Alternative to Surge Chambers for Goldstone Water Supply Distribution

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When three of the six pressure-surge chambers in the Goldstone Water Supply Distribution System became inoperative, a study was undertaken to determine whether the surge chambers are a necessarily integral part of the system to safeguard against water hammering. An alternate cost effective method of safeguarding against this phenomenon was found, and is expected to be implemented in the system by the end of Calendar Year 1980.

I. Introduction

The Water Supply Distribution System (Ref. 1) at the Goldstone Deep Space Communications complex consists essentially of two supply lines. The source of the water supply is from the 3,800-m^3 (1,000,000-gallon) tank at Fort Irwin. Normally, water is pumped from this tank to an elevated 675-m^3 (177,000-gallon) tank at Venus Site. From Venus Site, water gravity feeds each tank at Echo Site, Apollo Site, Pioneer Site, and Mars Site. Water from Venus Site also gravity feeds the Microwave Test Facility (MTF) directly. If required, water from Fort Irwin could be selectively pumped into each site tank (Echo, Apollo, Pioneer and Mars) and/or supply MTF directly. Six pressure-surge chambers are installed (in groups of three) at the maximum operating pressures of 34 kg/cm^2 (450 psig) at the Fort Irwin pump house, and 5.5 kg/cm^2 (80 psig) at the Microwave Test Facility. Currently, one surge chamber at Fort Irwin, and two at the Microwave Test Facility are inoperative due to damaged internal rubber bladders.

The high repair and replacement costs of the damaged bladders, and technical considerations, prompted the effort to find an alternate means of handling water pressure surges.

II. Pressure Surge Chambers for Water Systems

Pressure surge chambers prevent "water hammer" in the pipeline. Water hammer is caused by either a sudden stoppage or a fast deceleration of the water flow in the pipeline. The instantaneous flow stoppage generates a pressure wave that propagates at the speed of sound, upstream from a valve (or blockage), until it reaches a larger diameter riser chamber (or tank); the pressure wave is then reflected back to the valve (or blockage) causing an increase in the line pressure. The pressure rise (dp) due to the hammer, however, can occur only if the stoppage time is equal to or less than $2L/a$ seconds; where L is the pipe length in meters (feet) and a is the pressure wave speed in water, having an average value of 1,220 m/s (4,000 ft/s).

III. Surge Pressures

Figure 1 shows two simple water systems consisting of a water tank, pipeline, and a shut-off valve. Figure 2 shows a steady-state system and Fig. 3 shows the instant when the valve was completely closed. At the instant of blockage, the water mass, immediately adjacent to the valve, decelerates to zero. The momentum (kinetic energy) of the water is converted to a pressure rise that, in turn, compresses the water and expands the pipe walls. The kinetic energy then sets up a pressure wave traveling upstream to the end of the pipe at sonic speed a of propagation. This pressure wave takes L/a seconds to reach the tank and $2L/a$ seconds to return back to the valve. This $2L/a$ turnaround time is referred to as "critical valve closing time"

The surge phenomenon (water hammer) repeats with decreasing pressure amplitudes until the total original kinetic energy is absorbed.

The pressure rise is given as (Refs. 2 and 3):

$$dP \simeq \frac{Wav}{10g} \text{ kg/cm}^2$$

where

W = specific weight of water (1 kg/l)

v = initial velocity of water in pipe (m/s)

a = pressure wave speed averaging (1220 m/s in water)

g = acceleration due to gravity (9.82 m/s/s)

Therefore,

$$dP \simeq \frac{1 \times 1220 \times v}{10 \times 9.82} \text{ kg/cm}^2$$

$$\simeq 12.42\, v \text{ kg/cm}^2$$

The maximum surge pressure (P_{max}), at the point of blockage, with a static pressure (P_s) is:

$$P_{max} = dP + P_s \text{ (kg/cm}^2\text{)}$$

The relationship of maximum surge pressures, occurring at a given static pressure with specific flow rates, is shown in Fig. 4. Figures 5 and 6 show the basic piping configuration at Goldstone. The Appendix shows the calculations for the specific flow condition under normal mode of operations. The flow rates of 0.76 m/s (2.5 ft/s) from Fort Irwin to Venus Site and 1.35 m/s (4.5 ft/s) from Venus Site to Microwave Test Facility (MTF) could create a maximum surge pressure of about 43 kg/cm^2 (615 psig) and 22.3 kg/cm^2 (320 psig), respectively. The adverse conditions when pumping suddenly stops (power failure) with maximum reversal of flow occurring when the check valve (or any valve) is shut within the $2L/a$ time period are shown in Figs. 47, 59, and 60 of Ref. 4. At a pressure head of about 300 m (1000 ft), a flow rate of about 2.9 m/s (9.5 ft/s) can be expected. At this rate, the flow when suddenly stopped could create a surge pressure of about 67.7 kg/cm^2 (970 psig) (Refs. 4 and 5).

IV. Surge Control

The maximum surge pressures are minimized with the use of three 200-1 (80-gal) pressure-surge chambers at each location. The pressure-surge chambers at Fort Irwin are designed for conditions up to 100 kg/cm^2 (1430 psig). At MTF, the design is for 34 kg/cm^2 (490 psig). The existing water supply distribution design arrangement at Goldstone has the following drawbacks:

(1) Expensive: six pressure vessels rather than four relief valves, and one short 2.5-cm (1-in.) diameter line and valves.

(2) System does not warrant such equipment for relieving pressure surges because of the difficulty in stopping the flows within the critical times.

(3) Difficult to check for equalizing air/nitrogen pressure in the surge chambers.

(4) Difficult to locate leakage.

(5) Cumbersome and difficult to repair and maintain.

(6) Apparent nonavailability of replacement parts because the manufacturer is out of business.

Methods that could be used to control the surge at Goldstone are:

(1) By gradually closing the valve, the chance of water hammer is minimized. This action slows the water flow (i.e., v is reduced); hence the maximum pressure ($P_{max} = P_s + dP$) is reduced.

(2) A controlled minimal by-pass or a relief valve could be used to dissipate the excessive surge pressures to the atmosphere or into a low-pressure reservoir.

(3) A combination of the above methods may be employed.

Before deciding on an alternate method to control surge, the causes of pressure surge should be identified. The typical causes are (1) quick closing plug valves (check valve), and hydro and pneumatic emergency control valves and (2) positive displacement pumping, intermittent pumping (partial loss of suction), and interrupted pumping (power failure).

Conditions that could trigger a pressure wave in the Goldstone Deep Space Communication Complex (GDSCC) Water Supply Distribution System are when the 15 cm or 20 cm (6 in. or 8 in.) gate valves in the system are shut off quickly, or during power failure when a reversal of flow from the Venus Site tank to the Fort Irwin pump house occurs, or when the surge control valve in the discharge line is suddenly closed. For the gate valves, the critical condition is that the valves must be shut within 8.0 seconds and 8.5 seconds at Venus Site and MTF, respectively, to create pressure waves. From a practical standpoint, it is manually impossible to completely shut the valves against the system normal flow rates within the critical time period to generate water hammering. When power failure occurs, the only energy momentarily available to drive the pumps in the forward direction at Fort Irwin is the kinetic energy due to the inertia of the rotating elements. As soon as the flow stops, reversal of flow occurs, and the check valve will instantaneously close. These rapid changes inside the line cause a series of water hammer waves that may result in a head rise at the check valve from 1.1 to 1.9 times the normal head pressure (Ref. 4). The intensity of the pressure waves depend on the time the check valve shuts after power failure. Normally, the check valve shuts the instant the reverse flow occurs and with a pump pressure head of about 300 m (1000 ft) (between Fort Irwin and Venus Site tank). If friction and pipe losses are neglected, pressure waves ranging from

$$\frac{1.1 \times 300}{9.76} + 1 \simeq 35 \text{ kg/cm}^2 \text{ (500 psig)}$$

to

$$\frac{1.9 \times 300}{9.76} + 1 \simeq 60 \text{ kg/cm}^2 \text{ (860 psig)}$$

can be expected at the check valve. A maximum pressure of about 36 kg/cm^2 (520 psig) was noted when a series of power failure situations were simulated. This small rise in pressure indicates that the system at GDSCC may not be prone to high-pressure surges during power failure. The relationship between head rise and transient conditions after power failure with some typical pressures identified are shown in Figs. 47 and 59 of Ref. 4.

V. Corrective Measures

The study revealed that for pressure surges to occur, instantaneous blockage or reversal of water flow is necessary. It was determined that instantaneous blockage of full flow is not possible within the distribution system under normal operating mode. With power failure, the chances of a pressure wave in the magnitude of about 67.7 kg/cm^2 (980 psig) at Fort Irwin is possible, due to the reversed flow from the Venus tank to the pump and closure of the check valves that stops the reverse flow. However, this possibility did not seem to exist when the system was tested with a series of power failure simulations. The entire Water Distribution System could be protected from possible water hammer pressure surges with the following alternative devices:

(1) Provide a 2.5-cm (1-in.) bypass line from upstream of the valve at the inlet to the Venus Site tank a line that discharges into the tank. The scheme is as shown in Fig. 7.

(2) At the Microwave Test Facility, provide a 2.5-cm (1-in.) full-flow relief valve set to open at the 11.5 kg/cm^2 (170 psig) upstream of the valve in the supply line with the discharge of the relief valve going to the atmosphere as shown in Fig. 8.

(3) At Fort Irwin, provide three parallel 1.25-cm (1/2-in.) full-flow relief valves set to open at 36 kg/cm^2 (520 psig) downstream of pump check valves with the discharge going to the suction line of the pumps as shown in Fig. 9

In the existing design, there is, in addition to the surge chambers, a pressure surge valve at the Fort Irwin pump house; also, the various site tanks have the capability of taking some pressure surges. The use of a 2.5-cm (1-in.) bypass line and relief valves will not only adequately relieve excess hydraulic pressure rise in the system, but will also provide the added protection for the system. While there is no need for replacing the damaged surge chambers with new ones, the existing surge chambers will be used as added protection from water hammer pressure waves. The damaged chambers at Fort Irwin are to be modified and used as an air/water surge chamber without a bladder. The two damaged bladders at the Microwave Test Facilities are to be replaced with heavy-duty truck tire tubing, and the chambers be recommissioned in the system.

VI. Conclusion

The steps that are being taken to safeguard the Goldstone Water Supply Distribution System have been accepted in principal by the outside consultants (Ref. 6), Facility Engineering, and GDSCC Engineering. The savings to be realized by using the alternative devices described above amount to approximately \$100k (\$10k vs the \$110k required to replace the inoperative surge chambers).

A test run will be carried out to ensure that the system is adequately protected from water hammer phenomena after the changes have been implemented.

References

1. *DSN Facility Status and Planning Journal*, TD505944, B Vol. (1) Section II, pp. 2-3, 2-4, Issue B, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1974, (JPL internal document).

2. Zahid, Z., "Surge Control in Water Systems," paper reprinted from *Water and Sewage Works*, Cleveland, Ohio, February, 1973 issue.

3. Linsley, Jr., R. K. and Franzini, J. B., *Elements of Hydraulic Engineering*, p. 271, McGraw Hill, New York, 1955.

4. Parmakian, J., *Waterhammer Analysis*, pp. 74-76, 93-95, Dover Publication, New York 14, New York, 1955.

5. *Cameron Hydraulic Data*, Edited by Westaway, C. R. and Loomis, A. W., p. 3-21, Ingersol-Rand, Woodcliff Lake, N. J., 1977 Edition.

6. *Alternate Recommendations for Water System Surge Chambers*, Report by Architects and Engineers Collaborative, North Figueroa St., L. A., CA. 90041, January 29, 1980.

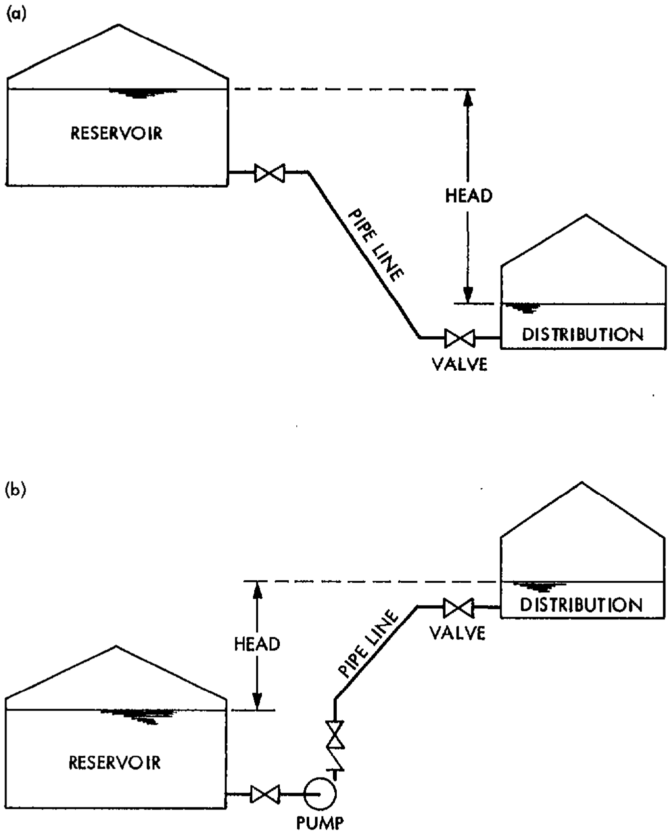


Fig. 1. Simple water supply distribution systems: a) gravity-fed system; (b) pump-fed system

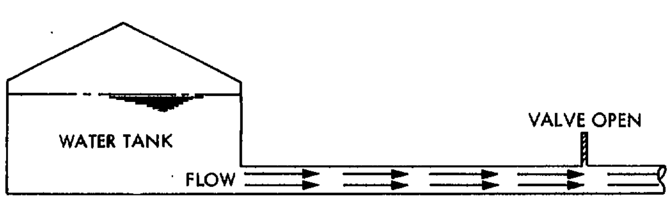


Fig. 2. Steady-state condition

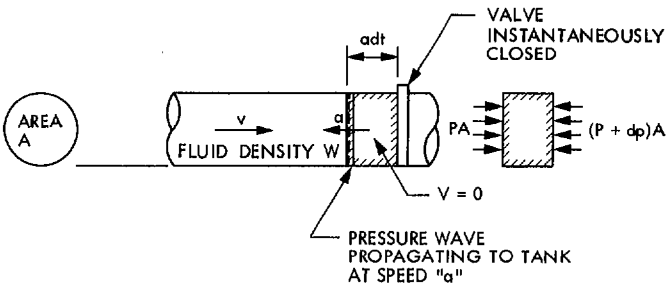


Fig. 3. Sudden stoppage of water flow (creation of water hammer)

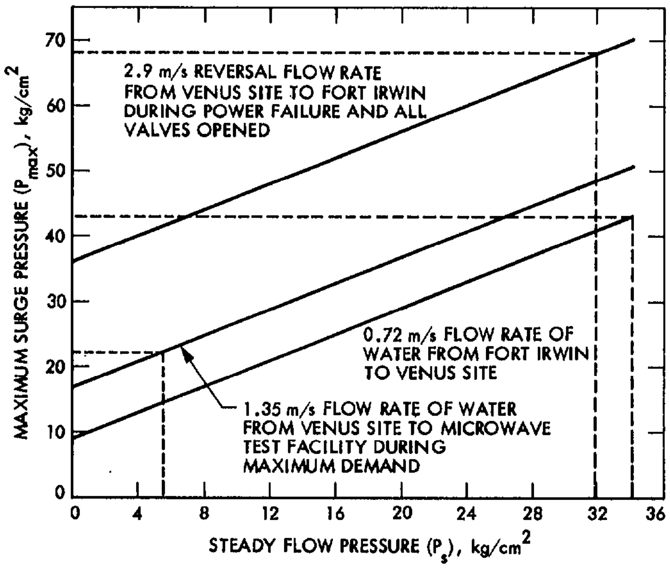
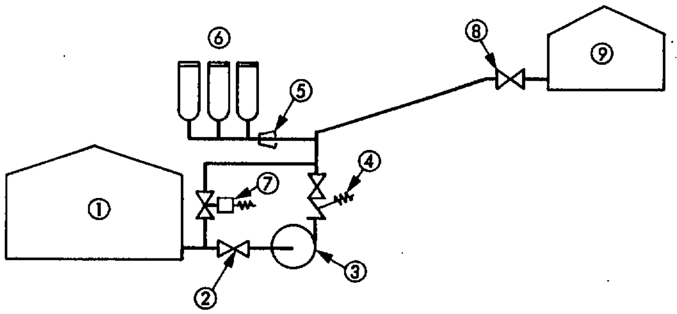


Fig. 4. $P_{max} = dP + P_s$



① FORT IRWIN TANK
② 20-cm GATE VALVE
③ MULTISTAGE PUMPS
④ 15-cm ANGLE GLOBE PRESSURE OPERATED VALVE
⑤ ENERGY ABSORBING ORIFICE
⑥ SURGE PRESSURE CHAMBERS
⑦ PRESSURE SURGE CONTROL VALVE
⑧ 15-cm GATE VALVE
⑨ VENUS SITE TANK

Fig. 5. Water supply from Fort Irwin to Venus Site tank

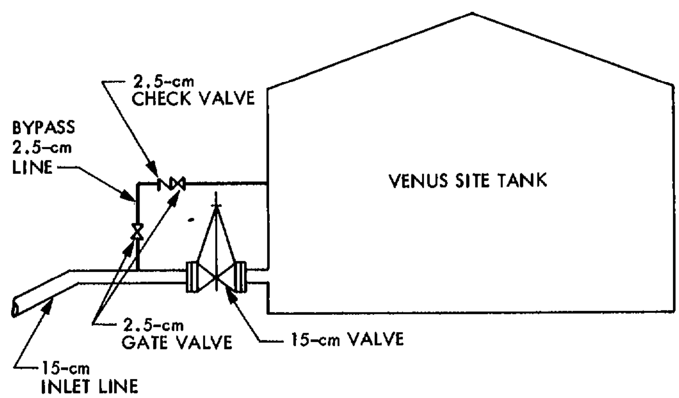


Fig. 7. 2.5-cm bypass line at inlet to Venus Site tank

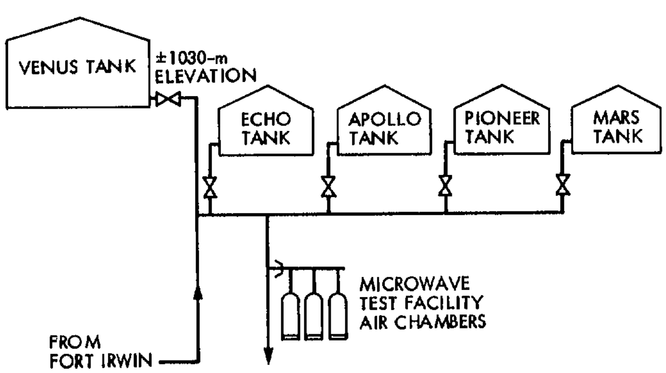


Fig. 6. Gravity-fed water supply distribution at GDSCC

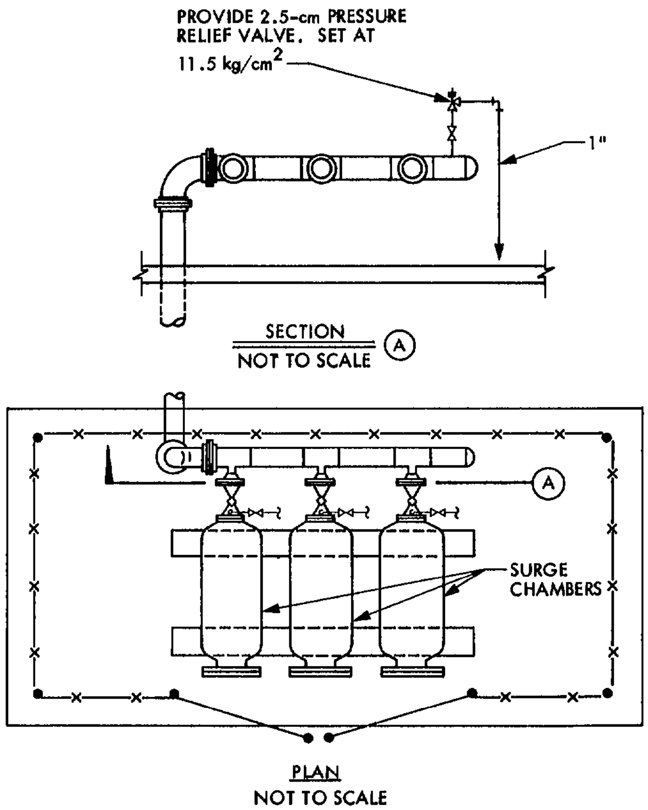


Fig. 8. MTF Station surge chambers

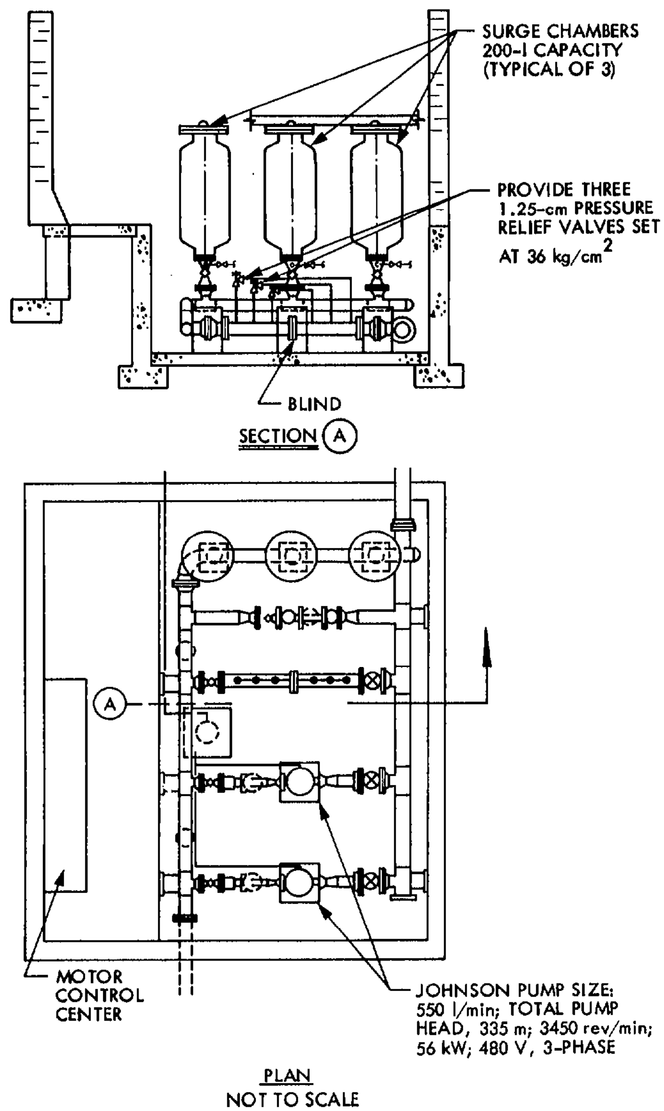


Fig. 9. Booster pumps station at Fort Irwin

Appendix
Calculation for Water Hammer Analysis

From Figs. 5 and 6,
Basic Data and Assumptions:

Pump maximum discharge	34 kg/cm^2	(490 psig)
Average pumping rate	570 1/min	(150 gal/min)
	9.5 1/s	(2.5 gal/s)
Fort Irwin tank water level	7.6 m	(25 ft max)
Fort Irwin tank elevation	760 m	(2400 ft)
Venus tank water level	6.5 m	(20 ft max)
Venus tank elevation	1030 m	(3400 ft)
Discharge line outside diam.	15 cm	(6 in.)
Discharge line inside diam.	13 cm	(5 in.)
Fort Irwin to Venus pipe length	4.82 km	(3 mi)
Cross section of inside diam.	133 cm^2	(0.1364 ft^2)
One gallon water	3.7851 1	(0.1337 ft^3 water)
Pressure at MRF air	5.5 kg/cm^2	(80 psig)
Venus to MTF pipe length	5.15 km	(3.2 mi)
Max flow occurs when three 6.3-cm (2.5-in.) fire hoses are in use at 6 1/s each	18 1/s	(5 gal/s)

Calculations:

Flow velocity $= \dfrac{\text{volume/s}}{\text{cross-section area of pipe}}$ m/s

Average pump discharge velocity $= \dfrac{9.5 \times 1000}{133 \times 100}$ m/s

0.72 m/s (2.5 ft/s)

Average discharge velocity at MTF $= \dfrac{18 \times 1000}{133 \times 100}$ m/s

1.35 m/s (4.5 ft/s)

With power failure, there is the possibility of flow from the Venus Site Tank to the Fort Irwin tank; if all valves remain opened, the reversal flow rate for a 13-cm (5-in.) inside diam. pipe with 300-m (1000-ft) hydraulic head is about 2230 1 (590 gal) per min or a flow velocity of 2.9 m (9.5 ft) per s.

Critical Time:

Time period in which the flow is stopped creating water hammer $= \dfrac{2 \times \text{length of pipe}}{\text{speed of pressure wave}}$ s

For pump to Venus tank $= \dfrac{2 \times 4820}{1220}$ s

= 7.9 s

≃ 8.0 s

For Venus tank to MTF $= \dfrac{2 \times 5150}{1220}$ s

= 8.44 s

≃ 8.5 s

Static Pressures (P_s):

Pressure at upstream of Venus tank gate valve is ~6.5 m (20 ft) water $= \dfrac{6.5}{9.76} + 1$ kg/cm^2

= 1.67 kg/cm^2 (24 psig)

Pressure at booster pumps with ~300 m (1000 ft) water $= \dfrac{300}{9.76} + 1$ kg/cm^2

= 31.73 kg/cm^2 (450 psig)

Surge Pressure (P_{max}):

When valves are shut within the critical time of 8.0 s at Venus tank gate valve P_{max} = (12.42 × 0.72) + 1.67 kg/cm^2

= 10.6 kg/cm^2 (150 psig)

At booster pump P_{max} = (12.42 × 0.72) + 34 kg/cm^2

= 43 kg/cm^2 (615 psig)

At booster pump, any discharge line valves during power failure P_{max} = (12.42 × 2.9) + 31.73 kg/cm^2

= 67.7 kg/cm^2 (970 psig)

At MTF air chambers P_{max} = (12.42 × 1.35) + 5.5 kg/cm^2

= 22.3 kg/cm^2 (320 psig)