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Sung-Mo Lee
Worcester Polytechnic Institute

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A Performance Evaluation of Low Pressure Carbon Dioxide Discharge Test

by

Lee, Sung-Mo

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Approved :

Robert Zalosh

Professor Robert G. Zalosh, Major Advisor
Fire Protection Engineering Department

Affiliate Professor Won K. Kim Co-Advisor
Fire Protection Engineering Department

Professor David Lucht, Head of Department
Fire Protection Engineering Department

Abstract

This paper describes a CO_2 extinguishing system test program to determine the ability and limitations of the NFPA 12 methodology to calculate system discharge times, discharge pressures and subsequent CO_2 concentrations in enclosures. For doing so, this paper compares the predicted values in pressures and concentrations generated from the flow calculations, which are based on the formulae in NFPA 12, with the results of actual full-scale system discharge tests. Furthermore, this paper also aims to determine whether the concentrations obtained could successfully extinguish deep-seated fires and flammable liquid fires in the enclosures at the actual discharge tests.

A total of twenty CO_2 system discharge tests were conducted under different conditions. If all the measured pressures at the three node points of pipe runs and the measured CO_2 concentrations in the test enclosures do not deviate from the predicted values of computerized flow calculations by more than ±10 percent, the tests are judged to be acceptable. The results of CO_2 concentration tests which were conducted under "no efflux" condition in the enclosures showed all agreements with the calculated concentrations in most cases, except that Test No. 1 for the longest pipe run of 502 ft (153m), showed a CO_2 concentration exceeding the permissible range, more than -10 percent. In the meantime, the longest pipe run which fell within the permissible range, ±10 percent, was 230 ft (70m) for Test No. 16, of which maximum percent of agent in pipe was 51 percent.

Test results have revealed the following important limitation of NFPA 12 methodology.

A low-pressure CO_2 extinguishing system with a pipe run exceeding roughly 492 ft (150m), designed and installed in compliance with the calculations based on the pressure drop equation in NFPA 12, is not likely to achieve the concentration required for fire extinguishment within the required discharge time. NFPA 12 methodology doesn’t provide formulae to calculate the time dependent quantity of CO_2 which is to be discharged into an enclosure after passing through the pipe network extending from the storage container. The flow calculations of a computer software program used for this test program, which is intended to eliminate such limitations, partially can calculate the quantity of CO_2 to be discharged into the enclosure within the determined discharge time. Especially, for a low-pressure CO_2 system, the delay time due to the vaporized CO_2 should be calculated as well.

Preface and Acknowledgements

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Especially, I wish to thank Professor En Sup Yoon, a director in Institute of Chemical Processes in Seoul National University who provided me with a distance learning program in Korea. Also, I wish to thank SH Engineering Corporation for their support of me with the test enclosures, test apparatus and professional personnel required for conducting a number of full-scale CO_2 discharge tests successfully. I would not have been able to write this paper without their support and cooperation.

I would also like to thank Taick K. Lee, P. E., for his great help and effort in conducting CO_2 discharge tests over a considerable period of time, as well as Hee W. Kim for his advice to me regarding many technical issues of low-pressure CO_2 extinguishing systems.

Finally, I would like to thank my wife, Herena, for her understanding, encouragement and patience during my study in WPI.

Table of Contents

List of Tables and Figures

Nomenclature

A – Area of opening / Free venting area

A_L – Total leakage area in enclosure

C – Carbon dioxide concentration fraction

C_d – Discharge coefficient of opening

D – Internal diameter in pipe

D_t – Delay time

EQL – Equivalent length of pipeline

f – Moody friction factor

G – Mass discharge flow rate

g – Gravitational constant

H – Latent heat of vaporization of liquid carbon dioxide

h – Static head between opening and top of enclosure

L – Length of pipe

L_e – Equivalent length of pipeline

P – Pressure

P_1 – Storage pressure

P_e – Allowable strength of enclosure

Q – Flow rate

R – Rate of carbon dioxide

T_1 – Average pipe temperature before discharge

T_2 – Average carbon dioxide temperature

t – Discharge time

V – Volume of piping

V_e – Enclosure volume

V_g – Volume of carbon dioxide added per volume of space

v – Velocity

W – Weight of carbon dioxide vaporized

w – Weight of piping

X – Volume concentration of carbon dioxide

X_i – Initial volume concentration of carbon dioxide

Y – Dimensionless ratio

$Y_{previous}$ – Y factor at the end of pipe section

Y_{final} – Final Y factor

Z – Dimensionless ratio

$Z_{average}$ – Average of Z factor

Z_{in} – Input of Z factor

Z_h – Elevation head

Z_0 – Output of Z factor

ρ – Fluid density

ρ_1 – Fluid density at pressure P_1

ρ_a – Density of atmosphere

ρ_c – Vapor density of carbon dioxide

ρ_m – Density of mixture of carbon dioxide and air

ρ_{mi} – Density of initial mixture of carbon dioxide and air

ρ_s – Density of surrounding air

1.0 Introduction

1.1 Background

From the mid-sixties to the early nineties, halon 1301 was the fire protection industry's standard for high-value asset protection requiring a clean, non-toxic, non-conductive suppression agent. However, worldwide concerns over depletion of the ozone layer by ozone depleting substances, ODS, such as halon 1301 for the fire protection industry, led to the adoption of the Montreal Protocol in 1987. Under the terms of the Montreal Protocol and its subsequent amendments and adjustments, the production of halon 1301 was banned from January 1, 1994. A dozen of halon alternative agents have been developed and marketed for use as fire extinguishing agents today.

Since the introduction of halon alternative agents, retrofit and replacement of existing halon systems has been a major concern of the fire protection industry. However, penetration into the retrofit and replacement market has been limited due to the large costs associated with replacing an existing halon system. In addition to new hardware and agent costs, a significant expense is the requirement that the exiting halon installation piping be changed in order for the performance of the clean agent system to comply with codes and standards such as NFPA 2001, Standard for Clean Agent Fire Extinguishing Systems, because no halon alternative agent has emerged as a "drop-in" replacement for halon 1301 up until now. In view of the disadvantages and limitations of halon alternative agents in retrofitability and/or replaceability, carbon dioxide, especially low-pressure carbon dioxide, can provide viable protection to significant assets in areas where evacuation is possible.

It is generally known that carbon dioxide systems have been installed and used worldwide for a long period of time since 1910's, and that the fire extinguishing performance of carbon dioxide systems is well established, esp. as long as they are designed and engineered in accordance with NFPA 12, Standard on Carbon Dioxide Extinguishing Systems, and a computer software program based on the calculation formula stipulated in NFPA 12 [3].

The main contents of this paper are to compare the predicted values generated from the flow calculations based on the calculation formula in NFPA 12 with the results of the actual full-scale system performance tests.

1.2 Properties of Carbon Dioxide

Carbon dioxide has a number of properties that make it a desirable fire extinguishing agent. It is noncombustible, it does net react with most substances, and it provides its own pressure for discharge from the storage container. Since carbon dioxide is a gas, it can penetrate and spread to all parts of a fire area. As a gas or as a finely divided solid called "snow" or "dry ice," it will not conduct electricity and, therefore, can be used on energized electrical equipment. It leaves no residue, thus eliminating cleanup of the agent itself.

At room temperature and pressure, carbon dioxide is a gas. It is easily liquefied by compressing and cooling, and, with further compressing and cooling, it can be converted to a solid. The effect of temperature changes on compressed carbon dioxide in a closed container is shown in Figure 1 [4].

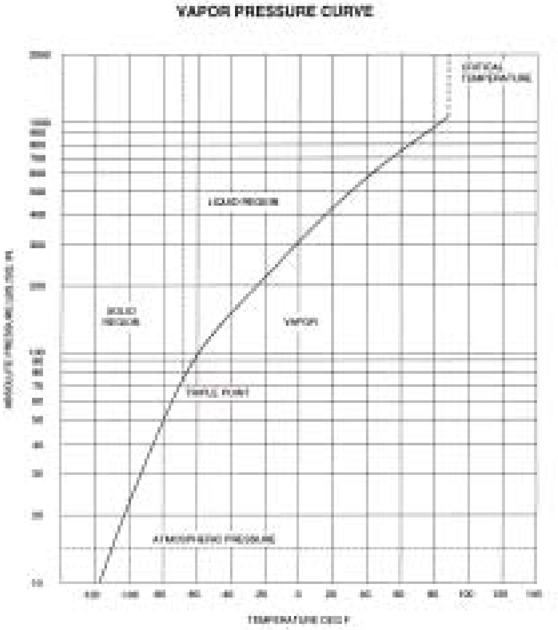


Figure 1. Variation of Pressure of Carbon Dioxide with Change in Temperature

On the part of the curve between –69.9°F (-57°C)and the critical temperature of 87.8°F (31°C), carbon dioxide in a closed container may be a gas or liquid. The pressure is related to the temperature, as long as both vapor (gaseous) and liquid states are present. As the temperature and pressure increase, the density of the vapor phase increases while the density of the liquid phase decreases. At 87.8°F (31°C), the density of the vapor becomes equal to the density of the liquid, and the clear demarcation between the two phases disappears. Above the critical temperature, high-pressure carbon dioxide exists only in a gaseous form.

When the temperature is reduced to –69.9°F (-57°C) at 75 psia (5.2 bars), carbon dioxide may be present in vapor, liquid, and solid forms in equilibrium with each other. Hence, the term "triple point" to describe this condition. Below the triple point, only vapor and solid phases can exist. Thus, when liquid carbon dioxide is discharged to atmospheric pressure, a portion instantly flashes to vapor while the remainder is cooled by evaporation and converted to finely divided snow, or dry ice, at a temperature near -110°F (-79°C). The proportion of CO_2 converted to dry ice depends upon the temperature of the stored liquid. Approximately 46 percent of the liquid stored at 0°F (-18°C) will be converted to dry ice, compared to approximately 25 percent for liquid stored at 70°F (21°C).

Carbon dioxide gas has a density of one and one-half times the density of air at the same temperature. The cold discharge has a much greater density, which accounts for its ability to replace air above burning surfaces and maintain a smothering atmosphere when used in local application systems. When carbon dioxide is used for total flooding, the resulting mixture of CO_2 and air will be more dense than the ambient atmosphere.

The extinguishing mechanisms of carbon dioxide are oxygen reduction and cooling. The cooling effect of carbon dioxide is relatively small but does make some contribution to fire extinguishment, particularly when carbon dioxide is applied directly to the burning material. Although the temperatures involved in a carbon dioxide discharge may approach -110°F (-79°C), the cooling capacity of the carbon dioxide is quite small compared to an equal weight of water. The latent heat of one pound of liquid CO_2 is about 120 Btu (123 kJ) from low-pressure storage and 64 Btu (67.5 kJ) from storage at

70°F (21°C). The cooling effect is most apparent when the agent is discharged directly on the burning material by "local application." A massive application quickly covering the entire surface area smothers the fire and helps cool the fuel.

In any fire, heat is generated by rapid oxidation of a combustible material. Some of this heat raises the unburned fuel to its ignition temperature, while a large part of the heat is lost by radiation and convection, especially in the case of surface burning materials. If the atmosphere that supplies oxygen to the fire is diluted with carbon dioxide vapor, the rate of heat generation is reduced until it is below the rate of heat loss. When the fuel is cooled below its ignition temperature, the fire dies out and is extinguished completely. The minimum concentration of carbon dioxide needed to extinguish surface burning materials, such as liquid fuels, can be determined accurately, since the rate of heat loss by radiation and convection is reasonably constant. Table 1 lists the minimum concentrations of CO_2 for some common liquid and gaseous fuels. The theoretical minimum CO_2 concentration is the actual concentration of CO_2 required to extinguish and prevent fire in a given fuel. The minimum design concentration is 20 percent more than the theoretical minimum CO_2 concentration, but never is less than 34 percent (per NFPA 12). It is difficult to obtain similar data for solid materials because the rate of heat loss by radiation and convection can vary widely, depending upon shielding effects caused by the physical arrangement of the burning material. Design concentrations for hazards containing solid fuels have been determined from testing and experience. NFPA 12 gives design concentrations for a number of such hazards.

Table1. Minimum Carbon Dioxide Concentrations for Extinguishment [6]

Vapor Fuels	CO_2/air [a] (v/v)	O_2 Concentration (%)	Theoretical[b] Minimum CO_2 Concentration	Minimum[b] Design CO_2 Concentration
Carbon Disulfide	1.59	8.1	60	72
Hydrogen	1.54	8.2	62	75
Ethylene	0.68	12.5	41	49
Ethyl Ether	0.51	13.9	38	46
Ethanol	0.48	14.2	36	43
Propane	0.41	14.9	30	36
Acetone	0.41	14.9	27	34
Hexane	0.40	15.0	29	35
Benzene	0.40	15.0	31	37
Methane	0.33	15.7	25	34
Higher Paraffin Hydrocarbons $C_n H_{2m}$ + 2m - 5			28	34

[a] Friedman 1989 [17]

[b] Table 2-3.2.1 of NFPA 12

Table 2 presents cup burner and full-scale data from VdS. It is interesting that the cup burner concentrations of certain fuels like n-heptane listed in Table 2 are significantly lower than the values listed in Table 1.

Table 2. Carbon Dioxide Extinguishing Concentration Data from VdS [7]

Fuel	ISO Cup Burner (%)		VdS Large Cup Burner (%)	Room Fire (%)	
	Fuel Unheated	Fuel Heated		Extinguished	Not Extinguished
Acetone	18.7	19.4	21.4		

Fuel	ISO Cup Burner (%)		VdS Large Cup Burner (%)	Room Fire (%)	
	Fuel Unheated	Fuel Heated		Extinguished	Not Extinguished
Diethyl ether	-	23.0			
Ethanol	20.8	23.0			
n-Heptane	19.6	21.1	23.3	24.1	23.1
n-Hexane	20.4	21.3			
Methanol	27.5	28.5	31.3		
n-pentane	-	21.6			
Toluol	15.9	16.7			
Polypropylene			21.5		
Polyethylene			20.8		
Wood crib				26.8	24.4

Carbon dioxide is normally present in the atmosphere at a concentration of approximately 0.03 percent. It is present in humans and animals as a normal byproduct of cellular respiration. In the human body, carbon dioxide acts as a regulator of breathing, thus ensuring an adequate supply of oxygen to the system. Up to a point, an increase in carbon dioxide acts as a regulator of breathing, thus ensuring an adequate supply of oxygen to the system. Up to a point, an increase in carbon dioxide in the blood causes an increase in breathing rate. The maximum increase in respiration occurs when breathing 6 to 7 percent CO_2 in air. Higher concentrations of CO_2 slow down breathing. Finally, with 25 to 30 percent CO_2 in air, a narcotic effect takes over and stops breathing almost immediately – even with a sufficient supply of oxygen in the air. Reduced oxygen supplies will cause a very much lower concentration of carbon dioxide to suppress breathing and cause death from asphyxiation. The exact concentration of carbon dioxide in air that will cause a decrease in respiration varies from person to person and is not constant even in the same person from time to time.

6 to 7 percent CO_2 is considered the threshold level at which harmful effects become noticeable in human beings [14]. At concentrations above 9 percent, most people lose consciousness within a short time. Since the minimum concentration of CO_2 in air used to extinguish fire far exceeds 9 percent, adequate safety precautions must be designed into every carbon dioxide fire extinguishing system. The dry ice that is produced during a discharge can produce "burns," due to the extreme low temperature. Personnel should be warned not to handle any residual snow after a discharge.

1.3 Methods of Application

Two basic methods are used to apply carbon dioxide in extinguishing fires. One method is to discharge a sufficient amount of the agent into an enclosure to create an extinguishing atmosphere throughout the enclosed area. This is called "total flooding." The second method is to discharge the agent directly onto the burning material without relying on an enclosure to retain the carbon dioxide. This is called “local application.”

In total flooding systems, carbon dioxide is applied through nozzles designed and located to develop a uniform concentration of CO_2 in all parts of an enclosure. Calculation of the quantity of carbon dioxide required to achieve an extinguishing atmosphere is based upon the volume of the room and the concentration of CO_2 required for the combustible materials in it.

The integrity of the enclosure is a very important part of total flooding, particularly if deep-seated fire potential exists in the hazard. If the room is tight, especially on the sides and bottom, the CO_2 extinguishing atmosphere can be retained for a long time to ensure complete control of the fire. If there are openings on the sides and bottom, however, the heavier mixture of carbon dioxide and air may leak out of the room rapidly. If the extinguishing atmosphere is lost too rapidly, glowing embers may remain and cause reignition when air reaches the fire zone. Thus, it is important to close all openings to minimize leakage or to compensate for the openings by discharging additional carbon dioxide. Because of the relative weight of carbon dioxide, an opening in the ceiling helps to relieve internal air pressure during the discharge, with very little effect on leakage rate after the discharge.

An extended discharge of CO_2 is used when an enclosure is not tight enough to retain an extinguishing concentration as long as it is needed. The extended discharge normally is at a reduced rate, following a high initial rate used to develop the extinguishing concentration in a reasonably short time. The reduced rate of discharge should be a function of the leakage rate, which can be calculated on the basis of leakage area, or of the flow rate through ventilating ducts that cannot be shut down.

Extended discharge is particularly applicable to enclosed rotating electrical equipment, such as generators, where it is difficult to prevent leakage until rotation stops. Extended discharge can be applied to ordinary total flooding systems, as well as to local application systems where a small hot spot may require prolonged cooling.

In local application systems, carbon dioxide is discharged directly on the burning surfaces through nozzles designed for this purpose. The intent is to cover all combustible areas with nozzles located so they will extinguish all flames as quickly as possible. Any adjacent area to which fuel may spread also must be covered, because any residual fire could cause reignition after the CO_2 discharge ends.

Local application discharge nozzles usually are designed for relatively low velocity to avoid splashing and air entrainment. Automatic detection is a necessity to provide fast response and minimize heat buildup. Although not essential, an enclosure would help retain carbon dioxide in the fire area. Local application of CO_2 can also be used for fast fire knockdown in an enclosure where final total flooding can provide absolute assurance that extinguishment will be complete.

The CO_2 supply may be stored in high- or low-pressure storage containers. Because of the differences in pressure, system design is influenced by the storage method. At temperatures and pressures above -69°F (-56°C) and 60 psig (4.2 bars), and below 88°F (31°C) and 1057 psig (72.9 bars), carbon dioxide liquid with overlying vapor may exist in equilibrium within a closed vessel. Within this range, there is a definite relationship between temperature, pressure and density. By comparing the pressure and liquid density at 70°F (838 psig and 47 lb per cubic foot), with the pressure and density at 0°F (291 psig and 63.7 lb per cubic foot), it is obvious that relatively large quantities of carbon dioxide liquid can be stored in relatively small, thin walled pressure vessels, hence, low-pressure storage container of CO_2. The term “low-pressure” is used in the industry to describe storage of carbon dioxide at temperatures below ambient, usually around 0°F (-18°C). The normal operating pressures range from 295 psig (20.3 bars) to

305 psig (20.9 bars). For the purpose of this paper, a total flooding system operated by a low-pressure CO_2 system is discussed.

1.4 Components of CO_2 System

The main components of a carbon dioxide system are the carbon dioxide supply, the discharge nozzles, and the piping system. These components, along with control valves and other operating devices, dispense the carbon dioxide and provide effective fire extinguishment.

The CO_2 supply is stored in low-pressure storage containers. Low-pressure storage containers are maintained at a temperature of approximately 0°F (-18°C) by use of insulation and mechanical refrigeration [12]. At this temperature, the pressure is approximately 300 psig (20.7 bars). A compressor, controlled by a pressure switch in the tank, circulates refrigerant through coils near the tank top. Tank pressure is controlled by condensation of carbon dioxide vapor by the coils. In the event of refrigeration failure, pressure relief valves bleed off some of the vapor to keep the pressure within safe limits. This permits some of the liquid to evaporate, creating a self-refrigerating effect that reduces the pressure in the tank. With a low-pressure CO_2 system, it is a common practice to protect multiple hazards from one central storage container. The quantity of carbon dioxide discharged into a particular hazard is controlled by opening and closing the discharge valve in a preset timed sequence.

Piping systems, normally empty, convey carbon dioxide from the storage container to open nozzles where there is a fire. Since the proper rate of flow is a critical requirement for fire extinguishment, it is important that the piping be designed and installed accurately. Minimum pressure in the pipeline must be kept well above the triple point pressure of 75 psia (5.2 bars). If the pressure of the flowing carbon dioxide falls below the triple point pressure, dry ice will form in the pipe and block orifices in the discharge nozzles, thus stopping the flow of carbon dioxide. NFPA 12 limits the design nozzle pressure to a minimum of 150 psia (10.3 bars) for a low-pressure CO_2 system.

Carbon dioxide drawn from the bottom of the storage container enters the piping as a liquid. Friction causes loss in pressure. As pressure drops, the liquid boils, resulting in a mixture of liquid and vapor in the piping. The vapor increases in volume as the mixture passes through the piping, with a further drop in pressure. Thus, the flow is two-phase, a mixture of liquid and gas, a fact that pressure drop calculations must take into account. NFPA 12 covers the calculation of CO_2 flow in some detail and provides pertinent equations and data tables. Although charts and tables are available for manual flow calculation of system piping, the use of an available computer software program speeds and simplifies the design of piping systems.

The piping must be adequately supported to prevent movement during the discharge, and provision must be made for its contraction and expansion. Because liquid carbon dioxide is a refrigerant, it will substantially reduce the pipe temperature during discharge. Low-pressure liquid, in particular, starts at 0°F (-18°C) and may reach temperatures as low as -50°F (-46°C) in the piping before the discharge ends.

Valves for controlling the discharge of carbon dioxide must withstand the maximum operating pressure, be absolutely bubbletight when closed, and be capable of both manual and automatic operation. Valves and allied devices, such as times and pressure switches, must be listed or approved for use in CO_2 systems. Nozzles used in total flooding simply may be orifices producing high-velocity jet streams.

2.0 Flow Calculation Method

2.1 Quantity of Carbon Dioxide

The quantity of carbon dioxide required for fire extinguishment depends upon the type of fire, the type of extinguishing system and conditions in the fire area. The design concentration for a given enclosure should be sufficient to extinguish fires in all the fuels that are present in the hazard. The minimum concentration used in total flooding systems is 34 percent carbon dioxide by volume. Minimum design concentrations for various liquids and gases are given in Table 1. NFPA 12 requires a 50 percent concentration for electrical wiring hazards, including small electrical machines; 65 percent for bulk paper and fur storage vaults; and 75 percent for dust collectors. These are specific hazards for which there is a background of test experience. Other materials should be tested to determine minimum CO_2 concentrations and holding time.

The quantity of carbon dioxide must be sufficient to achieve a minimum design concentration and to hold it until the fire is extinguished. A series of specific flooding factors has been established for surface fire hazards. These factors include an allowance for distributed leakage due to cracks around doors, porosity of the walls, and other small openings based on room sizes. The factors are greater for small rooms as below Table 3, because the anticipated leakage would be greater relative to volume. Surface fires, such as flammable liquid fires, are normally extinguished during a 1 minute carbon dioxide discharge. Leakage compensation must be in addition to the basic quantity.

Table 3. Flooding Factors to Achieve 34 Percent Design Concentration

Volume of Space (cu ft)	Volume Factor		Calculated Quantity Not Less than (lb)
	(cu ft/lb CO_2)	(lb CO_2/cu ft)	
Up to 140	14	0.072	-
141- 500	15	0.067	10
501- 1600	16	0.063	35
1601- 4500	18	0.056	100
4501- 50,000	20	0.050	250
Over 50,000	22	0.456	2500

Deep-seated fires require higher concentrations and much longer holding times. The rate of discharge must be high enough to develop a concentration of 30 percent in not more than 2 minutes, and the final design concentration must be achieved in not more than 7 minutes. Enclosures for deep-seated fires must be relatively tight, or it quickly becomes uneconomical to maintain the CO_2 design concentration. The basic quantity of CO_2 needed for deep-seated fire hazards is calculated using flooding factors given in Table 4.

Table 4. Flooding Factors for Specific Hazards

Design Concentraion	Flooding Factor		Specific Hazard
	($ft^3/lb\ CO_2$)	($lb\ CO_2/ft^3$)	
50	10	0.100	Dry electrical hazards in general(Spaces 0 - 2000 ft^3)
50	12	0.083(200lb) minimum	(Spaces greater than 2000 ft^3)
65	8	0.125	Record(bulk paper) storage, ducts, and covered trenches
75	6	0.166	Fur storage vaults dust collectors

2.2 Pipe and Orifice Size Determination

As is generally known, the liquefied compressed gas which has had the longest history of continuous use for fire suppression is carbon dioxide. NFPA 12 gives a method of calculating flow of CO_2 based on the doctoral dissertation of Dr. James Hesson (Pressure Drop for Two Phase Carbon Dioxide Flowing in Pipelines, IIT, 1953). This same basic methodology was adapted by Vic Williamson and later refined by Tom Wysocki to predict flow parameters for liquefied compressed gases like CO_2 [8]. Bernoulli's equation is a fundamental equation of hydrodynamics. A qualitative statement of this equation is that the sum of any changes in pressure head, velocity head, friction head and elevation head in a system is zero assuming no heat input or loss from the system. The Bernoulli theorem is a means of expressing the application of the law of conservation of energy to the flow of fluids in a conduit. The total energy at any particular point, above some arbitrary horizontal datum plane, is equal to the sum of the elevation head, the pressure head, and the velocity head. In its basic form, this equation can calculate hydraulic parameters for substances whose density is essentially constant with changes in pressure – in other words, for non-compressible flow.

$$Z_h + \frac{144P}{\rho} + \frac{v^2}{2g} = H \tag{2-1}$$

where Z_h = Elevation head
P = Static pressure
ρ = Density
v = Velocity
g = Gravitational constant

H is the total energy which is a constant for the fluid if there is no energy exchange between the fluid and surroundings occurs. In reality, there is energy exchange at least in the form of energy lost to friction in the pipe. The Hesson equation accounts for energy loss to friction. Hesson's adaptation of Bernoulli's equation permits calculations for substances whose density changes with changing pressure [16].

$$43.5\, Q^2\, f\, L \;-\; 7.97\, Q^2\, D \int_{P_0}^{P_f} \rho\, dp \;+\; D^5 \int_{\rho_0}^{\rho_f} \frac{d\rho}{\rho} \;=\; 0 \tag{2-2}$$

where Q = Flow rate in lbs/sec
f = Moody friction factor
L = Equivalent length of pipe in feet
D = Internal diameter of the pipe in inches
ρ = Fluid density in lbs/cu ft
P = Pressure in psi

The integration is done from the starting point of a pipe section to the end point of the pipe section. Both of these equations relating pressure, flow rate, pipe diameter, and pipe length require knowledge of the density of the flowing media as a function of the pressure in the pipe.

Liquefied compressed gases exhibit the characteristics of compressible flow. The density of the agent changes considerably as the pressure in the pipeline decreases. Theses agents also exhibit "two-phase" flow in that the flowing agent is comprised of a mixture of liquid and vapor. One of the major problems in predicting pressure drop and flow rate in such a system is deriving an accurate relation between agent density and pressure. Depending on the degree of accuracy needed for the type of fire suppression system, a more or less rigorous approach will be required to calculate the pressure density relationship.

For low-pressure carbon dioxide system work, the pressure in the storage container is set to 300 psig (20.7 bars). Density as a function of pressure is calculated by assuming that the carbon dioxide liquid will expand from a saturated condition at 300 psig (20.7 bars) with the enthalpy held constant. This approach provides the required degree of accuracy for calculating flow rates and system pressures for CO_2. For large complex carbon dioxide systems, transient conditions at the start and end of discharge may also need to be considered.

The problem of computing pipe sizes for carbon dioxide systems is complicated by the fact that the pressure drop is nonlinear with respect to the pipeline [9]. Carbon dioxide leaves the storage container as a liquid at saturation pressure. As the pressure drops because of pipeline friction, the liquid boils so as to produce a mixture of liquid and vapor. Because of this the volume of the flowing mixture increases and the velocity of flow must also increase. Thus, the pressure drop per unit length of pipe is greater near the end of the pipeline than it is at the beginning.

Pressure drop information for designing piping systems can best be obtained from curves of pressure versus equivalent length for various flow rates and pipe sizes. Such curves can be plotted using the theoretical equation given in tables in NFPA 12. The Y and Z factors in the equation depend on storage pressure and line pressure. These can be evaluated from the following equations.

$$Y = -\int_{P_1}^{P} p \, dP \qquad (2\text{-}3)$$

$$Z = -\int_{\rho_1}^{\rho} \frac{d\rho}{\rho} = \ln \frac{\rho_1}{\rho} \qquad (2\text{-}4)$$

where P_1 = Storage pressure in psia

P = Pressure at end of pipeline in psia

ρ_1 = Density at pressure P_1 in lbs/cu ft

ρ = Density at pressure P in lbs/cu ft

$\ln$ = Natural logarithm

In the above equation, *Z* is a dimensionless ratio. The *Y* factor has units of pressure times density and will therefore change the system of units. The storage pressure is an important factor in carbon dioxide flow. In low-pressure CO_2 systems, the starting pressure in the storage container will recede to a lower level, depending on whether all or only a part of the supply is discharged. Because of this, the average pressure during discharge will be about 285 psig (19.7 bars). The flow equation is based on absolute pressure; therefore, 300 psia is used for calculations involving low-pressure CO_2 systems.

Using the above base pressures of 300 psia, values have been determined for the Y and Z factors in the flow equation. For practical application it is desirable to plot curves for each pipe size that may be used. However, it will be noted that flow equation can be rearranged as given below.

$$\frac{L_e}{D^{1.25}} = \frac{3647Y}{(Q/D^2)^2} - 8.08Z \qquad (2\text{-}5)$$

where Q = Flow rate in lbs/min

D = Inside pipe diameter (actual) in inches

L_e = Equivalent length of pipeline in ft

Y & Z = Factors depending on storage and line pressure

The following equation or curves developed shall be used to determine the pressure drop in the pipe line.

$$Q^2 = \frac{(3647)\,(D^{5.25}Y)}{L_e + 8.08(D^{1.25}Z)} \qquad (2\text{-}6)$$

2.3 CO_2 Initial Transient Flow

At the beginning of a CO_2 discharge, the pipe network is generally warm compared to the temperature of the CO_2. When cold carbon dioxide flows into a warm pipe, the carbon dioxide will absorb heat from the pipe. If sufficient heat is available in the pipe, the flowing carbon dioxide will completely vaporize before it reaches the discharge nozzles. In most low-pressure carbon dioxide installations, there will be a noticeable delay (initial vapor time) in achieving predominantly liquid CO_2 flow at the nozzles. During this delay, the liquid CO_2 leaving the storage container will be vaporized by heat from the pipe.

Once the pipe is cooled to the approximate temperature of the flowing carbon dioxide, there is minimal heat influx into the flowing carbon dioxide. At this point in the discharge, the carbon dioxide entering the nozzle is predominantly liquid. The delay time from start of the discharge to when “liquid” flow is established at a nozzle is called the “initial vapor time.” During the initial vapor time, the flow rate from the nozzles will be less than the flow rate when liquid CO_2 is entering the nozzles. In low-pressure systems, the delay time and amount of carbon dioxide vaporized in cooling the piping should be calculated. Delay time and weight vaporized during this period may be calculated as follows [9].

$$Dt = \frac{wC_p(T_1 - T_2)}{0.913R} + \frac{1050V}{Q} \tag{2-7}$$

$$W = \frac{wC_p(T_1 - T_2)}{H} \tag{2-8}$$

where Dt = Delay time in sec

W = Weight of carbon dioxide vaporized in lb

w = Weight of piping in lb

C_P = Specific heat of metal in pipe (0.11 for steel)

T_1 = Average pipe temperature before discharge in °F

T_2 = Average carbon dioxide temperature in °F
(Note: Assume -5°F for low-pressure systems under normal conditions)

Q = System design flow rate in lbs/min

V = Volume of piping in cu ft

H = Latent heat of vaporization of liquid carbon dioxide in Btu/lb
(Note: About 120 Btu/lb for low-pressure systems)

2.4 Leakage Rate

It is good practice to ensure, where possible, that all openings below discharge nozzle level close automatically before carbon dioxide discharge. Openings to the protected volume that cannot be closed during discharge must be compensated for by increasing the quantity of carbon dioxide discharged. The leakage rate from an enclosure in the absence of forced ventilation depends mainly on the difference in density between the atmosphere within the enclosure and the air surrounding the enclosure [9].

The following equation can be used to calculate the rate of CO_2 loss, assuming that there is sufficient leakage in the upper part of the enclosure to allow free ingress of air. If there are openings in the wall only, air must flow in through this opening as well as CO_2 / air mix flow out through the same opening, therefore the area may be taken to be half the opening area. This is explained in NFPA 12 (2000) A-2-5.2.

$$R = 60C\rho_c A \frac{\sqrt{2g(\rho_a - \rho_s)h}}{\rho_1} \tag{2-9}$$

where R = Rate of CO_2 in lbs/min

C = CO_2 concentration fraction

ρ_c = Vapor density of CO_2 in lbs/cu ft

A = Area of opening in sq ft (flow coefficient included)

g = Gravitational constant 32.2 sq ft/sec

ρ_a = Density of atmosphere in lbs/cu ft

ρ_s = Density of surrounding air in lbs/cu ft

h = Static head between opening and top of enclosure in ft

Calculate the density of the atmosphere in the enclosure (ρ_a) using the following equatioin shown in NFPA 2001 (2000) C-2.7.1.4.

$$r_m = V_d \frac{C}{100} + \left(r_a \frac{(100 - C)}{100} \right) \tag{2-10}$$

where r_m = Clean agent / air mixture density (lb/ft^3)

r_a = Air density (0.075 lb/ft^3)

C = Clean agent concentration (%)

V_d = Agent vapor density at 70°F (lb/ft^3)
(Note : 0.114 lb/ft^3 for CO_2)

2.5 Free Venting Area

Discharging large quantities of CO_2 gas into a space necessitates some form of pressure relief venting to allow air to escape as carbon dioxide builds up. For buildings of normal construction porosity of the building fabric including leakage around doors and windows is usually sufficient as explained in NFPA 12 (2000) 2-6.2. For very tight enclosures, the area necessary for free venting shall be calculated from the following formula. Assuming the expansion of carbon dioxide to be 9 cu ft/lb will give satisfactory results [9].

$$A = \frac{Q}{1.3\sqrt{P_e}} \tag{2-11}$$

where A = Free venting area in sq in

Q = Calculated carbon dioxide flow rate in lbs/min

P_e = Allowable strength of enclosure in lbs/sq ft

2.6 Concentration Built in Enclosure

The volume of carbon dioxide required to develop a given concentration will be greater than the final volume remaining in the enclosure. In most cases carbon dioxide should be applied in a manner that promotes progressive mixing of the atmosphere. The displaced atmosphere is exhausted freely from the enclosure through various small openings or through special vents, as carbon dioxide is injected. Some carbon dioxide is therefore lost with the vented atmosphere. This loss becomes greater at high concentrations. This method of application is called “free-efflux” flooding. All flooding factors to calculate the quantity of carbon dioxide in Section 2.1 are based on the condition of “free-efflux” flooding. Under the above conditions the volume of carbon dioxide required to develop a given concentration in the atmosphere is expressed by the following equations [3].

$$e^{V_g} = \frac{100}{100 - \%CO_2} \tag{2-12}$$

$$\text{or}\quad V_g = 2.303\log_{10}\frac{100}{100-\%CO_2} \tag{2-13}$$

where V_g = Volume of carbon dioxide added per volume of space in cu ft

e = 2.718 (natural logarithm base)

Figure 2 shows carbon dioxide requirements for inert atmospheres based on a carbon dioxide expansion of 9 cu ft/lb. The top curve (complete displacement) and the bottom curve (no efflux) are theoretical extremes plotted for comparative purposes only. The middle curve (free efflux), the curve to be used, must be tempered by proper safety factors.

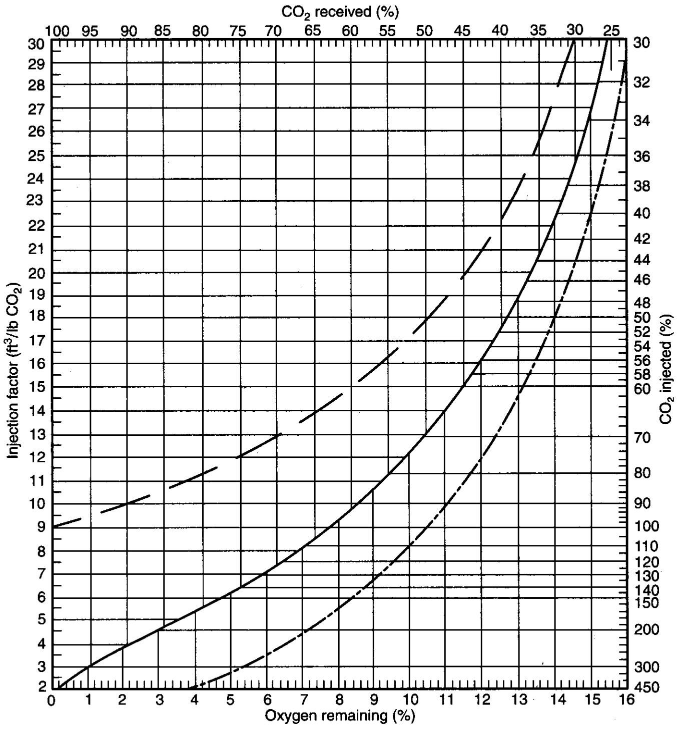


Figure 2. Carbon Dioxide Requirements for Inert Atmosphere

The computer model developed by Robert R. Zalosh and Cheng Wai Hung [15] can be used for a more accurate calculation of concentrations and pressures built in the enclosure. CO_2 concentration is usually stratified in the enclosure, not uniformlly mixed. Futhermore, the enclosure temperature varies significantly as discharge continues. For this complicated calculation of time dependent CO_2 concentration, the following correlation developed by Cheng Wai Hung [10] is clearly the best choice in calculation of CO_2 concentrations built in an enclosure during discharge and after discharge. Assuming well-mixed and incompressible flow so that CO_2 discharge will displace the air/gas mixture inside the enclosure immediately upon release (free efflux flooding), the solution of CO_2 concentration achieved in the enclosure during CO_2 discharge will be;

$$X = 100(1-e^{-(\frac{G\,t}{\rho_c\,V_e})}) \tag{2-14}$$

where X = Volume concentration of CO_2 in percentage

G = Mass discharge flow rate in kg/s

t = Discharge time in second

ρ_c = Density of gaseous CO_2 in kg/m^3

V_e = Enclosure volume in cubic meter

e = 2.718 (natural logarithm base)

and if constant volume leakage flow rate Q_L exists through openings or ventilation system, we have;

$$\frac{dX}{dt} = \frac{-(Q_L + G/\rho_c)X}{V} + \frac{G}{\rho_c V} \tag{2-15}$$

$$X = 100\frac{G}{G+Q_L\rho_c}(1-e^{\frac{-(G/\rho_c+Q_L)t}{V}}) \tag{2-16}$$

The maximum pressure produced by discharge will be given by the stage at which the leakage flow is equal to the discharge rate (neglecting thermal & hydrostatic effect), i.e.:

$$\sqrt{\Delta P} = \frac{G}{C_d\sqrt{2\rho_m}A_L} \tag{2-17}$$

where P = Enclosure pressure in Pa

C_d = Discharge coefficient of opening 0.61

ρ_m = Density of mixture of CO_2 and air

A_L = Total leakage area in enclosure in m^3

This equation is same as NFPA 12 when ρ_m is set at 45% CO_2 concentration at –79℃ and C_d is put equal to 1 i.e. $\sqrt{P} = 23.9\times(G\times60)/(A_L\times10^6)$.

After CO_2 discharge in the enclosure, the volume loss of carbon dioxide through the openings at any instant is given as;

$$\dot{m}_{L,CO_2} = XC_dA_L\sqrt{\frac{2\rho_c^{\,2}(\rho_m-\rho_a)gh}{\rho_m}} \tag{2-18}$$

This equation is similar to NFPA 12 by assuming neutral plane is at top of enclosure. This will imply;

$$-\frac{dX}{dt} = \frac{C_dA_L\rho_c}{V}\sqrt{2gh(\rho_c-\rho_a)}\left(\frac{X^3}{(\rho_c-\rho_a)X+\rho_a}\right)^{\frac{1}{2}} \tag{2-19}$$

Since the solution for concentration cannot be explicitly expressed in term of time t, an alternate approximate solution will be to re-write equation in the following form;

$$\frac{dX}{dt} \approx \frac{C_d A_L \rho_c}{V}\sqrt{\frac{2gh(\rho_c-\rho_a)}{\rho_{mi}}}(X^3)^{\frac{1}{2}} \qquad (2\text{-}20)$$

which will give solution;

$$X \approx \frac{1}{\left(\frac{1}{\sqrt{X_i}} - \frac{C_d A_L \rho_c t}{2V}\sqrt{\frac{2gh(\rho_c-\rho_a)}{\rho_{mi}}}\right)^2} \qquad (2\text{-}21)$$

where ρ_{mi} = Density of initial mixture of CO_2 and air

X_i = Initial volume concentration of CO_2 in percentage

3.0 Implementation of Flow Calculation

3.1 Manual Flow Calculation

In Section 2.2, several equations of flow calculations are discussed to determine pipe and orifice sizes, CO_2 initial transient flows, leakage rates and free venting area. The detail procedures of pressure drop and nozzle code calculations are described as below. The following equation shall be used to determine the pressure drop in the pipeline.

$$Q^2 = \frac{(3647)(D^{5.25}Y)}{L_e + 8.08(D^{1.25}Z)} \qquad (3\text{-}1)$$

Re-arrange terms to get $L_e Q^2 + 8.08Q^2 D^{1.25} Z - 3647 D^{5.25} Y = 0$, where L_e is known, Q is given, and D is given. Solve for Y.

$$Y = \frac{L_e Q^2 + 8.08 Q^2 D^{1.25} Z}{3647 D^{5.25}} \qquad (3\text{-}2)$$

For a given pipe section, the Y factor at the end of the pipe section is calculated by adding the increment in Y to the Y factor at the start of the pipe section ($Y_{previous}$).

$$Y = \frac{L_e Q^2 + 8.08 Q^2 D^{1.25} Z}{3647 D^{5.25}} + Y_{previous} \qquad (3\text{-}3)$$

To calculate pressure drop in a pipe network, start at the entrance to the storage container dip tube. $Y_{previous}$ will be zero (0). Take the following steps :

a) Account for any elevation change for the pipe section, using NFPA 12 Table A 1-10.5(f). Use Y for the inlet pressure corrected for elevation as $Y_{previous}$.

b) Solve for Y for the first approximation neglecting the Z term. Since the Z term will typically be small, it may be neglected for the first approximation.

c) Using the approximate value of Y, find Z from NFPA 12 Table A-1-10.5(a). Somewhat better accuracy is obtained by averaging the Z value for the inlet pressure and the outlet pressure.

d) Solve again for Y including the Z factor found in step c.

e) Find the pressure corresponding to Y from Table A-1-10.5(a) – this is the terminal pressure for the pipe section. Check that Z has not changed – if Z has changed use the correct value of Z and repeat step d.

f) Y from the preceding pipe section is $Y_{previous}$ for the succeeding pipe section.

g) Continue steps a through f for each pipe section between the storage container and the discharge nozzles.

For each nozzle, a code may be calculated using the method specified in NFPA 12, Paragraph 1-10.4. The procedure for manual calculation of nozzle codes follows:

a) Determine the pressure at the nozzle from the pressure drop calculation.

b) Find the discharge rate per square inch of equivalent orifice area corresponding to the pressure determined in Step a from NFPA 12 Table 1-10.5.2. Since values are given in 10 psi steps, it will be necessary to interpolate the discharge rates.

c) Divide the design nozzle flow rate by the discharge rate pre square inch found in step b. This gives the area of a perfect orifice as defined in NFPA 12, Paragraph 1-10.4.4.

d) Use the following equation to determine the orifice code as defined in NFPA 12. The *Area* is the area of the perfect orifice determined in step c. The *Code* is the diameter of a perfect rounded entry nozzle given in 32nds of an inch.

$$Code = 32\sqrt{\frac{4Area}{\pi}} \tag{3-4}$$

3.2 Computerized Flow Calculation

It is obvious from the detail calculation procedures in Section 3.1 that manual flow calculations for low-pressure CO_2 systems are time-consuming, tedious, and error prone.

This flow calculation can be greatly simplified by use of a computer software program of SH Engineering Corporation which is an existing proprietary program. This computer software program calculates pipes and nozzle systems, using all methods which are discussed and tabulated in Section 3.1.

Flow theory of this computer software program is in accordance with NFPA 12 with the following enhancements applied from recognized hydraulic calculation theory [8]:

a) Velocity Head Consideration

Full incoming velocity head is conserved in transitioning from pipe section to pipe section if pipe size does not change. One half the incoming velocity head is conserved if inlet pipe size does not equal outlet pipe size. One half incoming velocity head lost for side outlet branch of tee.

b) Minimum Flow Rate for Pipe Size

Theoretical minimum flow rates are used when the computer automatically sizes system piping. These flow rates are intended to assure completely turbulent flow in the pipe. The minimum flow rates do not apply when pipe sizes are fixed - there is no requirement in NFPA 12 to consider minimum flow rates. The minimum flow rate versus pipe ID used in the program is graphically illustrated in Figure 3.

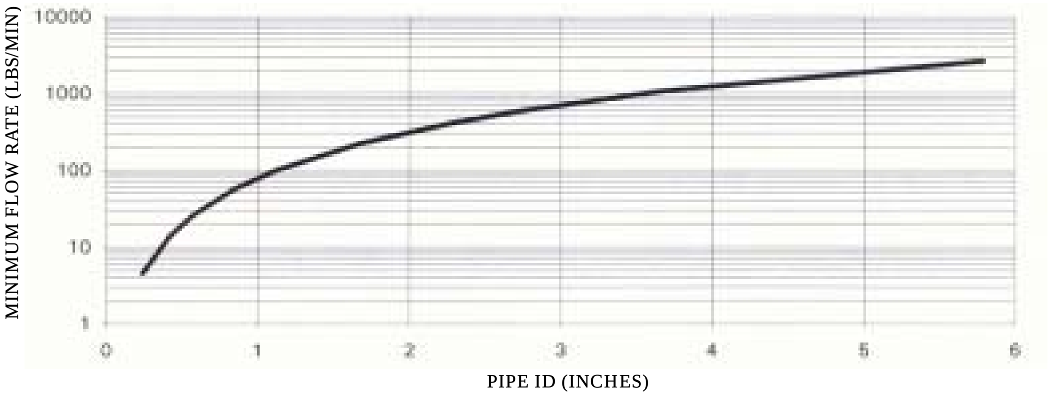


Figure 3. Low Pressure CO_2 Minimum Flow vs Pipe ID

c) Friction Factor

The computer software program uses friction factor values experimentally determined by Professor L.F. Moody in the pressure drop calculation. These friction factors are based on flow in the completely turbulent regime.

d) Vapor Time and Quantity Calculation

During the initial vapor time, the flow rate from the nozzles will be less than the flow rate when liquid CO_2 is entering the nozzles. For calculation purposes the program uses a vapor flow rate equal to 50% of the liquid flow rate. NFPA 12, Appendix A-3-3.1.2 recommends that the initial vaporization of carbon dioxide liquid as it flows into the pipeline be taken into account. NFPA 12 suggests that -5°F (-21°C) be used as the temperature of the flowing carbon dioxide for calculation of quantity of carbon dioxide vaporized. In accordance with NFPA 12, a heat of vaporization of 120 Btu/lb is used for the CO_2. The specific heat of steel pipe is 0.11 Btu/lb°F. Figure 4 shows the theoretical temperature of carbon dioxide as a function of pressure as it flows into the pipe. The computer software program uses these temperatures to calculate initial vapor time and vapor quantities.

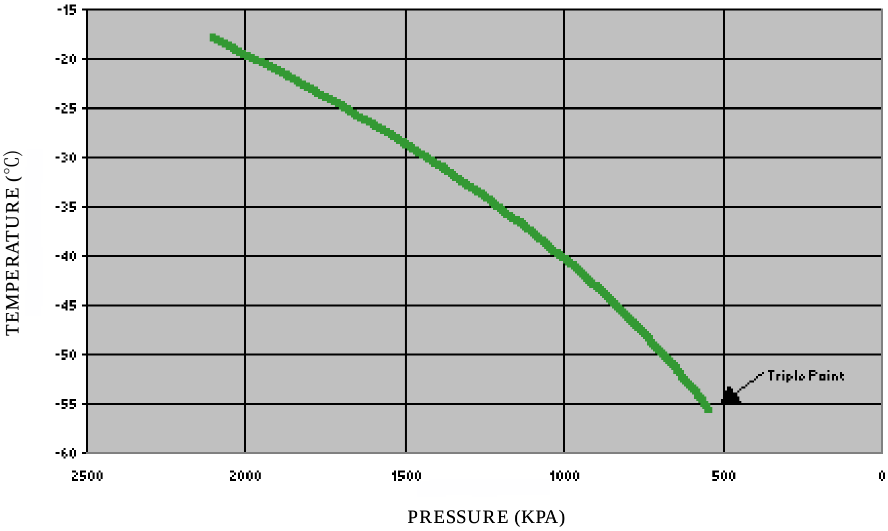


Figure 4. Saturated Carbon Dioxide

e) Orifice Codes

The NFPA 12 flow calculation method uses orifice codes that are based on a theoretically perfect standard orifice. The computer software program reports orifice codes per NFPA 12. The standard orifice defined in NFPA 12 is an orifice having a rounded entry with a coefficient of discharge not less than 0.98 and flow characteristics such that the CO_2 discharge rate per square inch of orifice area will match the discharge rates given on Tables 1-10.5.2 and 1-10.5.3 of NFPA 12.

In order to identify that the results of computerized flow calculations by a computer software program are same as those of manual flow calculations, pertinent flow calculations for a specific project were made. Calculation data in Appendix I present a comparison chart of the results using both manual flow calculations and computerized flow calculations. As a result, pressure data and nozzle codes obtained by computerized flow calculations do not show any marked difference from those obtained by manual flow calculations.

Computerized flow calculations by a computer software program have eliminated the tedious “cut and try” calculations. In a typical manual calculation, pipe sizes would be estimated based on flow rates. If the estimated pipe sizes were too small, this fact would become known when the pressure in the system fell below the acceptable minimum. Elevation correction factor is from NFPA 12, Table A 1-10.5(f). The factor for the nearest 10 psi increment is used. The computer software program calculates elevation “head” based on density as a function of calculated pressure (to 1 psi) at the start of the pipe section. “Z” factors are given in 10 psi increments in NFPA 12. To obtain reasonable accuracy in the manual calculation, the average of the Z factor for the inlet pressure and outlet pressure is used. More conservative (greater pressure drop) results would be obtained by using the Z factor for the 10 psi increment containing the outlet pressure. The computer software program calculates Z factors to 0.5 psi thus providing much greater accuracy than the 10 psi increment Z factors available in NFPA 12. For long pipe runs with significant pressure drop, the Z factor accounts for most of the observed difference between pressure calculated by computer and those calculated manually. The computer software program calculates velocity head pressure conversion to and from static pressure head due to changes in flow velocity at tee junctions and pipe size changes. The velocity head pressure changes due to these factors are typically quite small. Manual calculations using NFPA 12 do not account for velocity head pressure conversions. Some difference in calculated pressure is due to the greater precision used in the computerized flow calculation.

Nozzle codes are based on specific flow rates for the calculated pressures at the nozzles. The differences between the manually calculated nozzle codes and the computer calculated nozzle codes are due to the slight differences (typically less than 5%) between the pressures calculated manually and those calculated by the computer software program.

For detail procedures of the use of a computer software program for computerized flow calculations of a low-pressure CO_2 system, refer to Appendix II. This computer software program shall be compiled and executed on 486 or Pentium processor running Microsoft Windows 98 or 2000.

4.0 Test Description

4.1 Test Enclosures & System Apparatus

It is generally known that Underwriters Laboratories and Factory Mutual do not provide any standards for system performance tests of a carbon dioxide extinguishing system, while they have their own standards for clean agent fire extinguishing systems. Thus, test description in this paper is based on Korean Standard FIS 002, Standard for Gaseous Fire Extinguishing Systems [11].

Testing shall be conducted in three sizes of enclosures which are to be finished with 3/8 inch thick plywood, 4 inch thick polyurethane walls, and reinforcements with 2 inch angle iron frames indoors and are also to be finished with 16 gauge corrugated steel plates outdoors. See Figure 5 for the layout of test enclosures. The doors are equipped with rubber gaskets to ensure airtight seals, and all leakage areas are completely sealed to maintain the condition of “no efflux” flooding. An oxygen metering device is installed on the lower side of the wall to measure oxygen concentrations achieved in the test enclosures during discharge. Pressure relief vents are installed on the upper side of the walls to vent pressure built up from the discharge of large quantities of carbon dioxide into the test enclosures. The vents are to be closed, except for the pressure relief. Pressure transducers and thermocouples are installed at the storage container, the upstream pipe section of a directional valve, the downstream pipe section of a directional valve, and the inlet to discharge nozzle(s).

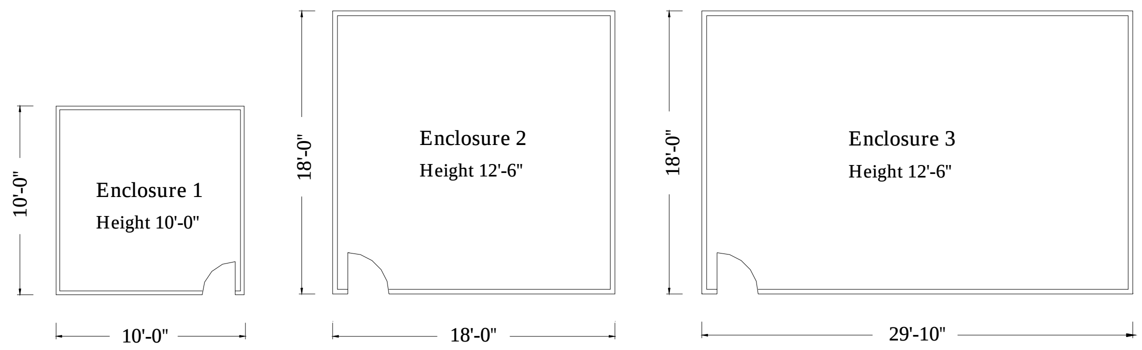


Figure 5. Layout of Test Enclosures

A 1220 lb (555 kg) capacity of a low-pressure liquid CO_2 storage container is controlled at about 0°F (-18°C) by means of insulation and refrigeration. The nominal pressure is thus maintained at about 300 psig (20.7 bars). The storage container is made, tested, approved, equipped, and marked in accordance with the current specifications of the American Society of Mechanical Engineers (ASME) Code. Distribution piping is Schedule 40 galvanized steel pipes, ASTM A-53 electric welded, Grade B. Discharge nozzles are permanently marked to identify the nozzles and to show the equivalent single orifice diameters.

4.2 Class A Fire Extinguishment Tests for Deep-Seated Fires

The Class A fire tests are to be conducted, using a wood crib. All fires shall be extinguished within 600 seconds after the end of system discharge, while actual measurement of extinguishment time is not required, and prevent re-ignition after 600 second soak period. The wood crib is to consist of four layers of six, trade size 2 by 2 inch by 18 inch long, kiln spruce, or fir lumber having a moisture content between 9 and 13 percent. The alternate layers of the wood members are to be placed at right angles to one another. The individual wood members in each layer are to be evenly spaced in forming a square determined by the specified length of the wood members. The wood members forming the outside edges of the crib are to be stapled or nailed together.

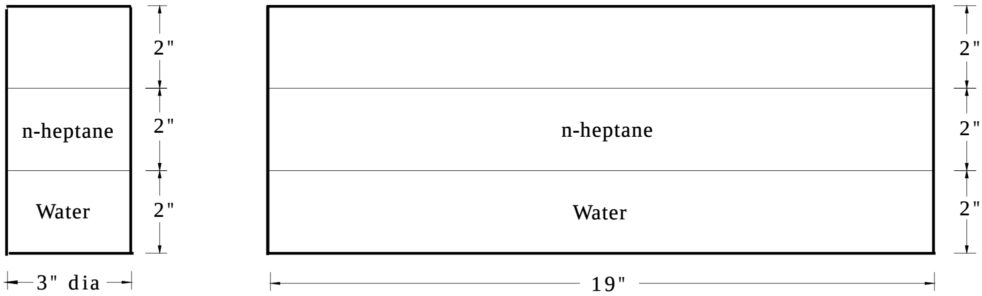
Ignition of the crib is to be achieved by the burning of commercial grade heptane in a square steel pan 2-1/2 ft^2 in area and not less than 4 inches high. The crib is to be centered with the bottom of the crib 12 inches above the top of the pan and the test stand constructed so that the bottom of the crib is exposed to the atmosphere. The oxygen concentration is to be measured by an oxygen concentration metering device at a location which is at the same height as the bottom of the wood crib and centered from the edge of the crib to the wall.

The heptane is to be ignited and the crib is to burn freely for 6 minutes outside the test enclosure of equivalent provisions are to be provided to insure adequate venting. The heptane fire is to burn for at least 3 minutes, with 0.40 gallons of heptane providing a 3 to 3-1/2 minute burn time. Less than 15 seconds before the end of the total pre-burn period of 6 minutes, the crib is to be moved into the test enclosure and placed on a stand such that the bottom of the crib is 24-30 inches above the floor. The time required to position the burning crib within the test enclosure and the initiation of system discharge shall not exceed 15 seconds. The door is to be closed and the system is to be actuated.

After the end of system discharge, observations shall be made for crib extinguishment. The enclosure is to remain sealed for a total of 10 minutes. After the 10 minute soak period, the crib is to be removed from the enclosure, observed to determine whether fuel remains to sustain combustion, and observed for signs of re-ignition.

4.3 Class B Fire Extinguishment Tests for Surface Fires

All fires shall be extinguished within 30 seconds after the end of system discharge, while actual measurement of extinguishment time is not required. The Class B fire extinguishment tests are to be conducted, using commercial grade heptane. The tests shall be conducted two times for each test enclosure. For the first extinguishment tests, a total of eight (8) round test cans shown in Figure 6 shall be installed within 2 inch from the corners of the test enclosure and 12 inch from the top or bottom of the test enclosure. For the second test, a square test pan shown in Figure 6 shall be installed in the center of the test enclosure. The pan is to be of steel not less than 1/4 inch thick with liquid-tight welded joints. The oxygen concentration is to be measured by an oxygen concentration metering device at a location which is equivalent to the height of the test pan.



First Test

Second Test

Figure 6. Cans & Pan for Class B Fire Extinguishment Tests

For each test, the heptane is to be ignited and is to burn freely for 30 seconds. Just prior to discharging agent into the enclosure, the door is to be quickly closed and the extinguishing system is to be manually operated.

4.4 Verification Test of Flow Calculation

An engineered extinguishing system unit shall be tested to determine that the flow calculation method as specified in Section 2.0 accurately predicts the discharge time, discharge pressure and subsequent CO_2 concentration in enclosure. Three test enclosures of varying volumes are to be constructed to test the limitations of the flow calculation method. Several different one or two nozzle piping arrangements are to be installed and tested to determine the accuracy of the flow calculation method. The following factors regarding the flow calculation method limitations and design considerations are to be included in establishing the piping arrangements:

a) Maximum discharge time

b) Minimum pipeline flow rates

c) Maximum variance in nozzle pressures within a piping arrangement

d) Maximum and minimum orifice area of nozzle relative to inlet pipe area

e) Type of pipe and pipe schedule, and type of fittings

f) Elevation changes

The low-pressure CO_2 storage container is to be filled to the intended weight and the pressure is to become stable. The storage container, piping, and enclosure are to be maintained at a temperature of 70°F (21°C) when possible. When not possible to maintain these items at a temperature of 70°F (21°C), the test is to be conducted at temperature other than 70°F (21°C), with appropriate temperature correction calculations. The extinguishing system unit is then to be discharged. During discharge, pressure measurements are to be taken at the storage container, piping, and nozzle, utilizing a calibrated pressure transducer with digital indicator recorded by video camera. The discharge time is to be measured by a stopwatch. During discharge, oxygen concentration measurements are to be taken in each enclosure with a calibrated oxygen concentration metering device to calculate CO_2 concentration.

The quantities of liquid CO_2 required to achieve the design concentrations in the test enclosures are to be calculated as described in Section 2.1. The design concentration for Class A, deep-seated fires is 50% and for Class B, surface fires 34%. The discharge times for Class A, deep-seated fires are to be 2 minutes to achieve 30% concentration, and to be determined by computerized flow calculations to achieve 50% concentration. Those for Class B, surface fires of all tests are to be 60 seconds. Although the CO_2 concentrations and flooding factors necessary for extinguishment of deep-seated or surface fires to be used for flow calculations as shown in Section 2.1 apply to the common enclosures under the condition of “free efflux” flooding, the test enclosures for this thesis are completely sealed enough to maintain the condition of “no efflux” flooding. Thus, the quantity of liquid CO_2 calculated under the condition of “free efflux” flooding needs to be recalculated under the condition of “no efflux” flooding. For doing so, the weight of liquid CO_2 is to be converted to the volume of gaseous CO_2, which is again to be converted to its equivalent CO_2 concentration. The calculated CO_2 concentrations in the condition of “no efflux” flooding in each enclosure are shown in Table 5.

Table 5. Calculated CO2 Concentrations in No Efflux Flooding

Test Room	Fire	Design Conc. in Free Efflux	Required CO_2 Q'ty	Calculated Conc. in No Efflux [a]	Discharge Time
Enclosure 1	Deep-Seated	30% 50%	43 lb (19.4 kg) 100 lb (45.4 kg)	27.22% 46.65%	120 sec By CFC [b]
Enclosure 1	Surface	34%	63 lb (28.6 kg)	35.52%	60 sec
Enclosure 2	Deep-Seated	30% 50%	173 lb (78.6 kg) 336 lb (152.5 kg)	27.22% 42.06%	120 sec By CFC [b]
Enclosure 2	Surface	34%	227 lb (102.9 kg)	32.87%	60 sec
Enclosure 3	Deep-Seated	30% 50%	287 lb (130.2 kg) 557 lb (252.7 kg)	27.22% 42.06%	120 sec By CFC [b]
Enclosure 3	Surface	34%	336 lb (152.2 kg)	30.42%	60 sec

[a] Concentration calculated at ambient temperature 68°F

[b] Computerized flow calculation

The measured discharge pressure, and CO_2 concentration within an enclosure shall not deviate from the predicted values of flow calculation by more than the following:

a) ±10 percent for discharge pressure, and

b) ±10 percent for CO_2 concentration within an enclosure

5.0 Discharge Tests

5.1 Brief Description

In order to validate the computerized flow calculations, it is necessary to compare the predicted values generated from the flow calculations of a computer software program with the results of the actual full-scale discharge tests. The full-scale discharge tests were carried out at the testing laboratory of SH Engineering Corporation located in the city of Incheon, Korea.

The discharge tests were designed to confirm that a total flooding low-pressure CO_2 system met the requirements in the following aspects:

a) Find the maximum length of CO_2 discharge pipe run in computerized flow calculation to meet the specified discharge time, nozzle pressure, and CO_2 concentration.

b) Carbon dioxide concentration is achieved in no more than the specified time.

c) All fires are extinguished within the specified time after the ends of system discharge.

5.2 Discharge Test Configuration and Conditions

Three sizes of test enclosures provided with pressure, temperature and oxygen concentration metering devices were used in the tests. Pressures and temperatures at the nodes of CO_2 discharge pipe run extending from the low-pressure CO_2 storage container to each test enclosure as arranged in Figure 7 were monitored, checked, and reviewed. Pressure relief vents sized by 10 square inches for Enclosure 1, 16 square inches for Enclosure 2, 18 square inches for Enclosure 3 were installed on the upper side of the wall of each test enclosure.

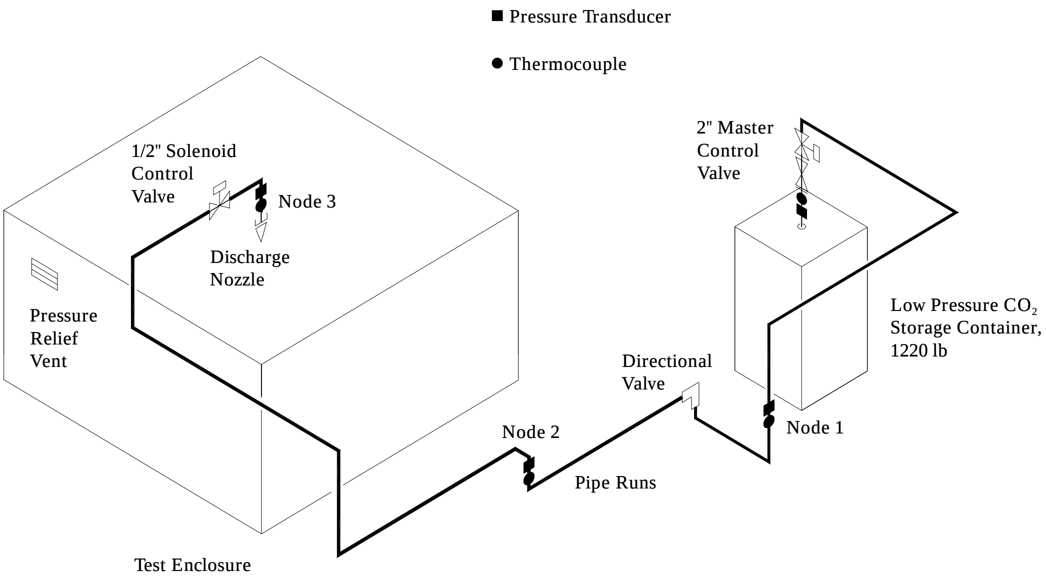


Figure 7. Test Arrangement

The measurements carried out in the tests comprise:

a) Pressures measured by WISE sensor P110 series sealed gauge pressure transducers with working range of 0 to 7256 psig (500 bars), and temperatures measured by WISE sensor T15X series stainless-steel thermocouples (28 gauge, type K) with working range of -148(-100) to 750°F (400°C) at the storage container, the upstream pipe section of a directional valve (Node 1), the downstream pipe section of a directional valve (Node 2), and the inlet to discharge nozzle(s) (Node 3).

b) Oxygen concentrations measured from sampling ports placed in the enclosure with COSMOS XPO-318 portable oxygen analyzers at a location which is at the same height as the bottom of the wood crib and centered from the edge of the crib to the wall for Class A fire tests, and at a location which is equivalent to the height of the test pan for Class B fire tests. The COSMOS XPO-318 is an automatic sampling instrument which may be used to measure the oxygen content of the atmosphere of any confined space over a range of 0-25%. The response time of oxygen analyzer connected with a 1m long sampling tube is maximum 20 seconds to 90% with accuracy of ± 0.7%. The Korea Testing Laboratory authorized by the Government calibrated the oxygen analyzer for the discharge tests. The CO_2 concentrations were obtained from the oxygen concentrations by using the following formula.

$$\%CO_2 = \frac{(21-O_2)}{21}\times 100 \tag{5-1}$$

c) The measured pressure data shown on KONICS KN-2000 series digital indicator recorded by a video camera. The whole testing processes were videotaped, and the test results were recorded every second and written into graphs later.

The pipe runs from the low-pressure CO_2 storage container to three sizes of test enclosures respectively were sized by computerized flow calculations and were installed to conduct the CO_2 discharge tests. The 1220 lb (555 kg) capacity of low-pressure CO_2 storage container was discharged into the test enclosures by manual opening of a 2 inch size of master control valve, which is maintained in the closed position, during the determined discharge time. After a full discharge of CO_2 into the test enclosure, a master control valve at the storage container outlet and a solenoid control valve at the inlet to a discharge nozzle were closed at the end of discharge time, which was checked by a stopwatch. The reason for installation of a half inch size of solenoid control valve at the inlet to a discharge nozzle, which was closed at the end of discharge time, was to discharge the exact quantity of CO_2 from the nozzle, not from the storage container.

5.3 Test Result

The test results were used to compare them with the predicted values in discharge pressure and CO_2 concentration generated from the flow calculations. A total of twenty (20) CO_2 discharge tests were conducted under different conditions. The isometric piping diagrams for all the tests are shown in Appendix III. All the pipe data from the isometric diagrams were entered in the computer software program, which ran to generate output data without any error messages. See computerized flow calculations in Appendix IV.

Table 6 shows the summary of test results of discharge pressure, CO_2 concentration, and fire extinguishment while the output data of computerized flow calculations are compared with those of actual full-scale discharge tests. See details of test reports in Appendix V. If the measured pressures at the three node points of each pipe run and the measured CO_2 concentration in the test enclosure do not deviate from the predicted values of the flow calculations by more than ±10 percent, the judgement of the test result is OK. A Class A, deep-seated fire should be extinguished within 600 seconds after the end of system discharge, and prevented re-ignition after 600 second soak period. A Class B, surface fire should be extinguished within 30 seconds after the end of system discharge.

The successful flow and fire test results proved to be as follows:

a) Enclosure 1

Test No. 5 with a 98 ft (30 m) long pipe run for a deep-seated fire and Test No. 8 with a 65 ft (20 m) long pipe run for a surface fire were OK.

b) Enclosure 2

Test No. 10 with a 164 ft (50 m) long pipe run for a deep-seated fire and Test No. 15 with a 98 ft (30 m) long pipe run for a surface fire were OK.

c) Enclosure 3

Test No. 16 with a 230 ft (70 m) long pipe run for a deep-seated fire and Test No. 20 with a 164 ft (50 m) long pipe run for a surface fire were OK.

Test No. 1 with 502 ft (153 m) long pipe run failed in both flow and fire tests. Except for Tests No. 5, 8, 10, 15, 16, 20 which were successful in both flow and fire tests and Tests No. 1 which failed in both flow and fire tests, all the other tests were successful in fire tests but failed in flow tests. As shown in the test reports of Appendix V, those tests failed in flow tests because the measured pressures at Nodes 1 and 2, which were located near to the storage container, fell within the permissible range of ±10 percent while the measured pressure at Node 3, which was located farthest from the storage container, went out of the permissible range. The longer the pipe run was, the greater differences were shown between the predicted pressure of the flow calculations and the measured pressure of the actual discharge tests.

Table 6. Summary of Test Results

Test No	Test Room	CO_2 System			Flow Test Result		Fire Test Result	
		Q' ty	Pipe Run	Pipe/CO_2 Volume [a]	Pressure	Concen-tration	Fire	Extingu-ishment
1	Enclosure 1	100 lb (45.4 kg)	502 ft (153 m)	219%	Fail	Fail	Class A	Fail
2	Enclosure 1	100 lb (45.4 kg)	230 ft (70 m)	121%	Fail	OK	Class A	OK
3	Enclosure 1	100 lb (45.4 kg)	164 ft (50 m)	85%	Fail	OK	Class A	OK
4	Enclosure 1	100 lb (45.4 kg)	131 ft (40 m)	72%	Fail	OK	Class A	OK
5	Enclosure 1	100 lb (45.4 kg)	98 ft (30 m)	59%	OK	OK	Class A	OK
6	Enclosure 1	63 lb (28.6 kg)	131 ft (40 m)	116%	Fail	OK	Class B	OK
7	Enclosure 1	63 lb (28.6 kg)	98 ft (30 m)	95%	Fail	OK	Class B	OK
8	Enclosure 1	63 lb (28.6 kg)	65 ft (20 m)	76%	OK	OK	Class B	OK
9	Enclosure 2	336 lb (152.5 kg)	131 ft (40 m)	44%	OK	OK	Class A	OK
10	Enclosure 2	336 lb (152.5 kg)	164 ft (50 m)	59%	OK	OK	Class A	OK
11	Enclosure 2	336 lb (152.5 kg)	197 ft (60 m)	73%	Fail	OK	Class A	OK
12	Enclosure 2	227 lb (102.9 kg)	197 ft (60 m)	108%	Fail	OK	Class B	OK
13	Enclosure 2	227 lb (102.9 kg)	164 ft (50 m)	87%	Fail	OK	Class B	OK
14	Enclosure 2	227 lb (102.9 kg)	131 ft (40 m)	65%	Fail	OK	Class B	OK
15	Enclosure 2	227 lb (102.9 kg)	98 ft (30m)	44%	OK	OK	Class B	OK

Test No	Test Room	CO_2 System			Flow Test Result		Fire Test Result	
		Q' ty	Pipe Run	Pipe/CO_2 Volume [a]	Pressure	Concen-tration	Fire	Extingu-ishment
16	Enclosure 3	557 lb (252.7 kg)	230 ft (70 m)	51%	OK	OK	Class A	OK
17	Enclosure 3	557 lb (252.7 kg)	262 ft (80 m)	60%	Fail	OK	Class A	OK
18	Enclosure 3	336 lb (152.2 kg)	230 ft (70 m)	85%	Fail	OK	Class B	OK
19	Enclosure 3	336 lb (152.2 kg)	197 ft (160 m)	70%	Fail	OK	Class B	OK
20	Enclosure 3	336 lb (152.2 kg)	164 ft (50 m)	56%	OK	OK	Class B	OK

[a] Percent of pipe volume vs. CO_2 liquid volume

6. Comparisons and Discussions

6.1 Typical Profile for CO_2 Discharge

For deep-seated fires, typical profiles of pressures at the nodes of pipe runs and CO_2 concentrations inside the test enclosures, which were obtained by successful discharge tests, are as shown in Figure 8. The profiles for surface fires also show similar aspects.

The pressure-time graph on the top shows the pressure changes of the storage container during CO_2 discharge. The downward curve shown during CO_2 discharge, is caused by the fact that a large quantity of CO_2 leaves the storage container at a time and then fills in the empty distribution pipe network up to the discharge nozzle(s) with vapor CO_2.

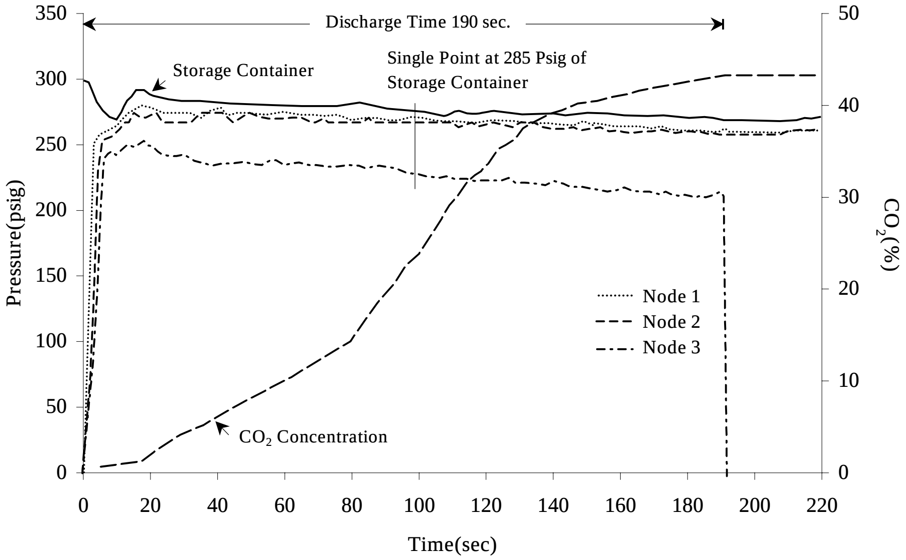


Figure 8. Typical Pressure & Concentration Profile for CO_2 Discharge

When the distribution pipe network is filled with CO_2 and liquid CO_2 flows inside the pipe network, the pressure inside the storage container recovers to some extent and decreases slowly as the CO_2 discharge continues. In determining a single point in the discharge which approximates an overall "average" condition of flow, it may be considered that in a well-designed system the conditions at the discharge nozzle will control the agent flow rate. A good "average" condition would be approximated by the "mid discharge" condition at nozzles. Neglecting initial transient conditions, the "mid discharge" condition will be the point at which half of the agent has been discharged from the nozzle and 300 psia (285 psig) of storage container.

The graphs for Node 1 at the upstream pipe section of a directional valve and Node 2 at the downstream pipe section of a directional valve exhibit a sudden pressure increase up to the peak soon after start of CO_2 discharge and then a slow pressure decrease as the discharge time progresses. At the end of determined discharge time, the main control valve located after the storage container and the solenoid control valve installed at the inlet to the discharge nozzle are immediately closed at the same time. Thus, after the end of discharge time, the captured CO_2 between the main control valve and solenoid control valve maintains a constant pressure for a some time. The graph for Node 3 at the inlet to a discharge nozzle exhibits its peak soon after the start of CO_2 discharge and then a slow-pressure decrease as the discharge time progresses. At the end of discharge time, the pressure drops sharply down to zero as the CO_2 discharge ends.

The CO_2 concentration curve shows a slow concentration increase while vapor CO_2 is flowing inside the distribution pipe network and a diagonal concentration increase when liquid CO_2 flows inside the pipe network. The timing of such transient flow was confirmed by checking the temperature measured by thermocouple, which was almost the same as the vapor time obtained from a flow calculation.

6.2 Enclosure 1 Discussions

For both deep-seated and surface fires, a number of discharge tests were conducted in the test enclosures and the test results were checked and reviewed carefully in order to determine how far the pipe runs designed by flow calculations could go while maintaining the minimum required pressure at the discharge nozzles and the specified CO_2 concentration inside the test enclosures within the discharge time required by NFPA 12.

Initially, it was presumed from an empirical point of view that the longest pipe run in which the low-pressure CO_2 system could maintain the adequate pressures at the discharge nozzles and the specified CO_2 concentrations in the enclosure within the discharge time would be approximately 492 ft (150 m), starting from the storage container. Thus, Test No. 1 for deep-seated fires in the Enclosure 1 was conducted with the pipe length of 502 ft (153 m) as well as with the sizes of pipe sections and discharge nozzles obtained from flow calculations based on that pipe length.

During Test No. 1, CO_2 was discharged for 245 seconds, which was the calculated discharge time, while the pressures at all four points, i.e., the storage container, the upstream pipe section of a directional valve (Node 1), the downstream pipe section of a directional valve (Node 2), and the inlet to a discharge nozzle (Node 3), were measured. Since pressure drop results at all node points in flow calculations are calculated, based on the point of time when the pressure of liquid CO_2 in the storage container reaches 300 psia (285 psig), the pressure drop results at all node points obtained from the actual discharge tests were compared with those of flow calculations at a point of time when the liquid CO_2 was at a pressure of 285 psig (19.7 bars).

The longer the pipe run is, the slower the recovery of pressure inside the storage container is. That’s because the longer pipe run causes a slower flow of vapor CO_2 inside the distribution pipe network. Because vapor CO_2 in a long pipe of 502 ft (153 m) delay the time of liquid flow, the pressure in the storage container couldn’t be recovered to the single point of average pressure 285 psig (19.7 bars). Thus, at Test No. 1, the measured pressures at Nodes 1, 2, and 3 at single point all went out of the permissible range of ±10 percent. In addition, Test No. 1 resulted in a failure of Class A fire extinguishment in the enclosure. CO2 concentrations also showed more than -10 percent difference from the calculated concentration due to the long initial vapor time in 190 sec, as shown on Appendix V - Test Report.

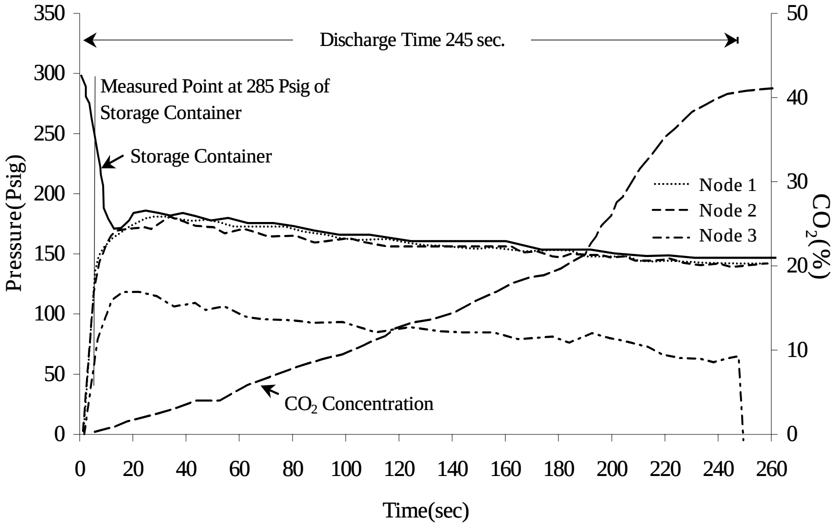


Figure 9. CO_2 Pressure & Concentration Profiles of Test No. 1 in Enclosure 1

Test No. 2 was conducted with a total pipe length of 230 ft (70 m). Flow calculation of the much reduced pipe length showed that the low-pressure CO_2 system could discharge 100 lb (45.4 kg) for 190 seconds, which was the quantity of CO_2 required for extinguishment of a deep-seated fire. From Test No. 2, the measured pressures turned out to be out of the permissible range, ±10 percent, at Node 3 only, but Class A fire extinguishment test was successful with the CO_2 concentration falling within the permissible range of ±10 percent. Test No. 3 and Test No. 4 were conducted in a successive manner with total pipe lengths of 164 ft (50 m) and 131 ft (40 m) respectively, which also resulted in a failure at Node 3 only. Unlike Test No. 1, Test Nos. 2, 3, and 4 didn’t deviate much from the permissible range, as shown on Appendix V - Test Report. That’s because the initial vapor time was reduced as the length of pipe run was reduced. From this, it is evident that the difference between the predicted pressure and the measured pressure becomes smaller as the initial vapor time becomes shorter.

Test No. 5 was conducted with the total pipe length of 98 ft (30 m). The measured pressures turned out to be successful at all the nodes, including Node 3, and Class A fire extinguishment test was also successful. From those discharge tests, it was confirmed that the test results for deep-seated fires in Enclosure 1 were consistent with the predicted values of flow calculations for the pipe runs of 98 ~ 131 ft (30 ~ 40 m) of which maximum percent of pipe volume vs. CO_2 liquid volume was 59 ~ 72%.

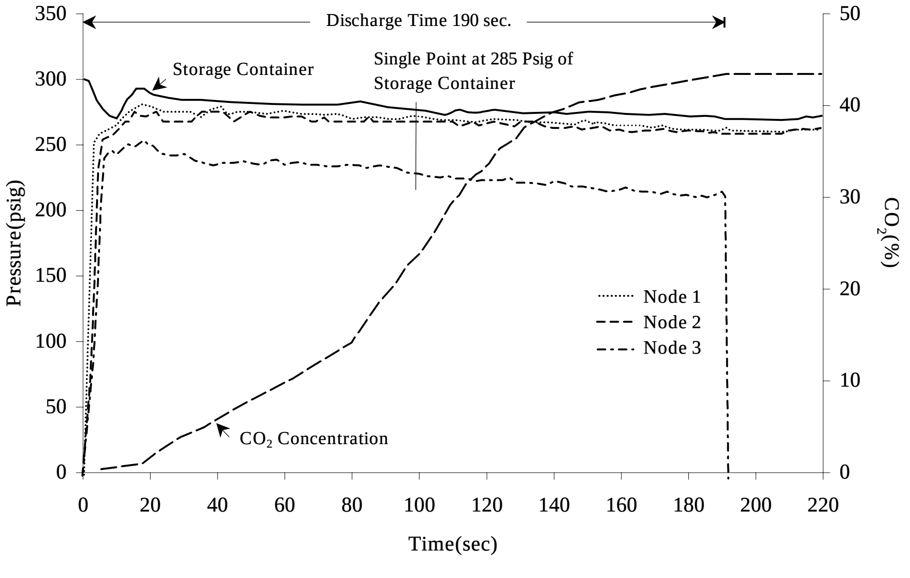


Figure 10. CO_2 Pressure & Concentration Profiles of Test No. 2 in Enclosure 1

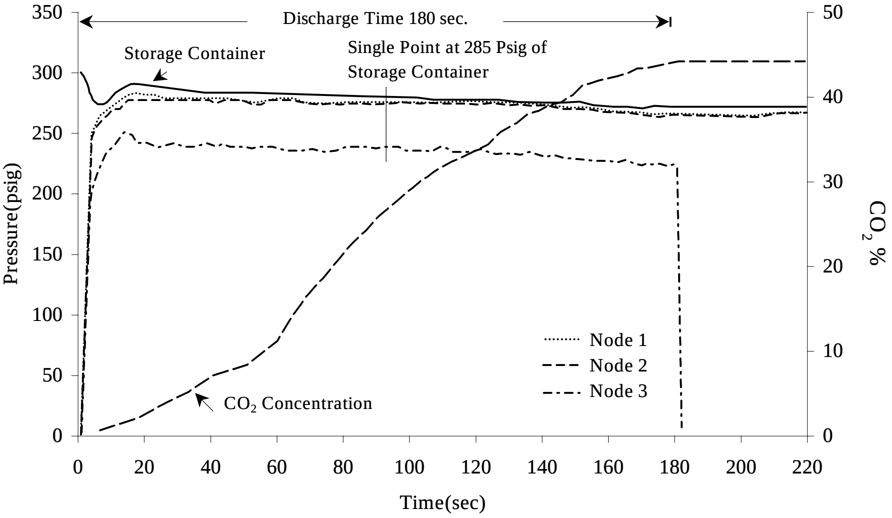


Figure 11. CO_2 Pressure & Concentration Profiles of Test No. 3 in Enclosure 1

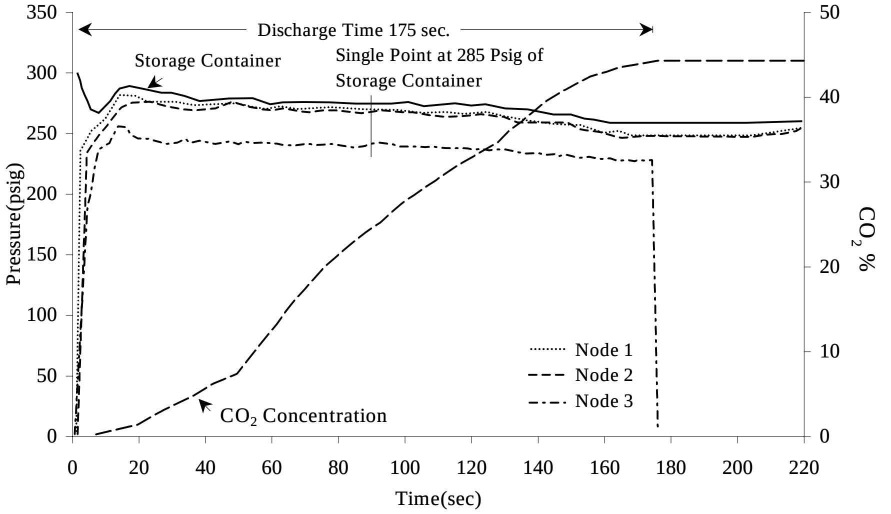


Figure 12. CO_2 Pressure & Concentration Profiles of Test No. 4 in Enclosure 1

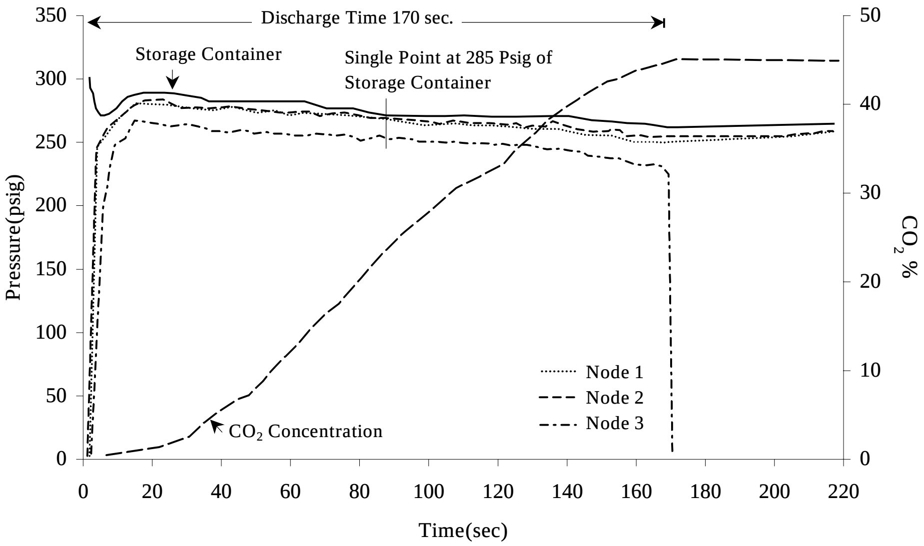


Figure 13. CO_2 Pressure & Concentration Profiles of Test No. 5 in Enclosure 1

For surface fires, it is evident that the total pipe run shall be shorter than that for deep-seated fires, because the quantity of CO_2 required for extinguishment of surface fires was 63 lb (28.6 kg), compared with 100 lb (45.4 kg) for deep-seated fires, and the discharge time was 60 seconds, compared with seven (7) minutes for deep-seated fires. Thus, Test No. 6 started with a total pipe run of 131 ft (40 m). The test failed at Node 3 only. Thus, Test No. 7 was conducted with a shorter pipe run of 98 ft (30 m), which also failed at Node 3 only.

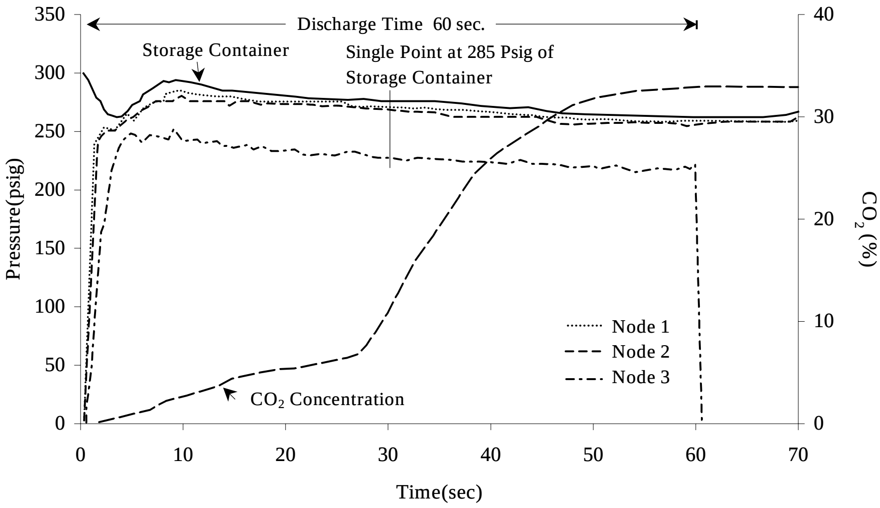


Figure 14. CO_2 Pressure & Concentration Profiles of Test No. 6 Enclosure 1

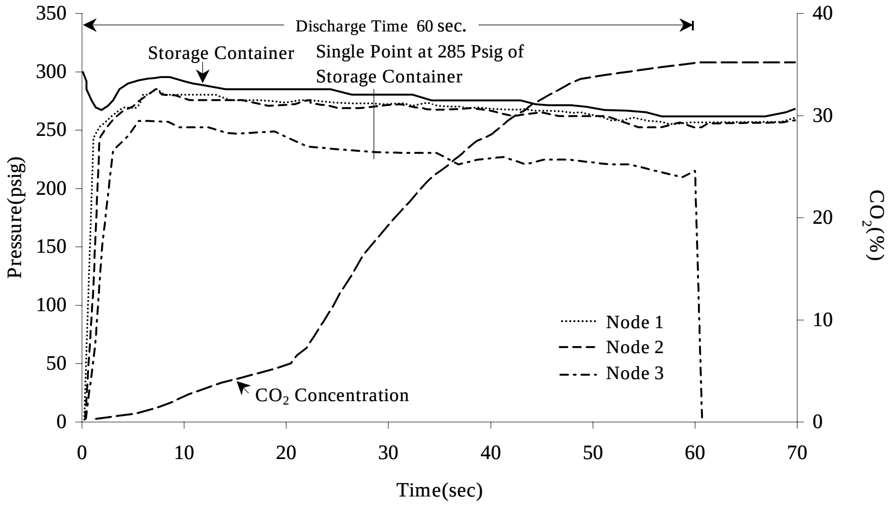


Figure 15. CO_2 Pressure & Concentration Profiles of Test No. 7 in Enclosure 1

Test No. 8 was conducted with the pipe run of 65 ft (20 m), and then the test turned out to be successful at Node 3 as well. Like the tests for deep-seated fires above, the test results fell within the permissible range at Node 3, because the initial vapor time was reduced due to the reduction of the length of pipe run. Class B fire extinguishment test was also successful with the length of pipe run. From those discharge tests, it was confirmed that the test results for surface fires in Enclosure 1 were consistent with the predicted values of flow calculations for the pipe runs of 65~98 ft (20~30 m) of which maximum percent of pipe volume vs. CO_2 liquid volume was 76~95%.

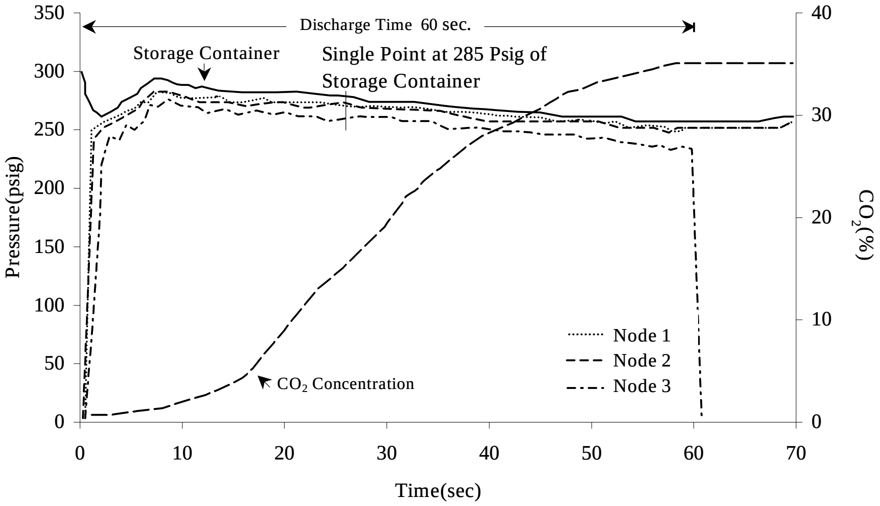


Figure 16. CO_2 Pressure & Concentration Profiles of Test No. 8 in Enclosure 1

6.3 Enclosure 2 Discussions

As the quantity of CO_2 required for a deep-seated fire in Enclosure 1 is 100 lb (45.4 kg) while the quantity of CO_2 for a deep-seated fire in Enclosure 2 is 336 lb (152.5 kg), it is evident that the maximum pipe run for deep-seated fires in Enclosure 2 shall be longer than the pipe run of 98 ~ 131 ft (30 ~ 40 m) found to be successful for deep-seated fires in Enclosure 1. Thus, Test No. 9 for a deep-seated fire in Enclosure 2 was conducted with the pipe run of 131 ft (40 m). The resulting pressures at all the nodes were found to be within the permissible range of ±10 percent, and Class A fire extinguishment test was also successful. Test No. 10 was conducted with a little longer pipe run of 164 ft (50m), and all the test results were successful.

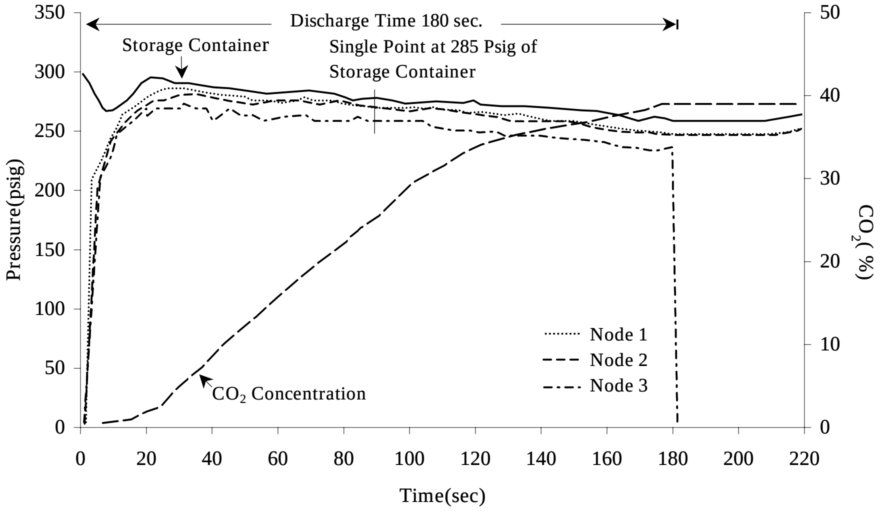


Figure 17. CO_2 Pressure & Concentration Profiles of Test No. 9 in Enclosure 2

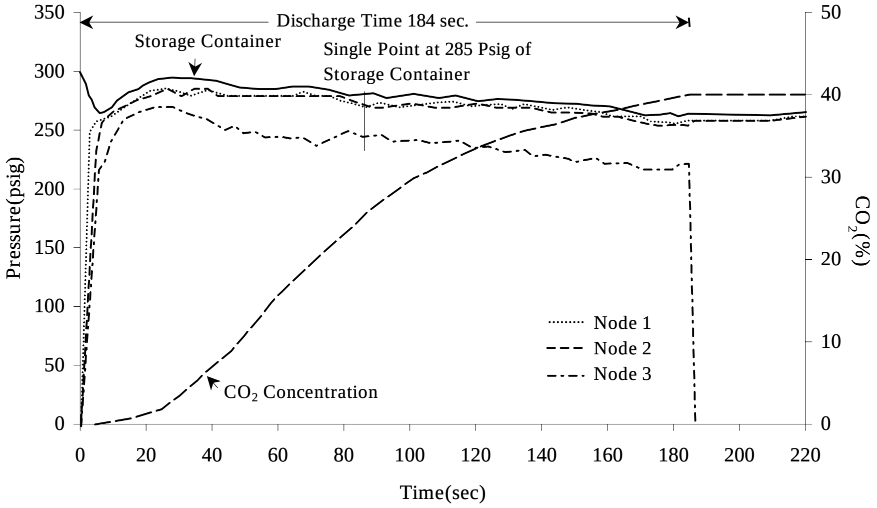


Figure 18. CO_2 Pressure & Concentration Profiles of Test No. 10 in Enclosure 2

Test No. 11 was conducted with the pipe run of 197 ft (60 m), but failed because the pressure at Node 3 was found to be out of the permissible range of ±10 percent, due to its long initial vapor time. From those discharge tests, it was confirmed that the test results for deep-seated fires in Enclosure 2 were consistent with the predicted values of flow calculations for the pipe runs of 164~197ft (50~60 m) of which maximum percent of pipe volume vs. CO_2 liquid volume was 59~73%.

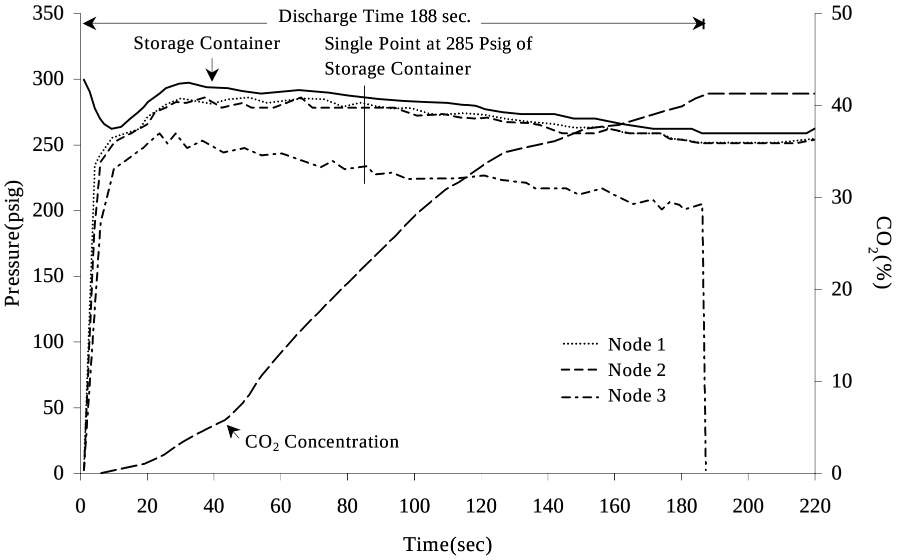


Figure 19. CO$_2$ Pressure & Concentration Profiles of Test No. 11 Enclosure 2

As the pipe run for surface fires in Enclosure 2 shall be shorter than that for deep-seated fires in the same enclosure, Tests Nos. 12, 13 and 14 were conducted with their respective pipe runs of 197 (60), 164 (50) and 131 ft (40 m), and their pressure results were found to be out of the permissible range at Node 3 only.

Test No. 15 was conducted with a little shorter pipe run of 98 ft (30 m), and all the test results were found to be successful, due to its short initial vapor time. From those discharge tests, it was confirmed that the test results for surface fires in Enclosure 2 were consistent with the predicted values of flow calculations for the pipe runs of 98~131 ft (30~40 m) of which maximum percent of pipe volume vs. CO$_2$ liquid volume was 44~65%.

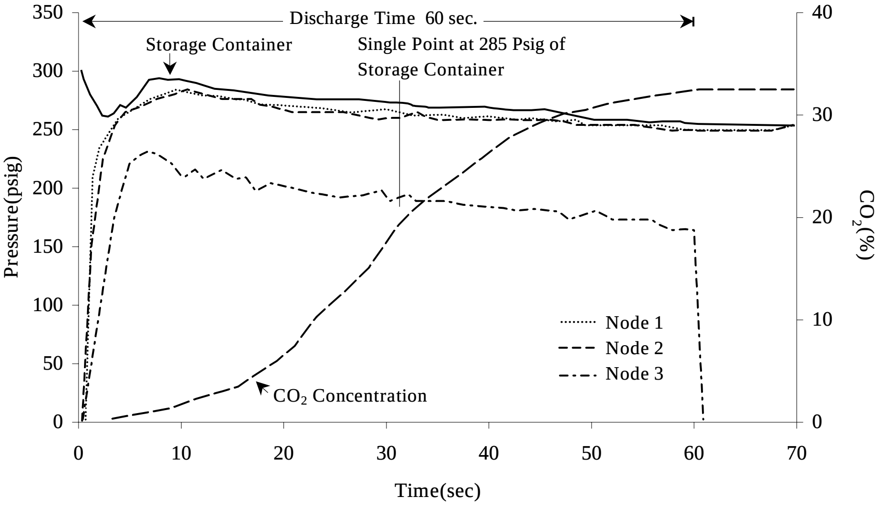


Figure 20. CO_2 Pressure & Concentration Profiles of Test No. 12 in Enclosure 2

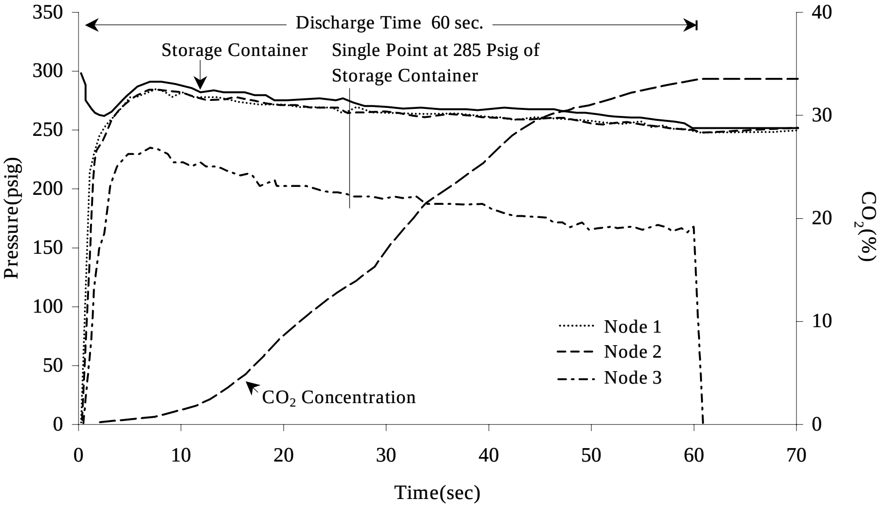


Figure 21. CO_2 Pressure & Concentration Profiles of Test No. 13 in Enclosure 2

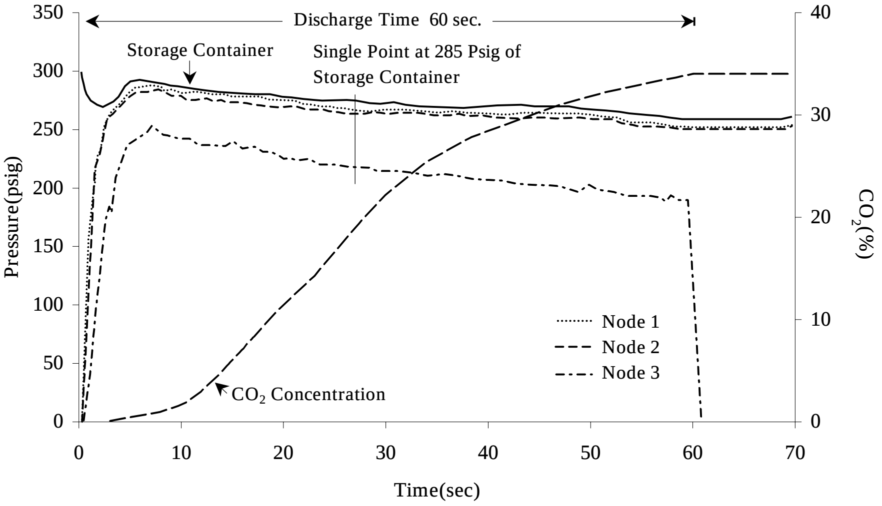


Figure 22. CO_2 Pressure & Concentration Profiles of Test No. 14 in Enclosure 2

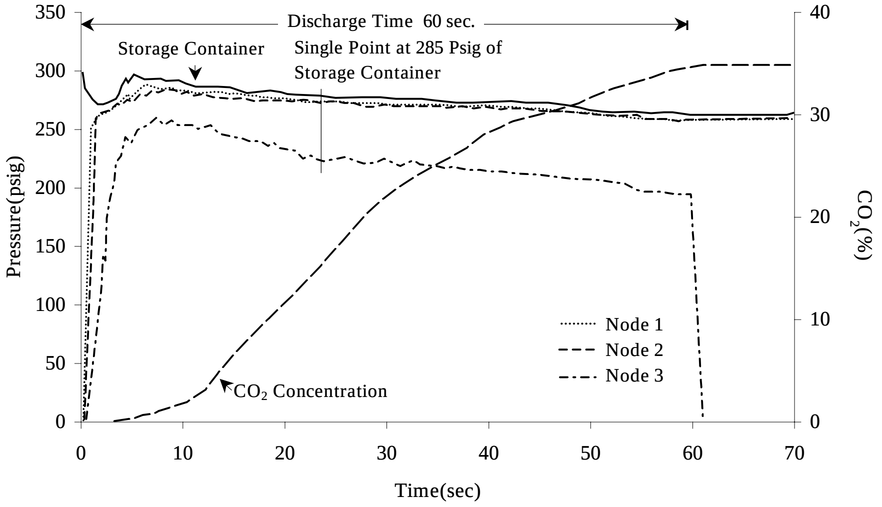


Figure 23. CO_2 Pressure & Concentration Profiles of Test No. 15 in Enclosure 2

6.4 Enclosure 3 Discussions

As a result of discharge tests for Enclosure 3 in the same manner as those for Enclosures 1 and 2 described in Sections 6.2 and 6.3, it was confirmed that the test results in Enclosure 3 were consistent with the predicted values of flow calculations for the pipe runs of 230~262 ft (70~80 m) for deep-seated fires and 164~197 ft (50~60 m) for surface fires, respectively. The maximum percent of pipe volume vs. CO_2 liquid volume was 51~60% for deep-seated fires and 56~70% for surface fires, respectively.

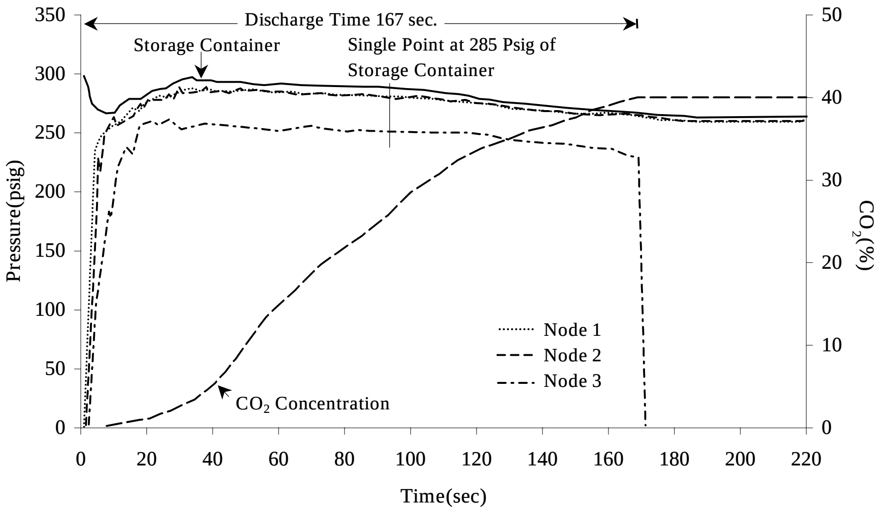


Figure 24. CO_2 Pressure & Concentration Profiles of Test No. 16 in Enclosure 3

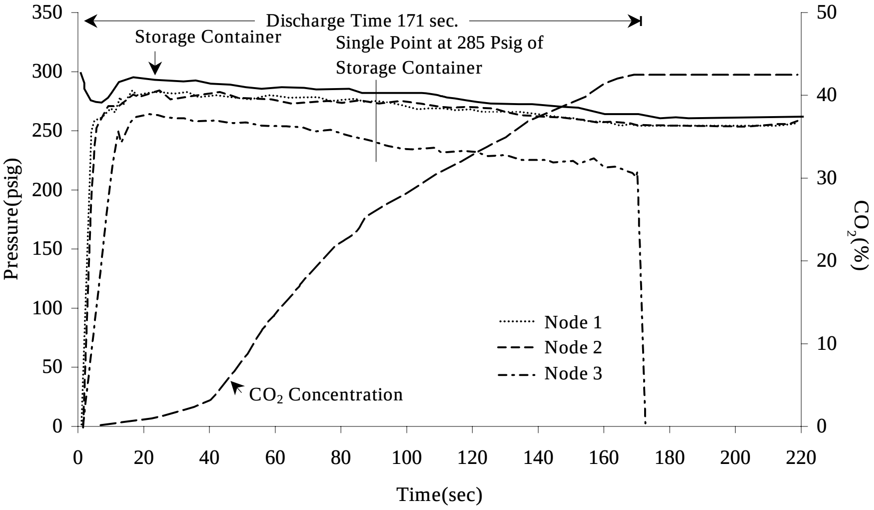


Figure 25. CO_2 Pressure & Concentration Profiles of Test No. 17 in Enclosure 3

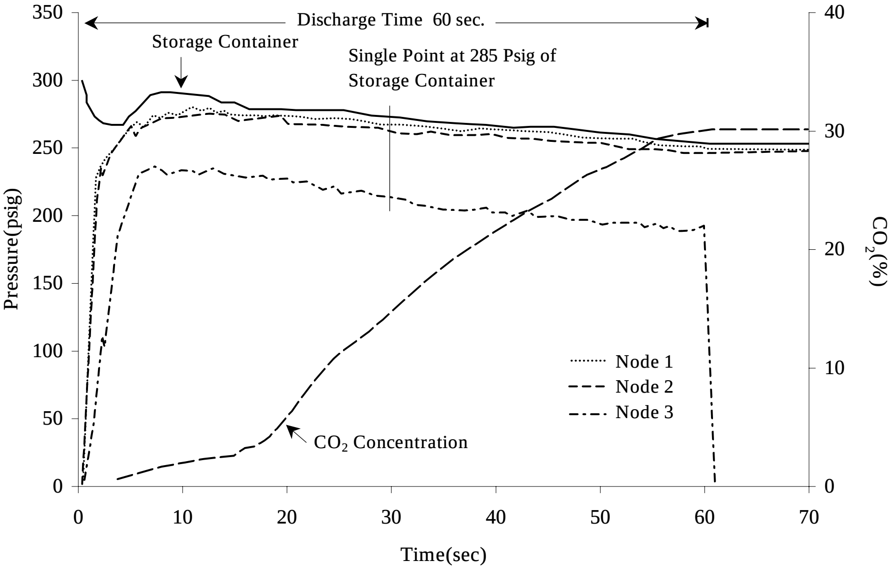


Figure 26. CO_2 Pressure & Concentration Profiles of Test No. 18 in Enclosure 3

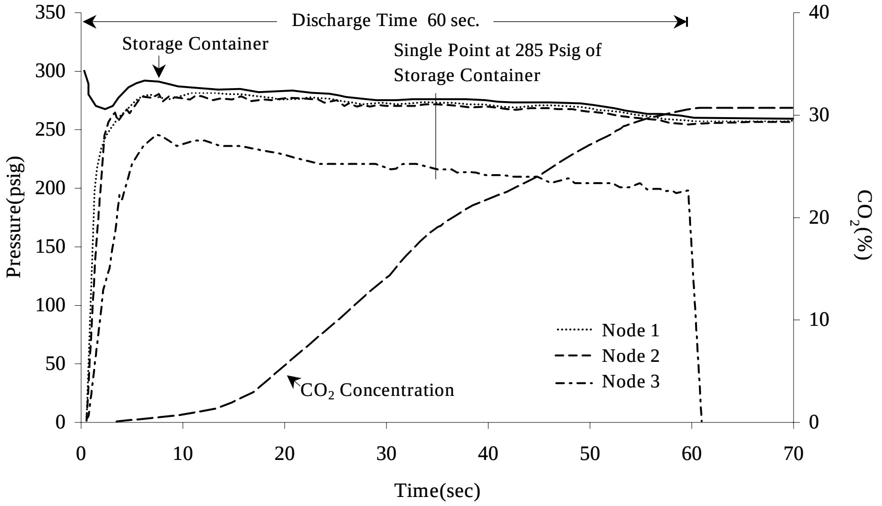


Figure 27. CO_2 Pressure & Concentration Profiles of Test No. 19 in Enclosure 3

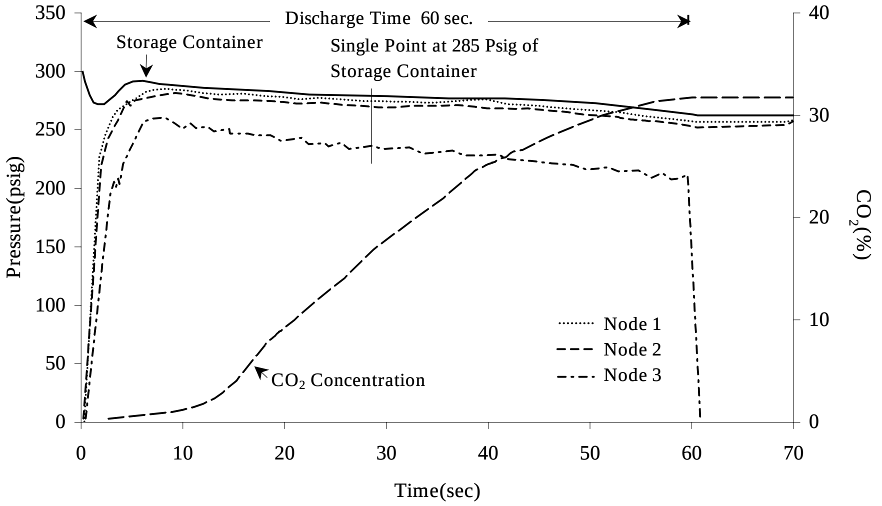


Figure 28. CO_2 Pressure & Concentration Profiles of Test No. 20 in Enclosure 3

7.0 Conclusion and Future Work

7.1 Conclusion

The conclusions this paper draws from the study are:

a) Although it was possible to conduct NFPA 12 method discharge flow calculations with pipe runs as long as 656~984 ft (200~300 m) length for a low-pressure CO_2 system, actual discharge tests showed that it was not possible to obtain the design CO_2 discharge rate (as measured by the pressure at the discharge end of the pipe) for pipe lengths longer than 98~230 ft (30~70 m), depending on the ratio of the pipe volume to the liquid volume of CO_2. Test No. 1 with a pipe run of 502 ft (153 m) resulted in failure to achieve the specified concentrations within the determined discharge time and failure to extinguish the fire. Therefore there could be problems in achieving reliable system designs using current NFPA 12 methodology for these long pipe runs.

b) The maximum allowable ratio of pipe volume to CO_2 liquid volume should be determined for proper system design and performance, i.e. for which their flow calculation methods can predict the required discharge pressures and agent concentrations. This paper indicates the most conservative maximum percent of pipe volume vs. liquid volume of low-pressure CO_2 system was 51~60% for deep-seated fires (which fell between the test results of Test Nos. 16 and 17), while 44~65% for surface fires (which fell between the test results of Test Nos. 14 and 15).

c) This paper discussed the limitations of NFPA 12 flow discharge methodology. NFPA 12 methodology doesn’t provide exact formulae to calculate the time dependent

12 methodology doesn't provide exact formulae to calculate the time dependent quantity of CO_2 which is to be discharged into an enclosure after passing through the pipe network extending from the storage container. One of the major problems in predicting pressure drop, flow rate, and initial vapor time in such a two-phase flow is deriving an accurate relation between agent density and pressure. Depending on the degree of accuracy needed for the low-pressure CO_2 system, a more or less rigorous approach will be required to calculate the pressure-density relationship.

7.2 Future Work

As this paper is designed to compare the predicted values of flow calculations based on the calculation formula on NFPA 12 and the actual full-scale discharge test results, I haven't touched on the time dependent pressure, temperature and CO_2 concentration developed during and following the discharge of carbon dioxide into the enclosures. A mathematical model [15] developed by Robert Zalosh and Cheng Wai Hung can be utilized to compare the predicted values of flow calculations with the results of actual full-scale discharge tests which were done in this study . Some of their correlations for model calculation were described in Section 2.5 of this paper.

Although it is not specified on NFPA 12, it is necessary to make further study on the possible damages on the equipment, walls, and ceilings in the enclosure during CO_2 discharge by predicting the pressures and temperatures to be built up inside the enclosure, based on calculations which are verified through full-scale discharge tests. It would also be necessary to continue to work to develop a computer software program by integrating the computerized flow calculations of the present-day computer software program with computer modeling of time dependent pressure, temperature and CO_2 concentraion in the enclosure.

In most low-pressure carbon dioxide extinguishing systems, there will be a noticeable delay, i.e., initial vapor time, in achieving predominantly liquid CO_2 flow at the discharge nozzles. During this delay, the liquid CO_2 leaving the storage container will be vaporized by heat from the pipe. For local application CO_2 systems, this initial vapor discharge is not considered as effective in extinguishing a fire [13]. Therefore, NFPA 12 requires a minimum of 30 seconds of CO_2 discharge for local application systems. It is anticipated that further testing with local application systems considering initial vapor time under various conditions will also be conducted to assure complete fire extinguishment.

8.0 Reference List

[1] **“UL 2166 - Standard for Halocarbon Clean Agent Extinguishing System Units”**, Underwriters Laboratories Inc., 1999

[2] “**UL 2127 - Standard for Inert Gas Clean Agent Extinguishing System Units”,** Underwriters Laboratories Inc., 1999

[3] **“NFPA 12 - Standard on Carbon Dioxide Extinguishing Systems”**, National Fire Protection Association, 2000

[4] Thomas J. Wysocki, **“Carbon Dioxide and Application Systems”**, Fire Protection Handbook 18th Edition, Section 6/Chapter 20, 1997

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Appendix I – Comparison of Manual and Computerized Flow Calculation Results

Pipe Input Data

Sec Start	Sec End	Pipe Size	D (in)	EQL (ft)	Elevation (ft)	Flow Rate (lbs/min)	Elev Corr.	Elev Psi
1	4	6 SCH 80	5.761	60.9	11	42000	0.443	-5
4	5	6 SCH 40	6.065	217.3	-15	42000	0.443	7
5	6	6 SCH 40	6.065	711.4	15.8	42000	0.443	-7
6	7	6 SCH 40	6.065	223	-3	42000	0.443	1
7	8	6 SCH 40	6.065	80	17.8	42000	0.443	-8
8	9	6 SCH 40	6.065	5.5	0	42000	0.343	0
9	10	6 SCH 40	6.065	211.6	9	42000	0.343	-3
10	11	2 1/2 SCH 40	2.469	23.8	0	1400	0.304	0
11	12	2 SCH 40	2.067	42.3	0	700	0.304	0
12	301	1 SCH 40	1.049	6.9	-0.8	350	0.304	0
12	302	1 SCH 40	1.049	80.7	-0.8	350	0.304	0
11	13	2 SCH 40	2.067	33.1	0	700	0.304	0
13	303	1 SCH 40	1.049	6.9	-0.8	350	0.265	0
13	304	1 SCH 40	1.049	77.7	-0.8	350	0.265	0
10	14	3 SCH 40	3.068	22.1	0	2800	0.304	0
14	15	2 SCH 40	2.067	22.3	0	700	0.265	0
15	305	1 SCH 40	1.049	6.9	-0.8	350	0.265	0
15	306	1 SCH 40	1.049	77.7	-0.8	350	0.265	0
14	16	3 SCH 40	3.068	22.6	0	2100	0.265	0
16	17	2 SCH 40	2.067	22.3	0	700	0.265	0
17	307	1 SCH 40	1.049	6.9	-.0.8	350	0.265	0
17	308	1 SCH 40	1.049	49.7	-0.8	350	0.265	0
16	18	2 1/2 SCH 40	2.469	61.2	0	1400	0.265	0
18	19	2 SCH 40	2.067	22.3	0	700	0.265	0
19	309	1 SCH 40	1.049	6.9	-0.8	350	0.265	0

Pipe Input Data

Sec Start	Sec End	Pipe Size	D (in)	EQL (ft)	Elevation (ft)	Flow Rate (lbs/min)	Elev Corr.	Elev Psi
19	310	1 SCH 40	1.049	60.8	-0.8	350	0.265	0
18	20	2 SCH 40	2.067	42.1	0	700	0.265	0
20	311	1 SCH 40	1.049	3.9	-0.8	350	0.265	0
20	312	1 SCH 40	1.049	58	-0.8	350	0.265	0

Manual Calculation													Computer Calculation
Sec Start	Sec End	Y_{start} = $Y_{previous}$ + $Elev(psia)$	Y_{approx}	$Z_{average}$	Z_{in}	Z_{out}	Y_{final}	Start (psia)	Start + Elev (psia)	End (psia)	Specific Rate	Orifice Code	Orifice Code
1	4	308	308	0.0675	0.000	0.135	310	300	295	295			
4	5	0	82	0.135	0.135	0.135	86	295	300	298			
5	6	540	807	0.1995	0.135	0.264	813	298	291	286			
6	7	760	844	0.264	0.264	0.264	851	286	287	285			
7	8	1263	1293	0.387	0.387	0.387	1304	285	277	276			
8	9	1304	1306	0.387	0.387	0.387	1317	276	276	276			
9	10	1448	1527	0.387	0.387	0.387	1539	276	273	271			
10	11	1583	1694	0.446	0.387	0.505	1746	271	271	266			
11	12	1746	1872	0.505	0.505	0.505	1902	266	266	262			
12	301	1902	2082	0.5625	0.505	0.620	2208	262	262	254	1723	16.3	16.2
12	302	1902	4011	1.1205	0.620	1.621	4262	254	254	165	880	22.8	23.3
11	13	1746	1844	0.505	0.505	0.505	1874	266	266	263			
13	303	1844	2024	0.5625	0.505	0.620	2150	263	263	256	1757	16.1	16.1
13	304	1844	3874	1.001	0.505	1.497	4099	256	256	176	949	21.9	22.6
10	14	1583	1715	0.446	0.387	0.505	1803	270	270	265			
14	15	1803	1869	0.505	0.505	0.505	1899	265	265	262			
15	305	1899	2079	0.5625	0.505	0.620	2205	262	262	254	1723	16.3	16.1

Manual Calculation													Computer Calculation
Sec Start	Sec End	$Y_{start} = Y_{previous} + Elev(psia)$	Y_{approx}	$Z_{average}$	Z_{in}	Z_{out}	Y_{final}	Start (psia)	Start + Elev (psia)	End (psia)	Specific Rate	Orifice Code	Orifice Code
15	306	1899	3929	1.001	0.505	1.497	4154	262	262	172	923	22.2	22.6
14	16	1803	1879	0.505	0.505	0.505	1935	264	264	261			
16	17	1935	2001	0.505	0.505	0.620	2031	261	261	259			
17	307	2031	2212	0.62	0.620	0.620	2351	259	259	250	1655	16.6	16.2
17	308	2031	3330	0.8925	0.620	1.165	0530	250	250	207	1184	19.6	19.3
16	18	1935	2221	0.5625	0.505	0.620	2287	261	261	252			
18	19	2287	2353	0.676	0.620	0.732	2393	252	252	249			
19	309	2393	2573	0.7865	0.732	0.841	2750	249	249	238	1502	17.4	16.8
19	310	2393	3982	1.172	0.732	1.612	4244	249	249	166	886	22.7	21.8
18	20	2287	2412	0.676	0.620	0.732	2452	252	252	247			
20	311	2452	2554	0.7865	0.732	0.841	2730	248	248	238	1502	17.4	16.9
20	312	2452	3968	1.172	0.732	1.612	4230	248	248	166	886	22.7	21.6

Appendix II – Detail procedure of Computerized Flow Calculation

GETTING STARTED

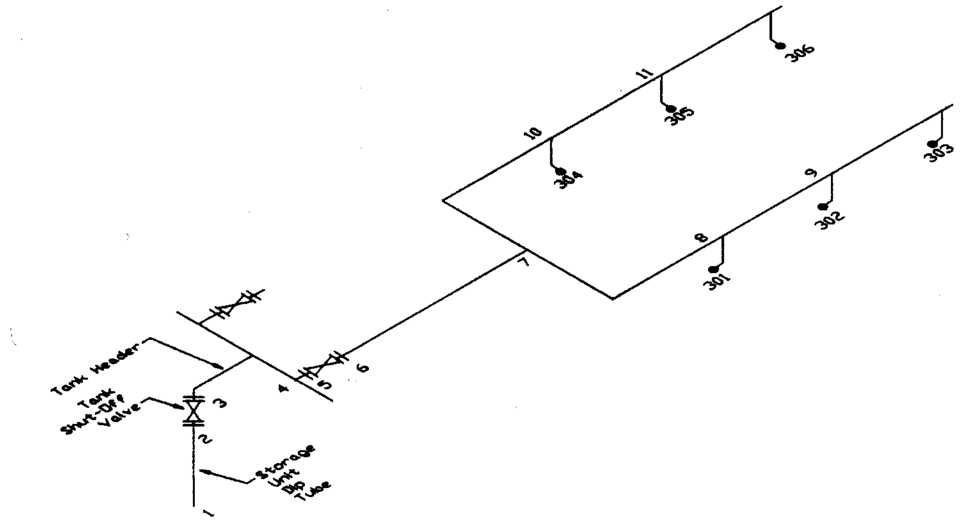
A sample data file (sample1.lp2) is installed with the program. To become familiar with the various screens and commands, please run the program and open the sample data file.

Online help is available for many of the screens in the program by pressing the F1 key any time a screen, text box, or command button is highlighted.

Once you are familiar with navigating the program, you are ready to make a new data file.

NEW DATA FILE

The first step in making a new data file is to define a piping system. Make a drawing showing the storage unit location, system pipe runs including lengths and elevation changes and nozzle locations. Note the location of all pipe fittings such as 90 degree elbows, tees, couplings or unions. Also note the location, size and equivalent length of system valves. An isometric such as shown in the sample below is convenient. (For clarity, only the pipe section numbers are shown on the sample isometric. For an actual project, the length of each pipe section and the flow rate or quantity of CO2 for each nozzle would also be indicated.)



Number the pipe sections Starting at the storage unit dip tube, number the pipe sections. The first section must always be 1 to 2 and include the dip tube. Working from the first section to each nozzle, assign a number for the start and end of each pipe section.

A new pipe section MUST BEGIN at:

each change in pipe size

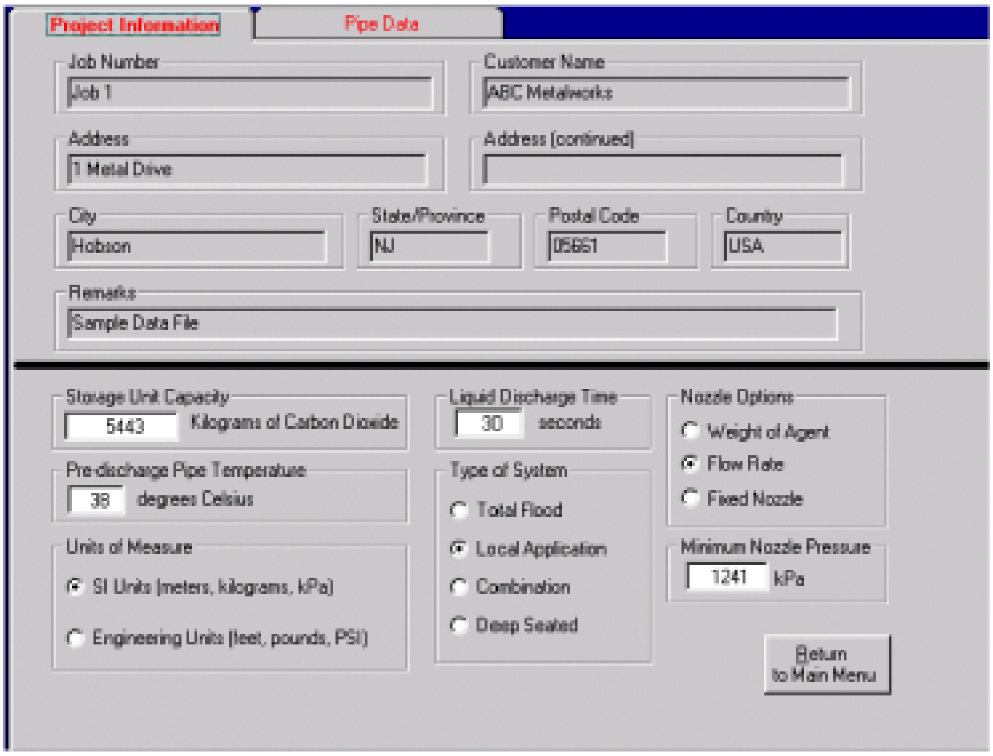
each point where the flow rate will change as at a tee junction.

Nozzles must be assigned an integer nozzle number between 301 and 599. (See program online help for "combination system" nozzle numbers.)

ENTER THE DATA

Once the pipe network has been designed and numbered, the data may be entered in the program.

Click the New Data Input File command button to open the Data Input Screen.



Job Number: Job 1
Customer Name: ABC Metalworks
Address: 1 Metal Drive
Address (continued):
City: Hobson
State/Province: NJ
Postal Code: 05661
Country: USA
Remarks: Sample Data File

Storage Unit Capacity: 5443 Kilograms of Carbon Dioxide
Liquid Discharge Time: 30 seconds
Nozzle Options: ○ Weight of Agent ● Flow Rate ○ Fixed Nozzle
Pre-discharge Pipe Temperature: 38 degrees Celsius
Type of System: ○ Total Flood ● Local Application ○ Combination ○ Deep Seated
Minimum Nozzle Pressure: 1241 kPa
Units of Measure: ● SI Units (meters, kilograms, kPa) ○ Engineering Units (feet, pounds, PSI)

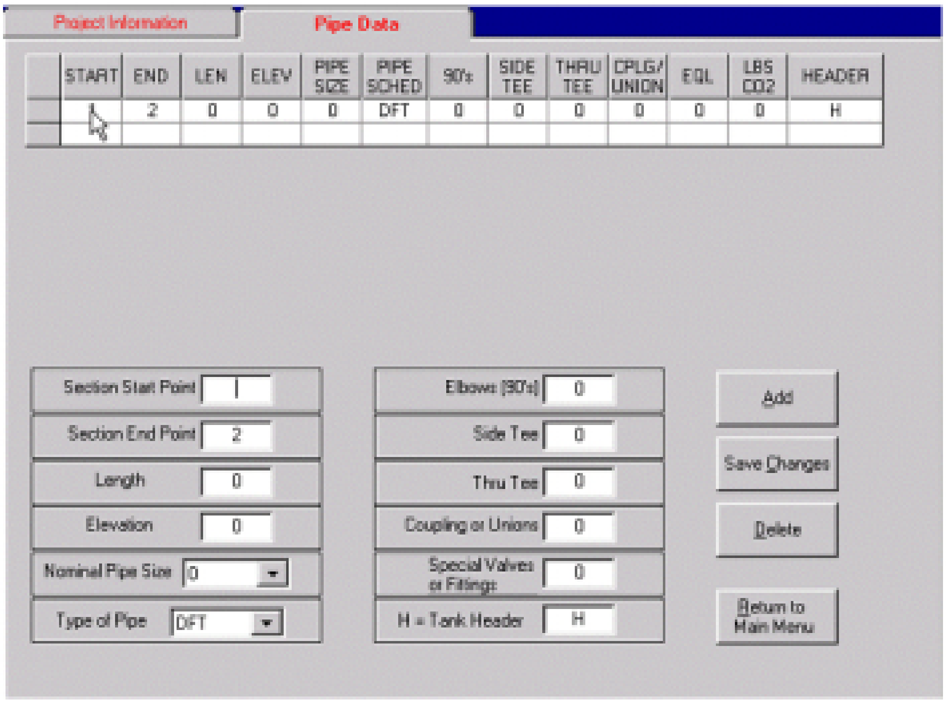
1. Fill in the Project Information (Job number, Customer Name, etc.).
2. Fill in the estimated capacity of the low pressure CO2 storage unit (this value must be verified after the flow calculation is completed, modified if necessary, and the calculation re-run).
3. Specify the design discharge time per applicable codes, standards and design specifications.
4. Choose the type of CO2 system: Total Flood, Local Application, Combination System, or Deep Seated.
5. In Nozzle Options, the method of data input for the nozzles may be selected. For most systems, the default value based on the type of CO2 system is suitable.
6. The Minimum Nozzle Pressure may be specified or use the default value.

Once the Project Information screen is complete, click the PIPE DATA tab.

On the new Pipe Data screen, note that Section 1 to 2 is already shown in the pipe grid. The length, elevation and pipe size for this section must be set to the correct values by

1. selecting Section 1 to 2 by clicking on the data grid row as illustrated below

2. editing the values for length, elevation, pipe size, etc. in the data editing boxes
3. clicking Save Changes (shortcut Alt + C).



START	END	LEN	ELEV	PIPE SIZE	PIPE SCHED	90's	SIDE TEE	THRU TEE	CPLG/ UNION	EQL	LBS CO2	HEADER
1	2	0	0	0	DFT	0	0	0	0	0	0	H

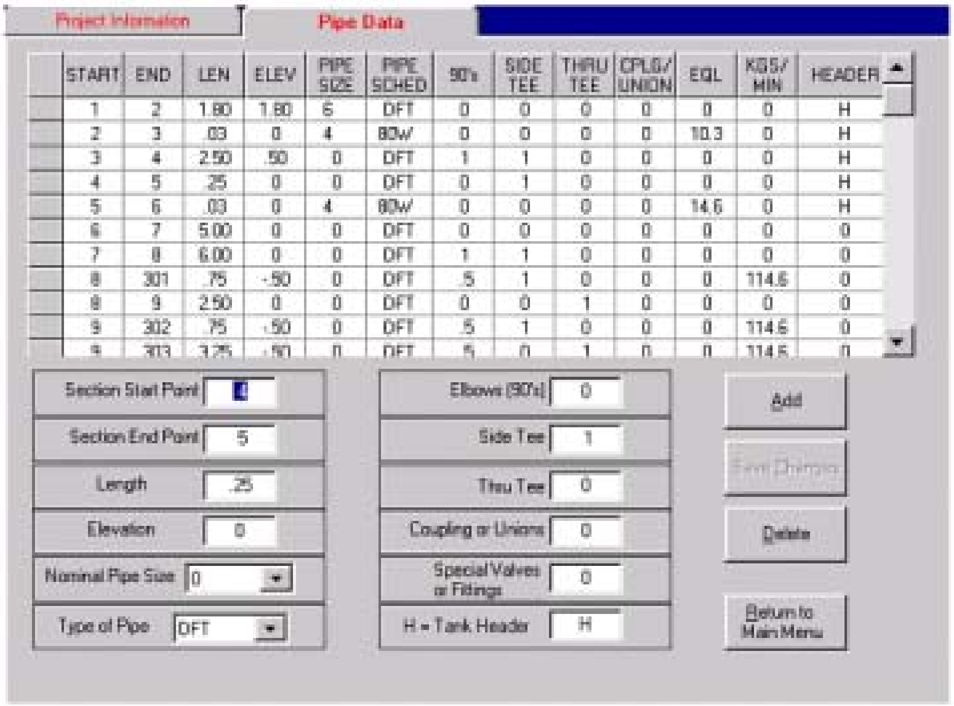
Section Start Point: 1
Section End Point: 2
Length: 0
Elevation: 0
Nominal Pipe Size: 0
Type of Pipe: DFT
Elbows (90's): 0
Side Tee: 0
Thru Tee: 0
Coupling or Unions: 0
Special Valves or Fittings: 0
H = Tank Header: H

Additional pipe sections are added to the pipe data grid by typing the desired data in the data editor boxes and clicking ADD (Alt + A). The illustration on the next page shows a completed pipe data screen.

Note that section 1 to 2 contains a tank shut off valve with an equivalent length of 10.3 meters of 6 inch Schedule 80 pipe. Section 5 to 6 contains a Master-Selector valve having an equivalent length of 14.6 meters of 4 inch Schedule 80 pipe. Both the size and equivalent length of all system valves must be specified.

Also note that the pipe sections up to and including the Master-Selector valve are designated as "Tank Header" sections by the "H" in the Header column. Tank header sections typically end after the Selector or Master-Selector valve. The default pipe type for a Tank Header is Schedule 80 pipe with welded or flanged connections.

Nozzles are identified with Section End Points greater than 300. The flow rate for each nozzle is specified in this example local application system. For the sample system, the specified flow rate is 114.6 kilograms per minute.



	START	END	LEN	ELEV	PIPE SIZE	PIPE SCHED	90's	SIDE TEE	THRU TEE	CPLG/ UNION	EQL	KGS/ MIN	HEADER
	1	2	1.80	1.80	6	DFT	0	0	0	0	0	0	H
	2	3	.03	0	4	80W	0	0	0	0	10.3	0	H
	3	4	2.50	.50	0	DFT	1	1	0	0	0	0	H
	4	5	.25	0	0	DFT	0	1	0	0	0	0	H
	5	6	.03	0	4	80W	0	0	0	0	14.6	0	H
	6	7	5.00	0	0	DFT	0	0	0	0	0	0	0
	7	8	6.00	0	0	DFT	1	1	0	0	0	0	0
	8	301	.75	-.50	0	DFT	.5	1	0	0	0	114.6	0
	8	9	2.50	0	0	DFT	0	0	1	0	0	0	0
	9	302	.75	-.50	0	DFT	.5	1	0	0	0	114.6	0
	9	303	3.75	-.50	0	DFT	.5	0	1	0	0	114.6	0

Section Start Point 4

Section End Point 5

Length .25

Elevation 0

Nominal Pipe Size 0

Type of Pipe DFT

Elbows (90's) 0

Side Tee 1

Thru Tee 0

Coupling or Unions 0

Special Valves or Fittings 0

H = Tank Header H

Completed Pipe Data Screen for sample1.lp2

RUN THE CALCULATION

When all the pipe data from the isometric is entered in the program, click the Return To Main Menu command (Shortcut Alt + R). From the Main Menu, click the Run Flow Calculation command. Answer YES to the prompt "Save Data File." Type the name of the data file in the space provided. The program automatically adds the "lp2" extension to the file name.

When the data file is saved, the flow calculation will run. If there are errors ("fatal errors") in the data file that prevent a hydraulic calculation, an Error Screen will describe the errors. If there are no "fatal errors," the Results Screen will be displayed.

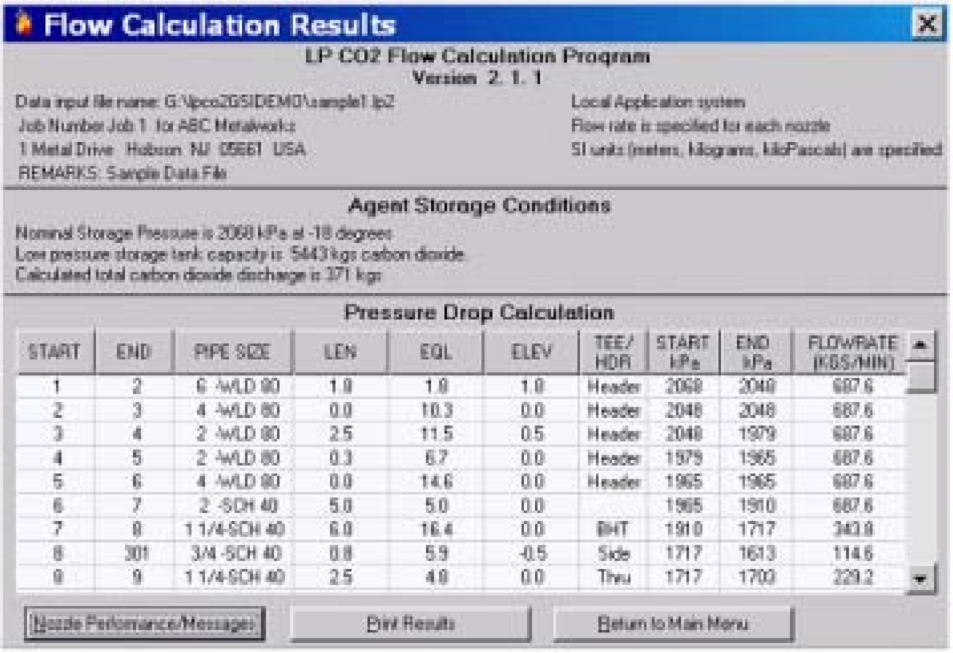
Checking Results

Caution: Examine all computer-generated results carefully. Because of the great numerical accuracy that is possible with modern computers, there is a tendency to "believe" everything a computer shows as "results." The computer program is only a tool to do the complex hydraulic calculations.

Even though the program does not generate an error message, it does NOT necessarily indicate that the system flow calculation, pipe network, and nozzles are correctly designed. The system designer must carefully check the output data to verify that the design meets all applicable codes, standards and job specifications.

Among the items which must be verified are:

- *The pipe data conforms to the isometric and installation pipe drawings.*
- *The quantity discharged from each nozzle for a total flood system is sufficient to produce the design concentration over the specified temperature range for the hazard.*
- *The flow rates and discharge times for every local application nozzle meet the listed limits for the nozzle and the discharge time requirements for the protected hazard.*
- *The pipe sizes are suitable for the flow rates.*
- *There is sufficient CO2 provided in storage.*
- *NO COMPUTERIZED CALCULATION CAN TAKE THE PLACE OF CAREFUL, ACCURATE ENGINEERING, QUALITY INSTALLATION, AND PROPER STARTUP AND COMMISSIONING PRACTICES.*



LP CO2 Flow Calculation Program
Version 2. 1. 1

Data input file name: G:\lpco2GS\DEMO\sample1.lp2
Job Number Job 1 for ABC Metalworks
1 Metal Drive Hobson NJ 05661 USA
REMARKS: Sample Data File

Local Application system
Flow rate is specified for each nozzle
SI units (meters, kilograms, kiloPascals) are specified

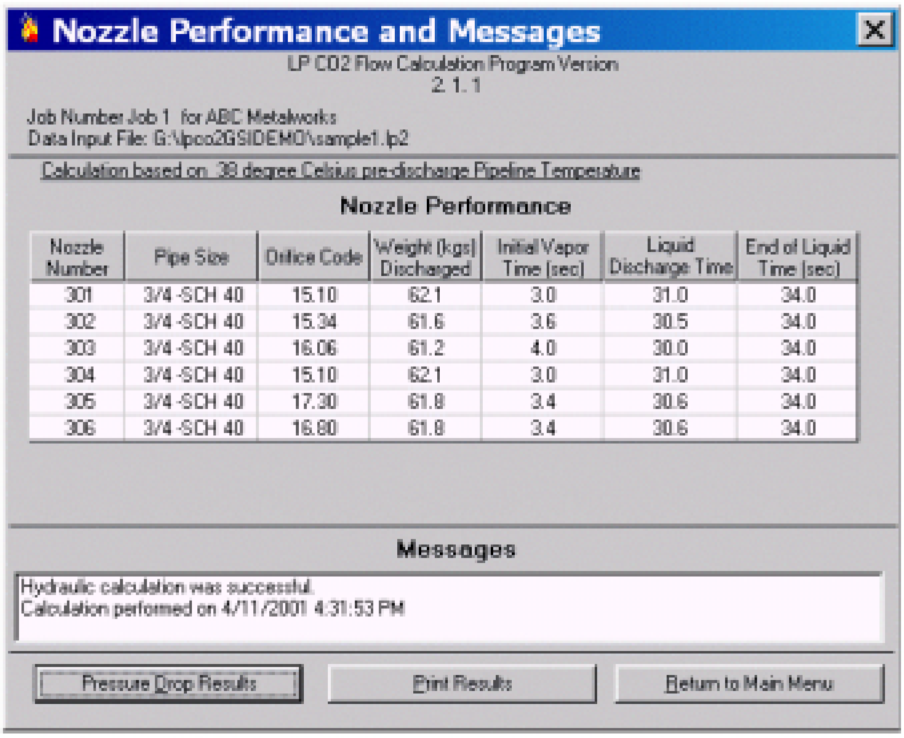
Agent Storage Conditions

Nominal Storage Pressure is 2068 kPa at -18 degrees
Low pressure storage tank capacity is 5443 kgs carbon dioxide
Calculated total carbon dioxide discharge is 371 kgs

Pressure Drop Calculation

START	END	PIPE SIZE	LEN	EQL	ELEV	TEE/ HDR	START kPa	END kPa	FLOWRATE (KGS/MIN)
1	2	6 -WLD 80	1.8	1.8	1.8	Header	2068	2048	687.6
2	3	4 -WLD 80	0.0	10.3	0.0	Header	2048	2048	687.6
3	4	2 -WLD 80	2.5	11.5	0.5	Header	2048	1979	687.6
4	5	2 -WLD 80	0.3	6.7	0.0	Header	1979	1965	687.6
5	6	4 -WLD 80	0.0	14.6	0.0	Header	1965	1965	687.6
6	7	2 -SCH 40	5.0	5.0	0.0		1965	1910	687.6
7	8	1 1/4-SCH 40	6.0	16.4	0.0	BHT	1910	1717	343.8
8	301	3/4 -SCH 40	0.8	5.9	-0.5	Side	1717	1613	114.6
8	9	1 1/4-SCH 40	2.5	4.8	0.0	Thru	1717	1700	229.2

Flow Calculation Results for Pipe Network in sample1.lp2



LP CO2 Flow Calculation Program Version
2.1.1

Job Number Job 1 for ABC Metalworks
Data Input File: G:\lpco2GSIDEMO\sample1.lp2

Calculation based on 38 degree Celsius pre-discharge Pipeline Temperature

Nozzle Performance

Nozzle Number	Pipe Size	Orifice Code	Weight (kgs) Discharged	Initial Vapor Time (sec)	Liquid Discharge Time	End of Liquid Time (sec)
301	3/4 -SCH 40	15.10	62.1	3.0	31.0	34.0
302	3/4 -SCH 40	15.34	61.6	3.6	30.5	34.0
303	3/4 -SCH 40	16.06	61.2	4.0	30.0	34.0
304	3/4 -SCH 40	15.10	62.1	3.0	31.0	34.0
305	3/4 -SCH 40	17.30	61.8	3.4	30.6	34.0
306	3/4 -SCH 40	16.80	61.8	3.4	30.6	34.0

Messages

Hydraulic calculation was successful.
Calculation performed on 4/11/2001 4:31:53 PM

Flow Calculation Results showing Nozzle Size, Discharge times and Quantities for sample1.lp2

The data input and the results may be printed to the computer's Windows system printer. The Print Options dialog enables the user to select what to print and which Windows system printer should received the output.

☑ Print Data Input

☐ Print Calculation Results

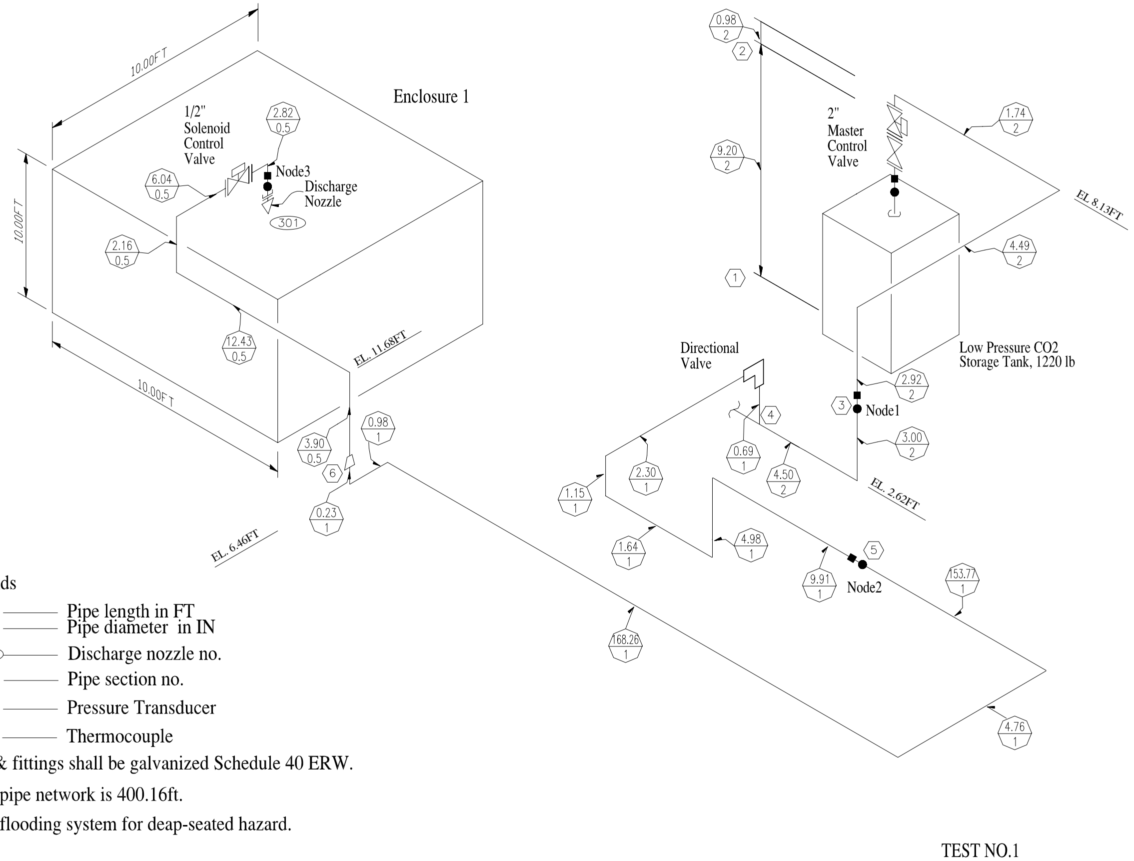
☑ Print to HP LaserJet III

Print Options Dialog

The program has many additional features which are described in the online Help.

Please remember that no computer program can replace the full and careful attention of a qualified engineer who is expert in the design and application of low pressure carbon dioxide systems

Appendix III – Isometric Piping Diagram



Notes

1. Legends

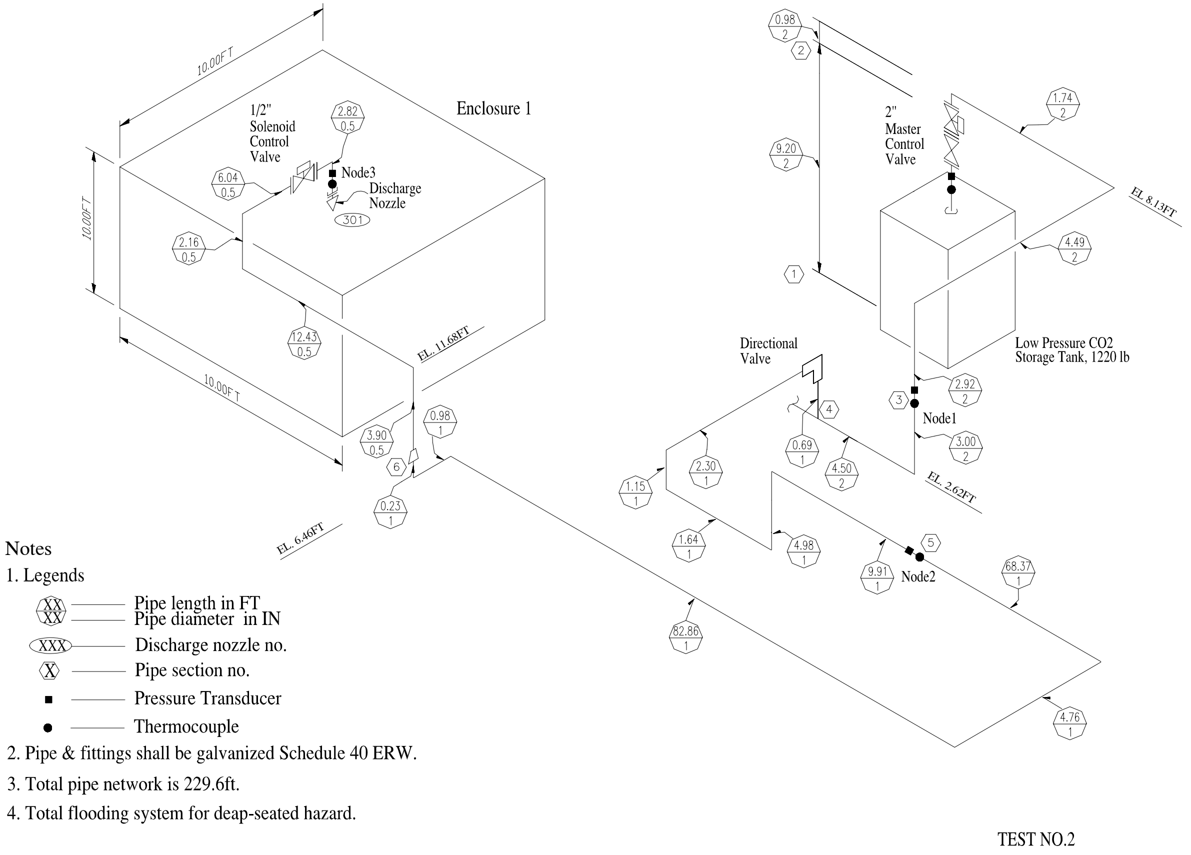
XX ——— Pipe length in FT
XX ——— Pipe diameter in IN
XXX ——— Discharge nozzle no.
X ——— Pipe section no.
■ ——— Pressure Transducer
● ——— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 400.16ft.

4. Total flooding system for deap-seated hazard.

Figure III-1. Isometric Piping Diagram for Test No. 1



Notes

1. Legends

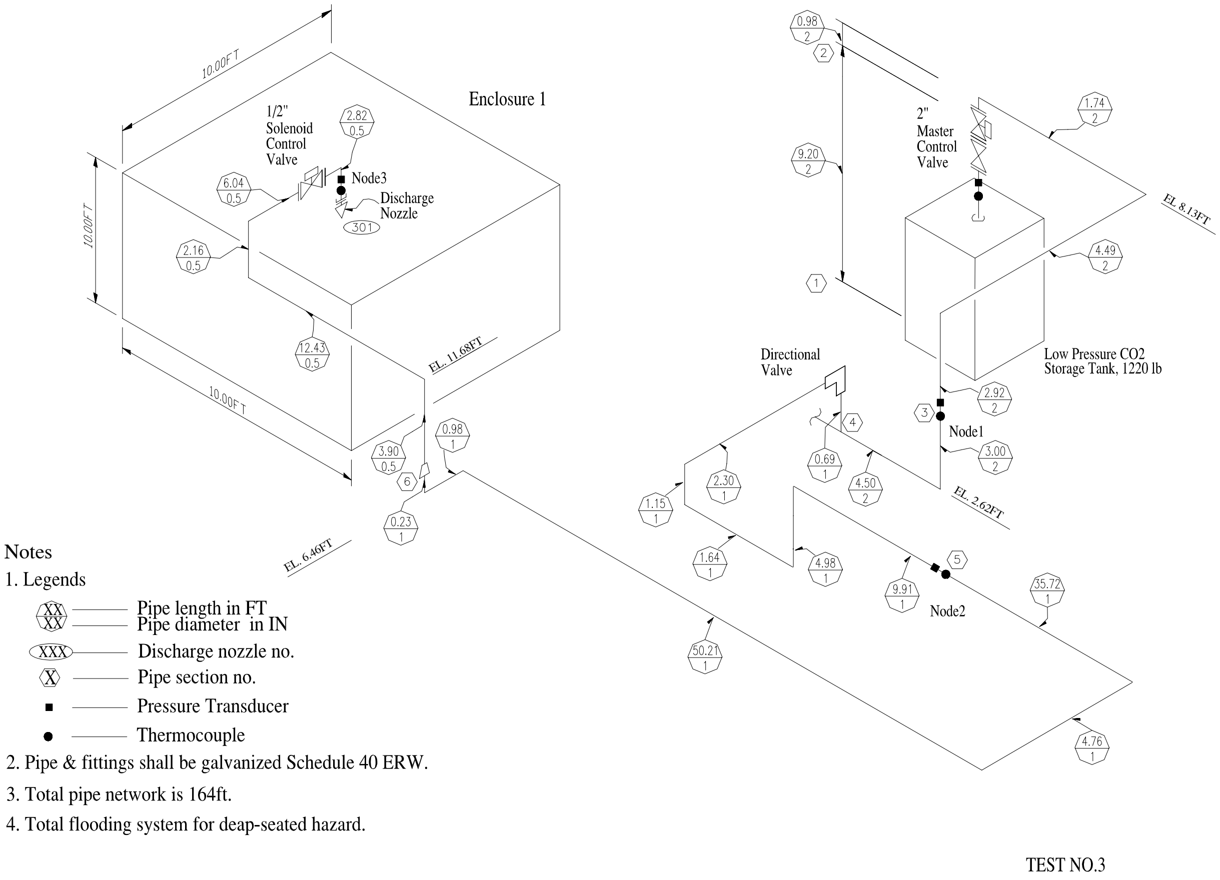
XX/XX —— Pipe length in FT / Pipe diameter in IN
XXX —— Discharge nozzle no.
X —— Pipe section no.
■ —— Pressure Transducer
● —— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 229.6ft.

4. Total flooding system for deap-seated hazard.

Figure III-2. Isometric Piping Diagram for Test No. 2



Notes

1. Legends

XX/XX —— Pipe length in FT / Pipe diameter in IN

XXX —— Discharge nozzle no.

X —— Pipe section no.

■ —— Pressure Transducer

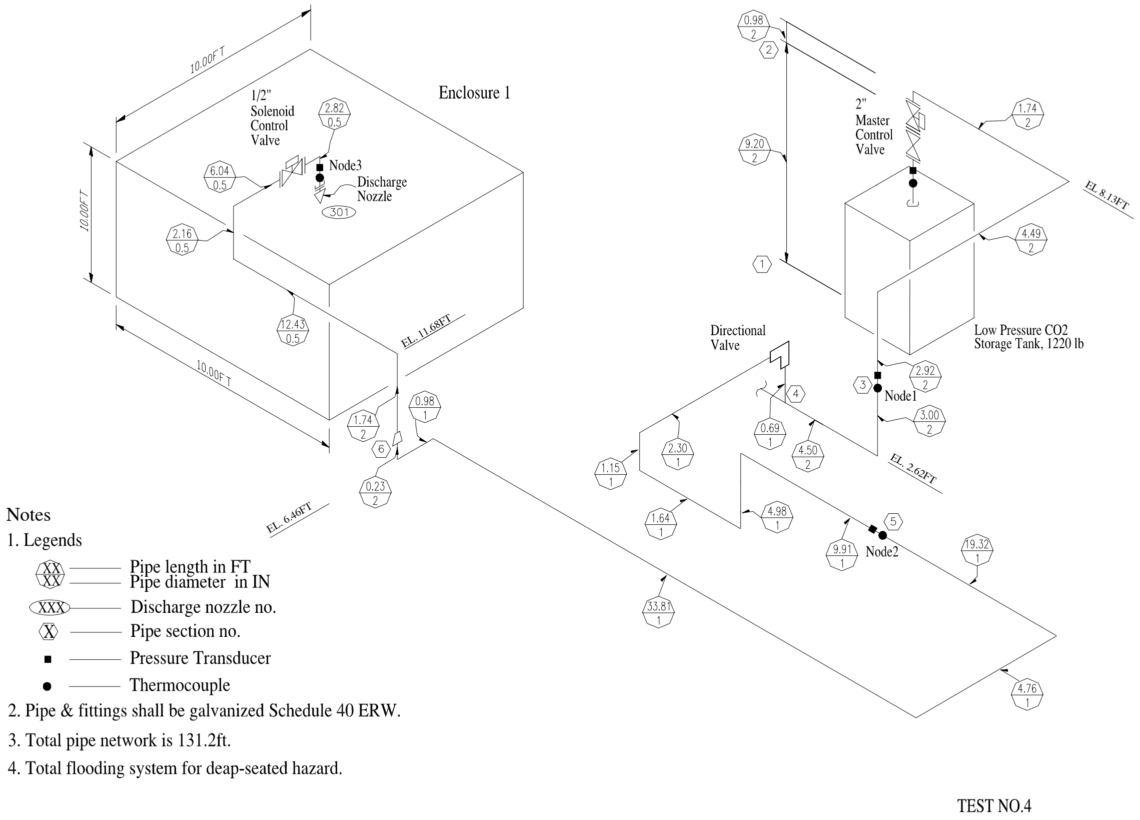
● —— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 164ft.

4. Total flooding system for deap-seated hazard.

Figure III-3. Isometric Piping Diagram for Test No. 3



Notes

1. Legends

XX/XX ——— Pipe length in FT / Pipe diameter in IN

XXX ——— Discharge nozzle no.

X ——— Pipe section no.

■ ——— Pressure Transducer

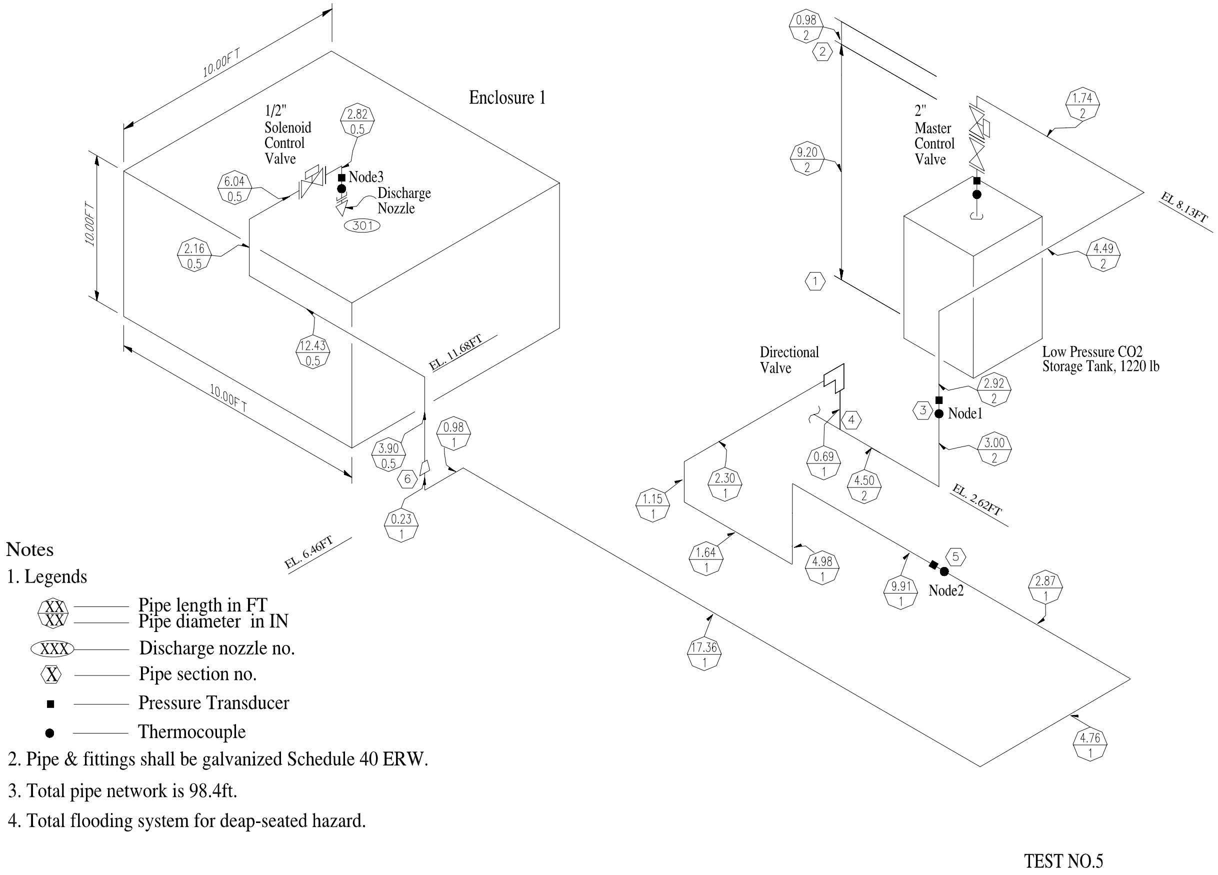
● ——— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 131.2ft.

4. Total flooding system for deap-seated hazard.

Figure III-4. Isometric Piping Diagram for Test No. 4



Notes

1. Legends

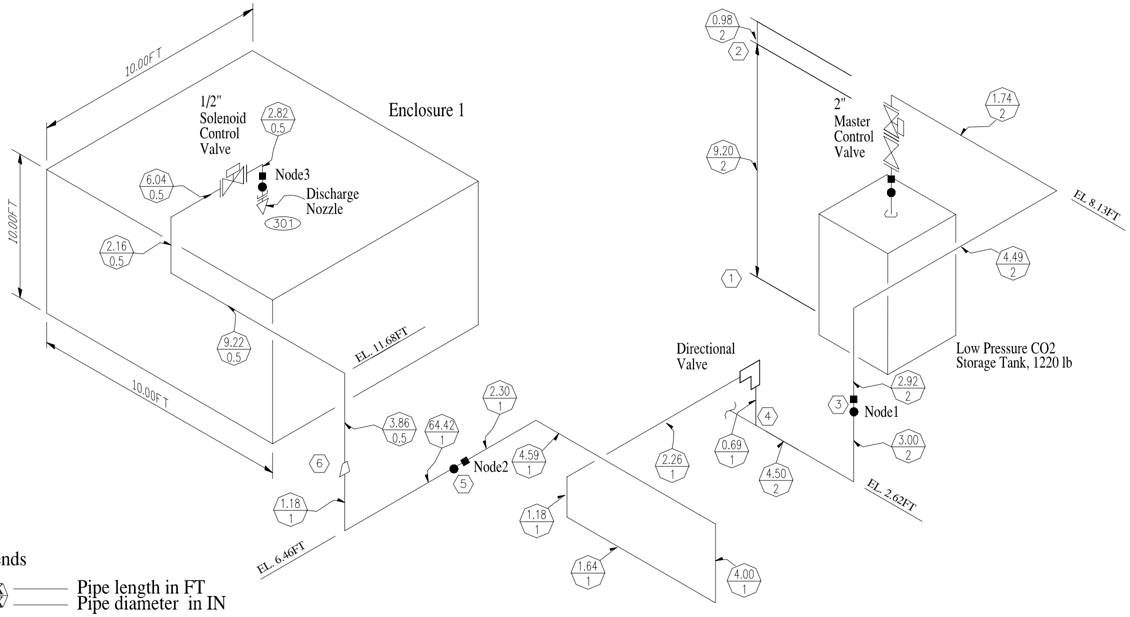
XX ——— Pipe length in FT
XX ——— Pipe diameter in IN
XXX ——— Discharge nozzle no.
X ——— Pipe section no.
■ ——— Pressure Transducer
● ——— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 98.4ft.

4. Total flooding system for deap-seated hazard.

Figure III-5. Isometric Piping Diagram for Test No.5



Notes

1. Legends

XX/XX ——— Pipe length in FT / Pipe diameter in IN

XXX ——— Discharge nozzle no.

X ——— Pipe section no.

■ ——— Pressure Transducer

● ——— Thermocouple

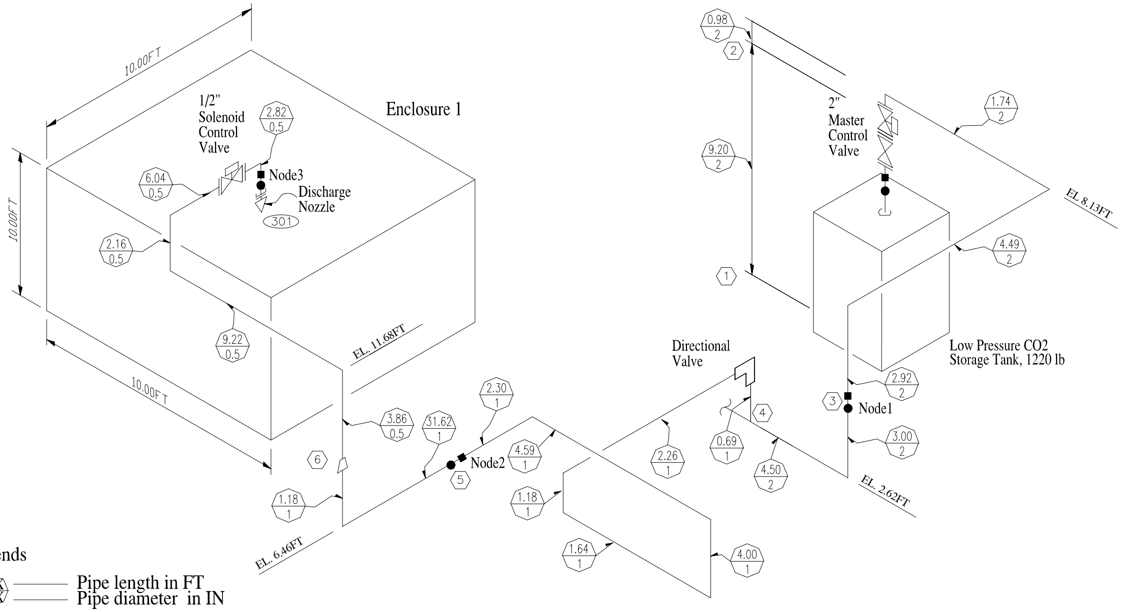
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 131.2ft.

4. Total flooding system for surface fire hazard.

TEST NO.6

Figure III-6. Isometric Piping Diagram for Test No. 6



Notes

1. Legends

XX / XX —— Pipe length in FT / Pipe diameter in IN

XXX —— Discharge nozzle no.

X —— Pipe section no.

■ —— Pressure Transducer

● —— Thermocouple

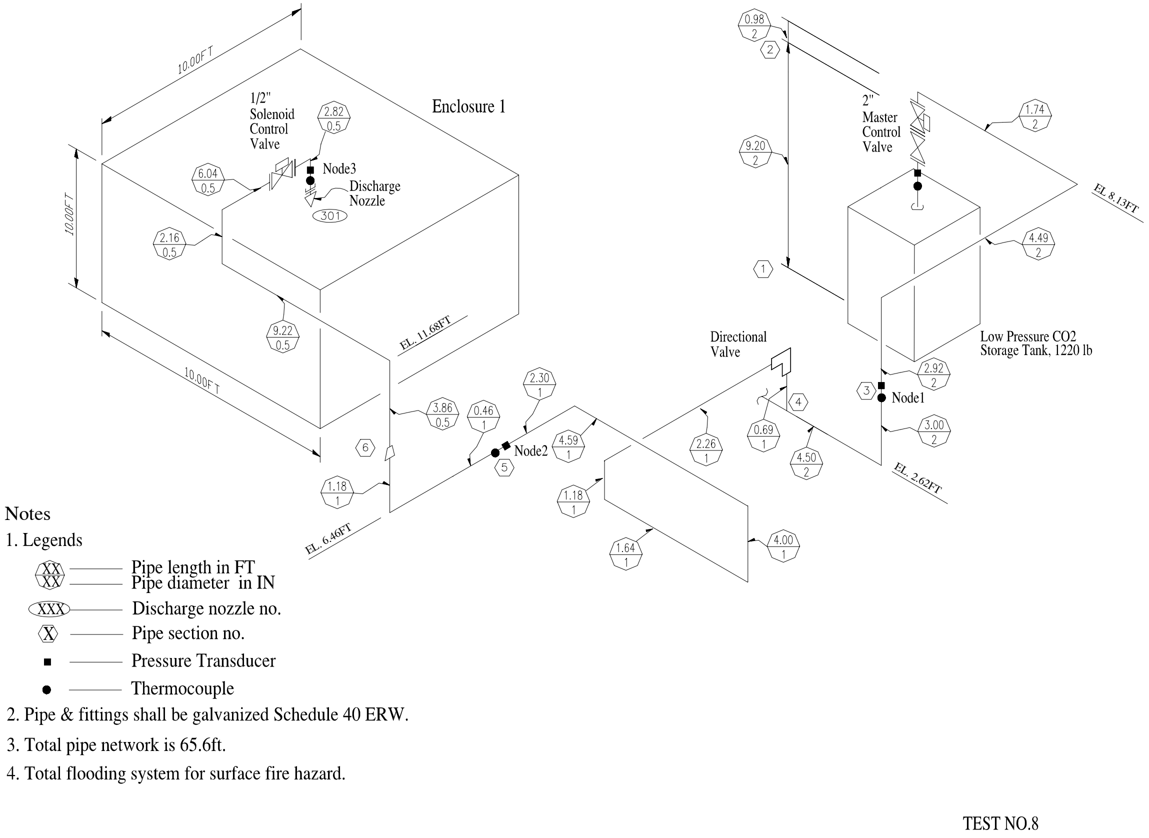
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 98.4ft.

4. Total flooding system for surface fire hazard.

TEST NO.7

Figure III-7. Isometric Piping Diagram for Test No. 7



Notes

1. Legends

XX / XX — Pipe length in FT / Pipe diameter in IN

XXX — Discharge nozzle no.

X — Pipe section no.

■ — Pressure Transducer

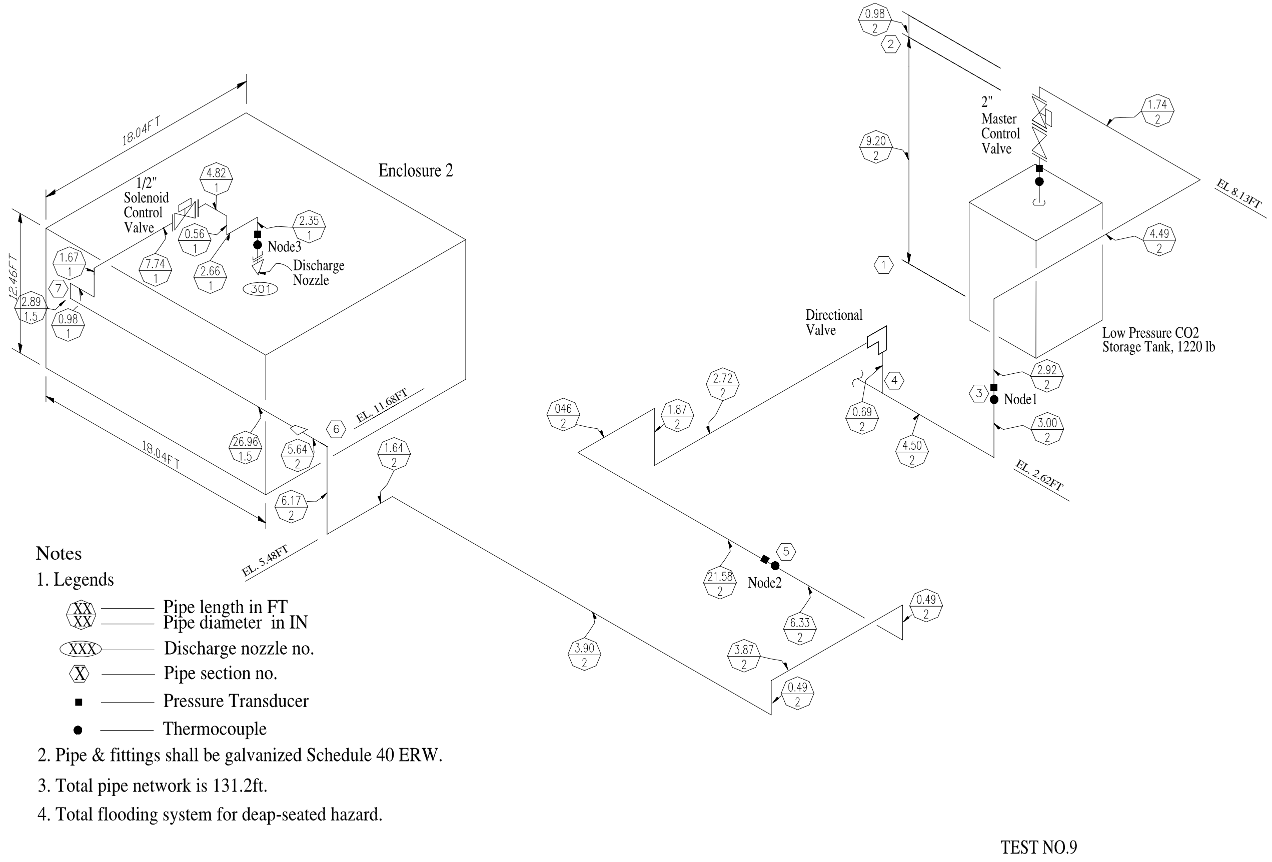
● — Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 65.6ft.

4. Total flooding system for surface fire hazard.

Figure III-8. Isometric Piping Diagram for Test No. 8



Notes

1. Legends

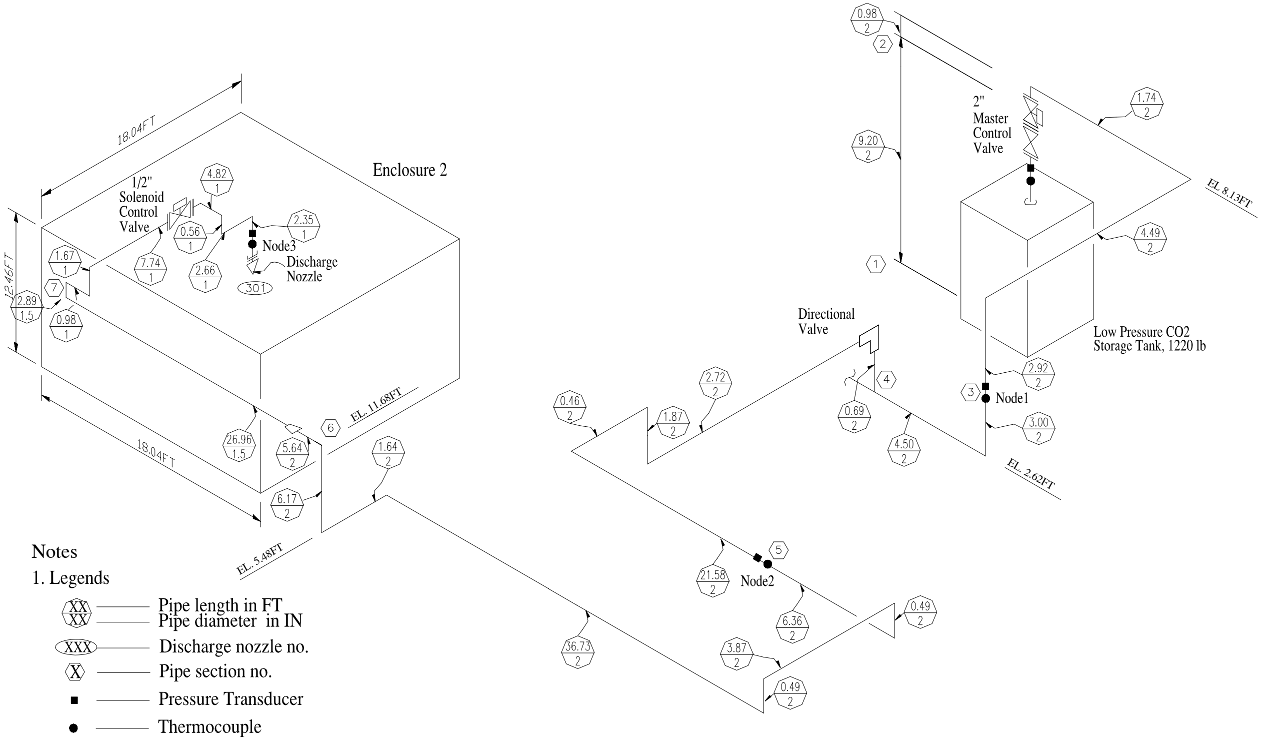
XX / XX	Pipe length in FT Pipe diameter in IN
XXX	Discharge nozzle no.
X	Pipe section no.
■	Pressure Transducer
●	Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 131.2ft.

4. Total flooding system for deap-seated hazard.

Figure III-9. Isometric Piping Diagram for Test No. 9



Notes

1. Legends

XX ——— Pipe length in FT
XX ——— Pipe diameter in IN
XXX ——— Discharge nozzle no.
X ——— Pipe section no.
■ ——— Pressure Transducer
● ——— Thermocouple

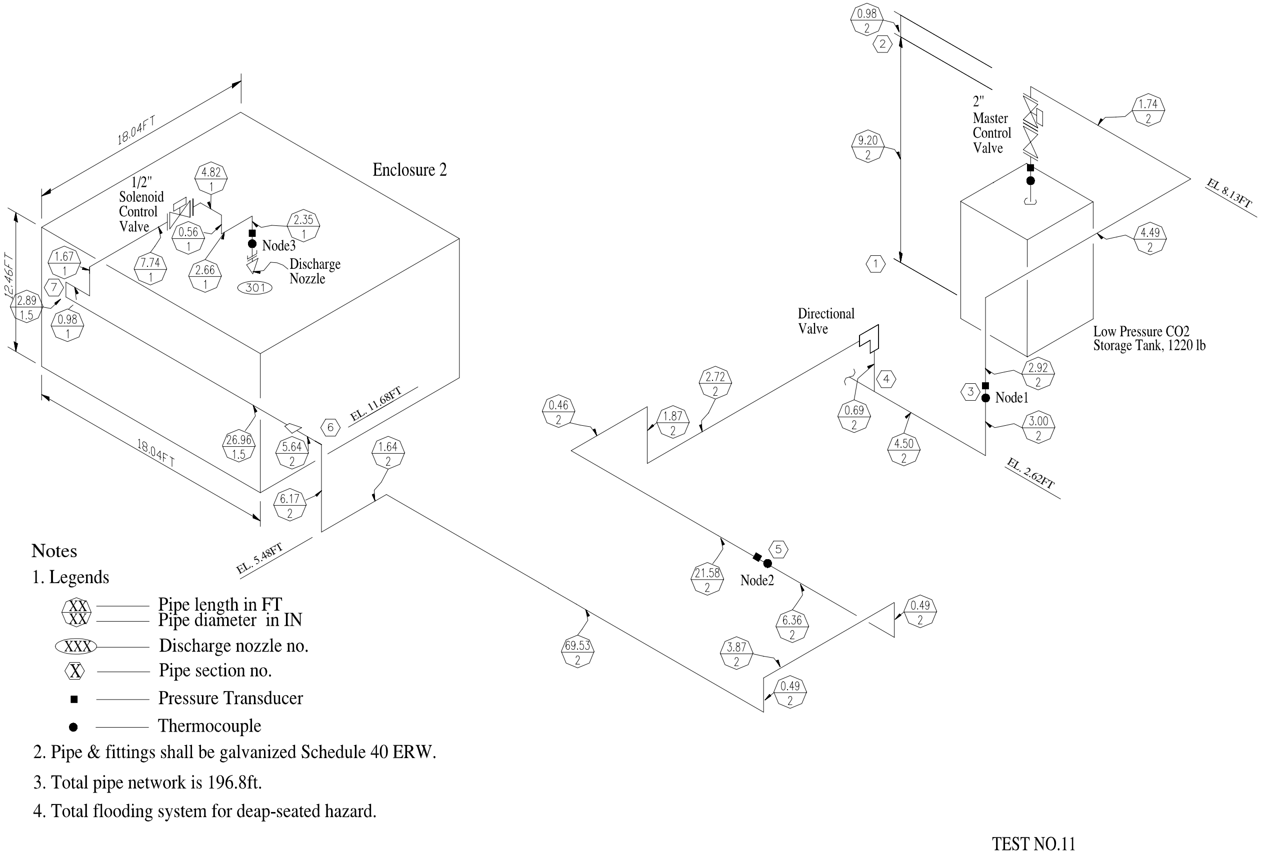
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 164ft.

4. Total flooding system for deap-seated hazard.

TEST NO.10

Figure III-10. Isometric Piping Diagram for Test No. 10



Notes

1. Legends

XX / XX —— Pipe length in FT / Pipe diameter in IN

XXX —— Discharge nozzle no.

X —— Pipe section no.

■ —— Pressure Transducer

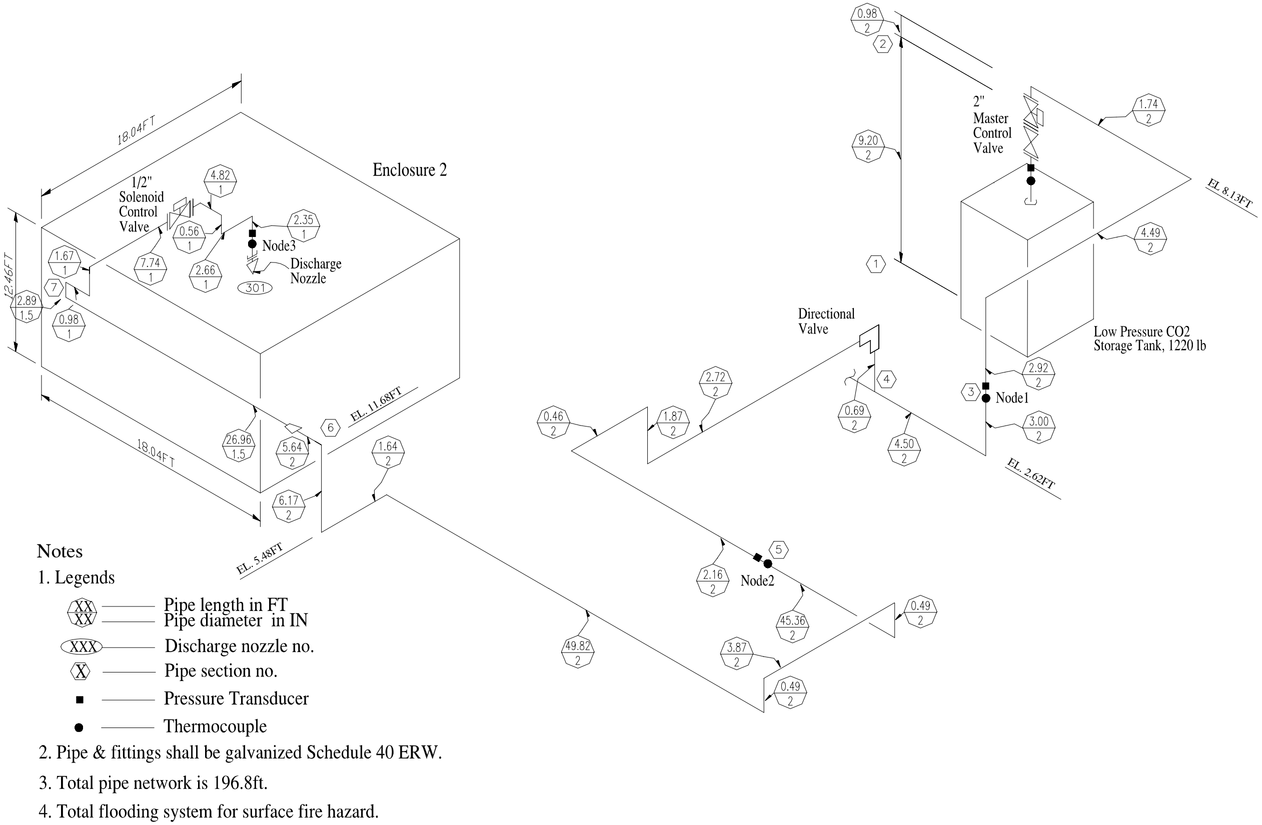
● —— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 196.8ft.

4. Total flooding system for deap-seated hazard.

Figure III-11. Isometric Piping Diagram for Test No. 11



Notes

1. Legends

XX / XX ——— Pipe length in FT / Pipe diameter in IN

XXX ——— Discharge nozzle no.

X ——— Pipe section no.

■ ——— Pressure Transducer

● ——— Thermocouple

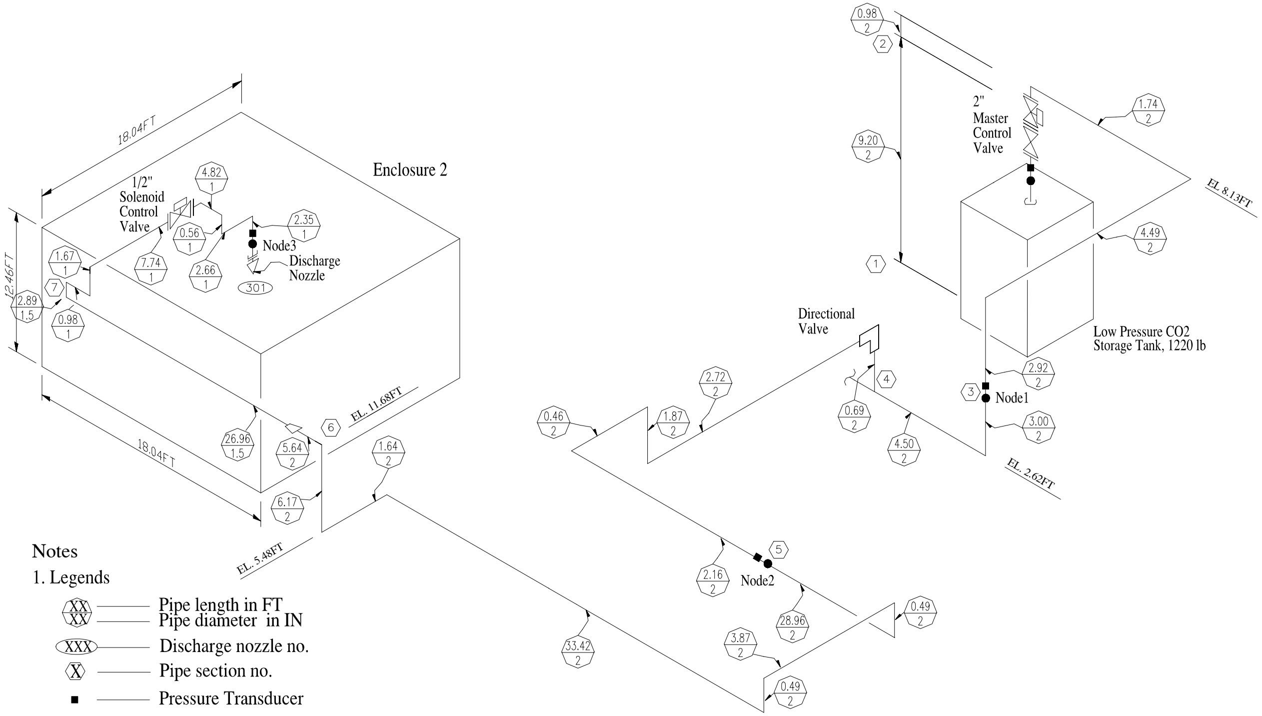
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 196.8ft.

4. Total flooding system for surface fire hazard.

TEST NO.12

Figure III-12. Isometric Piping Diagram for Test No. 12



Notes

1. Legends

XX / XX	Pipe length in FT Pipe diameter in IN
XXX	Discharge nozzle no.
X	Pipe section no.
■	Pressure Transducer
●	Thermocouple

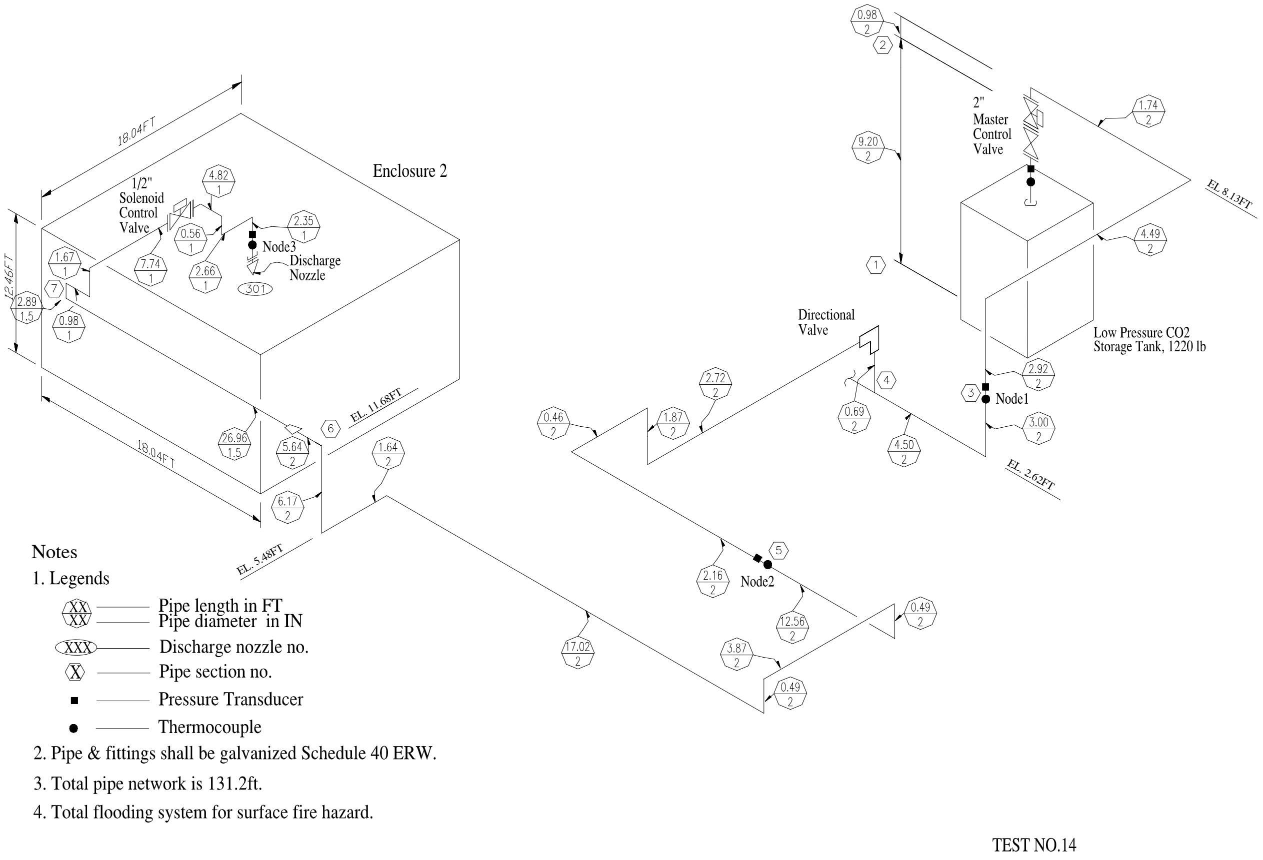
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 164ft.

4. Total flooding system for surface fire hazard.

TEST NO.13

Figure III-13. Isometric Piping Diagram for Test No. 13



Notes

1. Legends

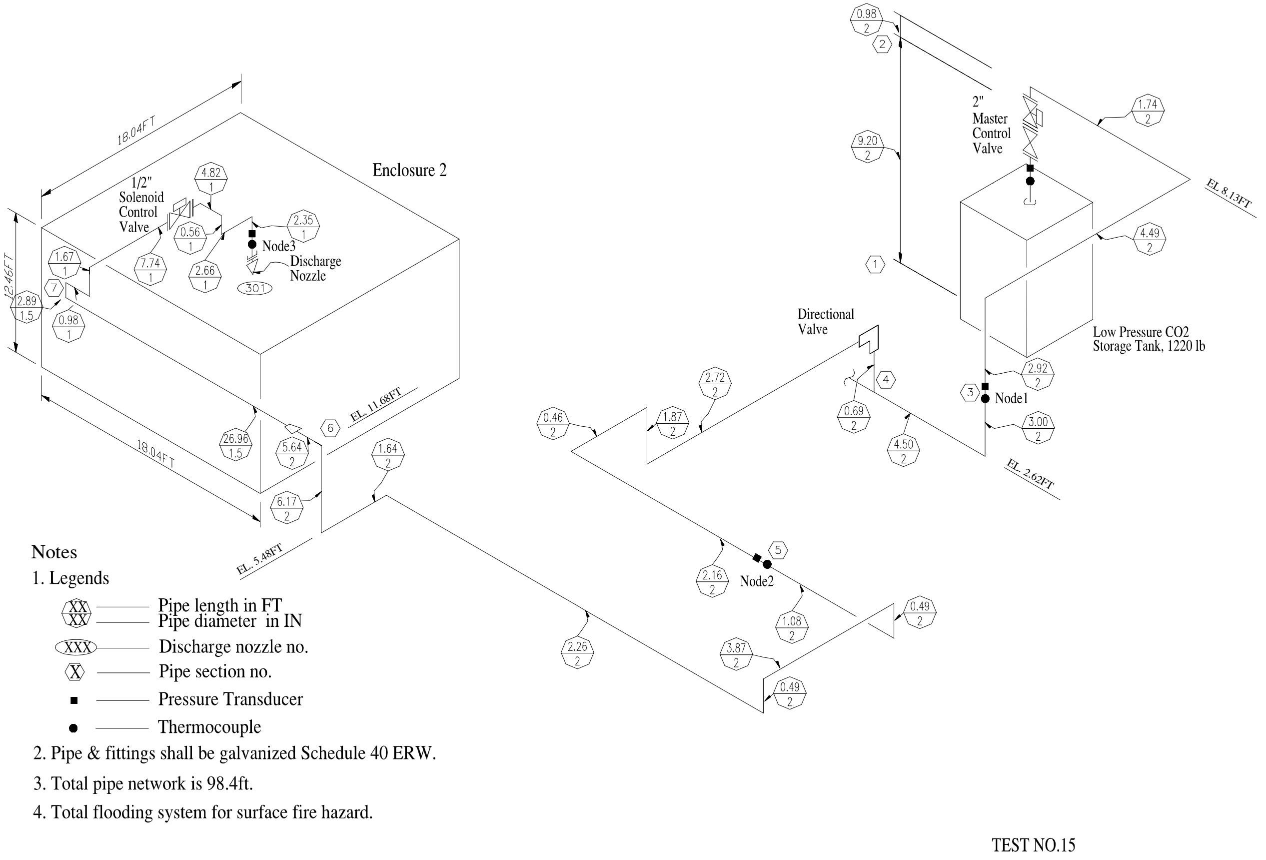
XX / XX	Pipe length in FT / Pipe diameter in IN
XXX	Discharge nozzle no.
X	Pipe section no.
■	Pressure Transducer
●	Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 131.2ft.

4. Total flooding system for surface fire hazard.

Figure III-14. Isometric Piping Diagram for Test No. 14



Notes

1. Legends

XX / XX —— Pipe length in FT / Pipe diameter in IN

XXX —— Discharge nozzle no.

X —— Pipe section no.

■ —— Pressure Transducer

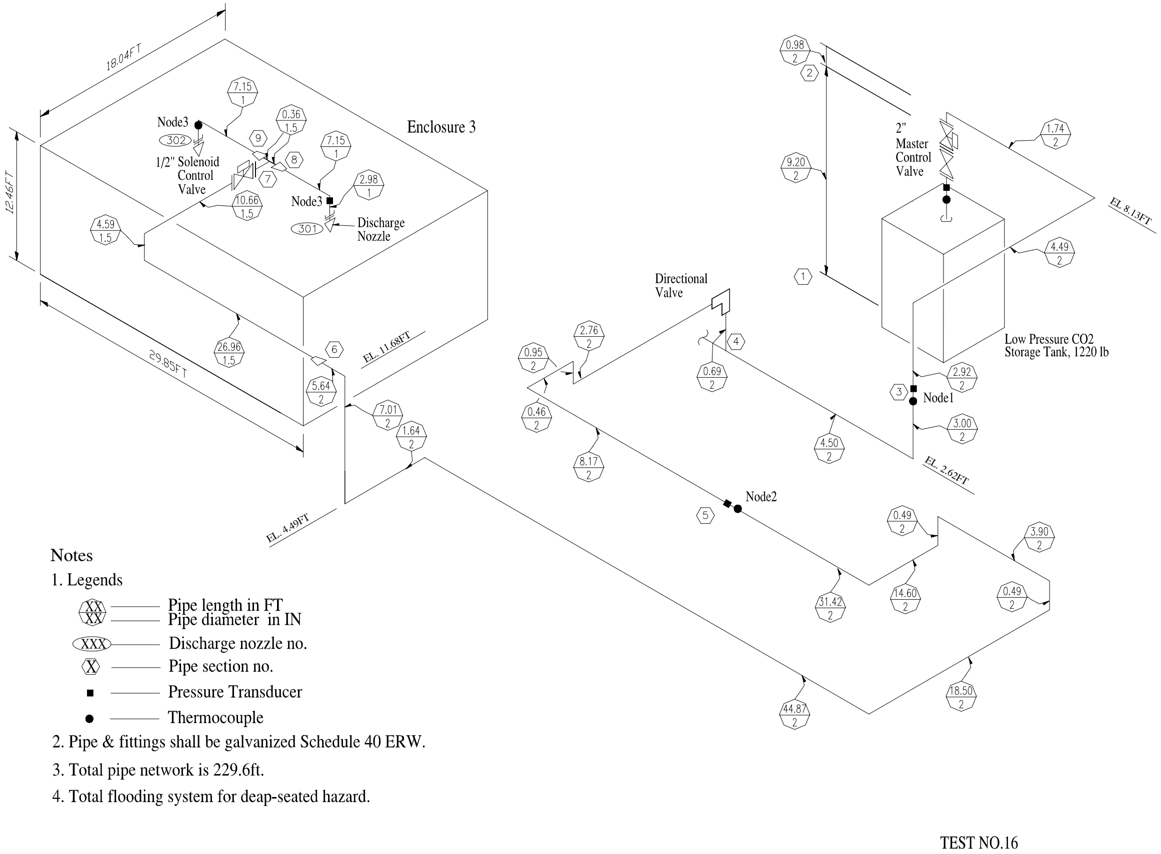
● —— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 98.4ft.

4. Total flooding system for surface fire hazard.

Figure III-15. Isometric Piping Diagram for Test No. 15



Notes

1. Legends

XX / XX ——— Pipe length in FT / Pipe diameter in IN

XXX ——— Discharge nozzle no.

X ——— Pipe section no.

■ ——— Pressure Transducer

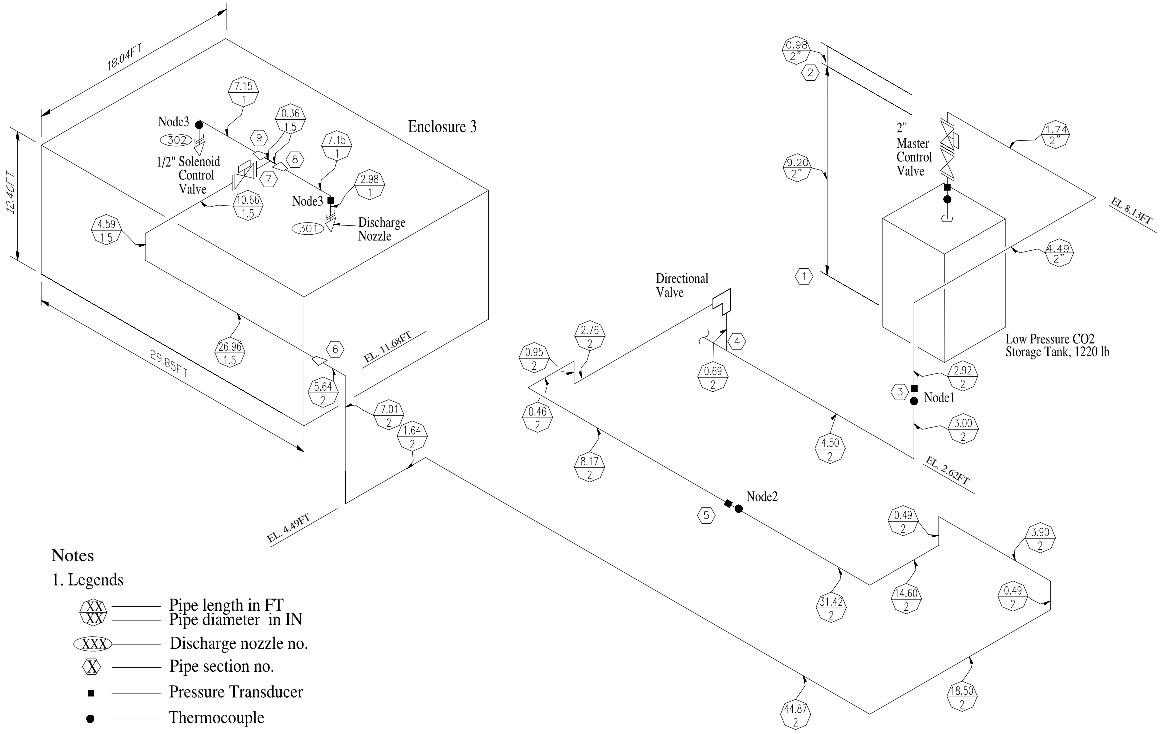
● ——— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 229.6ft.

4. Total flooding system for deap-seated hazard.

Figure III-16. Isometric Piping Diagram for Test No. 16



Notes

1. Legends

- ⬡XX/XX ——— Pipe length in FT / Pipe diameter in IN
- (XXX) ——— Discharge nozzle no.
- ⬡X ——— Pipe section no.
- ■ ——— Pressure Transducer
- ● ——— Thermocouple

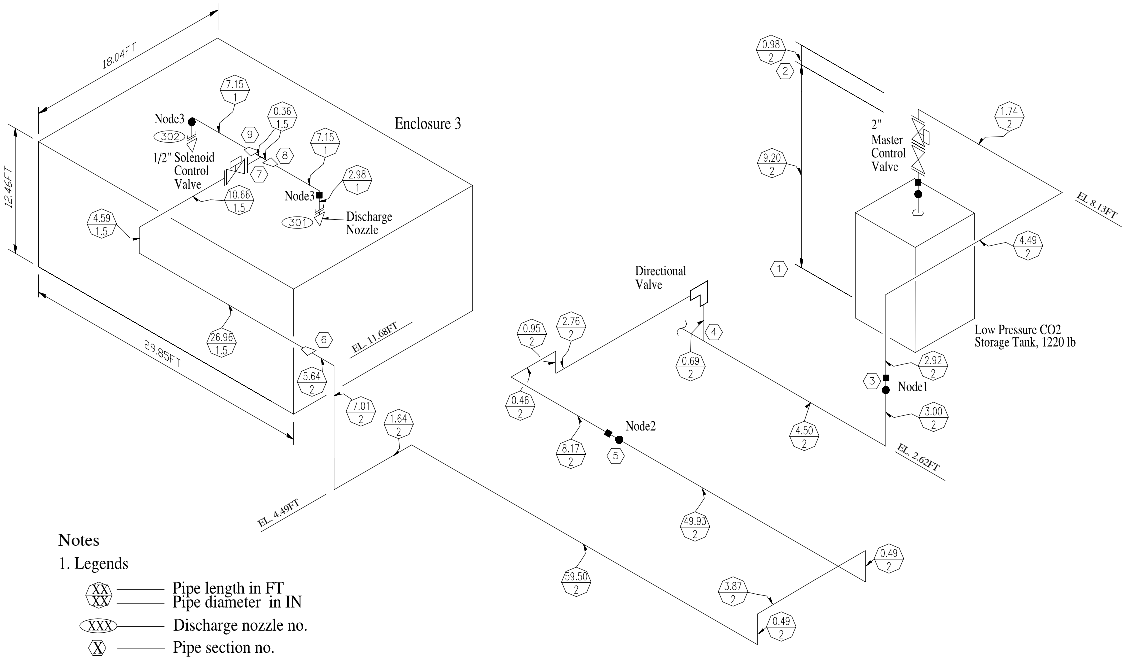
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 262.4ft.

4. Total flooding system for deap-seated hazard.

TEST NO.17

Figure III-17. Isometric Piping Diagram for Test No. 17



Notes

1. Legends

XX/XX ——— Pipe length in FT / Pipe diameter in IN

XXX ——— Discharge nozzle no.

X ——— Pipe section no.

■ ——— Pressure Transducer

● ——— Thermocouple

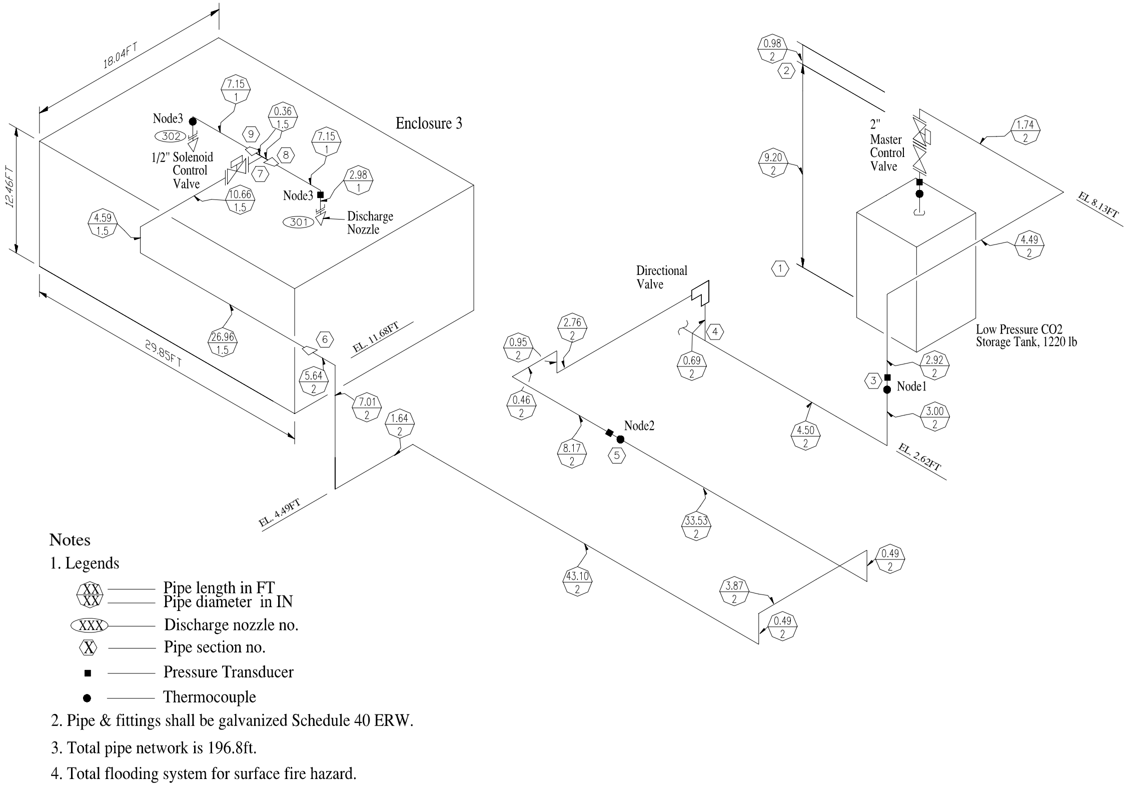
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 229.6ft.

4. Total flooding system for surface fire hazard.

TEST NO.18

Figure III-18. Isometric Piping Diagram for Test No. 18



Notes

1. Legends

- XX/XX ——— Pipe length in FT / Pipe diameter in IN
- XXX ——— Discharge nozzle no.
- X ——— Pipe section no.
- ■ ——— Pressure Transducer
- ● ——— Thermocouple

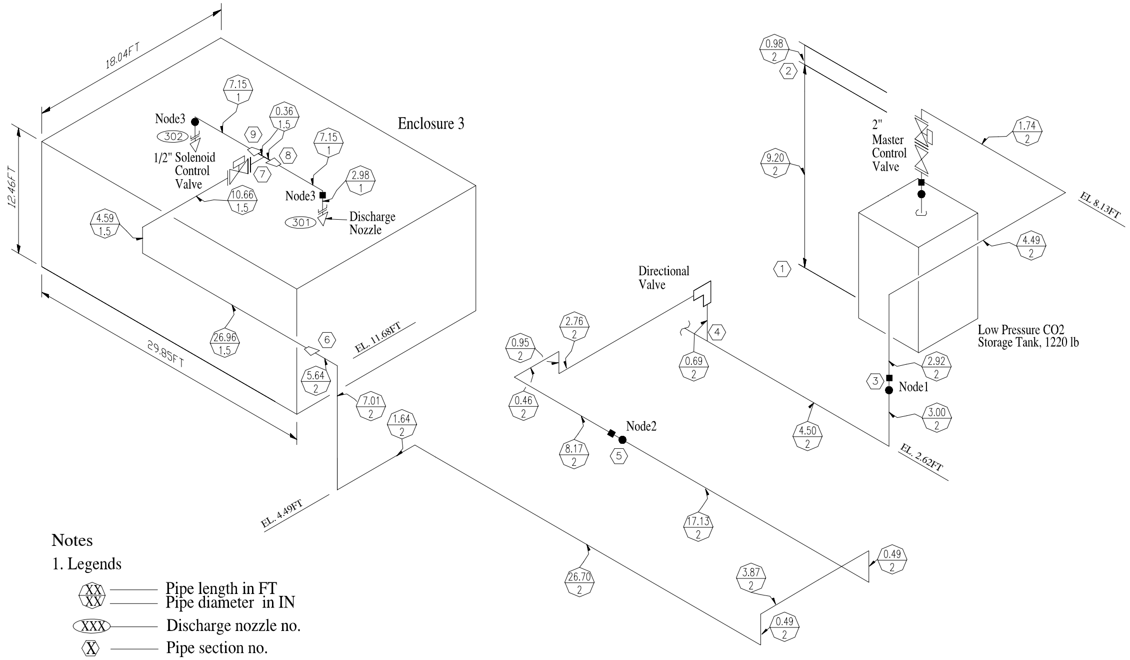
2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 196.8ft.

4. Total flooding system for surface fire hazard.

TEST NO.19

Figure III-19. Isometric Piping Diagram for Test No. 19



Notes

1. Legends

XX ——— Pipe length in FT
XX ——— Pipe diameter in IN
XXX ——— Discharge nozzle no.
X ——— Pipe section no.
■ ——— Pressure Transducer
● ——— Thermocouple

2. Pipe & fittings shall be galvanized Schedule 40 ERW.

3. Total pipe network is 164ft.

4. Total flooding system for surface fire hazard.

TEST NO.20

Figure III-20. Isometric Piping Diagram for Test No. 20

Appendix IV – Computerized Flow Calculation

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 1 for deep seated fire in enclosure 1.lp2
TR1 D L

REMARKS: Total Pipe Network Length is 501.8ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 100 lbs
17 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	40.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	40.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	40.0
4	5	1 -WLD 40	20.7	50.8	4.5		297	295	40.0
5	6	1 -WLD 40	429.0	443.5	0.2		295	293	40.0
6	301	1/2 -WLD 40	27.4	37.6	3.2		293	289	40.0

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	4.3	100	190	55	245

Calculated total carbon dioxide discharge is 100 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:39:49
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:39:52

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 2 for deep seated fire in enclosure 1.lp2
TR1 D L

REMARKS: Total Pipe Network Length is 229.6ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 100 lbs
53 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	40.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	40.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	40.0
4	5	1 -WLD 40	20.7	50.8	4.5		297	295	40.0
5	6	1 -WLD 40	157.2	171.7	0.2		295	295	40.0
6	301	1/2 -WLD 40	27.4	37.6	3.2		295	291	40.0

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	4.2	100	81	109	190

Calculated total carbon dioxide discharge is 100 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:34:11
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:34:13

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 3 for deep seated fire in enclosure 1.lp2
TR1 D L

REMARKS: Total Pipe Network Length is 164ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 100 lbs
60 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	40.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	40.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	40.0
4	5	1 -WLD 40	20.7	50.8	4.5		297	295	40.0
5	6	1 -WLD 40	91.9	106.4	0.2		295	295	40.0
6	301	1/2 -WLD 40	27.4	37.6	3.2		295	291	40.0

Calculation based on 66 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	4.2	100	59	122	180

Calculated total carbon dioxide discharge is 100 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:40:03
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:40:06

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 4 for deep seated fire in enclosure 1.lp2
TR1 D L

REMARKS: Total Pipe Network Length is 131.2ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 100 lbs
64 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	40.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	40.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	40.0
4	5	1 -WLD 40	20.7	50.8	4.5		297	295	40.0
5	6	1 -WLD 40	59.1	73.6	0.2		295	295	40.0
6	301	1/2 -WLD 40	27.4	37.6	3.2		295	291	40.0

Calculation based on 66 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	4.2	100	48	126	175

Calculated total carbon dioxide discharge is 100 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:34:26
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:34:28

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 5 for deep seated fire in enclosure 1.lp2
TR1 D L

REMARKS: Total Pipe Network Length is 98.4ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 100 lbs
67 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	40.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	40.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	40.0
4	5	1 -WLD 40	20.7	50.8	4.5		297	295	40.0
5	6	1 -WLD 40	26.2	40.7	0.2		295	295	40.0
6	301	1/2 -WLD 40	27.4	37.6	3.2		295	291	40.0

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	4.2	100	39	131	170

Calculated total carbon dioxide discharge is 100 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:40:14
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:40:17

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 6 for surface burning fire in enclosure 1.lp2
TR1.S.L

REMARKS: Total Pipe Network Length is 131.2ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 63 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	81.7
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	81.7
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	81.7
4	5	1 -WLD 40	16.7	45.4	3.5		297	294	81.7
5	6	1 -WLD 40	65.6	72.2	1.2		294	293	81.7
6	301	1/2 -WLD 40	24.1	33.3	3.2		293	277	81.7

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	6.9	63	28	33	60

Calculated total carbon dioxide discharge is 63 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:34:40
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:34:43

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 7 for surface burning fire in enclosure 1.lp2
TR1.S.L

REMARKS: Total Pipe Network Length is 98.4ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 63 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	77.2
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	77.2
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	77.2
4	5	1 -WLD 40	16.7	45.4	3.5		297	296	77.2
5	6	1 -WLD 40	32.8	39.4	1.2		296	296	77.2
6	301	1/2 -WLD 40	24.1	33.3	3.2		296	282	77.2

Calculation based on 70 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	6.4	63	21	39	60

Calculated total carbon dioxide discharge is 63 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:40:26
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:40:29

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 8 for surface burning fire in enclosure 1.lp2
TR1.S.L

REMARKS: Total Pipe Network Length is 65.6ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 63 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	72.7
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	72.7
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	72.7
4	5	1 -WLD 40	16.7	45.4	3.5		297	296	72.7
5	6	1 -WLD 40	1.6	8.2	1.2		296	296	72.7
6	301	1/2 -WLD 40	24.1	33.3	3.2		296	284	72.7

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1/2 -WLD 40	6.1	63	16	45	60

Calculated total carbon dioxide discharge is 63 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:34:57
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:34:59

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 9 for deep seated fire in enclosure 2.lp2
Tr2. D.L

REMARKS: Tota; Pipe Network Length is 131.2ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 336 lbs
215 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	121.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	121.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	121.0
4	5	2 -WLD 40	27.3	84.0	2.6		297	296	121.0
5	6	2 -WLD 40	28.5	75.7	6.2		296	293	121.0
6	7	1 1/2-WLD 40	29.9	33.9	2.9		293	292	121.0
7	301	1 -WLD 40	20.8	42.2	-1.2		292	289	121.0

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	7.5	336	27	153	180

Calculated total carbon dioxide discharge is 336 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:40:43
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:40:45

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 10 for deep seated fire in enclosure 2.lp2
Tr2. D.L

REMARKS: Tota; Pipe Network Length is 164ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 336 lbs
207 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	121.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	121.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	121.0
4	5	2 -WLD 40	27.3	84.0	2.6		297	296	121.0
5	6	2 -WLD 40	61.4	108.6	6.2		296	293	121.0
6	7	1 1/2-WLD 40	29.9	33.9	2.9		293	292	121.0
7	301	1 -WLD 40	20.8	42.2	-1.2		292	289	121.0

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	7.5	336	35	149	184

Calculated total carbon dioxide discharge is 336 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:35:19
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:35:22

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 11 for deep seated fire in enclosure 2.lp2
Tr2. D.L

REMARKS: Tota; Pipe Network Length is 196.8ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 336 lbs
199 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	121.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	121.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	121.0
4	5	2 -WLD 40	27.3	84.0	2.6		297	296	121.0
5	6	2 -WLD 40	94.2	141.4	6.2		296	293	121.0
6	7	1 1/2-WLD 40	29.9	33.9	2.9		293	292	121.0
7	301	1 -WLD 40	20.8	42.2	-1.2		292	289	121.0

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	7.5	336	43	145	188

Calculated total carbon dioxide discharge is 336 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-07 오전 9:24:47
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-07 Time: 오전 9:24:50

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 12 for surface burning fire in enclosure 2.lp2
Tr2. S.L

REMARKS: Total Pipe Network Length is 196.8ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 227 lbs

Pressure Drop Results

```
Sec    Sec       Nominal    Length   Equiv       Elev   Tee/     Start   Term    Flow
Start  End       Pipe Size  (ft)     Length(ft)  (ft)   Mfld     psi     psi     (lbs/min)

 1      2      2 -WLD 40     9.2     18.2        7.2   Header   300     297     285.6
 2      3      2 -WLD 40    10.1     26.6       -1.9   Header   297     297     285.6
 3      4      2 -WLD 40     7.5     12.7       -3.0   Header   297     297     285.6
 4      5      2 -WLD 40     7.9     28.6        2.6            297     296     285.6
 5      6      2 -WLD 40   113.5    156.7        6.2            296     291     285.6

 6      7    1 1/2-WLD 40   29.9     33.9        2.9            291     288     285.6
 7    301      1 -WLD 40    20.8     42.2       -1.2            288     272     285.6
```

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

```
Nozzle      Nominal     Nozzle  Weight (lbs)  Initial Vapor  Liquid       End of Discharge
Number      Pipe Size   Code    Discharged    Time (sec)     Time (sec)   Time (sec)
 301      1 -WLD 40     13.4        227           25            35             60
```

Calculated total carbon dioxide discharge is 227 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:35:41
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:35:43

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 13 for surface burning fire in enclosure 2.lp2
Tr2. S.L

REMARKS: Total Pipe Network Length is 164ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 227 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	260.3
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	260.3
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	260.3
4	5	2 -WLD 40	7.9	28.6	2.6		297	296	260.3
5	6	2 -WLD 40	80.7	123.9	6.2		296	293	260.3
6	7	1 1/2-WLD 40	29.9	33.9	2.9		293	292	260.3
7	301	1 -WLD 40	20.8	42.2	-1.2		292	278	260.3

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	12.2	227	16	44	60

Calculated total carbon dioxide discharge is 227 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:35:51
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:35:53

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 14 for surface burning fire in enclosure 2.lp2
Tr2. S.L

REMARKS: Total Pipe Network Length is 131.2ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 227 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	253.4
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	253.4
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	253.4
4	5	2 -WLD 40	7.9	28.6	2.6		297	296	253.4
5	6	2 -WLD 40	47.9	91.1	6.2		296	293	253.4
6	7	1 1/2-WLD 40	29.9	33.9	2.9		293	292	253.4
7	301	1 -WLD 40	20.8	42.2	-1.2		292	279	253.4

Calculation based on 66 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	12.0	227	12	48	60

Calculated total carbon dioxide discharge is 227 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:35:59
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:36:01

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 15 for surface burning fire in enclosure 2.lp2
Tr2. S.L

REMARKS: Total Pipe Network Length is 98.4ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 227 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	246.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	246.0
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	246.0
4	5	2 -WLD 40	7.9	28.6	2.6		297	296	246.0
5	6	2 -WLD 40	15.1	58.3	6.2		296	293	246.0
6	7	1 1/2-WLD 40	29.9	33.9	2.9		293	292	246.0
7	301	1 -WLD 40	20.8	42.2	-1.2		292	281	246.0

Calculation based on 66 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	11.6	227	9	51	60

Calculated total carbon dioxide discharge is 227 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:36:06
Calculation by SH Engineering
Lee, Sung-mo

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Fax: --
2004-01-14 Time: 오전 8:36:09

1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 16 for deep seated fire in enclosure 3.lp2
TR3.D.L555

REMARKS: Total Pipe Network Length is 229.6ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 557 lbs
373 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	224.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	224.0
3	4	2 -WLD 40	7.5	12.7	3.0	Header	297	296	224.0
4	5	2 -WLD 40	13.1	65.8	1.6		296	295	224.0
5	6	2 -WLD 40	128.6	215.1	7.0		295	290	224.0
6	7	1 1/2-WLD 40	42.2	63.3	4.6		290	286	224.0
7	8	1 1/2-WLD 40	0.4	8.5	0.0	BHT	286	286	112.0
8	301	1 -WLD 40	10.1	12.7	-3.0		286	286	112.0
7	9	1 1/2-WLD 40	0.4	8.5	0.0	BHT	286	286	112.0
9	302	1 -WLD 40	10.1	12.7	-3.0		286	286	112.0

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	7.4	278	40	129	169
302	1 -WLD 40	7.4	278	40	129	169

Calculated total carbon dioxide discharge is 557 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:36:15

1 (Continued)

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 17 for deep seated fire in enclosure 3.lp2
TR3.D.L555

REMARKS: Total Pipe Network Length is 262.4ft
Engineering units (ft, lbs, psia) are specified
Total flooding system for Deep Seated hazard
Flow rate is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 557 lbs
366 lbs discharged during first two minutes of flow

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	224.0
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	224.0
3	4	2 -WLD 40	7.5	12.7	3.0	Header	297	296	224.0
4	5	2 -WLD 40	13.1	65.8	1.6		296	295	224.0
5	6	2 -WLD 40	161.4	247.9	7.0		295	290	224.0
6	7	1 1/2-WLD 40	42.2	63.3	4.6		290	286	224.0
7	8	1 1/2-WLD 40	0.4	8.5	0.0	BHT	286	286	112.0
8	301	1 -WLD 40	10.1	12.7	-3.0		286	286	112.0
7	9	1 1/2-WLD 40	0.4	8.5	0.0	BHT	286	286	112.0
9	302	1 -WLD 40	10.1	12.7	-3.0		286	286	112.0

Calculation based on 70 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	7.4	279	44	127	171
302	1 -WLD 40	7.4	279	44	127	171

Calculated total carbon dioxide discharge is 557 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:36:22

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 18 for surface burning fire in enclosure 3.lp2
TR3.S.L

REMARKS: Total Pipe Network Length is 229.6ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 336 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	390.8
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	390.8
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	390.8
4	5	2 -WLD 40	13.0	65.7	1.6		297	294	390.8
5	6	2 -WLD 40	128.6	171.8	7.0		294	289	390.8
6	7	1 1/2-WLD 40	42.2	55.3	4.6		289	284	390.8
7	8	1 1/2-WLD 40	0.4	8.5	0.0	BHT	284	284	195.4
8	301	1 -WLD 40	10.1	12.7	-3.0		284	281	195.4
7	9	1 1/2-WLD 40	0.4	8.5	0.0	BHT	284	284	195.4
9	302	1 -WLD 40	10.1	12.7	-3.0		284	281	195.4

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	10.4	168	17	43	60
302	1 -WLD 40	10.4	168	17	43	60

Calculated total carbon dioxide discharge is 336 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:36:30
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:36:32
1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 19 for surface burning fire in enclosure 3.lp2
TR3.S.L

REMARKS: Total Pipe Network Length is 196.8ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 336 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	385.4
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	385.4
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	385.4
4	5	2 -WLD 40	13.0	65.7	1.6		297	296	385.4
5	6	2 -WLD 40	95.8	139.0	7.0		296	290	385.4
6	7	1 1/2-WLD 40	42.2	55.3	4.6		290	285	385.4
7	8	1 1/2-WLD 40	0.4	8.5	0.0	BHT	285	285	192.7
8	301	1 -WLD 40	10.1	12.7	-3.0		285	282	192.7
7	9	1 1/2-WLD 40	0.4	8.5	0.0	BHT	285	285	192.7
9	302	1 -WLD 40	10.1	12.7	-3.0		285	282	192.7

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	10.2	168	16	44	60
302	1 -WLD 40	10.2	168	16	44	60

Calculated total carbon dioxide discharge is 336 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:36:38
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:36:40
1 End of Printout

LP CO2 FLOW CALCULATIONS

Version 2. 3. 0

Data input file name: C:\Test No 20 for surface burning fire in enclosure 3.lp2
TR3.S.L

REMARKS: Total Pipe Network Length is 164ft
Engineering units (ft, lbs, psia) are specified
Total flooding system
Quantity of carbon dioxide is specified for each nozzle

Agent Storage Conditions

Nominal Storage Pressure is 300 psi at 0 degrees Fahrenheit
Low pressure storage unit capacity is 1220 lbs of carbon dioxide
Calculated total carbon dioxide discharge is 336 lbs

Pressure Drop Results

Sec Start	Sec End	Nominal Pipe Size	Length (ft)	Equiv Length(ft)	Elev (ft)	Tee/ Mfld	Start psi	Term psi	Flow (lbs/min)
1	2	2 -WLD 40	9.2	18.2	7.2	Header	300	297	377.5
2	3	2 -WLD 40	10.1	26.6	-1.9	Header	297	297	377.5
3	4	2 -WLD 40	7.5	12.7	-3.0	Header	297	297	377.5
4	5	2 -WLD 40	13.0	65.7	1.6		297	296	377.5
5	6	2 -WLD 40	63.0	106.2	7.0		296	292	377.5
6	7	1 1/2-WLD 40	42.2	55.3	4.6		292	286	377.5
7	8	1 1/2-WLD 40	0.4	8.5	0.0	BHT	286	286	188.7
8	301	1 -WLD 40	10.1	12.7	-3.0		286	285	188.7
7	9	1 1/2-WLD 40	0.4	8.5	0.0	BHT	286	286	188.7
9	302	1 -WLD 40	10.1	12.7	-3.0		286	285	188.7

Calculation based on 68 degree Fahrenheit pre-discharge Pipeline Temperature

Nozzle Performance Summary

Nozzle Number	Nominal Pipe Size	Nozzle Code	Weight (lbs) Discharged	Initial Vapor Time (sec)	Liquid Time (sec)	End of Discharge Time (sec)
301	1 -WLD 40	9.8	168	12	47	60
302	1 -WLD 40	9.8	168	12	47	60

Calculated total carbon dioxide discharge is 336 lbs

Messages

Hydraulic calculation was successful.
Calculation performed on 2004-01-14 오전 8:36:45
Calculation by SH Engineering
Lee, Sung-mo

Telephone: --
Fax: --
2004-01-14 Time: 오전 8:36:48
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Appendix V - Test Report

Test No	Amb Temp	Pressure					Concentration				Extinguishment	
		Node No	Calculation (psig) [d]	Permissible Range(±10%)	Test (psig)	Judgement	Calculation (%)	Permissible Range(±10%)	Test (%)	Judgement	Within 600sec [e]	Within 30sec [e]
1	68°F	1	282	253.8~310.2	96	Not Acceptable	27.22 [a]	24.50~51.31	11.87	Not Acceptable	Extinguished but Re-ignition	N/A
		2	280	252.0~308.0	92	Not Acceptable						
		3	274	246.6~301.4	43	Not Acceptable	46.65 [b]	41.98~51.31	41.23	Not Acceptable	Extinguished but Re-ignition	N/A
2	68°F	1	282	253.8~310.2	277	Acceptable	27.22 [a]	24.50~51.31	32.91	Acceptable	Extinguished and No Ignition	N/A
		2	280	252.0~308.0	275	Acceptable						
		3	276	248.4~303.6	233	Not Acceptable	46.65 [b]	41.98~51.31	42.02	Acceptable	Extinguished and No Ignition	N/A
3	66°F	1	282	253.8~310.2	277	Acceptable	27.10 [a]	24.39~51.03	32.88	Acceptable	Extinguished and No Ignition	N/A
		2	280	252.0~308.0	277	Acceptable						
		3	276	248.4~303.6	242	Not Acceptable	46.57 [b]	41.91~51.23	43.62	Acceptable	Extinguished and No Ignition	N/A
4	66°F	1	282	253.8~310.2	279	Acceptable	27.10 [a]	24.39~51.03	32.73	Acceptable	Extinguished and No Ignition	N/A
		2	280	252.0~308.0	276	Acceptable						
		3	276	248.4~303.6	242	Not Acceptable	46.57 [b]	41.91~51.23	45.02	Acceptable	Extinguished and No Ignition	N/A

Test No	Amb Temp	Pressure					Concentration				Extinguishment	
		Node No	Calculation (psig) [d]	Permissible Range(±10%)	Test (psig)	Judgement	Calculation (%)	Permissible Range(±10%)	Test (%)	Judgement	Within 600sec [e]	Within 30sec [e]
5	68°F	1	282	253.8~310.2	283	Acceptable	27.22 [a]	24.50~51.31	32.79	Acceptable	Extinguished and No Ignition	N/A
		2	280	252.0~308.0	282	Acceptable						
		3	276	248.4~303.6	256	Acceptable	46.65 [b]	41.98~51.31	46.43	Acceptable	Extinguished and No Ignition	N/A
6	68°F	1	282	253.8~310.2	277	Acceptable	35.52 [c]	31.97~39.07	33.53	Acceptable	N/A	Extinguished
		2	279	251.1~306.9	272	Acceptable						
		3	260	234.0~286.0	230	Not Acceptable						
7	70°F	1	282	253.8~310.2	277	Acceptable	35.60 [c]	32.04~39.16	34.96	Acceptable	N/A	Extinguished
		2	281	252.9~309.1	276	Acceptable						
		3	267	240.3~293.7	235	Not Acceptable						
8	68°F	1	282	253.8~310.2	279	Acceptable	35.52 [c]	31.97~39.07	35.12	Acceptable	N/A	Extinguished
		2	281	252.9~309.1	276	Acceptable						
		3	269	242.1~295.9	260	Acceptable						
9	68°F	1	282	253.8~310.2	277	Acceptable	27.22 [a]	24.50~46.27	33.02	Acceptable	Extinguished and No Ignition	N/A
		2	281	252.9~309.1	275	Acceptable						
		3	274	246.6~301.4	255	Acceptable	42.06 [b]	37.85~46.27	39.43	Acceptable	Extinguished and No Ignition	N/A

Test No	Amb Temp	Pressure					Concentration				Extinguishment	
		Node No	Calculation (psig) [d]	Permissible Range(±10%)	Test (psig)	Judgement	Calculation (%)	Permissible Range(±10%)	Test (%)	Judgement	Within 600sec [e]	Within 30sec [e]
10	68°F	1	282	253.8~310.2	279	Acceptable	27.22 [a]	24.50~46.27	32.75	Acceptable	Extinguished and No Ignition	N/A
		2	281	252.9~309.1	273	Acceptable						
		3	274	246.6~301.4	248	Acceptable	42.06 [b]	37.85~46.27	40.45	Acceptable	Extinguished and No Ignition	N/A
11	68°F	1	282	253.8~310.2	277	Acceptable	27.22 [a]	24.50~46.27	33.41	Acceptable	Extinguished and No Ignition	N/A
		2	281	252.9~309.1	276	Acceptable						
		3	274	246.6~301.4	238	Not Acceptable	42.06 [b]	37.85~46.27	41.21	Acceptable	Extinguished and No Ignition	N/A
12	68°F	1	282	253.8~310.2	277	Acceptable	32.87 [c]	29.58~36.16	32.09	Acceptable	N/A	Extinguished
		2	281	252.9~309.1	276	Acceptable						
		3	267	240.3~293.7	199	Not Acceptable						
13	68°F	1	282	253.8~310.2	277	Acceptable	32.87 [c]	29.58~36.16	33.31	Acceptable	N/A	Extinguished
		2	281	252.9~309.1	275	Acceptable						
		3	263	236.7~289.3	208	Not Acceptable						
14	66°F	1	282	253.8~310.2	279	Acceptable	32.80 [c]	29.52~36.08	33.98	Acceptable	N/A	Extinguished
		2	281	252.9~309.1	276	Acceptable						
		3	264	237.6~290.4	213	Not Acceptable						

Test No	Amb Temp	Pressure					Concentration				Extinguishment	
		Node No	Calculation (psig)[d]	Permissible Range(±10%)	Test (psig)	Judgement	Calculation (%)	Permissible Range(±10%)	Test (%)	Judgement	Within 600sec[e]	Within 30sec[e]
15	66°F	1	282	253.8~310.2	283	Acceptable	32.80[c]	29.52~36.08	34.16	Acceptable	N/A	Extinguished
		2	281	252.9~309.1	283	Acceptable						
		3	266	239.4~292.6	240	Acceptable						
16	68°F	1	282	253.8~310.2	275	Acceptable	27.22[a]	24.50~46.27	32.51	Acceptable	Extinguished and No Ignition	N/A
		2	280	252.0~308.0	274	Acceptable						
		3	271	243.9~298.1	249	Acceptable	42.06[b]	37.85~46.27	40.13	Acceptable	Extinguished and No Ignition	N/A
17	70°F	1	282	253.8~310.2	275	Acceptable	27.30[a]	24.57~46.35	32.99	Acceptable	Extinguished and No Ignition	N/A
		2	280	252.0~308.0	273	Acceptable						
		3	271	243.9~298.1	242	Not Acceptable	42.14[b]	37.93~46.35	41.77	Acceptable	Extinguished and No Ignition	N/A
18	68°F	1	282	253.8~310.2	279	Acceptable	30.42[c]	27.38~33.46	29.88	Acceptable	N/A	Extinguished
		2	279	251.1~306.9	275	Acceptable						
		3	266	239.4~292.6	236	Not Acceptable						
19	68°F	1	282	253.8~310.2	279	Acceptable	30.42[c]	27.38~33.46	30.25	Acceptable	N/A	Extinguished
		2	279	251.1~306.9	278	Acceptable						
		3	269	242.1~295.9	232	Not Acceptable						

Test No	Amb Temp	Pressure					Concentration				Extinguishment	
		Node No	Calculation (psig) [d]	Permissible Range(±10%)	Test (psig)	Judgement	Calculation (%)	Permissible Range(±10%)	Test (%)	Judgement	Within 600sec [e]	Within 30sec [e]
20	68°F	1	282	253.8~310.2	282	Acceptable	30.42 [c]	27.38~33.46	30.99	Acceptable	N/A	Extinguished
		2	281	252.9~309.1	277	Acceptable						
		3	270	243.0~297.0	247	Acceptable						

[a] Concentration achieved at 2 min in “no efflux” flooding of Table 5

[b] Concentration achieved at the end of discharge time in “no efflux” flooding of Table 5

[c] Concentration achieved at 1 min in “no efflux” flooding of Table5

[d] Term “psig” converted from the “psia” calculated in terminal pressure of Appendix IV

[e] Time after the end of system discharge

Appendix VI – Photographs of Test

Photograph 1. Test Enclosures

Photograph 2. Low Pressure CO2 Storage Container

Photograph 3. Directional Valve

Photograph 4. Discharge Pipes

Photograph 5. Inside of Enclosure

Photograph 6. CO2 Discharge into Enclosure