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Protection of Pipe Networks from Water Hammer Effects Using Air Vessels (Case Study: Bosat Kareem El-Dein Water Network)

حماية شبكات الأنابيب من تأثيرات المطرقة المائية باستخدام الأوعية الهوائية (حالة دراسية: محطة بساط كريم الدين لشبكة توزيع المياه)

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KEYWORDS:
Water hammer, Bentley HAMMER, Air vessel, Bosat Kareem El Dein pipe network, Method of characteristics, Hazen-Williams Formula

الملخص العربي:-ظاهرة المطرقة المائية غالبا ما تحدث فى شبكات توزيع المياه إما نتيجة التوقف المفاجئ للمضخات أو الغلق و الفتح السريع للمحابس الأمر الذى يؤدى إلى تولد ضغوط كبيرة (موجبة وسالبة) قد تُحدث مشاكل بالشبكة . فى هذه الدراسة تم استخدام برنامج Bentley HAMMER Vi 8 لدراسة تأثير معامل الخشونة على موجة المطرقة المائية فى الأنابيب

هناك عدة طرق للحماية من هذه الظاهرة منها استخدام الأوعية الهوائية,خزانات الفائض وصمامات عدم الرجوع و استخدام إحدى هذه الطرق يتوقف على عدة عوامل منها أساليب التصميم , الموقع, طبوغرافية المنطقة ولقد تم استخدام الأوعية الهوائية فى هذا البحث كوسيلة حماية من المطرقة المائية وذلك لميزتها فى إحتواء الضغوط السالبة عن الطرق الأخرى و بتكلفة أقل وقد تم تطبيق هذه الدراسة على مرفق وشبكة مياه بساط كريم الدين بالدقهلية. وقد توصل البحث إلى أن سرعة المياه وطول الأنبوب وقطره ونوعية مادته هى العوامل الرئيسية المؤثرة على ظاهرة المطرقة المائية, كما أن زيادة حجم الأوعية الهوائية المستخدمة فى الحماية يقلل من الوقت اللازم لتثبيط موجة المطرقة المائية وذلك مع مراعاة الناحية الاقتصادية بجانب الكفاءة فى اختيار الحجم المناسب لهذه الأوعية الهوائية.

***Abstract*—Water hammer phenomenon is usually happened in water distribution networks due to pumps power failure or sudden closure, opening valves which lead to generate massive positive and negative pressures that may be catastrophic. In this research Bentley HAMMER Vi 8 is used to study the effect of roughness coefficient on water hammer wave in pipes.**

There are different methods to control and reduce these transient effects such as surge tanks, air vessels and pressure reducing valves. Choosing one of these methods depends on the design criteria, location and topography that strongly affect the decision maker. Air vessel was chosen in this study as a protection method for its ability to deal with negative pressure more effectively and more economical than other forms of water hammer protection devices. This study was applied on Bosat Kareem El Dein water pipe network. The research concluded that water velocity, length of pipe, modulus of elasticity, inside diameter of pipe, pipe wall thickness and roughness coefficient are the main factors affecting the severity of water hammer. Also increasing the size of vessels decrease the damping time of the surge pressure wave, but this should be regarded from the economical point of view.

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I. INTRODUCTION

The main objective of pipe network analysis is the determination of discharge and associated of pipe network could be considered as one of the more complex mathematical problems that faces the engineers which have to be solved. A significant fraction of the entire set of the equations contains non-linear parameters and large number of these equations have to be solved simultaneously in which the flow resistance relate pipe pressure head to discharge.

Pipe surge and water hammer are two related but independent phenomena which arise when fluid flowing in a pipe as accelerated or decelerated. The associated pressure transient can be damaging to pipe network or components

The systems must be designed to avoid or withstand these phenomena

The history of water hammer analysis is marked by various clever and prac¬tical schemes for solving the momentum and continuity equations (Watters, 1984).

Koelle and Luvizotto (1991) presented a computer aided operation (CAO) model for the operation of pumped storage plants. This model was based on the use of the method of characteristics to deal with steady, transient, and unsteady conditions of operation. Karney and McInnis (1992) proposed an explicit algorithm for called an external energy dissipater, such as surge tank, relief valve, or reservoir.

It has been recognized for many years that the long pipelines of large diameter may experience severe transient loading. Despite this, there is a feeling among practitioners that networks are somehow intrinsically more robust than series pipe systems (Karney and McInnis, 1994).

Kameswara and Eswaran (1999) developed a computer program, HYTRAN, using the method of characteristics for calculating the time dependent head and velocity of water in a complex pipeline network due to a pump failure and load reduction on a turbine. The method had to be modified using a finite element method FEM (Izquierdo and Igiesias, 2002). for the incorporation of structural members such as pipes and penstocks when the effects of water structure interactions were important

Other methods have been introduced to solve the problem of water flow transient such as finite volume method (FVM) (Zhao and Ghidaoui, 2004) and wave characteristic method W'CM (Wood et al., 2005),

It was found that the transient flow significantly affects the probability of system failure due to the effect of valve closure which is a really important activity in the operation of piping system. Reliability analysis of pipe network regarding transient flow was carried out by Kwou and Lee (2008). The method of characteristics is commonly used for its simplicity and superior performance in comparison with the other approaches. Solution by the method of characteristics has two schemes, the explicit one and the implicit scheme. The latter is used in order to avoid the instability of calculation accordance to the Courant's formula. Water hammer simulation by implicit method was carried out by Afsher and Rohani (2008) and Afsher et al. (2010).

Water hammer could lead to over pressure which may require either excessive pipe wall thickness or some form of water hammer protections. The most suitable type hammer protection depends on the pipeline network as well as the flow characteristics of the network. However the most effective method of preventing negative pressures and also for reducing over pressures the use of compressed air vessels, also known as air chambers, pressurized surge tanks, pneumatic tanks or accumulators.

Abdel Kawi et al. (2013) carried out a water hammer oscillation in single pipeline due to sudden valve closure. Ramadan and Mustafa (2013) studied transient flow for controlling water hammer effect on hydroelectric power station using surge tank. The negative pressure associated with water hammer can cause vaporization of the water in the pipe as the pressure drops below atmospheric to vapor pressure which varies with water temperature. E.g. at water temperature 25o C the vapor pressure head is about -9.7 m of water.

II. THEORETICAL APPROACH

2.1. Method of Characteristics:

Different numerical methods have been introduced for studying the pipelines transient flow. These approaches include the explicit method of characteristics (MOC), characteristics rectangular grid is given in figure (1);

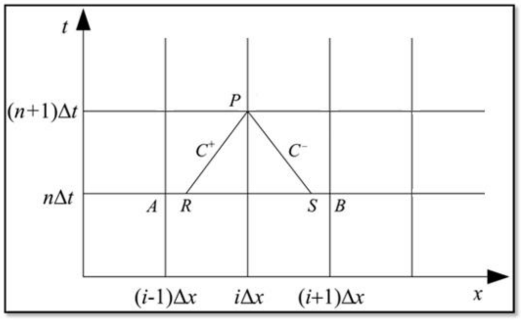


Fig (1): Characteristic rectangular grids

The equations of flow in pipe lines are the momentum and continuity equations. The approximate versions of these equations are obtained by neglecting the spatial variation of V and p, as it is much less than time-varying variation (Watters, 1984).

In accordance with momentum equation:

$$\frac{\partial V}{\partial t}+\frac{1}{\rho}\frac{\partial p}{\partial x}+g\frac{dz}{dx}+\frac{f}{2d}V\left|V\right|=0 \qquad (1)$$

And the continuity equation:

$$a^2\frac{\partial V}{\partial t}+\frac{1}{\rho}\frac{\partial p}{\partial x}=0 \qquad (2)$$

Where:

ρ: density of water (kg/m^3);

g: acceleration due to gravity (m/s^2);

d: pipe diameter(m);

V: mean velocity of water (m/s);

f: Darcy- Wiesbach friction factor (dimensionless);

z: node pipeline elevation (m); and

a : Pressure wave celerity (m/s).

If the above two equations have been replaced with two ordinary differential equations providing that certain rules are followed which relate the independent variables *x* and *t* in each case. If, in addition, *p* is replaced with γ (*H* - *z*), then better propagation of the pressure waves can be visualized because *H* is the height of the EL-HGL above the datum. This substitution gives:

$$\frac{dV}{dt}+\frac{g}{a}\frac{dH}{dt}+\frac{f}{2d}V\left|V\right|=0 \quad \frac{dx}{dt}=a \qquad (3)$$

While

$$\frac{dV}{dt}-\frac{g}{a}\frac{dH}{dt}+\frac{f}{2d}V\left|V\right|=0 \quad \frac{dx}{dt}=-a \qquad (4)$$

The fact that the relationship between x and *t* in equation must satisfy (*dx/dt*) =*a*, has caused the equation (*dx/dt*) = a to be called the characteristic of Equation (3). A similar line of reasoning suggests that (*dx/dt*) = - a is the characteristic of Equation (4).

Finite Difference Representation:

Referring to figure (1), equations (3) and (4) can be written in finite difference form as:

$$\frac{V_P-V_R}{\Delta t}+\frac{g}{a}\frac{H_P-H_R}{\Delta t}+\frac{f}{2d}V_R\left|V_R\right|=0 \qquad (5)$$

$$\frac{V_P-V_S}{\Delta t}-\frac{g}{a}\frac{H_P-H_S}{\Delta t}+\frac{f}{2d}V_S\left|V_S\right|=0 \qquad (6)$$

Values at points R and S are obtained by interpolation of the corresponding values at A, and B, respectively. When these equations are multiplied by Δt they become:

$$C^{+}:(V_p-V_R)+\frac{g}{a}(H_p-H_R)+\frac{f\Delta t}{2D}V_R\left|V_R\right|=0 \qquad (7)$$

$$C^{-}:(V_p-V_s)-\frac{g}{a}(H_p-H_s)+\frac{f\Delta t}{2D}V_s\left|V_s\right|=0 \qquad (8)$$

These equations will be referred as the characteristics equations C $^+$ and C $^-$

The ressure wave speed (a) is given by Featherstone and Nalluri (1982) as follows:

$a = \sqrt{k/\rho}$ for plastic (rigid) theory; and (9)

$a = 1/\sqrt{\rho\,(\frac{1}{k}+c\frac{d}{eE})}$ for elastic theoery. (10)

in which:

K : bulk's modulus of water (N/m^2);

E : Young's modulus of pipe material(N/m^2);

e : pipe wall thickness (m); and

c : cofficient depends on the pipe anchorage (dimensionless).

K for water = 2.1 *10^9 N / m^2

Hence for rigid theory a is given by:

$a = \sqrt{2.1 * 10^9 / 1000}$ = 1450 m /s

In this analysis (a) is assumed equal to 1250 m/ s, to simplify the analysis of water network as it consists of many types of pipes.

2.2 Hazen-Williams Formula:

Hazen-Williams equation is usually used in the analysis of pressure in water distribution networks and sewer mains. This formula is given by:

$Q = 0.85 .C. A .R^{0.63} .S^{0.54}$ (11)

In which:

Q : discharge in the pipe (m^3/s);
C: Hazen-Williams roughness coefficient (dimensionless);
A: flow area (m^2);
R : hydraulic radius (m.); and
S : friction slope (m/m.)

The following table (1) exhibits values of C for material of the pipe network under study

TABLE (1)
ROUGHNESS COEFFICIENTS (C)

Pipe material	Age	C
Cast-iron	New, unlined	130
	10 yr. Old	107-113
	20 yr. Old	89-100
	30 yr. Old	75-90
	40 yr. Old	64-83
Ductile- iron		140
PVC		140 -150
Steel		145-150
Asbestos Cement		140

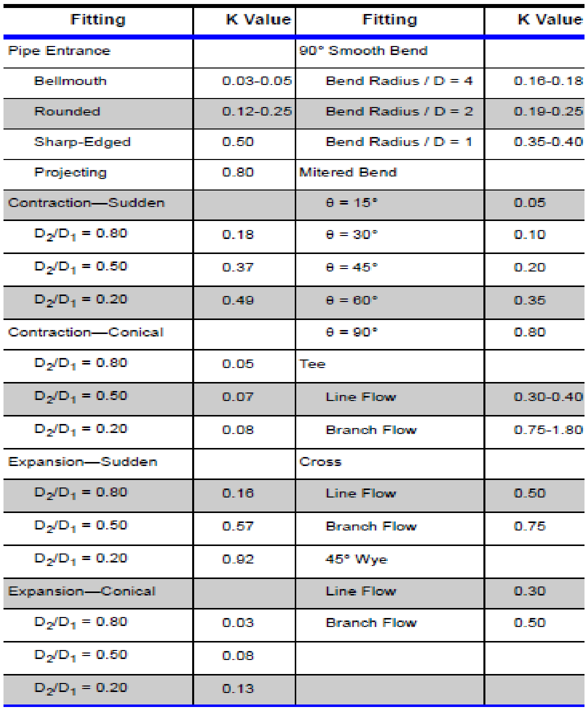
Minor losses:

The magnitude of these losses depends on the type of the fitting, which directly affects the flow in the pipe.
The following equation is used for calculating the head loss in fittings, such as valves, pipe entrance, contraction, expansion or other localized component is given by:

$h_m = K\,(V^2 / 2g)$ (12)

Where:
h_m: loss due to the minor loss element (m);
K: loss coefficient for the specific fitting;
V: mean velocity (m/s); and
g : gravitational acceleration (m/s^2)
Values of K are given in table (2).

TABLE (2)
TYPICAL VALUES OF FITTING K COEFFICIENT



Fitting	K Value	Fitting	K Value
Pipe Entrance		90° Smooth Bend	
Bellmouth	0.03-0.05	Bend Radius / D = 4	0.16-0.18
Rounded	0.12-0.25	Bend Radius / D = 2	0.19-0.25
Sharp-Edged	0.50	Bend Radius / D = 1	0.35-0.40
Projecting	0.80	Mitered Bend	
Contraction—Sudden		$\theta = 15°$	0.05
$D_2/D_1 = 0.80$	0.18	$\theta = 30°$	0.10
$D_2/D_1 = 0.50$	0.37	$\theta = 45°$	0.20
$D_2/D_1 = 0.20$	0.49	$\theta = 60°$	0.35
Contraction—Conical		$\theta = 90°$	0.80
$D_2/D_1 = 0.80$	0.05	Tee	
$D_2/D_1 = 0.50$	0.07	Line Flow	0.30-0.40
$D_2/D_1 = 0.20$	0.08	Branch Flow	0.75-1.80
Expansion—Sudden		Cross	
$D_2/D_1 = 0.80$	0.16	Line Flow	0.50
$D_2/D_1 = 0.50$	0.57	Branch Flow	0.75
$D_2/D_1 = 0.20$	0.92	45° Wye	
Expansion—Conical		Line Flow	0.30
$D_2/D_1 = 0.80$	0.03	Branch Flow	0.50
$D_2/D_1 = 0.50$	0.08		
$D_2/D_1 = 0.20$	0.13		

III. BENTLEY HAMMER V8I MODEL

At present the method of characteristics is the most general and exact technique for solving the governing equations. Fortunately this technique is also very compatible with numerical solutions by digital computer. These numerical solutions using the method of characteristics have been given by many researchers such as given by El-Alfy (1991), Bryan and McInnis (1992), El-Ghandour (2010), Afshar et al. (2010), and Wang and Yang (2015).used explicit –implicit method to study the flow transient in single pipe line.

Bentley model has been used for over 15 years on a large number of water and wastewater projects. It has been also required to model other fluid and tackle problems in other industry sectors, adding to its generality and confirming its robust algorithms. The following additional capabilities are required for the model:

Boundary conditions must be expressed as algebraic and/or differential equations based on their physical properties. This must be carried out for every hydraulic elements in the model and solved along with the characteristics equations.

Equations of state are incorporated to model vaporous cavitations, where water can change into vapor at low pressure.

The length of computational reaches must be set to achieve sufficient accuracy without resulting in too small and an excessively long execution time. Bentley model automatically sets an optimal time step based of pipe lengths, wave speeds, and overall system size.

Friction losses are assumed to be concentrated at solution points.

Different models can be implemented, ranging from steady state, to quasi steady to unsteady (transient).

Figure (2) shows the flow chart of Bentley HAMMER program

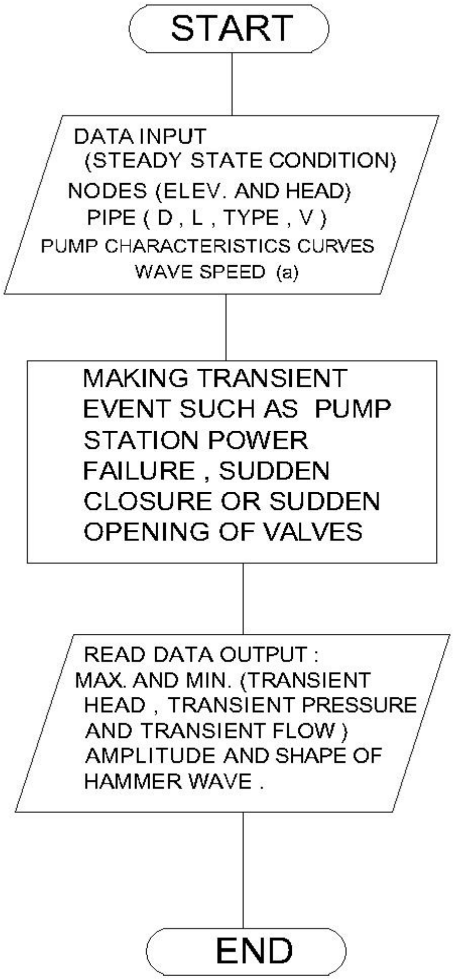
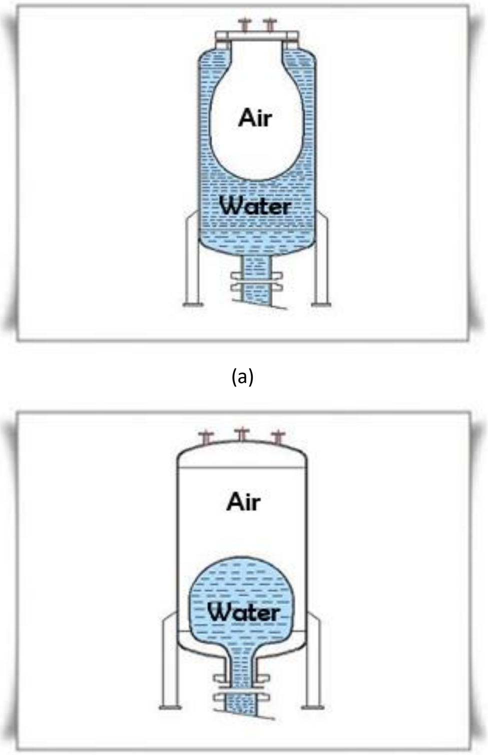


Fig (2): Bentley HAMMER flow chart

IV. AIR VESSELS

As the air vessels have some advantages in dealing with the negative pressures more effectively than other devices and also can maintain a positive pressure in the time at all stages following the pump trip (Wang et al., 2010). The problem with air vessel is that the air slowly dissolves into the water with which it is contact, particularly when under pressure. Therefore, top up compressor is needed with lower and upper limits switches to maintain a relatively constant water level under operating conditions. Another problem is the initial filling of air vessel. The volume of the air at standard atmospheric pressure may not be sufficient to provide the necessary volume under pressure. In order to solve this problem, the vessel can be built larger than necessary or it can be topped with compressor.

Bladder air vessels, Figure 3, are popular solution to this problem. Air is contained in airtight bladder in the vessel which expands as the air expands. Although the bladder may eventually need replacing, it saves compressor costs, and maintenance, therefore bladder air vessels are particularly valuable for remote locations since they require little maintenance. The bladder vessels can be classified into two types air in bladder type, Figure (a) and water in bladder type, Figure (b)



(a)

(b)

Fig.(3) : Air vessels with bladders

The bladder material is made from a highly elastic rubber, such as butyl rubber, and may be sized to expand to fit the entire vessel.

In first type the tank material is chosen compatible with water, while in the second type the bladder material is chosen compatible water.

Wang et al. (2010) studied the effect of air vessel on water hammer in high head pumping station using the method of characteristics. They showed that the air vessel volume is the key parameter that determines the protective effect on water hammer pressure. The position of air vessel should be close to the outlet of the pump.

Graphic, formula, and estimation methods are the widely used methods for determining the size of air vessel. However this can be determined by trial on the basis of these methods.

Design aids of air vessels for transient protection of large pipe networks are given by Ramalighan (2007) . Also Stephenson (2002) presented a simple guide for the design of air vessels.

V. BOSAT KAREEM EL- DEIN PUMP STATION

Bosat Kareem El- Dein pump station consists of six pumps each has specific speed 25 in SI units, design discharge 360 lit /sec under a design head of 48 m maximum head 64 m, Figure 4, which is required to pump water to about 640,000 capita for the required demand of about 160,000 cubic meter per day at the convenient pressure. Table (3) presents the cities and villages which have to be fed from this station. The table also demonstrates the consumption in cubic meter per day for every city and village according to year 2015.

Figure (4) illustrates Bosat Kareem El- Dein pipe network after simplification. Three main passes were studied, Path 1, Path 2, and Path 3.

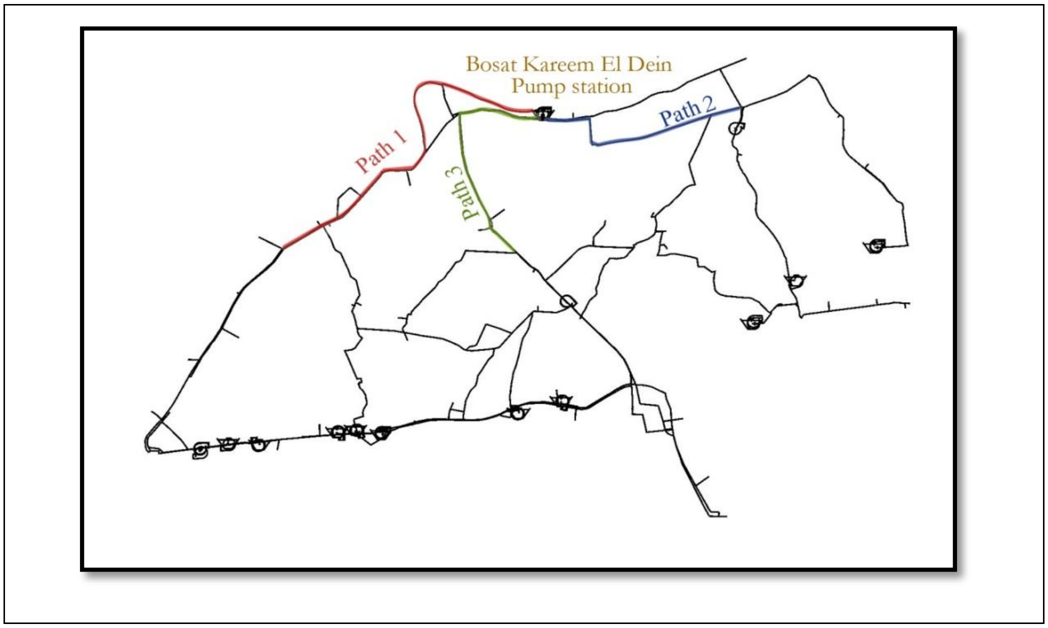
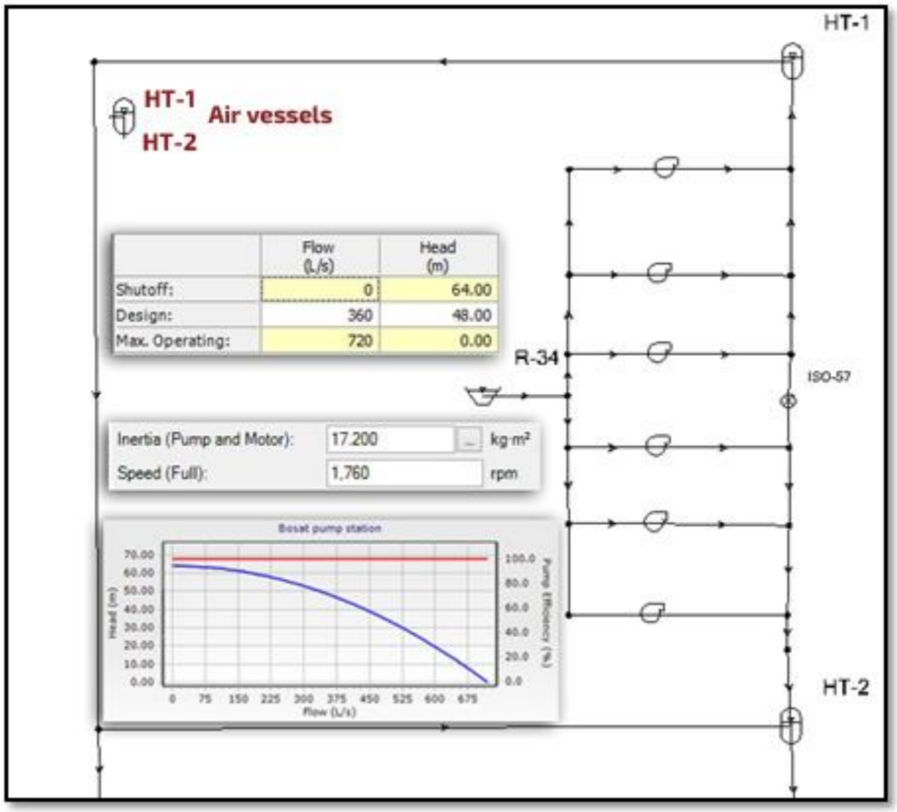


Fig. (4): Layout of Bosat Kareem El- Dein water network, showing the three Paths.
(Dakhlia Company, 2015)

Figure (5) exhibits Bosat Kareem El Dein pump station and pump characteristic curves (Dakhlia Company, 2015)



	Flow (L/s)	Head (m)
Shutoff:	0	64.00
Design:	360	48.00
Max. Operating:	720	0.00

Inertia (Pump and Motor): 17.200 kg·m²
Speed (Full): 1,760 rpm

Fig. (5) : Bosat Kareem El Dein pump station and pump characteristic curves

TABLE (3)
POPULATION AND DAILY CONSUMPTION FOR CITIES AND VILLAGES OF BOSAT NETWORK

NO.	Village / Citiy	Zone	Population	Consumption m3/day
1	Bosat Kareem El-Dein	Shirben	24093	5439.036
2	Monshaat Elgammal	Minyet Elnasr	11062	2497.241
3	Al-Nazl	Minyet Elnasr	17114	3863.547
4	Al-Bagalat	Minyet Elnasr	20583	4646.777
5	Mit Temama	Minyet Elnasr	12365	2791.488
6	Mit Hadeed	Minyet Elnasr	3371	760.970
7	Monshaat Mubarak	Mansoura	3418	771.626
8	Al-salam	Minyet Elnasr	2779	627.324
9	Kafr Abo Ali	Dekernes	1936	437.104
10	Mahalet Inshaq	Shirben	13929	3144.477
11	Al-Baramon	Mansoura	18080	4081.715
12	Al-Badala	Mansoura	6685	1509.118
13	Al-Khayaria	Mansoura	11902	2686.964
14	Mit Mazah	Mansoura	12605	2845.714
15	Kafr Mit Fatek	Mansoura	4701	1061.177
16	Al-Redania	Mansoura	6352	1434.032
17	Salamoun	Mansoura	20393	4603.703
18	Shuha	Mansoura	25935	5855.010
19	Kafr El-Elew	Mansoura	473	106.872
20	Kafr Saafan	Mansoura	2590	584.612
21	Minyet Mahalet Damna	Mansoura	14290	3226.109
22	Kafr Abd-Elmoamen	Dekernes	6022	1359.398
23	Al-Qebab Elkobra	Dekernes	2542	573.775

24	Kafr Alqebab	Dekernes	1580	356.736
25	Gezerat Alqebab	Dekernes	4364	985.144
26	Mahalet Damana	Dekernes	25235	7595.796
27	Monshaat Elsalam Kafr Elaagar	Mansoura	7138	1611.339
28	Demow	Dekernes	11217	2532.323
29	Mit Dafer	Dekernes	9531	2151.612
30	Alqebab Elsoghra	Dekernes	8673	1958.006
31	Almarsah & Alkhashashna	Dekernes	5099	1151.208
32	Kafr AlBaz	Dekernes	3528	796.414
33	Demeshalt	Dekernes	18855	4256.494
34	Mit AlNahal	Dekernes	8019	1810.363
35	Neger &Mit Shadad	Dekernes	17253	3894.927
36	AlZahyra & Kafr Alzahyra	Dekernes	4835	1091.564
37	Kafr Abu Naser	Dekernes	7384	1667.055
38	Al-Azazna	Dekernes	4076	920.081
39	Al-Qalubya	Dekernes	1909	430.964
40	Naser	Dekernes	3221	727.197
41	Mit Taref	Dekernes	12582	2840.387
42	Mit Shraf	Dekernes	3831	864.862
43	Mit Elsudan	Dekernes	4584	1034.855
44	Mit Saadan	Dekernes	2897	653.963
45	Ashmoun Alromman	Dekernes	9609	2169.311
46	Alkorama Algdeda	Dekernes	2523	569.621
47	Tranees Albahr	Mansoura	3560	803.638
48	Menyet Badaway	Mansoura	3859	871.183
49	Badaway	Mansoura	18024	4069.073
50	Kafr Badawy Elqadeem	Mansoura	8834	1994.262
51	Kafr Albaramoun	Mansoura	7806	1762.323
52	Kafr Badawy Elgeded	Mansoura	1967	444.102
53	Dekernes	Dekernes	77516	23332.628
54	Minyet Elnasr	Minyet Elnasr	65946	19850.002
55	Monshaat Mubarak	Mansoura	1924	434.305
56	Ezbet Albondera	Mansoura	2661	600.730
57	Alnozha	Mansoura	4346	981.080
58	Alkorama	Dekernes	8954	2021.488
59	Algenena	Minyet Elnasr	8203	1851.766
60	AlBashmour	Dekernes	2445	552.013
	Total =		637208	156546.6

VI. . RESULTS AND ANALYSIS

6.1 Influence of Pipe Friction

Variations of amplitude and damping time of the pressure surge wave, due to the change of pipe friction are given in this section**.** Two pipe lines were selected from the network, pipe No.426 and pipe No. 430. Values of Hazen Williams were changed by about 5 to 10 % of the actual ones

Figure (6) illustrates the shape of pressure wave for the actual value of Hazen Williams coefficient (C) for pipe line No.426, while figures (7) and (8) demonstrate the corresponding shape for decreasing and increasing the value of (C) respectively.

At time equal to about 80 sec, Figure (6) shows the amplitude of pressure wave varies approximately between 32 m and 15 m for the estimated value of (C), and varies between 21m and 19 m for decreasing the value of (C) as shown in figure (7) and also varies between 41 m and 19 m as given in figure (8) for increasing the value of (C).

Also for pipe No 430, Figure (9) shows the shape of the pressure wave for the actual value of (C), while Figures (10) and (11) exhibit the same of this wave for decreasing and increasing the value of (C).

At time about 80 sec, Figure (9) shows the pressure wave amplitude approximately ranges from 85 m to 63 m for the estimated value of (C), and ranges from 75 m to 60 m for decreasing (C) as shown in figure (10), and ranges from 90 m to 65 m for increasing the value (C) as shown in figure (11).

It may be concluded that decreasing the Hazen Williams Coefficient (C) by about 5 -10%, will increase friction through the pipeline and consequently decrease the amplitude and damping time of pressure wave appreciably.

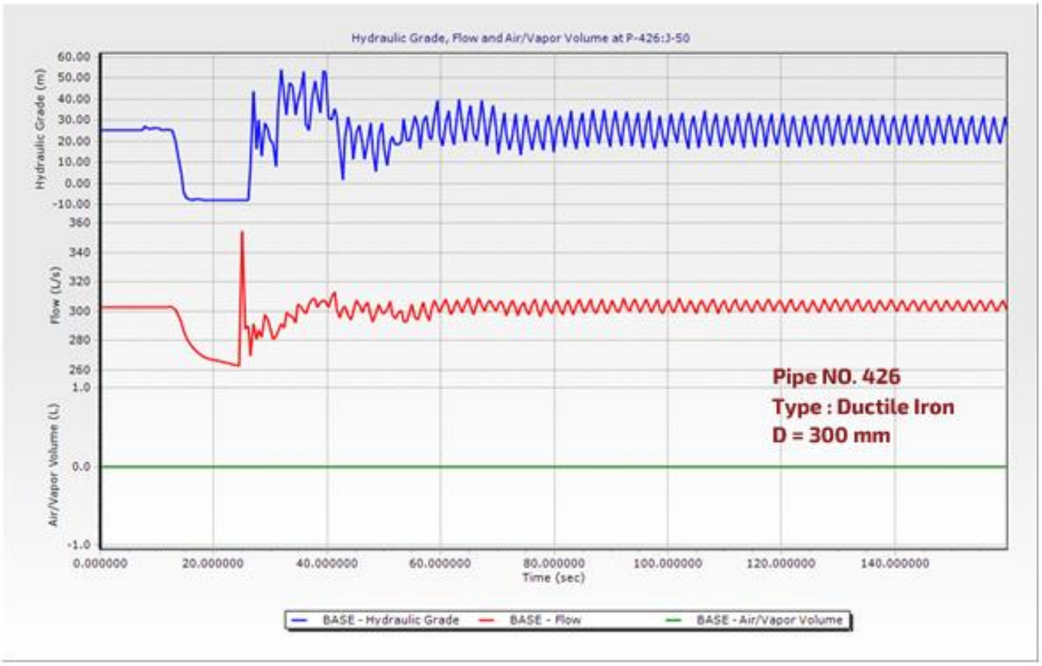


Fig. (6): Wave shape during transient event in pipe No.426 using the estimated (C)

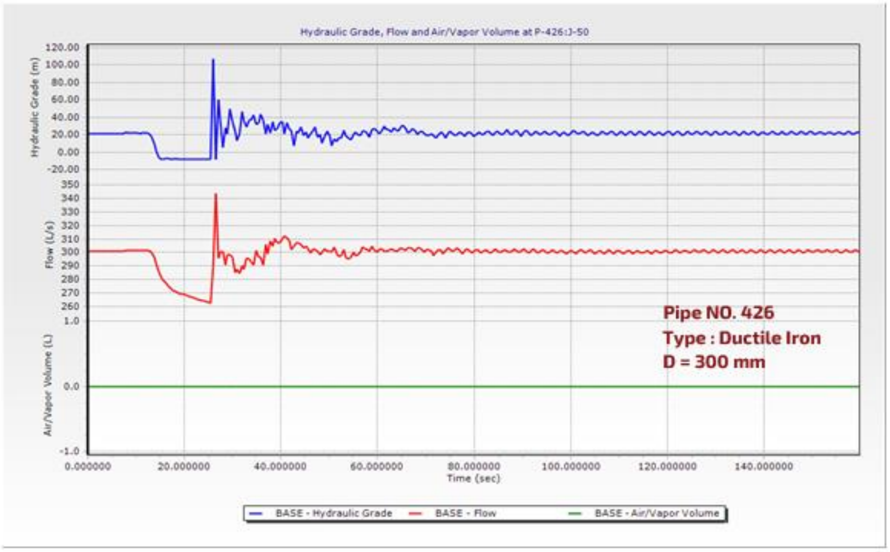


Fig.(7): The effect of reducing Hazen Williams coeff. (C) by about 5-10% in pipeline No.426

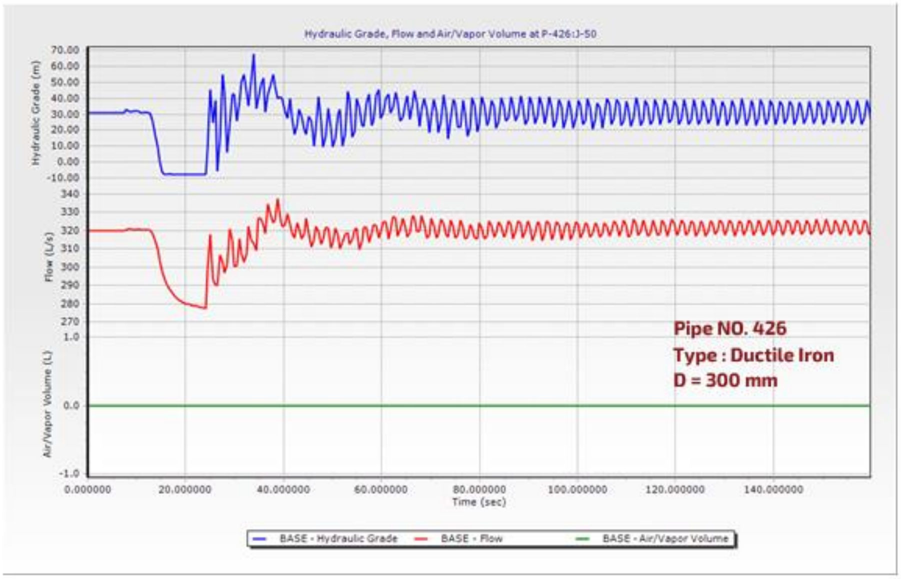


Fig.(8): Effect of increasing Hazen Williams coeff. (C) By about 5-10% in pipeline No.426

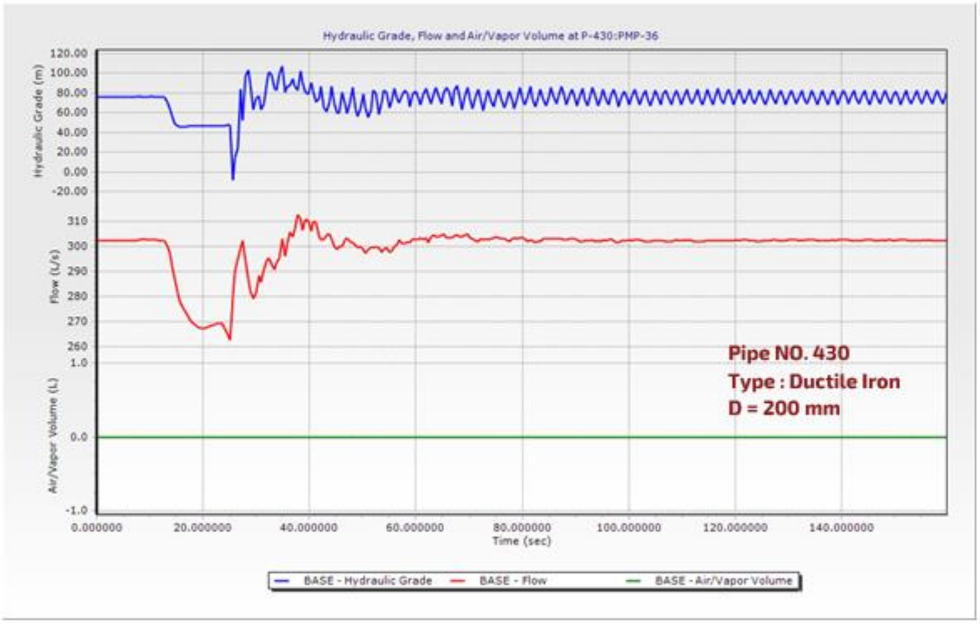


Fig.(9):Wave shape during transient event in pipe No.430 using the estimated (C)

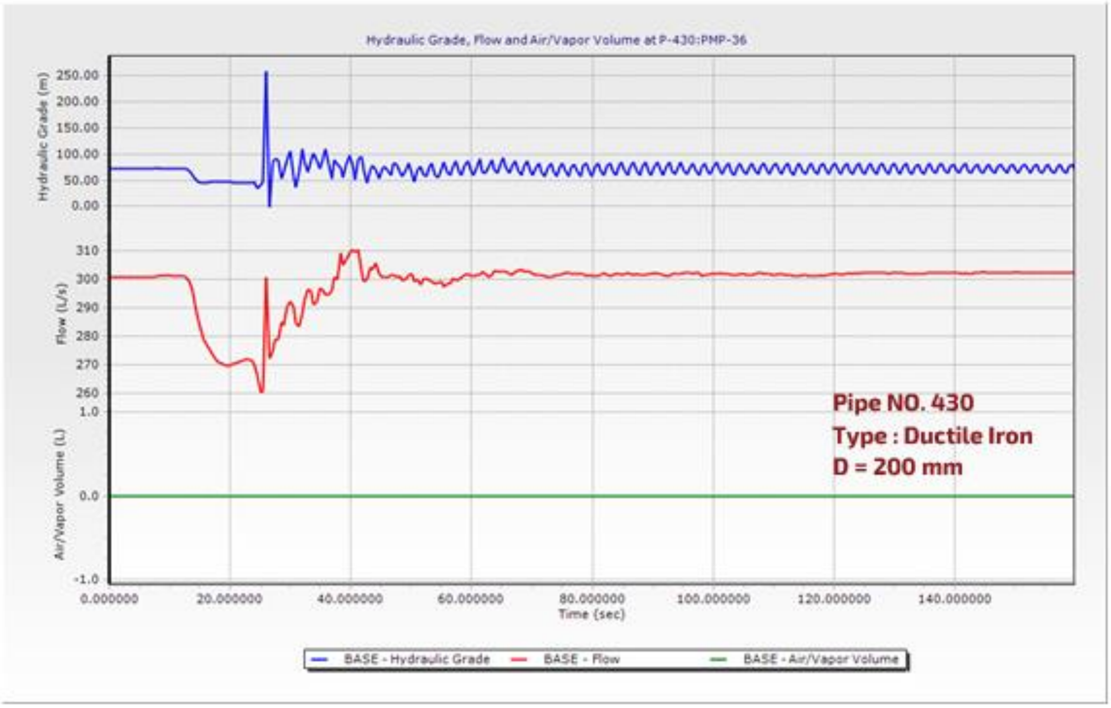


Fig.(10): Effect of reducing Hazen Williams coeff. (C) by about 5-10% in pipeline No.430

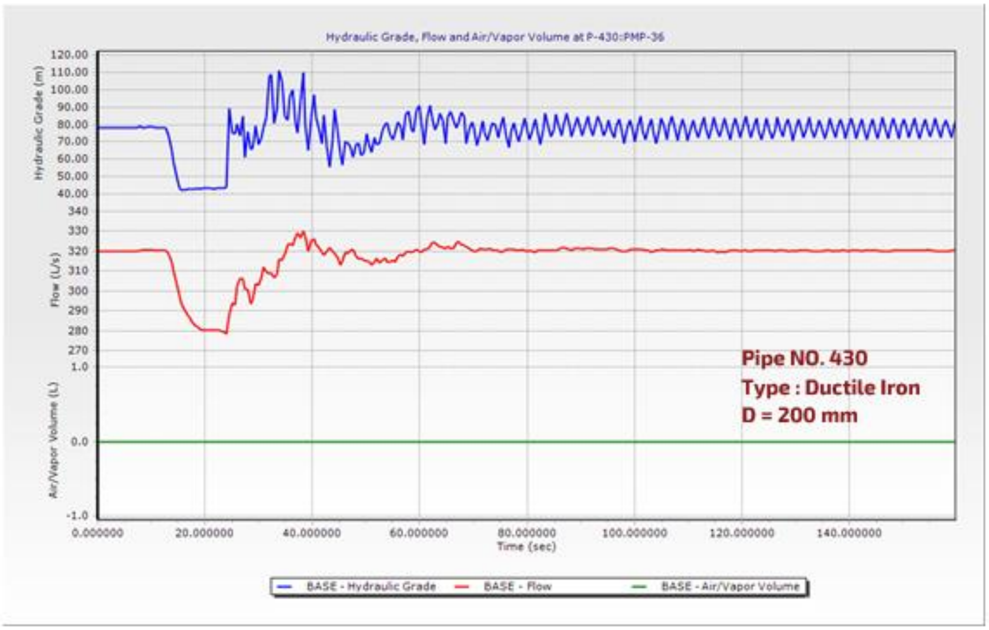


Fig. (11): Effect of increasing Hazen Williams coeff. (C) by about 5-10% in pipeline No.430

Estimation of roughness coefficients for the pipe network were carried out according to age, pipe material, pipe diameter and pipe wall thickness. These parameters have a direct effect on water hammer simulation.

6.2. Influence of Sizing Air Vessels

Water Hammer Vi8 model was applied on Bosat Kareem El- Dein water pipe network, three Paths have been considered Path 1, Path 2, and Path 3 as shown in Figure 4

Hazen William coefficient was estimated for every pipe in the network according to pipe material and age, Table (1), and minor losses of energy are incorporated in the model as given in Table (2). Figures (12,16 and 20) show the initial, minimum and maximum hydraulic grade lines for the three Paths respectively. It is noticed that Path2 is more influenced than the two other Paths; this is mainly due to, length of the Path no much bends, valves, elbows, diameter and type of pipes. Three main Paths, Path 1, Path 2 and Path 3 of Bosat Kareem El-Dein water network were studied. Path 2 was more influenced by the water pressure wave than the other two Paths due to the pump station stoppage. This mainly due higher velocity value in this Path, the increase of pressure head (Δ h) is given by:

$$(\Delta h) = a \cdot \Delta V/g \qquad (13)$$

Negative pressures are observed along the three Paths are about 6, 10, and 7 m pressure head respectively, which may cause evaporation of water in these Paths especially Path 2 at the normal temperature of water in the pipelines.

Two air vessels are used to tackle the problem of water hammer in this network, having different volumes 30, 50, 100, and 150 m^3 each. Size 100 m^3 gives nearly the same results as size 150 m^3 (not included). The difference between size 50 m^3 and 100 m^3 could be tolerated.

Path 1

Figures (12) through (15) exhibit the influence of air vessel volume on the pressure wave for volume 30, 50, 100 m^3 respectively.

Path 2

Figures (16) through (19) show the influence of air vessel volume on the pressure wave for volume 30, 50, 100 m^3 respectively.

Path 3

Figures (20) through (23) present the influence of air vessel volume on the pressure wave for volume 30, 50, 100 m^3 respectively.

It can be concluded that increasing the volume of the air vessel accelerate the maximum pressure to go down to the initial condition and increasing the values of minimum pressure.

Selection of the volume depends on avoiding negative pressure and also on the economical point of view.

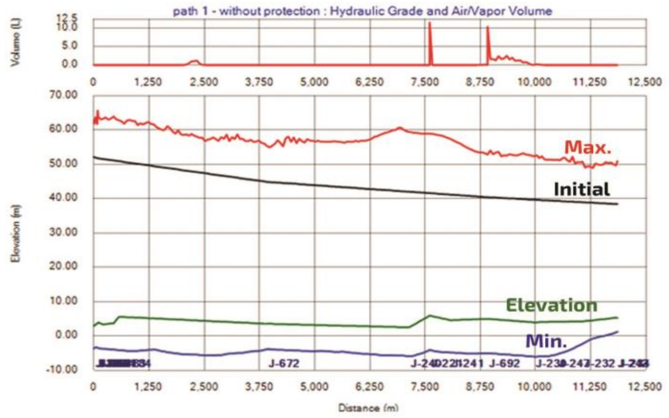


Fig. (12): Initial ,max. and min. H.G.L of path (1) after transient event (without protection)

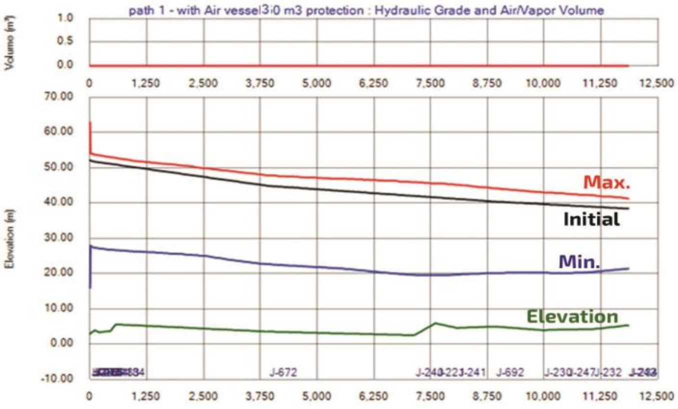


Fig. (13) : Initial , max. and min. H.G.L of path (1) after using Air vessel 30 m3

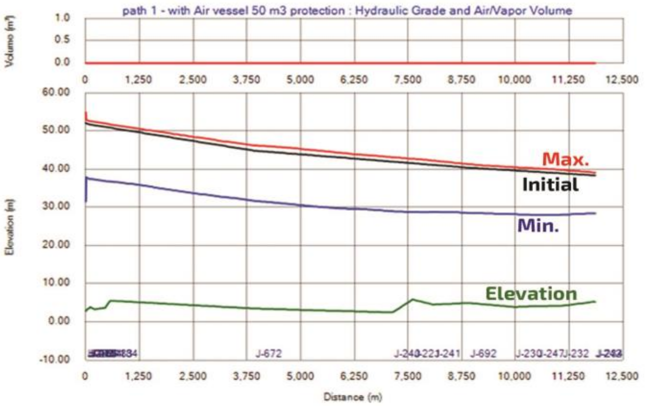


Fig. (14) : Initial , max. and min. H.G.L of path (1) after using Air vessel 50 m3

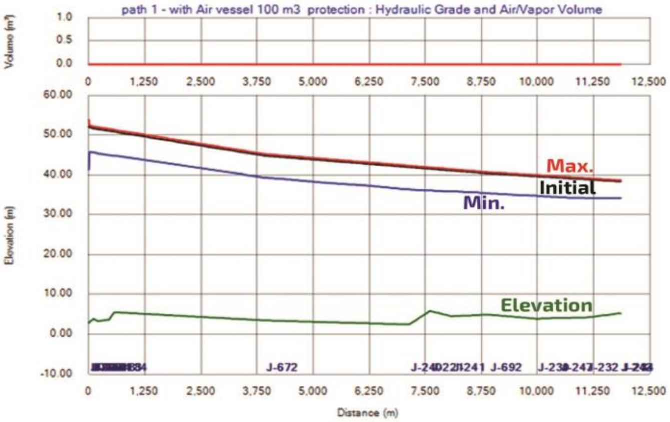


Fig. (15) : Initial , max. and min. H.G.L of path (1) after using Air vessel 100 m3

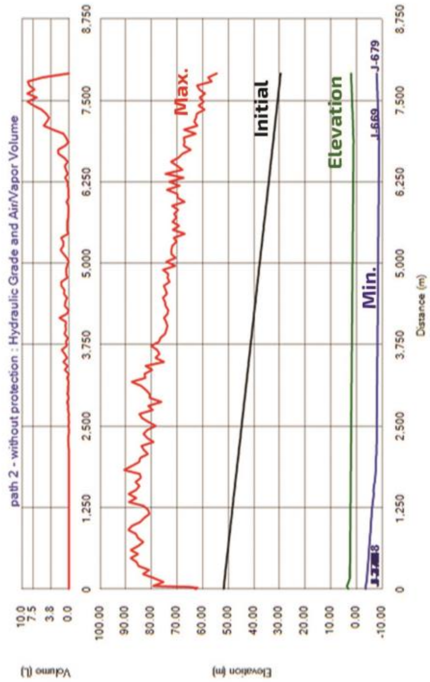


Fig. (16): Initial ,max. and min. H.G.L of path (2) after transient event (without protection)

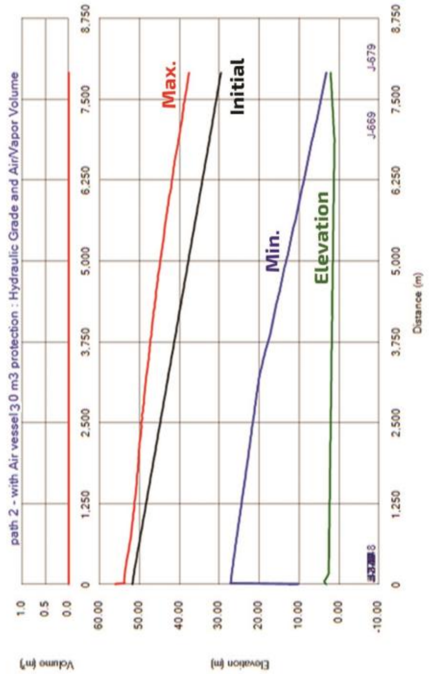


Fig. (17) : Initial , max. and min. H.G.L of path (2) after using Air vessel 30 m3

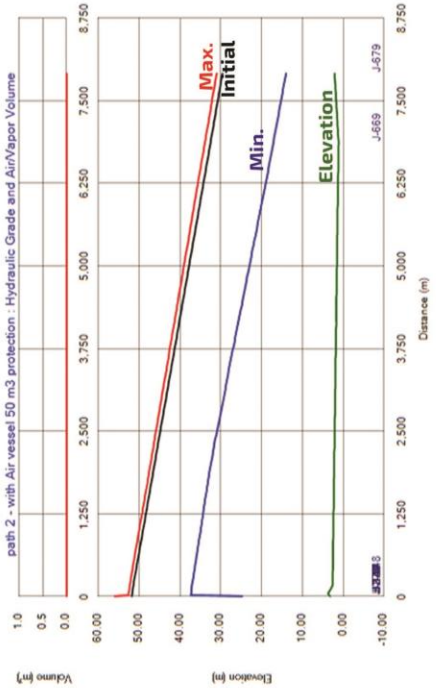


Fig. (18) : Initial , max. and min. H.G.L of path (2) after using Air vessel 50 m3

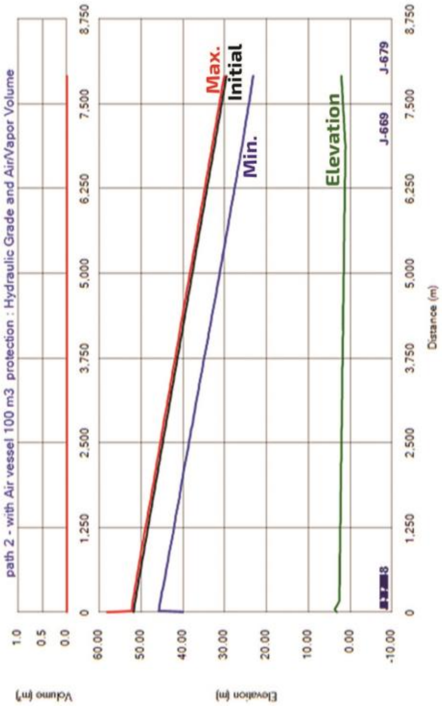


Fig. (19) : Initial , max. and min. H.G.L of path (2) after using Air vessel 100 m3

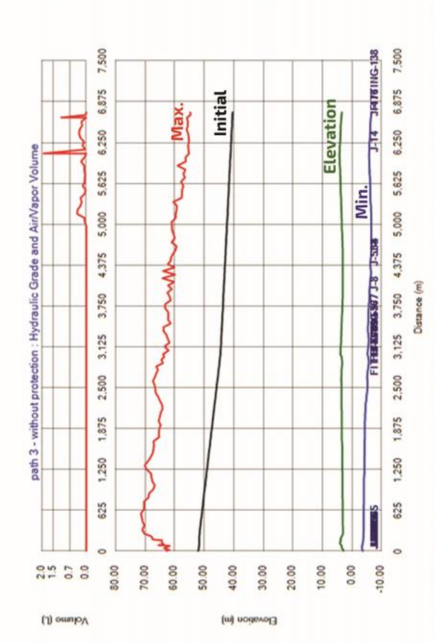


Fig. (20): Initial, max. and min. H.G.L of path (3) after transient event (without protection)

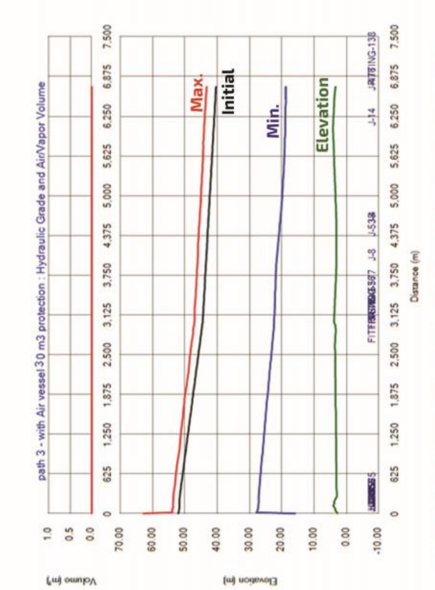


Fig. (21): Initial , max. and min. H.G.L of path (3) after using Air vessel 30 m3

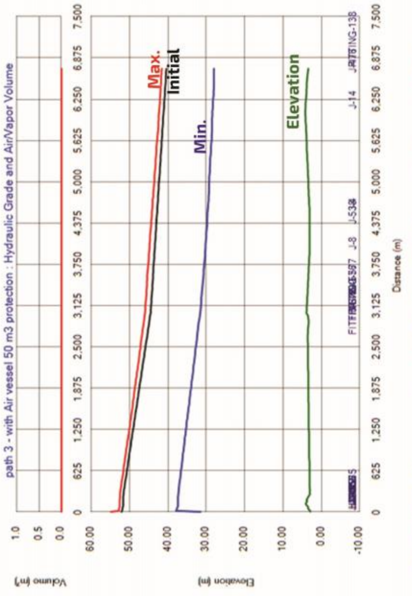


Fig. (22): Initial , max. and min. H.G.L of path (3) after using Air vessel 50 m3

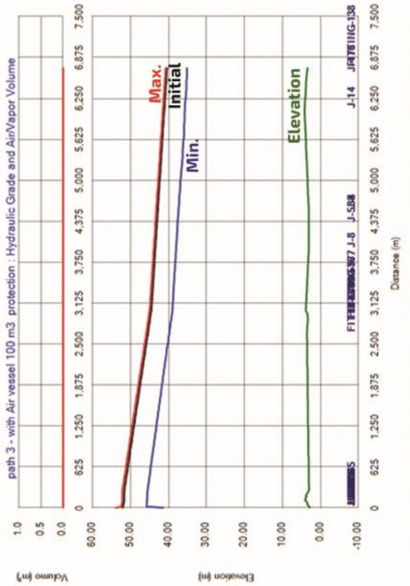


Fig. (23): Initial , max. and min. H.G.L of path (3) after using Air vessel 100 m3

VII. CONCLUSION

From the following research paper it could be concluded that:

- Water velocity, length of pipe, Modulus of elasticity, inside diameter of pipe, pipe wall thickness and roughness coefficient are the main factors affecting the severity of water hammer.
- Three main Paths, Path 1, Path 2 and Path 3 of Bosat Kareem El-Dein water network were studied. Path 2 was more influenced by the water pressure wave, due to the pump station stoppage, than the two other Paths, mainly due to higher water velocity.
- Increasing the friction resistance for Bost Kareem El Dein network by about 5 to 10 % has a pronounced effect on damping the pressure wave
- Substantial negative pressure heads have been observed for the three Paths, especially Path 2. This may lead to vapor pressure resulting in a destructive effect on the pipe network.
- The present research highlights that the air vessels are suitable means of protecting pipelines networks.

Increasing the size of vessels decrease the damping time of the surge pressure wave, but this should be regarded from the economical point of view. The optimal size is 100 m^3 but the economical size is 30 m^3

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