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Throttling and Booster Pumps Control of Al-Karkh Water Scheme

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Abstract

The Karkh water project has been constructed and put in operation in 1986, in order to supply drinking water to the Karkh district on the right side of Baghdad. Due to deficit in water in the Rusafa side the Baghdad Water Supply Administration (BWSA) has suggested a reasonable solution in which about (455000 m3/day) of water was to be transferred from Karkh to Rusafa water services. The transfer process, controlled by throttling two valves on the North reservoir in the Karkh service system. The throttling process, however, worked randomly creating many hydraulically problems. Therefore, it becomes very essential to suggest a proper solution so that a fair distribution could be achieved. Two solutions have been employed the first is by operating partial throttling of the terminal discharge valve at north reservoir (TDV). The second solution, which is the safest, is to use boosting pumps to transfer 455 MLD to Al-Rusafa side so as to reserve the right amount of water to all reservoirs.

In finding the best locations of boosting pumps the technique of contour line has been used, the optimal locations and the characteristic curves of the pumps have been discussed.

The research is expanded to include how to protect the pumps against damage that could be created by back flow and hammering.

A computer program has been developed in Quick Basic language to analysis the best throttling percentages. The Lagrange polynomial method has been implemented to find the medium values of combination between throttling percentage and field measurement of pressures.

الخلاصة

تم تشييد مشروع ماء الكرخ وتشغيله عام ١٩٨٦ لتجهيز مياه الشرب لمنطقة الكرخ في الجانب الأيمن من بغداد. ونظرا لشحة مياه الشرب في جانب الرصافة فقد أقرت دائرة ماء بغداد مقترحا لحل مناسب يتم بموجبة تحويل حوالي(٤٥٥٠٠٠) متر مكعب يوميا من شبكة ماء الكرخ إلى شبكة ماء الرصافة . وقد تطلب تنفيذ هذا الحل استخدام إسلوب الخنق لصمامين في الخزان الشمالي من منظومة ماء الكرخ، إلا إن عملية الخنق تجري بشكل عشوائي مما يتسبب عنها مشاكل هيدروليكية، وعلية بات من الضروري اقتراح حل مناسب للحصول على توزيع مقبول للمياه. تم تطبيق اثنين من الحلول، الأول يعتمد على الخنق الجزئي للتصريف من خلال صمام الموقع الطرفي للخزان الشمالي ، والحل الثاني وهو الأكثر أمانا يعتمد على استخدام مضخات منشطة لتحويل (٤٥٥) مليون لتر لجانب الرصافة بحيث يتم ضمان تجهيز جميع الخزانات بالكمية المناسبة من الماء.

في البحث الحالي أيضا تم استخدام طريقة الخط الكنتوري لإيجاد أفضل المواقع للمضخات المنشطة من خلال مناقشة المواقع المثلى ومنحنيات خواص المضخات. كما تضمن البحث كيفية حماية المضخات من الجريان العكسي وظاهرة الطرق المائي.

هذا وتم كتابة وفحص وتشغيل برنامج حاسبة يمكن من خلاله إيجاد أفضل نسبة خنق وذلك على أساس استخدام طريقة سلسلة " لاكرانج " اعتمادا على القياسات الحقلية للضغوط في المنظومة.

1. Over Look on Al-Karkh Water Project

Several works have appeared dealing with simple system components such as pipes, reservoir and constant discharge pumps, pressures reducing valves (PRV) and booster pumps. The next presents repetition in some of the availability collection of studies that deal with the pumps in their subjects.

Colin et. al. [1] developed a method for analyzing the large distribution systems that content other essential system components, such as booster pumps, pressure reducing valves and check valves.

Anthany and Dowdy [2] was concerned with formulating the hour by hour demand forecasting problem within the framework of an on-line pump-scheduling scheme, and with comparing two well known statistical forecasting methods to evaluate their effectiveness in terms of accuracy and computational feasibility.

Abdul Razzak A. M. [3] presented a method to find both the optimal locations and characteristic curves of booster pumps within the pipe networks, and to improve the pressure heads at nodes below the satisfaction due to execution an unexpected expansion in the system on obligation to increase demand for any reason.

Ibrahim H. M. [4] studied some methods of pipe networks analysis for finding the best locations of booster pumps.

The Karkh treatment plant is located at 30 km North of Baghdad city on the west bank of Tigris. This project has been in commission since 1985.

The Tigris River is the water source supplying the city of Baghdad. The first stage (I) of construction of the Karkh water project consists of two identical streams each of 455000 m^3/day in capacity, with the provision for extension by the addition of a third similar stream to give a total output of 1365000 m^3/day. The treatment works include pre-settlement tanks clarifies, rapid gravity sand filters with full chemical treatment and a pumping station.

Water that is abstracted from the Tigris River will be treated and delivered by a system of pipelines to ground level storage reservoirs located throughout the city. The water which is taken from the reservoirs will be pumped into a pipe networks to consumers.

Stage II of the scheme which consists of the cross river link is designed to allow transfer of water between the systems supplying the east and west bank city areas of Baghdad.

The works are designed to cope with variations in raw water quality, in seasonal demand and are required to meet a daily demand rising from about 225000 m^3/day to 1365000 m^3/day.

2. Description of Transmission Pipelines

The transmission pipelines are designed to convey 1365 MLD of treated water pumped to the storage reservoirs at North reservoir, with a tee off for Taji and Saba Nissan works (Rusafa Network). The distances from the Treated Water Pumping Station (TWPS) to the North reservoir, Taji and cross river link branch off are 40 km, 26 km, and 31.45 km respectively, as shown in **Fig.(1)**.

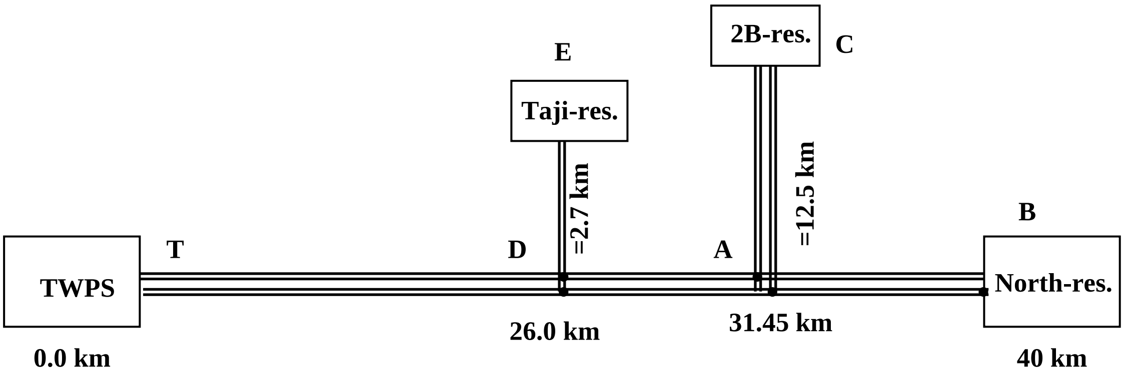

Figure (1) Transmission pipeline

The pipelines are 2300 mm and 2100 mm in diameter alternately changing in size at each cross over chamber. The cross river link pipelines are 1600 mm and 1400 mm in diameter while Taji branch is a single 800 mm in diameter pipeline.

The pipelines are of ductile iron designed for normal operating pressure up to (9.4 Bar) and were tested to 13.6 Bar. Air valves are provided at all high points all along the pipeline and also downstream side of delivery manifold in the (TWPS) to expel air during filling of line and letting in air in case of negative pressures during surge conditions. These air valves will ensure that the minimum pressure in the transmission pipelines does not fall below 2 m below atmospheric.

A magnetic flow meter is provided on each of the two pipelines downstream of the (TWPS) for measuring the flow through each line. The flow through a single transmission pipeline, when for instance an adjacent length of the other pipeline is isolated should under normal circumstances be about half the design flow, i.e. 682.5 MLD.

3. Field work

The practical aspects of this study was to measure the pressure at certain locations for the system shown in **Fig.(1)**.

3-1 Method of Measurement

The procedure of measuring the pressure is carried out by placing the Bourdon gage inside the air valves, which are already fitted to the system. The experiment was repeated times. Each time the percentage of throttling of inlet valve at north reservoir is changed.

The first point of measurement was at point B, which is located (39.926 km) from Karkh treatment plant, **Fig.(1)**. The second point for measurement is at point A which is the point of cross river link to 2B-reservoir. The measurements were taken from valve chambers (COVC) (7) which is located (31.964 km) from Karkh treatment plant. Point C is located at distance (0.5 km) from 2B-reservoir, and it is the nearest measuring point to the reservoir. Point D is located where the Taji pipeline branched from the transmission pipelines, which is located (25.964 km) from Karkh treatment plant. Measurements are taken also in COVC (6), which is located (26.967 km) from Karkh treatment plant since it is the only possible measuring location.

The last measuring point is E, which is located at a distance (0.5 km) from the Taji reservoir. This point was the nearest point to the Taji reservoir.

The results of pressures with various percentages throttling for the terminal discharge valve at North reservoir are shown in **Table (1)**.It should be noted that the pressures at point (T) are taken from the control room at (TWPS).

Table (1) Pressure measurements

Location	**Terminal discharge valve (TDV) throttling % at north reservoir**					
	0	**15**	**25**	**35**	**45**	**50**
	Pressure Head (m)					
PB	8	10	13.25	16	19	23
PA	17	18	21.1	23.5	25	27
PC	4	5	6.25	6.3	6.35	6.7
PE	21	22	22.5	23.1	24	24.5
PD	25	26	29.1	31	36	41
PT	69.8	69.85	70	70.1	71	71.4

3-2 Estimation of the Excessiveness Quantity

For estimation the amount of excessiveness the difference between the storage of the water in each reservoir has been record within specified time through which the demand has been computed, as shown in **Table (2)** and then the following water balance relationship.

Excessiveness quantity = total inside flow – total out flow

Table (2) Estimation of excessiveness quantity

Reservoir	Water Elevation Before Shutdown Ho (m)	Water Elevation After Shutdown H_1 (m)	Shut down time t (min)	$H=H_1-H_2$ (m)	Volume = Area ×H (m^3)	Flow = Volume/t (m^3/sec)
North	3.58	3.93	32	0.35	250×190×0.35 (16625)	8.668
Taji	3.00	3.25	26	0.25	50×50×2×0.25 (1250)	0.80
2B	2.5	2.8	20	0.30	2×150×34×0.3 (3060)	2.55

Sum=12.01 m^3/sec

Therefore, the excessiveness quantity =1140000-12.01*60*60*24=103200 m^3/day

3-3 Transmission Pipelines Analysis

The field measurements of pressures at nodes are the key to analyze the transmission pipelines, whereas the difference between these readings represents the head loss between the nodes. The Darcy-Wisbach equation was applied, together with the minor losses equation to calculate the values of flows in the system, taking into consideration that pipes are being connected in parallel, bearing different flow, in conformity with the difference in its diameters with the head loss constancy of both.

The value of roughness coefficient (*e*) increases with life and for the ductile iron was increased from (0.15 mm) in 1986 to (0.30 mm) in 1989 [5], thereby its value was taken equal to (0.5mm) in 2001. The value of friction coefficient (f) was determined by the method of trial and error applying Equation (1), for all transmission pipes sinse e/D and Re are within the limits, of using this equation. The local loss coefficient (K), was acquired from the available references of different fittings in the system [6].

$$\mathbf{f = \frac{0.25}{\left[\log\left(\frac{e}{3.7D} + \frac{5.74}{R_e^{0.9}}\right)\right]^2}} \quad \text{...} \mathbf{(1)}$$

where:

D = pipe diameter

Re = Reynold number

e = Roughness coefficient

The flows in the system change as throttling percentage changes at the North reservoir, and thereby a program was constructed, to calculate the flow for any possible throttling percentage (from 0 to 50%), whereas the throttling percentage higher than 50% is illegal, because it results in reducing the arriving quantity of water to the North reservoir, and reducing water coming from Al-Karkh water project.

Lagrange polynomial method was applied in the program to find out the medium values of the throttling percentages and reading pressures. **Table (3)** represents the acquired results by running the program.

Table (3) Flow in transmission pipelines

% Throttling	**QTD$_{\phi 2.3}$**	**QTD$_{\phi 2.1}$**	**QDE$_{\phi 0.8}$**	**QAD$_{\phi 2.3}$**	**QAD$_{\phi 2.1}$**	**QAB$_{\phi 2.3}$**	**QAB$_{\phi 2.1}$**	**QAC$_{\phi 1.6}$**	**QAC$_{\phi 1.4}$**
0	591913	477728	40911	582494	470273	473489	382593	202250	146684
15	584232	471525	40911	582494	470273	446243	360566	202250	146683
25	564575	455654	50174	560098	452185	442013	357146	21279	156866
35	552448	445863	57672	553892	449249	431982	349037	232895	168927
45	518734	418641	71186	533616	401948	38675	311926	242585	175961
50	477995	385748	83555	471666	382094	314725	254247	253165	183640

The resulted flow from operating the program was compared with the actual registered ones from the control room in the three reservoir sites and the control room in TWPS. Thus, the results of comparison are illustrated in **Table (4)**.

Table (4) The comparison between actual and calculated flow for reservoirs

Throttling (%)	**Flow from TWPS m^3/d**		**Flow to Taji res. (m^3/d)**		**Flow to 2B res. m^3/d**		**Flow to North res. m^3/d**	
	Given	**Calc.**	**Given**	**Calc.**	**Given**	**Calc.**	**Given**	**Calc.**
0	1160000	1069642	31000	40911	160000	348934	832000	856082
15	1160000	1055758	30000	40911	160000	348934	819000	806810
25	1140000	1020230	30000	50174	200000	373146	793000	799159
35	1150000	998310	38000	57672	220000	401823	756000	781019
45	1070000	937375	40000	71186	225000	418546	662000	698002
50	1060000	863743	50000	83555	300000	436805	610000	437887

3-4 The Hydraulic Performance of Pipelines Leading to 2B Reservoir

Drawing the (H.G.L.) to the transmission pipeline AC as in **Fig.(2)**, illustrates that H.G.L. is passing under that line in a certain location, and specifically under the North bridge and this confirms that a negative pressure existence and it changes as the throttling percentages change **Table (5)**.

Table (5) Negative pressure under the north bridge

Throttling %	0	15	25	35	45	50
Negative pressure	-3.618	-2.6188	-1.266	-1.098	-0.972	-0.536

Although to date it has been working with this pipeline, a more common occurrence is the pumping at some intermediate points of this pipeline as one is interested in determining the power required to meet flow rate and pressure demands specified for the system.

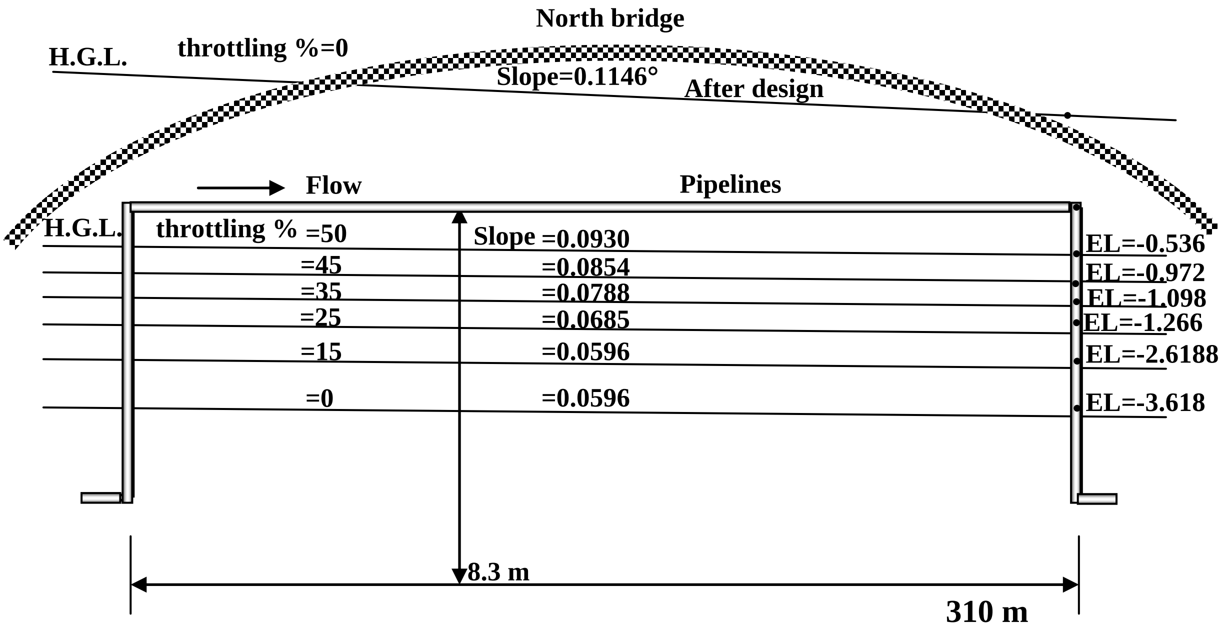

Figure (2) Various H.G.L. for various throttling percentage under the North bridge

3-5 Calculation of Additional Head Required for AC Line to Convey the Required Flow

The required value of the allowable pressure was specified on the line AC, based on the pipes height, being existed under the North bridge to avoid a negative pressure occurrence in that line and thereby its value was taken equal to be (9m) in point (C). The amount of that pressure is useful in specifying the added head to the AC line, in order to convey the required quantity of water, as well as to find out the best location of boosting pumps according to the contour lines methods, that based on the idea.

The location of the booster pumps in the pipe net works may be depend on pointing the contour line that passes through a limited value of pressure heads that decrease gradually from the value of the fixed head node by a limited portion [7].

In this study, the contour line was passed through the point of minimum allowable pressure head in the system and the booster pumps are located in the point of intersection of the pipeline AC with the contour line as shown in **Fig.(3)**.

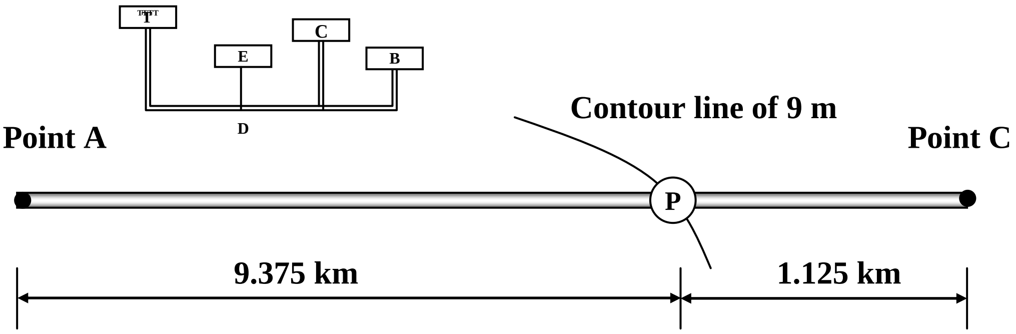

Figure (3) Best location of boosting pump station

Determination of head must take into account the pressure on the suction side (HA) as well as static head, friction losses, and desired residual pressure on the discharge side. Therefore, the required total head (H_r) at the maximum flow design condition can be calculated as:

$$H_r = HC_a - HA + H_F \quad \text{...} \quad (2)$$

where: HC_a is the minimum allowable pressure along the pipeline AC = 9m.

The computer program was developed to calculate the additional head required of the transmission pipeline AC to convey 455 MLD to 2B res. It shows also the effect of drawing this quantity on the arriving amount of flow to both reservoirs Taji and the North for any percentage of throttling. The results of running the program are shown in **Table (6)**.

Table (6) Calculation of additional head required on AC line

Throttling Y_o	TD m^3 /day	DE m^3 /day	AB m^3 /day	HB m	H_r* m
0	1069642.0	40911.44	573730.8	12.93	16.02
15	1055758.0	40911.44	559847.3	14.12	15.01
25	1020230.0	50174.59	515055.6	17.81	11.97
35	998310.3	57672.11	485638.5	20.57	9.55
45	937375.6	71186.55	411189.4	22.89	8.91
50	863743.3	83555.9	325187.7	25.67	8.10

* additional required head.

4. Controlling Devices

The primary considerations in the design of booster station are the pumping equipment and the controlling devices. The pumps should not be operated for long time in the event of a gland (or seal) failure.

4-1 Back Flow Control

A schematic arrangement of piping and flow path in constant speed pump is shown in **Fig.(4)**. Supply water under fluctuating pressure enters the suction header and flows into the pump, where it is boosted to a higher pressure. This varying high pressure water enters the PRCV, **Fig.(5)**, and the pressure is reduced to the constant pressure, desired over the design flow range. Flow reversals through spear pump and other two pump circuits are prevented by the checking feature of the PRCV, which also depends on the pressure fluctuations caused by sudden flow changes. The diameter of PRCV that satisfies the system requirement is calculated from **Fig.(6)**.

The head loss of PRCV (Hv) varies from (1 to 10 m) and it is based on valve operation of 80% open because operating the valve at less than full-open position is desirable for good pressure regulation. However the pressure loss of PRCV (Hv) is taken as 10ft (3.3m) in this study.

Therefore, required diameter of PRCV can be calculated by using the equation of 10ft (3.3 m) head loss from **Fig.(6)**.

$$D_v = 0.21055537\, Q^{0.48}$$

$$D_{v1.4\phi}=0.21055537\,(35091.6)^{0.48}=34.74 \text{ in} = 83 \text{ cm}$$

$$D_{v1.6\phi}=0.21055537\,(48389.8)^{0.48}=40.63 \text{ in} = 104 \text{ cm}$$

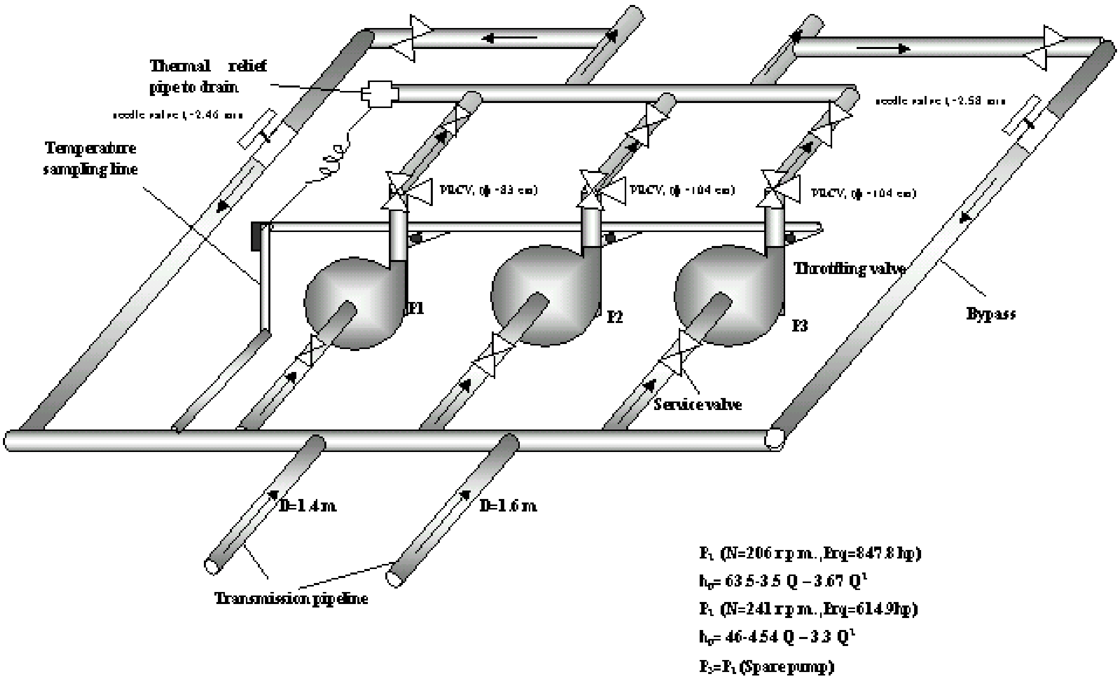

Figure (4) Final arrangement of booster pump station

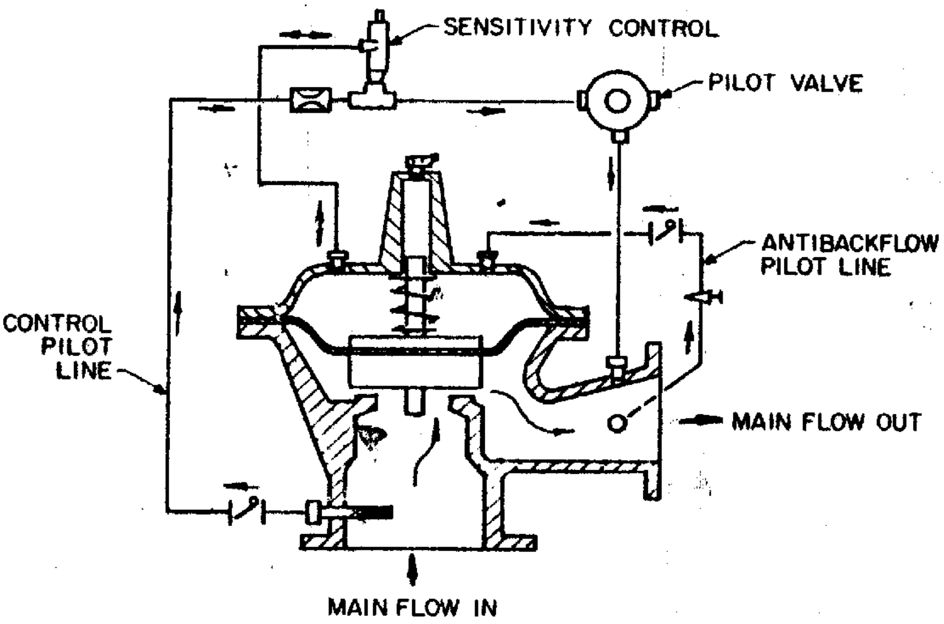

Figure (5) Typical pressure reducing and check valve to maintain constant system pressure and prevent back flow

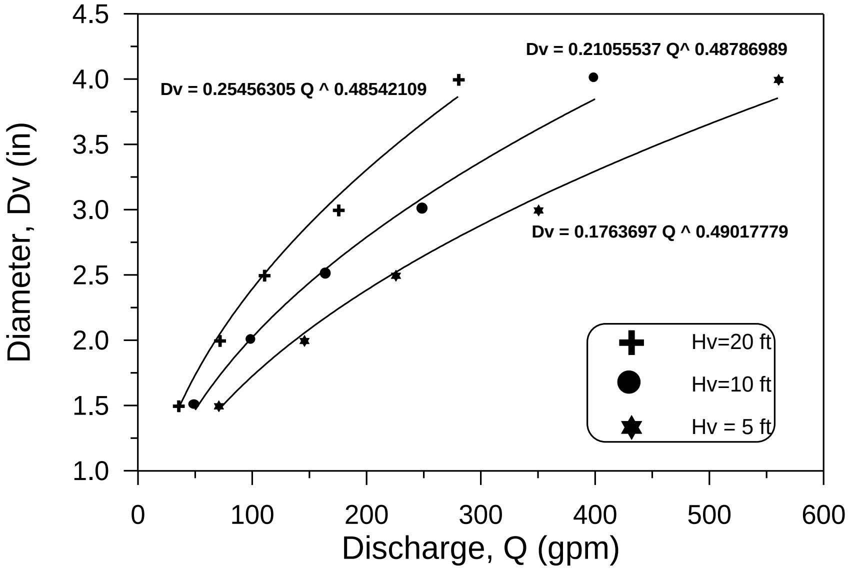

Figure (6) Typical PRCV flow chart
(ft × 0.3048 = m, gpm × 0.2271 = m^3/ h; in × 25.4 = mm)

4-2 Water Hammer Control

In this work, the surge pressure due to a pump stopping will be absorbed by the free end of the pipeline AC at the inlet of 2B-res. (i.e., the wave speed can not be reflected), therefore one case may generate water hammer; sudden closing in the pump discharge line with pump stops.

Excessively high surge pressure from the operation of stop valves can be avoided by using an excellent throttling device, Needle valve as shown in **Fig.(7)**, in which a closing characteristic is much closer to the linear characteristic, having a closing time of te=0.72 t_t. where t_t is the total closing time.

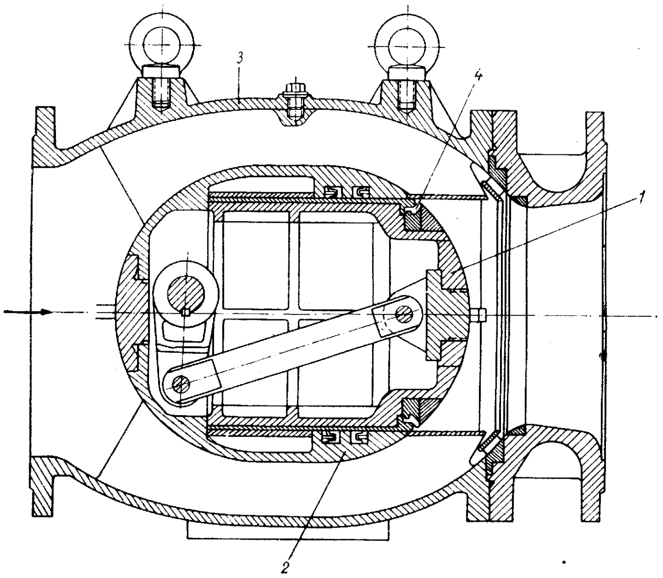

Figure (7) Needle valve as a throttling device (cross section)

The bad case occurs when terminal closing occurs and stops the pumps. The closing time of a Needle valve with an approximately linear characteristic, mounted on the by – pass line, so that the valve should secure a progressive reduction of flow velocity in order to keep water hammer within the permitted limits can be computed as follows:

1. Wave speed or propagation speed (a) is computing by the means of Equation:

$$\mathbf{a} = \frac{\mathbf{1481.7}}{\sqrt{\mathbf{1} + \frac{\mathbf{E_L}}{\mathbf{E_p}} \frac{\mathbf{D}}{\boldsymbol{\delta}_\mathbf{p}} \left(\mathbf{1} - \boldsymbol{\mu}_\mathbf{p}^2\right)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3)}$$

where:

E_L: liquid modulus of elasticity in kPa, for water $E_L = 2.2\times10^6$ kPa

E_p: Pipe modulus of Elasticity in kPa, for ductile iron, $E_P = 1.57\times10^8$ kPa

D: Pipe diameter in m

δ: Pipe wall thickness in m., for ductile iron, δ=k (0.001D+0.5), in which k constant depending on the type of apparatus (for pipes k=9)

μ_p: Pipe Poisson’s ratio for ductile iron $\mu_p = 0.26$

$$\mathbf{a} = \frac{\mathbf{1481.7}}{\sqrt{\mathbf{1} = \frac{\mathbf{1.6}}{\mathbf{0.019}} \times \frac{\mathbf{2.22\times10^6}}{\mathbf{1.57\times10^8}} \left(\mathbf{1} - \mathbf{0.26^2}\right)}} = \mathbf{1023.1\ m/s}$$

2. Reflection time is determined by the general relation.

$$\mathbf{t_r} = \frac{\mathbf{2\times L}}{\mathbf{a}} = \frac{\mathbf{2\times3000}}{\mathbf{1023.1}} = \mathbf{5.86}\ \text{sec}$$

3. Maximum over pressure / under pressure is computed making use the equation:

$$\mathbf{H.o.p = H_{u.p} = a / g \times V \times k = (1023.1 / 9.81) \times 1 \times 1.5 = 158\ m}$$

4. Admissible value of over pressure /under pressure ($H_{o.p.a}$/H_u.p.a) within the pipeline is determined. In the case of **Fig.(8)**, the under pressure is limited at a vacuum equal to (-2) m, admitted in the highest point under north bridge, located at 1.69 km. At that point, the under pressure can drop to 8.2-2 = 6.2 m under pressure transmission to the pump is made linearly.

Allowed over pressure Ho.p.a = Hu.p.a = (8.56.2) / (3000-1690) ×3000=5.26 m

Thus, the pressure wave at the pump can oscillate only between the values 8.5 + 5.26 = 13.76 and 8.5 – 5.26 =3.24 Thus, it follows that at the most unfavorable point, situated at (1.69 to 2.0) km, a vacuum is formed less than –2, this vacuum is allowed, so there is no danger of liquid stream break down which could amplify water hammer.

5. Maximum pressure to which pipeline walls are subjected is checked, to this end we make of use this relation.

$$H=H_{o.p} + H_{st} + hst = 13.76 = 1.4 \text{ dan /sq. cm}$$

6. The effective closing time of the needle valve is then computed with relation:

$$t_e = \frac{1}{g} \times \frac{L}{2} \times \frac{V_o}{H_{st}} \sqrt{1+z}$$

where: z-allowed rise of overpressure, relative to static head H_{st}.

$$t_e = \frac{1}{9.81} \times \frac{3000}{0.618} \times \frac{1.51}{8.5} \times \sqrt{1+0.618} = 111.8 \sec$$

where: $0.618 = z = \frac{5.26m}{8.5m}$

7. A needle valve is chosen with a ratio $t_e / t_t = 0.72$ and a total closing time

$$t_t = t_e / 0.72 = 155.3 \text{ sec} = 2.58 \text{ min}$$

The same procedure was repeated to find the total closing time for D=1.4m, $t_{t\phi1.4} = 2.46$ min.

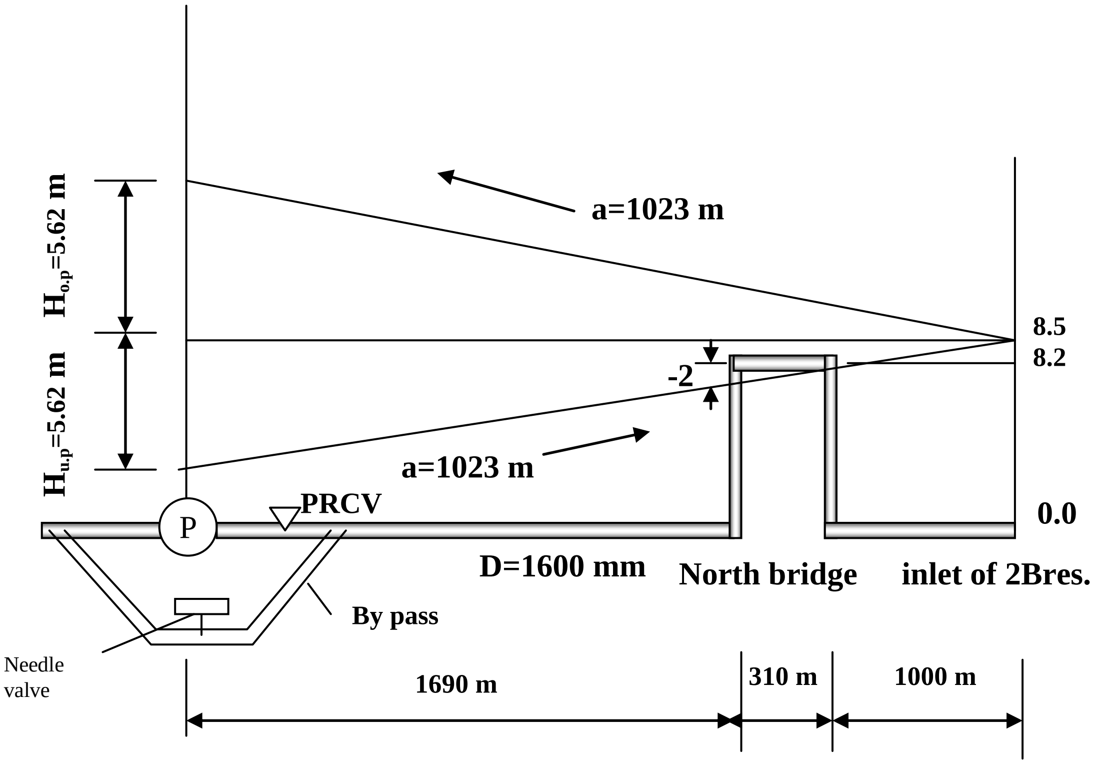

Figure (8) Water Hammer Control by Using Needle Valve

5. Discussion of the Results

1. The differences in flow through the transmission pipelines TD and AB, as shown in **Table (4)** results almost from excessiveness that has never been taken into consideration in flow calculations, while the effect of line DE is neglected, as its rate of flow is very low compared with the flow of the rest transmission pipelines.
2. From **Table (3)** it can be noticed that the actual and calculated flow of the transmission line AC comply with the throttling percentage increases, in which the negative pressure decreases at the bottom of the north bridge, however, there are some practical considerations which must be addressed. Entrained air and dissolved gases will come out of solution at negative pressures and accumulate at the summit of the pipeline; these bubbles will constrict the flow and cause local losses, which will reduce the capacity of the pipeline AC. They can not be removed by traditional means such as air release valves because these devices require positive pressure to force out the gases. Therefore, it has been working with this pipeline a more common occurrence by the pumping at some intermediate point in the pipelines that leads to 2B res.
3. The additional head required varies from (16.02m) at fully open (zero throttling) to (8.1m) at 50% throttling as in **Table (5)**, this variation may be small compared with the flow reduction in (twps) and North reservoir at the same throttling percentages. Therefore, neglecting the throttling (fully open valve) and using booster pumps shall prompt an optimal solution in conveying the required flow to 2B-res.

6. Conclusions

The present study indicates the following conclusions and recommendations regarding the water transference system from Karkh to Rusafa water services.

1. Throttling is not the right method to be used in transferring drinking water from Karkh to Rusafa water services. Throttling process may create many hydraulically problems for the system of Karkh service of which the high rate of minor losses reduce the coming flow from the source of Karkh water treatment plant, greater flows to illegal excessiveness and finally it is a random process.

2. Boosting pressure with pumps is a better alternative to be used for water transferring from Karkh to Rasafa water systems. Booster pumps are hydraulically more efficient than throttling method if these booster pumps are carefully designed for this purpose.

3. Now, in operating the throttling method by (25 to 35%), more than 71000 m3/day of water is retained in the Karkh water treatment plant, this is , due to excessive head loss exerted by throttling on the pumping set of the plant.

4. Through the field investigation, it has been discovered that events of negative pressures frequently occur in the transmission pipelines leading to 2B reservoir under North bridge and this pressures decreases as throttling percentages increases.

5. The best location of boosting pump on pipeline to 2B reservoir is 9.4 km from branching point. However, an acceptable location is already exits, but 0.6 km far from the best one.

6. Using a PRCV of 104 cm in diameter on the 1600 mm diameter pump discharge pipeline and an 83 cm in diameter on the 1400 mm diameter pump discharge pipeline shall almost prevent the back flow and give fairly a constant additional head that is required to be developed by the booster pumps for the transmission pipelines to 2B-res.

7. For keeping water hammer within the permitted limits, a Needle valves may be used and mounted on the bypass pipes with closing time (2.58 min) on the 1600 mm dia. pipeline and (2.46 min) on the 1400 mm dia. pipeline.

7. References

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Notations

COVC	Valve chambers.
TDV	Terminal discharge valve at north reservoir.
PRCV	Pressure reducing and check valve
D	Pipe diameter (L).
D_v	PRCV diameter (L).
e	Equivalent roughness height (L).
E	Models of elasticity of liquid.
E_p	Models of elasticity of pipe material.
f	The friction factor.
g	Acceleration due to gravity (L^2/T).
H	The head (L).
H_f	Friction head loss (L).
H_L	Minor head loss (L).
Ho.p	The over pressure due to sudden closed in pump discharge line (L).
H_p	Total head of the pump (L).
H_{st}	Static head of pumping system (L).
$H_{u.p}$	The under pressure due to sudden closed in pump discharge line (L).
HCa	The minimum allowable pressure at point C (L)
H_o	Water elevation before shutdown (L)
H_1	Water elevation after shutdown (L)
H_s	Suction head (L)
H_d	Discharge head (L)
H.G.L	Hydraulic grade line
H_v	Setting head of pressure reducing valve (L).
k	Minor head loss coefficient.
L	Pipe length (L).
N	Rotation speed (r.p.m).
P	Pressure (L).
Q	The flow (L^3/T).
Re	Reynolds number.
t_e	Effective closing time of needle valve (T).
t_t	Total closing time of needle valve (T).
z'	Allowed rise of over pressure, $z'=H_o.P/H_{st.}$
η	Efficiency of the pump expressed as percentage.
μ_p	Poisson ratio of pipe.
E.G.L.	Energy grade line
Z_1 and Z_2	Elevation head (L)
δ	Pipe wall thickness (L)