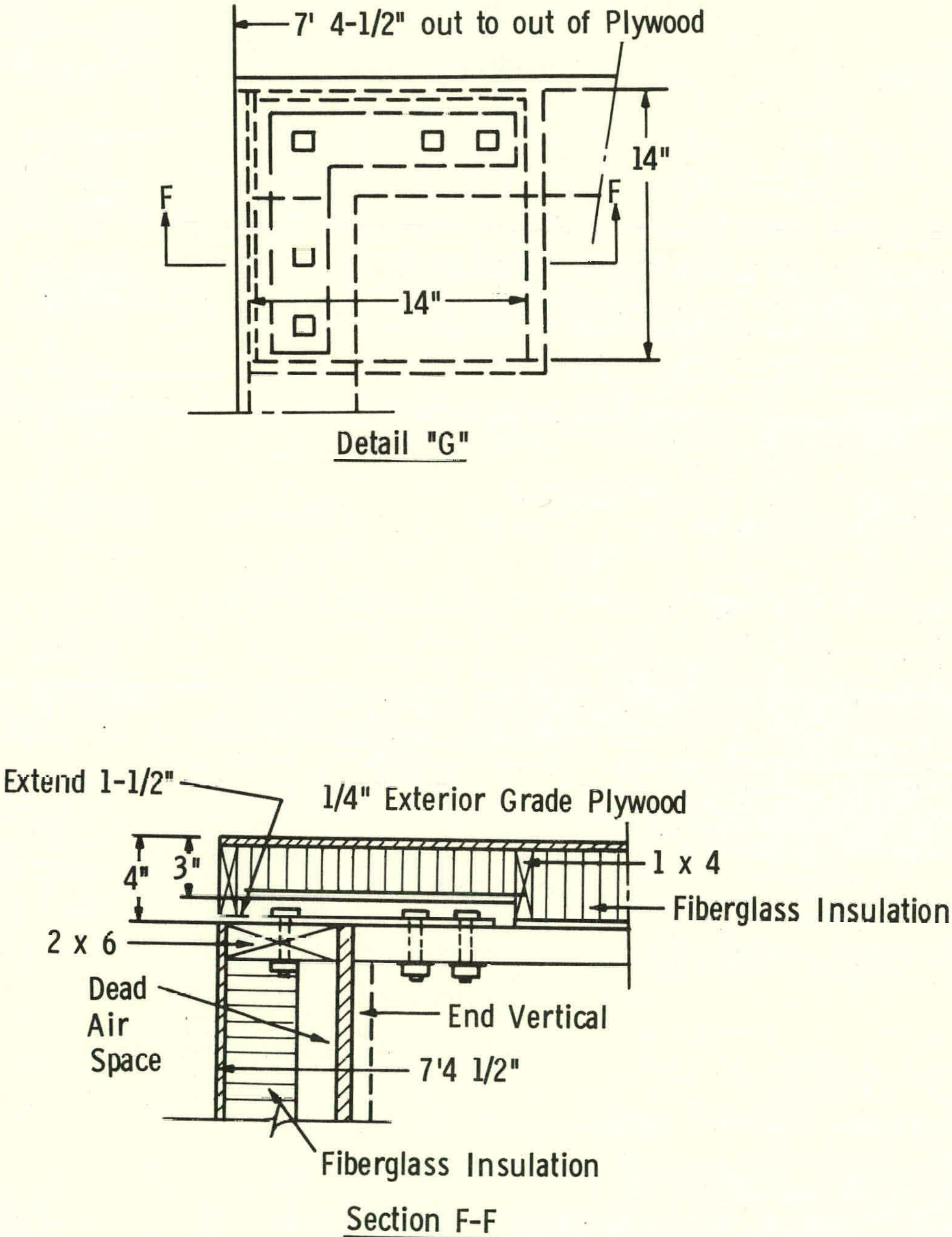


Figure F-7. Closure at End of Cover over Bolted Joint

APPENDIX G. SAMPLE SPECIFICATIONS FOR STEEL TANKS

In this appendix, comments and other material that is not part of the sample specifications are written in italics.

Part 1. SPECIFICATIONS FOR STEEL TANKS WITH CAPACITY BETWEEN 120 GALLONS AND 5000 GALLONS

1.0 <u>WORK INCLUDED (Provide)</u>

1.1 All materials, parts, and work related to steel tanks as indicated on drawings or specified.

1.2 Steel tanks with capacities between 120 gallons and 5000 gallons.

1.3a Steel tanks located inside the building.

1.3b Steel tanks suitable for underground burial.

Choose 1.3a or 1.3b as appropriate to your installation.

1.4 Steel tanks that will have a minimum service life of 20 years.

If the tank is located so that it will be difficult to repair or replace, 30 years may be more appropriate.

1.5 Steel tank accessories such as manholes, extensions, couplings, ladders, hold-down straps, supports, saddles, etc.

1.6 Steel tanks with coatings that will protect them against corrosion.

1.7 Steel tanks that will be able to withstand thermal cycling temperatures between 50°F and 200°F.

1.8 Steel tanks that will be capable of withstanding an operating pressure of 125 psig.

Item 1.8 is required only if the tank will operate at above-atmospheric pressure. Specify a pressure appropriate to your installation.

1.9 Steel tanks that will be used for storage of potable hot water.

Item 1.9 is required for large domestic hot water systems.

2.0 <u>RELATED WORK</u>

2.1 Cast-in-place concrete.

2.2 Anchor bolts.

2.3 Piping.

2.4 Liquid-level gauges, temperature sensors, thermometers, and pressure gauges.

2.5 Excavation and compacted fill.

Item 2.5 is required for underground tanks only.

3.0 DETAILS

3.1 All details shall be in accordance with the standards of the National Board of Fire Underwriters, Underwriters Laboratories, Inc., the ASME Boiler and Pressure Vessel Code, American Water Works Association, etc., as applicable for steel tanks.

Include other standards-writing organizations and state and local governments as necessary.

3.2 Contractor shall be responsible for all dimensions of the steel work and shall check structural drawings in relation with other work and existing field conditions. Contractor shall be responsible for proper arrangement and fit of the work; and, if discrepancies are noted between the various drawings and work, the Contractor shall notify the Owner immediately in writing and shall not proceed until so directed.

3.3 The omission of any material shown on the drawings or called for by these specifications shall not relieve the Contractor of the responsibility for furnishing and installing such materials, even though such drawings may have been approved.

4.0 APPLICABLE CODES AND STANDARDS

4.1 HUD Intermediate Minimum Property Standards, Solar Heating and Domestic Hot Water Systems, 1977 edition.

4.2 The ASME Boiler and Pressure Vessel Code.

Item 4.2 is required if the tank will operate at above-atmospheric pressure and is recommended for other steel tanks.

5.0 CONSTRUCTION

5.1 Materials

All tanks shall be fabricated from Class "A" open hearth or basic oxygen steel. Thickness of shells and head shall be in strict accordance with Underwriters' specifications. All heads and shell rings shall be of one-plate construction. Plates should be gauged and inspected by an Underwriters' representative before fabrication. The plates shall be free from physical imperfections such as laminations, cracks, mill scale, etc. All steel must be in good condition and free from rust.

5.2 Fabrication

Tanks shall be lap-welded continuously on the inside and outside according to Underwriters' specifications. Nozzles for manholes and outlets for pipe connections shall also be continuously welded inside and outside.

5.3 Welding

All welding for tanks shall be done electrically by qualified welders in strict accordance with the latest edition of the ASME Unfired Pressure Vessel Code and Underwriters' specifications.

5.4 Openings and Accessories

All openings, except those for vents or for valves or pipe connections communicating with the interior of the tank, shall be equipped with substantial covers. Thieving and gauging openings shall have approved self-closing covers, but manhole covers may be of either bolted or approved self-closing type.

5.4.1 Pipe Connections

Pipe connections shall be supplied by welding standard threaded flanges or spuds to the tank, all to be steel of good welding quality. All openings in the tank shall be protected by metal covers, or their equivalent, while tank is in storage or in transit. The size of the opening for each pipe connection should be of the size of the pipe connected, except if noted otherwise. Tank openings shall be plugged until pipe connections are made. All couplings for pipe connections shall be continuously welded inside and outside the tank and plates.

5.4.2 Manhole

Each manhole shall have a 3/8-inch thick or heavier steel cover plate with two 1/2-inch diameter steel lift handles welded to plate and shall be provided with 1/8-inch thick oil resistant ring gasket, etc. Provide in manhole cover plate a 3-inch half coupling with brass plug welded to a 3-inch I.P.S. hole in plate. The cover plate and gasket shall be secured by 5/8-inch diameter brass bolts and nuts.

Manholes can vary with individual tank manufacturers and manhole turrets are available as options. A manhole is required only on tanks of 500 gallon-capacity or larger.

5.4.3 Vent

A vent is required only for unpressurized tanks. The breather vent permits the proper outflow and inflow of air *during filling and emptying operations. Venting prevents the development of dangerous interior pressure or possible collapse of the tank due to vacuum and permits the normal expansion and contraction of the contents caused by varying temperatures. Sizes are as follows: 120 gallons to 500 gallons, 1-inch diameter; 500 gallons to 3000 gallons, 1-1/2-inch diameter; 3000 gallons to 5000 gallons, 2-inch diameter. Specify the vent diameter in the item below.*

Provide a vent to the atmosphere for the tank. The vent shall be at least _________ inches in diameter.

5.4.4 Ladder

Provide a ladder from the manhole opening to the bottom of each tank. The ladder shall have 3/8-inch x 2-1/2-inch bar steel sides not less than 16 inches apart and 3-inch diameter steel rod rungs spaced on about 12-inch centers. Rungs shall go through the sides and be welded in place. The ladder shall be properly fastened to tank with angles, etc.

5.4.5 Hold-Down Straps

Provide hold-down straps according to details and schedule of straps as shown on drawings.

5.4.6 Lifting Lugs

Provide lifting lugs as detailed on drawings.

6.0 TESTING

For unpressurized tanks, specify the following leak test:

Before they are painted, all steel unpressurized tanks shall be tested and proved tight against leakage under a test pressure of not less than 5 nor more than 7 psi. In the event of leakage, tanks shall be made tight as approved and the test repeated.

For pressurized tanks, specify the follow leak test:

Before they are painted, all pressurized steel tanks shall be tested and proved tight against leakage as specified in the ASME Unfired Pressure Vessel Code. The ASME Unfired Pressure Vessel Code requires leak testing at a pressure of not less than 1 1/2 times the design operating pressure. In the event of leakage, tanks shall be made tight by methods approved in the ASME Unfired Pressure Vessel Code and the test repeated.

7.0 COATINGS

7.1 Exterior Painting

Where exterior corrosion is not a problem, the following exterior coatings can be specified:

Storage tanks shall be thoroughly sandblasted and painted on the outside at the factory with two coats of approved red lead and oil paint and with one coat of black asphaltum paint. The red lead coatings shall be of different shades to facilitate inspection of the painting. All damaged spots shall be touched up.

For underground tanks, where conditions are generally more corrosive, good protection can be provided by the asphaltic paints or bituminous coatings applied either hot or cold. The Steel Tank Institute P3 method provides good exterior protection under severe conditions. A nominal 1/8-inch thick coating of fiberglass-reinforced polyester also provides protection under severe conditions.

Sandblasting to remove all of the rust and mill scale is important to insure adhesion of the paint. If the mill scale is not removed before the paint is applied, the scale will begin to flake off--taking the paint with it--after an exposure of a few months to about three years. The exact time will depend on the humidity and corrosive conditions as well as the thickness and permeability of the paint film.

7.2 Interior Coatings

Storage tanks shall be thoroughly sandblasted and coated on the inside with four coats of baked-on phenolic epoxy. The thickness of each coat shall be 5 to 7 mills.

To complete the protection of the tank interior we recommend installing a replaceable zinc, aluminum, or magnesium bar in the tank. The bar must be in electrical contact with the tank and must be submerged in the water. Electrical currents flowing between the tank and the bar protect small areas of the tank where the coating has chipped or cracked.

8.0 PROVISIONS FOR DRAINAGE

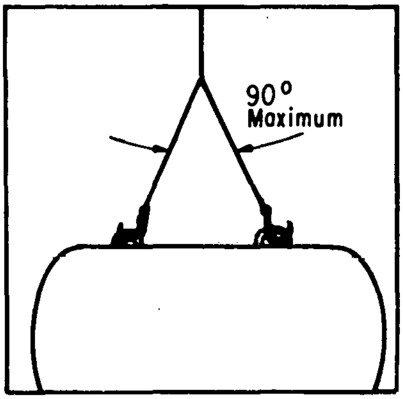
Openings for drains shall be as specified in the ASME Boiler and Pressure Vessel Code.

9.0 INSULATION

Storage tanks shall be insulated with 6 inches of fiberglass and 2 inches of polyurethane foam, vapor sealed to prevent ingress of moisture.

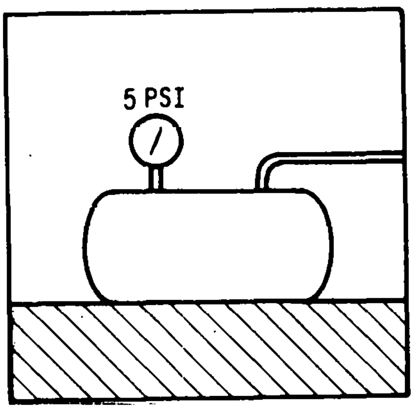
You must calculate the required thickness of insulation as shown in Chapter 1 of this manual and insert the correct numbers in the section above. The insulation specified above is not adequate if groundwater should ever rise above the bottom of the insulation. If the tank must be installed *where groundwater could be a problem, you should specify the entire thickness of the insulation to be closed-cell polyurethane or closed-cell polystyrene foam. You should also increase the thickness of the insulation exposed to groundwater, since water can halve the resistance to the flow of heat of closed-cell foams.*

10.0 INSTALLATION



10.1 Lifting Tanks

Handle the tank carefully. Use cables or chains of adequate length (not more than 90° between the chains) attached to lift lugs. Use shackles if necessary.

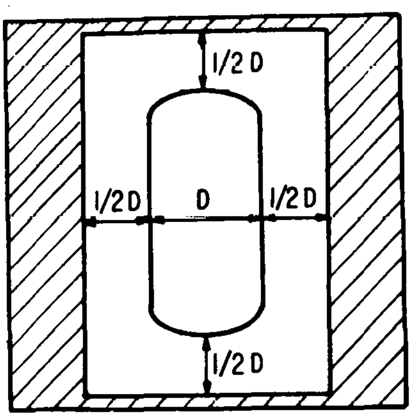


10.2 Testing

To insure compliance with applicable codes and regulations, tank and piping should be retested at job site before being covered, enclosed, or placed in use, using 5 psig air pressure as soap solution is brushed over weld seams. Replace tin caps with pipe plugs or capped piping before test. Keep away from manholes or ends of tanks that are under test. Do not leave tanks under pressure unattended. This test is not a substitute for the ASME pressure vessel certification test.

When pressure testing piping, isolate the tank from the piping.

If tanks are dropped or subjected to an impact, retest tanks.

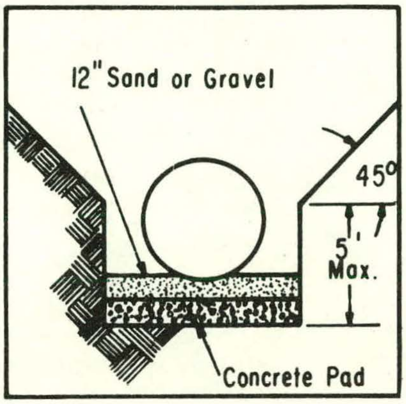


10.3 Hole Size

Hole must be large enough to allow clearance equal to 1/2 the tank diameter on all sides.

Observe OSHA regulations regarding supporting the walls of the hole and slanting the sides if the hole is deeper than 5 feet.

10.4 Hole Depth

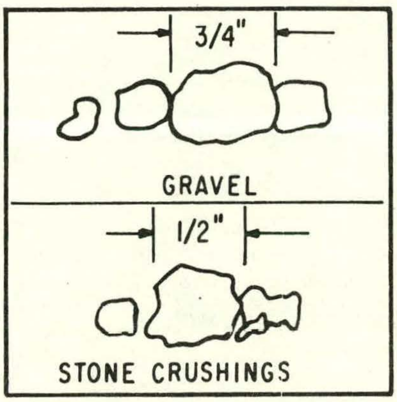


Unsupported vertical wall height shall not exceed 5 feet with ideal soil conditions. Slope upper walls of the hole at 45°. For less than ideal soil conditions reduce the vertical wall height.

The bottom of the excavation shall be level and firm. A full-length concrete pad shall be used. At least 12 inches of clean sand or gravel, suitably graded or leveled, shall be placed before installation of the tank.

Caution: Do not place steel tanks directly on concrete slab or grout tanks in wet concrete. Do not place tanks on timbers, beams, or cradles.

10.5 Bed and Backfill Material

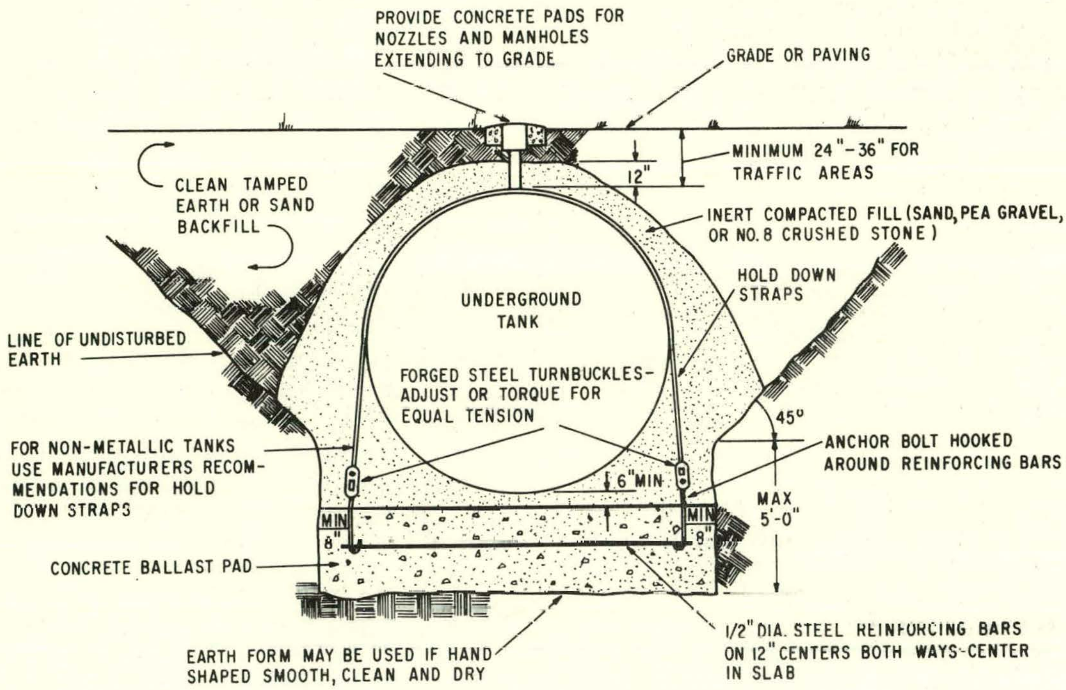


The tanks shall be surrounded with at least 12 inches of non-corrosive inert material such as clean sand, earth, or gravel well tamped in place. Do not allow ashes or other corrosive material to come into contact with tank.

Washed and free-flowing stone or gravel crushings with angular particle size between 1/8 inch and 1/2 inch in diameter are acceptable alternate bed and backfill materials.

10.6 Anchoring

Tanks must be anchored where high water tables exist. Surface water could flow into hole or other water conditions could exist in a dry hole. Strap size shall be selected from the table below. The turnbuckles shall be tightened until the hold-down straps are snug against the tank. Caution: Excessive tightening can distort the tank.

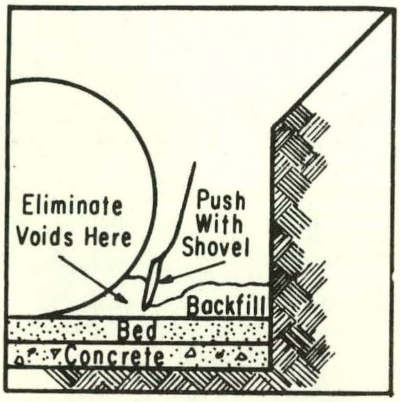


Hold-down Strap Size

Turnbuckle Size	3/4"	7/8"	1"	1-1/8"	1-1/4"	1-3/8"	1-1/2"
Strap Size	1/4" x 3"	3/8" x 3"	3/8" x 3"	3/8" x 3"	3/8" x 4"	1/2" x 4"	1/2" x 4"
Maximum Load Per Strap	9,500 lb.	13,000 lb.	17,000 lb.	22,000 lb.	28,000 lb.	33,000 lb.	40,000 lb.

10.7 Backfilling

Use the same materials as for bedding. Push backfill under the tank with a board or shovel to eliminate all voids beneath the tank.



The bottom sides of the tank should be fully and evenly supported. This can be accomplished only by hand shoveling and tamping. Use hand-guided power equipment and place fill in 6-inch layers until the bottom quadrant is complete.

The use of saddles or "chock blocks" of any sort interferes with the proper distribution of the load to the backfill and may cause failure due to high stress concentrations. They should not be used.

Backfill to the top of the tanks with clean sand, earth, or gravel. Backfill must be free of large rocks, debris, or corrosive material that could damage tanks. Do not allow tanks to be impacted during backfilling.

10.8 Barricade

Barricade the tank area to prevent vehicular travel over the tanks until installation is complete.

10.9 Filling Tanks

Do not fill tanks until backfill is to the top of tanks. Since tanks are held down by straps, it is neither necessary nor desirable to add water for hold down.

10.10 a No Traffic Loads

Tanks not subjected to traffic loads need a minimum cover of 24-inch backfill or 12-inch backfill plus 4-inch reinforced concrete to meet NFPA 30 requirements.

10.10 b Traffic Loads

Tanks subjected to traffic loads must have a cover depth of 36 inches backfill plus 8 inches of asphalt or a minimum of 18 inches backfill plus 6 inches of concrete reinforced with steel rebars.

Use either Section 10.10 a or 10.10 b as required by your particular installation.

11.0 CAPACITY AND DIMENSIONAL REQUIREMENTS

Fill in the blanks to complete this section. This example applies to horizontal cylindrical tanks. If your installation requires another tank shape or if you have special dimensional requirements (such as special locations for pipe fittings), state your requirements in this section.

11.1 Nominal capacity of the tank shall be __________ gallons.

11.2 Nominal outside diameter of the tank shall be ________ feet.

11.3 Approximate overall length of the tank shall be ________ feet.

12.0 DRAWINGS

Include drawings that are applicable to your particular installation in this section. A sample drawing is shown in Figure G-1.

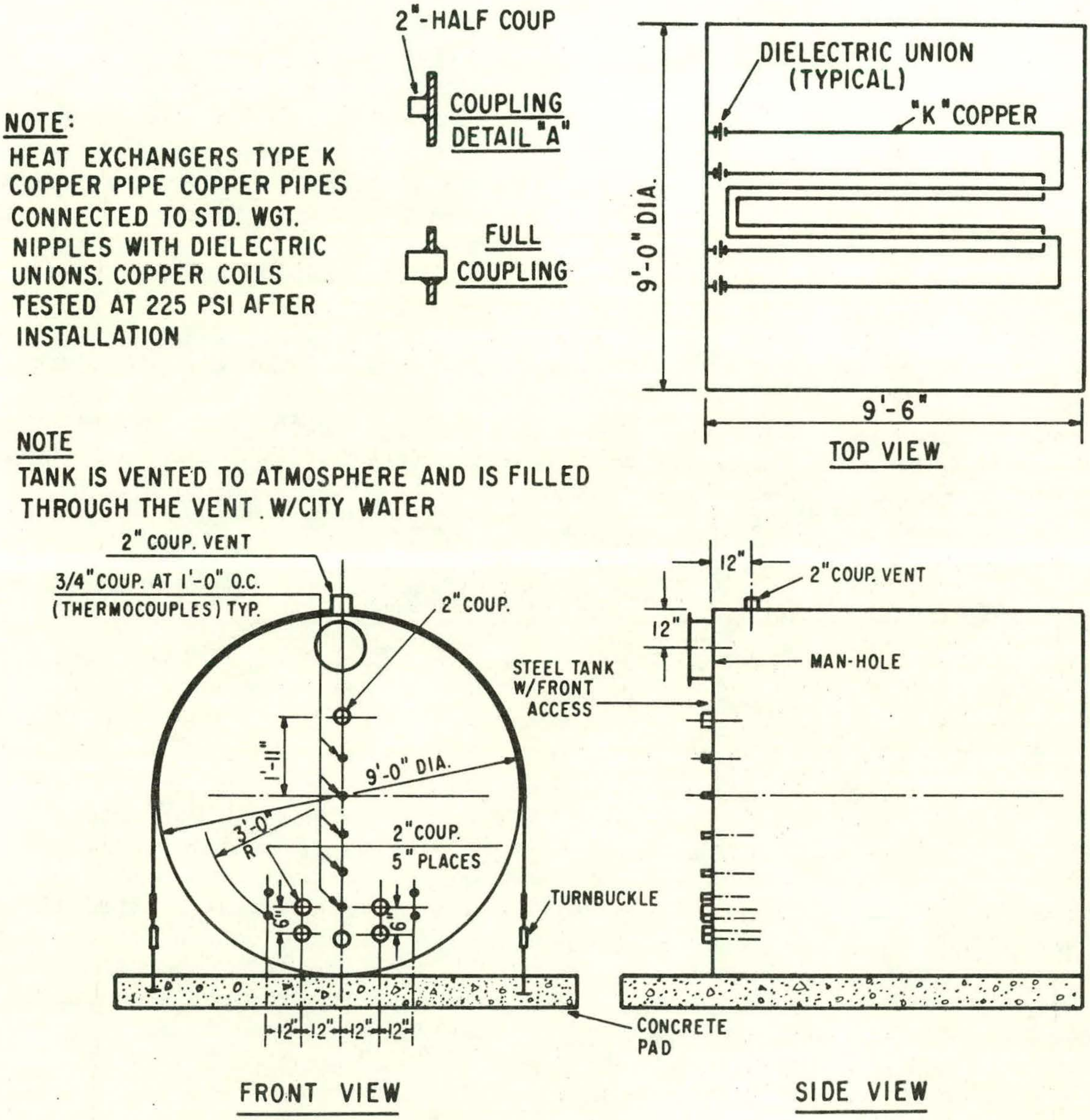


Figure G-1. Sample Drawing of a Steel Tank 9'-6" Long x 108" O.D.

Part 2. SPECIFICATIONS FOR DOMESTIC HOT WATER TANKS WITH CAPACITY UP TO 120 GALLONS

1.0 WORK INCLUDED (Provide)

1.1 All materials, parts, and work related to steel tanks as indicated on drawings or specified.

1.2 Steel tanks with capacities up to 120 gallons.

1.3 Steel tanks located inside the building.

1.4 Steel tanks that have a minimum service life of 20 years.

1.5 Steel tanks that can withstand thermal cycling between 50°F and 200°F.

1.6 Steel tanks that will be capable of withstanding an operating pressure of 125 psig.

1.7 Steel tanks that will be used for storage of potable hot water.

1.8 Steel tanks that include an integral heat exchanger capable of meeting the requirements of the HUD Intermediate Minimum Property Standards.

2.0 RELATED WORK

2.1 Plumbing make-up water supply connection.

2.2 Electrical standard 115-volt AC wall outlet.

3.0 DETAILS

3.1 All details shall be in accordance with the HUD Intermediate Minimum Property Standards, 1977 edition, and HUD Intermediate Standards for Solar Domestic Hot Water Systems, July 1977.

3.2 Contractor shall be responsible for all dimensions of the steel work and shall check structural drawings in relation to all other drawings and shall verify all dimensions in relation with other work and existing field conditions. Contractor shall be responsible for proper arrangement and fit of the work; and, if discrepancies are noted between the various drawings and work, the Contractor shall notify the Owner immediately in writing and shall not proceed until so directed.

3.3 The omission of any material shown on the drawings or called for by these specifications shall not relieve the Contractor of the responsibility for furnishing and installing such materials, even though such drawings may have been approved.

4.0 APPLICABLE CODES AND STANDARDS

4.1 HUD Intermediate Minimum Property Standards, 1977 edition, and HUD Intermediate Standards for Solar Domestic Hot Water Systems, July 1977.

Indicate applicable state and local building, plumbing, and electrical codes.

5.0 MATERIALS

5.1 Steel tank uniformly lined with 1/2 inch of seamless hydraulic stone.

5.2 Fiberglass insulation.

5.3 Internal heat exchanger.

5.4 Tank exterior of heavy-gauge steel finished with baked enamel.

6.0 PRESSURE RATINGS

6.1 The tank shall be designed to withstand a maximum operating pressure of 125 psig.

6.2 The tank shall be designed to withstand a maximum operating temperature of 200°F and thermal cycling temperatures between 50°F and 200°F.

7.0 COATINGS

7.1 The interior of the tank shall be uniformly lined with 1/2 inch of seamless hydraulic stone.

7.2 The exterior of the tank shall be heavy-gauge steel finished with baked enamel.

8.0 TANK PROTECTION

A 125 psig, 200°F ASME pressure-temperature safety valve shall be fitted to the tank. The discharge from the valve shall be directed to within 12 inches of the floor or as required by local codes.

9.0 INTEGRAL HEAT EXCHANGER

9.1 The tank shall be fitted with a double-walled heat exchanger. If either wall of the heat exchanger leaks, the leak shall be visible from the outside of the tank so that the tank can be replaced or repaired before contamination of the potable water by toxic heat-exchange fluid is possible.

The above specification is necessary to comply with the HUD Minimum Property Standards if a toxic fluid (such as ethylene glycol-water solution) is used to heat the potable water. If a *nontoxic heat exchange fluid is used or if an intermediate loop of nontoxic fluid is used to heat the potable water, then a single-walled heat exchanger can be specified. A heat exchanger that uses two concentric tubes coextruded or pressure bonded together does not satisfy the HUD Minimum Property Standards for a double-walled heat exchanger because leaks cannot be detected before the potable water is contaminated.*

9.2 The heat exchanger shall have a minimum heat exchange surface of

____________ square feet.

One of the most common mistakes in solar system design is the failure to provide enough heat exchange surface. A method of calculating the required heat exchange surface is given in Appendix D of this manual.

10.0 ELECTRIC IMMERSION HEATER

The tank shall include a 4500-watt electric immersion heater located approximately 1/3 of the distance down from the top of the tank.

An electric immersion heater is usually specified for a one-tank DHW system. You may need to specify a different wattage to suit your system. Gas and other forms of auxiliary heat are rarely specified for a one-tank system.

Since the auxiliary heat enters the second tank of a two-tank system, the first tank does not need an auxiliary heater.

11.0 TEMPERING VALVE

A tempering valve shall be installed at the hot-water outlet of the tank. The tempering valve shall limit the temperature of the water delivered to the house to 140°F by mixing cold water with the hot water.

12.0 CAPACITY AND DIMENSIONAL REQUIREMENTS

The tank shall have a capacity of ________ gallons.

Specify a size to suit your installation. If you require special locations for the potable water inlet and outlet and heat exchanger connections, specify them in this section.

13.0 DRAWINGS

Include drawings appropriate to your system. A sample drawing of one type of system is shown in Figure G-2.

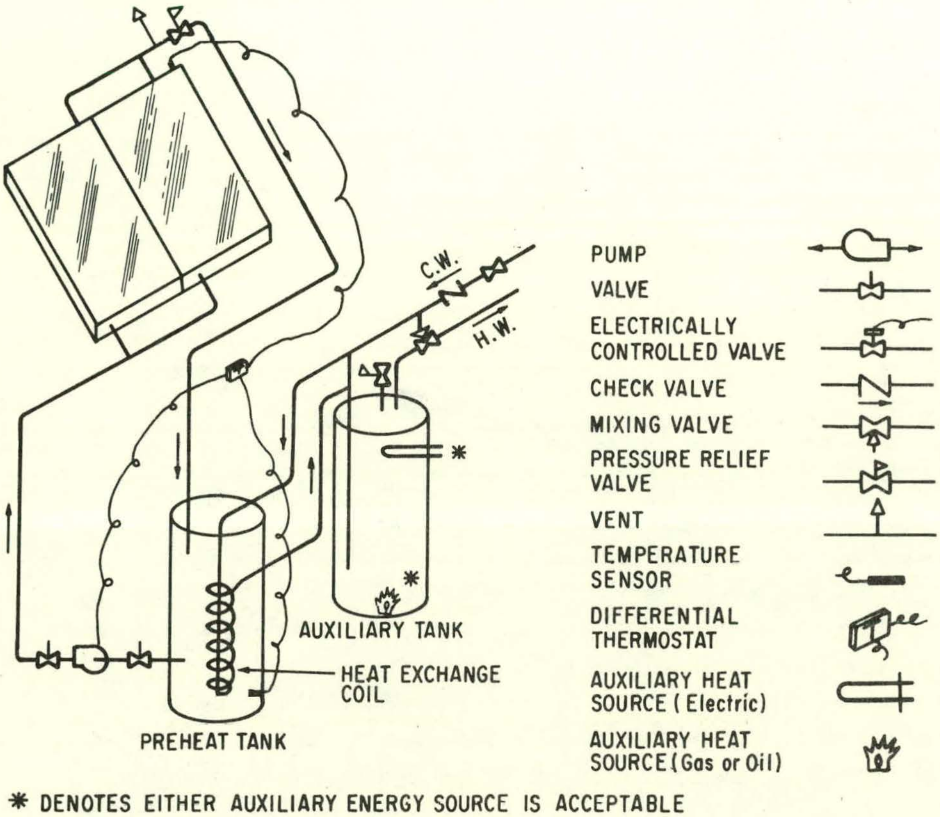


Figure G-2. Sample System Schematic

A vented (low pressure) drain-down system is shown.

APPENDIX H. SAMPLE SPECIFICATIONS FOR CONCRETE TANKS

In this appendix, comments and other material that is not part of the sample specifications are written in italics.

Part 1. SAMPLE SPECIFICATIONS FOR CAST-IN-PLACE CONCRETE TANKS

1.0 <u>WORK INCLUDED (Provide)</u>

1.1 All concrete and cement work as indicated in these specifications and shown on drawings.

1.2 Dovetail anchor slots.

1.3 Reinforcing, forming, and accessories.

1.4 Pockets for installation of items required by other trades using templates provided by trades requiring same.

1.5 Concrete for supports or pits required by other trades.

1.6 Grouting.

1.7 Setting anchor bolts.

1.8 Expansion joint filler.

1.9 Protection of all slabs being installed.

1.10 Recesses as shown on drawings.

1.11 Cutting, patching, repairing, and pointing up around sleeves, pipes, and hangers.

1.12 Floor hardeners.

2.0 <u>RELATED WORK</u>

2.1 Porous or compacted fill below slabs on ground.

2.2 Anchor bolts and other items requiring building into concrete will be furnished by others and installed under this contract.

2.3 Waterproofing and vapor barrier.

2.4 Rigid insulation on slabs and against foundation walls.

3.0 <u>DETAILS</u>

3.1 All details shall be in accordance with the American Concrete Institute Standards, "Building Code Requirements for Reinforced Concrete (ACI 318)," and "Manual of Standard Practice for Detailing Concrete Structures (ACI 315)," except as qualified.

3.2 The Contractor shall be responsible for all dimensions of the concrete work and shall check structural drawings in relation to all other drawings and shall verify all dimensions in relation with other work and existing field conditions. The Contractor shall be responsible for proper arrangement and fit of the work; and, if discrepancies are noted between the various drawings and work, the Contractor shall notify the Owner immediately in writing and shall not proceed until so directed.

3.3 The omission of any material shown on the drawings or called for by these specifications shall not relieve the Contractor of the responsibility for furnishing and installing such materials, even though such drawings may have been approved.

4.0 APPLICABLE CODES

4.1 The "Building Code Requirement for Reinforced Concrete (ACI 318-71)" shall be applicable.

Include applicable state and local building codes.

5.0 MATERIALS

5.1 Cement

All cement shall conform to the "Standard Specifications for Portland Cement," ASTM Designation C150. No cement that has become lumpy or has in any way deteriorated shall be used.

5.2 Water

Water used in mixing concrete shall be clean and free from deleterious amounts of acids, alkalies, or organic materials.

5.3 Aggregates

Concrete aggregates shall conform to the "Standard Specifications for Concrete Aggregates" (ASTM C 33).

5.3.1 The maximum size of coarse aggregates shall not be larger than 1/5 of the narrowest dimension between forms nor larger than 3/4 of the minimum clear spacing between reinforcing bars.

(The mixture should possess sufficient workability that the concrete can be placed without honeycombs or voids.)

5.3.2 Fine aggregate shall be natural sand for stone concrete.

5.3.3 All aggregates that are frozen or contain frozen particles must be completely thawed before they are used.

5.4 Reinforcing Steel

Reinforcing steel must be correctly rolled to section and free from surface defects, scale, oil that will destroy or reduce the bond and shall be stored on the job in such a manner as to be kept clean and free of scale. Thin powdery rust is not considered detrimental and need not be removed. Reinforcing steel shall comply with ASTM-A615-68. Bars shall be Grade 40 or Grade 60 as required. Raised markings on bars should identify manufacturer and sizes and distinguish the grade.

5.4.1 Welded wire fabric reinforcing shall meet the requirements of ASTM Specification A 185, current edition, and shall be tagged so as to identify the type and grade of steel and the size.

5.5 Placing of Reinforcement

All reinforcement shall be rigidly wired in place with adequate spacers and chairs.

5.5.1 All reinforcement within the limits of a day's pour shall be rigidly wired in place before concreting starts.

5.5.2 In all concrete surfaces exposed to the weather, bars including ties shall be a minimum of 2 inches clear of forms.

5.5.3 The Contractor shall conform with "C.R.S.I. Recommended Practice for Placing Reinforcing Bars," latest edition.

5.6 Design of Concrete Mixtures

5.6.1 All concrete, unless otherwise specified, shall be controlled concrete and shall be proportioned as outlined in Section 4.2.3, the Building Code of the American Concrete Institute (ACI 318-71), except as otherwise required by these specifications. The allowable design stresses are based on the minimum 28-day compressive strength. The laboratory trial mixtures shall develop concrete of compressive strength 25 percent higher than the required minimum to be acceptable for use in the field. Laboratory tests shall include the admixtures to be used.

5.6.2 All concrete except in footings shall contain Plastiment Retarding Densifier as manufactured by the Sika Chemical Corp., Lyndhurst, New Jersey, or equal. For low temperature conditions, Plastocrete 161 HE or equal may be used instead of Plastiment in walls and slabs. Proportions of all admixtures shall be as recommended by manufacturer's representative. Admixtures must be by same manufacturer as air-entraining agent.

5.6.3 The proportions of aggregate to cement for any concrete shall be such as to produce a non-segregating plastic mixture of such consistency as will give the required finish and can be worked readily into corners and angles of forms and around reinforcement with the method of placement employed. Required changes in consistency must be accomplished by changes in the proportioning of the mix without changing the W/C ratios established for the job.

5.6.4 For concrete exposed to the elements, "SIKA AER" by Sika Chemical Corp. or equal shall be added to the concrete mix in the amount and manner recommended by the manufacturer in order to obtain an air content of 5.0 percent, plus or minus 1.5 percent of the volume of the concrete, for 1-inch maximum stone aggregates and 6.0 percent, plus or minus 2.0 percent, for 3/4-inch maximum stone aggregate. Air-entraining agent must be by the same manufacturer as other additives.

5.6.5 The slump of concrete shall be 5 inches maximum.

5.7 Testing and Inspection

5.7.1 Services Required

5.7.1.1 The Owner will retain at his expense the services of an independent testing laboratory.

5.7.1.1.1 Analysis and testing of all aggregate to be used on the project in accordance with this specification and applicable ASTM specifications.

5.7.1.1.2 Design of concrete mixtures to produce specified strength from aggregates as delivered.

5.7.1.1.3 Inspection of mixing and placing, air content control, slump testing of all concrete, and obtaining specimen cylinders.

5.7.1.1.4 Compression testing of specimen cylinders taken from the concrete actually placed in the work.

5.7.1.1.5 Checking of mix, moisture content of aggregates, additives, gradation of aggregates, cement, temperature of cement during summer months, etc.

5.7.1.1.6 Checking that reinforcing is rigidly secured and mesh raised to proper position.

5.7.2 Preliminary Tests of Controlled Concrete

5.7.2.1 The Contractor shall furnish the laboratory with sufficient material to make the required tests indicated under "Design of Concrete Mixes."

5.7.2.2 The source of supply of the aggregate and cement shall not be changed during the course of the job without previous notice to the Owner, and the material from any new source shall be subject to acceptance or rejection as based on appearance for exposed concrete and on tests to be made by the testing laboratory at the Contractor's expense.

5.7.3 Testing of Concrete

5.7.3.1 During the progress of the work, for every class of concrete placed or for any amount of concrete placed or for any amount of concrete placed on any one day, four test cylinders shall be made and stored in accordance with ASTM C 31. One of the specimens shall be tested after 7 days and three after 28 days. The 7-day strength will be assumed to have 65 percent of the 28-day strength. Compression tests shall be conducted in accordance with ASTM C 39. The method of sampling fresh concrete shall be in accordance with ASTM C 143.

5.7.3.2 Slump tests shall not exceed the maximum recommended by the American Concrete Institute.

5.7.3.3 All test cylinders shall be marked with date they were made, together with full information on materials, proportions, water, air, and cement content and other pertinent data.

5.7.3.4 The Owner has the authority to order, at Contractor's expense, for any class of concrete, increase in cement content and mix redesign for remaining work, if either:

5.7.3.4.1 Average 7-day strength of any two tests representing class is less than 65 percent of specified strength; or

5.7.3.4.2 Average 28-day strength of any two tests representing class is less than 90 percent of specified strength.

5.7.4 Additional Field Tests

The Owner shall have the right to order the making of load tests, compression tests on specimens taken from the concrete in place or any other part thereof at any time during the course of construction. If the tests show that concrete tested is not in accordance with specifications, the Owner may condemn such concrete and the Contractor, at his own expense, shall remove such condemned concrete and replace same with new concrete to the satisfaction of the Owner.

5.7.4.1 Whenever such tests are ordered because original field tests have failed to comply with the requirements, or there is evidence of faulty workmanship, violation of specifications or likelihood of concrete having been frozen, the cost of the tests shall be borne by the Contractor.Whenever these tests are ordered for any other reason, the costs of the test shall be borne by the Contractor, if the concrete test is not up to specifications; otherwise, the cost of the same will be borne by the Owner.

5.7.4.2 Should the Owner incur additional engineering fees or should additional work other than tests be required because original field tests have failed to comply with the requirements, the additional fees and the additional work shall be charged to the Contractor.

5.8 Mixing of Concrete

5.8.1 Ready-mixed concrete shall be mixed and delivered in accordance with the requirements set forth in the "Standard Specifications for Ready-Mixed Concrete" (ASTM C 94).

5.8.2 All measurement of materials shall be done by weight with allowance for moisture content of aggregates. Admixtures shall be dispensed by automatic, metered devices with at least plus or minus 5 percent accuracy. These dispensers shall be regularly inspected and certified as to accuracy by the manufacturer of the admixture.

5.8.3 The concrete shall be mixed until there is a uniform distribution of the materials and shall be discharged completely before the mixer is recharged. For job-mixed concrete, the mixer shall be rotated at the speed recommended by the manufacturer and mixing shall be continued for at least 1 1/2 minutes after all materials are in the mixer. For mixers larger than 1 cubic yard capacity, the minimum mixing time shall be increased 15 seconds for each additional 1/2 cubic yard of concrete or fraction thereof.

5.8.4 The driver of each transit mix truck shall supply the Contractor's superintendent at the building with a certificate stating the time he left the plant and the mix of the concrete he is delivering. The certificate shall also state the amount of water and cement in the concrete. Failure to comply with these requirements shall be sufficient grounds for rejecting the concrete.

5.8.5 The certificates mentioned above must be written and signed by an authorized official of the transit mix company. Time at completion of each load of transit mix concrete shall be inserted on certificate by the Contractor's superintendent. Contractor's superintendent shall retain all certificates at the job for the inspection of the testing laboratory.

5.8.6 Not more than 1 hour shall elapse from the time water is introduced into the drum until it is discharged. No water shall be added to a mix that has stiffened to increase its workability. Retempering of partly set concrete shall not be permitted.

5.8.7 The Owner shall have the right to have the Contractor discontinue the services of the concrete supplier if, in his opinion, the supplier is not providing satisfactory continuity of delivery and cooperation.

5.9 Preparation of Equipment and Place of Deposit

5.9.1 Before placing concrete, all equipment for mixing and transporting the concrete shall be cleaned, all debris and ice shall be removed from the spaces to be occupied by the concrete, forms shall be thoroughly wetted (except where the surrounding atmosphere is below 40°F) or oiled, and reinforcement shall be thoroughly cleaned of ice or other coatings. Water shall be removed from place of deposit before concrete is placed. All reinforcement, forms, and ground with which the concrete is to come in contact shall be free from frost. Concrete shall not be deposited during rain unless adequately protected, and in any case preparations shall be on hand to protect newly placed concrete from the rain until it has hardened sufficiently so that it will not be damaged.

5.10 Conveying and Depositing

5.10.1 Concrete shall be conveyed to the place of final deposit by methods which will prevent segregation or loss of materials. Concrete shall be deposited as near as practicable in its final position to avoid segregation due to handling and flowing. No concrete that has partially hardened or been contaminated by foreign materials shall be deposited nor shall retempered concrete be used.

5.10.2 Concrete shall be placed directly and as near the final position as possible and in layers not exceeding 18 inches in depth to avoid inclined planes or the piling up of the concrete in the forms in such a manner as to permit the escape of water or the free flow of the concrete.

5.10.3 No cold joints resulting from the stoppage of concreting for lunch or other reasons shall be permitted when the temperature is high and an early set may occur.

5.10.4 Concrete shall be placed through canvas, wood, rubber, or metal elephant trunks (6 inches minimum diameter) in order to avoid a free fall of over 3 feet below the chutes or hopper. The maximum rate of placement shall be 2 feet 6 inches per hour. Concrete shall not be allowed to ricochet against forms that have exposed surfaces. Concrete shall be deposited directly to the center of forms. Drop chutes shall be spaced at approximately 10 feet on centers maximum. The use of drop chutes longer than 12 feet shall be prohibited. For inspection purposes adequate illumination in the interior of the forms shall be provided.

5.10.5 An excess of water will accumulate at the top as the result of a poor mix, insufficient fines, or too-rapid placing. This shall be watched and corrected. When this does occur, the water can be removed by boring 1-inch holes in the nonexposed side of the form.

5.10.6 Vibration

5.10.6.1 Vibrate the entire depth of each new layer of concrete and penetrate a few inches into the layer below to insure a consolidation of layers, providing this layer has not partially hardened, since a wavy line between layers may result. Do not use vibrators to move concrete laterally. Penetrate the concrete with the vibrator vertically and not at an angle. Make sure the concrete is placed against the face of previously placed concrete; otherwise, segregation and air pockets will occur.

5.10.6.2 Thoroughly vibrate the new concrete close to the joint of hardened concrete.

5.10.6.3 Contractor shall not permit internal vibrators to come in contact with the forms. This will mar the face of the form and show up as a defect.

5.10.6.4 Special attention with the vibrators should be paid to such locations as corners, cutouts, places with large number of bars, etc.

5.10.6.5 Internal vibrators may also be supplemented at different locations by the use of form vibrators, rubber or wooden mallets, or hand spading to insure good results.

5.10.6.6 Contractor shall not place concrete until he has sufficient vibrators on hand, including spares, to suit the particular design.

5.10.6.7 Avoid over-vibration. Prolonged vibration may reduce the initial air content of the air-entrained concrete to more than half.

5.10.7 Once concreting is started, it shall be carried on as a continuous operation until the placing of the panel or section is completed. The locations of construction joints shall be at the point of minimum shear. The top surface shall be generally level.

5.10.8 Where new concrete is to be bonded to existing concrete, the forms shall be tightened and the surfaces of the existing concrete shall be swept with a stiff brush or scraped to remove laitance and roughened. The bonding surface shall be cleaned, wet, and covered with a thin layer of mortar 1:1-1/2 mix just before placing the new concrete.

5.11 Curing and Protection

5.11.1 Curing

5.11.1.1 The top surface of all slabs shall be sprayed with an approved liquid membrane-forming compound in accordance with the directions of the manufacturer as soon as the newly placed surface has been finished and will not be marred by application.

5.11.1.2 The liquid membrane-forming compound shall meet the requirements of "Specifications for Liquid Membrane-Forming Compounds for Curing Concrete" (ASTM C 309) and shall contain a fugitive dye.

5.11.1.3 The Contractor shall submit test reports from an independent testing laboratory or other acceptable data including a manufacturer's guarantee proving compatibility with all types adhesives as well as separate cement toppings.

5.11.1.4 Acuricon, manufactured by Anti-Hydro Waterproofing Company, Newark, New Jersey, or other sodium silicate compounds meeting the above requirements, are acceptable.

5.11.1.5 Surfaces subject to heavy rainfall within 3 hours of compound application shall be resprayed.

5.11.1.6 Where practicable, forms shall be kept in place for a 7-day curing period. The top exposed concrete surface shall be kept wet and the wood forms shall be kept moist. In order that the curing water may reach the surfaces of walls, the forms shall be loosened to allow the water to be poured over the top and thus run down between the concrete and the forms.

5.11.1.7 If it is not practicable to keep forms on for 7 days, cover concrete with fabrics which have moisture retaining properties. Such covers also shall be kept continuously moist to insure a film of water on the surface.

5.11.2 Hardening

5.11.2.1 Exposed concrete floors after thoroughly wet curing shall be allowed to dry and then be hardened with Lapidolith as manufactured by Sonneborn Div. of Countech, Inc., or equal. Hardener shall be applied in strict accordance with manufacturer's printed directions, under the direct supervision of manufacturer's representative, in no fewer than three coats. Surplus allowed to remain on the surfaces after third coat dries shall be removed by scrubbing or buffing.

5.11.3 Protection

5.11.3.1 Protect concrete from construction traffic and action of sun, rain, flowing water, frost, snow, or mechanical injury for a period of 2 weeks after placing. Traffic areas shall be provided with raised runways.

5.11.3.2 Reinforcement left exposed to the weather before the next concrete placing shall be coated with a wash of cement and water to prevent the staining of the concrete due to rusting. This coating shall be removed prior to the next concreting. If the exposed concrete finish becomes stained due to rusted reinforcing steel, the surface shall be cleaned.

5.11.4 Cold Weather Protection

All concrete shall be maintained at a temperature of at least 50°F for not less than 4 days after it is deposited. During the next 3 days it should be protected from freezing. The housing, covering, or other protection used shall remain in place and intact at least 24 hours after artificial heating is discontinued. No dependence shall be placed on calcium chloride or other chemicals for the prevention of freezing. The Contractor shall follow "Recommended Standards for Cold Weather Concrete," ACI 604. Calcium chloride shall not be used to prevent freezing or to accelerate concrete set.

5.11.5 Hot Weather Protection

During hot weather, forms, reinforcing steel, and sub-grade shall be sprayed periodically with water. The placing temperature of concrete shall not be more than 90°. Special care shall be taken to place the concrete as quickly as possible after mixing. After finishing, concrete shall be cured as quickly as possible without marring the surface to prevent moisture evaporation. The Contractor shall follow "Recommended Standards for Hot Weather Concrete" ACI 605.

5.12 Forms and Centering

5.12.1 All forms shall conform to the lines, dimensions, and shapes of the concrete as indicated on the drawings. They shall be watertight to prevent leakage of mortar and shall be smooth except where otherwise required and shall be free from defects where the concrete is to be left exposed. The forms shall be in such condition and have ample supports so that they will not bulge or get out of line or level as concrete is placed. For exposed work, the maximum tolerance in line and level will be 1/16 inch at the joints. It will be the concrete contractor's responsibility to see that forms are supported well enough to insure the safety of workmen and the public. Design of form-work shall comply with ACI 347.

5.12.2 Form lumber shall be moisture-resistant concrete form plywood not less than 5/8 inch thick in accordance with Department of Commerce Product Standard PS 1-66 for softwood plywood, Plyform Class 1, B-B, exterior, or structural equivalent.

5.12.3 For surfaces exposed to view in the finished work, use new, clean, smooth plywood free from blemishes, in sizes as large as practicable and square cut. Handle, store, place, and fit forms in an approved manner.

5.12.4 As the forms for exposed concrete become worn or damaged, they shall be replaced as often as necessary to obtain a smooth finish.

5.12.5 Corners of exposed slabs, walls, etc., shall be sharp and square.

5.12.6 Coat forms with a concrete releasing agent at each use. Form coatings shall not be of material that will leave stains on the concrete or that might cause injury to paint that is applied to exposed concrete. Magic Kote by Symons Corporation, or equal, will be acceptable for exposed concrete.

5.12.7 All keys shall be securely held in position by continuous wood blocking rigidly secured to forms of reinforcing.

5.12.8 All slabs and wall forms shall be cambered 1/8 inch for each 8 feet of span, unless otherwise required. Camber shall be 1/2 inch for each 8 feet of cantilever span. The camber shall be checked and forms adjusted if necessary to maintain the camber before the initial set takes place.

5.12.9 Provide temporary clean-out openings at the base of all forms and other points where necessary to facilitate cleaning and inspection for placing concrete.

5.12.10 In exposed work, metal tools shall not be placed against the concrete to wedge forms loose. Only wood wedges shall be used.

5.12.11 Proper shoring shall be provided under the forms for concrete work to support all construction loads and reshoring shall be provided for all floor wall slabs before stripping. Supports for forms shall consist of wood or steel posts or of hung units of a size and spacing as required to support the weight of the forms, concrete, and construction live load. Each post shall be secured against horizontal movement by bracing or other means at the top and bottom. Forms shall not be removed until a thorough examination indicates that the floor walls have developed ample strength to carry the load put upon them.

5.12.11.1 This shall not be interpreted as permitting the removal of forms under slabs in less than the following periods:

66 hours when the average air temperature is 60° or higher.

90 hours when the average air temperature is below 60°.

Attention of the Contractor is called to the statement that the above requirements are minimum requirements and that the shores and reshores shall be kept in place for sufficient length of time to assure the safety of the structure.

5.12.11.2 The average temperature is defined as the average of the daily temperature for the period from the time of pouring to the time of stripping. Temperatures recorded by the local weather bureau are to be used.

If artificial heat and protection are provided for the concrete, the average temperatures of the concrete shall be used instead of the air temperatures. It will be acceptable to assume that the temperature of the concrete slabs is the average temperature of the air directly above the slab at a representative location midway between heaters.

5.12.11.3 Forms shall be left in place and the shorings not disturbed for a longer period than above stated if so required by the condition of the concrete, by severe weather conditions, or by lack of adequate heating and protection.

5.13 Finishes Other Than for Floors

5.13.1 All interior and exterior walls and other concrete surfaces shall be left as they come from the forms. Deep voids and honeycombs which are structurally unacceptable may be filled following the procedure given under patching.

5.13.2 In all foundation walls below grade and tank walls the ties and spreaders shall be cut back to a depth of approximately 1 1/2 inches. Any honeycombed concrete or voids shall be cut back to sound concrete. All cuts shall be to a depth of at least 1 1/2 inches with the edges perpendicular to the surface. All holes resulting from cutting back for scale pockets, honeycomb, surface voids, and the removal of form wires or spreaders shall, however, be filled with cement mortar.

5.13.3 In all concrete exposed to view, cone-shaped snap ties are to be used. Ties are to be placed in horizontal lines in a regular pattern. Voids created by cone-shaped snap ties are to remain exposed.

5.13.4 Patching

5.13.4.1 Any concrete that is not formed as shown on the drawings or for any reason is not of alignment or level or shows a defective surface shall be considered as not conforming with the intent of these specifications and shall be removed from the job by the Contractor at his expense unless the Owner grants permission to patch the defective area.

5.13.4.2 After forms are removed, all concrete shall be inspected and any deep voids, honeycombing, or other defective areas shall be patched when so directed. Where necessary, defective areas shall be chipped away to a depth of not less than 1 inch with edges perpendicular to the surface. For extensive repairs, the Contractor shall use an epoxy mixture as per manufacturer's instructions to obtain better adhesion to the existing surface. The area to be patched and a space at least 6 inches wide entirely surrounding it shall be wetted to prevent absorption of water from the patching mortar.

5.13.4.3 A grout of equal parts Portland cement and sand, with sufficient water to produce a brushing consistency, shall then be well brushed into the surface, followed immediately by patching mortar. The mortar shall not be richer than 1 part cement to 2 parts sand. The amount of mixing water shall be as little as consistent with the requirements of handling and placing. The mortar shall be retempered without the addition of water by being allowed to stand for a period of 1 hour during which time it shall be mixed with a trowel to prevent setting.

5.13.4.4 The mortar shall be thoroughly compacted into place and screened off so as to leave the patch slightly higher than the surrounding surface. It shall be left undisturbed for a period of 1 to 2 hours to permit initial shrinkage before being finished. All patches shall be thoroughly cured.

5.14 Floor and Slab Finishes

5.14.1 General

5.14.1.1 Finished concrete slabs shall be worked so that large aggregate will not be visible in the top surface.

5.14.1.2 All slabs must be protected during construction to prevent marring and defacement.

5.14.1.3 Where the allowable tolerances in surface elevation of slabs are exceeded, the Owner may direct the Contractor to grind or patch the floor to bring the surface within the requirements. Grinding shall be done as soon as possible but not before 3 days of cure. Patching material shall be Epolith Patcher as manufactured by Sonneborn Div. of Countech, Inc., or equal. Patching shall be done as soon as possible but not before 28 days of cure.

5.14.2 Finishes

After the concrete has been struck off, consolidated, and leveled, the surface shall be roughened with stiff brushes or rakes before final set.

5.15 Concrete Slabs on Ground

5.15.1 All non-framed concrete slabs on ground shall be placed on 6-inch clean sand or bankrun gravel fill, well tamped. Cover fill with vapor barrier in wide rolls with joints lapped. Slabs shall be reinforced.

5.15.2 Where a working slab is indicated as a base for construction, the working slab may be placed directly on existing soil and the vapor barrier omitted.

5.16 Joint Fillers and Sealants

5.16.1 Expansion joint fillers shall be of preformed, nonextruding resilient type, such as cork or sponge rubber (not a fill containing asphalt or tar), and conforming to ASTM D-1752. Joint fillers shall be used for the full depth of slab to within 1/2 inch of the finished slab and shall be of 1/2 inch thickness.

5.16.2 All expansion joints shall be sealed with Sonolastic NP2 as manufactured by Sonneborn Div. of Countech, Inc., or equal, installed in accordance with manufacturer's instructions.

5.17 Provisions for Work of Other Trades and Contractors

5.17.1 Contractors for other trades requiring slots, chases, recesses, or openings in concrete work will be required to furnish information regarding the size and location of same before concrete forms have been erected.

5.17.2 All slots, chases, recesses, or openings indicated on the contract drawings, which are not formed by sleeves, frames, boxes, or other equipment furnished by other trades, shall be provided in locations shown by this Contractor as part of his contract.

5.17.3 The Contractor shall do all grouting and filling with concrete as required throughout except as otherwise specified, including frames in concrete walls and openings after pipes are in place. Confine the grout vertically. Grouting exposed to weather shall be an epoxy grout, Colma-Dur Grout with Colma Quartzite aggregate (Sika Chemical Corporation) or equals, installed in accordance with manufacturer's instructions.

5.17.4 When pipes embedded in slabs are larger than 1-1/2 inches O.D., or when they come closer than 1-1/2 inches from either upper or lower surface of the slab, expanded metal of 6-inch x 6-inch #10 x #10 welded wire mesh shall be laid and extended beyond such conduit or piping at least 8 inches on all sides. Minimum 1-1/2 inch concrete cover is required for any pipes. Pipes or conduits having an outside diameter larger than one third the slab thickness shall not be placed in the slab.

5.17.5 Pipes shall be spaced not closer than three diameters on centers and where possible they must be so placed as to avoid changing the locations of the reinforcement from that shown on the drawings.

5.17.6 Sleeves, boxes, and other openings shall not be permitted unless shown on a drawing submitted to and approved by the Structural Engineer.

5.17.7 The Contractor shall carefully point around all pipe sleeves where carried through slabs and concrete walls to present a neat finish.

5.17.8 The Contractor shall furnish and install all inserts as required.

5.17.9 Inserts and anchors carrying pipe and equipment loads shall be rated by manufacturer for safe allowable loads. Submit details and location drawings for approval and for possible additional reinforcement in concrete at insert.

5.17.10 All inserts at exposed surfaces shall be rust and stain proof.

6.0 DRAWINGS

Include drawings that are applicable to your particular installation in this section. Sample drawings are shown in Figures H-1 through H-7.

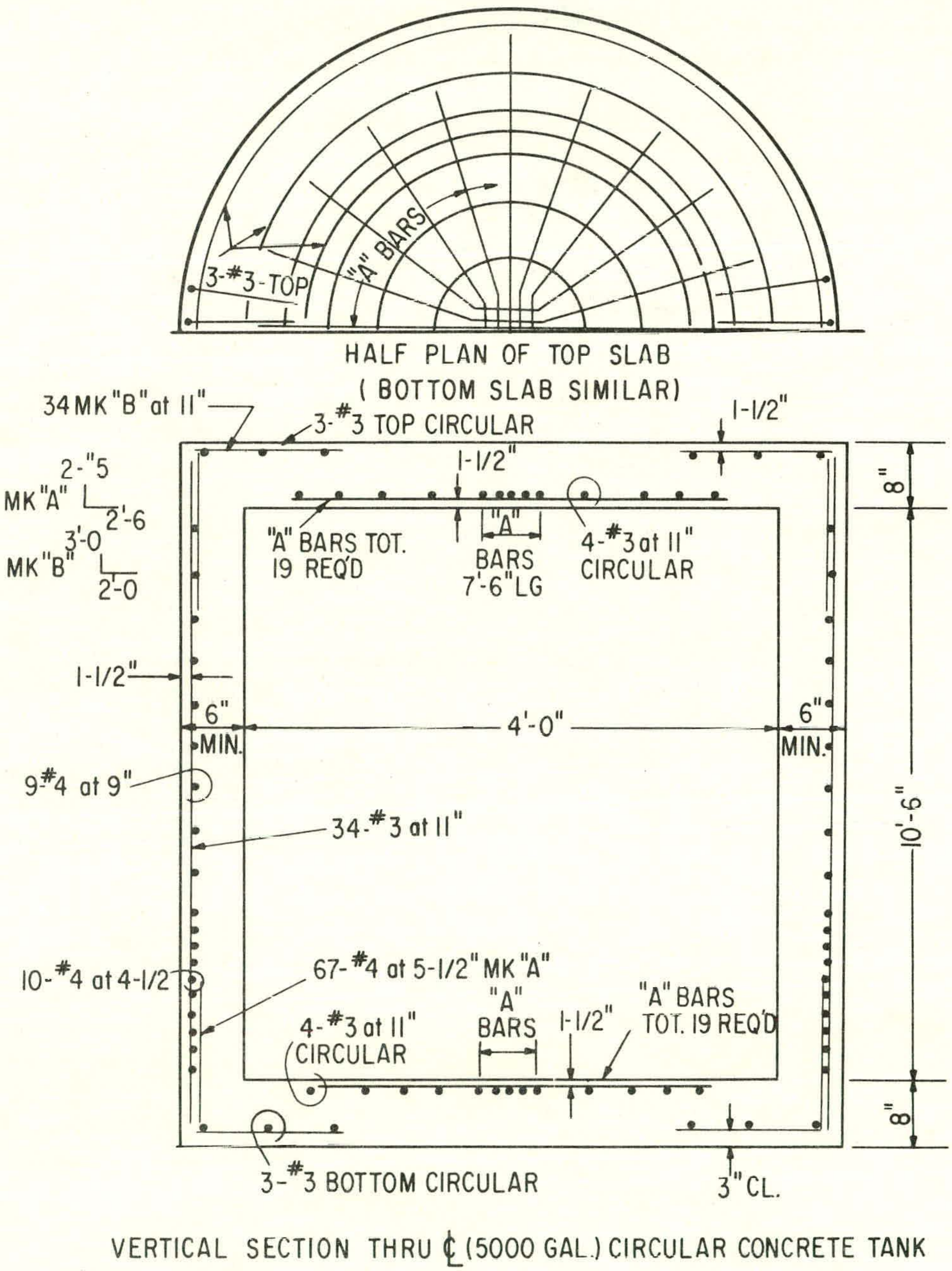


Figure H-1. Sample Drawing of a Circular Concrete Tank

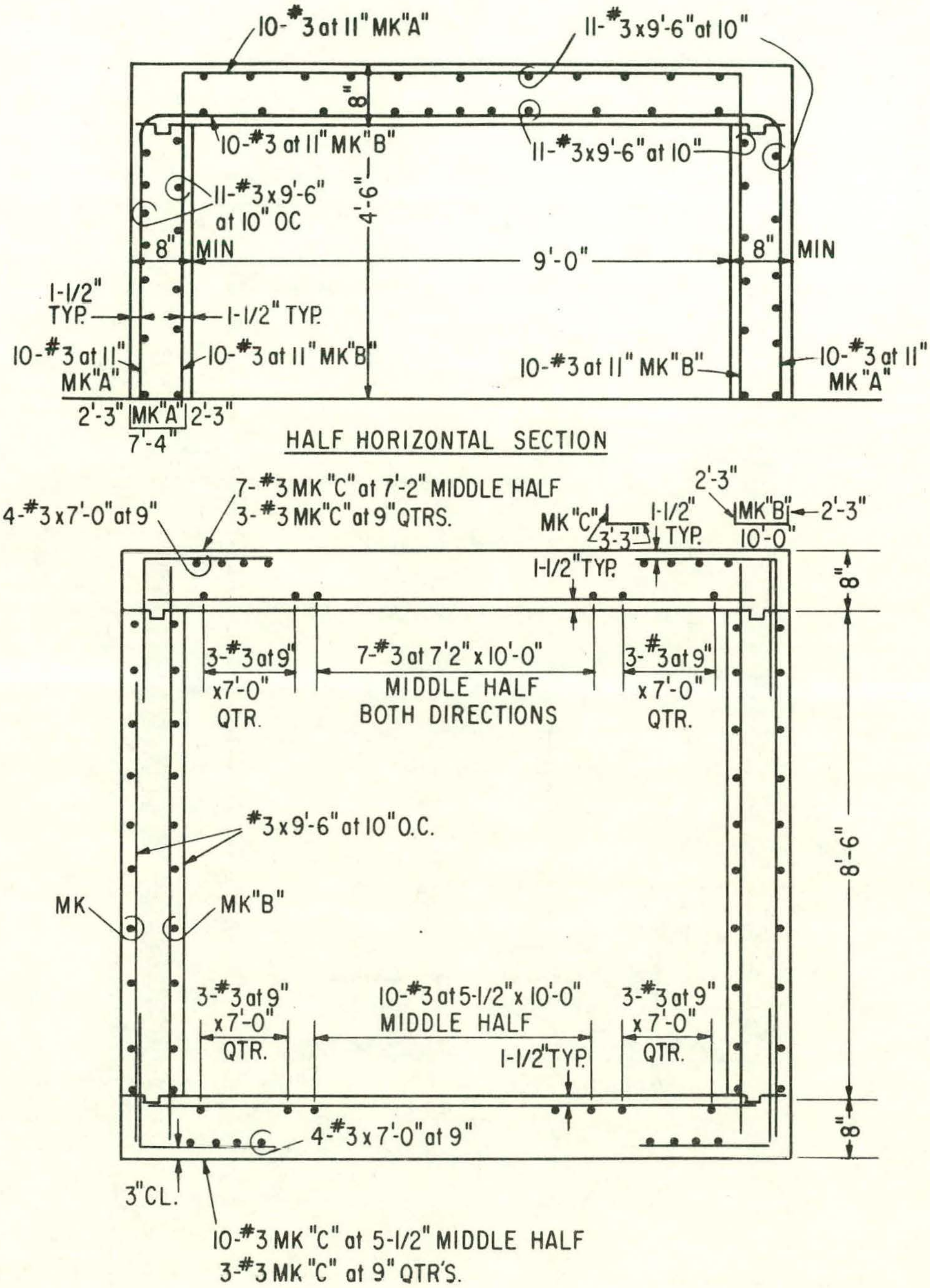


Figure H-2. Sample Drawing of a Rectangular Concrete Tank

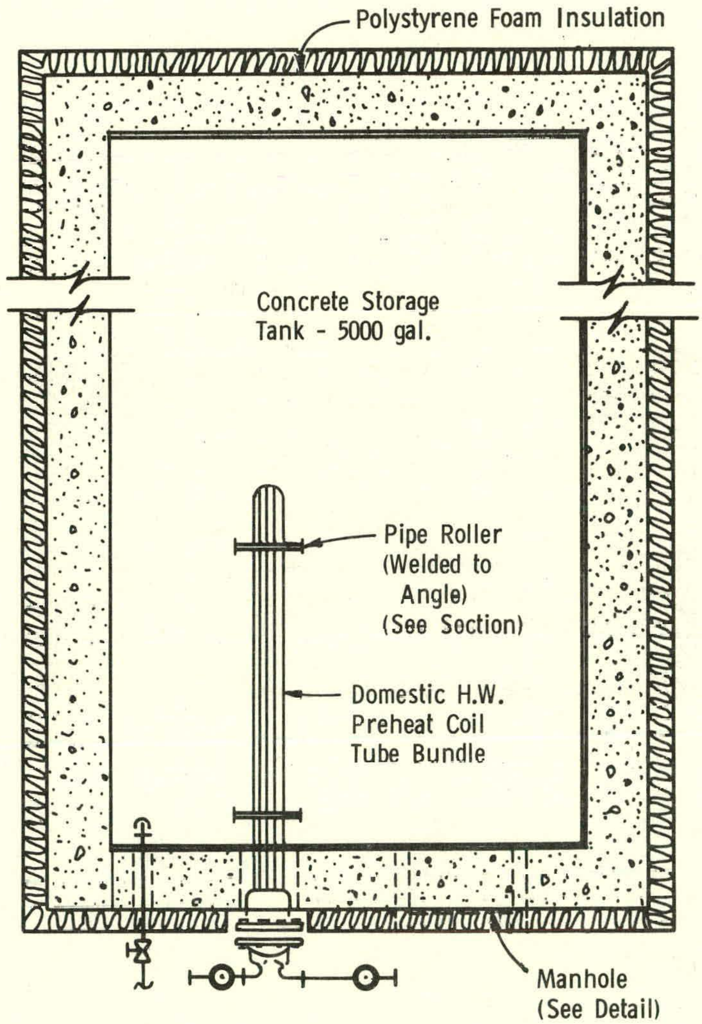


Figure H-3. Plan View of a Rectangular Concrete Tank (not to scale)

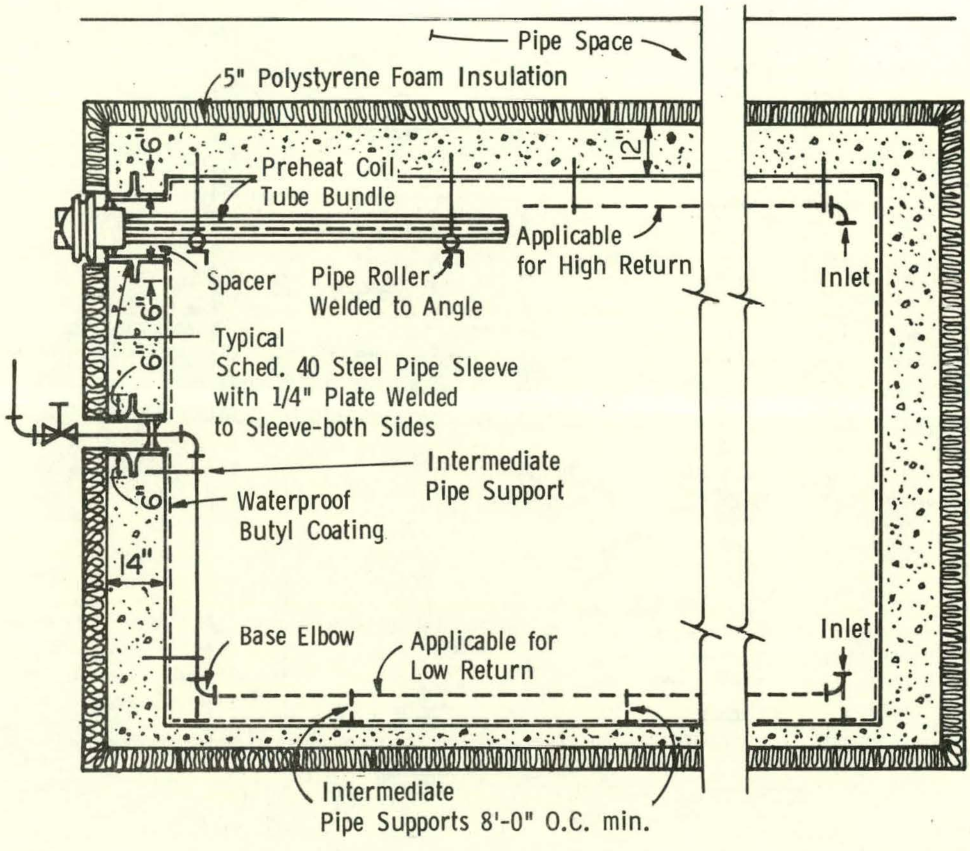


Figure H-4. Section through Rectangular Concrete Tank (not to scale)

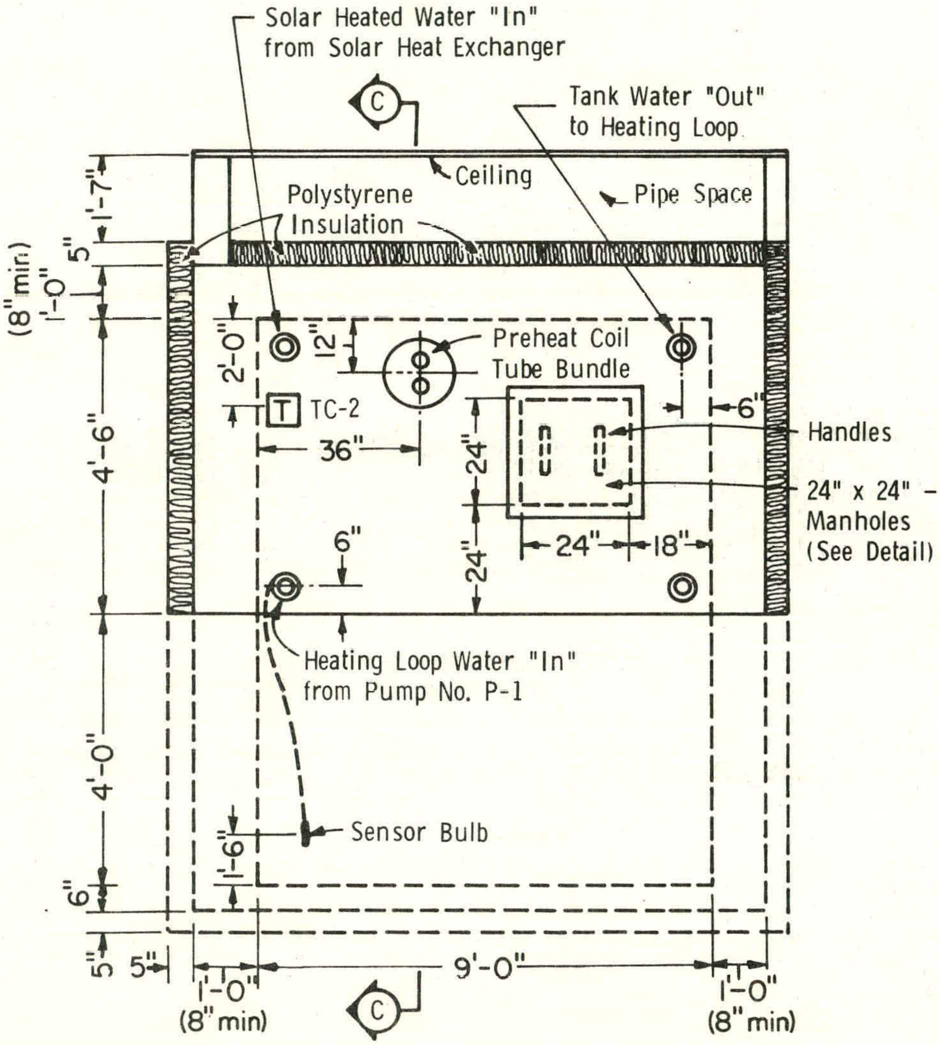
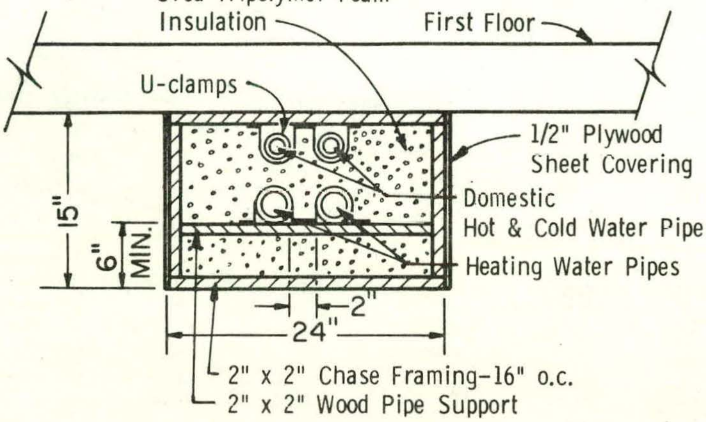
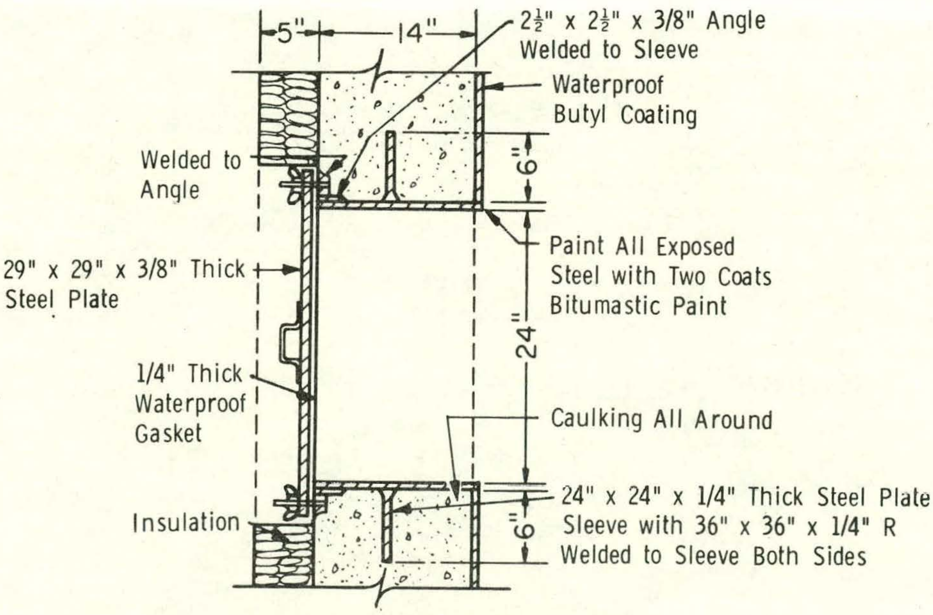


Figure H-5. Front View of Rectangular Concrete Tank
(not to scale)



DETAIL OF PIPE CONDUIT



DETAIL OF MANHOLE

Figure H-6. Details of Rectangular Concrete Tank

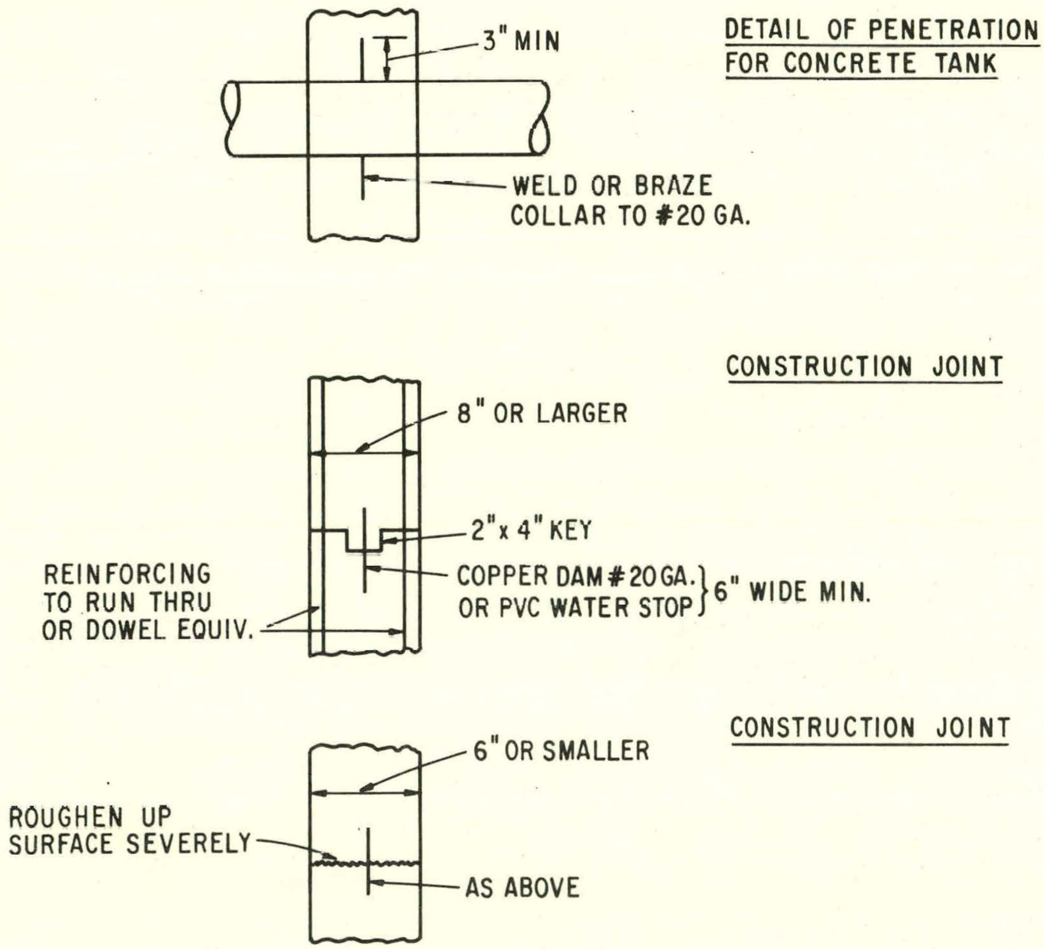


Figure H7. Details of Penetrations and Joints for Concrete Tanks

Part 2. PRECAST CONCRETE TANKS

Section A. SAMPLE SPECIFICATIONS FOR PRECAST CONCRETE TANKS

1.0 WORK INCLUDED (Provide)

1.1 Precast concrete solar energy storage tanks as indicated in these specifications and shown on the drawings.

1.2 Installation of precast concrete solar energy storage tanks.

1.3 All fittings, connections, and internal piping.

1.4 All internal heat exchangers.

1.5 Insulation.

1.6 Waterproof liners.

2.0 RELATED WORK

2.1 Excavation and grading.

2.2 Solar system piping external to tanks.

2.3 Electrical wiring.

3.0 DETAILS

3.1 All details shall be in accordance with HUD Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems, Vol. 5 (1977).

3.2 The Contractor shall be responsible for all dimensions of the work and shall check tank drawings in relation to all other drawings and shall verify all dimensions in relation with other work and existing field conditions. The Contractor shall be responsible for proper arrangement and fit of the work; and, if discrepancies are noted between the various drawings and work, the Contractor shall notify the Owner immediately in writing and shall not proceed until so directed.

3.3 The omission of any material shown on the drawings or called for by these specifications shall not relieve the Contractor of the responsibility for furnishing and installing such materials, even though such drawings may have been approved.

4.0 APPLICABLE CODES

4.1 HUD Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems, Vol. 5 (1977).

Include applicable state and local codes.

5.0 MATERIALS

5.1 Tank Construction

5.1.1 The external precast shell shall be 3500 psi, minimum, concrete with steel reinforcing.

5.1.2 A 2-inch thick layer of urethane foam insulation shall cover the interior of the tank.

Refer to Chapter 1 and Appendix C for discussion of insulation thickness. Other insulation thicknesses can be specified.

5.1.3 A waterproof liner shall be provided on the sides and bottom to prevent water loss by leakage and prevent insulation degradation by water absorption. The liner shall be capable of withstanding temperatures of at least 160°F.

The 160°F temperature limit can be increased, if necessary. Consult tank manufacturers for availability of liners that can withstand high temperatures.

5.2 Piping and Connections

5.2.1 Two fitting plate(s) shall be provided in 1/4-inch painted steel over two 18-inch x 18-inch port(s) at opposite ends of tank with fittings.

5.2.2 Special: Sixteen 1-1/2-inch copper fittings.

5.2.3 Plates shall be bolted in place and sealed with an elastomeric sealant to prevent entry of groundwater.

5.2.4 Internal piping shall be provided in copper as follows: deep pipe, shallow pipe, collector suction, sensor well, etc.

5.2.5 Internal heat exchangers shall be provided as follows: One shallow heat exchanger and piping in series of smooth copper coils 60 feet x 1/2 inch in diameter.

Refer to Appendix D, "Determining Heat Exchanger Size," before specifying heat exchangers.

5.2.6 An atmospheric vent shall be provided for preventing pressure or vacuum build-up inside tank. (1-inch diameter minimum).

5.2.7 Access shall be provided by means of one 18-inch x 18-inch top port with sealable cover.

6.0 INSTALLATION

6.1 Tanks shall be installed in an excavated hole on minimum of 4 inches crushed and leveled stone with 2 feet clearance all around tank. Hand-tamp backfill in place. CAUTION, DO NOT COMPACT WITH MACHINERY OR ALLOW MACHINERY OVER BACKFILLED TANK. Grade earth cover to drain away from tank.

6.2 Direct and unobstructed access to excavated hole with a minimum of 14 feet head clearance shall be provided for tank carrier approaching long side of hole. Hole shall be no wider than 9 feet, 6 inches at top.

6.3 Provide a concrete casing 30 inches in diameter x 2 feet, 2 inches thick, with cover, sealed to tank top for access from grade. Seal cover to casing with elastomeric sealant to prevent entry of water.

7.0 CAPACITY AND DIMENSIONAL REQUIREMENTS

Fill in the blanks to complete this section. This example applies to rectangular tanks. If your installation requires another tank shape or if you have special dimensional requirements (such as special locations for pipe fittings), state your requirements in this section.

7.1 Nominal capacity of the tank shall be ________ gallons.

7.2 Width of the tank shall be ________ feet, ________ inches.

7.3 Length of the tank shall be ________ feet, ________ inches.

7.4 Height of the tank shall be ________ feet, ________ inches.

8.0 OPERATION

8.1 Water level inside tank shall not exceed 6 inches below inside top of tank.

8.2 Debris, chemicals, sharp objects, or other items which may damage or degrade tank liner shall be prevented from entering tank.

9.0 DRAWINGS

Include drawings that are applicable to your particular installation in this section. A sample drawing is shown in Figure H-8.

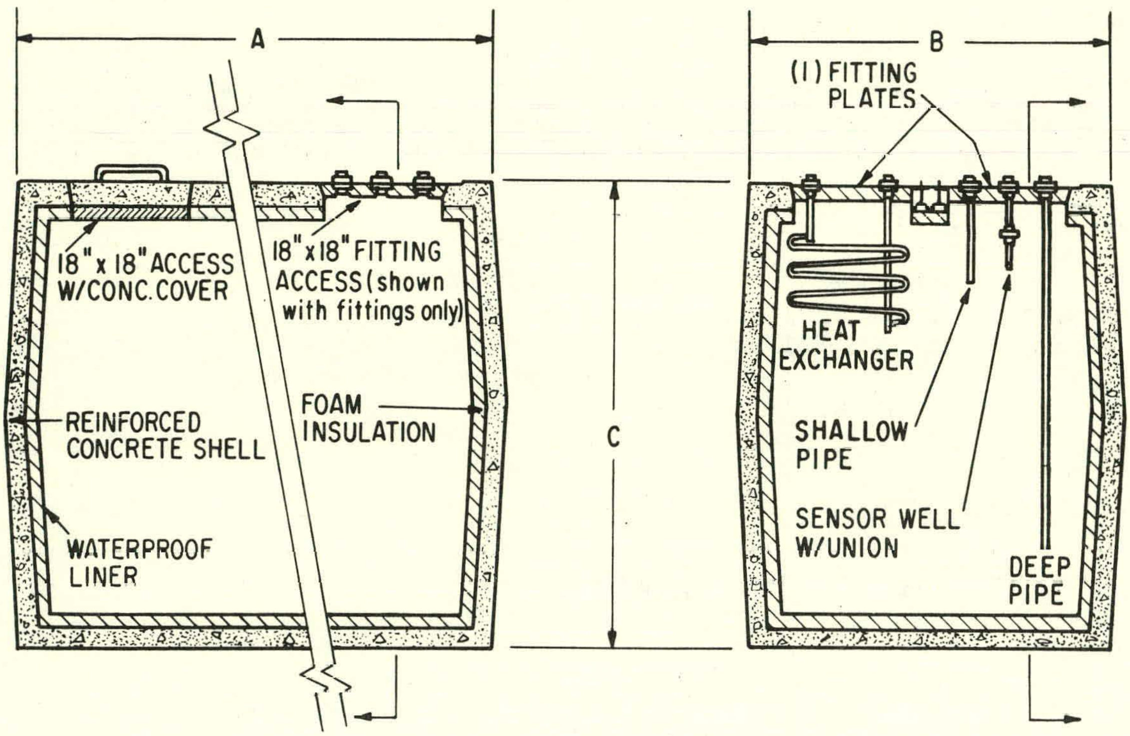


Figure H-8. Precast Concrete Tank
Drawings courtesy of Solatherm Corporation, 1255 Timber Lake Drive, Lynchburg, Virginia 24502. Because of the difficulty of shipping heavy objects, you should consult the manufacturer for availability of tanks, liners, and components.

Section B. SAMPLE SPECIFICATIONS FOR USING UTILITY VAULTS FOR THERMAL ENERGY STORAGE

Sections 1.0 through 4.0 of this sample specification are the same as for Section A, "Sample Specifications for Precast Concrete Tanks."

5.0 MATERIALS

5.1 Tank Construction

Thermal storage shall be provided by adapting a precast concrete transformer vault. Modify tank to provide three access holes in the top of the tank -- one 30-inch manhole with cover in the center and two 8-inch-diameter holes in diametrically opposite corners as shown on the drawings.

5.2 Tank Insulation

To prevent thermal losses to the ground, the tank shall be insulated as follows:

5.2.1 Bottom

- 10-inch concrete pad.
- Two layers of pentaclorophenol-treated 2-inch x 12-inch boards.
- One layer of 4-inch foam glass.
- Epoxy sealer coating.

5.2.2 Sides

- Four inches of polyurethane foam, with a waterproof barrier of fiberglass and mastic.
- One layer of pentaclorophenol-treated 2 by 12-inch boards.
- Epoxy sealer coating.

5.2.3 Top

- 4 inches of polyurethane foam, with a waterproof barrier of fiberglass and mastic.
- Two layers of pentaclorophenol-treated 2-inch x 12-inch boards.

5.3 Lining

A waterproof liner shall be provided on the sides and bottom to prevent water loss by leakage. The liner shall be capable of withstanding temperatures of at least 160°F.

The 160°F temperature limit can be increased, if necessary. Since this is a non-standard application, the liner must be specially fabricated.

5.4 Piping

Ordinary black steel, schedule 40, pipe shall be used throughout the system.

5.5 Pipe Insulation

5.5.1 Underground

Either of two types of insulation material shall be used for underground insulation.

- 1-1/2-inch foam glass, covered with mastic.
- 1-1/2-inch polyurethane foam, covered with fiberglass and mastic.

5.5.2 Aboveground

- The aboveground piping shall be insulated with 1-1/2-inch fiberglass pipe insulation.
- The hose connections shall be insulated with 3/8-inch foamed plastic insulation.

6.0 INSTALLATION

Place the transformer vault below ground upon a 10-inch slab of concrete after covering the slab with two layers of pentachlorophenol-treated 2-inch x 12-inch boards and 4 inches of foam glass insulation. The periphery of the tanks shall be insulated with 4-inch waterproofed polyurethane. The polyurethane insulation shall be protected by a layer of pentachloraphenol-treated 2-inch x 12-inch boards. The boards shall extend above the ground level. The top of the tank shall be insulated with waterproofed polyurethane and 2 layers of pentachlorophenol-treated 2-inch x 12-inch boards.

7.0 CAPACITY AND DIMENSIONAL REQUIREMENTS

Fill in the blanks to complete this section. This example applies to rectangular tanks. If your installation requires another tank shape or if you have special dimensional requirements (such as special locations for pipe fittings), state your requirements in this section.

7.1 Nominal capacity of the tank shall be ______ gallons.

7.2 Width of the tank shall be ______ feet, ______ inches.

7.3 Length of the tank shall be ______ feet, ______ inches.

7.4 Height of the tank shall be ______ feet, ______ inches.

8.0 DRAWINGS

Include drawings that are applicable to your particular installation in this section. Sample drawings are shown in Figures H-9 through H-11.

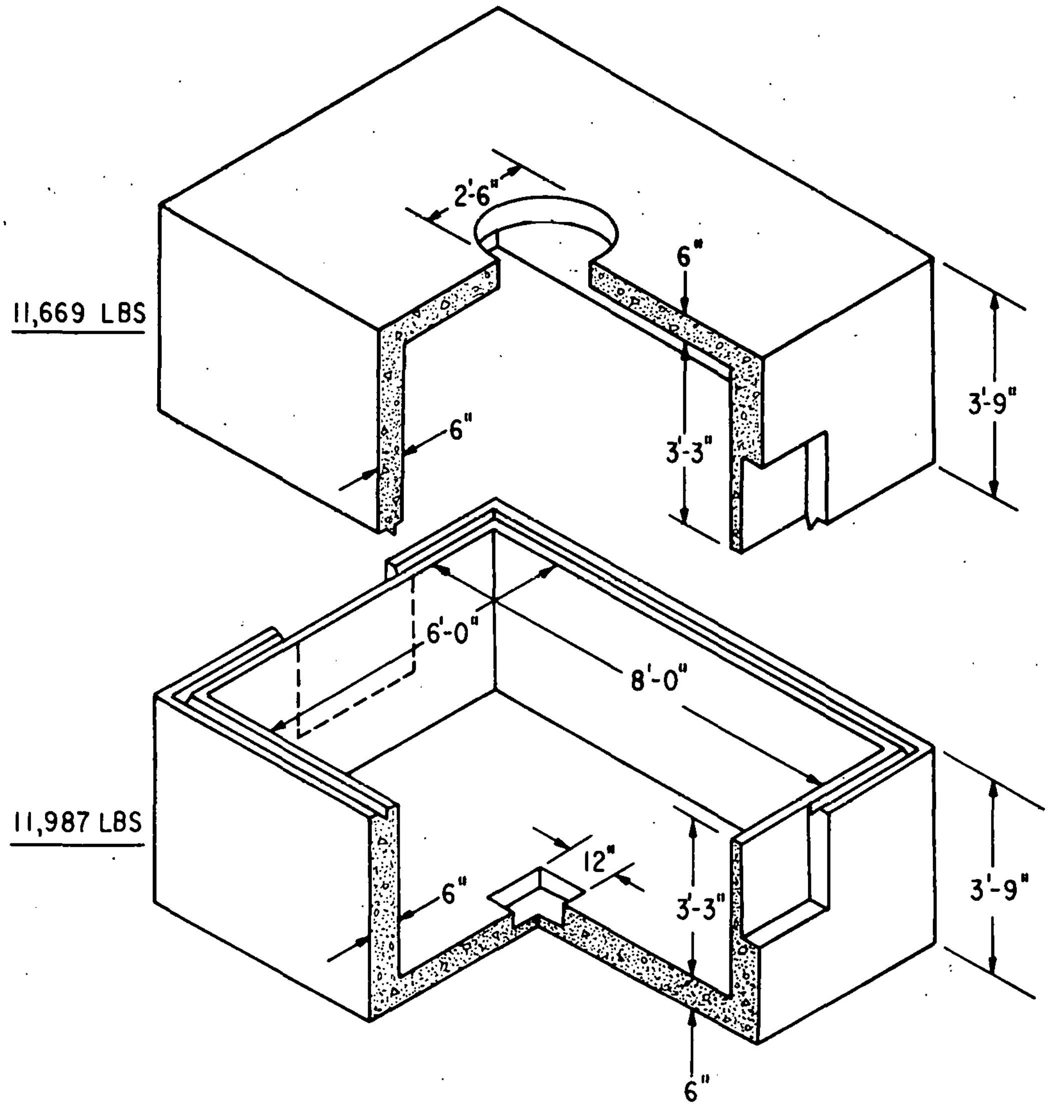


Figure H-9. Typical Utility Vault
Drawing courtesy of Smith Cattleguard Co., Midland, Virginia.

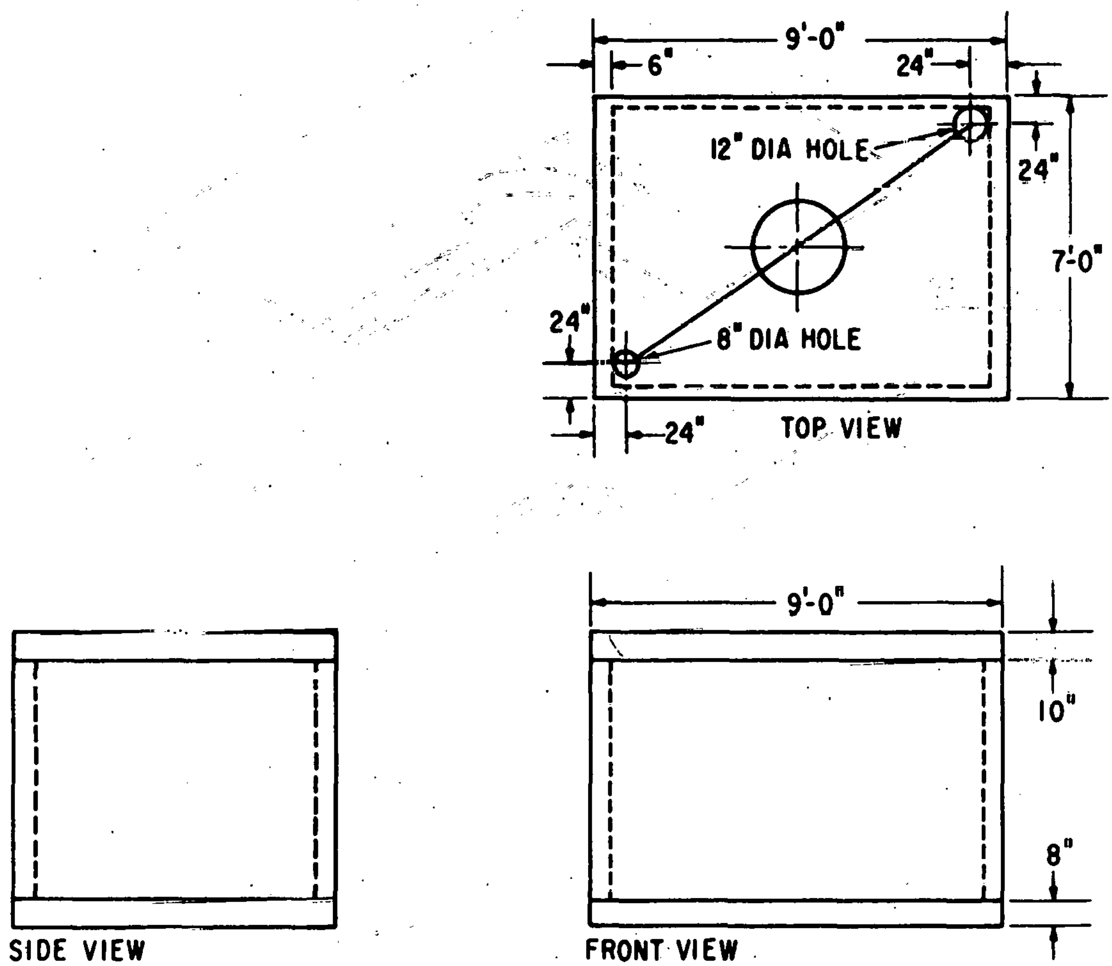


Figure H-10. Modified Utility Vault

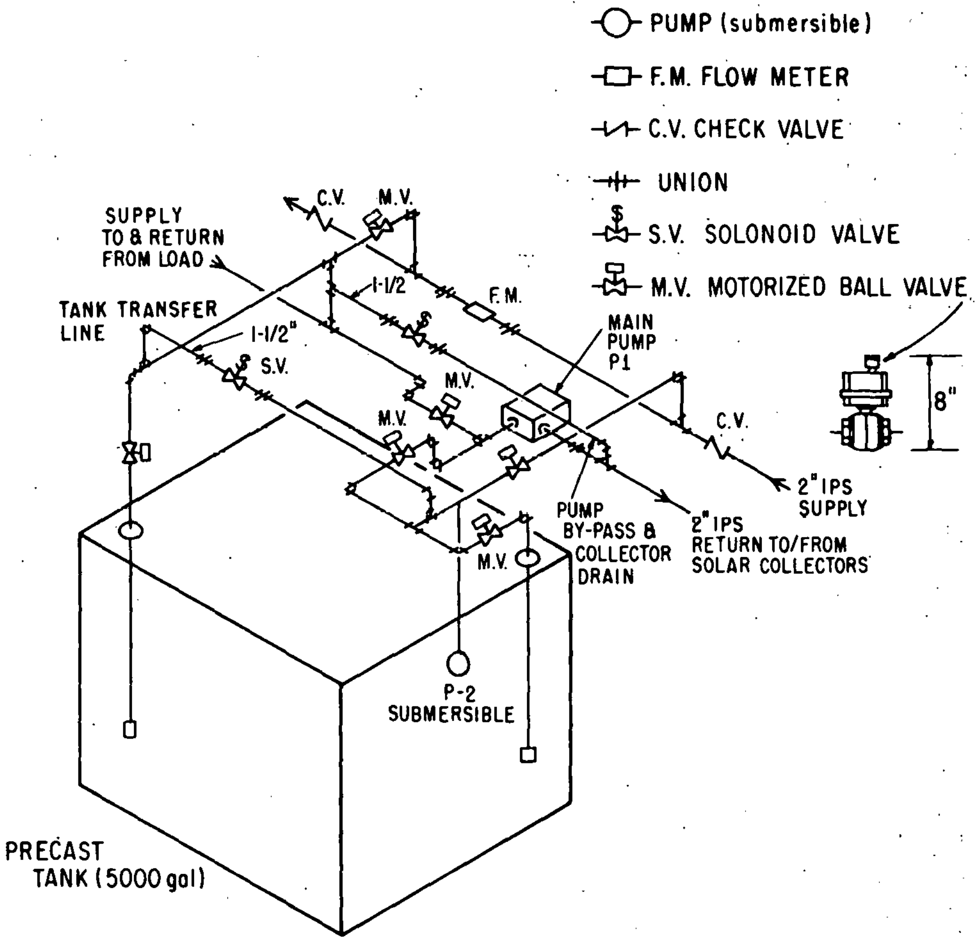


Figure H-11. Piping Schematic

Section C. SAMPLE SPECIFICATIONS FOR USING SEPTIC TANKS FOR THERMAL ENERGY STORAGE

Sample specifications for using septic tanks for thermal energy storage are similar to those in Section B, "Sample Specifications for Using Utility Vaults for Thermal Energy Storage." The following specifications, taken from the Uniform Plumbing Code, can be used to specify the tank construction.

5.1 Tank Construction

5.1.1 Plans shall show all dimensions, reinforcing, structural pertinent data as may be required.

5.1.2 Septic tanks shall be constructed of sound durable materials, concrete not subject to excessive corrosion or decay and shall be watertight. Each such tank shall be structurally designed to withstand all anticipated earth or other loads.

5.1.3 The walls and floor of each poured-in-place concrete septic tank shall be monolithic; the maximum length of any section of unreinforced concrete septic tank wall shall be 6 feet, and no cross-section of any such unreinforced concrete wall or floor shall be less than 5 inches in thickness. The minimum compressive strength of any concrete septic tank wall, top and covers, or floor shall be 2500 pounds per square inch.

5.1.4 Concrete septic tank covers shall be reinforced and shall have a minimum compressive strength of 2500 pounds per square inch.

5.1.5 All septic tank covers shall be capable of supporting an earth load of not less than 300 pounds per square foot when the maximum coverage does not exceed 3 feet.

5.1.6 Access to each septic tank shall be provided by at least two manholes 20 inches in minimum dimension or by an equivalent removable cover slab.

5.1.7 All concrete septic tanks shall be protected from corrosion by being coated inside with an approved bituminous coating or by other acceptable means. The coating shall extend to at least 4 inches below the water line and shall cover all of the internal area above that point.

5.1.8 To facilitate placement of a precast septic tank that is to be placed outside, dig the hole before the tank is delivered. The hole should be 1 foot larger than the outside measurements or diameter of the tank. The bottom of the hole must be level. In installing a two-section tank, the bottom section containing the floor is set in place with the aid of a derrick. An asphalt material as in paragraph 5.1.7 should be spread on top edge to seal it to the top section which is then placed.

Part 3. WATERPROOFING CONCRETE TANKS

Section A. SAMPLE SPECIFICATIONS FOR PLASTIC LINERS FOR CONCRETE TANKS

1.0 WORK INCLUDED (Provide)

Furnish all labor, materials, and equipment and install in place all liners for concrete tanks as shown on the drawings and as specified herein.

2.0 RELATED WORK

Concrete tank installation.

3.0 DETAILS

All work shall be done in strict accordance with the drawings and these specifications and subject to the terms and conditions of the contract.

4.0 APPLICABLE CODES AND STANDARDS

ASTM D-1593.

ASTM D-792-A.

ASTM D-882, Method B.

ASTM D-1992.

ASTM D-1004.

ASTM D-1790.

ASTM D-1239.

ASTM D-1203, Method A.

ASTM D-1204.

5.0 MATERIALS

5.1 General

The materials supplied under these specifications shall be first-quality products, designed and manufactured specifically for the purposes of this work, which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes.

5.2 Description of Materials

The plastic lining shall consist of widths of calendered plastic sheeting fabricated into large sections by means of special factory-sealed seams to fit the jobsite.

5.3 Polyvinyl Chloride Physical Characteristics

PVC materials shall be manufactured from domestic virgin polyvinyl chloride resin and specifically compounded for the use in tank. Reprocessed material shall not be used. It shall be produced in a standard minimum width of at least 76 inches (193 cm).

Certification test results showing that the sheeting meets the specification shall be supplied on request.

The PVC materials shall have the following physical characteristics:

Property	Test Method	30 Mil
Thickness	ASTM D-1593	± 5%
Specific Gravity	ASTM D-792-A	1.23
Tensile Strength, lbs./in. width	ASTM D-882, Method B	66
Modulus @ 100% Elongation, lbs/in.	ASTM D-882, Method B	30
Ultimate Elongation, %	ASTM D-882, Method B	325
Oven Aging (Wt. Loss, % max.)	2" x 4" sample 16 hrs. in a forced air circulating over @ 212°F	0.4
Tear Resistant:		
A. Elmendorf, grams	ASTM D-1922	6000
B. Graves Tear, lbs. min.	ASTM D-1004	8.25
Low Temperature Impact, °F	ASTM D-1790	-20
Water Extraction (% loss max. 104°F for 24 hrs.)	ASTM D-1239	.15
Volatility % loss max.	ASTM D-1203, Method A	.75
Dimensional Stability (@212°F, 15 min.) % max. change	ASTM D-1204	5
Resistant to Soil Burial:		
Tensile Strength Loss	Par. 4c. (1) per	5.0
Elongation Loss	Bureau of Reclamation procedure.	20.0

5.4 Chlorinated Polyethylene Characteristics

The CPE materials shall be manufactured from domestic chlorinated polyethylene resin and shall be specifically compounded for use in concrete tanks. Reprocessed materials shall not be used.

(Similar to PVC above)

5.5 Splicing Materials

Splicing materials shall be supplied by the fabricator of the lining material. These materials shall be used according to instruction supplied by the fabricator of the lining material. The Contractor shall be responsible for the proper splicing of all materials in the field.

6.0 FACTORY FABRICATION

Individual calender widths of CPE and PVC materials shall be factory fabricated into large panels. Lap joints with a minimum width of 1/2 inch (13mm) shall be used. Factory made splices shall have a strength of 80 percent of the specified sheet strength. If reinforced CPER is used in the combination liner, the splice used to seal the CPER to PVC shall be a dielectric seal. Panels shall be as large as can be conveniently handled on the jobsite. The panels shall be fabricated as shown on the shop drawings. After fabrication, the lining shall be folded in both directions and packaged for minimum handling in the field. Packaging shall be substantial enough to prevent damage to the contents.

7.0 SHOP DRAWINGS

Furnish shop drawings for the approval of the engineers and obtain such approval before proceeding with the work. These drawings shall show extent sizes and complete details of the CPE/PVC lining including recommendations for terminating the membrane.

8.0 PREPARATION OF SURFACES

The surface to receive the liner shall be smooth and free of sharp objects that could puncture the lining. All holes and hollow areas shall be filled in and compacted. Before beginning the application of the lining material, the surface shall be examined and found satisfactory for installation of the lining material.

9.0 INSTALLATION OF LINING MATERIALS

9.1 General

Installation shall be performed by a contractor that has previously installed a minimum of 500,000 square feet of this material or by a contractor that has a fabricator field representative in attendance. The lining material shall be placed over the prepared surfaces to be lined in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on the shop drawings. The lining shall be closely fitted and sealed around inlets, outlets, and other projections through the lining. Any portion of lining damaged during installation shall be removed or repaired with an additional piece of lining as specified hereinafter.

9.2 Field Joints

Lap joints shall be used to seal factory fabricated panels together in the field. Lap joints shall be formed by lapping the edges of panels a minimum of 2 inches. The contact surfaces of the panels shall be wiped clean to remove all dirt, dust, or other foreign materials. Sufficient cold-applied bonding adhesive as recommended by the fabricator shall be applied to the contact surfaces in the joint area and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out. Field-made splices shall have a strength of 80 percent of the specified sheet strength.

9.3 Joints to Structures

All curing compounds and coatings shall be completely removed from the joint area. Attachment of the plastic to concrete shall be made by adhesive as recommended by the manufacturer. Unless otherwise shown on the drawings, the minimum width of concrete to liner joint shall be 8 inches.

9.4 Pressure rolling the overlap seam will accelerate bond and rolling or brooming the entire surface will smooth the membrane and assure complete bond.

9.5 Corners

All inside and outside covers should be double covered by using an additional strip of the membrane centered on the axis of the corners.

9.6 Joints

Control joints should be treated same as corners. Expansion joints are triple covered by placing a strip of membrane over the joint with the protective film intact and facing the surface. The membrane is then applied in the normal manner.

9.7 Repairs to PVC

Any necessary repairs to the PVC or CPE shall be patched with the lining material itself and cold applied bonding adhesive. The bonding adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

9.8 Quality of Workmanship

All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of PVC or CPE of the proper size.

9.9 Guarantee

The Contractor shall guarantee the installation to be waterproof and free of defective materials and faulty workmanship for a period of 5 years and shall replace at his expense all other materials disturbed as originally placed, all in a first-class and workmanlike manner at no additional cost to the Owner.

10.0 LEAK TEST

Before continuing with the work and placing of concrete or masonry wearing surface, the membrane installation shall be given a 24-hour test. Drains, if any, shall be plugged to contain the water. Leaks, if any, shall be repaired and surface retested. Cost of such tests shall be included in the contract price. Unusual loss of water will indicate failure of waterproofing application.

11.0 PROTECTION

11.1 As soon as membrane surfaces are dry after the leak test, membrane surfaces shall be covered with the specified protection board.

11.2 In case of delays that result in the accumulation of dirt, dust, construction debris, or other foreign matter, the following procedure shall be performed:

- All loose debris shall be removed, and an additional coating of the liquid membrane formulation of a 50 mil thickness shall be applied.

- Completed work of this section shall be protected from damage by subsequent building operation. Any damage to membrane or protection board shall be repaired immediately to the Owner's satisfaction.

Section B. SAMPLE SPECIFICATIONS FOR RUBBER LINERS FOR CONCRETE TANKS

The sample specifications for rubber liners are similar to the sample specifications for plastic liners given in Section A. Since butyl rubber is usually a 30-to-50-mil coating of spray-on liquid instead of a sheet material, modification of Sections 5.0, "Materials," and 9.0, "Installation of Lining Materials," is required. Section 6.0, "Factory Fabrication," is not applicable to butyl rubber liners and should be deleted.

5.0 MATERIALS

The lining materials shall be a solvent-based spray-on coating of liquid butyl rubber. Before starting work, the Contractor shall provide the Owner with a letter stating that the lining material will not deteriorate under the water temperatures anticipated in the tank. Temperature information can be obtained from the Mechanical Engineering Consultant.

9.0 INSTALLATION OF LINING MATERIALS

9.1 General

The installation shall be performed by a Contractor who has previously installed a minimum of 500,000 square feet of this material or by a Contractor who has a manufacturer's field representative in attendance. The lining materials shall be sprayed onto the concrete under very strict safety conditions with an airless spraygun so that its thickness when dry is 50 mils. It shall be sealed to all concrete structures and other openings in accordance with the details shown on the shop drawings. Any portion of the lining that is damaged during installation shall be repaired as specified hereinafter.

9.2 Repairs

Any necessary repairs shall be made by cleaning and respraying the damaged area. The resprayed area shall extend a minimum of 8 inches beyond the damaged area.

9.3 Quality of Workmanship

All lining material, on completion of the work, shall be tightly bonded to the concrete. There shall be no evidence of peeling or looseness at tank penetrations. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Engineer, be replaced or resprayed with an additional layer of lining materials.

9.4 Guarantee

The Contractor shall guarantee the installation to be waterproof and free of defective materials and faulty workmanship for a period of 5 years and shall replace at his expense all other material disturbed as originally placed, all in first-class and workmanlike manner at no additional cost to the Owner.

Part 4. SAMPLE SPECIFICATIONS FOR INSULATION OF CONCRETE TANKS

1.0 WORK INCLUDED (Provide)

All materials, labor, tools, and supplies necessary to insulate concrete tanks as described herein and on the drawings.

2.0 RELATED WORK

Construction of concrete tanks.

3.0 DETAILS

3.1 All details shall be in accordance with local fire and building codes and NFPA standards.

3.2 The Contractor shall be responsible for all dimensions of the concrete work and shall check structural drawings in relation to all other drawings and shall verify all dimensions in relation with other work and existing field conditions. The Contractor shall be responsible for proper arrangement and fit of the work; and, if discrepancies are noted between the various drawings and work, the Contractor shall notify the Owner immediately in writing and shall not proceed until so directed.

3.3 The omission of any material shown on the drawings or called for by these specifications shall not relieve the Contractor of the responsibility for furnishing and installing such materials, even though such drawings may have been approved.

4.0 APPLICABLE CODES

4.1 National Fire Codes: Volume 4, Building Construction and Facilities.

4.2 Federal Specification HH-I-524b, Type II, Class B.

4.3 ASTM C 36.

Include applicable state and local building and fire codes.

5.0 MATERIALS

5.1 Rigid Insulation Boards

Rigid polystyrene foam insulation boards (STYROFOAM* SM brand insulation or equal) shall be used. Insulation shall have a minimum compressive strength of 25 psi, maximum conductivity (k) of 0.185 Btu per hour per square foot per inch of thickness at 40°F, and shall conform to Federal Specification HH-I-524b, Type II, Class B. Insulation shall be_____ inches thick.
See Chpater 1 to determine insulation thickness.

* Trademark of The Dow Chemical Company

5.2 Gypsum Wallboard

Gypsum wallboard a minimum of 1/2 inch thick conforming to ASTM C 36 shall be applied over insulation on top and sides of tank.

Since the polystyrene foam is flammable, the gypsum wallboard is necessary for fire protection if the tank is inatalled in the interior of a building. If the tank is installed in an exterior location above ground, wood or aluminum siding can be substituted for the gypsum board. If the tank is installed underground, no siding material is required.

5.3 Wood Nailers

Use wood nailer strips of exterior grade hardwood 2 inches wide (nominal) by the thickness of the rigid insulation.

Nailers are required to support wallboard or siding.

5.4 Fasteners

5.4.1 Wood nailers to concrete wall

Use masonry nails, lead plugs with screws or bolts, power-driven mechanical fasteners, or pneumatic nailers. Penetration of the fasteners into the concrete wall shall be 1/2 to 3/4 inch.

5.4.2 Gypsum Wallboard to Wood Nailers

Use annularly threaded drywall nails or self-tapping drywall screws having 5/8 to 3/4 inch wood nailer penetration.

5.5 Adhesive

Use STYROFOAM #11 brand mastic or equal for bonding polystyrene insulation to concrete. CAUTION: Adhesive solvents are highly flammable. Follow manufacturer's instructions carefully.

5.6 Roofing

Roofing is required only for tanks in exterior locations. For interior locations cover the top with gypsum wallboard.

Use complete elastomeric roofing system, 1/16 inch thick. Include flashing and sealing at all penetrations as specified by the roofing manufacturer. The Contractor shall submit a written report to the Owner stating that all roofing work was done in accordance with the manufacturer's requirements.

6.0 INSTALLATION

6.1 Installation of Wood Nailers

Install wood nailers on 16-inch centers on sides and top and along floor, ceiling, and corner junctures of the concrete tank. Use the specified fasteners and the specified adhesive in beads or spots to fasten the nailers to the concrete.

6.2 Installation of Insulation

6.2.1 Remove old paint, dirt, and loose material from the tank walls and top.

6.2.2 Use adhesive applied in spots or strips to secure insulation to the concrete. Uniformly press the insulation against the tank to insure a good bond. Two or more layers of insulation can be laminated together with adhesive to provide the required thickness.

6.3 Installation of Gypsum Wallboard

6.3.1 Check the fit of the wallboard panel. Trim wallboard if necessary to fit corners, etc.

6.3.2 Apply adhesive to the wallboard in spots or beads. Wallboard must be installed within 10 minutes after application of the adhesive.

6.3.3 Install the wallboard over the insulation. Use firm hand pressure over the entire surface of the wallboard to press the wallboard against the insulation, level the board, and close up the butt joints.

6.3.4 Shim the wallboard 1/4 inch off the floor to provide a relief gap and nail the wallboard to the wood nailers.

6.3.5 Tape and spackle the wallboard.

APPENDIX I. SAMPLE SPECIFICATIONS FOR FIBERGLASS-REINFORCED PLASTIC (FRP) TANKS

In this appendix, comments and other material that is not part of the sample specifications are written in italics.

1.0 WORK INCLUDED (Provide)

1.1 All materials, parts, and work related to fiberglass-reinforced plastic (FRP) tanks as indicated on drawings or specified.

1.2 FRP tanks that will have a capacity range between 500 gallons and 5000 gallons.

1.3 FRP tanks suitable for underground burial or location inside a building.

1.4 FRP tanks that will have a minimum service life of 20 years.

If the tank is located so that it will be difficult to repair or replace, 30 years may be more appropriate.

1.5 FRP tanks that will be able to withstand thermal cycling temperatures between 90°F and 180°F.

Adjust these temperature limits to suit your particular installation.

1.6 FRP tank accessories such as manways, ladders, piping, lifting lugs, fittings, etc.

1.7 Installation of items required by other trades in the installation of the tank.

2.0 RELATED WORK

2.1 Cast-in-place concrete.

2.2 Anchor bolts.

2.3 Piping.

2.4 Liquid-level gauges, pressure gauges, temperature sensors, and thermometers.

2.5 Excavation and compacted fill.

3.0 DETAILS

3.1 All details shall be in accordance with the standards of the National Board of Fire Underwriters, Underwriters Laboratories, Inc., ASTM.

Include other standards-writing organizations and state and local governments as necessary.

3.2 Contractor shall be responsible for all dimensions of the work and shall check structural drawings in relation to all other drawings and shall verify all dimensions in relation with other work and existing field conditions. Contractor shall be responsible for proper arrangement and fit of the work; and, if discrepancies are noted between the various drawings and work, the Contractor shall notify the Owner immediately in writing and shall not proceed until so directed.

3.3 The omission of any material shown on the drawings or called for by these specifications shall not relieve the Contractor of the responsibility for furnishing and installing such materials, even though such drawings may have been approved.

4.0 APPLICABLE CODES AND STANDARDS

4.1 HUD Intermediate Minimum Property Standards, Solar Heating and Domestic Hot Water Systems, 1977 edition.

4.2 Proposed ASTM Standard Draft No. 10, dated September 15, 1977.

4.3 Underwriters Laboratories, Inc. (U.L.), File MH7991, dated October 13, 1965, for storage of flammable liquids as updated under U.L. follow-up service in letter of January 15, 1976.

4.4 National Fire Protection Assoc. (NFPA 30) Flammable and Combustible Liquids Code and (NFPA 31) Standard for Installation of Oil Burning Equipment.

Include other standards and state and local building codes as required.

5.0 CONSTRUCTION, FIBERGLASS-REINFORCED POLYESTER TANKS

5.1 The tank shall be equal to fiberglass-reinforced polyester underground storage tanks suitable for use with potable water and shall bear the NSF label. Tank shall be constructed and reinforced with bisphenol resins to withstand temperatures of 180°F.

Consult manufacturers for information on temperature limits and resin types. Most manufacturers offer several resin types with different temperature limits. Specify a temperature limit that cannot be exceeded by your system.

6.0 WATER STORAGE REQUIREMENTS

6.1 All tanks must be vented, as tanks are designed for operation at atmospheric pressure only.

6.2 Tanks shall be capable of storing liquids with specific gravity up to 1.1.

6.3 Tanks shall be capable of storing liquids up to maintained temperature of 180°F at the tank's interior surface.

Use a temperature limit appropriate to your system.

7.0 ACCESSORIES

7.1 Fiberglass Flanged Manway

The manway shall have a 22-inch inside diameter and shall be furnished complete with U.L. approved gasket, bolt, and cover, and at locations indicated on the drawings.

7.2 Suction Line

The suction line shall be installed on site by the Contractor. Pipes shall be terminated a minimum of 4 inches from the bottom of the tank.

7.3 Lifting Lugs

Provide lifting lugs on each tank at location indicated on the drawings. Lugs shall be capable of withstanding weight of tank with a safety factor of 3:1.

7.4 Ladders

Ladders shall be standard carbon steel supplied by the tank manufacturer. Refer to drawings for locations.

7.5 Fittings-Threaded NPT

7.5.1 All threaded fittings on U.L.-labeled tanks shall be of a construction material consistent with the requirements of the U.L. label. All fittings shall be supplied with cast iron plugs.

7.5.2 All standard threaded fittings are 4 inches in diameter and shall be half couplings. Reducers are to be used for smaller sizes where specified and provided by Contractor.

7.5.3 All threaded fittings shall have machine tolerances in accordance with the ANSI standard for each fitting size.

7.5.4 Fittings shall be able to withstand a minimum of 300 foot-pounds of torque and 2000 foot-pounds of bending.

Consult the tank manufacturer for availability of accessories. Add accessories to or delete accessories from the specifications as required by your installation.

8.0 LOADING CONDITIONS

8.1 External Hydrostatic Pressure

Tank shall be capable of being buried in ground with 3 feet of overburden over the top and with the hole fully flooded with a safety factor of 3:1 against general buckling.

Specification 8.1 is applicable only to underground tanks.

8.2 Internal Load

Tank shall be able to withstand 5 psi air pressure test with 5:1 factor. Test for leakage prior to installation.

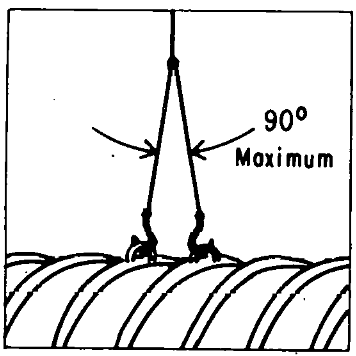
9.0 INSTALLATION

Items 9.4-9.11 apply to unpressurized underground tanks only. For above-ground installations and for tank temperatures exceeding 150°F, consult the tank manufacturer for installation instructions. The specifications for installing FRP tanks are based on information supplied by Owens-Corning Fiberglas Corporation, Toledo, Ohio.

Tanks shall be tested and installed with pea gravel or approved alternate backfill material according to the manufacturer's installation instructions.

9.1 Handling

9.1.1 Lifting Tanks



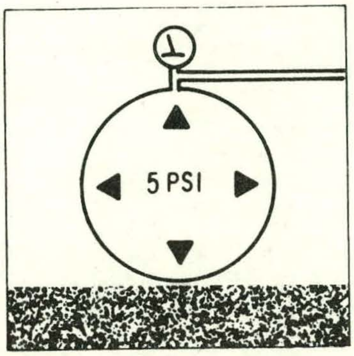
Use installation lift lug(s) to lift tank. Larger tanks have multiple lift lugs; all must be used. Do not use chains or cables around tanks. If tanks have to be moved (do not roll), set on smooth ground, free of rocks and foreign objects, and rechock. Capacity of lifting equipment must be checked before moving tank.

9.1.2 Chocking Tanks

Tanks should not be dropped, rolled, or impacted. Chock the tanks until ready for installation and tie them down if high winds are expected. Use minimum 1/2-inch diameter nylon or hemp rope over each tank and tie to wooden stakes of adequate size to prevent tanks from being moved by high winds.

9.2 Testing

Before installing tanks, tighten and soap fittings and pressure test tank at 5 psi for minimum of one hour. Isolate tank from piping when pressure testing piping. Do not approach ends of tanks or manways that are under test. Tanks under pressure should not be left unattended.



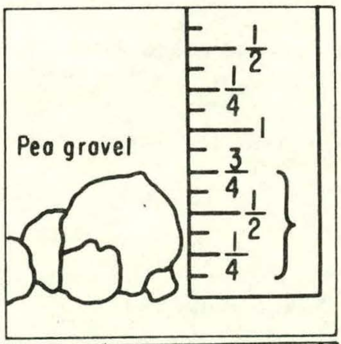
If tanks are dropped or impacted after initial test, retest tanks and soap areas of impact to check for tank damage. If damage has occurred, do not attempt repairs.

After completing the testing all tanks must be vented, as tanks are designed for operation at atmospheric pressure only.

9.3 Insulation

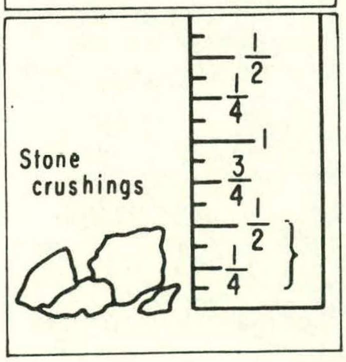
Because underground FRP tanks derive support from their surroundings and many types of insulation deteriorate in the presence of soil or water, you should consult with the tank manufacturer before writing this section on insulation. Refer to Chapter 1 of this manual for minimum R-values of insulation.

9.4 Bed and Backfill Material



9.4.1 Gravel

Use a naturally rounded clean aggregate with particle size not less than 1/8 inch or more than 3/4 inch in diameter. Use this description when specifying or ordering, because material is known by different names in different areas. This material is commonly called pea gravel.

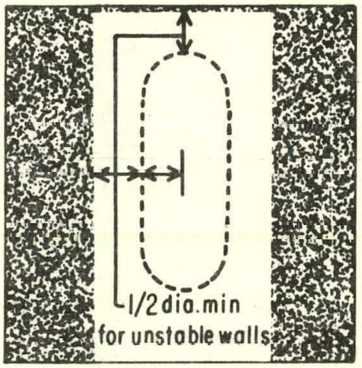


9.4.2 Washed stone or gravel crushings with angular particle size between 1/8 inch and 1/2 inch in diameter are acceptable alternate bed and backfill materials. This material must meet ASTMC-33 paragraph 9.1 requirements for quality and soundness.

Caution: In freezing conditions backfill must be dry and free of ice. Do not use other backfill materials.

The tank warranty will be automatically voided if other than approved (above) bed and backfill materials are employed without approval.

9.5 Hole Size

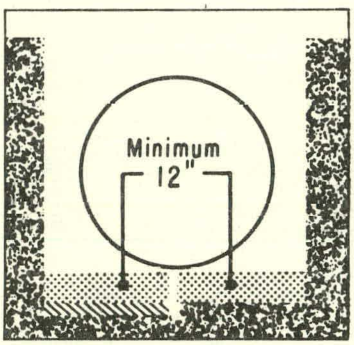


Hole must be large enough to allow a distance equal to a minimum of 1/2 the tank diameter from the ends and sides of tanks to hole walls. A qualified soil-testing laboratory can provide data and recommendations for soils having less than 750 lbs./sq. ft. cohesion as calculated from an unconfined compression test or for soils with an ultimate bearing capacity of less than 3500 lbs./sq. ft.

Observe OSHA regulations regarding supporting the walls of the hole and slanting the sides if the hole is deeper than 5 feet.

9.6 Burial Depth and Cover

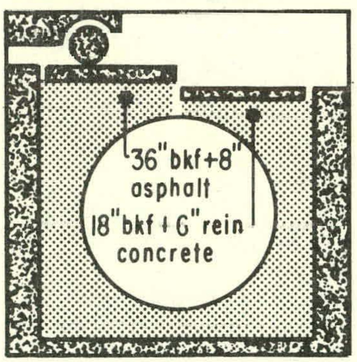
9.6.1 Hole Depth



Burial holes must be deep enough to allow a minimum of 12 inches required backfill bed over the hole bottom or concrete slab.

Cover depth is determined by type of pavement on surface.

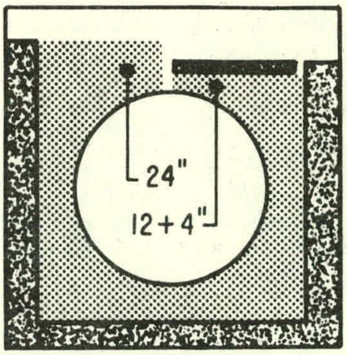
9.6.2 Traffic Loads



Tanks subjected to traffic loads must have a cover depth of 36 inches backfill plus 8 inches of asphalt or a minimum of 18 inches backfill plus 6 inches of concrete reinforced with steel re-bars.

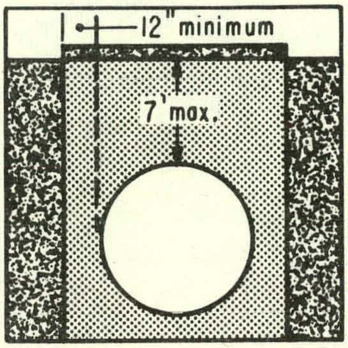
9.6.3 Hillside Installation

Tanks may be buried on moderate slopes providing the downhill side consists of undisturbed native soil and is at least as high as the top of the tank in the installed condition. The maximum slope permitted is 10°. Fill dirt on the downhill side of the tank hole is not permitted.



9.6.4 No Traffic Loads

Tanks not subjected to traffic loads need a minimum cover of 24 inches backfill or 12 inches backfill plus 4 inches reinforced concrete to meet NFP 30 requirements.



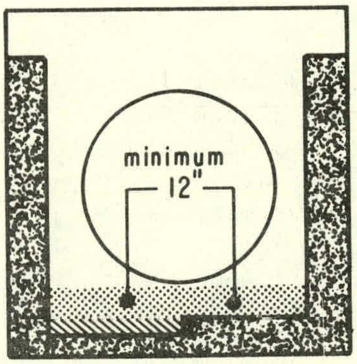
9.6.5 Pad Dimensions

Reinforced concrete paving must extend at least 12 inches beyond tank outline in all directions.

9.6.6 Maximum Burial Depth

Depth of cover for tanks 10 feet or less in diameter in both traffic and no-traffic conditions must not exceed 7 feet over tank top.

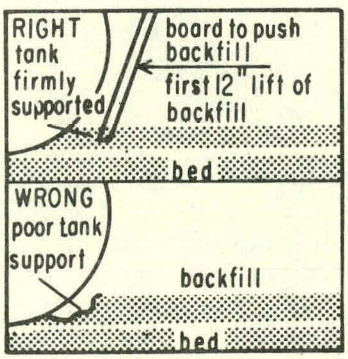
9.7 Installation Procedure--Dry Hole



9.7.1 Bed

Provide a 12-inch minimum level backbed over hole bottom or concrete slab. Bed must be smooth and level. Place tanks in hole on backfill bed.

Caution: Do not place fiberglass tanks directly on concrete slab or grout tanks in wet concrete. Do not place tanks on timbers, beams, or cradles.

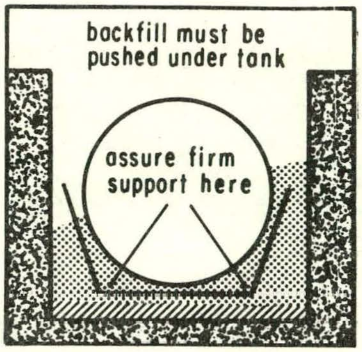


9.7.2 High Water

Tanks, whether strapped or not, must never be left on the bed without backfill to the top of tank if there is any chance of more than 12 inches of water in the hole.

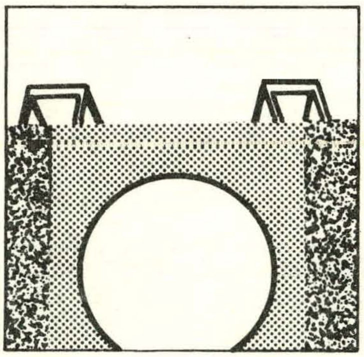
9.7.3 Backfilling

Use the same materials as for bedding. At start of backfilling, care must be taken to push approved backfill material completely beneath tank bottom, between ribs, and under end caps to provide necessary support. A board or similar device should be used to push backfill under the tank.



Unanchored tanks installed with backfill to the top of the tank but without backfill to grade should be filled with water or product as ballast. Do not add water or product in tank before backfill material is even with top of tank.

Complete backfilling to top of tank with approved backfill. Be sure backfill is free of large rocks, debris, or foreign materials that could damage the tank. Avoid impacting tanks during the backfilling.



9.7.4 Leveling to Grade

Excavation should be brought to grade with stone or gravel crushings meeting the specifications shown in Section 9.4 if blacktop is used. Otherwise either approved backfill may be used to grade.

9.7.5 Barricade

Tank area must be barricaded to prevent any vehicle travel over the tanks until installation is complete.

9.8 Installation Procedure--Wet Hole

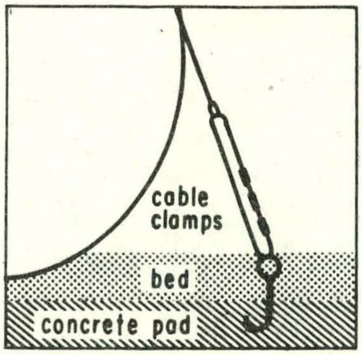
Do not install the tank in a wet hole until the cause of the wetness has been determined. If the cause of the wetness is a high water table, the storage system must be redesigned to prevent excessive heat loss due to wet insulation.

If the wetness in the hole is not caused by a high water table, consult the tank manufacturer for instructions on installing the tank.

9.9 Anchoring

9.9.1 Hold-Down Straps

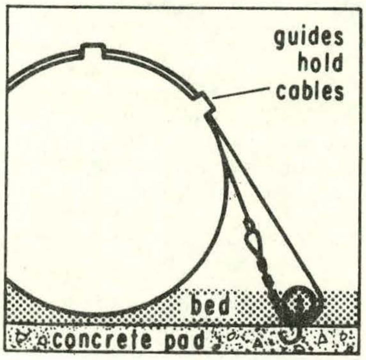
Use fiberglass hold-down straps on top of all designated ribs. Anchor points should be equal to tank diameter plus 1 foot on each side of tank, regardless of diameter of tank. Anchor points at bottom of hole must be aligned with designated rib ± 1 inch. Do not use straps or cables between ribs of tanks. All straps should be mechanically tightened to give snug fit of strap to tank.



9.9.2 Concrete Pad

Anchor the bolts in concrete and attach them to ends of straps with wire cable (see table in Section 9.9.4) and triple clamp with at least three clamps. (Be sure there is a 12-inch bed between concrete pad and tanks).

9.9.3 Alternate Cable System



Triple clamp cable to strap. Thread cable around anchor and bring to top of tank. Repeat procedure with anchor on other side and triple clamp cables together at top of tank.

9.9.4 All Anchoring Methods

Minimums per anchor location

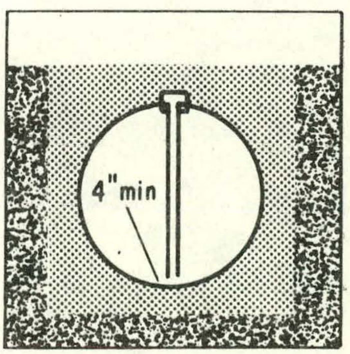
Tank Diameter	6' or less	8'	10'
Wire Rope	(6 x 19 plow steel)		
Diameter	3/8"	1/2"	1/2"
Tensile St.	9,000	12,500	16,000 lbs.
Turnbuckle Diameter			
Hook Type	3/4"	1-1/8"	1-1/8"
Eye Type	1/2"	3/4"	3/4"

9.9.5 Turnbuckles (not illustrated)

Hook or eye type turnbuckles may be used in place of all or a portion of the cable described in this section.

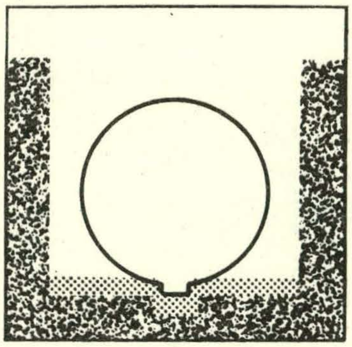
9.10 Piping and Sump

9.10.1 Suction Pipe



The length of storage-to-load suction pipe shall be selected to provide a minimum of 4 inches clearance between the bottom of the pipe and the bottom of the tank.

The pump and attached piping must be free to move with the tank. Use fill box around fill pipe at grade where asphalt or concrete pad is used. Do not place brick or other spacing material on top of tanks.



9.10.2 Tanks with Sumps

When installing a tank equipped with a sump, modify excavation and bedding to provide a 12-inch deep by 24-inch diameter hole centered at the sump location. After the tank is placed, the void surrounding the sump is to be hand backfilled and hand tamped before backfilling is added around the tank.

9.11 Filling Tanks

Do not fill tanks until backfill is to top of tank. Never add product or water for hold down in dry hole conditions until backfilling is completed.

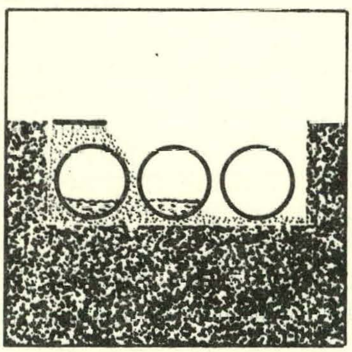
9.12 Adding Tanks to Existing Installations

Tanks can be added to existing installations. It is important to remember that fiberglass tanks require good foundation support from surrounding soil.

9.12.1 Isolated Burial (Preferred)

Install tanks in a separate hole that is a minimum of 3 feet from edge of original tank installation hole. Undisturbed soil between new excavation and original hole must be maintained. Keep surface loads off existing tanks.

9.12.2 Burial in Same Hole (Alternate)



Lower water level in existing tanks to less than 1/4 tank capacity.

Remove surface pad, if one exists, to lower backfill.

Excavate for new tanks, leaving as much backfill as possible around existing tanks.

During installation, existing tanks must not be allowed to move. Shoring may be required to retain backfill.

Install new tanks as described earlier in these instructions, leaving a minimum of 24 inches between new tanks and existing tanks.

10.0 CAPACITY AND DIMENSIONAL REQUIREMENTS

Fill in the blanks to complete this section. This example applies to horizontal cylindrical tanks. If your installation requires another tank shape or if you have special dimensional requirements (such as special locations for pipe fittings), state your requirements in this section.

1. Nominal capacity of the tank shall be _______ gallons.

2. Nominal outside diameter of the tank shall be ________ feet.

3. Approximate overall length of the tank shall be ________ feet.

11.0 DRAWINGS

Include drawings that are applicable to your particular installation in this section. Sample drawings for a typical on-site-insulated tank, typical manway and NPT fitting details, and a typical factory-insulated tank are shown in Figures I-1, I-2, and I-3, respectively.

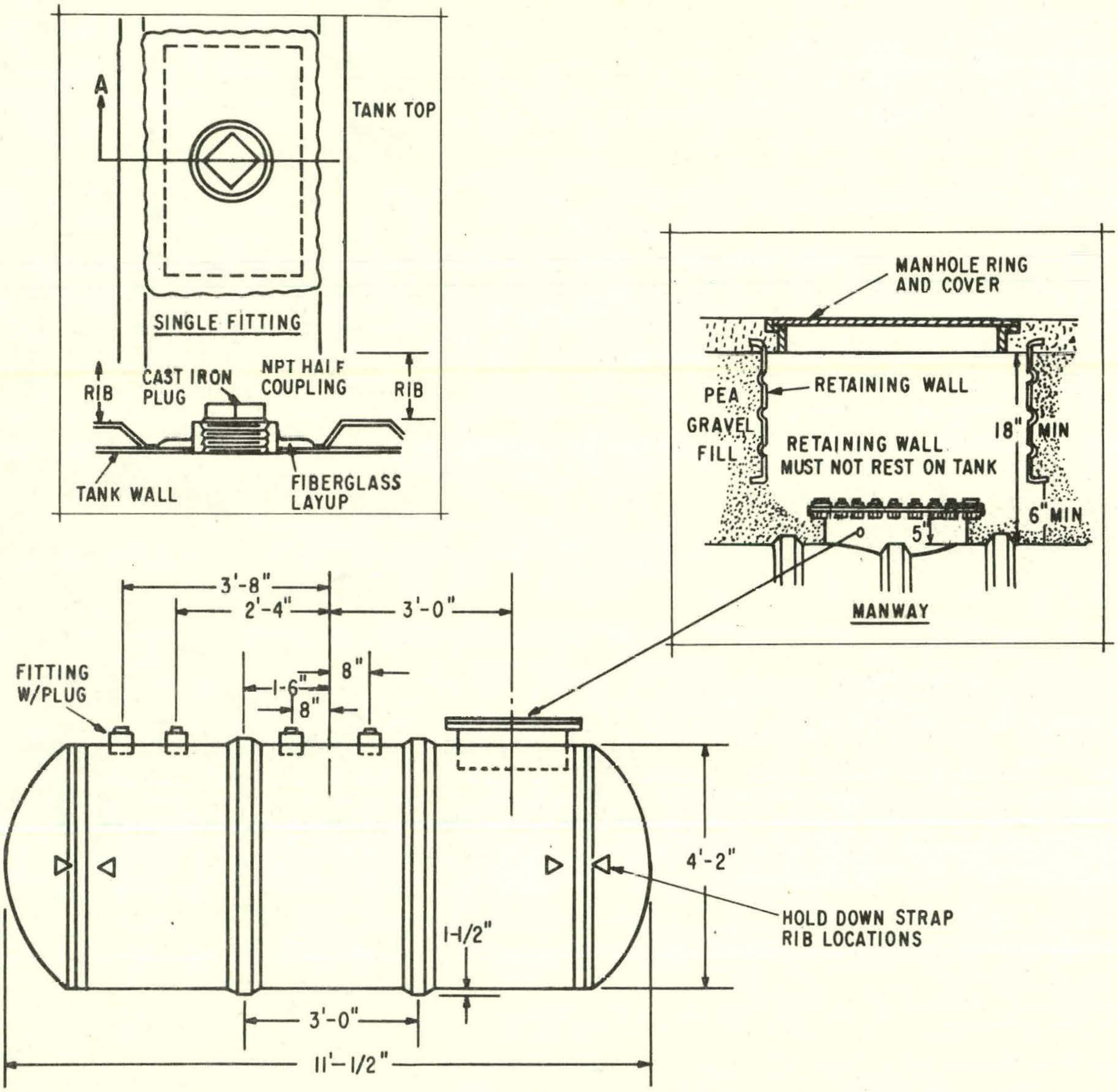


Figure I-1. Sample Drawing of FRP Tank before Installation of Insulation (Courtesy of Owens-Corning Fiberglas Corporation, Toledo, Ohio)

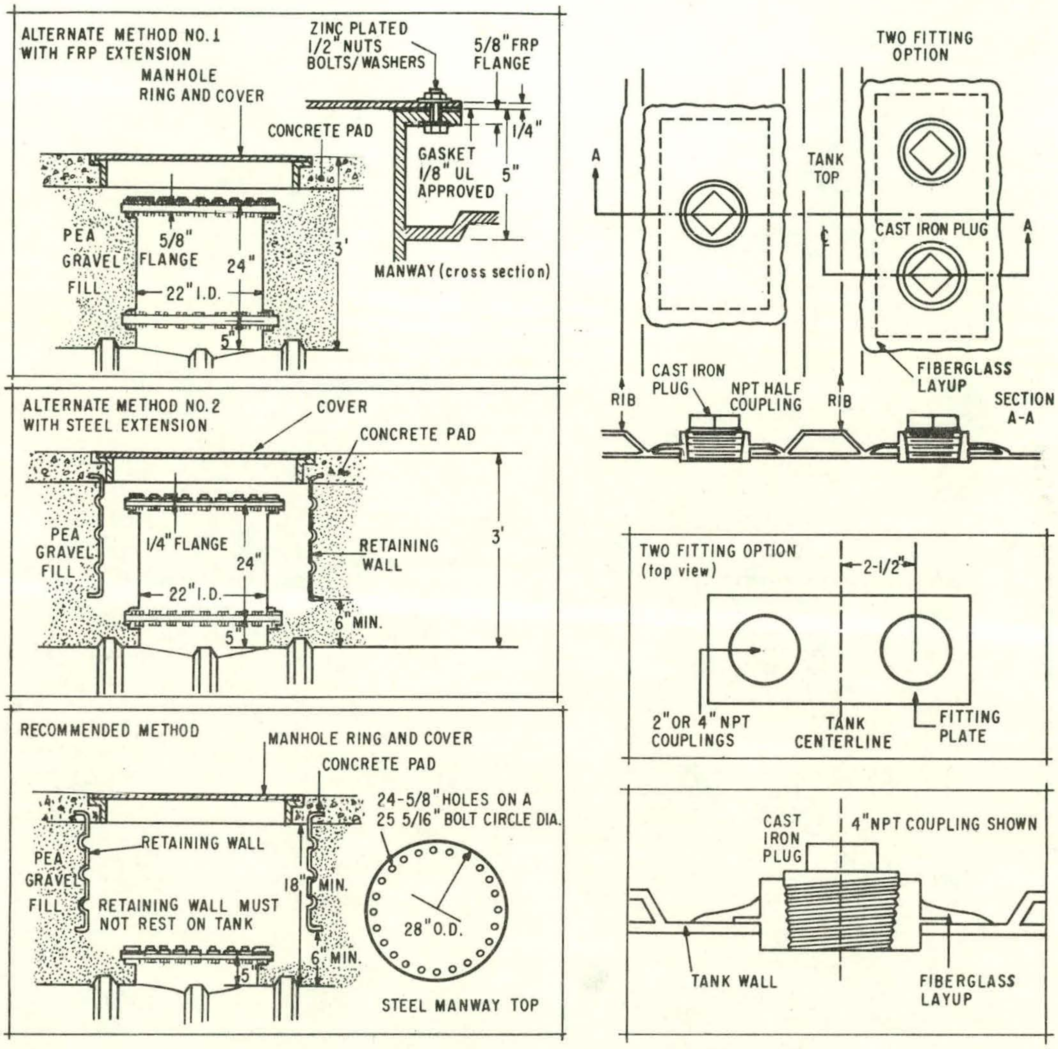


Figure I-2. Typical Manway and NPT Fitting Details for FRP Tanks (Courtesy of Owens-Corning Fiberglas Corporation, Toledo, Ohio)

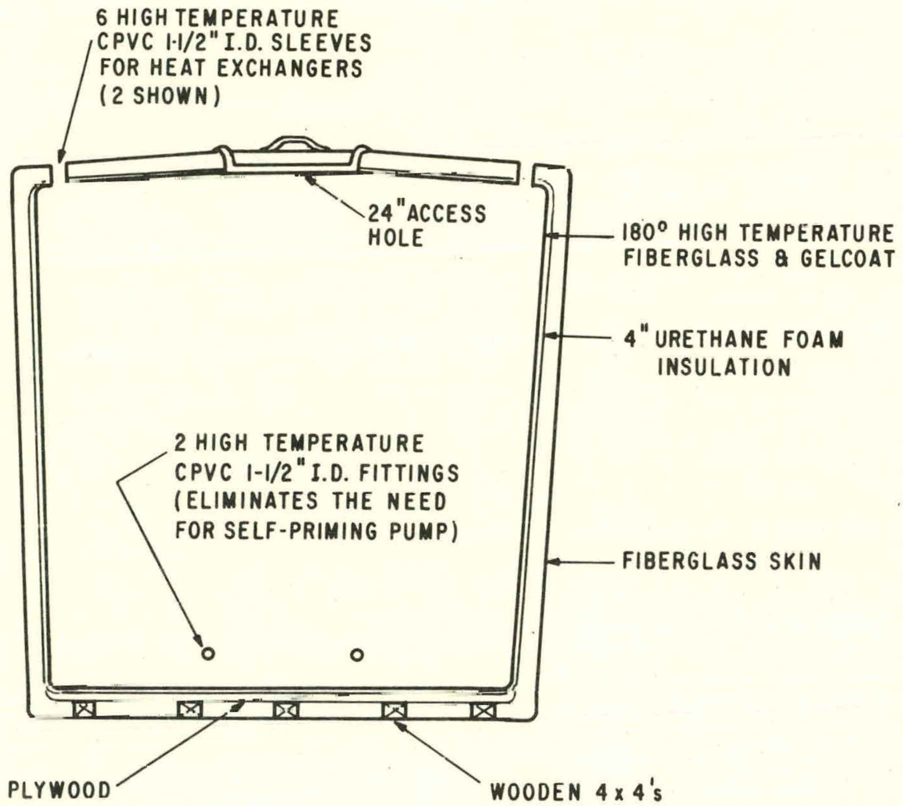


Figure I-3. Sample Drawing of a Factory-insulated FRP Tank (Courtesy of Solar Systems, Novato, California)

GLOSSARY

absolute pressure	Also called absolute head. Pressure measured relative to vacuum. Absolute pressure is the gauge pressure plus the atmospheric pressure.
active system	A solar system that uses pumps or fans to circulate a heat transfer fluid through solar collectors and to distribute heat to the building; the opposite of a passive system.
air-type collector	A solar collector that uses circulating air as a heat transfer fluid.
ambient temperature	The temperature of the surroundings as measured by a dry-bulb thermometer.
antifreeze loop	A circuit, consisting of the solar collectors, a pump, and a heat exchanger, through which an antifreeze solution is pumped.
aqueous solution	A mixture of a substance (such as ethylene glycol) with water.
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, 345 East 47th Street, New York, New York 10017.
ASME	American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.
auxiliary system	A system that provides heat when solar energy alone is insufficient, a backup system.
Btu	British thermal units. The amount of heat required to raise 1 pound of water 1 degree Fahrenheit; the basic unit of heat in the English system of units.
cathodic protection	A method of corrosion protection in which a highly reactive metal bar is placed in the system liquid. To be effective the metal bar must be more reactive than the most reactive metal component in the system and must have a continuous electrical path to the most reactive metal component.

centrifugal pump	A type of pump in which a fluid is flung outward by the rotation of an impeller. See positive displacement pump.
coil-in-tank heat exchanger	A coil of tubing submerged inside a tank. One heat transfer fluid is pumped through the tubing while the other flows over the outside of the tubing by natural convection.
collector	A device constructed to absorb solar energy and convert it to useful heat.
collector coolant	A heat transfer fluid used in solar collectors.
convection, forced	A means of transferring heat in which the heat transfer fluid is moved by external means such as a pump or fan.
convection, natural	A means of transferring heat in which the heat transfer fluid is moved by the buoyancy of its warmer parts.
convector	A heat exchanger that uses natural convection of air to transfer heat from water or steam to a building.
cooling season	The time of year (usually June to September, but varying with climate) when air conditioning is desirable to maintain comfortable room temperatures.
daily temperature range	The difference between the warmest storage temperature attained in a day and the coolest storage temperature reached on the same day.
DHW	Potable domestic hot water.
dielectric bushing	An electrically insulating pipe connector used to connect dissimilar metals in plumbing.
differential thermostat	A device that uses a measured temperature difference (such as the temperature difference between the collectors and storage) to control a device (such as a pump or fan).

drainback system	A method of protecting the solar collectors against freezing by draining the collector water into the storage tank on cold nights.
draindown system	A method of protecting the solar collectors against freezing by draining the collector water into the sewer on cold nights.
effectiveness	The ratio of actual heat transferred in a heat exchanger to the maximum possible heat that could be transferred in a perfect heat exchanger.
electrolytic solution	A liquid that conducts electricity via ions and electrons. When dissimilar metals are in contact with an electrolytic solution, galvanic corrosion can occur. See dielectric bushing.
expansion tank	A device used to limit the pressure increase caused by thermal expansion of the liquid in a sealed system. The expanding liquid compresses air in the expansion tank.
f - Chart	A method devised at the University of Wisconsin for calculating the performance of solar energy systems.
flow rate	The volume or mass of fluid that flows past a point in a pipe or duct per unit of time. In the English system the units of volumetric flow rate are typically gallons per minute or cubic feet per minute, and the units of mass flow rate are typically pounds per minute.
fluid	A substance that cannot retain its shape without an external container; a gas or a liquid.
forced convection	See convection, forced.
fouling factor	A factor ($°F \cdot ft^2 \cdot hr/Btu$) that expresses the degradation of heat exchanger performance caused by scaling or biological fouling. The fouling factor is the inverse of the scaling coefficient.
FRP	Fiberglass-reinforced plastic.

gauge pressure	Pressure measured relative to atmospheric pressure.
head	The maximum distance a liquid can rise in a pipe. Head is used as a measure of pressure.
heat capacity	The amount of heat (Btu) required to raise the temperature of 1 pound of a substance 1 degree Fahrenheit. Heat capacity is measured in units of Btu per pound per degree Fahrenheit. Compare the definition of heat capacity with the definition of specific heat.
heat distribution	As used here, heat distribution refers to transport of heat from storage to the parts of a building where heat is required.
heat exchanger	A device for transferring heat from one fluid to another while preventing mixing of the two fluids.
heating season	The time of year (usually October to May, but varying with climate) when heating is required to maintain comfortable room temperatures.
heat of fusion	The amount of heat per unit mass that must be removed from a liquid to freeze it when the liquid is initially at its freezing temperature.
heat storage device	A device that absorbs heat and holds it until the heat is needed to warm a building or domestic hot water.
heat transfer coefficient	The amount of heat that can be transferred across a unit area of surface per unit of time per unit of temperature difference between one side of the surface and the other (Btu/hr·°F·ft^2).
heat transfer fluid	A liquid or gas used to transport heat from one location to another. Typical heat transfer fluids include air, water, and antifreeze solution.
heat-transfer relaxation length	The ratio of input heat to the heat that can be absorbed per unit length of rock bed. The heat-transfer relaxation length is an abstract quantity that is closely

related to the minimum length of rock bed in which thermal stratification occurs. The rock bed length should be at least five times the heat-transfer relaxation length to ensure stratification.

hybrid system — A solar energy system that combines features of active and passive systems.

hydronic system — A heating system in which water is heated by solar energy or by a boiler and distributed to heat exchangers located at various points in the building. The heat exchangers in a hydronic system are typically radiators, baseboard convectors, fancoil units, floor panels, or ceiling panels.

insolation — The amount of solar energy incident on a unit of surface area per unit of time ($Btu/hr \cdot ft^2$). Notice the differences in spelling and meaning between insolation and insulation. Insolation is an acronym from incoming solar radiation.

insulation — A material used to restrict the flow of heat or electricity.

iteration — A method of solving mathematical equations that do not have closed-form solutions. Iteration involves making an initial guess at the solution and refining the guess by repeated application of the mathematical formulas until the change in the refined guess becomes negligible.

laminar flow — Fluid flow in which little mixing between fluid layers occurs. Laminar flow occurs at low Reynolds numbers. Compare with turbulent flow and transitional flow.

latent heat — The amount of heat per unit of mass required to change phase. Heat of fusion is an example of latent heat.

life-cycle cost analysis — A method of comparing the cost of a solar energy system with the cost of a conventional system by totaling the costs of each system over the lifetime of the solar system. Items usually included are first cost, mortgage interest, fuel, electricity, repairs, and other taxes.

liquid-type collector	A solar collector that uses a circulating liquid as a heat transfer fluid.
maximum operating temperature	The highest temperature at which the storage system can operate. Maximum operating temperature may be determined by the maximum temperature that the collectors can attain, the temperature limitations of materials in the system, the boiling point of water, or the pressure limitation of a sealed system.
minimum operating temperature	The lowest temperature at which useful heat can be extracted from storage.
natural convection	See convection, natural.
net positive suction head	The absolute head (pressure) available at the inlet to a pump, abbreviated NPSH. Pumps will be damaged by cavitation if the NPSH does not exceed the pump's requirement.
nonpotable fluid	A fluid which does not meet Public Health Service standards for drinking water or state or local standards for drinking water.
operating temperature range	The difference between maximum operating temperature and minimum operating temperature for a specified length of time. See daily temperature range.
Pacific Regional Handbook method	A method devised at Los Alamos Scientific Laboratory for calculating the performance of solar systems.
parasitic losses	The power required to circulate heat transfer fluids and operate controls.
passive system	A solar system that does not use pumps or fans to circulate a heat transfer fluid through solar collectors or to distribute heat to the building; the opposite of an active system.
payback period	The length of time until the fuel savings of a solar system begin to exceed the difference in cost between a solar system and a conventional system. See life-cycle cost analysis.

phase change system	A type of thermal energy storage system in which heat is stored by melting a substance and released by freezing the substance.
plenum (plural plena)	A space at the inlet or outlet of a rock bed used to distribute the air uniformly to the rocks.
positive displacement pump	A pump in which the fluid is squeezed between solid parts such as a piston and cylinder. Compare with centrifugal pump.
potable water	Water that meets federal, state, and local quality and safety standards for human consumption.
pressure gradient	A change of pressure per unit of length.
psi	Pounds per square inch; a unit of pressure. Unless otherwise specified, pressure is measured relative to atmospheric pressure. Compare with psig and psia.
psia	Pounds per square inch, absolute pressure. Absolute pressure is always measured relative to vacuum; that is, it is larger than gauge pressure by the atmospheric pressure. Compare with psi and psig.
psig	Pounds per square inch, gauge pressure. Gauge pressure is always measured relative to atmospheric pressure. Compare with psi and psia.
resistance heating	A method of heating with electricity in which electricity passing through a resistor is converted directly to heat.
retrofit	As used here, retrofit means to install a solar energy system in an existing building or in a building not originally designed for solar energy.
Reynolds number	The dimensionless number $\rho vd/\mu$ where ρ = fluid density, v = fluid velocity, d = a characteristic distance or diameter, and μ = fluid viscosity. The Reynolds number is closely related to the ratio of inertial force to viscous force in the fluid. Laminar flow occurs at low Reynolds numbers, and turbulent flow occurs at high Reynolds numbers.

rock bed face velocity	The volumetric air flow rate divided by the gross cross-sectional area of the rock bed. The face velocity is an abstract quantity that does not equal the actual air velocity in the small passageways between the rocks.
R-value	Resistance of insulation to heat conduction given in units of $°F \cdot ft^2 \cdot hr/Btu$.
scaling coefficient	A factor ($Btu/hr \cdot °F \cdot ft^2$) that expresses the degradation of heat exchanger performance due to formation of scale on the heat exchange surfaces. The scaling coefficient is the inverse of the fouling factor.
sealed system	A solar system that excludes oxygen by closing all vents and inlets and outlets for liquids. Exclusion of oxygen in this manner limits one type of corrosion, but requires an expansion tank to limit pressures.
sensible heat	Heat that, upon flowing into a storage medium, increases the temperature of the medium. The constant of proportionality between the flow of heat and the temperature increase is the heat capacity of the medium.
sensor	A device that measures pressure or temperature and relays the information to a controller.
shell-and-tube heat exchanger	A type of heat exchanger consisting of a bundle of tubes within an outer shell and baffles to direct the fluid flow. One heat transfer liquid is pumped through the space between the tubes and the shell.
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association, 8224 Old Court House Road, Vienna, Virginia 22180
solar house	A house that derives a substantial portion of its heat from the sun.
space heating	Heating a building to maintain a comfortable indoor temperature.

specific heat	The ratio of the heat capacity of a substance to the heat capacity of water (1 Btu per pound per degree Fahrenheit). Unlike heat capacity, specific heat is a dimensionless (unitless) quantity. Compare the definition of specific heat with the definition of heat capacity.
storage medium	As used here, a storage medium is a substance that stores heat in a solar system.
storage system	The part of a solar system that includes a storage medium in a container with heat exchangers, pumps, valves, and other components necessary to transfer heat into and out of the storage medium.
tank-in-tank heat exchanger	A tank containing a heat transfer liquid submerged in a tank containing another heat transfer liquid. Natural convection occurs on both sides of the inner-tank wall.
temperature stratification	Thermal stratification.
tempering valve	A valve that limits the temperature of water flowing from a domestic hot water tank by mixing it with cold water.
TES	Thermal energy storage.
thermal stratification	Separation of hot and cool parts of the storage medium within the storage unit.
thermistor	A type of temperature sensor.
thermosyphoning	Motion of a fluid caused by buoyancy of its warmer parts; natural convection.
thermosyphon system	A pumpless solar system in which buoyancy, acting on water heated by the collector, causes the water to rise into the storage tank. Thermosyphon systems are usually limited to domestic hot water systems in the tropics because the storage tank must be mounted above the collectors and there is no protection against freezing.
toxic fluid	A gas or liquid that is poisonous, irritating, and/or suffocating, as classified in the Hazardous Substances Act, Code of Federal Regulations, Title 16, Part 1500.

traced tank	A type of heat exchanger in which the heat transfer fluid is carried in a tube wrapped around the storage tank; a wraparound heat exchanger.
transitional flow	Fluid flow that is on the borderline between laminar flow and turbulent flow.
turbulent flow	Fluid flow in which mixing between adjacent layers is prevalent. Turbulent flow occurs at high Reynolds numbers. See laminar flow and transitional flow.
void fraction	The ratio of air space volume in a rock bed to the total volume of the rock bed.
volumetric heat capacity	The amount of heat a unit volume of a storage medium contains per unit change of temperature, expressed as $Btu/ft^3 \cdot °F$.
wraparound heat exchanger	A tank that has fluid passages wrapped around it. The fluid passages are typically a tube soldered to the outside of the tank (a traced tank) or a metal panel with integral fluid passageways clamped around the tank.

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- Bruce Anderson.
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  Solar heating and cooling with emphasis on the interaction between solar energy and buildings. Both active and passive solar systems are discussed. This book assumes that its reader has considerably more technical expertise than is required for reading The Solar Home Book by Anderson and Riordan.

- Bruce Anderson with Michael Riordan.
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  Describes and discusses many types of solar systems and components. Written for the reader who does not have a highly technical background, The Solar Home Book covers many aspects of solar system design and construction and gives examples of systems in operation.

- Steve Baer.
  Sunspots: Collected Facts and Solar Fiction.
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