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Hydro Pneumatic Tank Design for Surge Protection of Irrigation Pipeline Systems

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

In this paper, a simple irrigation pipeline system is proposed to represent the common situation of lifting water from a reservoir to another higher reservoir through a pipeline. Bentley HAMMER model is used to perform simulation and analysis of steady state and transients in the irrigation pipeline system. To protect the irrigation pipeline system against positive and negative hydraulic transient pressures due to power failure, a hydro pneumatic tank is employed. The diameter, liquid and tank volumes are studied versus max pressure and vapor volume affecting the irrigation pipeline system.

It is concluded that decreasing the diameter till 1/6 times the pipeline diameter, the max pressure decreases. More decreasing the diameter, the max pressure increases. Decreasing the diameter till 1/4 times the pipeline diameter, no vapor is formed. More decreasing the diameter, the vapor exists. As the liquid volume decreases; the max pressure increase for each value of the diameter, while the vapor increases for the diameters less than or equal 1/6 times the pipeline diameter. The time after which check valve of pump closes varies according to the diameter and liquid volume.

Design chart and nine design equations are obtained to get easy and effective design for hydro pneumatic tank. Employing the deduced design chart or the obtained design equations accomplish savings 55% in the diameter and 51% in liquid and tank volumes for the hydro pneumatic tank.

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Keywords: Transient flow; surge pressure; water hammer; air chamber; air bottle; shock trap.

1. INTRODUCTION

Studying transient flow (water hammer) in irrigation pipeline systems is as important as that of the steady state conditions. Transient pressures are important when the rate of flow is changed rapidly, such as resulting from pump shutdown or rapid valve closure. These disturbances create travelling pressure waves (surges) of large magnitudes. The irrigation pipeline systems have to be designed to withstand these additional transient pressures [1].

Pressure ratings define the pipes mechanical strength and have a significant influence on their cost [2] and [3].

Transient pressures in irrigation pipeline systems are usually high at pump stations, control valves, high elevation areas, and locations with low static pressures [4].

At some time, irrigation pipeline systems are started up, switched off, or subjected to unexpected flow changes. Also, they may suffer the effects of human errors, equipment breakdowns, or any risky disturbances. The safety of irrigation pipeline systems and its personnel, proper operation for equipment and devices, and public health have to be concerned to attain safe and reliable design and operation, [1].

Transient high pressures can cause rupture of pipe and pump casings, pipe leakage and/or collapse, vibration, excessive pipe displacements, support deformation and/or failure [5].

Cavitation can be found due to vacuum conditions at specific locations such as pumps or within pipes. That is when low pressures in the system are close to the vapor pressure of the fluid. Tiny air bubbles are formed and transported to a high-pressure region, where they implode causing excessive stresses on the pipe walls [6] and [7].

Oscillations of water masses through an irrigation pipeline may cause vibrations and suction of air into the pipeline. Strong hydraulic vibrations may damage pipeline, internal lining, or system equipment. Also, long-term moderate surges may gradually lead to fatigue failure [6] and [7].

Regarding of contamination, erosion and resuspension of settled particles can be happened due to high intensities of fluid shear stresses from hydraulic transients. Also, the intrusion of contaminated ground water into a pipe at a leaky joint and/or through cracks in a pipe can be occurred due to low pressure transients [6] and [7].

The rapid changes in pressure cause transient disturbances due to operational or other changes in a system. These disturbances propagate as pressure waves that travel at the speed of sound in the fluid medium. The speed of sound depends on the compressibility of water and the elasticity of the pipe [6] and [8].

$$h = \frac{v*c}{g} \tag{1}$$

Where, h: maximum head (Joukowski head, m); c: speed of the sound wave in the pipe (wave celeric, m/s); v: initial velocity of the liquid (m/s); and g: 9.81 (m/s^2).

The wave speed can be calculated from the properties of the conduit material and the fluid. The wave speed is of the order of the speed of propagation of sound in the fluid. For instance, c =1500 m/s in a closed conduit carrying water. Thus for water in a rigid pipe, and an initial water velocity of 2 m/s, then suddenly stopping the flow with a rapid valve closure results in a head of about 300 m (30 bar). The maximum closure time that gives this head is given by:

$$t = \frac{2*L}{c} \tag{2}$$

Where: L: length of pipe (m); and t: the time (the time it takes for a pressure wave to travel the pipe length and back again, s).

Hence if the pipe is 500 m long, the maximum closure time is about 0.67 s. A closure at this time or less produces a Joukowski head. For closure times up to 10 times this (6.7 s), the pressure is reduced in an inverse proportion. So, only a maximum pressure of 3 bar would be expected. Thus according to the closure time, there can be a high pressure that could damage pipeline systems. Pipes that are not ruptured can suffer gradual decay if the pressure surge occurs frequently [6] and [8].

Some common operational events that require transient analysis are mainly pump startup and shutdown, valve closing and opening, rapid changes in demand conditions, changes in transmission conditions, and pipe filling or draining [6] and [9].

Rapidly varying pressure and flow conditions (water hammer) in irrigation pipeline systems are characterized by variations that depend on both position and time. These conditions are described by the continuity equation (3) and the momentum equation (4) [1].

$$\frac{\partial H}{\partial t} = -\frac{c^2}{gA}\frac{\partial Q}{\partial x} \tag{3}$$

$$\frac{\partial H}{\partial x} = -\frac{1}{gA}\frac{\partial Q}{\partial t} + f(Q) \tag{4}$$

Where: H: pressure head (pressure/density); Q: volumetric flow rate; c: sonic wave speed in the pipe; A: cross sectional area; g: gravitational acceleration; and f(Q) represents a pipe resistance term which is a function of flow rate.

A transient flow solution is obtained by solving equations (3) and (4) along with the appropriate initial and boundary conditions. Various methods for solving these partial differential equations have been developed [6].

The arithmetic method calculates the hydraulic transient pressure for a time period $t \leq 2$ L/c, which is simple and can be obtained using equation (1). It has to be noted that the effect of friction is neglected [6] and [10].

The graphical solution is similar to the arithmetic method but allows for friction to be considered by assuming that it can be specified at one of the end points of the pipeline. It is used to determine the transient pressures at the beginning and end points of a pipeline in steps of 2 L/c seconds. There are also other graphical methods that have been developed to calculate hydraulic transient pressures in compound pipes, pump discharge lines, branched pipes, relief valves, and air chambers [6] and [10].

Method of characteristics (MOC) is a popular method that is used for solving the hydraulic transient equations. For a constant wave speed, it is capable of capturing the location of steep wavefronts, illustrating wave propagation, and efficiency of computations [6] and [11].

The wave characteristic method (WCM) is discussed, and it is concluded that for the same modeling accuracy the WCM normally requires fewer calculations and faster execution times than MOC. The use of the WCM is more suitable for analyzing large pipe networks [1].

Also, algebraic method is generally based on the method of characteristics [1].

Finite-difference methods include two categories based on the time discretization schemes. They are implicit methods and explicit methods. The implicit methods allow for larger time steps to be used in the simulations while preserving numerical stability [6].

There are several programs that can model very detailed and complex pipeline systems, such as Flowmaster (Flowmaster Ltd), Wanda (Delft University), Hammer (Haestad Systems), and Pipenet (Sunrise Systems) [8]. There are also other packages to model pipeline systems with less price and capabilities, such as HiTrans and Hytran [8]. However, all programs describe the pipeline system as a series of nodes with pipes in between them.

In this paper, a simple irrigation pipeline system is proposed to represent the common situation of lifting water from a reservoir to another higher reservoir through a pipeline. Bentley HAMMER model is used to perform simulation and analysis of steady state and transients in the irrigation pipeline system. A hydro pneumatic tank is employed to protect the irrigation pipeline system against positive and negative hydraulic transient pressures due to power failure. The diameter, liquid and tank volumes are studied versus max pressure, vapor volume affecting the irrigation pipeline system, and also the time after which check valve of pump closes.

2. SURGE PROTECTION

During a hydraulic transient state, irrigation pipeline systems can be subjected to high and low pressure cycles. The first step is the change in the fluid velocity (discharge) in the pipeline system. Sudden changes in the velocity are preferred to be avoided to minimize the occurrence of pressure transients in the pipeline systems. Most control devices and operating procedures are designed in such a manner to avoid sudden velocity changes.

Check valves are control means that close at the moment when forward flow stops. The valve must be either closed quickly before reverse flow becomes large, or closed slowly over a time interval greater than the critical time of closing (2L/c). Otherwise, excessive high pressure could occur at the time of closure of the check valve [6].

Surge relief valves are used when it is necessary to close valves fast to create a reduction in the flow velocity. A surge relief valve opens when a prescribed minimum pressure is exceeded in the pipeline systems. It is generally located adjacent to the device that is expected to be closed rapidly, and provides an escape for the flowing liquid before objectionable pressure transients occur in the system [6].

Air release and air vacuum valves are important, especially when filling an empty line of a pipeline system. They are placed to remove all air from the system slowly. Usually, these valves are located at the ends of the pipeline so the line can be pressurized and all air can be forced out [6] and [9].

Surge tanks are open standpipes that are connected to the irrigation pipeline systems. The main purpose of surge tanks is reducing the amplitude of pressure fluctuations by reflecting the incoming pressure waves, and also storing or providing water in order to accelerate or decelerate water slowly. According to its configuration, a surge tank may be classified as a simple tank, an orifice tank, a differentiation tank, a one-way tank or a closed tank [6] and [12].

An open-end surge tank is a device that is placed on the discharge side of a pump station to control both positive and negative hydraulic transient pressure waves. Its disadvantage may be the excessive height required. Instead, another device can be employed, which is an air chamber. It is called also a hydro pneumatic tank, an air bottle or a shock trap. However, it is a small pressurized vessel, which contains both air and liquid. It is connected to the discharge line of the pump station. Its purposes are avoiding negative pressures and column separation that may occur during daily operation conditions, and decreasing excessive positive pressure. It can be regarded as a local high flexibility of the pipe, or a high local compressibility of the liquid [8] and [13].

3. MATERIALS AND METHODS

A simple irrigation pipeline system is proposed. It represents the common situation of lifting water from a reservoir to another higher reservoir through a pipeline. Bentley HAMMER model is used to perform the simulation and analysis of both steady state and hydraulic transients in the irrigation pipeline system. The employed software is Bentley HAMMER V8i (SELECTseries4).

The proposed irrigation pipeline system is composed of a pump station that draws water from a reservoir (Res 1, with normal water level of (383.00) m) and conveys 468 L/s along a transmission pipeline to another reservoir (Res 2, with normal water level of (456.00) m) for a total static lift of 73 m, as illustrated in Fig. 1. The level of a constant-speed pump is (363.00) m and its speed is 1760 rpm. Irrigation pipeline includes eight pipes in series with different lengths, in addition to the suction and discharge pipes connected to the pump. All pipes are made of ductile iron and have a diameter of 600 mm. Data for pipes' lengths and nodes' elevations are shown in Tables 1 and 2 respectively.

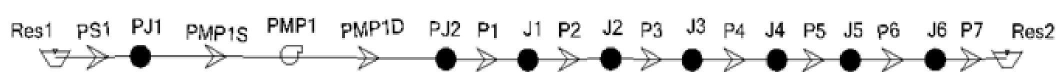

Fig. 1. The irrigation pipeline system

Table 1. Pipes' lengths

Pipe	PS1	PMP1S	PMP1D	P1	P2	P3	P4	P5	P6	P7
Length, m	50	40	10	20	380	300	250	400	250	175

Table 2. Nodes' elevations

Node	PJ2	J1	J2	J3	J4	J5	J6
Level, m	(363.00)	(408.00)	(395.00)	(395.00)	(386.00)	(380.00)	(420.00)

For the proposed irrigation pipeline system, two hydraulic transient analyses (without protection and with protection) are performed employing the model software. That is to determine its vulnerability to transient events. Then, suitable surge-protection equipment is recommended to protect the proposed irrigation pipeline system from damage.

When the change of flow is rapid or sudden, the resulting transient pressure can cause surges or water hammer. There are many possible causes for rapid or sudden changes in a pipe system, including power failures, pipe breaks, or a rapid valve opening or closure. These can result from natural causes, equipment malfunction, or human error.

In this paper, the impact of a power failure for several minutes is simulated and analyzed. It is assumed that power is interrupted suddenly and without warning. The purpose of this type of transient analysis is to ensure that the irrigation pipeline system and its components can withstand the resulting transient pressures and determine how long it must be waited for the transient energy to dissipate.

Fig. 2 shows the steady state hydraulic grade line (HGL) and elevations along the irrigation pipeline system employing the model software. Fig. 3 illustrates the steady state (initial) hydraulic grade line (in black color) as well as the maximum (in red color) and minimum (in blue color) transient head envelopes along the irrigation pipeline system, in addition to the elevations (in green color). Pressures (max, min and initial), velocities (max and min) and vapor volume for transient state along the irrigation pipeline system employing the model software are shown in Figs. 4, 5 and 6 respectively.

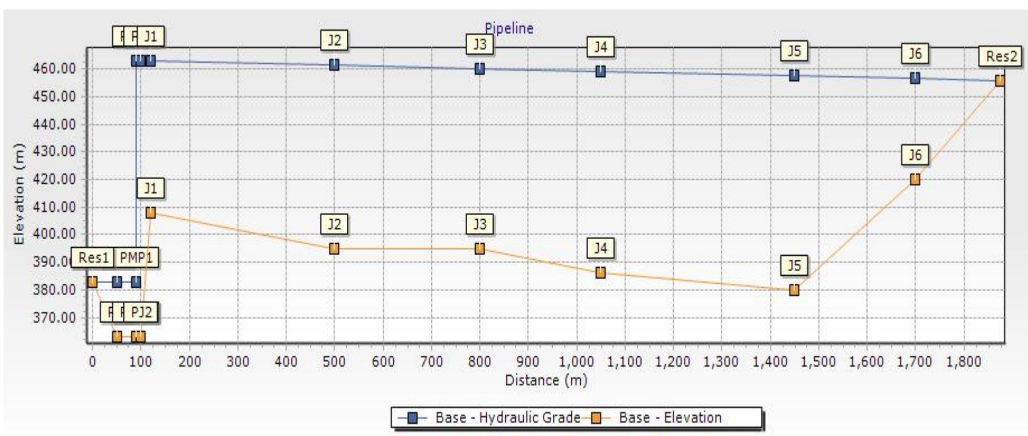

Fig. 2. Hydraulic grade line and elevations along the irrigation pipeline system

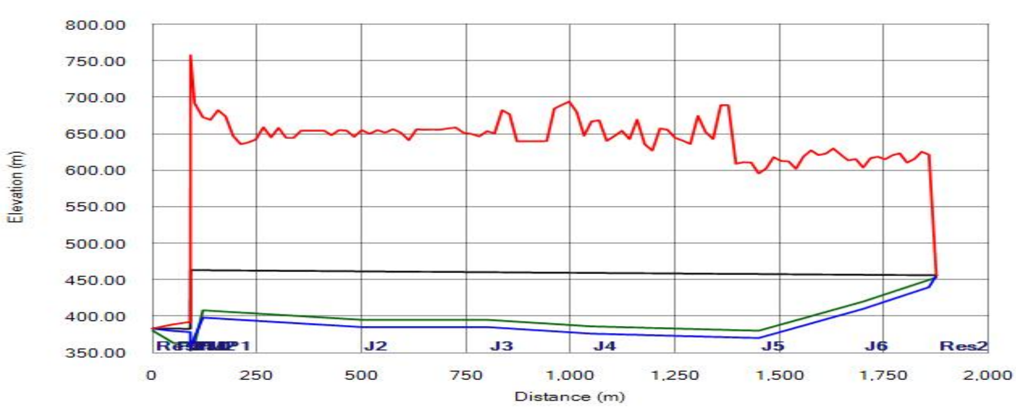

Fig. 3. Hydraulic grade (max, min and initial) and elevations for transient state along the irrigation pipeline system

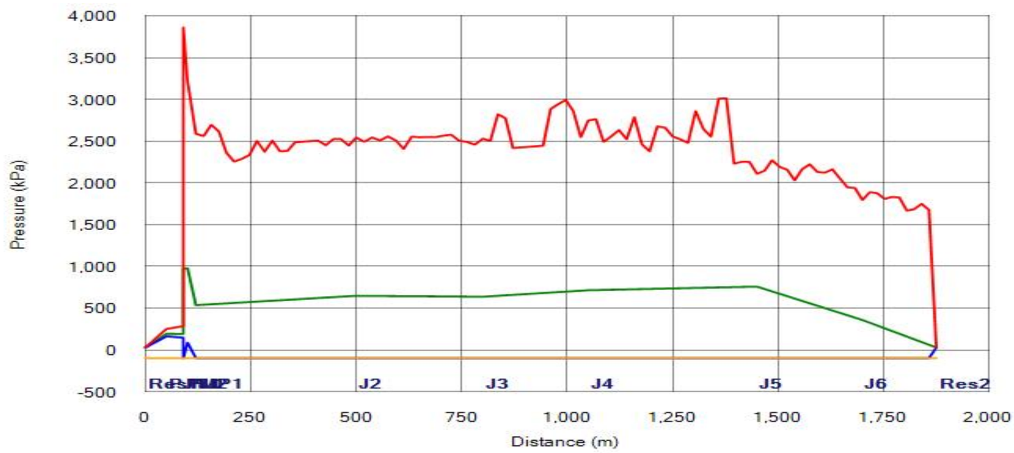

Fig. 4. Pressures (max, min and initial) for transient state along the irrigation pipeline system

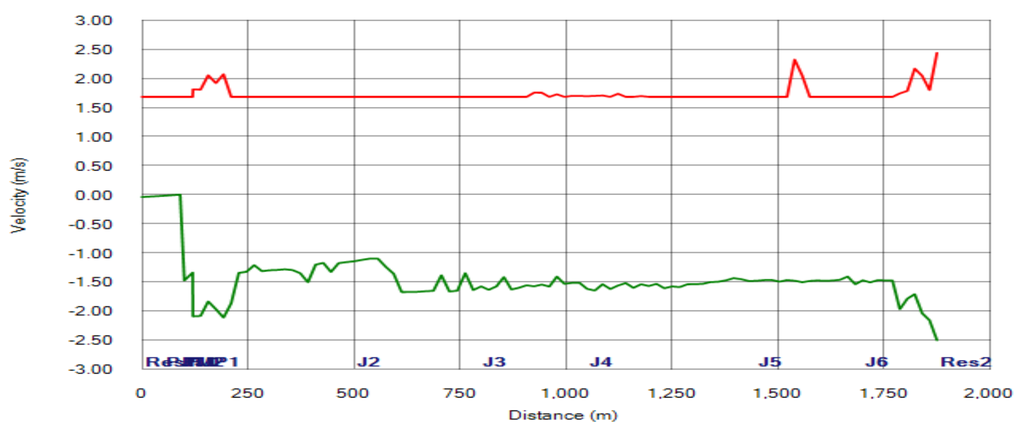

Fig. 5. Velocities (max and min) for transient state along the irrigation pipeline system

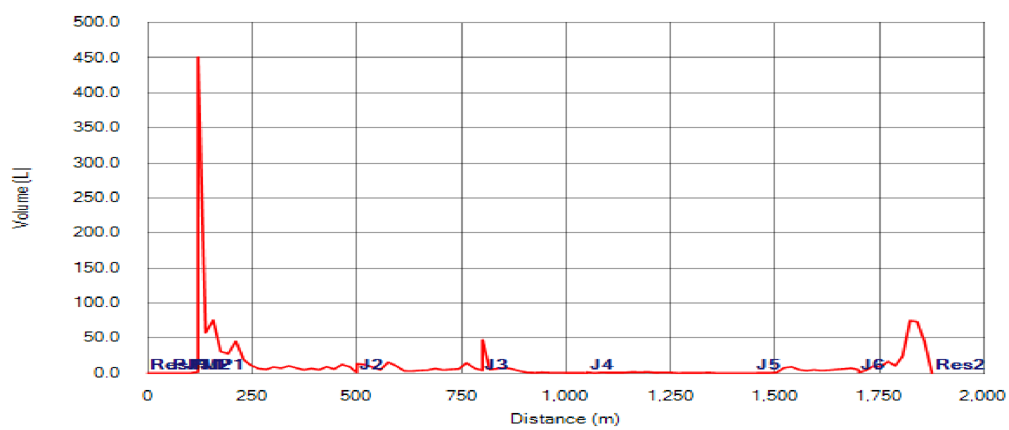

Fig. 6. Vapor volume for transient state along the irrigation pipeline system

Due to the power failure, the irrigation pipeline is subjected to a max pressure of 3,862 kPa as shown in Fig. 4. The max velocity reached the great value of 2.44 m/s and a max vapor volume of 450.9 liters is formed as found from Figs. 5 and 6 respectively.

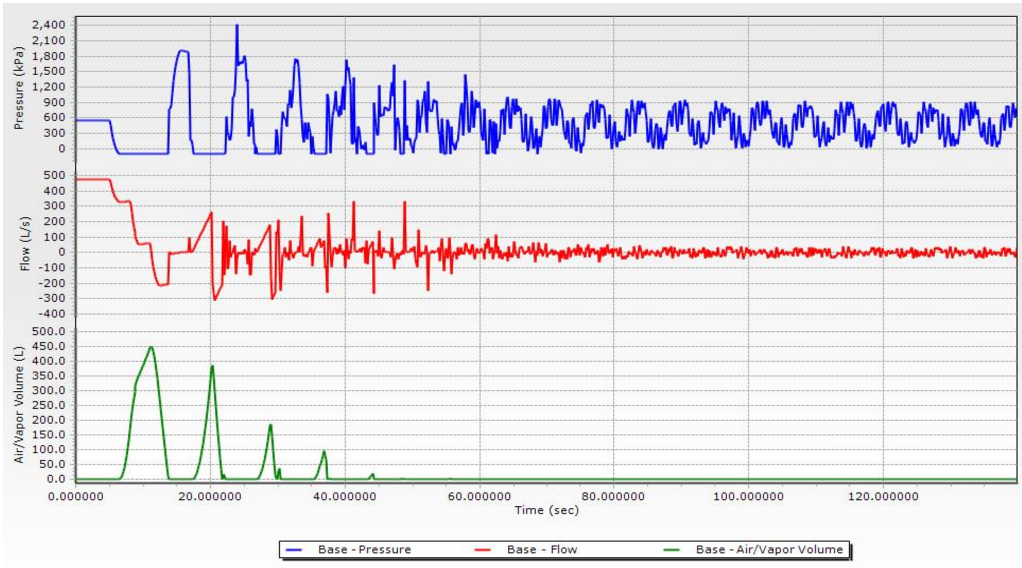

Fig. 7. Pressure, flow and vapor volume for transient state at node J1 of the irrigation pipeline system

As shown in Fig. 7, a vapor pocket grows at node J1 (downstream the pump station) and gradually collapses due to return flow from the receiving reservoir Res 2. The resulting sudden transient pressures propagate away from the node J1 sending a shock wave through the irrigation pipeline.

4. HYDRO PNEUMATIC TANK DESIGN

The change in the fluid velocity (discharge) in the irrigation pipeline system is the first step that leads to a hydraulic transient. During a hydraulic transient state, a pipeline may be subjected to objectionable high and low pressure cycles. The high pressures can damage the pipeline system components; such as valves, pumps, and other pipeline components. Hence, sudden changes in the velocity should be avoided to minimize the occurrence of pressure transients in the system.

As many control devices, hydro pneumatic tanks are designed to avoid sudden velocity changes. In this paper, a hydro pneumatic tank is employed to protect the irrigation pipeline system against a power failure.

High pressures are mainly due to the sudden collapse of the vapor pocket at node J1. The hydro pneumatic tank is put at node J1 (downstream the pump station), as shown in Fig 8. That is to supply flow into the pipeline upon the power failure, to keep the upstream water column moving and to minimize (or prevent) the size of the vapor pocket. The diameter of hydro pneumatic tank (tank inlet orifice) is taken as 450 mm. Its volume is taken to be 20,000 liters with liquid volume of 14,200 liters.

Fig. 9 illustrates the transient initial hydraulic grade line (in black color) as well as the maximum (in red color) and minimum (in blue color) transient head envelopes along the protected irrigation pipeline system, in addition to the elevations (in green color). Pressures (max, min and initial), velocities (max and min) and vapor volume for transient state along the protected irrigation pipeline system employing the model software are shown in Figs. 10, 11 and 12 respectively.

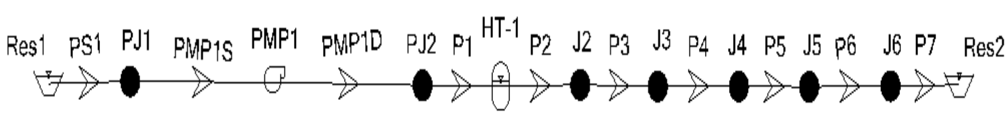

Fig. 8. The protected irrigation pipeline system with surge tank

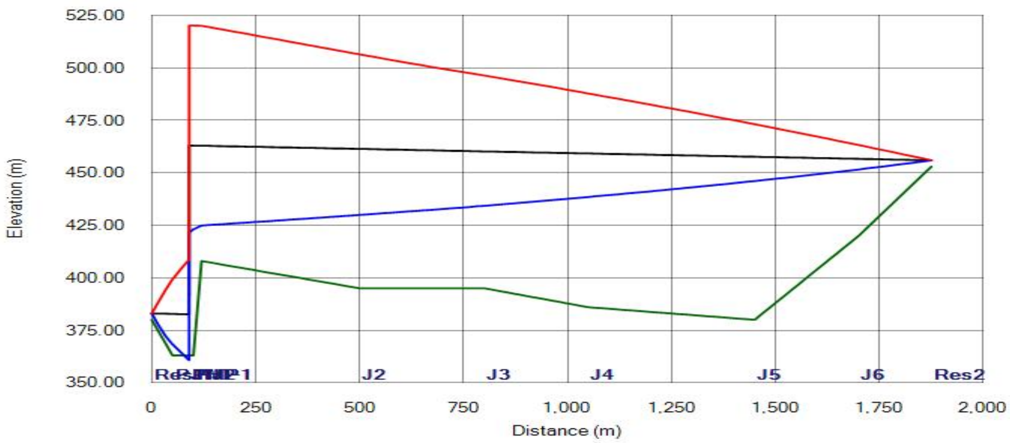

Fig. 9. Hydraulic grade (max, min and initial) and elevations for transient state along the protected irrigation pipeline system

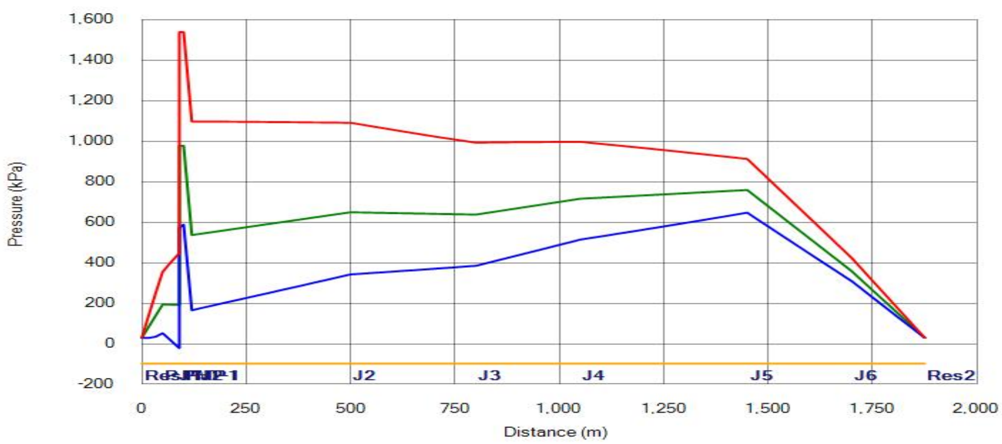

Fig. 10. Pressures (max, min and initial) for transient state along the protected irrigation pipeline system

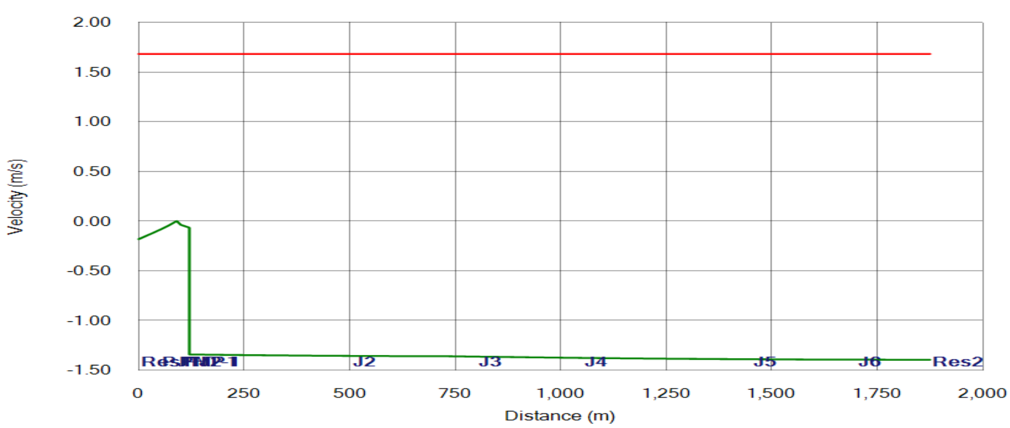

Fig. 11. Velocities (max and min) for transient state along the protected irrigation pipeline system

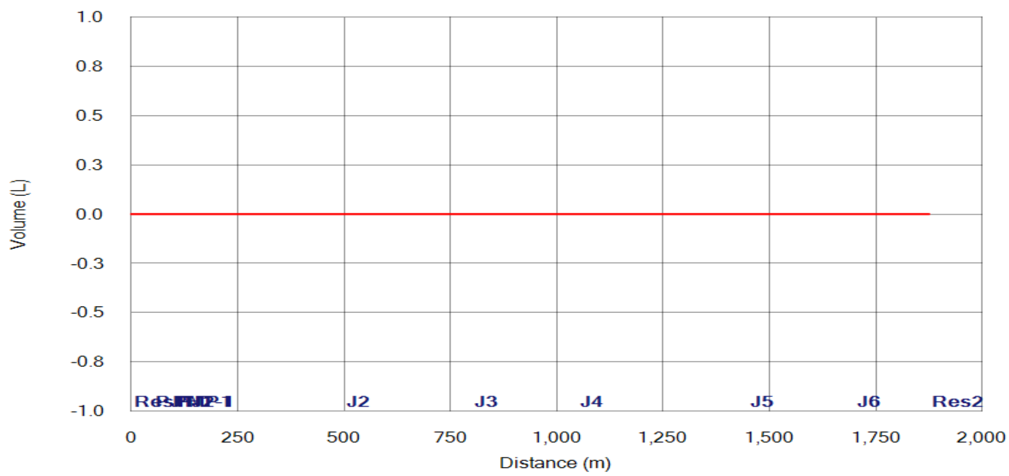

Fig. 12. Vapor volume for transient state along the protected irrigation pipeline system

From the Figs. 9 through (12) of the protected irrigation pipeline; when the power failure happened, the irrigation pipeline is subjected to a max pressure of only 1,538 kPa. The max velocity is only 1.68 m/s with no vapor volume at all.

5. ANALYSIS FOR THE HYDRO PNEUMATIC TANK DESIGN

As discussed previously, the hydro pneumatic tank protected effectively the irrigation pipeline against transient effects due to power failure. The main parameters of the hydro pneumatic tank design are its diameter (tank inlet orifice), tank volume and liquid volume. These parameters are going to be studied against the two main categories for the irrigation pipeline system; namely max pressure and vapor volume.

In the last section (hydro pneumatic tank design), the employed diameter for the hydro pneumatic tank is chosen to be 450 mm (75% of the diameter of the irrigation pipeline) by judgment. Also, the employed liquid volume for the hydro pneumatic tank is 14,200 liters (30.3 times the discharge (Q) moving through the irrigation pipeline) and tank volume is 20,000 liters (1.4 times the liquid volume).

In this section, various hydro pneumatic tank designs are performed using different values for the main parameters: the diameter, the liquid and tank volumes. The values for the hydro pneumatic tank diameter are studied each 50 mm starting descending from 600 mm (the diameter of the irrigation pipeline). Also, the values for the liquid volume are studied for 30 Q, 25 Q, 20 Q, and so on till 5 Q. The values for the tank volume is taken the same as 1.4 times the liquid volume.

The Tables 3 through 14 illustrate transient results for various hydro pneumatic tank designs employing Bentley HAMMER V8i (SELECT series 4).

Table 3. Transient results for hydro pneumatic tank design with 600 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1581	0	5.89
16380	11700	1692	0	5.89
13104	9360	1846	0	5.89
9828	7020	2066	0	5.91
6552	4680	2380	0	5.94
3276	2340	2760	0	6.03

Table 4. Transient results for hydro pneumatic tank design with 550 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1570	0	5.89
16380	11700	1681	0	5.89
13104	9360	1834	0	5.89
9828	7020	2053	0	5.91
6552	4680	2367	0	5.94
3276	2340	2754	0	6.03

Table 5. Transient results for hydro pneumatic tank design with 500 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor Volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1559	0	5.89
16380	11700	1669	0	5.89
13104	9360	1820	0	5.89
9828	7020	2038	0	5.91
6552	4680	2352	0	5.94
3276	2340	2745	0	6.03

Table 6. Transient results for hydro pneumatic tank design with 450 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1547	0	5.89
16380	11700	1656	0	5.89
13104	9360	1805	0	5.91
9828	7020	2021	0	5.91
6552	4680	2335	0	5.94
3276	2340	2733	0	6.05

Table 7. Transient results for hydro pneumatic tank design with 400 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1532	0	5.89
16380	11700	1639	0	5.89
13104	9360	1786	0	5.91
9828	7020	2000	0	5.91
6552	4680	2313	0	5.94
3276	2340	2717	0	6.05

Table 8. Transient results for hydro pneumatic tank design with 350 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1507	0	5.89
16380	11700	1611	0	5.89
13104	9360	1754	0	5.91
9828	7020	1965	0	5.92
6552	4680	2280	0	5.94
3276	2340	2691	0	6.05

Table 9. Transient results for hydro pneumatic tank design with 300 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1461	0	5.89
16380	11700	1558	0	5.91
13104	9360	1695	0	5.91
9828	7020	1900	0	5.92
6552	4680	2214	0	5.95
3276	2340	2643	0	6.06

Table 10. Transient results for hydro pneumatic tank design with 250 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1374	0	5.91
16380	11700	1460	0	5.92
13104	9360	1581	0	5.92
9828	7020	1771	0	5.94
6552	4680	2079	0	5.97
3276	2340	2537	0	6.09

Table 11. Transient results for hydro pneumatic tank design with 200 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1229	0	5.95
16380	11700	1290	0	5.95
13104	9360	1381	0	5.97
9828	7020	1530	0	5.98
6552	4680	1799	0	6.03
3276	2340	2288	0	6.17

Table 12. Transient results for hydro pneumatic tank design with 150 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1053	0	6.16
16380	11700	1082	0	6.17
13104	9360	1125	0	6.19
9828	7020	1199	0	6.22
6552	4680	1348	0	6.31
3276	2340	1735	0	8.41

Table 13. Transient results for hydro pneumatic tank design with 100 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	979	6.0	8.75
16380	11700	979	6.9	8.78
13104	9360	979	8.3	8.80
9828	7020	990	12.5	8.92
6552	4680	1026	20.0	8.98
3276	2340	1119	37.6	9.00

Table 14. Transient results for hydro pneumatic tank design with 50 mm diameter

Tank volume, Lit	Liquid volume, Lit	Max pressure, kPa	Vapor volume, Lit	Time after which check valve of pump closes, sec
19656	14040	1942	158.5	9.05
16380	11700	1947	159.4	9.05
13104	9360	1952	160.8	9.05
9828	7020	1963	163.0	9.06
6552	4680	1977	166.9	9.06
3276	2340	2009	176.8	9.06

From these transient results, the following are deduced:

a) The max pressure decreases as the diameter decreases till the diameter of 100 mm (1/6 times the pipeline diameter). More decreasing the diameter, the max pressure increases.
b) There is no vapor till the diameter of 150 mm (1/4 times the pipeline diameter). More decreasing the diameter, the vapor exists.
c) For each value of the diameter, the max pressure increases as the liquid volume decreases.
d) For the diameters less than or equal 100 mm (1/6 times the pipeline diameter), the vapor increases as the liquid volume decreases.
e) The time after which check valve of pump closes varies according to the diameter and liquid volume.

6. RESULTS AND DISCUSSION

Reviewing the Tables 3 through (14), the time after which check valve of pump closes is taken into consideration as an additional precaution against power failure of the irrigation pipeline system. The time after which check valve of pump closes is not to exceed 6 seconds. This implies excluding the diameters less than or equal 150 mm (1/4 times the pipeline diameter), as shown in Tables 12, 13 and 14. Also, the diameters less than or equal 100 mm (1/6 times the pipeline diameter) are excluded because vapor exists for all values of the liquid volume, as shown in Tables 13 and 14.

In order to make the hydro pneumatic tank design easy and effective, regression analyses for the Tables 3 through (11) are performed. Design chart for the hydro pneumatic tank is deduced and illustrated in Fig. 13 for nine different diameters. The obtained nine design equations are shown in Table 15 with the values of correlation factor (R^2).

To get a hydro pneumatic tank design; according to the permissible max pressure of the pipeline, the diameter and the liquid volume are got easily from the design chart directly or they are calculated using the design equations.

For 1,800 kPa permissible max pressure as an example; on the design chart a diameter of 250 mm is selected and the liquid volume is got to be 7,060 liters, as shown in Fig. 14. Another way for design is that the obtained equation in Table 15 concerning 250 mm diameter is solved for P_{max} = 1,800 kPa and the solution is L = 7,060 liters (L: liquid volume). Finally, the tank volume is 9,884 liters, where the tank volume is 1.4 times the liquid volume.

Table 15. Design equations for hydro pneumatic tanks according to the diameter

Diameter, mm	Design equations for hydro pneumatic tanks	Correlation factor, R^2
600	$P_{max} = 6E\text{-}06L^2 - 0.1995L + 3173.8$	0.9994
550	$P_{max} = 6E\text{-}06L^2 - 0.1993L + 3159.4$	0.9993
500	$P_{max} = 6E\text{-}06L^2 - 0.1995L + 3144.6$	0.9992
450	$P_{max} = 6E\text{-}06L^2 - 0.1994L + 3126.2$	0.9991
400	$P_{max} = 6E\text{-}06L^2 - 0.1992L + 3102.2$	0.9991
350	$P_{max} = 6E\text{-}06L^2 - 0.2009L + 3073.4$	0.9989
300	$P_{max} = 7E\text{-}06L^2 - 0.2016L + 3006.8$	0.9987
250	$P_{max} = 7E\text{-}06L^2 - 0.1988L + 2854.4$	0.9978
200	$P_{max} = 4E\text{-}06L^2 - 0.1271L + 2222.8$	0.9992

P_{max}: max pressure (kPa), L: liquid volume (Lit)

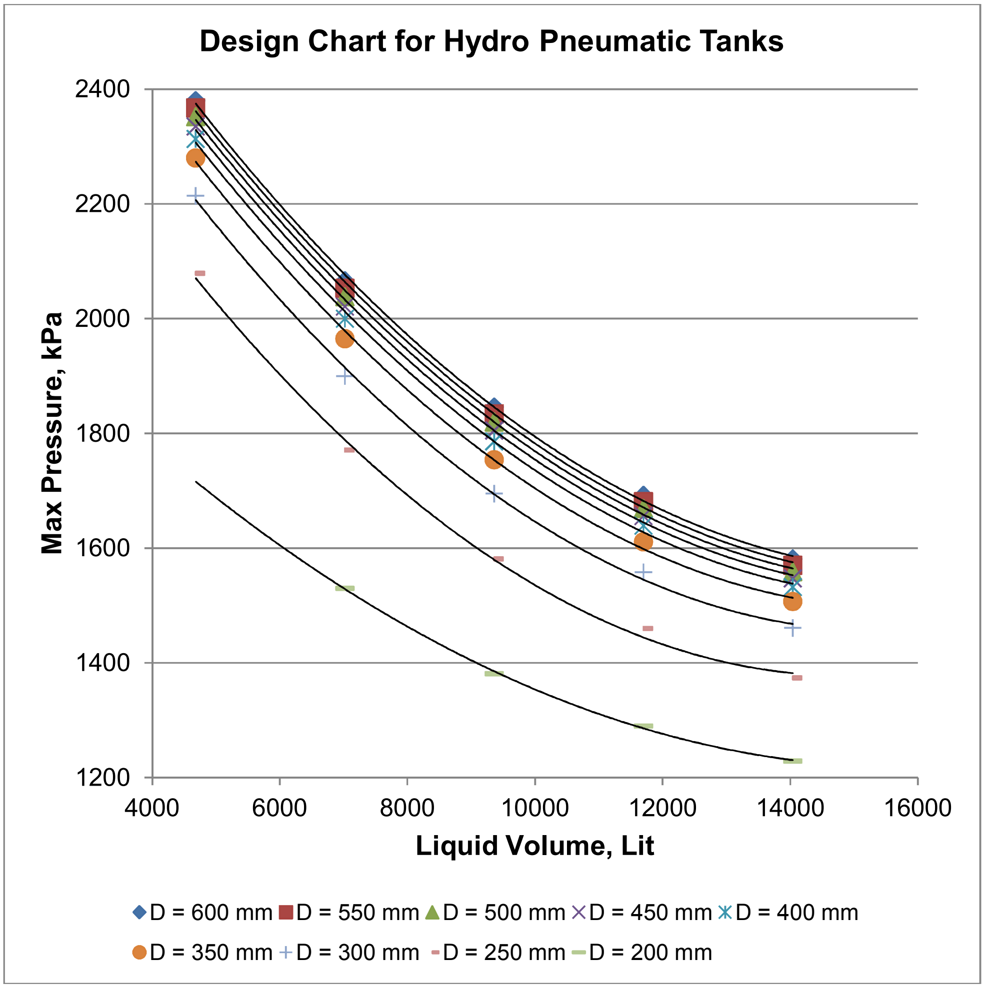

Fig. 13. Design chart for hydro pneumatic tanks

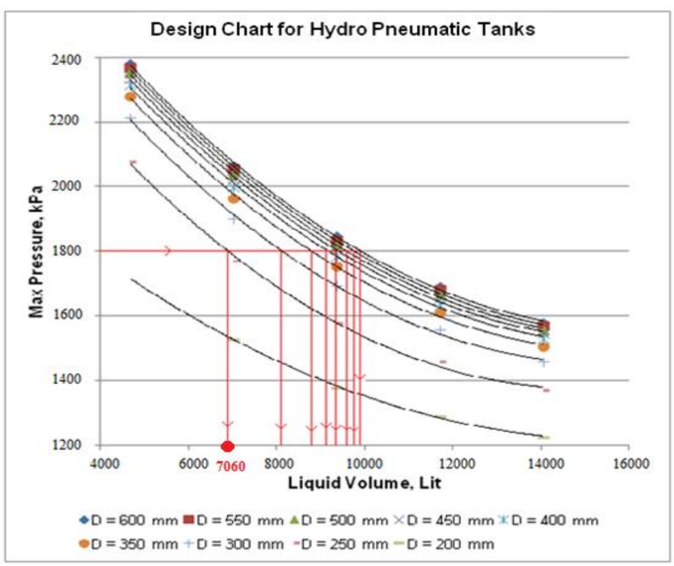

Fig. 14. Example for hydro pneumatic tank design, the permissible max pressure is 1,800 kPa

For this example also, there are other seven alternatives for the hydro pneumatic tank design as shown in Fig. 14 and Table 16.

Table 16. Design alternatives for hydro pneumatic tank, the permissible max pressure is 1,800 kPa

Diameter, mm	Liquid volume, Lit	Tank volume, Lit
600	9740	13636
550	9590	13426
500	9390	13146
450	9200	12880
400	8950	12530
350	8490	11886
300	8490	11886
250	7060	9884

The used hydro pneumatic tank to protect the proposed irrigation pipeline system reduces the max pressure (P_{max}) to be 1,538 kPa. Employing the deduced design chart or the obtained design equations accomplish the same value of the max pressure through a hydro pneumatic tank with a diameter of only 200 mm (instead of 450), a liquid volume of only 6,880 Lit (instead of 14,200), and a tank volume of only 9,632 Lit (instead of 20,000). Savings in the hydro pneumatic tank design are 55 % for the diameter and 51 % for the liquid and tank volumes.

7. CONCLUSIONS

It is concluded that decreasing the diameter till 100 mm (1/6 times the pipeline diameter), the max pressure decreases. More decreasing the diameter, the max pressure increases. Decreasing the diameter till 150 mm (1/4 times the pipeline diameter), no vapor is formed. More decreasing the diameter, the vapor exists. As the liquid volume decreases; the max pressure increase for each value of the diameter, while the vapor increases for the diameters less than or equal 100 mm (1/6 times the pipeline diameter). The time after which check valve of pump closes varies according to the diameter and liquid volume.

Design chart is deduced and nine design equations are obtained to get easy and effective design for hydro pneumatic tank. Employing the deduced design chart or the obtained design equations accomplish savings 55% in the diameter and 51% in liquid and tank volumes for the hydro pneumatic tank.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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