Active Fog Catcher

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Abstract

The active fog catching senior project team has been asked to develop a device that will harvest water from the atmosphere, namely fog, using active means. The project will be centered on maximizing water collection rate, with efficiency as a secondary concern. The final design utilizes a refrigeration system in which fans pull air across the cold evaporators inside of a duct. Water condenses on the evaporators and drain into a collection container. It was decided to focus on maximizing water collection at the cost of efficiency because the feasibility of actively harvesting fog must be proved before trying to make the system efficient. A Copeland condensing unit that provides 2,490 Btu/min of heat transfer from the evaporator to the incoming fog is used in tandem with three expansion valves and four evaporators. Two Vernier expansion valves will allow the system to be finely adjusted while a third ball valve is used to coarsely adjust the flowrate. In addition, temperature and pressure gauges will be used to monitor the performance of the system and add additional control over the system. Speed controllers are connected in series to the fans in order to allow for variable flowrate. For testing, the system was placed in a high humidity environment and the fans were set to run at a predetermined flowrate. The Vernier expansion valves were adjusted until the first couple coils were frosting and the kWh consumption of the system was monitored using a watt meter. The results showed that the optimal flowrate for this system was between 140-150 cfm. In addition, it was discovered that pulsing the fans (toggling between the set point flowrate and the maximum flowrate for a brief period of time) would promote condensate to form droplets and drip out of the evaporators. The results showed that at the optimum flowrate, with pulsing, and a relatively high humidity the system could capture an experimental maximum steady state condensation rate of .307 gal/kWh. This amounted to approximately one gallon of water collected in six hours, at an energy cost of approximately forty cents.

Chapter 1: Introduction, Objectives and Specifications

Introduction

California is experiencing one of the worst droughts in state history. In order to assist the state in providing clean water for domestic and agricultural use, methods of obtaining fresh water by means other than traditional processes such as extracting groundwater and reservoirs are being researched. This senior project team of four Cal Poly undergraduate mechanical engineering students (Will Beechinor, Kai Zhang, Carson Hand and Michael Giglio) has been asked to explore the feasibility of using an active means to extract water from the air. More specifically, the project is focused on extracting water from coastal fog, but will also pursue the possibility of extracting water from air with high humidity levels. The ultimate goal of this project is to produce a working prototype that demonstrates the viability of actively catching fog as a supplementary water collection method. This prototype will also function as a lab instrument from which future undergraduate HVAC students at Cal Poly will have the opportunity to learn from.

Due to the limited resources available for this project, the focus of the design will be mostly on water collection, rather than efficiency. This is because a design for maximum efficiency would require a large amount of custom parts, largely unobtainable with the budget provided (such as compressors/evaporators specialized for low pressure and temperature differences). Maximum water collection is more attainable, given the scope of the project, and the design could be made more efficient in later iterations with more resources. We hope that in the event of a successful project, this design will be used as a foundational technology to help provide clean water to citizens of California and to others who suffer from a lack of consistent water around the world.

Objective and Specifications

The overall goal for this project is to create a device that can harvest moisture from the air through an active means. This project will eventually become an addition to the HVAC lab and will be used to demonstrate concepts to future students. A QFD (Quality Function Deployment) analysis was performed to provide a better understanding of the problem definition and quantify customer requirements. It is important to note that for this project the sponsor's main interest is solely water collection rate. The other specifications were created by this team to provide design goals and guides for the project and do not influence whether or not the design is a success or failure from the viewpoint of the sponsor.

Table 1: Engineering specifications for building an active fog catcher.

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
1	Water Collection Rate	.295 gal/ft^2/day	Min	H	A,T
2	Power Consumption	.0288 kWh/ft^2/day	+.05	H	A,T,S
3	Capital Cost	$3,000	Max	H	A,T
4	Operating Cost	$.4936/ft^2/day	±.05	M	A,T
5	Volumetric Footprint	27 ft^3	Max	L	I
6	Set Up/Take Down Time	30 min	+ 10	L	T
7	Warm Up Time	10 min	+ 10	M	T
8	# of Non-Standard Parts	5	Max	L	I
9	Weight	100 lb.	+ 25	M	T

* High (H), Medium (M), Low (L)

** Analysis (A), Test (T), Similarity to Existing Designs (S), Inspection (I)

Table 2: Engineering preferences for building an active fog catcher.

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
10	Sound Intensity	90 Decibels	Max	L	T
11	Number of Interface Points	3	+2	L	I

* High (H), Medium (M), Low (L)

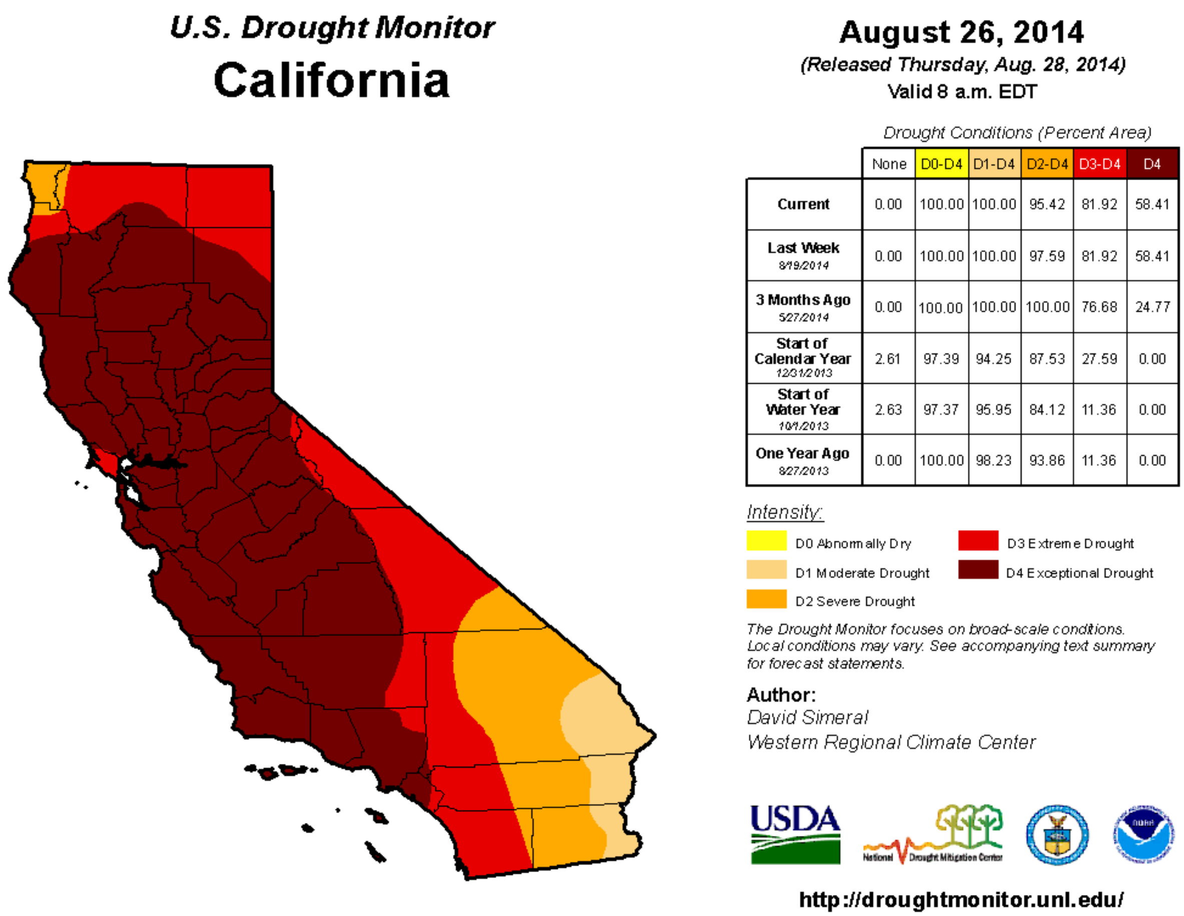
** Analysis (A), Test (T), Similarity to Existing Designs (S), Inspection (I)

Of the specifications derived from the QFD analysis (Appendix A), water collection rate, power consumption, and capital cost were deemed most critical for project success. The prototype will be designed for lab demonstrations as well as outdoor use. Due to the open ended nature of the project, the rest of the specifications are fairly mutable and subject to project needs.

Chapter 2: Background

The Problem

Water collection and purification is not a new concept. For places around the world where there have been serious water shortages, different ideas for harvesting usable water have been explored. The most obvious water collection techniques might be trivial, but they are necessary options to consider before water collecting becomes too difficult, expensive, or inefficient. If there is not enough rainfall to support a large body of fresh water, one might turn to groundwater beneath the surface and dig wells to collect the valuable resource. For places like the Atacama Desert in Chile, rainfall is so infrequent that there is no water to harvest at a reachable depth below the surface. Due to the increasing severity of the California drought, as shown in the figure below, new options must be explored in order to compensate for the water shortage.



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	100.00	95.42	81.92	58.41
Last Week 8/19/2014	0.00	100.00	100.00	97.59	81.92	58.41
3 Months Ago 5/27/2014	0.00	100.00	100.00	100.00	76.68	24.77
Start of Calendar Year 12/31/2013	2.61	97.39	94.25	87.53	27.59	0.00
Start of Water Year 10/1/2013	2.63	97.37	95.95	84.12	11.36	0.00
One Year Ago 8/27/2013	0.00	100.00	98.23	93.86	11.36	0.00

Figure 1. California drought map. (1)

Competitors

Desalination

The earth is covered by water, but only 3% is contained inland and the other 97% is contained by the ocean. Unfortunately, the large amount of salt water cannot be consumed by humans in its natural state because of its high salinity content. This problem gave birth to a technique of water extraction known as desalination where the salt is extracted from the water to provide drinkable water. There are two primary processes for desalting salt water: membrane and filtration processes and thermal processes. In the first method water is forced through selectively permeable membranes are used to filter the water to a state that is useable. Membrane and filtration processes can be further broken down into reverse osmosis (RO), microfiltration (MF), nanofiltration (NF), and Ultrafiltration (UF). In the second method heat is added to the salt water which causes the water to vaporize and travel to a collector while leaving behind salt or very salty water known as brine. This process mimics the natural water cycle, but can be performed much more quickly. The thermal desalination processes can be broken up into multi- stage flash distillation (MSF), multiple-effect distillation (MED), and vapor compression distillation (VP). Other desalination processes include electron dialysis (ED) where an electric current is used to move salt ions through a selectively permeable membrane and electrodeionisation (EDI) where ion-exchange methods are used to separate the water and salt (2). The figure below shows that reverse osmosis and multi-stage flash distillation account for approximately 86.8% of the installed capacity.

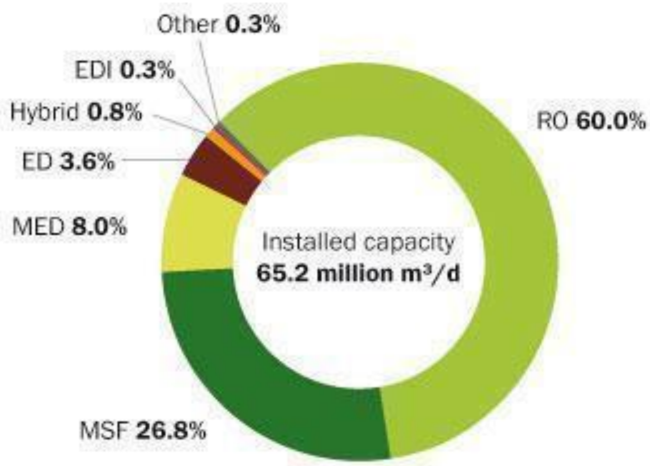


Figure 2. Worldwide desalination capacity by type in 2010. (3)

To allow for a more complete understanding pictorial representations of the two most common desalination types, reverse osmosis and multi-stage flash, are shown in Figure 3 and Figure 4 respectively.

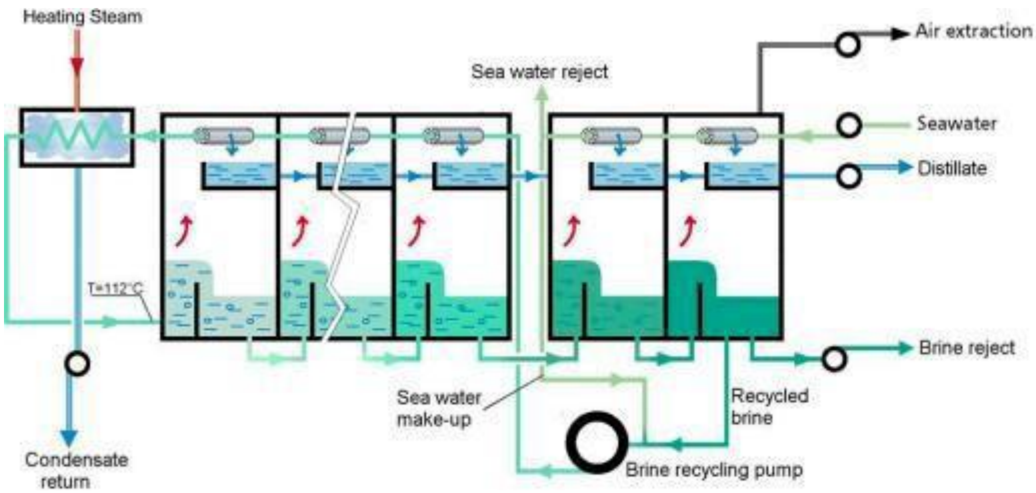


Figure 3. Multi-stage flash desalination process. (4)

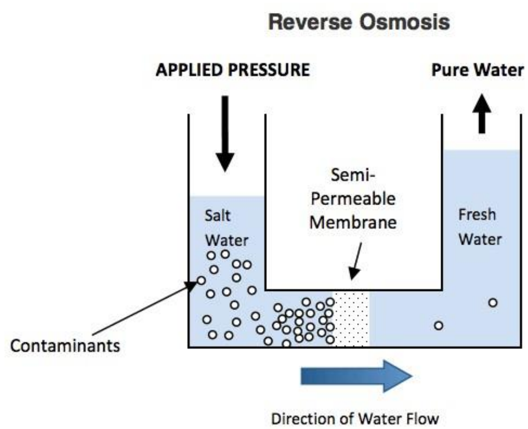


Figure 4. Reverse osmosis process. (5)

Table 3: This table shows the first year cost of the water production for various desalination plants around the world. It also details the year of the projected cost and the source where the information was obtained. (2).

Facility or Location	US$/kgal (first year)	US$/m³ (first year)	Operational?	Year	Source
Ashkelon, Israel	2.03	0.54	Yes	2002	EDS (2004), Segal (2004), Zhou & Tol (2005)
Ashkelon, Israel	2.00	0.53	Yes	2003	NAS (2004)
Ashkelon, Israel	2.10	0.55	Yes	2004	Wilf & Bartels (2005)
Ashkelon, Israel	2.34	0.62	Yes	2005	Red Herring (2005), Semiat (2006)
Bahamas	5.60	1.48	Yes ?	2003	NAS (2004)
Carlsbad, CA (Poseidon)	2.90	0.77	No	2005	San Diego Daily Transcript (2005)
Dhekelia, Cyprus	4.14	1.09	Yes	1996	Segal (2004)
Dhekelia, Cyprus	5.40	1.43	Yes	2003	NAS (2004)
Eilat, Israel	2.80	0.74	Yes	1997 ?	Wilf & Bartels (2005)
Hamma, Algiers	3.19	0.84	No	2003	EDS (2004), Segal (2004)
Larnaca, Cyprus	2.84	0.75	Yes	2000	Segal (2004)
Larnaca, Cyprus	3.20	0.85	Yes	2003	NAS (2004)
Larnaca, Cyprus	3.23	0.85	Yes	2001 ?	Wilf & Bartels (2005)
Moss Landing, CA (Cal Am)	4.75[1]	1.28[1]	No	2005	MPWMD (2005b)
Moss Landing, CA (Poseidon)	3.63	0.96	No	2005	MPWMD (2005b)
Perth, Australia	3.49	0.92	No	2005	Water Technology (2006)
Singapore	1.75	0.46	Yes	2002	Segal (2004)
Singapore	1.70	0.45	Yes	2003	NAS (2004)
Sydney, Australia	4.21[2]	1.11[2]			
Tampa Bay, FL	Four bids from 1.75 to 2.18	0.46 to 0.58	No	1999	Semiat (2000)
Tampa Bay, FL	2.10	0.55	No	2003	Segal (2004)
Tampa Bay, FL	2.18	0.58	No	2003 ?	Wilf & Bartels (2005)
Tampa Bay, FL	2.49	0.66	No	?	Arroyo (2004)
Trinidad	2.77	0.73	Yes	?	Segal (2004)
Trinidad	2.80	0.74	Yes	2003	NAS (2004)

The production cost ranges from $(1.72-5.6)/kgal which can provide a useful datum to compare against when evaluating the performance of the active fog catching design. The best reverse osmosis procedures use approximately 12 kWh/kgal and with the current energy cost in California being approximately $.1736/kWh (6). The price of a reverse osmosis plant is approximately $2.08/kgal.

Construction is underway in Carlsbad, CA to build the largest desalination plant in the western hemisphere. This plant will use reverse osmosis, and will be capable of making 50 million gallons of freshwater daily. The average cost to turn one acre-foot -- about 325,000 gallons -- of salt water into fresh water ranges from $800 to $1,400. Water bills would rise $5-7 dollars a month to pay for desalination. The water authority in San Diego will pay $2,014-2,257 per acre-foot (325,000 gallons). Unfortunately, desalination is very energy intensive, requiring approximately 38 Megawatts a day which translates to about double the cost of more common water extraction techniques. Furthermore, desalination is usually only a temporary option for more remote locations until drought conditions lessen naturally or cheaper water sources become available. (7)

Passive Collection: Meshes

Another option currently being researched at MIT and tested in Chile is passive water collection. This method employs large nets with material properties that assist in the condensation of water droplets that are strategically placed to allow fog clouds to pass through the nets and deposit water. Some prototypes can produce around 500 gallons per catcher per day. Although this is a significant number it obviously does not compete with the 50 million gallons produced by desalination plants. Passive fog catching also is dependent on favorable fog and wind conditions which seriously limit its consistency and requires more space.

In particular two scientists from MIT investigated the effects of surface geometry on collection rates of fog. Their datum was Rachel meshes that have been reported to collect anywhere from 10^{-1}-10^{1} L/m^2/day. The variables that were investigated were width of the mesh fibers, shade coefficient, and composition of mesh material. Each of their designs were tested in a controlled-humidity glove box that kept the relative humidity at 100% and the temperature at 26.4 ± .5 °C. The humid air was propelled by a fan towards the meshes at a speed on 2 m/s. Their design consisted of a wire meshes that were dip-coated in a 50% fluorodecyl POSS/50 wt. % PEMA solution in Asahiklin at a concentration of 10 mg/mL. The results of the experiment showed that for fog conditions where the size of the radius condensed water droplet ranged from 1-40μm and the velocity ranged from 1-10 m/s their mesh could collect more efficiently than the Rachel meshes that are the current industry standard. In particular they predict that in Chile, where passive fog collection in a primary means for obtaining water, where the average fog radius is r = 13μm and average wind speed is v = 6 m/s their meshes may be able to collect up to 12 L/m^2/day. (17)

Figure 5. Passive fog catching meshes. (8)

This project will take an "active" approach to the fog catching process. This means that a form of energy will be used to augment water collection yields. Ideally, the process will collect more water than is possible with passive collection methods, while operating at much lower energy than desalination. The higher yield from the active approach will be attributed to the fact that there will be a higher flow rate through the system as well as additional cooling to encourage condensation.

Active Collection

Active fog catchers are uncommon and for the most part underdeveloped, but there are a few designs that exist and are worth mentioning in this report:

The first, shown in Figure 6, is the WMS1000 that was designed by inventor, Marc Parent and sponsored and built by Eolewater. The wind turbine is used to generator power that is supplied to the compressor of a refrigeration cycle. A condenser with a moisture exchange surface 1 m wide and 5 km wide allows the system to collect up to 1500 liters of water a day depending on the climate. (19)

Figure 6. The WMS100 water collecting wind turbine. (18)

Another concept that utilizes a refrigeration system is the Airdrop, shown below in Figure 7. A refrigeration system is used to condense water into an underground storage area and a pump is then used to move the water through pipes to irrigate the roots of plants which prevents surface loss. (18)

Figure 7. The Airdrop water collection system in possible agricultural application. (18)

Departing from the use of a refrigeration cycle is the A2WH, shown below in Figure 8. This system uses solar heat to drive airflow over a spongy surface that captures the water. Once the sponges are full the solar energy is used to heat up the system which causes the water to turn to vapor and exit the sponges where it is collected.

Figure 8. The A2WH active moisture harvester. (18)

Dehumidifier

One process very similar to the active approaches mentioned above is dehumidification. Dehumidification is the process of removing moisture from the atmosphere in order to keep a comfortable level of humidity. This process is very common in homes that are located in high humidity areas and is used to prevent mold from accumulating in dark moist areas. In practice, there are two main types of dehumidifiers, refrigeration dehumidifiers and absorption/adsorption dehumidifiers. Refrigeration dehumidifiers use vapor compression cycles to cool the air to the dew point, at which water vapor begins to condense. The water is collected in a collection chamber and the dry air is heated to room temperature before exiting the system.

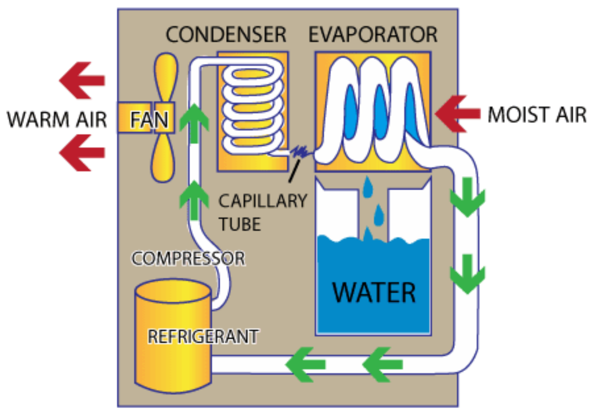


Figure 9. Dehumidification process. (9)

Absorption and Adsorption dehumidifiers rely on a mechanical means of extracting water that usually in the form of a rotating disk with sponge like qualities to extract water.

Background Science

Weather and Fog Information

There are two major types of fog in California, radiation fog and advection fog. For both types, fog is formed when the relative humidity of the air reaches 100%, and water vapor condenses on tiny particles in the air, creating the "foggy" appearance. Radiation fog is produced by rapid surface cooling due to radiation heat loss. It usually forms at night under clear skies with calm winds when heat absorbed by the ground during the day is radiated into space. As the ground continues to cool, the humidity of moist air will reach 100% and fog will form. Radiation fog is always found at ground level and usually remains stationary. According to the National Weather Service Weather Forecast Office, the depth of the radiation fog can vary from 3 feet to about 1000 feet. (10) Radiation fog commonly forms on floors of interior valleys.

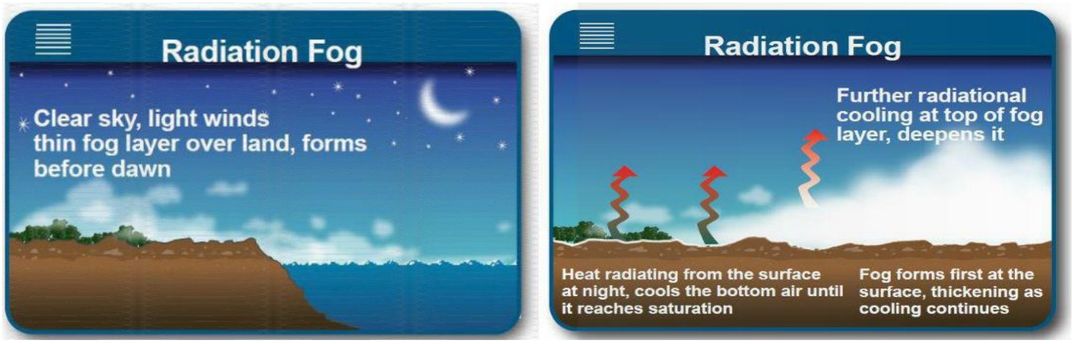


Figure 10. Radiation fog formation. (11)

The other type of fog in California is advection fog. The difference between the two types of fog is that in the advection fog case, the condensation is caused by the horizontal movement of warm moist air over a cold surface; while that of radiation fog is caused by a reduction in surface temperature.

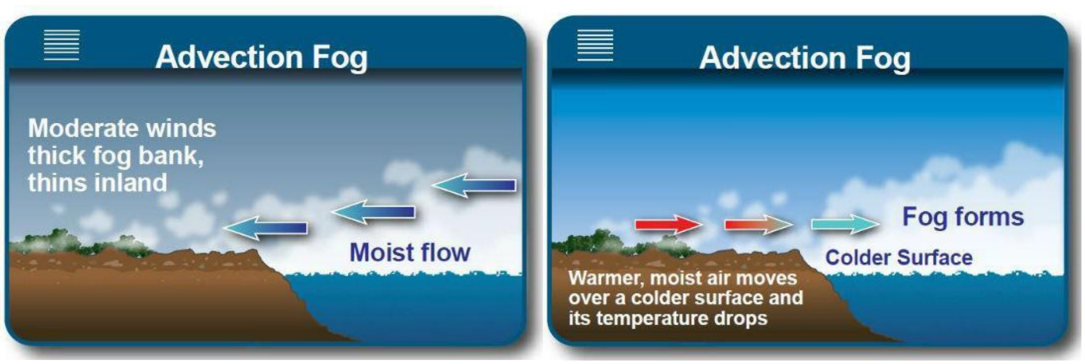


Figure 11. Advection fog formation. (11)

Advection fog is common in California coastal areas in summer. For example, when warm, moist air flows over a cold inland area, where its temperature drops at night due to radiation cooling, the moist air will be cooled from below. If the air is near saturation, moisture will condense out of the cooled air and form fog. In both cases air above the surface are cooled to its dew point with 100% relative humidity.

According to the Experimental Aircraft Info website, the following conditions are needed for the formation for both radiation fog and advection fog: a clear sky, light winds, relatively high humidity and a stable atmosphere. (12) A clear sky allows the long wave radiation to leave the earth, and the absence of clouds will prevent any of the radiation from being trapped between the cloud and the ground. With a light wind, sufficient condensation forms on condensation nuclei to form very small droplets. If the wind is too strong, stratus which lies a few hundred meters above ground is likely to develop and it will be detached from the ground.

Condensation Types

There are two types of condensation that we are primarily concerned with: dropwise and filmwise condensation. Dropwise condensation is where the vapor condenses on a surface that is not already wetted by the condensate, while filmwise condensation is where the vapor is condensing on thin layers of condensate already present. The heat transfer coefficient of dropwise condensation is often 10 to 20 times higher than filmwise condensation, and twice as high in the circumstances in which they are the closest. (13)

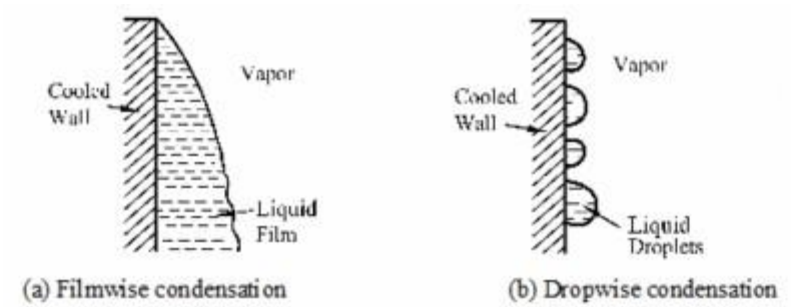


Figure 12. Filmwise and dropwise condensation. (14)

Dropwise condensation requires that the surface be continually bared to the vapor by the formation and coalescence of drops, and the wiping action of running drops. Drops are formed at nucleation sites on the surface, and they grow until neighboring drops combine. This continues until the drops reach maximum size, and are caused to “drop” due to gravity. (13)

Surface Effects on Condensation

In order to make dropwise condensation possible, a non-wetting agent is usually required. One such agent is polytetrafluoroethylene, or Teflon. The goal of these “dropwise promoters” is to make sure that the vapor condenses in drops rather than in a film. One of the more cutting edge ways that this can be accomplished is by having a complex pattern of hydrophilic- hydrophobic material. (13)

A more common and affordable dropwise promoter, such as Teflon, is ideal for a project of this scope. Teflon coatings have been found to be effective in promoting dropwise condensation for use with steam cycles. Teflon is best bonded to metals, and aluminum in particular. This is because the Teflon can fill in the holes in the porous oxide layer of the aluminum, providing a strong mechanical bond. It is important that the Teflon layer be kept thin (ideally in the ten-thousandths of an inch range), because the thermal conductivity of Teflon is low (so if it is too thick, the surface doesn’t get cold, and condensation rate suffers). (15)

Pressure Effects on Condensation

Increased pressure increases the dew point of vapors, as shown in the figure below.

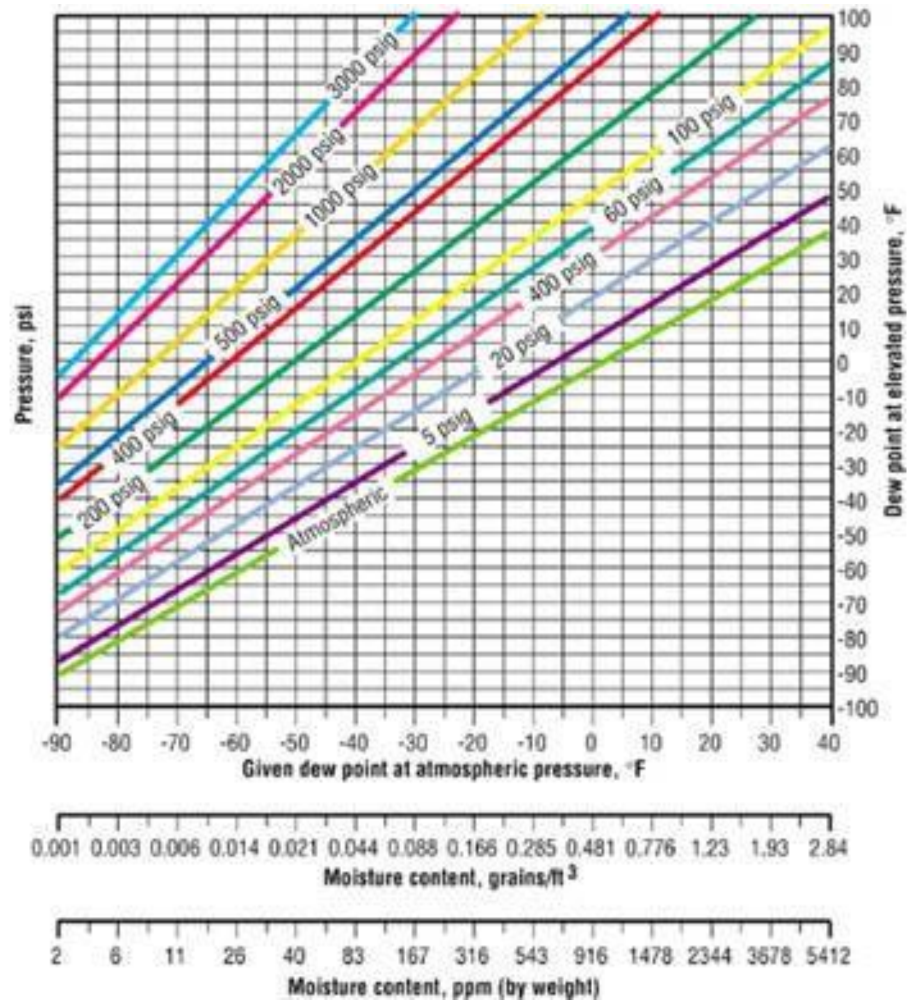


Figure 13. New dew point vs. old dew point based on pressure difference. (16)

This can be very useful when working with pure vapors, but it is not as useful for pulling water out of the air. This is because pressurization takes a large amount of energy, and when working with an air and water vapor mixture, a lot of the energy used to pressurize the mixture is being used to pressurize the air, which is useless for this application. Given this information, this design will not utilize pressurization to aid in condensation.[1]

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1 Information obtained through conversation with Dr. Christopher Pascual.

Chapter 3: Design Development

Preliminary Design

The preliminary aspects of design development for this project began with some very broad brainstorming for three main functions of the system: fog intake, water condensation, and finally extraction. The goal of these preliminary brainstorm sessions was to obtain a very broad spectrum of ideas for ways to manipulate fog (air and water vapor mixture), as well as water in a liquid state. Changes in pressure, changes in temperature, adsorption, absorption, and electrical stimulation were some of the general concepts produced by these sessions. These concepts all evolved into respective mechanical operations such as the use of fans or pumps, refrigeration lines, electrical current flow, magnetic fields, or even simple geometries and assemblies to encourage the use of gravity or pressure differences.

Some ideas seemed more feasible than others and it was easy to classify some ideas as impractical for the scope of this project. Our research quickly showed us that using magnetic fields and electrical current would not help us extract water from the air, and that using mechanical means of separation alone would not provide a maximum water collection rate. Other ideas, like increasing the pressure of a volume of fog seemed quite productive and viable. This idea, similar to a few others, took a little more convincing and reminding in order to classify it in the “no-go” category. Dr. Pascual, a professor in thermodynamics and fire protection, reminded the team that most of the work that would go into changing the pressure of a volume of fog would act to compress the air and not the water in the system, leaving the majority of water molecules in the vapor state.

Pugh matrices (Appendix B) were used to help evaluate what the best ideas for each of the main functions of the system were (one matrix for fog intake, water condensation, and extraction). From the matrices, it was determined that the top ideas were a funnel or fan for fog intake, a refrigeration heat exchanger for condensation, and gravity for water extraction.

Concerning fog intake, a funnel works very well in situations where there is a coastal breeze that can help move fog into the device at no energy cost. A fan is good for the situation where there isn’t enough wind, and fog must be moved into the device at the lowest energy cost possible. The other options, such as moving the device through the fog, or using a lung-like expandable bag would not provide the necessary flowrate and consume much more energy than is desired.

Concerning condensation, refrigeration is one of the only viable options given the requirements of our project. As lowering temperature is the only feasible way of reaching the dew point of water vapor (pressurization uses an incredible amount of energy, most of which is wasted pressurizing the air), the options for condensing the fog are fairly limited.

Refrigeration is the only reliable method of cooling our condensation surface, as the lab demonstration requirement prohibits the use of underground cooling pipes and chemical methods, and using wind chill or other environmental means is highly unreliable, as well as being unavailable in a lab setting.

Concerning water extraction, gravity seemed the best way to remove water from the collection surface, provided the surface is oriented vertically. Using a squeegee or shaking the surface would require more energy, and possibly inhibit condensation while they are active. Using a magnetic field was a possibility, but it could possibly interfere with any electronics within the device, as well as condensation.

The following ideas were pieced together based on all three of the main functions. Most of these ideas utilized a refrigeration cycle, some sort of fan, and gravity-based condensate extraction.

The Tower

This design uses a refrigeration system to cool a reservoir of water at the base of a rectangular tower. The cold water is pumped up to the top, and is allowed to flow down over a series of alternating thermally conductive platforms, cooling them down. Fog is sucked into the tower at the base just above the cold water reservoir via a fan at the top of the tower. The air flows up the tower in the opposite direction of the water, condensing water on the cool undersides of the platforms. This condensate then drips down the tower along with the cool water, and collects in the cold water reservoir. An overflow valve keeps the cold water reservoir at the appropriate volume. The cold air exits through the top of the tower, and is blown over the hot coolant coils, The refrigeration cycle utilizes a compressor to heat up the coolant before blowing the cold air over it, and an expansion valve to cool it down before it runs back through the water.

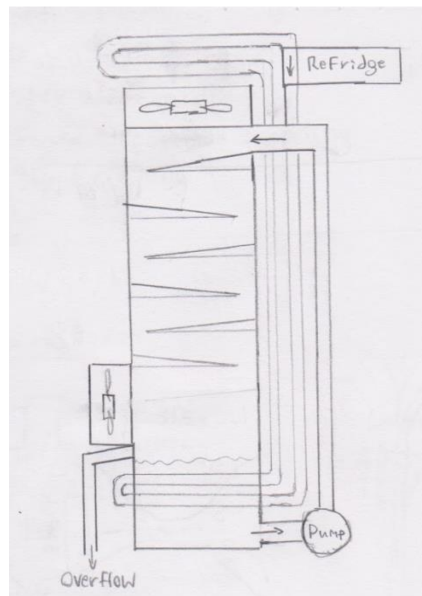

Figure 14. The Tower Concept Design

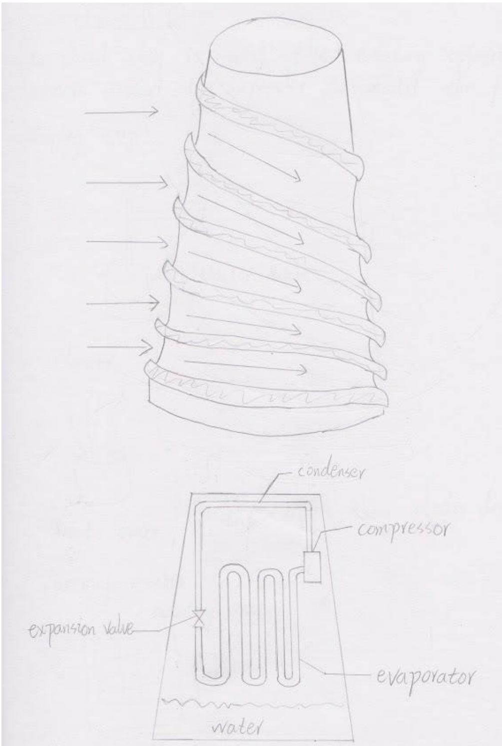

Figure 15. The Helix Design Concept

The Helix

The helix utilizes pressure difference to intake fog. The helix spins to create a vortex which sucks in nearby fog. To prevent fog from going upward, the blades of the helix are made with an angle to guide fog flow downward. As the helix continues to spin, fog eventually gets sucked into the helix through the holes on outside the helix. A refrigeration cycle is used to perform the condensation of the fog. A compressor will be installed on one side of the helix. The compressed refrigerant goes upward to the condenser, which will be placed at the open top of the helix for heat dissipation to the surrounding. The refrigerant then cools down through an expansion valve that is located on the other side of the helix. The cooled refrigerant eventually goes to the evaporator, which is a collections of U-tubes that cool and condensate the intake fog. The condensate water droplets drop down due to the gravity and are stored in a tank at the bottom.

The U-Duct

A fan is used to pull fog into the u-shaped duct and into cooled circular fins that provide a condensation surface for the water droplets. A refrigeration system that runs through small pipes into the fins creates a temperature difference between the fog and the metallic fins. The water condenses on these fins and runs down until it reaches the drainage holes in the bottom of the device. The fins also provide the added feature of reducing the head loss around the bend of the duct. Since the entrance and exit ducts are directly in contact there will be heat transfer from the incoming warm air to the exciting cold air. A duct at the exit was added to direct the cold dry air away from the inlet. The figure to the right is a concept sketch of the top view of the U-duct design.

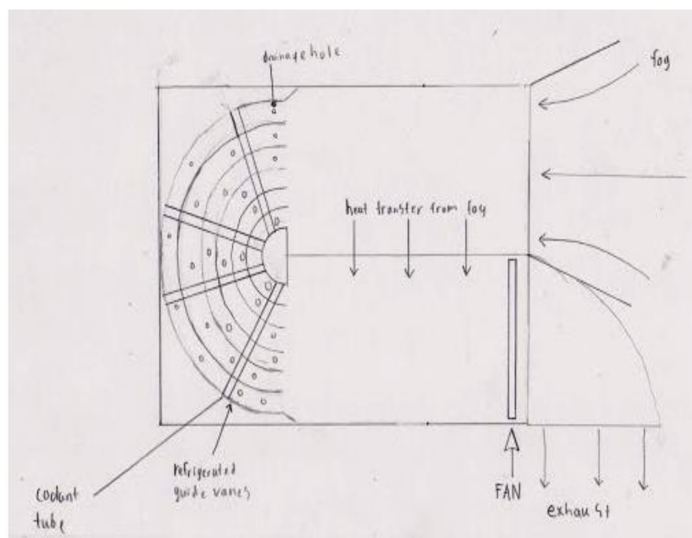

Figure 16. The U-Duct Concept Design

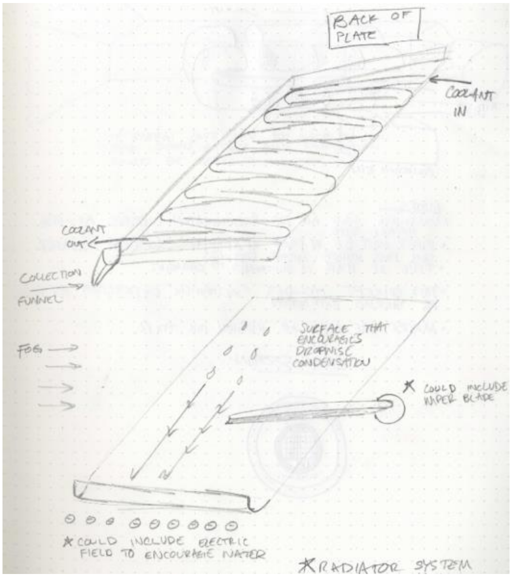

Figure 17.The Concept Design of the Plate Collector

The Plate Collector

This concept differed from the other concepts in that it utilized the natural wind currents of the fog to provide the necessary flowrate over the system. The Plate Collector aimed to highlight a unique and possible improved extraction technique after water had condensed on the cooling surface. The drawing shows a windshield wiper-like device that would squeegee the water off of the plate at constant intervals to try to improve the rate of dropwise condensation on the cooled plate. The drawback with this design is that the cooling surface is very restricted in terms of size. There is no real opportunity to keep it variable for testing. The Plate Collector also relies on the natural movement of fog which, in fact, does not always move significantly.

The Annulator

The Annulator concept was centered around a counter flow heat exchanger. It aimed to incorporate extraction tools into an existing type of heat exchanger. The drawing shows the counter flow heat exchanger with two juxtaposed pipes but then also makes reference to changing the relative pipe geometry to an annular orientation. The extraction would take place on grates or meshes located inside the inner pipe through which the fog would flow and be cooled down by the outer pipe of coolant. This concept would however be difficult to make in order to reach a reasonable length of heat exchanger to adequately cool the fog.

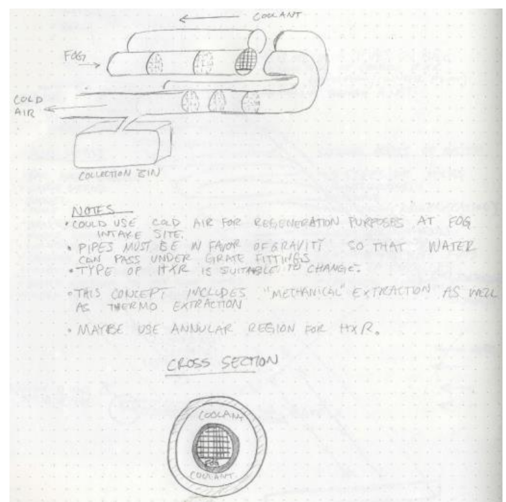

Figure 18. The Concept Design of the Annulator

The top concepts were evaluated against each other using a decision matrix. Each concept was rated on a scale of 1-5 in the following categories: water collection, power consumption, capital cost, operating cost (outside of energy use), volumetric footprint, setup and takedown time, warm up time, number of non-standard parts, and weight. These categories were also weighted based on importance to success of the project. These criteria and weights we're established using a QFD house of quality (seen in Appendix A), which ensures that our specifications match up with the customer requirements. Using this matrix, it was determined that the best concept was "The Regenerator." This final decision matrix can be seen in Appendix C.

Lead Concept

The concept design, shown below in Figure 19 that the team will move forward with will be based around a large duct with a centrifugal blower at one end to draw in fog through the duct. The system will also include a vapor compression refrigeration system that will cool a heat exchanger located inside the duct to act as the primary cooling mechanism for the incoming fog. In addition to the thermal extraction of this heat exchanger, the duct will also house a mesh or other type of mechanical extraction tool. The location of the mesh with respect to the primary heat exchanger will likely be kept variable in order to determine the best location for the additional water extraction. The extracted water from the mechanical mesh as well as from the primary heat exchanger will drip down into a collection bin at the bottom of the duct. The two byproducts from cooling and extracting water from the fog, cold air and cold water, will be used to either pre-cool the fog entering the duct, or cool the refrigeration lines after the primary heat exchanger (evaporator). The layout of the design may be changed down the road once it is calculated whether or not the regenerative gains are worth the additional geometric complexity and associated head loss. The regenerative processes that will be analyzed are: fog to cold air byproduct, hot coolant to cold air byproduct, fog to cold condensate, hot coolant to cold condensate. If the calculated gains are sufficient, all four will be included in the final design.

Once the system components of the Regenerator were identified a solid model, Figure 20, was created to gain a better understanding of the geometry of the system and how each component interacts with each other. From the preliminary model components that will be difficult to manufacture such as the evaporator, shown as a grey slab with blue coils, were identified. By calling attention to these features early they can be redesigned so they are more simple to manufacture or more effective in terms of their location.

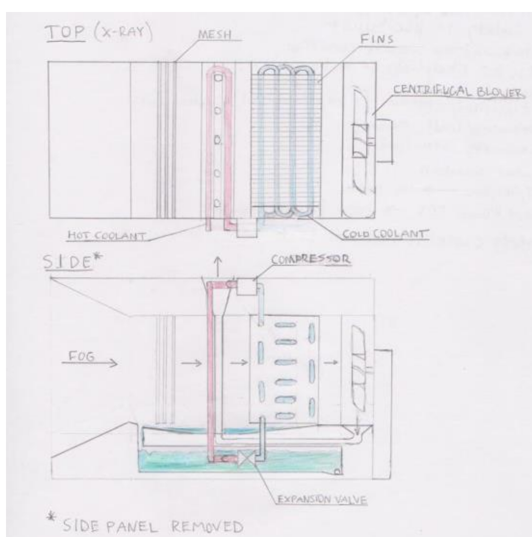

Figure 19. The Regenerator.

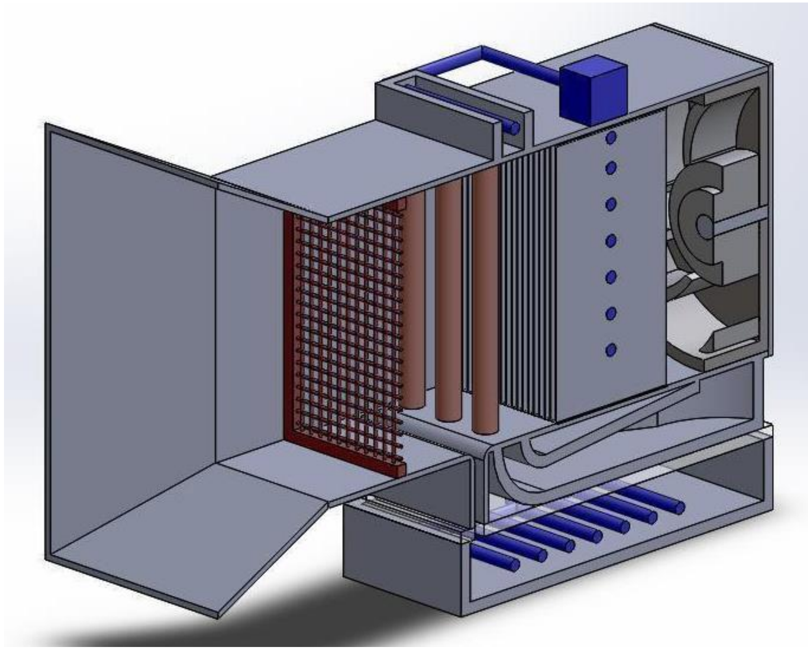

Figure 20. The Solidworks model of the Regenerator.

Theoretical Calculations for Justification of Concept

The amount of water that this project aims to collect is first and foremost based on the amount of water that competing techniques can collect. As mentioned before, the main competition is that of the passive fog catchers. In addition to this bench mark for water collection, we have defined a range of collection rates for which our system will run at. First an absolute maximum collection rate based on a psychrometric analysis of the air at given sets of temperature and humidity conditions was defined. This psychrometric analysis was based on the fact that air at colder temperatures can't hold as much water as air at higher temperatures. Thus by cooling a volume of fog, water is forced to condense out of the air.

The process began by assuming an ideal set of conditions for which the system will operate. This ideal state consisted of standard atmospheric conditions (pressure at roughly 14.7 psi) and fog at 100 percent relative humidity. A range of ambient fog temperatures, 35 to 65 degrees Fahrenheit was also determined based on past data provided by (20). Constant density was also assumed for the air and water mixture for these temperatures and calculations.

The basic approach to these calculations was to determine the mass of water in the mixture at the ambient temperature and also at a cooler temperature above the freezing point of water. This can be done by first reading off the humidity ratio, ω, from the psychrometric chart at the specified temperature and relative humidity, ϕ. The humidity ratio is given in terms of mass of water per mass of air and can thus be manipulated along with the total mass of the system to yield only the mass of the water. After determining the mass of the water at the ambient temperature as well as the cooled temperature one can determine the amount of water available to extract by subtracting the mass of the water at the ambient temperature from the mass of water at the cooled temperature. This final value represents all water that would theoretically be forced out of the air during the cooling process. An example calculation can be seen in the EES code attached at the end of the document. (Appendix D1)

The rate of heat transfer of the system can also be determined by accounting for a mass flowrate through the system and enthalpy states. Both states points on the psychrometric chart are also associated with an enthalpy value as well as a humidity ratio. Thus, the First Law of Thermodynamics of an open system can be used to determine the heat transfer rate, $\dot{Q}$ (Appendix D1)

Unfortunately, it is almost impossible to extract all the water available from a certain volume of air and water mixture, so the above calculations only produce a maximum theoretical value. These values are, however, significant enough to attempt to achieve even a fraction of and convinced the team that using a refrigeration system along with an induced flowrate of fog was the smart way to go. It was discovered early, as one might intuitively think, that the amount of water available for extraction is directly proportional to the flowrate of the system. Thus, comparisons of gallons per cubic foot per minute (g/cfm) became useful. With this measurement the team could assess the maximum potential water extraction depending on temperature difference. In essence the team was able to determine that a reasonable amount of water could be extracted for even small temperature changes. This information can be seen in the color band plot below.

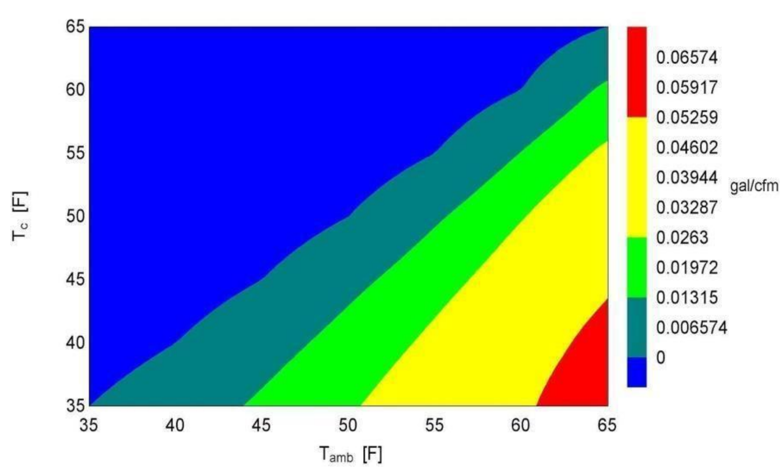

Figure 21. Color band plot showing gallons per cubic foot per minute depending on two independent temperatures (ΔT)

The other bench mark for water collection is a minimum target value based on the water extracted by a simple window air conditioner. Even though the main function of an air conditioner is not to extract water, water is still a byproduct of the vapor compression system that most air conditioners use to cool air. An experiment has been performed in order to determine the amount of water that a 5,000 Btu air conditioner running at approximately 450 Watts can produce. The collection rate was found to be approximately ⅓ of a gallon in one hour, this test was performed at 85% relative humidity, and approximately 250 cfm.

Chapter 4: Description of the Final Design

Detailed Design Description:

The final design, shown in Figure 22, consists of a refrigeration cycle where the evaporator sits in a fan-fed rectangular duct. The refrigeration cycle is powered by a 2490 btu/hr rated Copeland condensing unit, which is composed of a ¼ hp semi-hermetic compressor, a fan- blown condenser, and a receiver. This unit is connected via 1/8th inch copper tubing to four evaporators within the duct. The copper tubing will be routed with the help of ¼ inch brass compression fittings (unions and tees). The duct is rectangular and made of ¼ inch polycarbonate plastic. The evaporators are positioned such that there is a pair of front and back evaporators side by side with another identical pair. The evaporator pairs are connected in series, with the coolant running through the back evaporator first and the front evaporator second. The fog is drawn into the duct using a pair of fans (one per pair of evaporators). These fans will be run a variety of flowrates to test the optimal operating condition for condensation, but are rated for 230 cfm. The four evaporators and two fans will be connected to the inside of the duct using pegs fixed to the duct floor, such that they are held in place but not fixed. The coolant (R134a) lines will run out of the top portion of the back of the duct and connect the evaporators to the condensing unit. Since one pair of evaporators is connected in parallel to the other pair, the entering and exiting lines meet in a T-joint before and after the condensing unit. In order to control the coolant flowrate, two expansion valves and a ball valve will be connected in parallel between the receiver and the evaporators. The ball valve will control broad flowrate change, while the expansion valves will be used to fine-tune the system flowrate. Two Yellow Jacket temperature and pressure gauges will be used to monitor the high-side and low side pressures and temperatures to provide added control and precision to the system. The entire duct will be screwed to a fixed plate along with the condensing unit. The condensing unit will be directly behind the duct in order to route some of the cold air coming out of the duct through the condenser. The duct will be mounted at a 3 degree angle, tipped forward as seen in figure 23. This will allow condensation to flow out the front of the duct, which will have a small lip with a break and one corner, channeling the condensate into a collection bin. This requires that the system be on an elevated surface.

The entire system is mounted on a table with wheels to allow for some mobility. The power cords from the two fans and the condensing unit will be connected through a power strip, a wattmeter, and then plugged into a standard outlet.

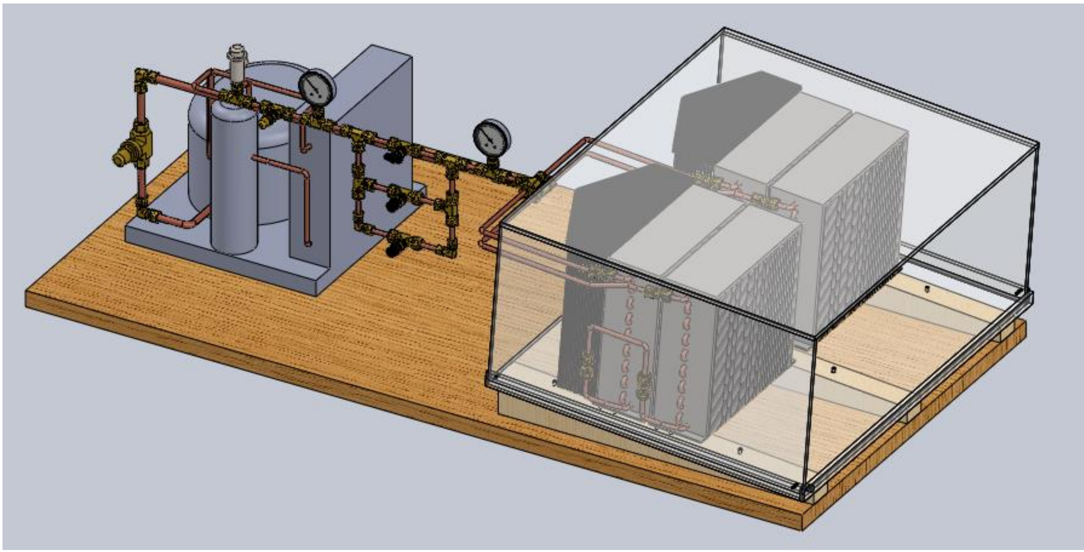

Figure 22. Isometric view of the final design.

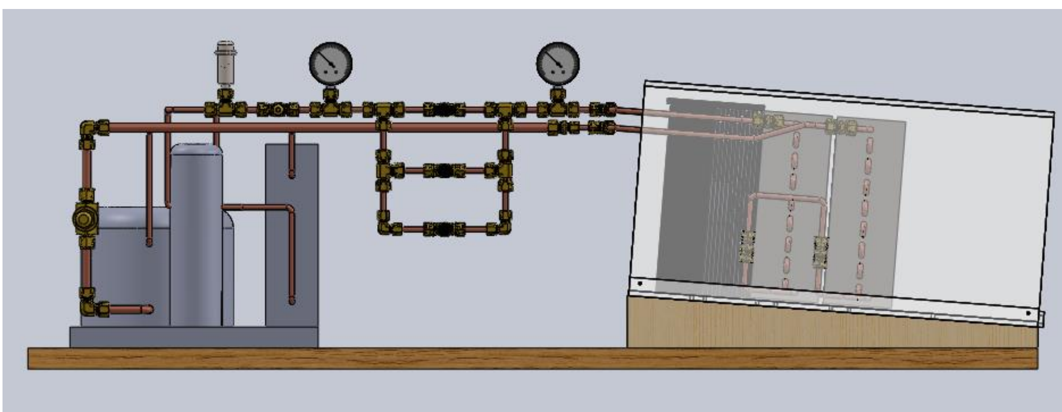

Figure 23. Front view of the final design which allows the wedges and tilt of the unit to be seen as well as the connections to the compressor.

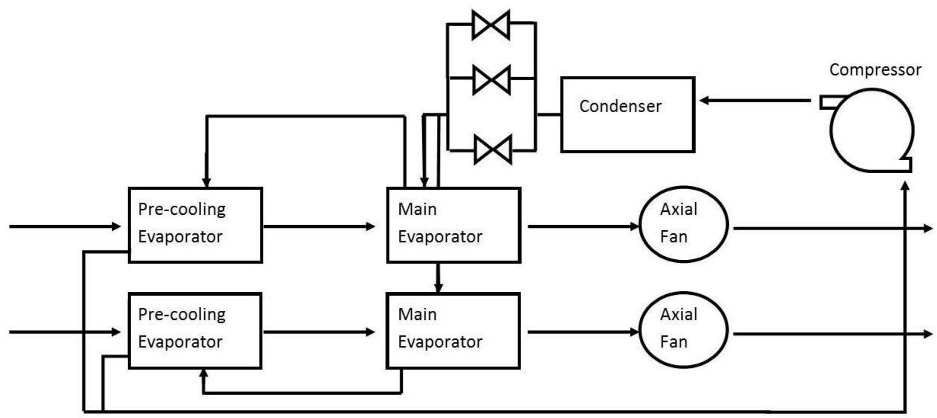

Figure 24. Final design system diagram.

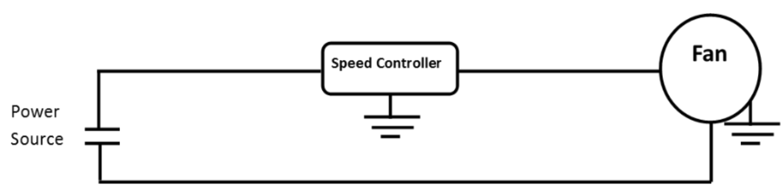

Figure 25. Wiring diagram for fan and speed controller

Analysis Results

Air to air regeneration was included in our preliminary design in the hopes that its usefulness would outweigh the additional geometric complexity and head loss it would bring. Analysis in EES modeled the air-air heat exchanger as a series of tubes running vertically through the duct. The flow parameters were pulled from the previously completed psychrometric analysis, and the NTU-Effectiveness method was used to determine the heat transfer provided by the heat exchanger in the most favorable conditions expected. These assumptions include turbulent flow throughout the system to provide maximum heat transfer, and a generous twenty degree Fahrenheit temperature difference. The analysis showed a maximum heat transfer of approximately 8 btu/hr per tube, depreciating as more tubes were added. It was calculated that more than 30 tubes would be needed to reach a twentieth of the heat transfer that our main evaporator provides, around 2490 btu/hr. It was concluded that the effectiveness of the air to air regeneration is low, such that it is not worth including in the final design. (Appendix D2)

Water to coolant regeneration was also a feature of the preliminary design. Using an EES code similar to the one that modeled the air to air regeneration, it was found that the water- coolant regeneration would only be able to provide 35 btu/hr of heat transfer with 10 feet of submerged copper piping. This is also very low compared to the heat transfer of the main heat exchanger. Unfortunately, the increased thermal conductivity of the water is offset by the extremely low flowrate due to using only the water we collect. Similar to the air to air regeneration, it was concluded that water to coolant regeneration was not effective enough to include in the final design. (Appendix D3)

It was also very important to analyze the refrigeration cycle in order to determine the state of the refrigerant at every point in the cycle. This was modeled in EES using an ideal refrigeration cycle with first law analysis. The rated cooling load of 2490 btu/hr, compressor work output of ¼ hp, expected 55 to 35 degrees Fahrenheit temperature drop, and rated maximum pressures of 440 psig high side and 162 psig were used to define the other points in the system. The analysis showed that our compressor will be sufficient to handle to cooling load of 2307 btu/hr calculated via the psychrometric analysis, and provided a flowrate of 0.008 lbm/s that is fairly standard for similar cycles, and easily attainable using the selected expansion valves. This code does not take into account the series and parallel evaporators that are present in the design. In the ideal model, a constant specific enthalpy across all four evaporators and an undivided flow through the compressor and condenser make a single evaporator model very similar to the four evaporator model. Different behavior is expected in the prototype, and extensive testing with different refrigerant flowrates will be conducted to fill in this analytical gap and determine the optimal flowrate for condensation. (Appendix D4)

Sizing the fan to draw the fog through the system consisted of two analysis steps. First, the system was modeled using the energy equation of fluid dynamics in which pressure head is related to fluid speed, among other things. The model included losses due to the complex geometry of the system (multiple heat exchangers, meshes, screens) and losses due to the length of the duct. Losses due to changes in height and pressure were excluded since the duct is open to atmospheric pressure and is does not undergo significant elevation changes. EES software helped to model this system curve by revealing how the pressure head would vary with changes in flowrate. Second, the system curve was compared to a variety of fans by means of overlaying the fan performance curves on the system curve plots. The main precaution for selecting the axial fan was ensuring that the fan would not try to operate in the stall region. There were a few fans that showed an operating point with our system outside of the stall region and it turned out that the fans on the old Cal Poly ME condensing units possessed these ideal qualities. Thus, for the sake of saving money, one of these fans was selected to provide the ideal flowrate of approximately 230 CFM.

Cost Analysis and Bill of Materials

The following is a list of all the equipment needed to produce this system. The list is split up into subcategories based on the type of component and the total cost for the system is shown and the bottom.

Fittings:

Description	Source	Part Number	Quantity	Cost ($)
Easy-Align Brass Compression Tube Fitting, Straight Connector for 1/4" Tube OD	McMaster Carr	5220K23	8	25.20
Easy-Align Brass Compression Tube Fitting, Tee for 1/4" Tube OD	McMaster Carr	5220K137	6	50.64
Quick-Assembly Brass Tube Fitting, Inline Tee for 1/4" Tube OD X 1/8 NPT Female Pipe	McMaster Carr	7473T83	3	58.53
Easy-Align Brass Compression Tube Fitting, Reducing Straight Connector for 3/8" X 1/4" Tube OD	McMaster Carr	5220K284	1	10.93
Easy-Align Brass Compression Tube Fitting, 90 Degree Elbow for 3/8" Tube OD	McMaster Carr	5220K55	2	14.30
Quick-Assembly Brass Tube Fitting, Inline Tee for 3/8" Tube OD X 1/4 NPT Female Pipe	McMaster Carr	7473T85	1	21.60
Easy-Align Brass Compression Tube Fitting, 90 Degree Elbow for 1/4" Tube OD	McMaster Carr	5220K53	2	12.38
Quick-Assembly Brass Tube Fitting, Inline Tee for 1/4" Tube OD X 1/4 FNPT	McMaster Carr	7473T84	1	19.63
			Total	213.21

Gauges and Valves:

Description	Source	Part Number	Quantity	Cost ($)
2 1/2" Gauge (°F), Red Pressure, 0-500 Psi R134A	Test Equipment Depot	49051	1	15.18
2 1/2" Gauge (°F), Red Compound, 30" 0-120 Psi R134A	Test Equipment Depot	49052	1	15.18
Access Valve, Half Union, 1/8 MPT, Pk 5	Grainger	20W306	1	8.49
Access Valve, Half Union, 1/4 MPT, Pk 5	Grainger	20W307	1	10.09
SS High-Pressure Proportional Relief Valve, 1/4 in. MNPT x 1/4 in. Swagelok Tube Fitting, Buna N Seal	Swagelok	SS-4R3A1-BU	1	157.50
Brass 1-Piece 40 Series Ball Valve, 0.6 Cv, 1/4 in. Swagelok Tube Fitting	Swagelok	B-42S4	1	46.88
Brass Low-Flow Metering Valve, 1/4 in. Swagelok Tube Fitting, Vernier Handle	Swagelok	B-SS4-VH	2	257.92
			Total	511.24

Fasteners:

Description	Source	Part Number	Quantity	Cost ($)
Screw for Wood, Phillips, Type 316 Stainless Steel, No. 8, 1" Long, packs of 25	McMaster Carr	9029A729	1	6.76
Bracket, Zinc-Plated Steel, 2" Length of Sides	McMaster Carr	17715A44	4	7.28
Fasteners	Miners Ace Hardware	N/A	42	25.86
Fasteners	Miners Ace Hardware	N/A	56	15.21
			Total	55.11

Duct Components:

Description	Source	Part Number	Quantity	Cost ($)
Weld-On 16 Cement (5 oz tube)	Tap Plastics	N/A	1	9.25
Polycarbonate Clear Sheets .236"x25"x30" for Duct	Tap Plastics	N/A	4	266.68
			Total	275.93

Refrigeration Supplies:

Description	Source	Part Number	Quantity	Cost ($)
Condensing Unit	URI	M2FH0026IAA103	1	400.00
Repurposed Condensers	N/A	N/A	4	0
Multipurpose Copper Tubing, 1/8" Tube Size, 1/4" OD, .152" ID, .049" Wall, 50' Coil	McMaster Carr	8955K112	1	79.46
Copper Tubing 3/8"x50'	Miners Ace Hardware	N/A	1	6.46
Copper Tubing 3/8"x50' and Fasteners	Miners Ace Hardware	N/A	5	7.38
Solid State Variable Speed AC Electric Motor Control	Amazon	8811007	2	49.08
			Total	542.38

Miscellaneous Supplies:

Description	Source	Part Number	Quantity	Cost ($)
Electric Tape 3/4"	Miners Ace Hardware	N/A	1	0.85
Tripp Lite Eco Green Switched 7 Outlet Conserve Energy Surge Protector	Amazon	TLP76MSG	1	27.17
Mobile 24"W x 48"L Rectangular Activity Table with 1.25" Thick High Pressure Oak Laminate Top and Standard Height Adjustable Legs	Belnick Inc	XU-A2448-REC-OAK-H-A-CAS-GG	1	74.99
Graduated Clear Plastic Cylinder, 1000 ml Cap, 10.0 ml Graduations, 17-1/4"	McMaster Carr	4436T37	1	27.35
			Total	130.36

System Cost:

Description	Cost ($)
Fitting Total	260.72
Gauge and Valve Total	521.44
Fasteners Total	55.11
Refrigeration Supplies Total	542.38
Duct Components Total	275.93
Miscellaneous Total	130.36
Total Shipping Cost	240.56
System Cost	2026.50

Material, Geometry, & Component Selection

Material selection was for this design was largely driven by industry standard practice. The evaporators and condenser are stock, and they use the standard aluminum fins with copper tubing. ¼ inch OD copper tubing was the obvious choice for our refrigerant lines, as the aforementioned evaporators and condenser already had it built in. ¼ inch brass compression fittings were chosen because of their relatively low cost and appropriate pressure ratings. Only the duct gave much of a choice in the way of material selection. Instead of standard aluminum, ¼ inch clear polycarbonate sheets were chosen for the duct material because of its safety (it is not very brittle), corrosion resistance, UV light resistance (it resists ultraviolet light degradation), clarity (so students in the lab can see the condensation that occurs on the evaporators), machinability (it can be easily sawed), low thermal conductivity (it can be used at temperatures from -30 °F up to 190°F), (21) low electrical conductivity, light weight, rigidity. Weld-on 16 acrylic plastic cement was chosen for gluing the polycarbonate sheets together. Weld-on 16 is a very high strength, clear, fast curing acrylic cement that apply to extruded acrylics. Initial bonds form very quickly, bond strength continues to develop very rapidly reaching a substantial level within hours (22). In addition, joints are water and weather resistant. A rectangular duct geometry was chosen to fit the shape of the evaporators, and is the most easily manufacturable shape. The coolant lines run out the top corners of the duct so that pressure gauges can be attached near the expansion valves and be visible to the user. Since weld-on 16 is a chemical solvent, gloves and safety glasses are required for the gluing process of the rectangular duct. The instructions are as follows. Apply weld-on 16 to the edge of one of the sheets. Bring the two surfaces in gentle contact for several seconds to allow the dry surfaces to be softened. Assemble with firm pressure while parts are still wet. Clamp assembled parts for at least 24 hours. Thereafter, strength will continue to increase gradually for some weeks.

Component selection was more involved. The main component of this design is the condensing unit. This includes the compressor and condenser with a coupled fan. This component was chosen using the heat load calculated using the psychrometric analysis in EES. The unit purchased has a higher heat capacity than is required, and has the desired accessories, such as a power cord, receiver with a shutoff valve, and suction service valve. The evaporators are actually condensers pulled from old condensing units. These fit the design needs particularly well because the fins are not as close together as on regular evaporators. This will allow more room for condensation to occur while not having water droplets spanning the space between fins. This does result in a lower overall surface area per evaporator, but this will be balanced by using multiple evaporators.

Expansion valves come in step sizes and their capacity is dependent upon the flowrate of the refrigeration cycle. The flowrate of the R134a in this system was calculated and the compared to water through specific gravity. Charts provided by Swagelok were then used to identify which model of expansion valve was desirable for this purpose. A brass expansion valve with a Vernier scale was chosen because it would be able to endure the system cycle and would provide the most accurate means for controlling the evaporators. To complement the expansion valves a ball valve was chosen that would allow the system flowrate to be coarsely adjusted to a point where the system can be fine-tuned use the Vernier expansion valves. The expansion and ball valve assembly would be built from six ¼ in compression tee fittings as seen in Appendix F. Finally, two Yellow Jacket pressure and temperature gauges will be used to monitor the temperature of the evaporator and condenser as well as the pressure throughout the system.

Safety Considerations

The design for the safe operation of the system have been considered from two aspects, design safety and operation safety. In terms of design safety, four major potential hazards have been identified with corrective actions. First of all, the non-corrosion resistant components will be coated with oil, paint, or grease as the system will be in contact of water, and corrosion may occur and damage the components; Second of all, the large suction force at the entrance of the duct may pull user's hair or sleeves into the machine and create injuries. A solid screen will be installed at the entrance of the duct to prevent objects other than fog from getting in; thirdly, sharp edge plastic corner protectors will be added to sharp edges to prevent cuts. Lastly, contact with refrigerant can cause a variety of injuries including burns and frostbite. And the system will contain hot pressurized refrigerant, which may result in injuries if the hot pipes explode due to high pressure. Therefore, a housing will be installed to the condensing unit to prevent the hot pressurized refrigerant from spilling out of the machine. The housing will also prevent user from touching the hot pipes and getting burned.

However, during the testing of the system two of the four major potential hazards have been proven to have negligible effects on safety. The first one was that the system is already resistant to corrosion, including the fittings, condensing unit, and the evaporators which all have been treated to be corrosion-proof, and the wooden base and the duct assembly made out of polycarbonate. Therefore corrosion of the system will not be a major concern in terms of safety. Secondly, the suction force at the entrance of duct was tested to be minimal and is not strong enough to pull user's hair or sleeves into the fan blades. Furthermore, the evaporators located in front of the fans also act like an extra protection that keeps user from getting hurt by the fans.

As far as the sharp edges of the system and the hot pressurized refrigerant, future corrective actions are necessary to ensure safety, such as adding sharp edge plastic corner protectors to sharp edges and placing the hot pipes in a housing to prevent user from getting hurt by the spilled hot refrigerant. But meanwhile since the system is going to be used as a lab prototype, we did not take the corrective actions mentioned above for the sake of disassembling and modifying the system. One thing to keep in mind is that the returning refrigerant line will be hot when the condensing unit is functioning, so the user shall never touch it unless and condensing unit is off and cools down.

In addition, the system was modified during the testing phase by adding two fan speed controllers. To prevent electrocution, all the wiring junctions have been capped and covered by electrical tape, and the control panels were also placed in two electrical boxes to further prevent any electrical leakage.

Apart from the potential hazards, several design considerations have also been implemented to assure the safe operation of the system. Valves, switches, and indicators are all readily accessible without excessive stretching. Both the condensing unit and the evaporators are removable for service and maintenance. For the aspect of operation safety, an operator's manual with safety guidelines is provided in appendix G to assure certain precautions will be taken by the user. Such as turn on the fans first then the condensing unit when starting the system; turn off the condensing unit when shutting down the system; disconnecting all power sources before attempting to perform any maintenance procedures. More details can be found in the operator's manual.

Maintenance and Repair Considerations

Maintenance and repair considerations have been extensively considered in the design. The cooling pipes were routed to the evaporators underneath top walls of the duct, closed by a removable duct ceiling. This will allow for the evaporators to be easily removed from the duct for repairs, without the need for severing the coolant lines. It also allows for easy access to the fans. It is likely that a buildup of salt or other contaminants on the evaporator fins or the fan blades will occur over the life of the system and thus will require cleaning in order to best utilize the system. In this case, the evaporator or fan should be taken out of the system through the top of the duct and hosed down and wiped clean. Should the need to drain and repair the coolant lines arise, a service valve has been placed near the condensing unit to allow for easy maintenance. Compression fittings have been chosen for the coolant lines to allow for line reorientation and easy pipe replacement, should repair be required.

Even though exposure to small amounts of the refrigerant R134a often produce no effect, but it can also cause harm or death in certain circumstances. Therefore recharge of refrigerant shall only be down by trained personnel. Ideally, a system only needs to be charged once as refrigerant is not consumed during cooling or heating. In addition, due to the large number of fittings, bends in the coils, refrigerant leakage may happen over the life of the system and may be difficult to identify. In the event of a suspicious leakage, soapy water can be sprayed on the pipes and rely on bubbles to identify any leaks. The user should also provide ventilation and contact a qualified service technician to do the repair.

Chapter 5: Product Realization

Manufacturing:

There were a few main groups of manufacturing processes for our system. These processes included: preparing the reclaimed condensers and the purchased condensing unit, preparing the duct and platform surface, and piping between the condensing unit and the evaporators. Due to the puzzle-like nature of our prototype (using reclaimed and new parts) we aimed to maintain a high level of flexibility during our manufacturing process. We were able to make adjustments to meet new criteria on a fairly efficient basis.

Preparing the reclaimed condensers (now used as evaporators) consisted of cutting the copper piping that connected the condensers to their old units. We then flushed out the condensers with acetone and pressurized air to evacuate any loose particles. For the new condensing unit we asked George Leon to solder on a section of copper pipe to the high pressure side of the unit in preparation for future piping.

The platform assembly was quite straight forward once the two by four foot by ¾ inch wooden sheet was purchased. We coated the wood with a marine grade water resistant spray to try to minimize the swelling effects of water collecting internally in the wood. After three coats of the spray the wood was ready to be mounted with the prototype. The duct was constructed by cutting ¼ inch polycarbonate sheets to outline a two foot wide by 10 inch tall duct. The sheets of polycarbonate extended a foot and a half in depth so to encompass 2 sets of evaporators 2 deep. Further polycarbonate had to be cut to aid in the redirection of air flow at the end of the duct toward the condenser so as to increase the regenerative effects of the cold air. Finally, small strips of polycarbonate approximately 10 inches tall were cut and placed inside of the duct to minimize the amount of air flowing past the duct without coming into contact with the cooling coils.

Prior to assembling the top and sides of the duct, the bottom of the duct (including the evaporators) were attached ¼ inch wood screws to the wooden platform at an angle of 6 degrees. This angle was achieved by cutting foot long strips of 2 by 4 inch lumber in half from corner to corner. The angle was incorporated to allow the water to collect at the front of the duct once reaching the bottom of the coiling fins. The top and sides of the duct were left off until the end so that the piping process could be made as easy as possible.

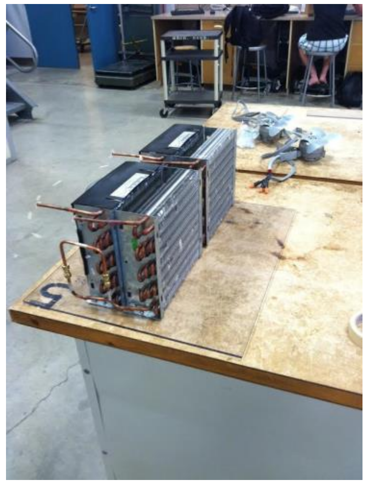

Figure 26. Evaporator Layout (Two rear evaporators providing the main cooling and two forward evaporators functioning as pre-cooling devices)

Once the condensing unit and duct were securely attached to the wooden platform we began the piping process. This process consisted of bending and attaching the 1/4 inch and 3/8 inch copper piping according the order displayed in the plan. Compression unions, T-joints, and 90 degree bends were used in connecting piping, splitting the flow of refrigerant and weaving the piping in order to connect the evaporators to the condensing unit. Between the receiver and the inlet to the evaporators we included the expansion valve assembly that consisted of two expansion valves and a ball valve. These were also connected using the same joints as mentioned above. Lastly high and low pressure gauges were placed on their respective sides of refrigerant flow to monitor the state of the operating system.

Figure 27. Expansion Valve and Gauge assembly

After the piping was finished we performed a leak test to ensure that the connections were solid and that the system could be filled with refrigerant. After a few adjustments of the fittings, the system was charged with refrigerant by Dr. Peuker and the amount of refrigerant was recorded for future reference. We then attached to top of the duct to the rest of the system and began preparing to operate the system for testing by becoming familiar with the operating controls of the system.

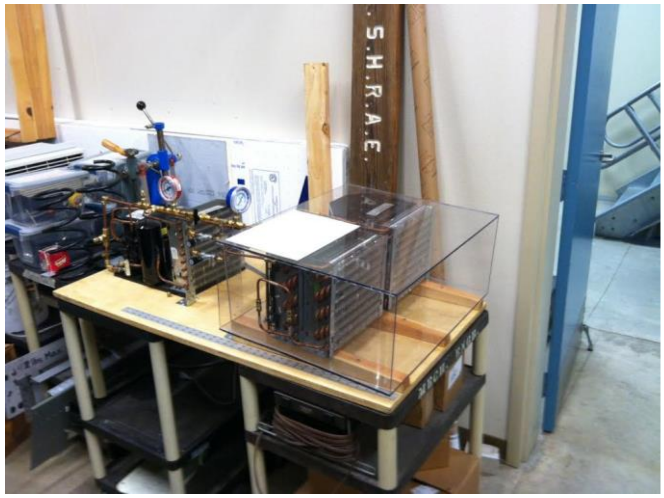

Figure 28. Assembly with condensing unit on the far left and duct with enclosed evaporators on the right.

Chapter 6: Design Verification (Testing)

Design Verification Plan

This section will elaborate on the design verification plan (DVP) first presented in the preliminary design report and will provide a detailed description of the tests performed to validate the objectives and specifications of the Active Fog Catcher.

Figure 29. Testing photos

The testing for this prototype followed a Monte Carlo structure. As many of the variables of experimentation were determined by the weather (temperature, humidity, wind, fog), it seemed like the most sensible way to take data. Tests were performed in a variety of temperature and humidity conditions. Tests were performed on Cal Poly campus, in Atascadero, Morro Bay, and Santa Margarita at all times during the night and early morning in order to find the maximum humidity condition. Flowrate was varied for the tests in order to generate the curves seen below. Most data was taken at a fairly constant vapor-compression cycle operation point, with a high side pressure of approximately 90 psi, and a low side pressure of 20 psi, with a saturation temperature of 25°F. This lead to the freezing of the first couple coils in the first evaporators.

Table 5. Test data for applicable trials of the active fog catcher.

Conditions		RH (%)	T (F)	V (cfm)	H_2O (ml)	H_2O (gal)	Energy (kWh)	H_2O Rate (Gal/kWh)	Energy (SS)* (kWh)	H_2O Rate (SS)* (Gal/kWh)
Frost	Unpulsed	84%	56	155	630	0.166	0.95	0.175	0.78	0.213
Frost	Unpulsed	83%	53	154	330	0.087	0.57	0.153	0.40	0.218
Frost	Unpulsed	85%	54	191	230	0.061	0.50	0.122	0.33	0.184
Frost	Unpulsed	83%	54	106	260	0.069	0.51	0.135	0.34	0.202
Frost	Pulsed	82%	56	106	530	0.140	0.69	0.203	0.52	0.269
Frost	Pulsed	88%	54	155	430	0.114	0.54	0.210	0.37	0.307
Frost	Pulsed	85%	55	192	220	0.058	0.45	0.129	0.28	0.208
Frost	Pulsed	93%	46	153	250	0.066	0.44	0.150	0.27	0.245
	Pulsed	87%	57	154	440	0.116	0.56	0.208	0.39	0.298

*Steady state

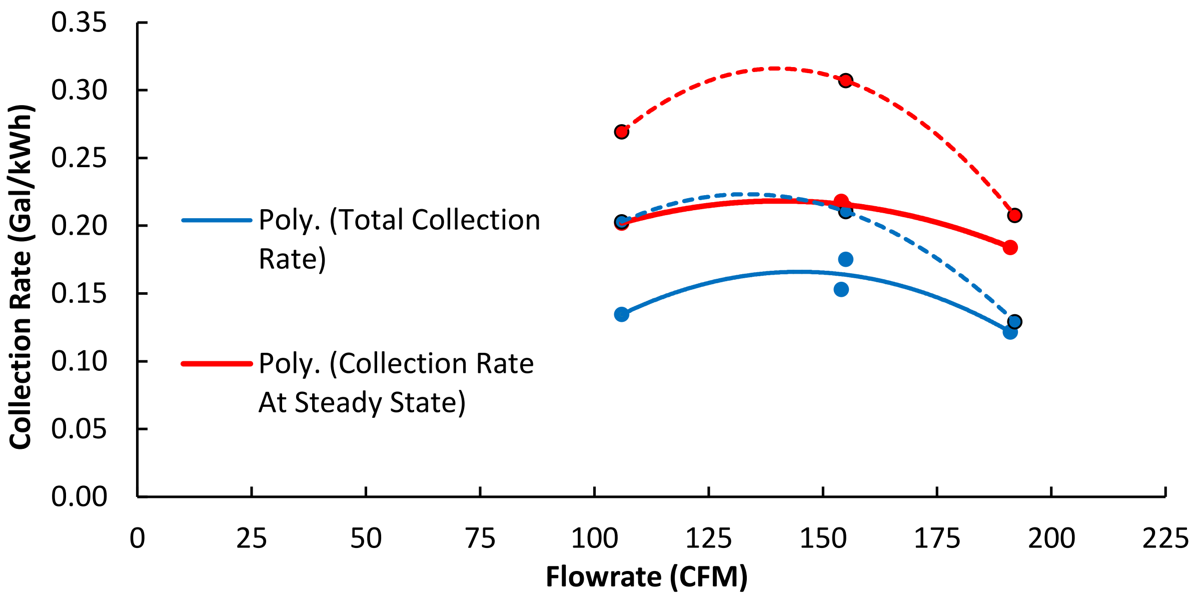

Figure 30. Collection rate vs. flowrate for applicable 85% humidity, frosted, pulsed and unpulsed, experimental trials.

Table 5 shows the test data for all of our relevant experimental trials (with fan speed variation). “Frost” denotes whether an operating condition where the first three coils on each evaporator were allowed to frost, and “pulsed” denotes an operating condition where the fans were turned up to maximum speed for 5-15 seconds every ten minutes. The table also has two collection rate values for each trial, a regular collection rate and a steady state collection rate. The regular rate is simply the total amount of water collected divided by the total power used during the entire test period. The steady state rate is the amount of water collected divided by the power used from the first drop collected to the end of the test period. The steady state collection rate is meant to give an idea of how the prototype would perform during long periods of operation. As a reference, the startup throughout all of the tests averaged about 17 kWh of energy usage, and lasted approximately 25-30 minutes.

Figure 30 shows a graphical representation of the test data; a collection rate as a function of flowrate. The graph depicts the regular and steady state collection rates for pulsed and unpulsed trials around 85% (±3%) relative humidity. Only tests performed at the frosted operating condition were graphed for the sake of consistency. Trendlines were added in order to show the approximate relationship between flowrate and collection rate. The graph shows that there is a “sweet spot” flowrate that results in the maximum collection rate. For 85% humidity, this maximum occurs around 150 cfm for the unpulsed trials and 140 for the pulsed trials. In 100% humidity fog conditions, it is expected that this maximum would shift to the right, as there would be no need to allow for more time to cool the air to the dew point. It is suspected that this maximum is due to the flowrate providing an optimal balance between providing maximum water vapor movement through the system while still allowing enough time for the air to be cooled to the dew point and water condensed out of it. Too low a flowrate results in less water moving through the evaporators than they can condense, wasting cooling energy. Too high a flowrate results in wasting cooling energy to cool air that moves too quickly through the evaporators to reach the dew point.

The graph also shows that pulsing yields a higher water collection rate. While the exact reason behind this is unknown, the team’s theory is that by increasing the flowrate, it causes many of the condensed water droplets on the evaporator fins to start rolling and collecting other droplets before falling off of the fins. This frees up that space for more condensation to occur, as condensation is easier on a bare surface than on other droplets. It is also apparent that the pulsing is less effective at higher flowrates. This makes sense because at higher flowrates, a pulse is less of a flowrate increase, and less relative flowrate change would result in less relative droplet movement.

Chapter 7: Conclusions and Recommendations

Without test data for 100% humidity fog conditions, it is difficult to come to a definitive conclusion regarding the effectiveness of the prototype. However, based on the collected data, it can be said that the prototype operates comparably to a dehumidifier in 80-95% humidity (suboptimal conditions). Concerning the other competition, the prototype is able to collect water much faster than passive collectors given a certain area, and in non-foggy conditions, but at a non-zero energy cost. It also collects water much less energy efficiently than desalination, but without the enormous capital investment and footprint. That being said, there are several areas for improvement with this prototype that could potentially push it into viability.

The condensing unit is one of the parts with the greatest room for improvement. The installed condensing unit is undersized for the evaporator area of the system. This results in only partial cooling taking place in the evaporator array, specifically focused in the first halves of the first two evaporators. The single plane of coils in the condenser makes it hard for the condensing unit to reject enough heat to support such a large evaporator array. This leads to the compressor working at capacity for the entirety of operation. Additionally, the compressor is designed for a refrigerator/freezer application, which means a high temperature difference (~50°F), while the prototype design condition has a low temperature difference (0-5°F). The compressor is designed for this high temperature difference because refrigeration and freezer applications require the system to be able to reject heat to high temperature ambient air (>90°F). While operating in foggy conditions, it would only have to reject heat to much lower temperature ambient air (<60°F). This is an inefficient operating point for the installed compressor. Currently, the compressor heats the refrigerant to a high temperature, it rejects as much as it can through the small condenser, and then the expansion valves have to provide considerable restriction in order cool it down to the proper evaporator temperature. Ideally, the compressor would heat the refrigerant to a lower temperature, but at a higher flowrate. The refrigerant would then reject heat through a larger condenser and reach the expansion valves at ambient temperature. Minimal restriction through the expansion valves would then put the refrigerant at the operation temperature. This would allow for a more efficient use of compressor work, and a more thorough cooling of the evaporator array.

The location of the refrigeration lines between the condensing unit and the evaporators could also be relocated. The central location of this line makes a solid duct connection between the back of the evaporator duct and the front of the condenser, for regeneration purposes, difficult. During testing, a flexible cardboard piece was used to create a moderately effective guide around the refrigeration lines and expansion valve assembly, but a more permanent and polished solution would be ideal in future iterations. Additionally, it was found that while using the regeneration, the large flowrate provided by the condenser fan was overpowering the evaporator fans when set for a low flowrate. In a future regenerative duct connection, it would be beneficial to have a way to open up additional passages so that the condenser can pull air from the outside while still receiving all the cold air that passed through the evaporators. This would allow for full use of regeneration while allowing for independent evaporator airflow control.

The current water draining method also has some room for improvement. While the tilted duct does let all of the collected water drain out eventually, it isn't very consistent. Water tends to puddle up, and only falls down once it grows to a size that allows it to overcome its surface tension. This leads to inconsistent "bursts" of water collection that can make it difficult evaluate the effectiveness of a certain operating point over short time periods. It also often leads to a large amount of residual water lingering in the duct after a test, which can make data collection slightly less accurate. The challenge here would be to devise a way to quickly and consistently drain the water from the evaporators without diverting any air flow away from them.

In its current form, the active fog catcher may not be an economically viable source for everyday water usage, however, its portability and size might make it useful for water collection during emergencies, such as earthquakes, where traditional water procurement methods are not available. With so many areas of possible improvement, it is not hard to believe that with some additional work, the active fog catcher could become a viable source of supplementary water collection for day to day use.

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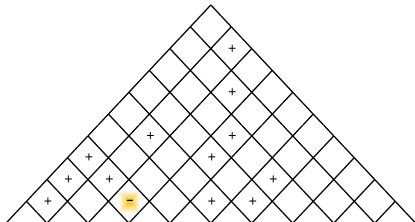
Appendix A: QFD

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▿

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

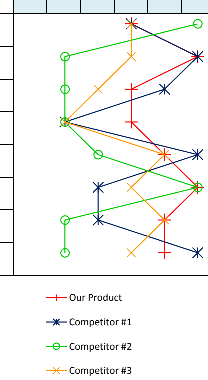


Column #	1	2	3	4	5	6	7	8	9	10
Direction of Improvement	▲	▼	▼	▼	▼	▼	▼	▼	▼	▼

WHO: Customers

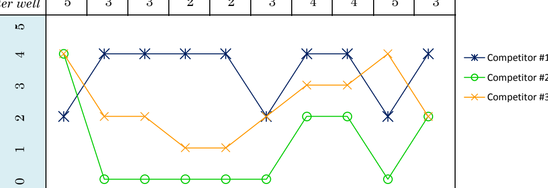
NOW: Current Product Assesment - Customer Requirements

Row #	Weight Chart	Relative Weight	Peuker (Sponsor)	Students and Staff	Operating Technicians and Man		Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	Volume/Area/Time	Power	Capital Cost	Operating Cost	Weight	Volumetric Footprint	Set up/Take Down Time	Warm up Time	Number of Non-Standard parts	Sound Intensity	Our Current Product	*Passive Collection*	*Desalination*	*Ground Water Well*	Row #
1		22%	8	8	8		9	High Water Yield	●					▿		▿			3	3	5	3	1
2		19%	7	7	7		9	Low Energy		●						▿			5	5	1	3	2
3		6%	5	1	1		9	Inexpensive			●	●					○		3	4	1	2	3
4		11%	6	2	4		9	Portable		▿			●	●	●				3	1	1	1	4
5		12%	3	5	5		3	Simple Interface							○				4	5	2	4	5
6		11%	4	6	2		9	Operation Time Efficiency	▿						▿	●			5	2	5	3	6
7		9%	1	3	6		9	Standard Parts			▿						●		4	2	1	4	7
8		8%	2	4	3		9	Quiet										●	4	5	1	3	8



	1	2	3	4	5	6	7	8	9	10
HOW MUCH: Target	44 gallons per day per unit	.0288 kWh/ft^2/day	$3,000	$.4936/ft^2/day	100 lb	27 ft^3	30 min	10 min	3	90 Db
Max Relationship	9	9	9	9	9	9	9	9	9	9
Technical Importance Rating	211.1	186.1	67.59	58.33	100	122.2	147.2	141.7	102.8	75
Relative Weight	17%	15%	6%	5%	8%	10%	12%	12%	8%	6%
Weight Chart										
Competitor #1: *Passive Collector*	3	5	5	5	5	3	5	5	3	5
Competitor #2: Desalination	5	1	1	1	1	1	3	3	1	3
Competitor #3: *Ground water well*	5	3	3	2	2	3	4	4	5	3

Current Product Assesment - Engineering Specifications



Column #	1	2	3	4	5	6	7	8	9	10

Appendix B: Pugh Matrices

Air Intake										
Concept Criteria	AC Unit Fan	Funnel	Large Surface /Mesh	Pump /Compressor	Linear Motion	Collapsible Cones	Spinning Helix	Wind Mill	Lung Thing
Air Intake rate		-	-	s	-	-	-	-	-
Power Consumption	D	+	+	-	-	-	-	-	-
Capital Cost		+	s	-	-	-	-	-	-
Operating Cost	A	+	+	-	-	-	-	-	s
Volumetric Footprint		-	-	s	-	s	-	-	-
Warm Up Time	T	+	+	-	-	s	s	-	+
Weight		+	-	-	-	s	-	-	+
Sound Intensity	U	+	+	-	-	s	+	+	+
Σ+		6	4	0	0	0	1	1	3
Σ-	M	2	3	6	8	4	6	7	4
ΣS		0	1	2	0	4	1	0	1

Codensation

Concept Criteria	AC Unit Condensing	Common Heat Exchanger	Underground	Wind Chill	Fin Cooling	Mesh Cooling	Cooling Plate	Chemicals
Condensation Rate	D	s	-	-	s	+	-	+
Power Consumption		s	+	+	s	-	+	+
Capital Cost	A	+	-	+	-	-	+	-
Operating Cost		+	+	+	+	-	s	-
Volumetric Footprint	T	+	-	-	-	-	-	+
Warm Up Time		s	+	+	-	-	+	+
$\Sigma+$	U	3	3	4	1	1	3	4
$\Sigma-$		0	3	2	3	5	2	2
ΣS	M	3	0	0	2	0	1	0

Water Extraction

Concept Criteria	Gravity	Blow Particles	Squeegee	Suction	Magnetic Field	Shake it Off
Extraction Rate		+	+	+	+	+
Power Consumption	D	-	-	-	s	-
Capital Cost	A	-	-	-	-	-
Operating Cost	T	-	-	-	s	-
Sound Intensity	U	-	-	-	s	-
$\Sigma+$	M	1	1	1	1	1
$\Sigma-$		4	4	4	1	4
ΣS		0	0	0	3	0

Appendix C: Final Decision Matrix

Concept / Criteria	Weight	The Regenerator		The U-Duct		The Plate Collector		The Helix		The Tower		The Annulator	
	Factor	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Water Collection	0.24	5	1.20	3	0.72	2	0.48	3	0.72	4	0.96	3	0.72
Power Consumption	0.20	5	1.00	3	0.60	3	0.60	4	0.80	1	0.20	1	0.20
Capital Cost	0.14	2	0.28	3	0.42	5	0.70	1	0.14	2	0.28	2	0.28
Operating Cost	0.08	3	0.24	3	0.24	5	0.40	2	0.16	1	0.08	3	0.24
Volumetric Footprint	0.08	4	0.32	2	0.16	5	0.40	2	0.16	1	0.08	2	0.16
Set Up/Take Down	0.09	5	0.45	4	0.36	5	0.45	4	0.36	3	0.27	5	0.45
Warm Up Time	0.06	3	0.18	3	0.18	4	0.24	3	0.18	2	0.12	3	0.18
# of Non-Standard	0.07	4	0.28	2	0.14	5	0.35	1	0.07	2	0.14	1	0.07
Weight	0.04	3	0.12	3	0.12	3	0.12	2	0.08	2	0.08	3	0.12
Total Score			4.07		2.94		3.74		2.67		2.21		2.42

Appendix D1: Psychrometric Analysis EES Code

$T_{amb} = 55$ [F] *Intake temperature*

$T_c = 35$ [F] *Cooled temperature*

$\dot{V} = 50$ [ft^3/min] *Volumetric flowrate*

$\rho = \rho[AIRH2O, T = T_{amb}, R = \phi, P = P]$ *Density of water air mixture at inlet temp*

$\phi = 1$ *Relative Humidity*

$P = 14.7$ [psi] *Atmospheric Pressure*

$\dot{m} = \dot{V} \cdot \rho$ *Mass flowrate*

$t = 1$ [min] *Time*

$$vel_{fog} = \frac{\dot{V}}{A_{duct}} \cdot \left| 0.016666667 \cdot \frac{ft/sec}{ft/min} \right|$$ *Velocity of fog*

epsilon = .5 efficiency of system

$omega1 = \omega[AIRH2O, T = T_{amb}, R = \phi, P = P]$ *Humidity Ratio of inlet state*

$omega2 = \omega[AIRH2O, T = T_c, R = \phi, P = P]$ *Humidity Ratio of cooled state*

$$1 + omega1 = 1 + omega2 + \frac{\dot{m}_w}{\dot{m}_a}$$ *simplified mass balance*

$\dot{m} = \dot{m}_a + \dot{m}_{v1}$ *Total mass flowrate*

$\dot{m}_{v1} = omega1 \cdot \dot{m}_a$ *flowrate of vapor*

$$v_{w,gal} = \frac{\dot{m}_w}{\rho} \cdot \left| 7.481 \cdot \frac{gal/min}{ft^3/min} \right|$$ *Volume of water available*

$\dot{Q} = \dot{m}_a \cdot [h_1 - h_2] + \dot{m}_w \cdot h_w$ *Heat transfer rate*

$h_1 = \mathbf{h}[AIRH2O, T = T_{amb}, R = \phi, P = P]$ *Enthalpy of inlet state*

$h_2 = \mathbf{h}[AIRH2O, T = T_c, R = \phi, P = P]$ *Enthalpy of cooled state*

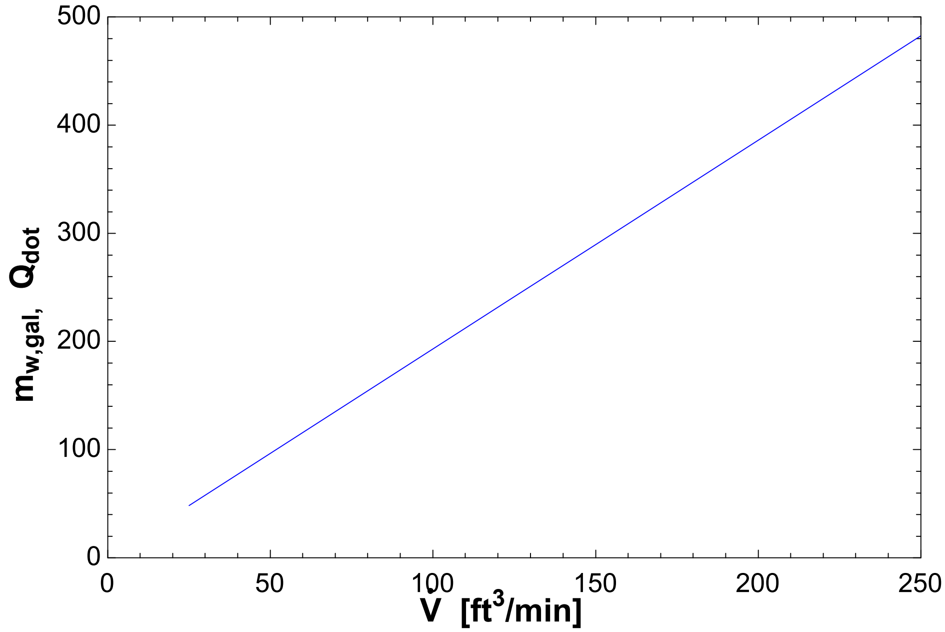
$h_w = \mathbf{h}[water, T = T_c, P = P]$ *Enthalpy of water*

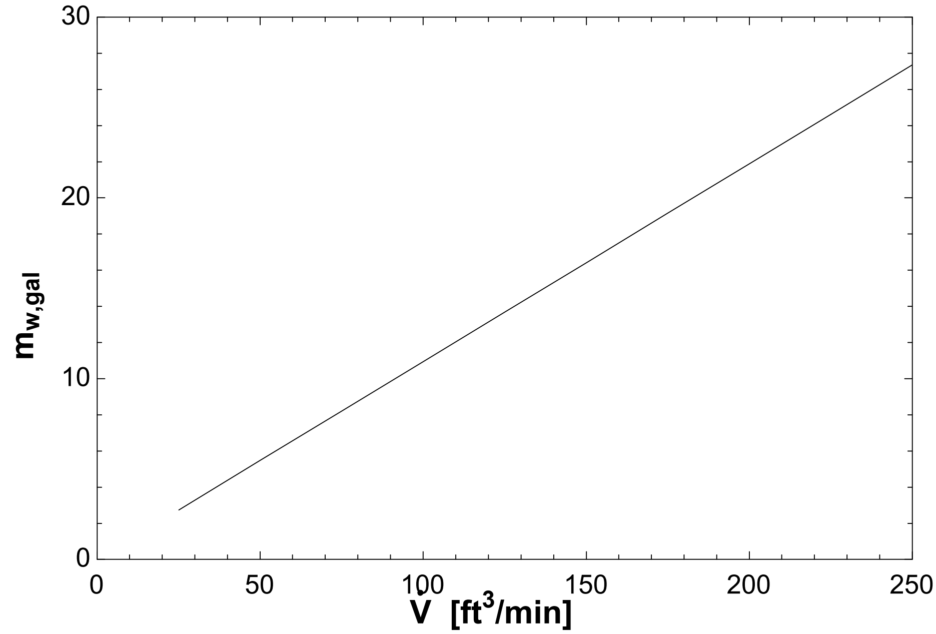
$$Ratio = \frac{omega1 - omega2}{h_1 - h_2 + [omega1 - omega2] \cdot h_w}$$

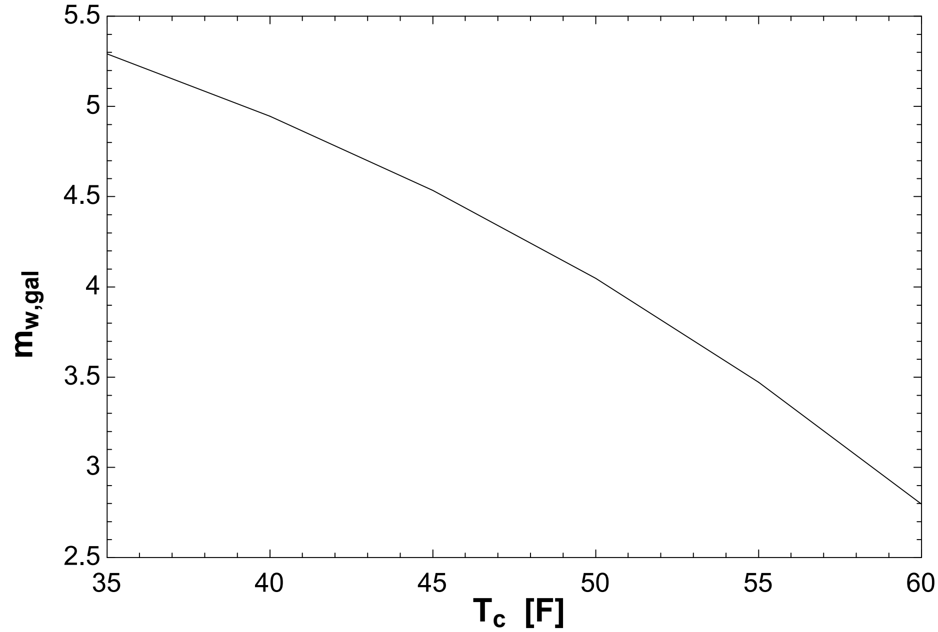
$$A_{duct} = \frac{9}{12} \cdot \frac{18}{12}$$ *Area of duct*

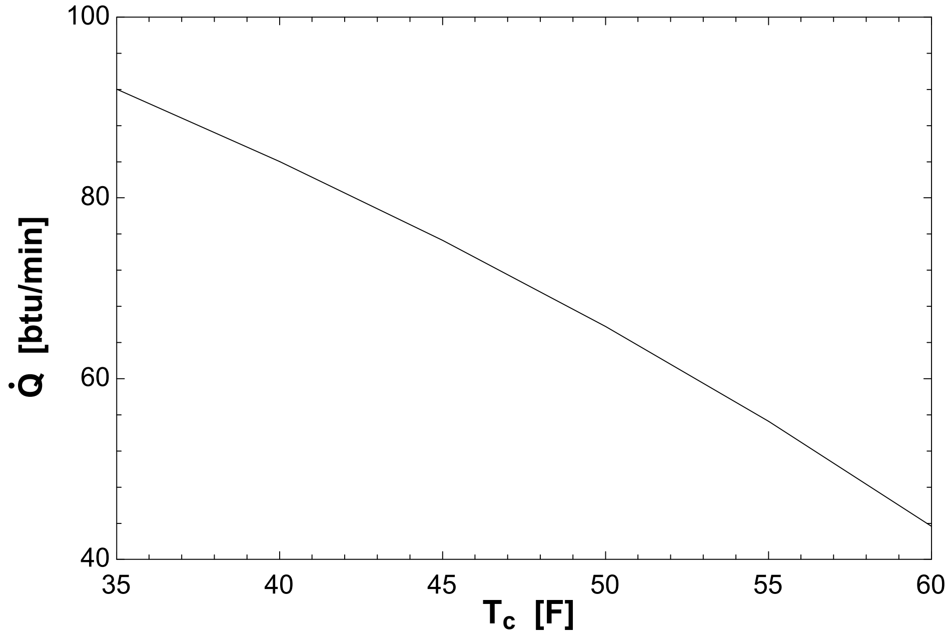
Parametric Table: Table 5

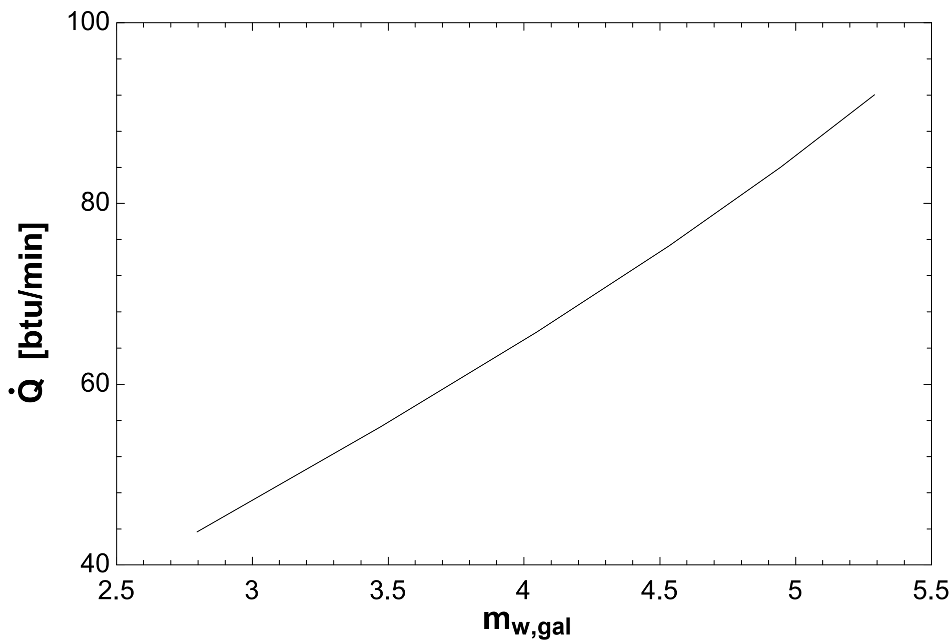
	vel_{fog} [ft/s]	ε	A_{duct} [ft2]	$v_{w,gal}$ [gal/min]
Run 1	5	0.5	*1.272E-08*	0
Run 2	5	0.5	*0.000509*	0.01111
Run 3	5	0.5	*0.001018*	0.02222
Run 4	5	0.5	*0.001527*	0.03333
Run 5	5	0.5	*0.002036*	0.04444
Run 6	5	0.5	*0.002545*	0.05556
Run 7	5	0.5	*0.003054*	0.06667
Run 8	5	0.5	*0.003563*	0.07778
Run 9	5	0.5	*0.004072*	0.08889
Run 10	5	0.5	*0.004581*	0.1

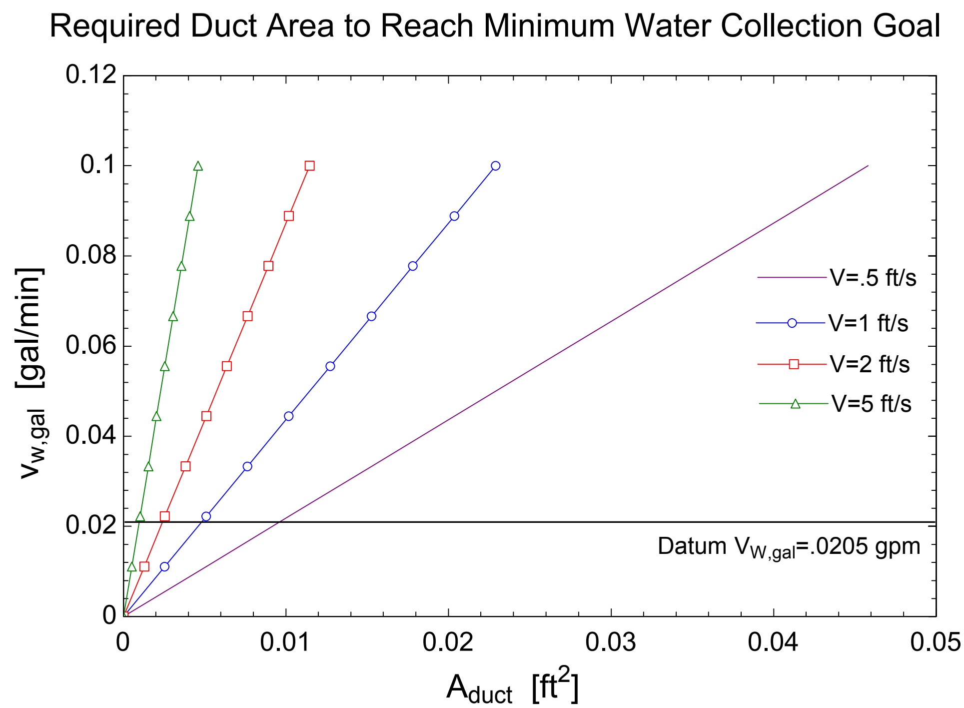



30
20
10
0
0
50
100
150
200
250
$m_{w,gal}$
$\dot{V}$ [ft^3/min]


5.5
5
4.5
4
3.5
3
2.5
35
40
45
50
55
60
$m_{w,gal}$
T_c [F]


100
80
60
40
35
40
45
50
55
60
Q̇ [btu/min]
T_c [F]


100
80
60
40
2.5
3
3.5
4
4.5
5
5.5
Q̇ [btu/min]
m_w,gal



Required Duct Area to Reach Minimum Water Collection Goal
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.01
0.02
0.03
0.04
0.05
V=.5 ft/s
V=1 ft/s
V=2 ft/s
V=5 ft/s
Datum V W,gal=.0205 gpm
v W,gal [gal/min]
A duct [ft2]

$\dot{m}_{aa} = 3.8$ *Mass Flowrate Through System*

$A_2 = 0.833$ *Area of Duct*

$V_2 = \frac{\dot{m}_{aa}}{\rho \cdot A_2}$ *Air Speed in Duct*

$T_2 = 55$ *Air Temperature in Duct*

$N_6 = 10$ *Number of Pipes*

$D_6 = \frac{1}{12}$ *Diameter of Pipes*

$A_6 = D_6^{2} \cdot \frac{\pi}{4}$ *Area of Pipes*

$V_6 = \frac{\dot{m}_{aa}}{\rho \cdot A_6 \cdot N_6}$ *Air Speed in Pipes*

$T_6 = 35$ *Air Temperature in Pipes*

$L_6 = \sqrt{A_2}$ *Length of Pipes*

$A_s = \pi \cdot D_6 \cdot L_6$ *Pipe Surface Area*

$Pr = 0.707$ *Prandtl Number*

$k_{air} = \mathbf{k}\left[AIRH2O, T = T_2, R = \phi, P = P\right]$ *Thermal Conductivity of Air*

$\mu = \mathbf{Visc}\left[AIRH2O, T = T_2, R = \phi, P = P\right] \cdot \left| 0.016666667 \cdot \frac{lbm/(ft*min)}{lbm/(ft*hr)} \right|$ *Dynamic Viscosity*

$\nu_{air} = \frac{\mu}{\rho}$ *Kinematic Viscosity*

$\rho = \rho\left[AIRH2O, T = T_2, R = \phi, P = P\right]$ *Density of water air mixture at inlet temp*

$\phi = 1$ *Relative Humidity*

$P = 14.7$ *Atmospheric Pressure*

$h_6 = NuD_6 \cdot \frac{k_{air}}{D_6}$ *Convection HT Coefficient In the Pipe*

$NuD_6 = 0.023 \cdot ReD_6^{\left[4 / 5\right]} \cdot Pr^{0.3}$ *Nusselt Number, Assume Turbulent Flow*

$ReD_6 = V_6 \cdot \frac{D_6}{\nu_{air}}$ *Reynold's Number in Pipe*

$h_2 = NuD_2 \cdot \frac{k_{air}}{D_6}$ *Convection HT Coefficient Outside the Pipe*

$$NuD_2 = 0.3 + \frac{0.62 \cdot ReD_2^{0.5} \cdot Pr^{[1/3]}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{(2/3)}\right]^{[1/4]}} \cdot \left[1 + \left(\frac{ReD_2}{282000}\right)^{(5/8)}\right]^{[4/5]}$$ *Nusselt Number, Assume Turbulent Flow*

$$ReD_2 = V_2 \cdot \frac{D_6}{\nu_{air}}$$ *Reynold's Number Over Pipe*

$$cp_2 = \mathbf{Cp}\left[AIRH2O, T = T_2, R = \phi, P = P\right]$$ *Specific Heat of Air (Specific heat difference less that 1%)*

$$Cmin = cp_2 \cdot \dot{m}_{aa} \cdot \left| 60 \cdot \frac{1/hr}{1/min} \right|$$ *Minimum Heat Capacity Rate*

$$U = \frac{1}{\frac{1}{h_6} + \frac{1}{h_2}}$$ *Total Heat Transfer Coefficient*

$$NTU = U \cdot \frac{A_s}{Cmin}$$ *NTU - Number of Transfer Units*

$$eps = 1 - \mathbf{exp}\left[1 \cdot NTU^{0.22} \cdot \left(\mathbf{exp}\left[-1 \cdot NTU^{0.78}\right] - 1\right)\right]$$ *Effectiveness*

$$\dot{q} = eps \cdot Cmin \cdot \left[T_2 - T_6\right]$$ *Heat Transfer Per Pipe*

$$\dot{q}_T = \dot{q} \cdot N_6$$ *Heat Transfer Total (sum of pipes)*

SOLUTION

Unit Settings: Eng F psia mass deg

A_2 = 0.833 [ft^2]
A_6 = 0.005454 [ft^2]
A_s = 0.2389 [ft^2]
Cmin = 55.74 [btu/(hr*F)]
cp_2 = 0.2445 [btu/(lbm*F)]
D_6 = 0.08333 [ft]
eps = 0.005911
h_2 = 1.982 [btu/(ft^2*hr*F)]
h_6 = 4.717 [btu/(ft^2*hr*F)]
k_{air} = 0.01423 [btu/(hr*ft*F)]
L_6 = 0.9127 [ft]
μ = 0.0007212 [lbm/(ft*min)]
$\dot{m}_{aa}$ = 3.8 [lbm/min]
NTU = 0.005983
NuD_2 = 11.61
NuD_6 = 27.62
ν_{air} = 0.009493 [ft^2/min]
N_6 = 10
P = 14.7 [psi]
ϕ = 1
Pr = 0.707
$\dot{q}$ = 6.59 [btu/hr]
$\dot{q}_T$ = 65.9 [btu/hr]
ReD_2 = 527.1
ReD_6 = 8050
ρ = 0.07597 [lbm/ft^3]
T_2 = 55 [F]
T_6 = 35 [F]
U = 1.396 [btu/(ft^2*hr*F)]
V_2 = 60.05 [ft/min]
V_6 = 917.1 [ft/min]

No unit problems were detected.

Parametric Table: Table 2

	N_6	$\dot{q}$ [btu/hr]	$\dot{q}_T$ [btu/hr]
Run 1	1	8.746	8.746
Run 2	2	8.364	16.73
Run 3	3	8.048	24.14
Run 4	4	7.773	31.09
Run 5	5	7.529	37.64

Parametric Table: Table 2

	N_6	$\dot{q}$ [btu/hr]	$\dot{q}_T$ [btu/hr]
Run 6	6	7.308	43.85
Run 7	7	7.107	49.75
Run 8	8	6.921	55.37
Run 9	9	6.75	60.75
Run 10	10	6.59	65.9
Run 11	11	6.44	70.84
Run 12	12	6.3	75.6
Run 13	13	6.168	80.18
Run 14	14	6.043	84.6
Run 15	15	5.925	88.87
Run 16	16	5.813	93.01
Run 17	17	5.706	97
Run 18	18	5.604	100.9
Run 19	19	5.507	104.6
Run 20	20	5.415	108.3

Appendix D3: Water to Coolant Regeneration EES Code

$T_{w,1} = 35 + 459.67$ *Water inlet temperature*

$P_{w,1} = 14.7$ [psia] *Water inlet pressure*

$\dot{m}_w = 0.000694$ [lbm/s] *Water mass flowrate*

$T_{c,1} = 55 + 459.67$ *Coolant inlet temperature*

$P_{c,1} = 454.7$ [psia] *Coolant inlet pressure*

$\dot{m}_c = 0.008$ [lbm/s] *Coolant mass flowrate*

$Cp_w = \mathbf{Cp}\left[water, T = T_{w,1}, P = P_{w,1}\right]$ *Water heat capacity*

$Cp_c = \mathbf{Cp}\left[R134a, T = T_{c,1}, P = P_{c,1}\right]$ *Coolant heat capacity*

$Cw = \dot{m}_w \cdot Cp_w$ *Water heat capacity rate*

$Cc = \dot{m}_c \cdot Cp_c$ *Coolant heat capacity rate*

$D = \frac{1}{48}$ *Pipe Diameter*

$L = 10$ *Length of Pipes*

$A_s = \pi \cdot D \cdot L$ *Pipe Surface Area*

$Pr = 0.707$ *Prandtl Number*

$k_w = \mathbf{k}\left[water, T = T_{w,1}, P = P_{w,1}\right] \cdot \left| 0.000277778 \cdot \frac{1/s}{1/hr} \right|$ *Thermal Conductivity of Water*

$\mu_w = \mathbf{Visc}\left[water, T = T_{w,1}, P = P_{w,1}\right] \cdot \left| 0.000277778 \cdot \frac{1/s}{1/hr} \right|$ *Dynamic Viscosity*

$\nu_w = \frac{\mu_w}{\rho_w}$ *Kinematic Viscosity*

$\rho_w = \rho\left[water, T = T_{w,1}, P = P_{w,1}\right]$ *Density of water air mixture at inlet temp*

$V_w = \frac{\dot{m}_w}{\rho_w \cdot A_w}$ *Water velocity*

$A_w = 2 \cdot \frac{2}{12}$ *Water area*

$k_c = \mathbf{k}\left[R134a, T = T_{c,1}, P = P_{c,1}\right] \cdot \left| 0.000277778 \cdot \frac{1/s}{1/hr} \right|$ *Thermal Conductivity of Coolant*

$\mu_c = \mathbf{Visc}\left[R134a, T = T_{c,1}, P = P_{c,1}\right] \cdot \left| 0.000277778 \cdot \frac{1/s}{1/hr} \right|$ *Dynamic Viscosity*

$\nu_c = \frac{\mu_c}{\rho_c}$ *Kinematic Viscosity*

$\rho_c = \rho[R134a, T = T_{c,1}, P = P_{c,1}]$ *Density of Coolant air mixture at inlet temp*

$V_c = \dfrac{\dot{m}_c}{\rho_c \cdot A_c}$ *Coolant velocity*

$A_c = \dfrac{\pi}{4} \cdot D^2$ *Coolant pipe area*

$h_c = NuD_c \cdot \dfrac{k_c}{D}$ *Convection HT Coefficient In the Pipe*

$NuD_c = 0.023 \cdot ReD_c^{[4/5]} \cdot Pr^{0.3}$ *Nusselt Number, Assume Turbulent Flow*

$ReD_c = V_c \cdot \dfrac{D}{\nu_c}$ *Reynold's Number in Pipe*

$h_w = NuD_w \cdot \dfrac{k_w}{D}$ *Convection HT Coefficient Outside the Pipe*

$$NuD_w = 0.3 + \frac{0.62 \cdot ReD_w^{0.5} \cdot Pr^{[1/3]}}{\left[1 + \left(\dfrac{0.4}{Pr}\right)^{(2/3)}\right]^{[1/4]}} \cdot \left[1 + \left(\frac{ReD_w}{282000}\right)^{(5/8)}\right]^{[4/5]}$$

Nusselt Number, Assume Turbulent Flow

$ReD_w = V_w \cdot \dfrac{D}{\nu_w}$ *Reynold's Number Over Pipe*

$Cmin = Cw$ *Lowest C, Cw, Minimum Heat Capacity Rate*

$Cr = \dfrac{Cw}{Cc}$ *Ratio of C's, low over high*

$U = \dfrac{1}{\dfrac{1}{h_w} + \dfrac{1}{h_c}}$ *Total Heat Transfer Coefficient*

$NTU = U \cdot \dfrac{A_s}{Cmin}$ *NTU - Number of Transfer Units*

$eps = \dfrac{1 - \mathbf{exp}[-NTU \cdot (1 - Cr)]}{1 - Cr \cdot \mathbf{exp}[-NTU \cdot (1 - Cr)]}$ *Effectiveness*

$\dot{q} = eps \cdot Cmin \cdot [T_{c,1} - T_{w,1}] \cdot \left| 3600 \cdot \dfrac{Btu/hr}{btu/s} \right|$ *Heat Transfer*

SOLUTION

Unit Settings: Eng R psia mass deg

A_c = 0.0003409 [ft^2]
A_s = 0.6545 [ft^2]
A_w = 0.3333 [ft^2]
Cc = 0.002599 [btu/(s*R)]
Cmin = 0.0006989 [btu/(s*R)]
Cp_c = 0.3249 [btu/(lbm*R)]
Cp_w = 1.007 [btu/(lbm*R)]
Cr = 0.2689
Cw = 0.0006989 [btu/(s*R)]
D = 0.02083 [ft]
eps = 0.6905
h_c = 0.009025 [btu/(ft^2*s*R)]
h_w = 0.001675 [btu/(ft^2*s*R)]
k_c = 0.00001465 [btu/(ft*s*R)]
k_w = 0.00008842 [btu/(ft*s*R)]
L = 10 [ft]
μ_c = 0.0001583 [lbm/(ft*s)]
μ_w = 0.001138 [lbm/(ft*s)]
$\dot{m}_c$ = 0.008 [lbm/s]
$\dot{m}_w$ = 0.000694 [lbm/s]
NTU = 1.323
NuD_c = 12.84
NuD_w = 0.3947
ν_c = 0.000002006 [ft^2/s]
ν_w = 0.00001823 [ft^2/s]
Pr = 0.707
$P_{c,1}$ = 454.7 [psia]
$P_{w,1}$ = 14.7 [psia]
$\dot{q}$ = 34.74 [btu/hr]
ReD_c = 3089
ReD_w = 0.03812
ρ_c = 78.89 [lbm/ft^3]
ρ_w = 62.42 [lbm/ft^3]
$T_{c,1}$ = 514.7 [R]
$T_{w,1}$ = 494.7 [R]
U = 0.001413 [btu/(ft^2*s*R)]
V_c = 0.2975 [ft/s]
V_w = 0.00003335 [ft/s]

No unit problems were detected.

Appendix D4: Ideal Refrigeration Cycle Analysis EES Code

$T_1 = 35$ *Temperature at Compressor inlet*

$T_2 = \mathbf{T}[R134a, P=P_2, h=h_2]$ *Temperature at Compressor outlet*

$T_3 = 55$ *Temperature at Condenser outlet*

$T_4 = T_1$ *Temperature at Evaporator inlet*

$P_1 = \mathbf{P}[R134a, T=T_1, x=x_1]$ *Pressure at Compressor inlet*

$P_2 = 454.7$ *Pressure at Compressor outlet*

$P_3 = P_2$ *Pressure at Condenser outlet*

$P_4 = P_1$ *Pressure at Evaporator inlet*

$x_1 = 1$ *Quality at Compressor inlet*

$x_4 = \mathbf{x}[R134a, T=T_4, h=h_4]$ *Quality at Evaporator inlet*

$h_1 = \mathbf{h}[R134a, T=T_1, x=x_1]$ *Specific Enthalpy at Compressor inlet*

$h_3 = \mathbf{h}[R134a, T=T_3, P=P_3]$ *Specific Enthalpy at Condenser outlet*

$WdotC = 1 / 4 \cdot \left| 0.7068 \cdot \frac{btu/s}{hp} \right|$ *Work done by the Compressor*

$QdotE = 2307 \cdot \left| 0.000277778 \cdot \frac{btu/s}{Btu/hr} \right|$ *Heat transfer in the Evaporator*

Evaporator

$QdotE = mdot \cdot [h_1 - h_4]$ *Evaporator First Law*

Compressor

$WdotC = mdot \cdot [h_2 - h_1]$ *Compressor First Law*

Condenser

$QdotC = mdot \cdot [h_3 - h_2]$ *Condenser First Law*

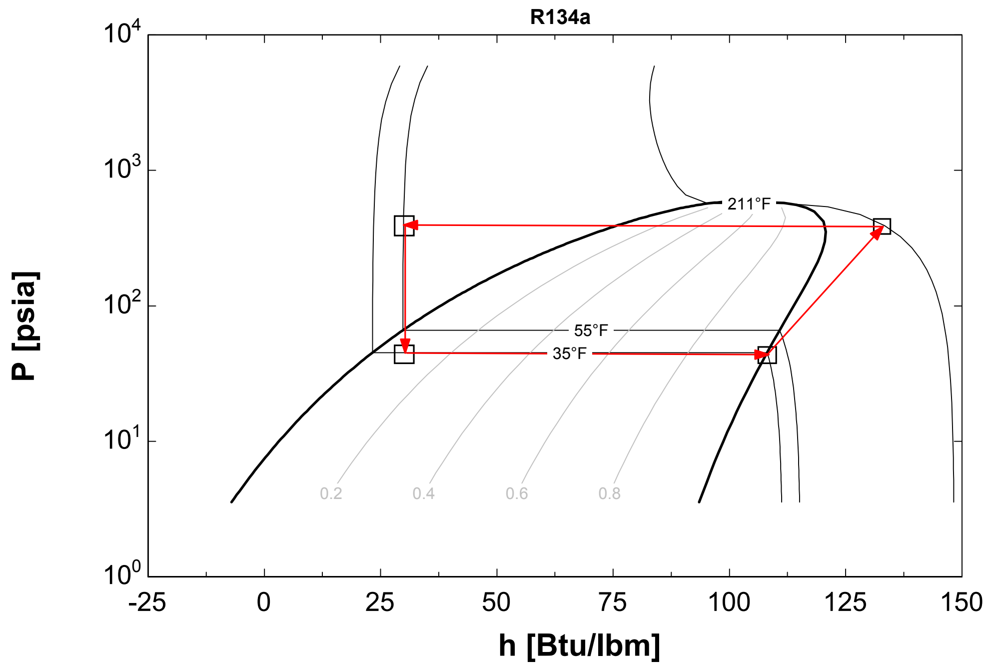
Expansion Valve

$h_3 = h_4$ *Expansion Valve First Law*

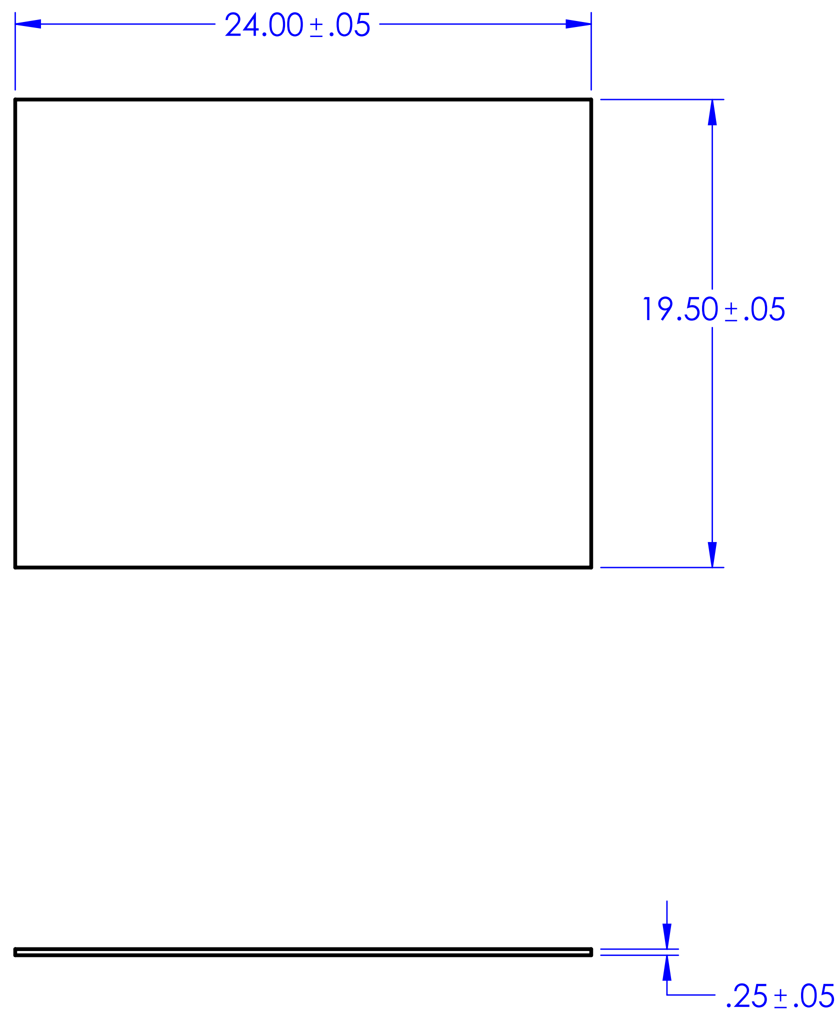
SOLUTION

Unit Settings: Eng F psia mass deg

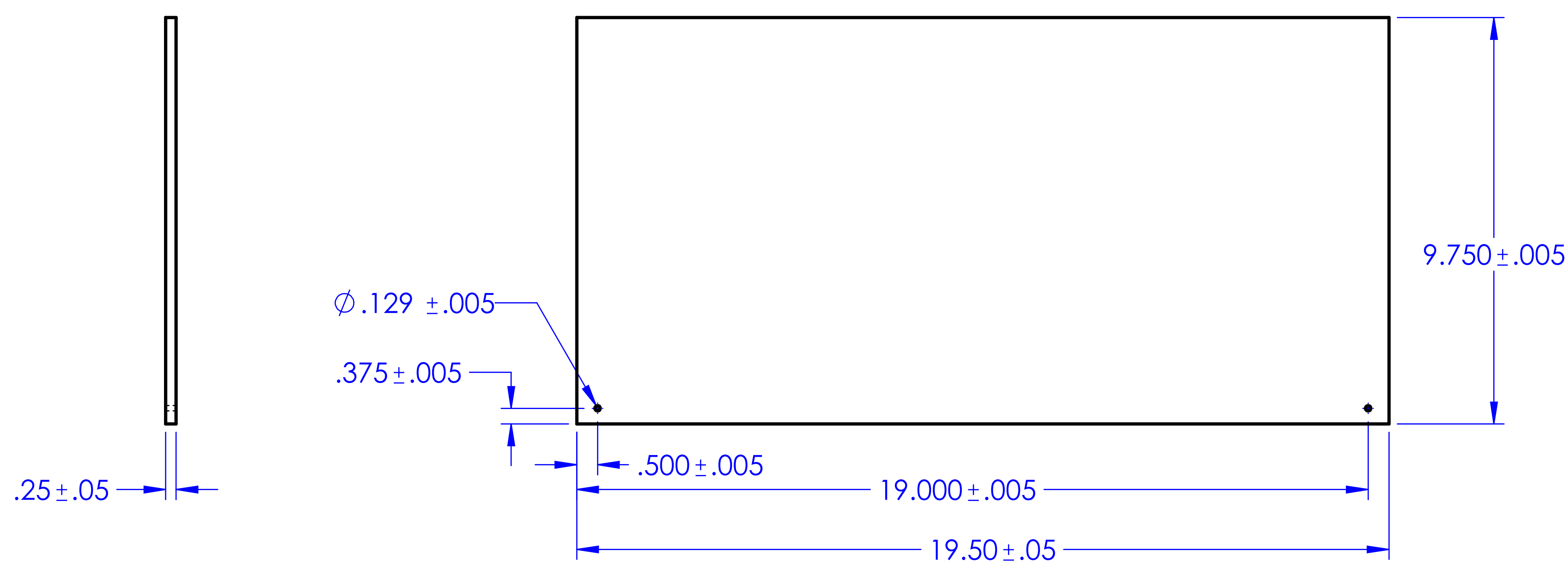
h_1 = 108.1 [btu/lbm]	h_2 = 129.6 [btu/lbm]	h_3 = 29.97 [btu/lbm]
h_4 = 29.97 [btu/lbm]	mdot = 0.008203 [lbm/s]	P_1 = 45.12 [psia]
P_2 = 454.7 [psia]	P_3 = 454.7 [psia]	P_4 = 45.12 [psia]
QdotC = -0.8175 [btu/s]	QdotE = 0.6408 [btu/s]	T_1 = 35 [F]
T_2 = 211.6 [F]	T_3 = 55 [F]	T_4 = 35 [F]
WdotC = 0.1767 [btu/s]	x_1 = 1	x_4 = 0.07908


R134a
P [psia]
h [Btu/lbm]
10^4
10^3
10^2
10^1
10^0
-25
0
25
50
75
100
125
150
211°F
55°F
35°F
0.2
0.4
0.6
0.8

Appendix E: Solidworks Drawings

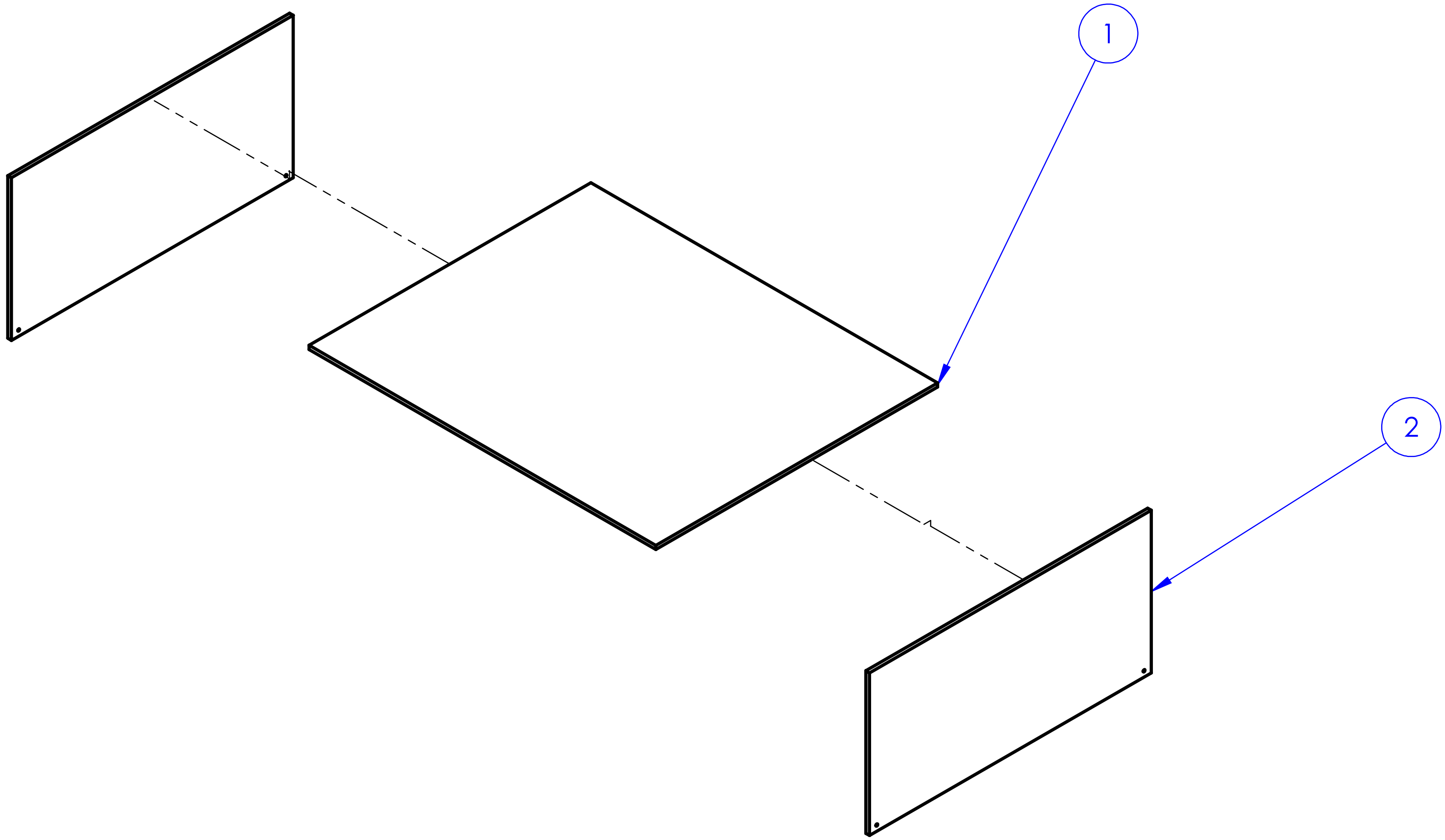


Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title:Duct Top		Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:TD1	Nxt Asb:TDF	Date:6/1/2015	Scale:1:8	Chkd. By:

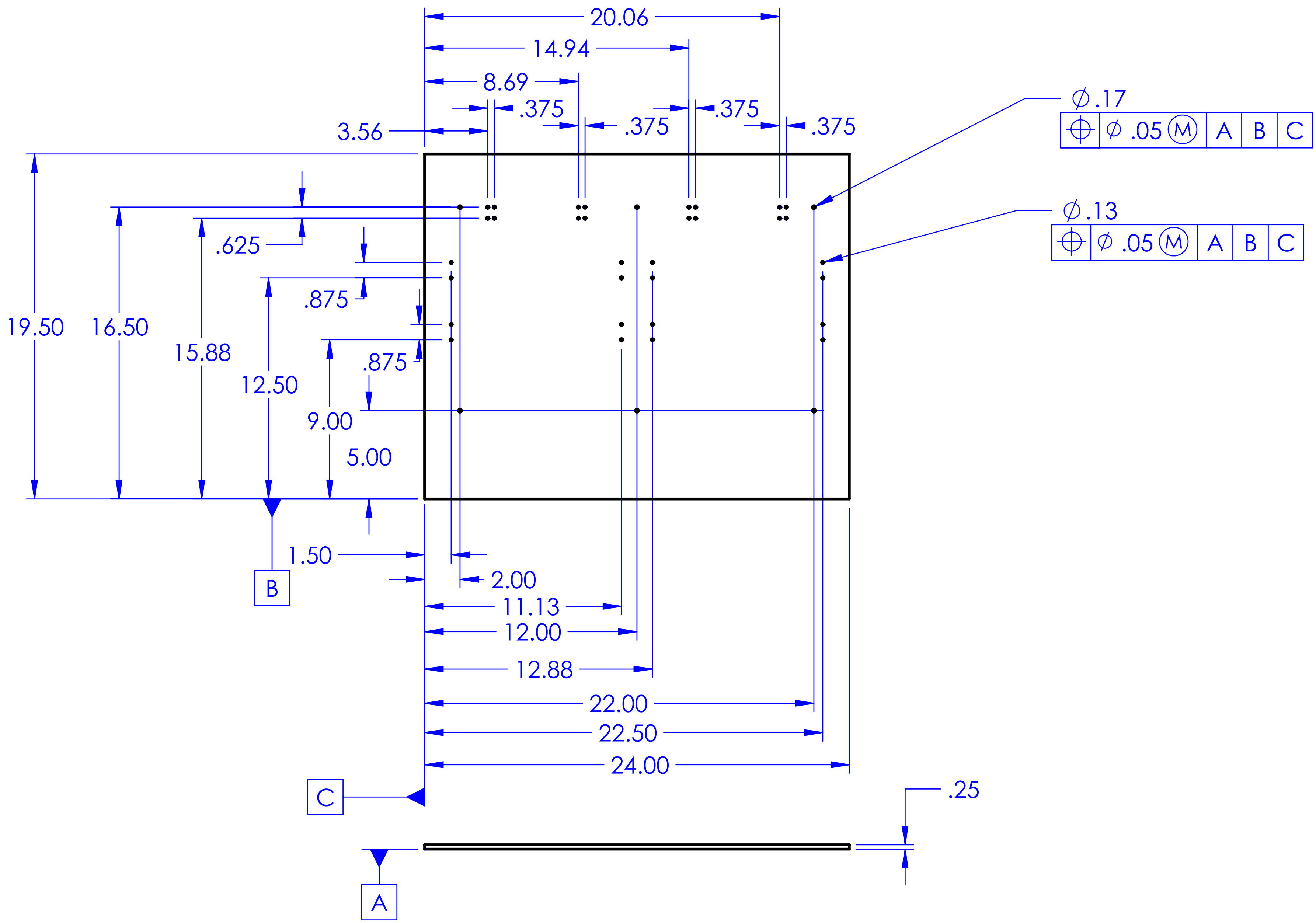


Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title: Duct Side	Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:TD2	Nxt Asb:TDF	Date:6/2/2015	Scale:1:4	Chkd. By:

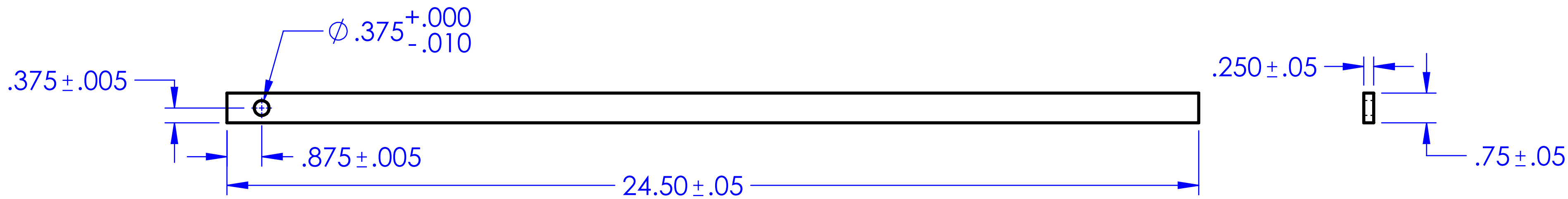
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TD1	Top of Duct	1
2	TD2	Side of Duct	2



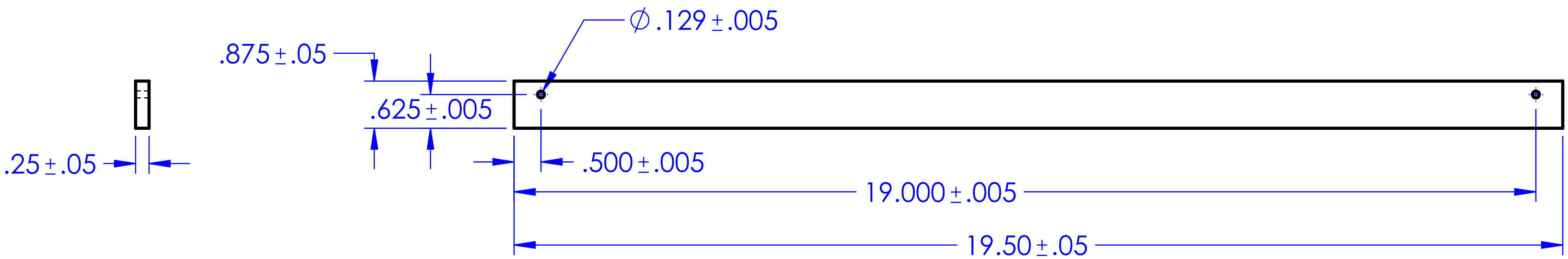
Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title:Top Duct Assembly	Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:TDF	Nxt Asb:FA	Date:6/4/2015 / Scale: 1:8	Chkd. By:



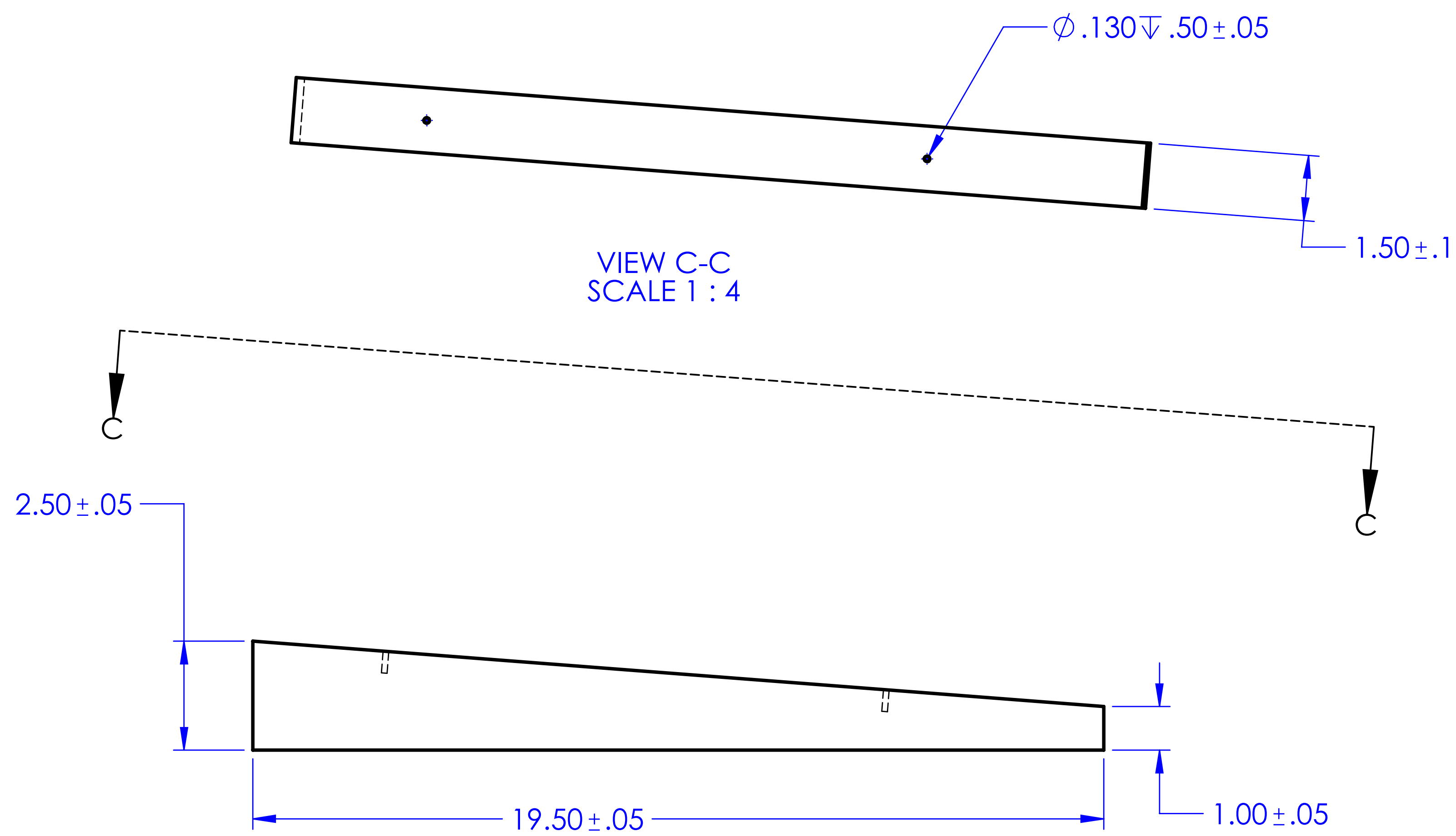
Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title: Bottom Duct	Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:DB1	Nxt Asb:DBF	Date:6/1/2015 — Scale: 1:8	Chkd. By:



Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title:Front Duct Lip		Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:DB3	Nxt Asb:DBF	Date:6/1/2015	Scale: 1:4	Chkd. By:

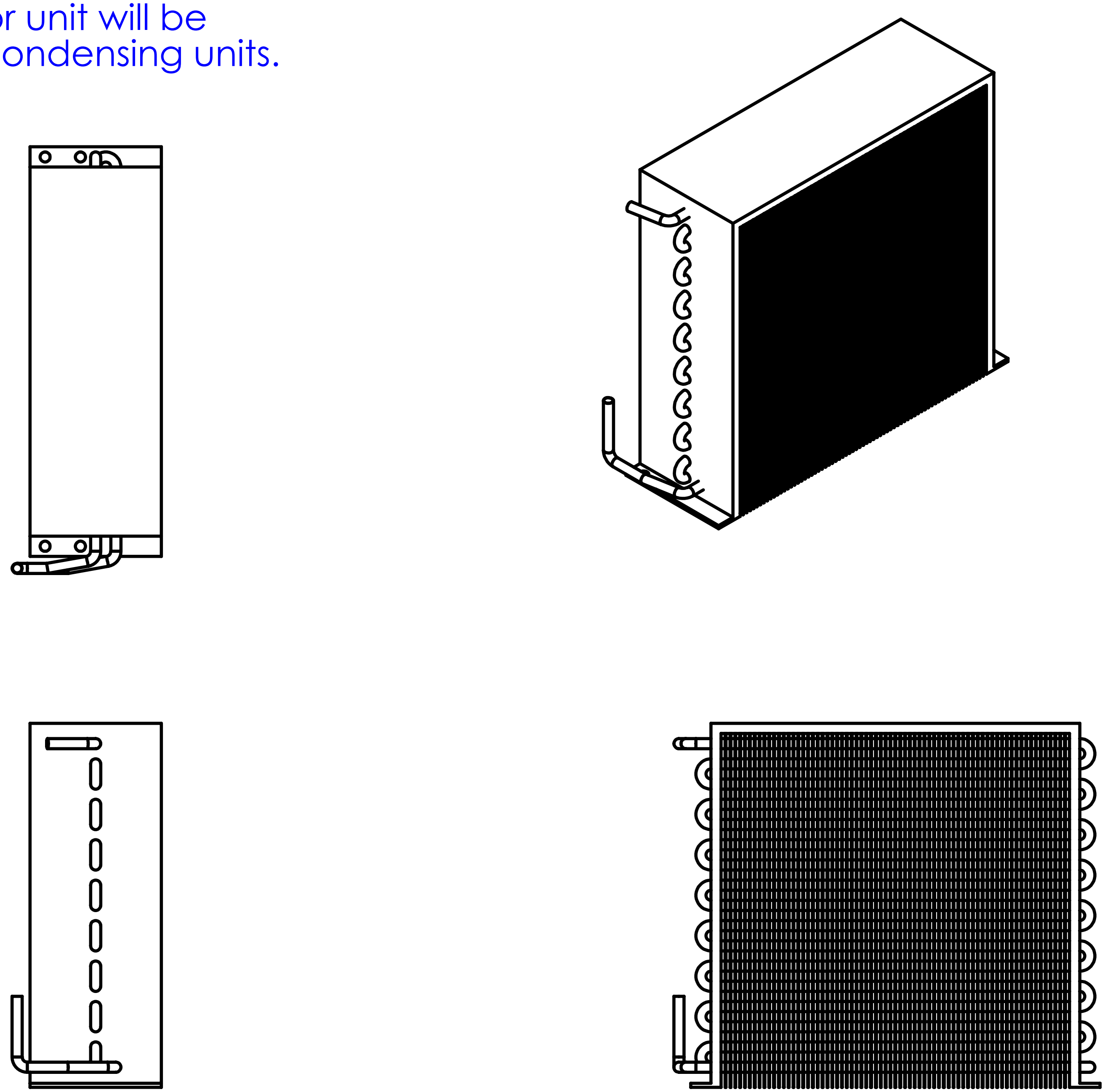


Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title:Duct Side Lip		Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:DB2	Nxt Asb:DBF	Date:6/2/2015	Scale:1:4	Chkd. By:



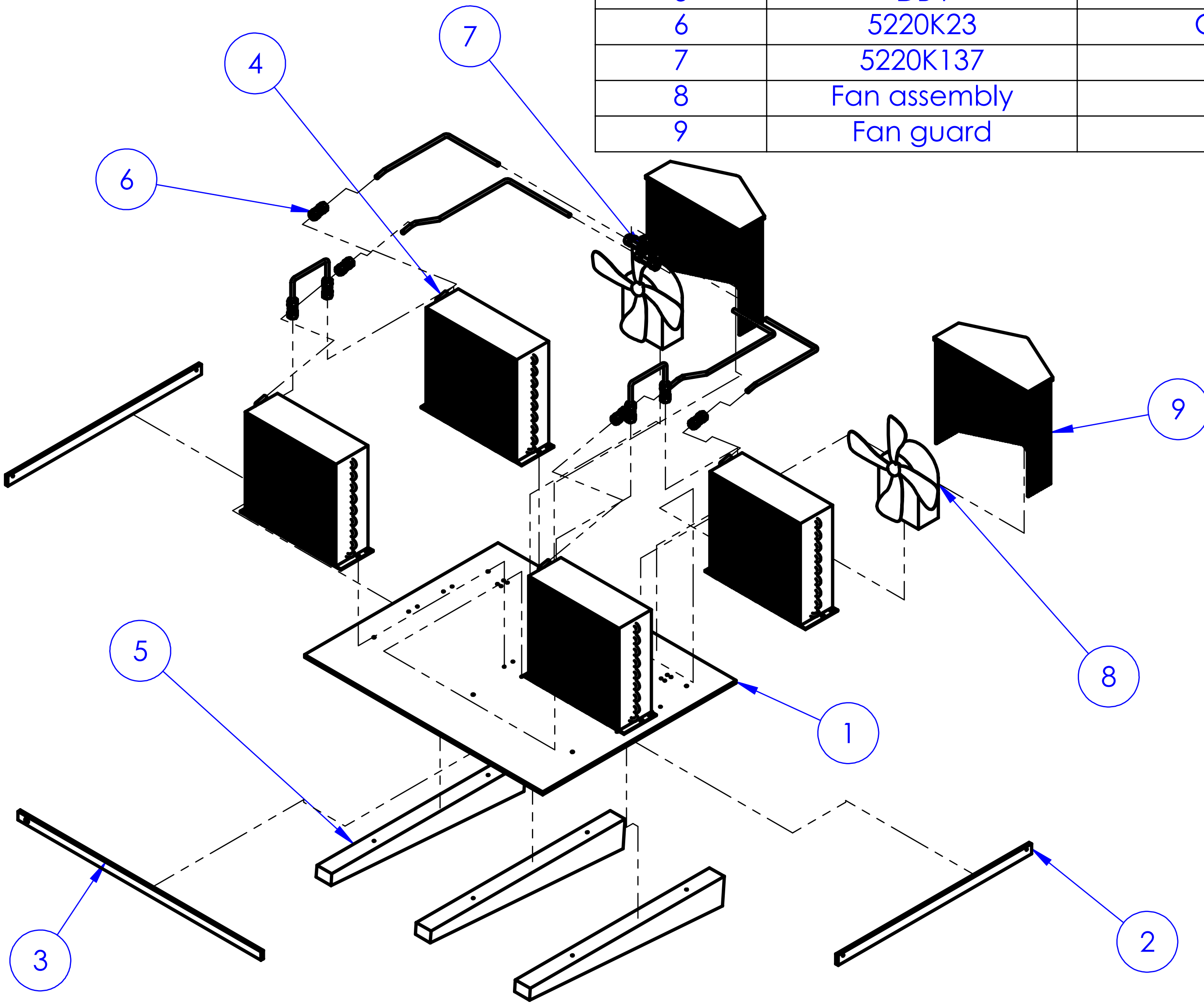
Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title:Inclined Base	Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:DB4	Nxt Asb:DBF	Date:6/1/2015 — Scale: 1:4	Chkd. By:

Note: The evaporator unit will be taken from existing condensing units.



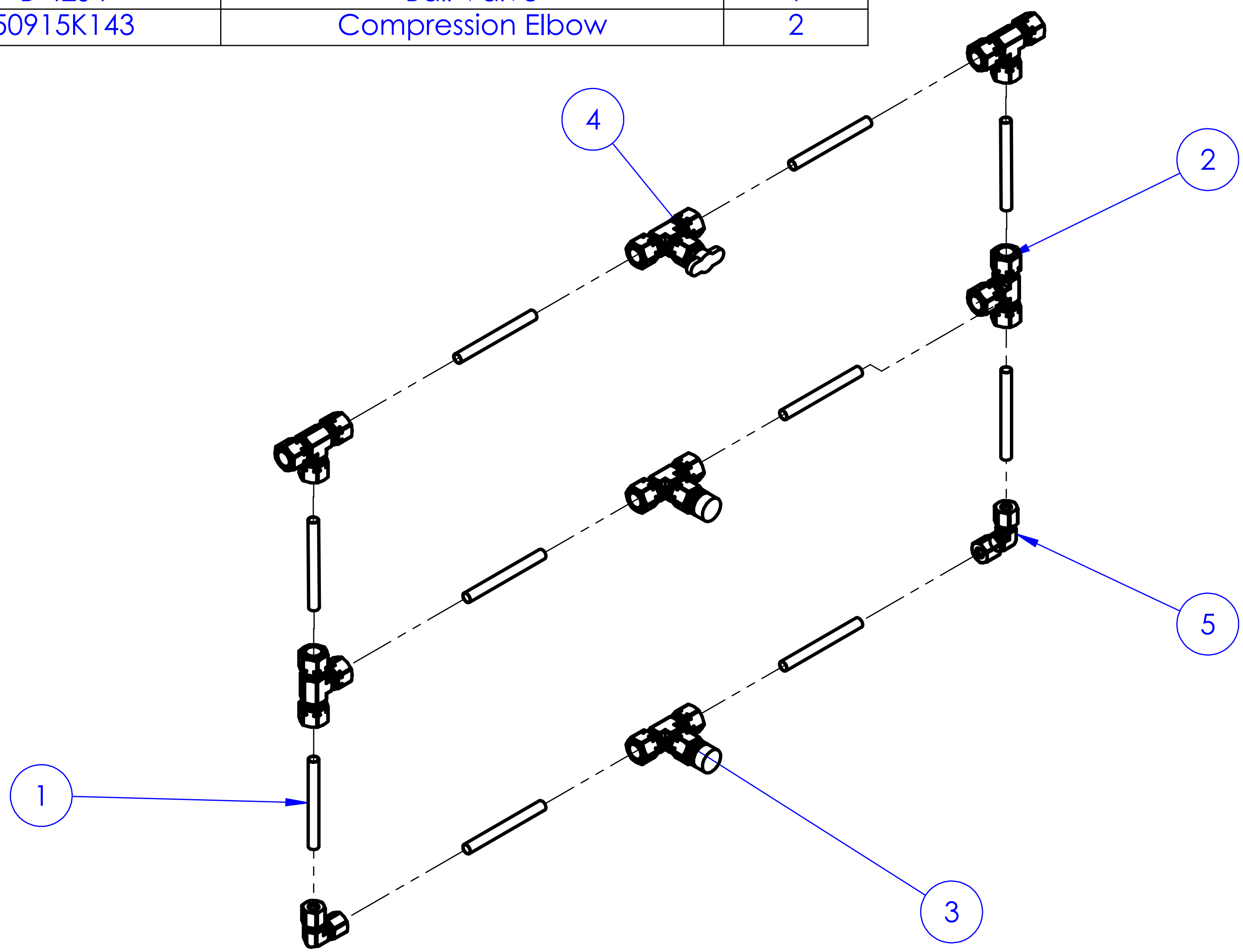
Cal Poly Mechanical Engineering	Lab Section:05	Final Report	Title: Evaporator Assembly		Drwn. By:William Beechinor
ME 429 - Fog Catchers	Dwg. #:D4	Nxt Asb:BDF	Date:6/2/2015	Scale:1:4	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DB1	Bottom Plate of the Duct	1
2	DB2	Side Lip	2
3	DB3	Lip	1
4	D4	Evaporator Assemly	4
5	DB4	Wood Guide	3
6	5220K23	Compression Union	4
7	5220K137	Compression Tee	2
8	Fan assembly	Fan assembly	2
9	Fan guard	Fan guard	2



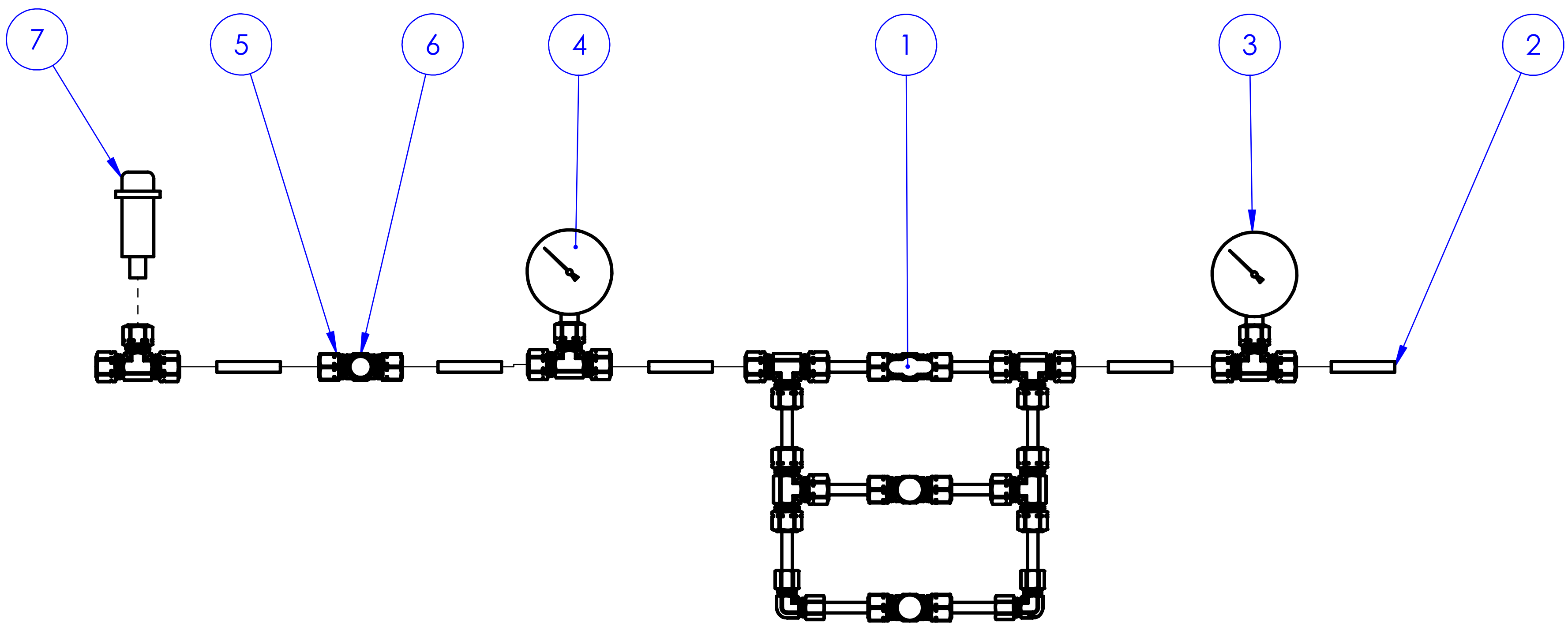
Cal Poly Mechanical Engineering	Lab Section:05	Final Report	Title:Bottom Duct Sub Assembly	Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:BDF	Nxt Asb:FA	Date:6/2/2015 Scale: 1:12	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SP01	Straight Pipe	10
2	5220K139	Compression Tee	4
3	B-SS4-VH	Metering Valve	2
4	B-42S4	Ball Valve	1
5	50915K143	Compression Elbow	2



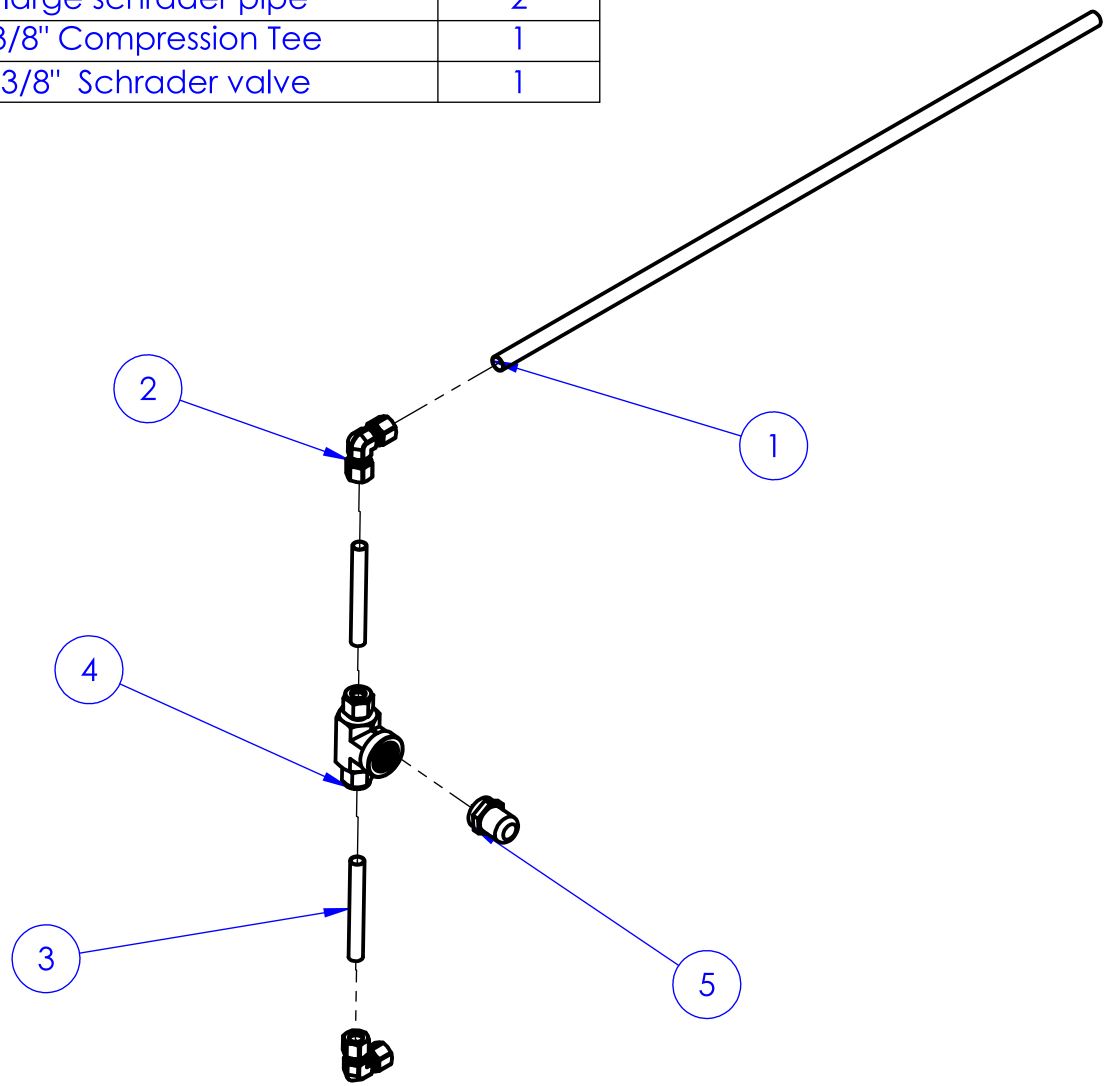
Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title: Expansion Valve Assembly	Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:EXPA1	Nxt Asb: PIP1	Date:6/4/2015 Scale: 1:4	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	EXPA1	Expansion Valve Assembly	1
2	SP02	Quarter Inch Copper Pipe	5
3	49052	Blue Pressure Gauge	1
4	49051	Red Pressure Gauge	1
5	5220K139	Compression Tee	2
6	20W307	1/4" Schrader Valve	1
7	SS-4R3A1-BU	High Pressure Relief Valve	1



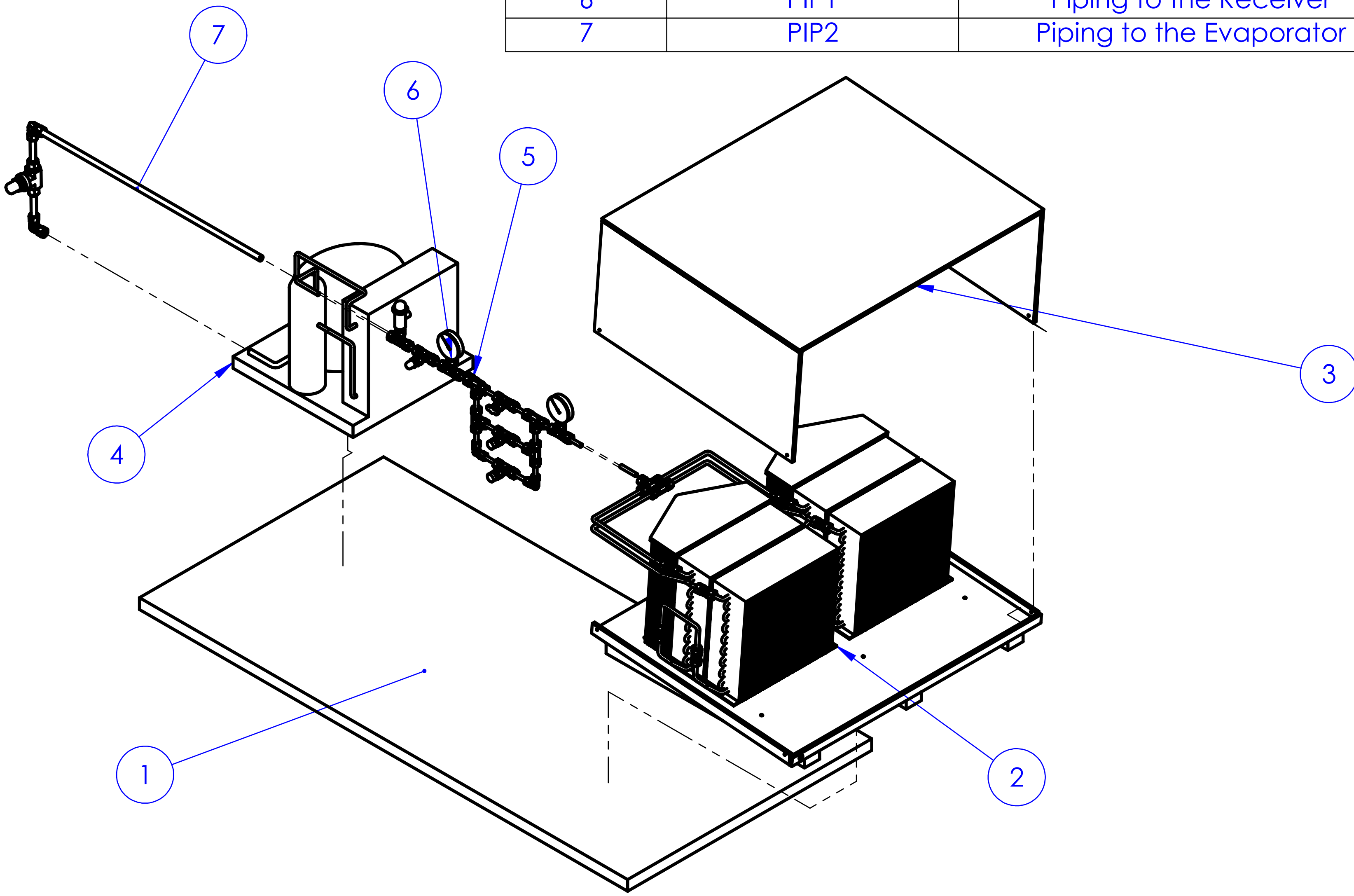
Cal Poly Mechanical Engineering	Lab Section:06	Final Report	Title: Evaporator to Receiver Piping	Drwn. By:William Beechinor
ME 430 - Fog Catchers	Dwg. #:PIP1	Nxt Asb: FA	Date:6/4/2015 / Scale: 1:4	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SP03	To Condenser Pipe	1
2	50915K145	3/8" Compression Elbow	2
3	SP04	large schrader pipe	2
4	7473T215	3/8" Compression Tee	1
5	20W307	3/8" Schrader valve	1



Cal Poly Mechanical Engineering ME 430 - Fog Catchers	Lab Section:06	Final Report	Title: Evaporator to Compressor Piping	Drwn. By:William Beechinor
	Dwg. #:PIP2	Nxt Asb: FA	Date:6/4/2015 / Scale: 1:5	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Table	Table	1
2	BDF	Bottom of the Duct Assembly	1
3	TDF	Top of the Duct Assembly	1
4	Condensing Unit	Condensing Unit	1
5	50915K251	Expansion Compression Joint	1
6	PIP1	Piping to the Receiver	1
7	PIP2	Piping to the Evaporator	1



Cal Poly Mechanical Engineering ME 430 - Fog Catchers	Lab Section:06	Final Report	Title: Final Assembly		Drwn. By:William Beechinor
	Dwg. #:FA	Nxt Asb:	Date:6/4/2015	Scale: 1:11	Chkd. By:

Appendix F: Vendor List and Contact information

Amazon
www.amazon.com

Biz Chair
www.bizchair.com
800-924-2472

Grainger
www.grainger.com
661-327-4651

McMaster Carr
www.mcmaster.com
562-641-2800

Miners Ace Hardware
www.acehardware.com/home/index.jsp
805-543-2191

Swagelok Los Angeles
www.ventura.swagelok.com
800-252-7087

TAP Plastics
www.tapplastics.com
408-265-6400

Test Equipment Depot
www.testequipmentdepot.com
781-665-0780

United Refrigeration Inc.
www.uri.com
805-928-0972

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Easy-Align Brass Compression Tube Fitting

90 Degree Elbow for 1/4" Tube OD

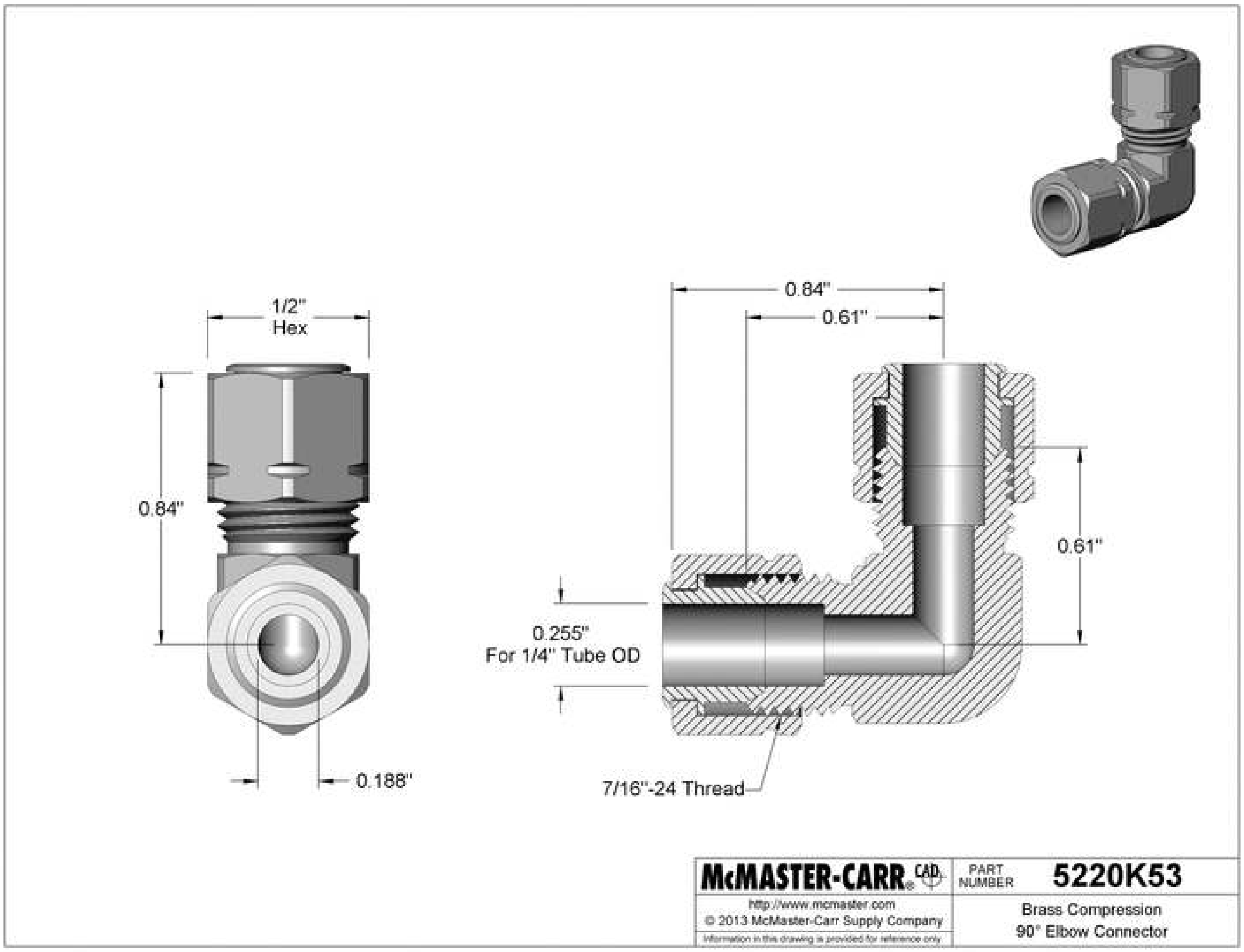
In stock
$6.19 Each
5220K53

For Tube OD	1/4"
Pressure Rating	
Maximum psi @ 72° F	1,400
For Tube Wall Thickness	0.030"
Temperature Range	–65° to 250° F
Tubing	Use with copper, aluminum, firm and hard polypropylene, polyethylene, and nylon
Additional Specifications	90° Elbow Connectors, Tube-to-Tube Easy-Align
RoHS	Compliant

Also known as flareless fittings, these brass fittings are the most commonly used compression tube fitting. They are UL listed for flammable liquids, and can also be used with air, water, oil, and drinking water (where noted).

Easy-align fittings have a sleeve built into the nut, so they are always positioned for correct installation. They do not have to be disassembled to install and can be used on plastic tubing without changing the sleeve material.

Connections: Compression.



The information in this 3-D model is provided for reference only.

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Easy-Align Brass Compression Tube Fitting

90 Degree Elbow for 3/8" Tube OD

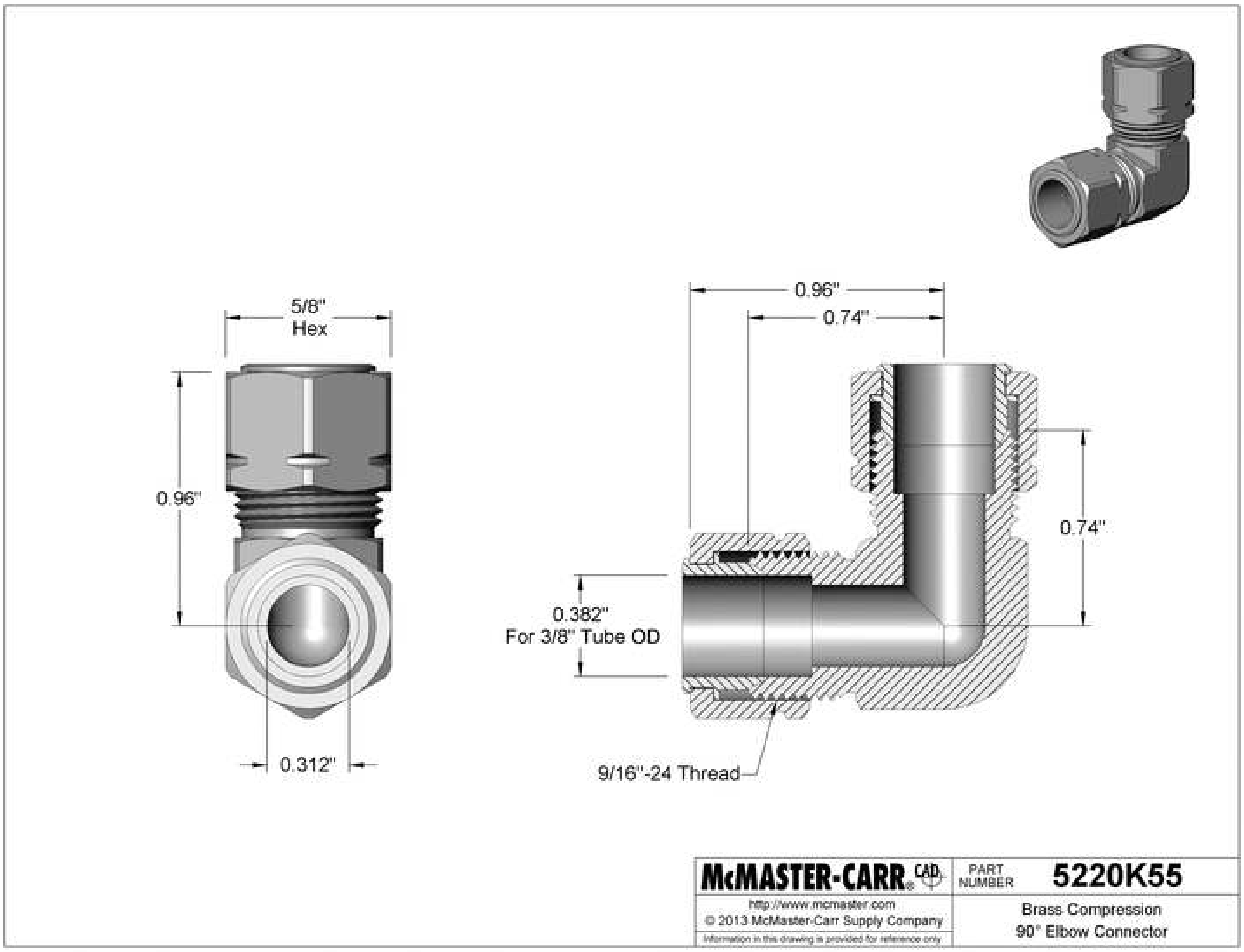
In stock
$7.15 Each
5220K55

For Tube OD	3/8"
Pressure Rating	
Maximum psi @ 72° F	1,000
For Tube Wall Thickness	0.032"
Temperature Range	–65° to 250° F
Tubing	Use with copper, aluminum, firm and hard polypropylene, polyethylene, and nylon
Additional Specifications	90° Elbow Connectors, Tube-to-Tube Easy-Align
RoHS	Compliant

Also known as flareless fittings, these brass fittings are the most commonly used compression tube fitting. They are UL listed for flammable liquids, and can also be used with air, water, oil, and drinking water (where noted).

Easy-align fittings have a sleeve built into the nut, so they are always positioned for correct installation. They do not have to be disassembled to install and can be used on plastic tubing without changing the sleeve material.

Connections: Compression.



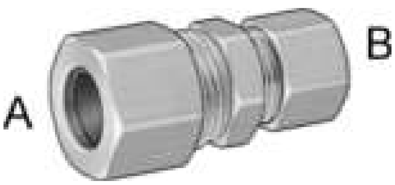
The information in this 3-D model is provided for reference only.

McMASTER-CARR
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Easy-Align Brass Compression Tube Fitting

Reducing Straight Connector for 3/8" x 1/4" Tube OD

In stock
$10.93 Each
5220K284

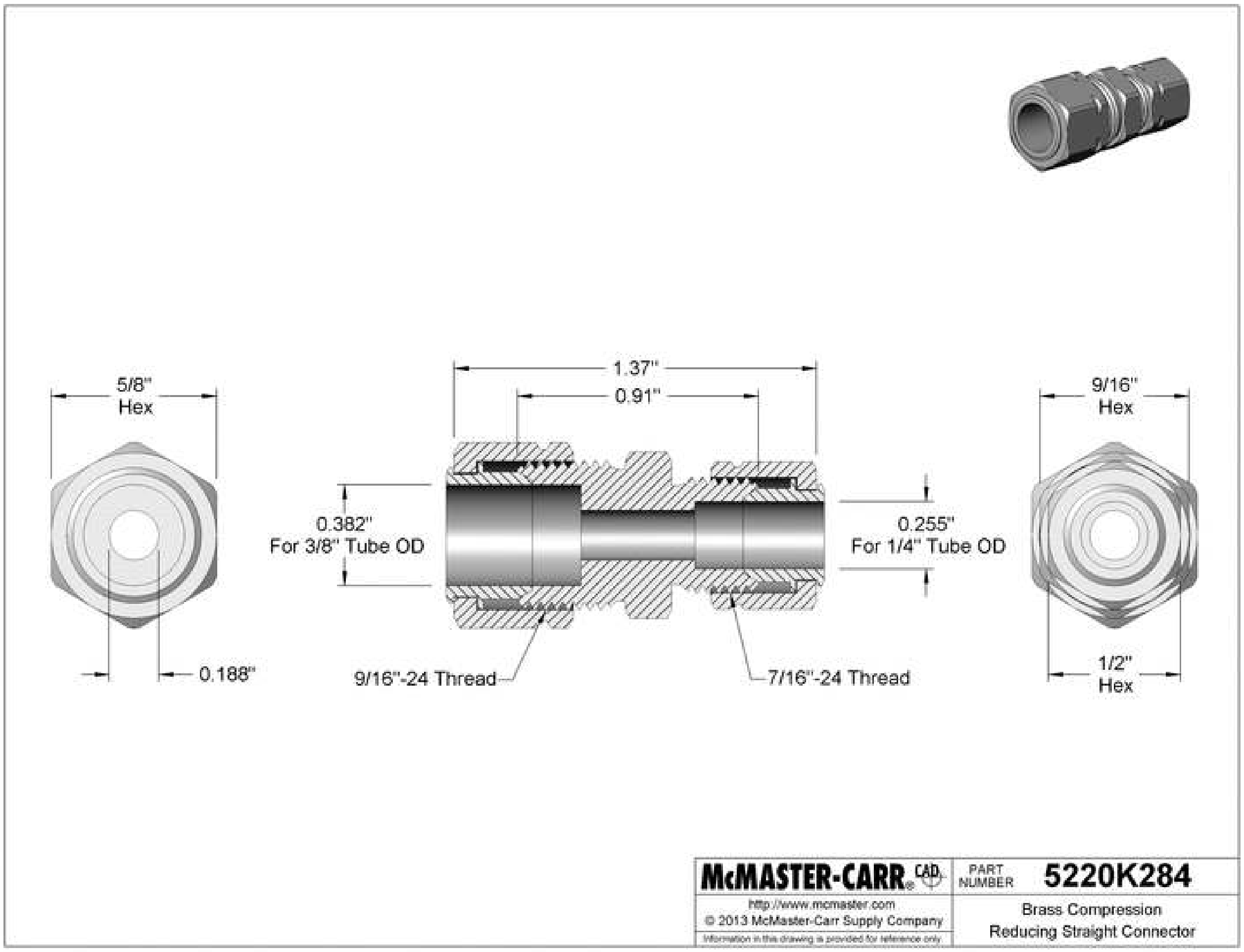


For Tube OD	
(A)	3/8"
(B)	1/4"
Pressure Rating	
Maximum psi @ 72° F	1,000
For Tube Wall Thickness	0.032"
Temperature Range	–65° to 250° F
Tubing	Use with copper, aluminum, firm and hard polypropylene, polyethylene, and nylon
Additional Specifications	Reducing Straight Connectors, Tube-to-Tube Easy-Align
RoHS	Compliant

Also known as flareless fittings, these brass fittings are the most commonly used compression tube fitting. They are UL listed for flammable liquids, and can also be used with air, water, oil, and drinking water (where noted).

Easy-align fittings have a sleeve built into the nut, so they are always positioned for correct installation. They do not have to be disassembled to install and can be used on plastic tubing without changing the sleeve material.

Connections: Compression.



The information in this 3-D model is provided for reference only.

McMASTER-CARR
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Easy-Align Brass Compression Tube Fitting

Straight Connector for 1/4" Tube OD

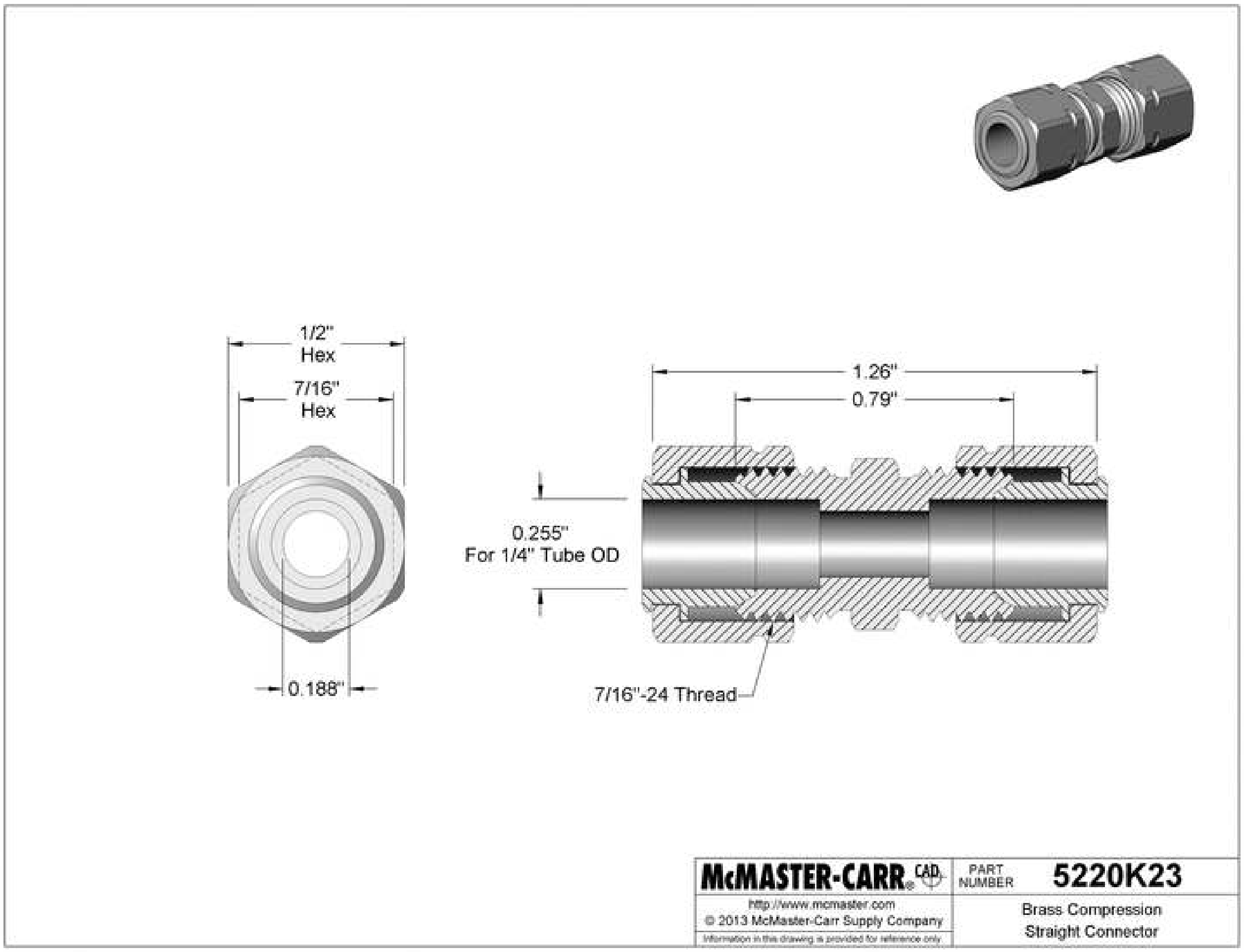
In stock
$3.15 Each
5220K23

For Tube OD	1/4"
Pressure Rating	
Maximum psi @ 72° F	1,400
For Tube Wall Thickness	0.030"
Temperature Range	–65° to 250° F
Tubing	Use with copper, aluminum, firm and hard polypropylene, polyethylene, and nylon
Additional Specifications	Straight Connectors, Tube-to-Tube Easy-Align
RoHS	Compliant

Also known as flareless fittings, these brass fittings are the most commonly used compression tube fitting. They are UL listed for flammable liquids, and can also be used with air, water, oil, and drinking water (where noted).

Easy-align fittings have a sleeve built into the nut, so they are always positioned for correct installation. They do not have to be disassembled to install and can be used on plastic tubing without changing the sleeve material.

Connections: Compression.



The information in this 3-D model is provided for reference only.

MCMASTER-CARR
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Easy-Align Brass Compression Tube Fitting

Tee for 1/4" Tube OD

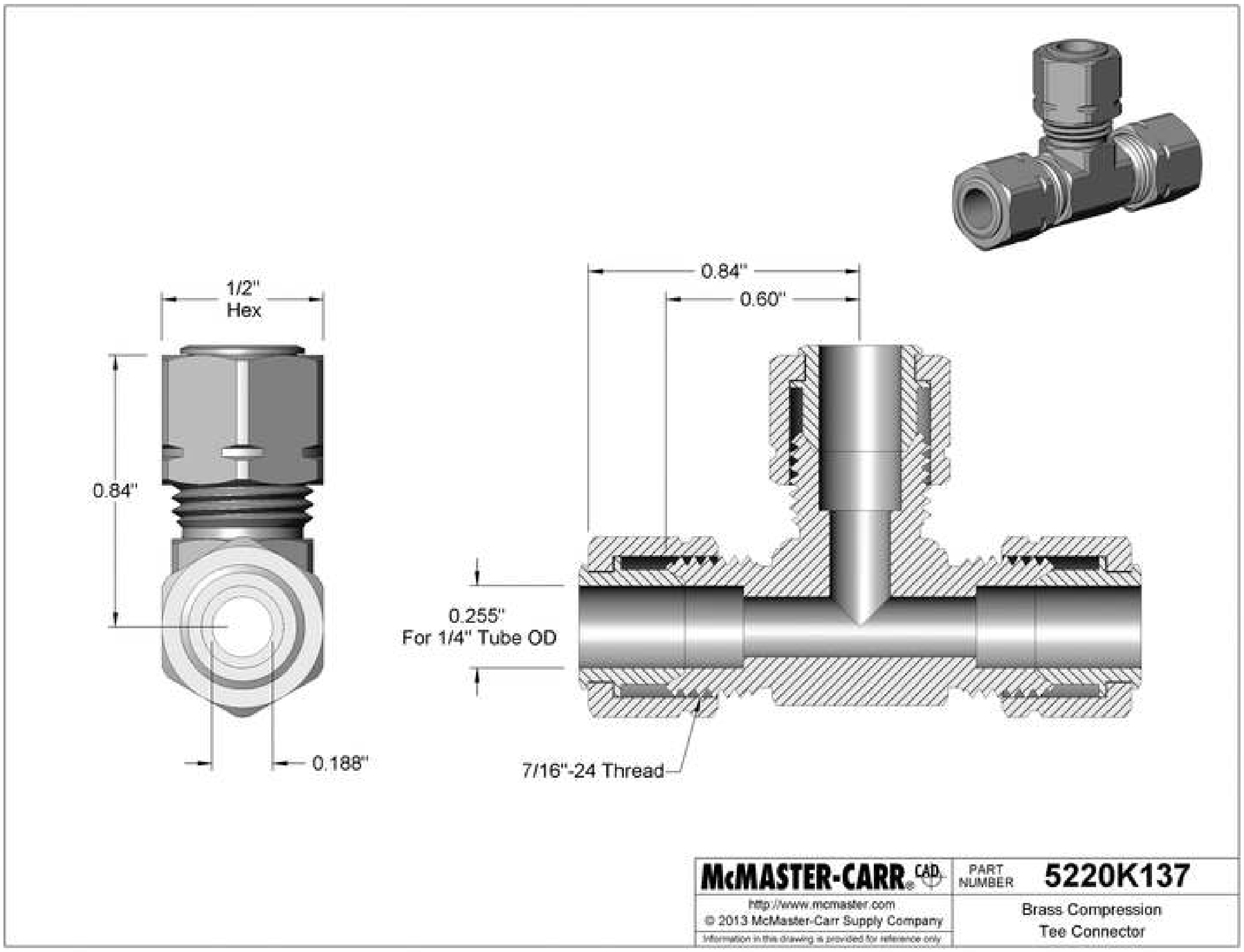
In stock
$8.44 Each
5220K137

For Tube OD	1/4"
Pressure Rating	
Maximum psi @ 72° F	1,400
For Tube Wall Thickness	0.030"
Temperature Range	–65° to 250° F
Tubing	Use with copper, aluminum, firm and hard polypropylene, polyethylene, and nylon
Additional Specifications	Tee Connectors, Tube-to-Tube Easy-Align
RoHS	Compliant

Also known as flareless fittings, these brass fittings are the most commonly used compression tube fitting. They are UL listed for flammable liquids, and can also be used with air, water, oil, and drinking water (where noted).

Easy-align fittings have a sleeve built into the nut, so they are always positioned for correct installation. They do not have to be disassembled to install and can be used on plastic tubing without changing the sleeve material.

Connections: Compression.



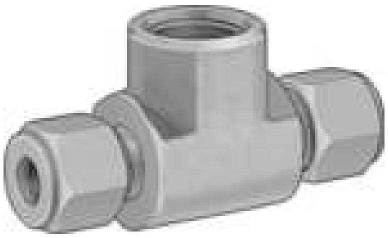
The information in this 3-D model is provided for reference only.

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Quick-Assembly Brass Tube Fitting

Inline Tee for 1/4" Tube OD x 1/4 NPT Female Pipe

In stock
$19.63 Each
7473T84

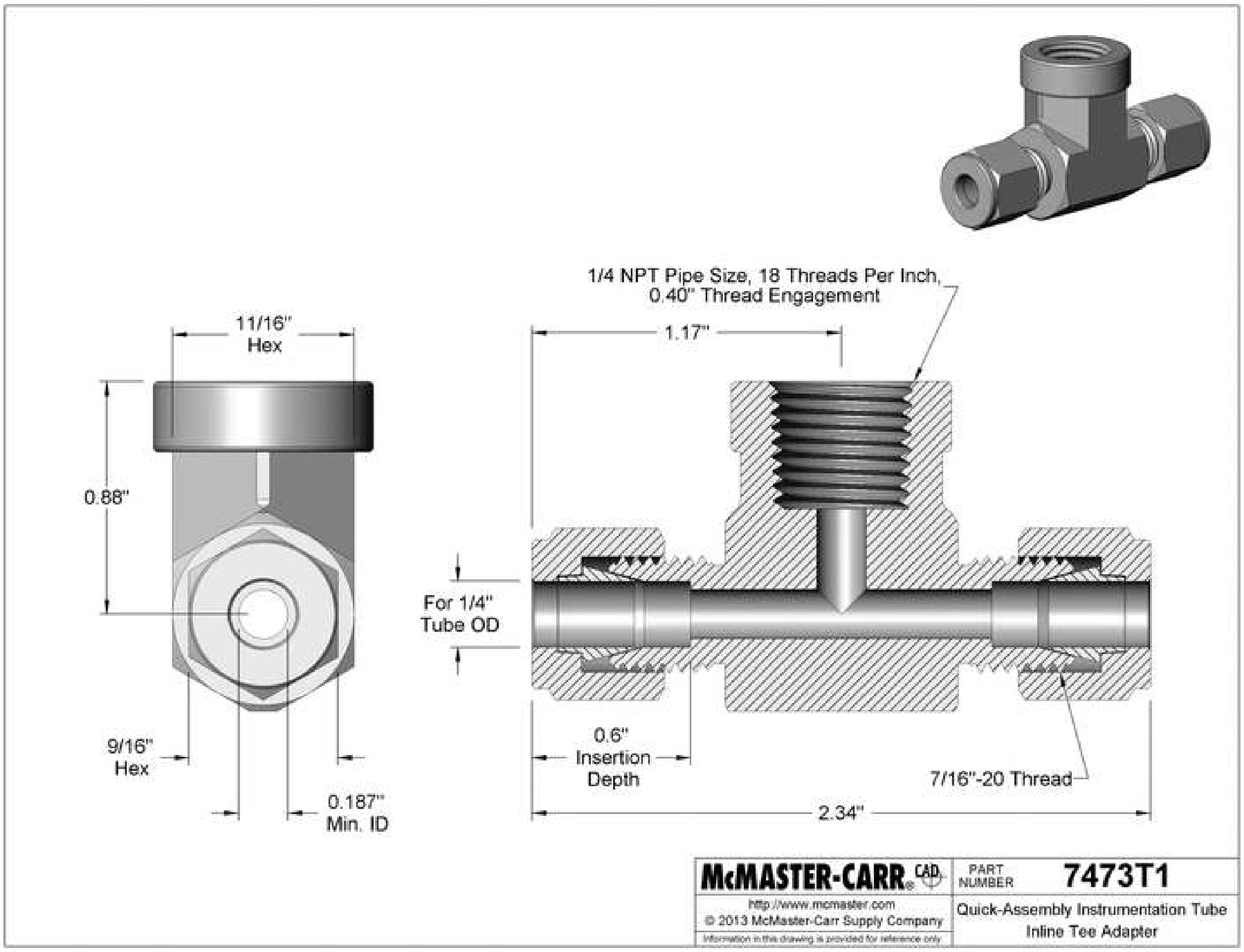


For Tube OD	1/4"
Pipe Size	1/4
Pressure Rating	
For Tube Wall Thickness	0.035"
Maximum psi @ 72° F	1,700
Temperature Range	–40° to 350° F
Tubing	Use with seamless copper tubing that meets ASTM B68, B75, or B88.
Additional Specifications	Inline Tee Adapters, Tube-to-Female Threaded Pipe
RoHS	Not Compliant

Offering good corrosion resistance, these brass fittings have one sleeve (ferrule) instead of two for a quick, convenient assembly. Use with air, water, steam, oil, natural gas, gasoline, hydraulic fluid, and alcohol. The nut has a molybdenum disulfide coating that provides lubrication for easy installation. Fittings are compatible with Parker CPI fittings.

Connections: Compression or NPT threads.

Also known as branch tees.



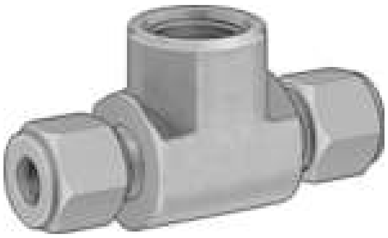
The information in this 3-D model is provided for reference only.

McMASTER-CARR
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Quick-Assembly Brass Tube Fitting

Inline Tee for 1/4" Tube OD x 1/8 NPT Female Pipe

In stock
$19.51 Each
7473T83

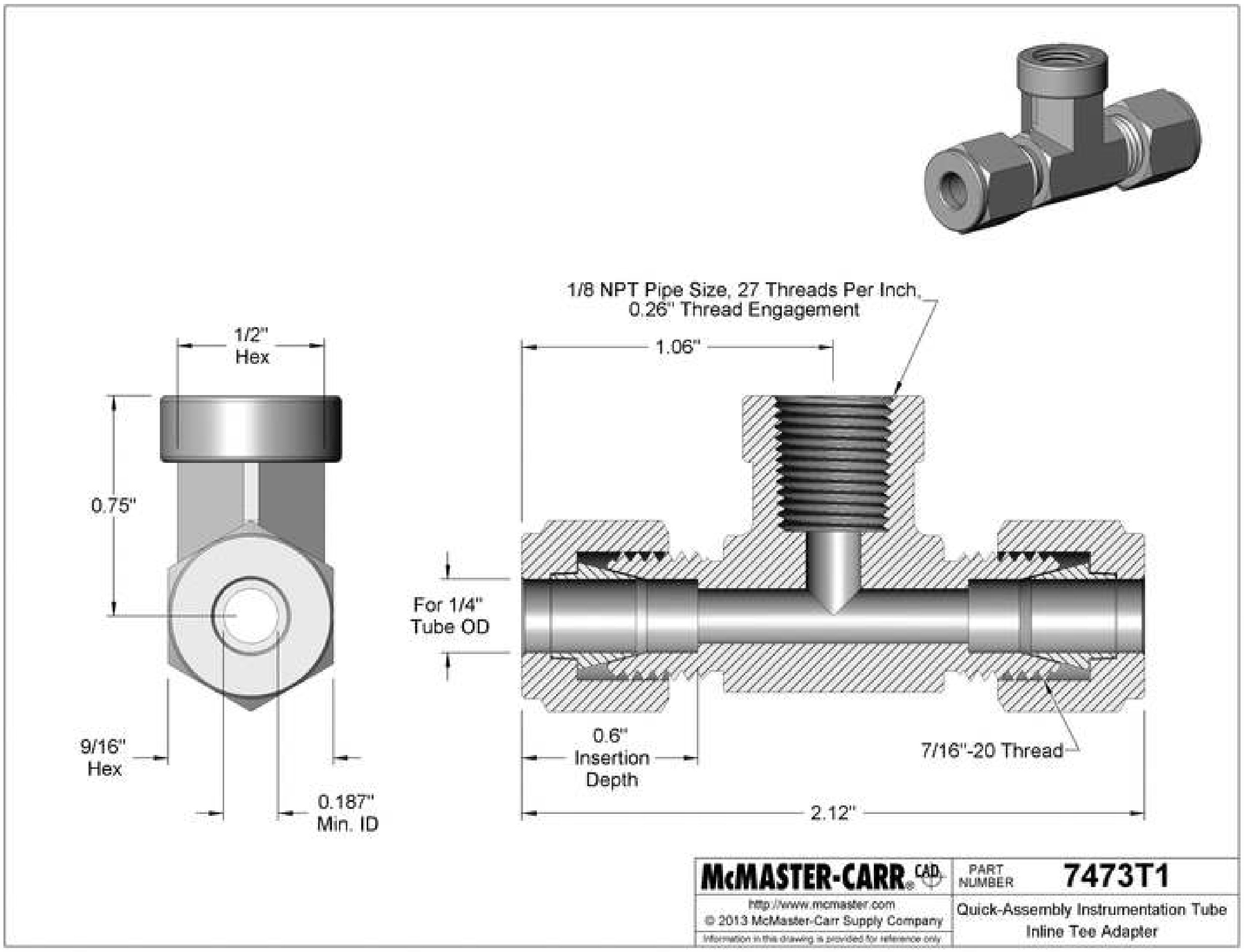


For Tube OD	1/4"
Pipe Size	1/8
Pressure Rating	
For Tube Wall Thickness	0.035"
Maximum psi @ 72° F	1,700
Temperature Range	–40° to 350° F
Tubing	Use with seamless copper tubing that meets ASTM B68, B75, or B88.
Additional Specifications	Inline Tee Adapters, Tube-to-Female Threaded Pipe
RoHS	Not Compliant

Offering good corrosion resistance, these brass fittings have one sleeve (ferrule) instead of two for a quick, convenient assembly. Use with air, water, steam, oil, natural gas, gasoline, hydraulic fluid, and alcohol. The nut has a molybdenum disulfide coating that provides lubrication for easy installation. Fittings are compatible with Parker CPI fittings.

Connections: Compression or NPT threads.

Also known as branch tees.



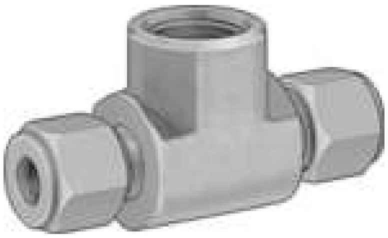
The information in this 3-D model is provided for reference only.

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Quick-Assembly Brass Tube Fitting

Inline Tee for 3/8" Tube OD x 1/4 NPT Female Pipe

In stock
$21.60 Each
7473T85

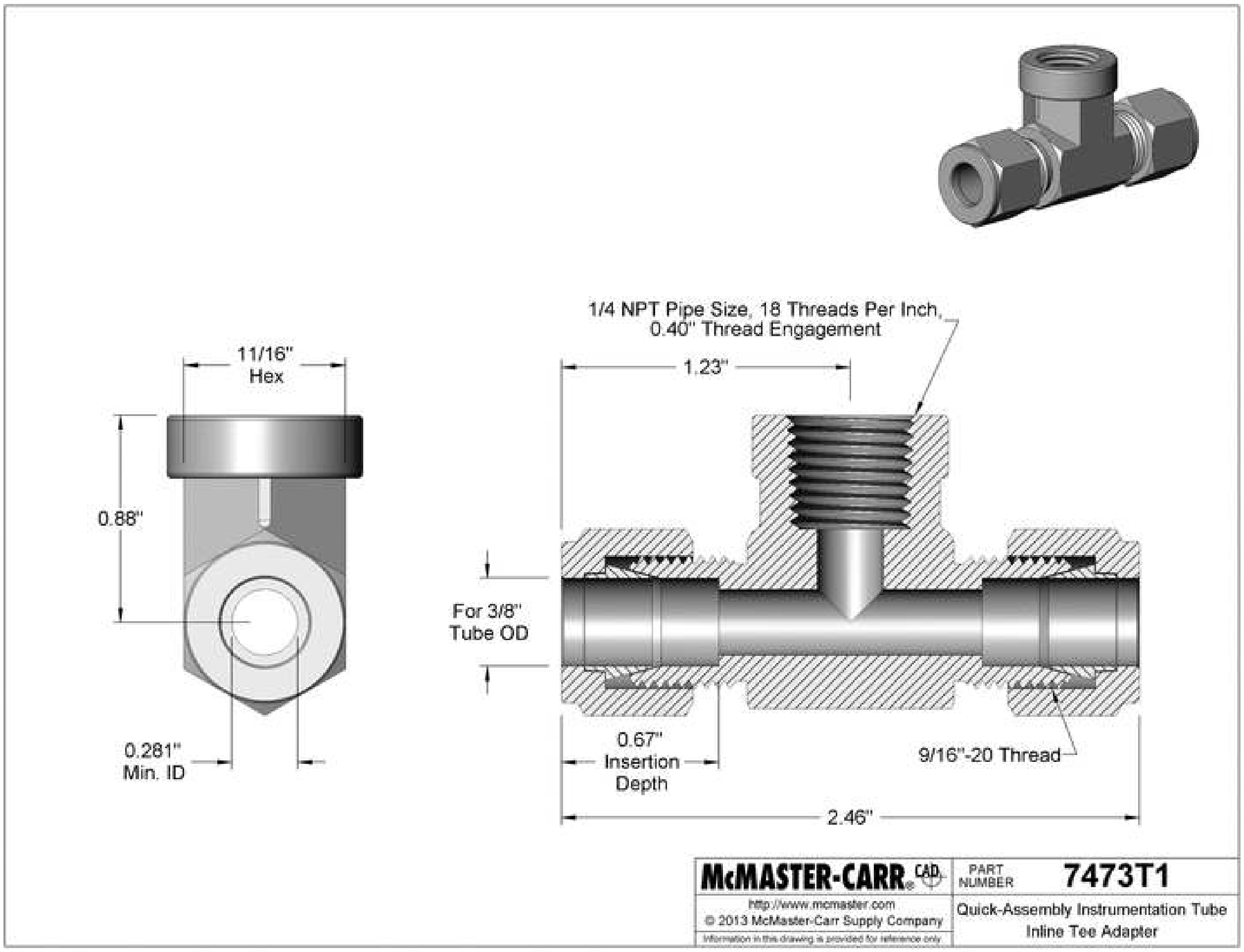


For Tube OD	3/8"
Pipe Size	1/4
Pressure Rating	
For Tube Wall Thickness	0.035"
Maximum psi @ 72° F	1,100
Temperature Range	–40° to 350° F
Tubing	Use with seamless copper tubing that meets ASTM B68, B75, or B88.
Additional Specifications	Inline Tee Adapters, Tube-to-Female Threaded Pipe
RoHS	Not Compliant

Offering good corrosion resistance, these brass fittings have one sleeve (ferrule) instead of two for a quick, convenient assembly. Use with air, water, steam, oil, natural gas, gasoline, hydraulic fluid, and alcohol. The nut has a molybdenum disulfide coating that provides lubrication for easy installation. Fittings are compatible with Parker CPI fittings.

Connections: Compression or NPT threads.

Also known as branch tees.



The information in this 3-D model is provided for reference only.

YELLOW JACKET

Yellow Jacket 49051
2 1/2" Red Pressure Gauge, °F, R-134A/404A/507

- **Flutterless technology with surge protector minimizes the needle pulsation for improved accuracy**
- **1/8" NPT Male connection**
- **3-2-3% accuracy**
- **Calibration traceable to NIST standards**

Yellow Jacket 49051 shown

Yellow Jacket 49051 2 1/2" gauge (°F), red pressure, 0-500 psi, R-134a/404A/507 has a steel case for durability and high-visibility dials with colored temperature scales for easy reading.

Ordering Information			
Model	**Description**	**More Info**	**Buy Now**
49051	Yellow Jacket 49051 2 1/2" Gauge (°F), Red Pressure, 0-500 Psi, R-134A/404A/507	More Info>>	Sale $12.81 (Reg. $17.08)
Optional Accessories			
49189	Yellow Jacket 49189 Replacement Crystal for Both °C And °F	More Info>>	Sale $5.72 (Reg. $7.15)

Yellow Jacket Catalog | Yellow Jacket Price List

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Yellow Jacket 49052
2 1/2" Blue Compound Gauge, °F, R-134A/404A/507

- **Flutterless technology with surge protector minimizes the needle pulsation for improved accuracy**
- **1/8" NPT Male connection**
- **3-2-3% accuracy**
- **Calibration traceable to NIST standards**

Yellow Jacket49052

Yellow Jacket 49052 2 1/2" gauge (°F), blue compound, 30"-0-120 has a steel case for durability and high-visibility dials with colored temperature scales for easy reading.

Ordering Information

Model	Description	More Info	Buy Now
49052	Yellow Jacket 49052 2 1/2" Gauge (°F), Blue Compound, 30"-0-120 Psi, R-134A/404A/507	More Info>>	Sale $12.81 (Reg. $17.08)
Optional Accessories			
49189	Yellow Jacket 49189 Replacement Crystal for Both °C And °F	More Info>>	Sale $5.72 (Reg. $7.15)

Yellow Jacket Catalog | Yellow Jacket Price List

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Safe Product Selection:
The complete catalog contents must be reviewed to ensure that the system designer and user make a safe product selection. When selecting products, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Caution:
Do not mix or interchange valve components with those of other manufacturers.

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Find thousands of Swagelok products by utilizing our enhanced product search. Choose your product group and continue to narrow your results, or read more about Swagelok Products by clicking on the Details tab.

Products

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Part No.: B-42S4
Description: Brass 1-Piece 40 Series Ball Valve, 0.6 Cv, 1/4 in. Swagelok Tube Fitting
Price: USD 46.88
Availability: Usually ships within 1 business day

My Part No.: Click to add your own part number with an optional comment.
My Description:

Quantity: Buy Quote
Click on the "Contact" link on the right to contact Swagelok Los Angeles about loading all of your part numbers.

SPECIFICATION SUMMARY

Actuator Type	Manual
Body Material	Brass
Flow Path	Standard (2-way)
Flow Pattern	Straight (2-way)
Service Class	General
End Connection 1 Size	1/4 in
End Connection 1 Type	Swagelok® tube fitting
End Connection 2 Size	1/4 in
End Connection 2 Type	Swagelok® tube fitting
Handle Color	Black
Handle Style	Lever
Ball/Stem Material	Brass
Cleaning	Swagelok® Standard cleaning SC-10
Lubricant	Dow M111
O-Ring	PTFE
Ring/Disc Material	PTFE-coated brass
Testing	Testing according to WS-22
Max Temperature with Pressure Rating	150 F 2500 PSIG /65 C 172 BAR
Orifice	0.125'' /3.2 mm
Room Temperature Pressure Rating	100 F 2500 PSIG /172 BAR 37 C

Download PDF
Animation

Kits
One-Piece Instrumentation Ball Valves - 40G & 40 Series (Catalog) ⊞ Add to Site Favorites

Additional Documentation
Instruction Card

Safe Product Selection:
The complete catalog contents must be reviewed to ensure that the system designer and user make a safe product selection. When selecting products, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Caution:
Do not mix or interchange valve components with those of other manufacturers.

Products

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Products

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Part No.: SS-4R3A1-BU
Description: SS High-Pressure Proportional Relief Valve, 1/4 in. MNPT x 1/4 in. Swagelok Tube Fitting, Buna N Seal
Price: Quote
Availability: Call for Availability

My Part No.: Click to add your own part number with an optional comment.
My Description:

Quantity: Buy Quote

Click on the "Contact" link on the right to contact Swagelok Los Angeles about loading all of your part numbers.

SPECIFICATION SUMMARY	
Service Class	High Pressure
Size	1/8in
Valve Material	316 Stainless Steel
End Connection 1 Size	1/4 in
End Connection 1 Type	Male NPT
End Connection 2 Size	1/4 in
End Connection 2 Type	Swagelok tube fitting
Approval	No Approval
Cleaning	Swagelok SC-10
Lubricant	Dow Corning Molykote 55 Grease
Manual Override	No
Seal Material	Buna N
Testing	No Optional Testing
Max Temperature Pressure Rating	250°F @ 4910 PSIG /121°C @ 338 BAR
Room Temperature Pressure Rating	6000 PSIG @ 100°F /413 @ BAR 37°C
Download PDF	Relief Valves (Catalog) ⊞ Add to Site Favorites
CAD	Sales Drawing
Additional Documentation	
Instruction Card	

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Quick-Connects
Regulators
Sample Cylinders
Tubing and Tube Accessories
Valves
Welding System

Safe Product Selection:
The complete catalog contents must be reviewed to ensure that the system designer and user make a safe product selection. When selecting products, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Caution:
Do not mix or interchange valve components with those of other manufacturers.

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Products

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Products

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Part No.: B-SS4-VH
Description: Brass Low-Flow Metering Valve, 1/4 in. Swagelok Tube Fitting, Vernier Handle
Price: USD 128.96
Availability: Call for Availability

My Part No.: Click to add your own part number with an optional comment.
My Description:

Quantity: Buy Quote
Click on the "Contact" link on the right to contact Swagelok Los Angeles about loading all of your part numbers.

SPECIFICATION SUMMARY

Body Material	Brass
Cleaning Process	Standard Cleaning and Packaging (SC-10)
Connection 1 Size	1/4 in.
Connection 1 Type	Swagelok® Tube Fitting
Connection 2 Size	1/4 in.
Connection 2 Type	Swagelok® Tube Fitting
eClass (4.1)	37010203
eClass (5.1.4)	37010203
eClass (6.0)	37-01-02-03
eClass (6.1)	37-01-02-03
Feature	Vernier handle
Flow Pattern	2-Way, Shutoff, Straight
UNSPSC (11.0501)	40141609
UNSPSC (4.03)	40141602
UNSPSC (SWG01)	40141602

Download PDF Metering Valves (Catalog) Add to Site Favorites
CAD Sales Drawing
Additional Documentation
Instruction Card

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How can we improve our **Product Images**?

Compare

Access Valve, Half Union, 1/4 MPT, PK5

JB INDUSTRIES

Price
$10.09 / pkg. of 5

Deliver one time only

Auto-Reorder Every 1 Month

1 Add to Cart

+ Add to List

Confirm ZIP Code to determine availability.

ZIP Code

95380 Save

Be the first to write a review | **Ask & Answer**

Item # **20W307** Mfr. Model # **A31484-G** UNSPSC # **40141609**

Catalog Page # **4206** Shipping Weight **0.35 lbs.**

Country of Origin **USA** | *Country of Origin is subject to change.*

Note: Product availability is real-time updated and adjusted continuously. The product will be reserved for you when you complete your order. More

Technical Specs

Item	**1/4 Access Valve**	Connection	**1/4 MPT**
Type	**Brass Fitting**	For Use With	**Tubing Connections**
Description	**Half Union MPT Connection**	Package Quantity	**5**

Access Valve, Half Union, 1/8 MPT, PK5

JB INDUSTRIES

Price
$8.49 / pkg. of 5

Deliver one time only
Auto-Reorder Every 1 Month

1 Add to Cart
+ Add to List

Confirm ZIP Code to determine availability.
ZIP Code
95380 Save

Be the first to write a review | Ask & Answer

How can we improve our **Product Images**?

Compare

Item # **20W306** Mfr. Model # **A31482-G** UNSPSC # **40141609**
Catalog Page # **4206** Shipping Weight **0.25 lbs.**

Country of Origin **USA** | *Country of Origin is subject to change.*

Note: Product availability is real-time updated and adjusted continuously. The product will be reserved for you when you complete your order. More

Technical Specs

Item	**1/4 Access Valve**	Connection	**1/8 MPT**
Type	**Brass Fitting**	For Use With	**Tubing Connections**
Description	**Half Union MPT Connection**	Package Quantity	**5**

Makrolon® GP sheet

General purpose

Makrolon® GP sheet is a polished surface, UV stabilized, transparent polycarbonate product. It features outstanding impact strength, superior dimensional stability, high temperature resistance, and high clarity. This lightweight thermoformable sheet is also easy to fabricate and decorate. Makrolon GP sheet is offered with a five (5) year Limited Product Warranty against breakage. The terms of the warranty are available upon request.

Applications

Industrial glazing, machine guards, structural parts, thermoformed and fabricated components

Typical Properties

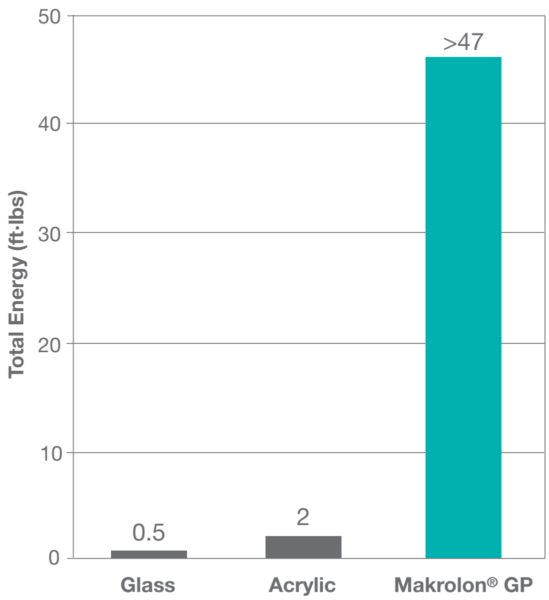
Property	Test Method	Units	Values
PHYSICAL			
Specific Gravity	ASTM D 792	–	1.2
Refractive Index	ASTM D 542	–	1.586
Light Transmission, Clear @ 0.118˝	ASTM D 1003	%	86
Light Transmission, I30 Gray @ 0.118˝	ASTM D 1003	%	50
Light Transmission, K09 Bronze @ 0.118˝	ASTM D 1003	%	50
Light Transmission, I35 Dark Gray @ 0.118˝	ASTM D 1003	%	18
Water Absorption, 24 hours	ASTM D 570	%	0.15
Poisson’s Ratio	ASTM E 132	–	0.38
MECHANICAL			
Tensile Strength, Ultimate	ASTM D 638	psi	9,500
Tensile Strength, Yield	ASTM D 638	psi	9,000
Tensile Modulus	ASTM D 638	psi	340,000
Elongation	ASTM D 638	%	110
Flexural Strength	ASTM D 790	psi	13,500
Flexural Modulus	ASTM D 790	psi	345,000
Compressive Strength	ASTM D 695	psi	12,500
Compressive Modulus	ASTM D 695	psi	345,000
Izod Impact Strength, Notched @ 0.125˝	ASTM D 256	ft·lbs/in	18
Izod Impact Strength, Unnotched @ 0.125˝	ASTM D 256	ft·lbs/in	60 (no failure)
Instrumented Impact @ 0.125˝	ASTM D 3763	ft·lbs	>47
Shear Strength, Ultimate	ASTM D 732	psi	10,000
Shear Strength, Yield	ASTM D 732	psi	6,000
Shear Modulus	ASTM D 732	psi	114,000
Rockwell Hardness	ASTM D 785	–	M70 / R118
THERMAL			
Coefficient of Thermal Expansion	ASTM D 696	in/in/°F	3.75×10^{-5}
Coefficient of Thermal Conductivity	ASTM C 177	BTU·in/hr·ft²·°F	1.35
Heat Deflection Temperature @ 264 psi	ASTM D 648	°F	270
Heat Deflection Temperature @ 66 psi	ASTM D 648	°F	280
Brittleness Temperature	ASTM D 746	°F	-200
Shading Coefficient, clear @ 0.236˝	NFRC 100-2010	–	0.97
Shading Coefficient, Gray or Bronze @ 0.236˝	NFRC 100-2010	–	0.77
U factor @ 0.236˝ (summer, winter)	NFRC 100-2010	BTU/hr·ft²·°F	0.85, 0.92
U factor @ 0.375˝ (summer, winter)	NFRC 100-2010	BTU/hr·ft²·°F	0.78, 0.85
ELECTRICAL			
Dielectric Constant @ 10 Hz	ASTM D 150	–	2.96
Dielectric Constant @ 60 Hz	ASTM D 150	–	3.17
Volume Resistivity	ASTM D 257	Ohm·cm	8.2×10^{16}
Dissipation Factor @ 60 Hz	ASTM D 150	–	0.0009
Arc Resistance			
Stainless Steel Strip electrode	ASTM D 495	Seconds	10
Tungsten Electrodes	ASTM D 495	Seconds	120
Dielectric Strength, in air @ 0.125˝	ASTM D 149	V/mil	380
FLAMMABILITY			
Horizontal Burn, AEB	ASTM D 635	in	<1
Ignition Temperature, Self	ASTM D 1929	°F	1022
Ignition Temperature, Flash	ASTM D 1929	°F	824
Flame Class @ 0.060˝	UL 94	–	HB
@ 0.394˝	UL 94	–	V-0

*Typical properties are not intended for specification purposes.
**Some properties characterized using non-textured sheet.

makrolon® GP

Makrolon® GP sheet

Impact Resistance*



*Instrumented Impact per ASTM D 3763, sample thickness 0.125″ nominal

Standard Products Comparison

Property		Polycarbonate	Acrylic	Glass
Impact Resistance	Drop Ball Test, 0.5 lb	No Break	1.75 ft·lbs	0.7 ft·lbs
Cold Bend	Bend Radius	100x material thickness	180x material thickness	Not possible
Sheet Weight	0.125″	0.78 lb/ft^2	0.75 lb/ft^2	1.60 lbs/ft^2
Thermal Expansion Rate	–	3.75 x 10^{-5} in/in/°F	4.10 x 10^{-5} in/in/°F	5.0 x 10^{-6} in/in/°F
Shading Coefficient	0.236″ clear sheet	0.97	1.01	1.03
U Factor – Summer U Factor – Winter	0.236″	0.85 BTU/hr·ft^2·°F 0.92 BTU/hr·ft^2·°F	0.83 BTU/hr·ft^2·°F 0.91 BTU/hr·ft^2·°F	0.92 BTU/hr·ft^2·°F 1.02 BTU/hr·ft^2·°F
Sound Transmission Class	0.236″	29	30	27

Regulatory code compliance and certifications

- ICC-ES Evaluation Report ESR-2728
- Miami-Dade NOA #12-0605.05
- CPSC 16 CFR 1201 Category I and Category II: Safety Standard for Architectural Glazing Materials
- ANSI Z97.1-2004: American National Standard for Safety Glazing Materials Used in Buildings - Safety Performance Specifications and Methods of Test. Class A
- UL 972: Burglary Resistant Glazing Materials, UL File #BP2126
- UL 94: Flammability, UL File #E351891

Bayer MaterialScience

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WELD-ON 16

ACRYLIC PLASTIC CEMENT

SUBSTRATE RECOMMENDATIONS
WELD-ON 16 is especially formulated to bond acrylic plastic. It can also be used for bonding styrene, butyrate, PVC and polycarbonate, as well as other plastics and porous surfaces.

BONDING RECOMMENDATIONS
WELD-ON 16 is recommended as an excellent general purpose, high strength acrylic cement. It is especially useful where fast cure and high strength are desired for applications such as large housings, signs, plastic letters, industrial fabrications, display items, lenses and models.

GENERAL DESCRIPTION
WELD-ON 16 is a very high strength, clear, medium bodied, fast curing, bodied solvent-type acrylic cement. Applied to cast, molded or extruded acrylics, it will effect initial bonds within minutes and form strong joints within hours.This product may be thinned with WELD-ON 3 by approximately 10%. Initial bond forms very quickly so some parts may be handled within a few minutes of application. Bond strength continues to develop very rapidly reaching a substantial level within hours. Joints are water and weather resistant and will generally have similar physical and chemical properties to acrylic plastic.

BOND STRENGTH DATA
The following strength data was obtained with compressive shear loading at 0.05"/min.The materials tested were ¼" acrylic lap joints of 1 sq. in. bonding area.

SUBSTRATE MATERIAL	24 HOURS	1 WEEK
Acrylic	1700 PSI	2200 PSI
Polycarbonate	1000	1700
Styrene	900	1700

ADHESIVE PROPERTIES AND CHARACTERISTICS

COLOR:	Clear		
VISCOSITY:	800 cps		
WORKING TIME:	2 – 3 minutes		
FIXTURE TIME:	5 – 6 minutes		
80% STRENGTH:	16 hours		
SPECIFIC GRAVITY: 1.02 ± .040			
COVERAGE:	10mil:	28sq. ft./Pint	224 sq. ft./Gallon
	20mil:	14sq. ft./Pint	112 sq. ft./Gallon

DIRECTIONS FOR USE
- Parts to be joined should be clean and fit without forcing.
- Apply WELD-ON 16 to one or both surfaces with brush, polyethylene squeeze bottle or gun.
- If cement is applied to one surface, bring the two surfaces in gentle contact for several seconds to allow the dry surfaces to be softened.
- Assemble with firm pressure while parts are still wet.
- Hold or clamp assembled parts firmly until initial set. Joint strength will increase greatly in 24 hours. Thereafter, strength will continue to increase gradually for some weeks.

SHELF LIFE
Two years expectancy in tightly sealed containers. Stability of the product is limited by the permanence of the container and the evaporation of the solvent when container is open. Evaporation of solvent will cause the cement to thicken and reduce the effectiveness of the cement.

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SHIPPING

Shipping Information for Individual Containers Larger than One Liter: DOT Shipping Name: Flammable liquid, toxic, n.o.s. (Methyl Ethyl Ketone, Dichloromethane). DOT Hazard Class: 3 with subsidiary risk Hazard Class of 6.1. ID #: UN1992. Packaging Group: II. Label: Flammable Liquid & Toxic.
Shipping Information for Less than One Liter: No packaging or shipping exceptions available. May not be shipped as Consumer Commodity/ Limited Quantity/ ORM-D

SAFETY AND ENVIRONMENTAL PRECAUTIONS

WELD-ON 16 is a flammable, fast evaporating solvent cement and is considered a hazardous material. In conformance with the Federal Hazardous Substances Labeling Act, the following hazards and precautions are given. Purchasers who may repackage this product must also conform to all local, state and federal labeling, safety and other regulations.

DANGER - EXTREMELY FLAMMABLE - VAPOR HARMFUL - MAY BE HARMFUL IF SWALLOWED - MAY IRRITATE SKIN OR EYES

Keep out of reach of children. Do not take internally. Keep away from heat, spark, open flame and other sources of ignition. Contact with hot surfaces may produce toxic effects. Keep container closed when not in use. Store in the shade below 80°F. Use only in well ventilated area. Avoid breathing of vapors. Atmospheric levels should be maintained below established exposure limits. See Section II and VIII of the Material Safety Data Sheet. If airborne concentrations exceed those limits, use a supplied air respirator. Do not use a chemical cartridge respirator. For emergency and other conditions where short-term exposure guidelines may be exceeded, use an approved positive pressure self-contained breathing apparatus (SCBA). Do not smoke, eat or drink while working with product. Avoid contact with skin, eyes and clothing. May cause eye injury. Protective equipment such as gloves, goggles and impervious apron should be used. Carefully read Material Safety Data Sheet and follow all precautions. Contains Methyl Ethyl Ketone (78-93-3), Methylene Chloride (75-09-2) and Methyl Methacrylate Monomer (80-62-6). Methylene Chloride is a possible human cancer hazard based on test results with laboratory animals. Risk to your health depends on level and duration of exposure, as well as individual sensitivity. Do not use this product for other than intended use.

"Proposition 65 Warning": This product contains chemicals known to the State of California to cause cancer.

"Title III Section 313 Supplier Notification": This product contains toxic chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 and of 40CFR372. This information must be included in all MSDS's that are copied and distributed for this material.

FIRST AID

Inhalation: If ill effects from inhalation, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call physician.
Eye or Skin Contact: Flush with plenty of water for 15 minutes. If irritation persists, get medical attention.
Ingestion: If swallowed, do not induce vomiting. Contact physician immediately.

QUALITY ASSURANCE:

Every batch of this cement is checked to assure that consistent quality is maintained. An infrared absorption curve is recorded for each batch to ensure that this cement is properly formulated. Samples are taken from all batches and kept for a period of at least one year. A batch identification code is stamped on each can.

IMPORTANT NOTE:

This product is intended for use by skilled individuals at their own risk. These suggestions and data are based on information we believe to be reliable. Users should verify by test that this product, as well as these methods, are suited to their application. Since specific use, materials and handling are not controlled by IPS, our warranty is limited to the replacement of defective IPS products.

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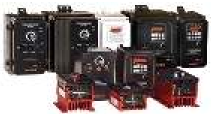

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OUR PRODUCTS

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Our Products >> KBWC-16K (H9001), Wall Mount, AC Fan Motor Control

KBWC-16K (H9001), Wall Mount, AC Fan Motor Control

The KBWC-16K is a Distributor packaged Solid State AC Motor Speed Fan Control. It is designed for mounting in a 2" X 4" electrical wall box. It operates from 115 VAC, 50/60 Hz and has a maximum rating of 6.0 Amps @ 25°C. The KBWC-16K provides infinitely variable speed motor control for Shaded Pole, Permanent Split Capacitor and Universal (AC/DC) motors. The variable speed motor control contains an on/off line switch, a high gain RFI noise suppression filter, a minimum speed trimpot and a flame retardant ABS enclosure. Applications include range hoods, vibrators, humidifiers, fireplace blowers, fans, laminar flow hoods, heat tunnels and stirrers. See data sheet D-160 for optional features. The "K" suffix indicates, mounting kit that includes individual packaging with dial plate, knob, mounting screws, wire connectors and instructions.

KBWC:

Item #: KBWC-16K

* Marked fields are required.

Qty*	1
Price	$25.85
Availability	In-Stock

Add To Cart

Terms and Conditions About Us

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(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Screw for Wood

Phillips, Type 316 Stainless Steel, Number 8, 1" Long

In stock
$6.76 per pack of 25
90294A729

Length	1"
Additional Specifications	Phillips—Type 316 Stainless Steel No. 8—#2 Drive
RoHS	Compliant

These flat head screws are beveled under the head, so they sit flush with the surface when installed.

McMASTER-CARR
(562) 692-5911
(562) 695-2323 (fax)
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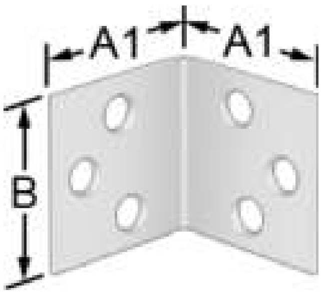
Bracket

Zinc-Plated Steel, 2" Length of Sides

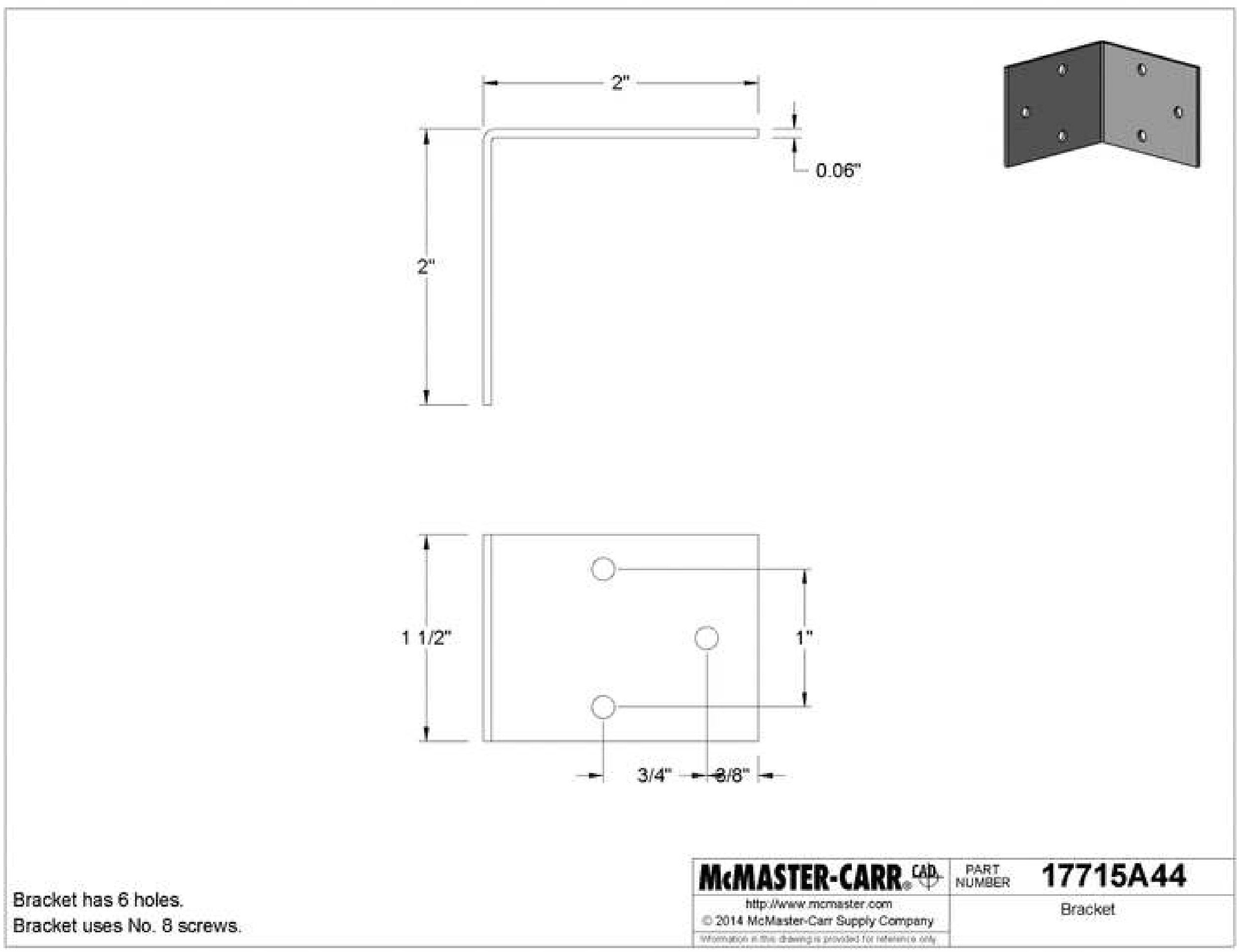
In stock
1-49 Each $1.82
50 or more $1.41
17715A44



Material	Zinc-Plated Steel
Length (A1), (A2)	2"
Width (B)	1 1/2"
Thickness	0.06"
Screw/Nail Size	No. 8
Number of Holes	6

Also known as angle brackets, corner brackets, and mending plates, these brackets support corners and joints. They do not include mounting fasteners.

Note: Prices are approximately 25% lower when you buy 50 or more of the same bracket.



The information in this 3-D model is provided for reference only.

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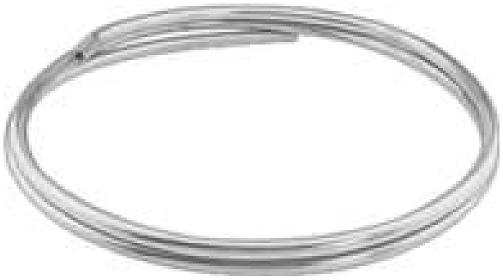
Multipurpose Copper Tubing

8955K112

1/8" Tube Size, 1/4" OD, .152"' ID, .049" Wall



Tube Size	1/8
OD	1/4"
Wall	0.049"
ID	0.152"
Maximum psi @ 70° F	2,200
Length	10 ft., 50 ft.
Temperature Range	-425° to 400° F
Additional Specifications	Coils Straight Lengths: Not bendable Coils: Bend by hand Use with brass compression fittings and copper solder-joint fittings

You know this copper Alloy 122 tubing as a tried-and-true favorite—it is versatile and has excellent heat transfer qualities. Use with water, air, oil, and hydraulic fluid. It meets ASTM B75. Tubing has seamless construction, which provides a smooth interior. Tubing can be sterilized with steam (autoclaving). Coils have a soft (annealed) temper.

Note: Tube size is an accepted industry designation, not an actual size.

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Text 75930

Graduated Clear Plastic Cylinder

In stock
$27.35 Each
4436T37

1000 ml Cap, 10.0 ml Graduations, 17-1/4" Height

Capacity	1,000 ml
Graduation Intervals	10.0 ml
Body Diameter	2 5/8"
Height	17 1/4"
Additional Specifications	(A) Clear

Measure and pour with precision. These autoclavable cylinders have a maximum temperature of 275° F. Styles A&B meet ISO 6706 standards and DIN 12680 TT, Class B tolerances.

(A) Clear cylinders are polymethylpentene.

Appendix H: Operator's Manual with Safety Guidelines

***Warning:** The Active Fog Catcher Prototype is under high pressure. Safety glasses MUST be worn at all times while interacting with the system.
***Warning:** Keep hands and fingers away from moving fan blades and the hot refrigerant returning pipes

Handling the Active Fog Catcher

The Active Fog Catcher Prototype utilizes a pressurized refrigeration system (R134a) and should be handled with care and caution. The prototype rests on a rigid table with rolling wheels. When moving the system, first unlock the braking mechanisms at the wheels, and gently push the table. Be careful not to push on the wood base of the prototype because it is not secured to the table. The rolling table can transmit a lot of unwanted vibration to the prototype when pushed over rough surfaces. Avoid asphalt when possible and maneuver around any unwanted rough surfaces. When taking the prototype off the table, be careful setting it back down so as not to disturb the connections on the refrigeration system.

Operating Conditions

The system runs best in high humidity conditions (75-100% RH). The colder the ambient condition, the less likely the compressor will overheat. The system shall never be operated in rainy conditions.

Turning on the Active Fog Catcher

First, check the pressure gauges to make sure there haven't been any significant leaks. The high pressure gauge should read approximately 70 psi in ambient conditions.

Second, make sure there is no debris or anything obstructing the duct or fans.

Make sure the graduated cylinder is in position to catch water.

Leave the ball valve close, but ensure that the expansion valves are mostly open (at least halfway on each valve)

Plug the cord from the power strip into a wall outlet and turn on the main power strip switch.

IMPORTANT: Turn on both fans prior to turning on the condensing unit

Flip the switch for the fans first and use the speed controller to set desired fan speed. Then turn on the condensing unit.

Running the system

Once the system is on and running, the operator should monitor both gauges as well as the condensing unit and evaporators. In order to extract water from the air, the evaporator fins need to be below the dew point but above the freezing point of water. By slowly closing the expansion valves, bring the low side temperature reading to about 32 degrees F. This should produce some frost on the first coils which is to be expected. Note that the response time for decreasing the pressure and temperature on the low side is very slow. The operator should continually monitor the temperature of the compressor simply by touch. If it is almost too hot to touch the system should be turned off to allow the compressor to cool down.

If water is not condensing or freezing on the coils, close the expansion valves slowly until they do. If the low side pressure gauge reads much less than 32 degrees F open the expansion valves to allow more refrigerant through the system.

When shutting off the device, first turn off the compressor followed by the fans and unplug the unit from the wall.