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EFFECT OF SERVICE LINE ON THE AVERAGE ENERGY CONSUMPTION OF WATER SUPPLY PUMPING STATION

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The pumps of high lift station consume a high magnitude of power to deliver the water supply to the community consumers, therefore it necessary to looking for means that help to reduce this consumption. The service pipe is an important part of water supply network but it is usually ignored in network analysis. The research focuses on the investigating the effects of this pipe on annual power consumption of pump station. The proposed model is constructed using EPAnet software and different values of diameter and C-coefficient are studied. Moreover, the effect of demand allocation is also studied. The results indicated that the increasing in diameter or in C-coefficient cause decreasing of annual power consumption. The application of demand allocation gives power consumption values less than that for no demand allocation application case. The statistical model showed the significance relationship among power consumption and service pipe properties, and showed that the effect of C-coefficient is higher than the effect of diameter.

Key words: power consumption, pump, service pipe, water network

1 INTRODUCTION

As the community develops and population increases, the demand of water increases. This will result in increasing the energy consumption due to increasing the required energy for the pumps in high lift pump station to supply larger quantities of water to the city.

The interrelationship between water and energy are recognized, while lately the concern of the scientists and policy makers on their dependency relationship has increased significantly [1].

The water supply projects are considered the most municipal energy consuming projects where 65% of their total operating cost is for energy [2].

The treated water pumping is considered the highest energy-consuming process, it forms 65.67% and 68.95% of the total annual energy consumption of the plant for 5 and 200 mgd water treatment plant respectively [3].

Many researches investigate the methods that can be used to minimize the consumed energy in water supply systems.

Nowadays, evolving the efficiency of the required energy of the buildings water supply systems is one of the buildings sustainable development strategies. Replacement of old, poorly maintained, and unappropriated pumps with new and efficient ones will minimize the consuming energy for operation of the water supply projects. However, manufacturing new pumps consume additional energy and generate carbon missions resulted from this energy [4].

Paper [5] shows the energy efficiency calculated for water supply systems and using theoretical model for finding the optimum pumping energy by arranging the building water tanks. The results illustrated that the energy efficiency of most of existent high-rise water supply systems is 0.25 and can be developed to 0.26-0.37 by relocating the water storage tanks. Also, the results shows that the annual electricity saving is 160-410TJ, which equal to 0.1-0.3% of Hong-Kong annual electricity consumption.

Gravity plays a significant role in water distribution systems, though sometimes elevated nodal pressure happens. Increasing pressure lead to damages in networks relating to operation and life. Therefore, water facilities are obliged to perform pressure management policies. Instead break down energy applying conventional measures, other options are available such as installing pumps work as turbines (PAT) which can recover the energy simultaneously. The research attempted to exploit each possibility of exchanging pressure reducing valve with PAT and checking PAT ability to minimize the pressure to appropriate level and generate notable amount of energy [6].

Paper [7] showed significant fundamentals related to water and energy efficiency. The research methodology was evolved including three solutions: firstly, using of water turbine in piping systems where the pressure is more than required and the pressure minimizing valves are installed, secondly, according to electricity cost and water demand, optimizing of pumping operation was done, and finally, using of other alternative renewable energy which include wind turbine to deliver energy to the pumping station. The results indicate that the using of turbine is useful in generating 370 KW.h that was lost by pressure reducing valve each day. Operating of pump based on optimization does not influence on the power consumption but decreasing the cost significantly. The wind turbine causes to reduce power generated by national power station and reduce the CO_2 emission.

So, the matter requires to looking for any means that lead to reduce the energy consumed. The service line is defined as the pipe runs between the utility's water main and the customer's place of use [8]. The service pipe is a primary part of water supply network because any human activity must be reached the water to different locations of using by mean of connecting internal network system by the external network system. Since the length of service pipe is very small compared with the very long lengths of water network pipes, so usually it is ignored in network analysis or power consumption calculation.

The present research attempts to appear the important of this part of water supply network on energy consumption through modeling of proposed community supplied water by pump station. The research objectives:

1) Investigating the effect of service pipe on the energy consumed by pump station through: study the effect of diameter of service pipe on the annual power consumption, and study the effect of Hazen-William coefficient of service pipe on the annual power consumption.
2) Compare the results of above two points with the results when using the principles of demand allocation.
3) Developing formula that can be used to estimate the annual power consumption of network have a service pipe with any value of C and d based on the annual power consumption of the same network but have the same service pipe but with different value of C and d.

2 MATERIALS AND METHODS

To investigate the effect of properties of service pipe on energy consumption at pump station, two parameters of service pipes are adopted:

1) Hazen-Williams coefficient that reflects the roughness of inner surface of pipe. Four values are used 80, 100, 120, and 140. The values range from 140 for very smooth pipes down to 90 or even 80 for old pipes [9]. The Hazen-Williams equation is selected for head loss computation since this equation is most accurate for the pipe sizes and velocities typically found in water supply practice [10].

   The form of Hazen-Williams equation in SI units [11]:

   $$h_L = 10.67 \times \left(\frac{\mathrm{Q}}{\mathrm{C}}\right)^{1.85} \times \frac{\mathrm{L}}{\mathrm{d}^{4.87}} \qquad (1)$$

   where:

   h_L: head loss in pipe (m).

   Q: fluid flow rate (m^3/s).

   C: Hazen-Williams coefficient of roughness.

   L: pipe length (m).

   d: pipe diameter (m).

2) Diameter that reflects the main physical properties of pipes. Five values are used: 0.5",0.75", 1.0", 1.5", and 2", corresponding to 12.5mm, 19mm, 25mm, 37.5mm, and 50mm in SI unit. The diameter of service pipe is from 0.75" to 2" depending on the distance involved and the rate of consumption [12].

The research is based on a proposed residential community consists of 450 single houses. Each house has two stories with 3m height for each story. The plan of division of the community is shown in the fig. 1.

a) There are 450 nodes at the ends of service pipes. The water is withdrawn during the day from them. The water losses are distributed over the 482 remaining nodes.
b) The water distribution method is pumping without storage through 24hour. The water is pumped to the upper tanks installed at the roof of each house.
c) The daily variation in water consumption follows a certain pattern [14]. Based on this pattern, the water flow rate variation in the primary pipe during average day is sown in fig. 3.
d) To eliminate the effect of variation in surface ground elevation, the elevation of reservoir, pump, and all nodes except the nodes at the ends of service pipes is taken to be zero.
e) To eliminate the effect of variation in surface ground elevation, the elevation of reservoir, pump, and all nodes except the nodes at the ends of service pipes is taken to be zero.
f) The length of service pipe is 20m. One meter segment is vertical from the urban main pipe, 10m segment is horizontal to house, and 9m segment is vertical to the inlet of the tanks at the roof. Therefore, the elevation of the nodes at the ends of service pipes is 9m.

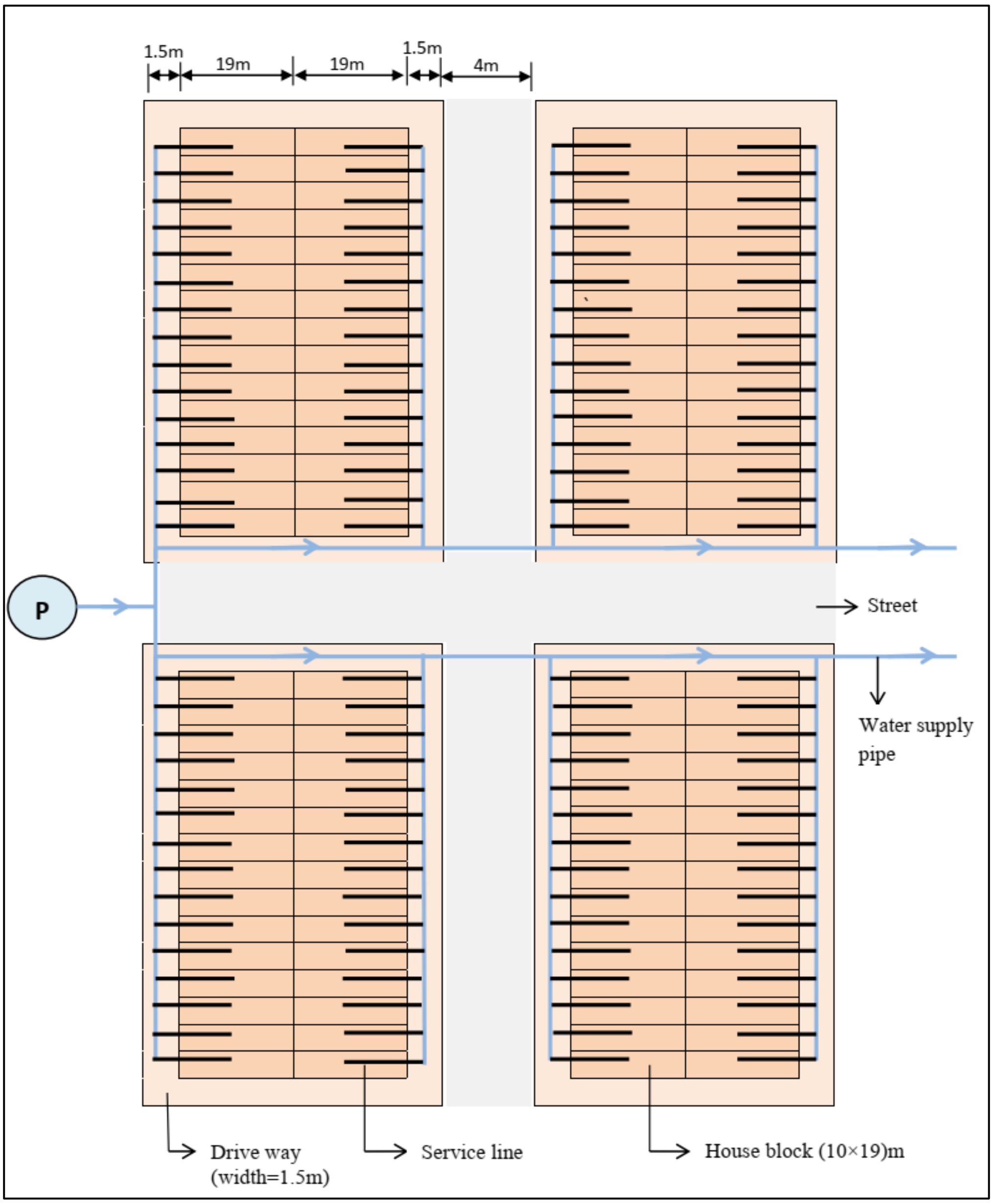

Fig. 1. Plan of division of proposed community

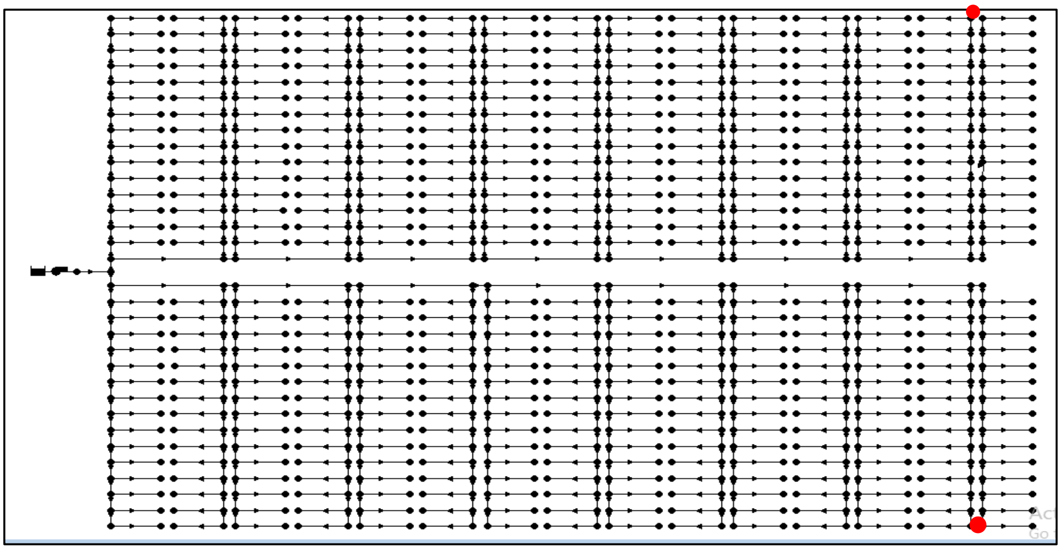

Fig. 2. Model of water supply network as shown in EPAnet software

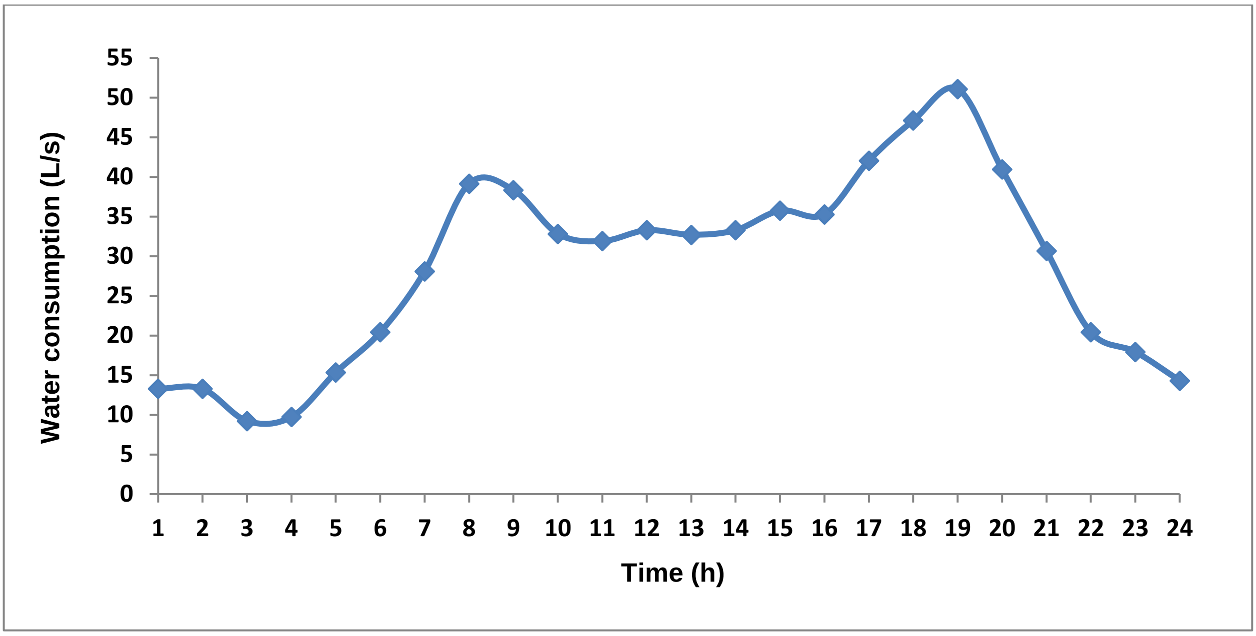

Fig. 3. Variation of water consumption in average daily demand

2.1 Design Criteria

The design criteria that applied for pipes network as following [12]:

1) The maximum speed at the hour of maximum discharge in all pipes is between (1-2) m/s.
2) The minimum working pressure at the end of service pipe at each roof of house is 15m H_2O during the hour of the maximum flow rate.
3) The diameter of pipe installed in the branch street is 50mm. The diameter of primary and sub-primary pipe is 200mm and (100 to 150) mm respectively. The diameters satisfy the velocity indicated in point 2 above.

2.2 Head – Discharge Pump Curve

The curve is constructed by EPAnet software. The option of single-point curve is selected. The curve is based on the desired operating point that introduced on the program. The maximum flow rate of the curve at shutoff head equal to 2×desired flow rate, and the maximum head of the curve at minimum flow rate equal 1.33×desired head [15].

The value of flow rate at desired operating point that introduced in the EPAnet software equals to the flow rate during the hour of maximum water consumption according to the pattern shown in the figure 3, whereas the value of desired head is adjusted until a pressure of 15m H_2O at the two most remote nodes achieve. The two most remote nodes are distinguished by red color as shown in figure 2. Logically, since all nodes have the same elevation and hydraulic properties, so a higher-pressure value will be achieved certainly in these nodes when the minimum required pressure achieve in the two most remote nodes.

2.3 Power Calculation

The annual power consumption is computed by carrying out the following steps using Excel Microsoft:

1) The discharge or (flow rate) – that follows the pattern of fig. 3 - and head of pump during each hour of day are obtained from EPAnet software, then the power of the pump for each hour is the computed as [16]:

$$Ppi = Qpi \times Hpi \times \gamma \tag{2}$$

Ppi: Pump power during hour (i) (KW).
Qpi: Pump flow rate during hour (i) (m^3/s).
Hpi: Pump head during hour (i) (m).
γ: Weight density of water (KN/m^3).
i: Hour of day range from 1 to 24.

2) The power consumption during each hour Phi in (KW.h) unit is calculated as:

$$Phi = Ppi \times 1\,hour = Qpi \times Hpi \times \gamma \times 1\,hour \tag{3}$$

3) The Power consumption during day of average water consumption Pd in (KW.h) equals the summation of power consumption during the 24 hour.

$$Pd = \sum_{i=1}^{i=24} Phi = \sum_{i=1}^{i=24} (Qpi \times Hpi \times \gamma \times 1\,hour) \tag{4}$$

4) The annual power consumption during the year Py in (KW.h) equals Pd multiplying by the number of days of one year:

$$Py = Pd \times 365 \qquad (5)$$

Substitute equation 4 in equation 5 yields:

$$Py = 365 \sum_{i=1}^{i=24}(Qpi \times Hpi \times \gamma \times 1\ hour) \qquad (6)$$

2.4 Demand Allocation

The water supply is withdrawn from the many points along the pipe network. To simplifying the network analysis, the water consumption is divided in the two nodes at ends of the pipe. The pipe length is divided to two segments and the water consumption from each segment is concentrated to the nearest node. This procedure is called demand allocation [17].

The demand allocation principle is applied on the network of the research. The service pipes with their connections are ignored, and the all consumptions along each pipe is divided equally into two nodes that locate at the two ends of that pipe. The new developed network is shown in the fig. 4.

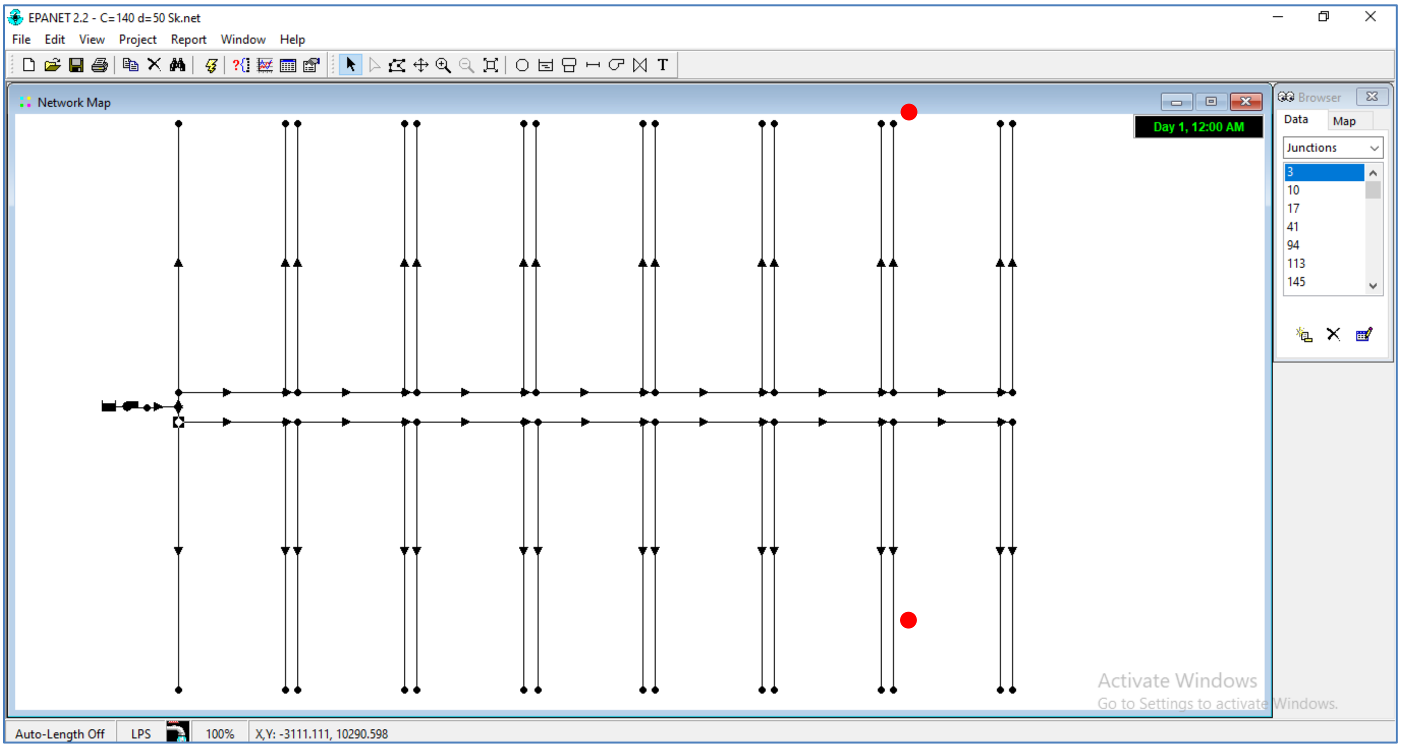

Fig. 4. Model of water supply network with applying of demand allocation as shown in EPAnet software

3 RESULTS AND DISCUSSION

To study the effect of service pipe properties on the power consumption, several commercial diameters [12.5mm, 19mm, 25mm, 37.5mm, and 50mm] with several values of Hazen-Williams coefficient [80, 100, 120, and 140] are adopted. The annual power consumption by pump is computed on the bases of the power consumption computed during the day of average water consumption as indicated in materials and methods paragraph. There are 84 runs are carried out using EPAnet software to cover the study of the effect of variables.

The effects of pipe diameter and C- coefficient on annual power consumption are shown in figures from fig. 5 to fig. 8. Each figure concerns with certain value of C-coefficient of the pipes network. The X-axis represents the different C-values of service pipe, whereas the Y-axis represents the annual power consumption.

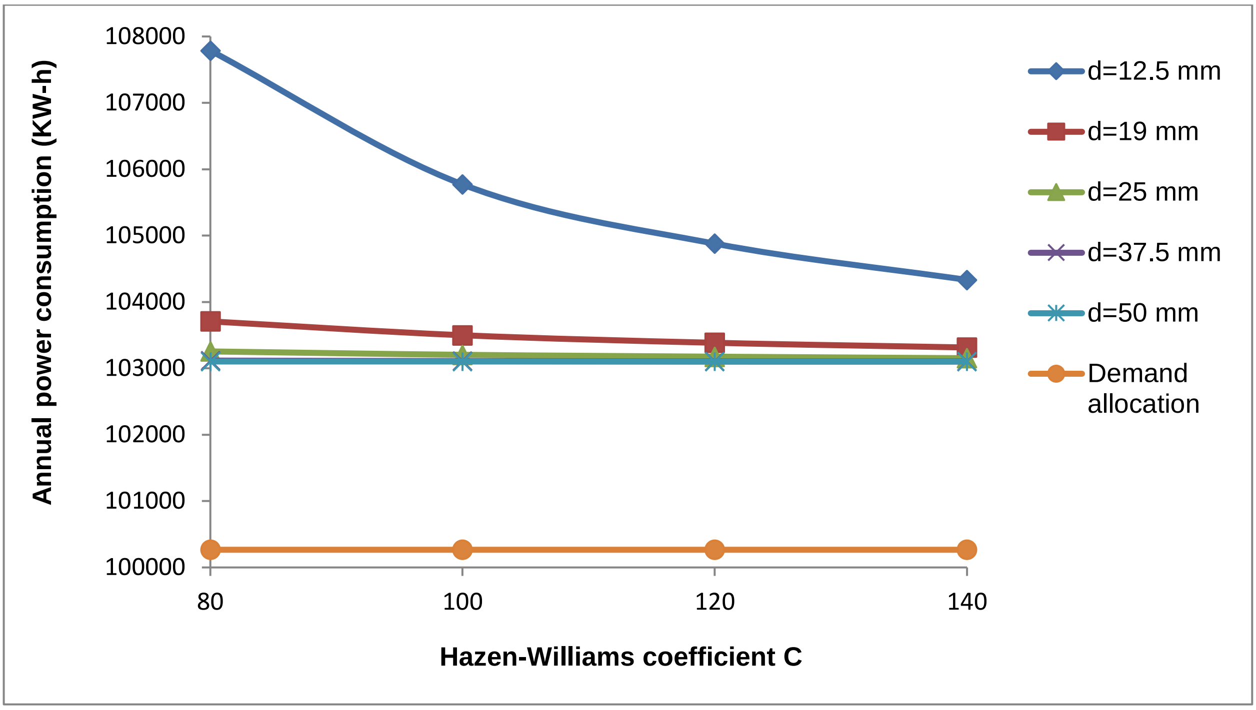

Fig. 5. Effect of diameter and Hazen Williams coefficient of the service pipe on the annual power consumption (C=80 for other network pipes)

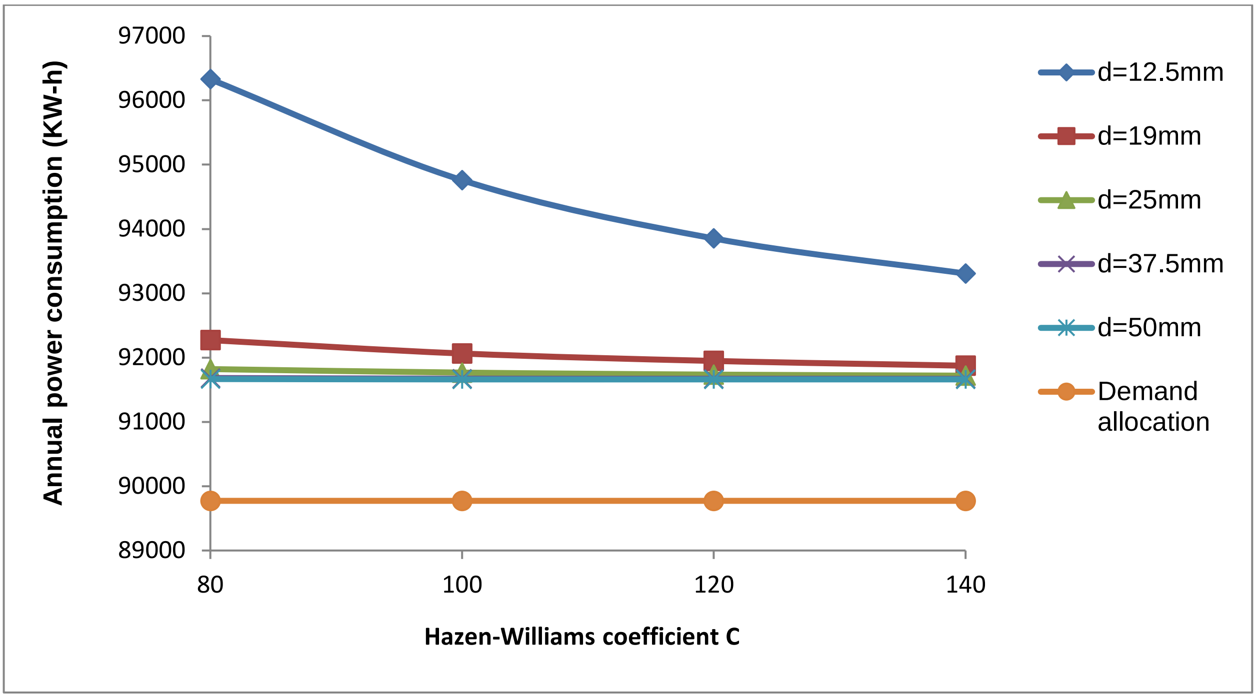

Fig. 6. Effect of diameter and Hazen Williams coefficient of the service pipe on the annual power consumption (C=100 for other network pipes)

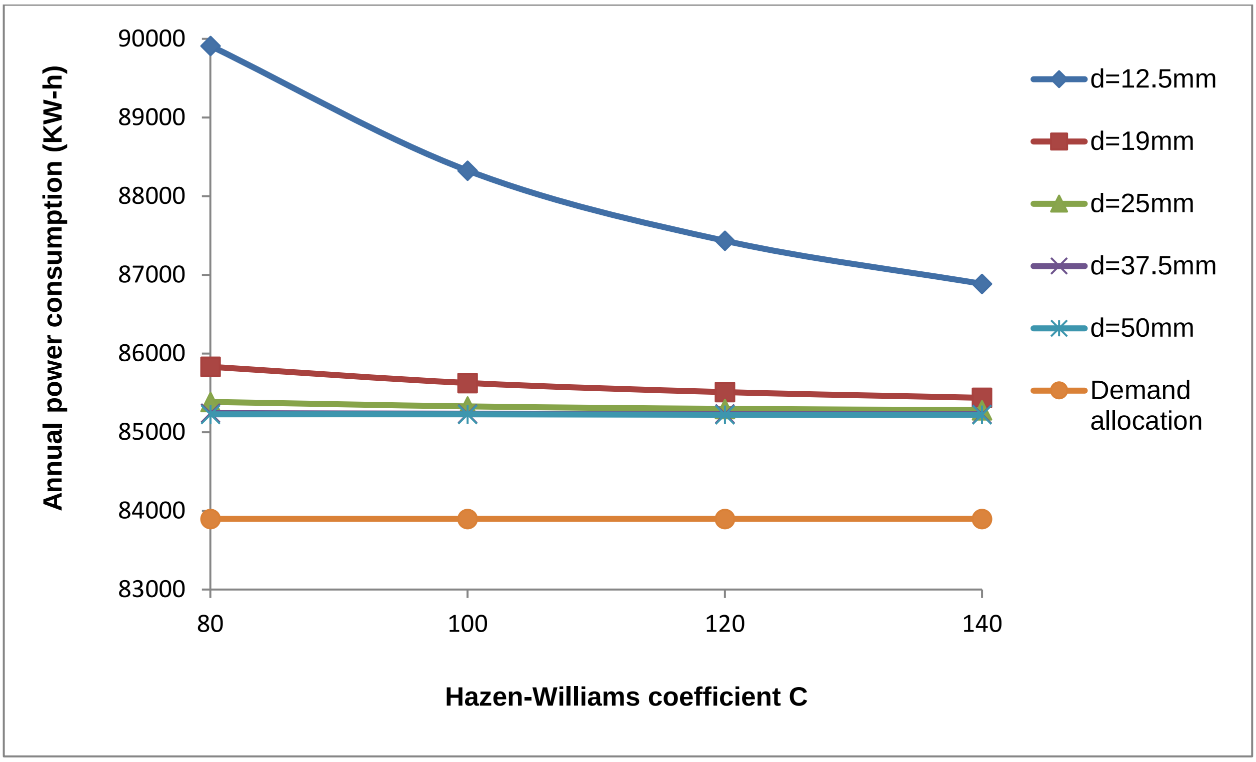

Fig. 7. Effect of diameter and Hazen Williams coefficient of the service pipe on the annual power consumption (C=120 for other network pipes)

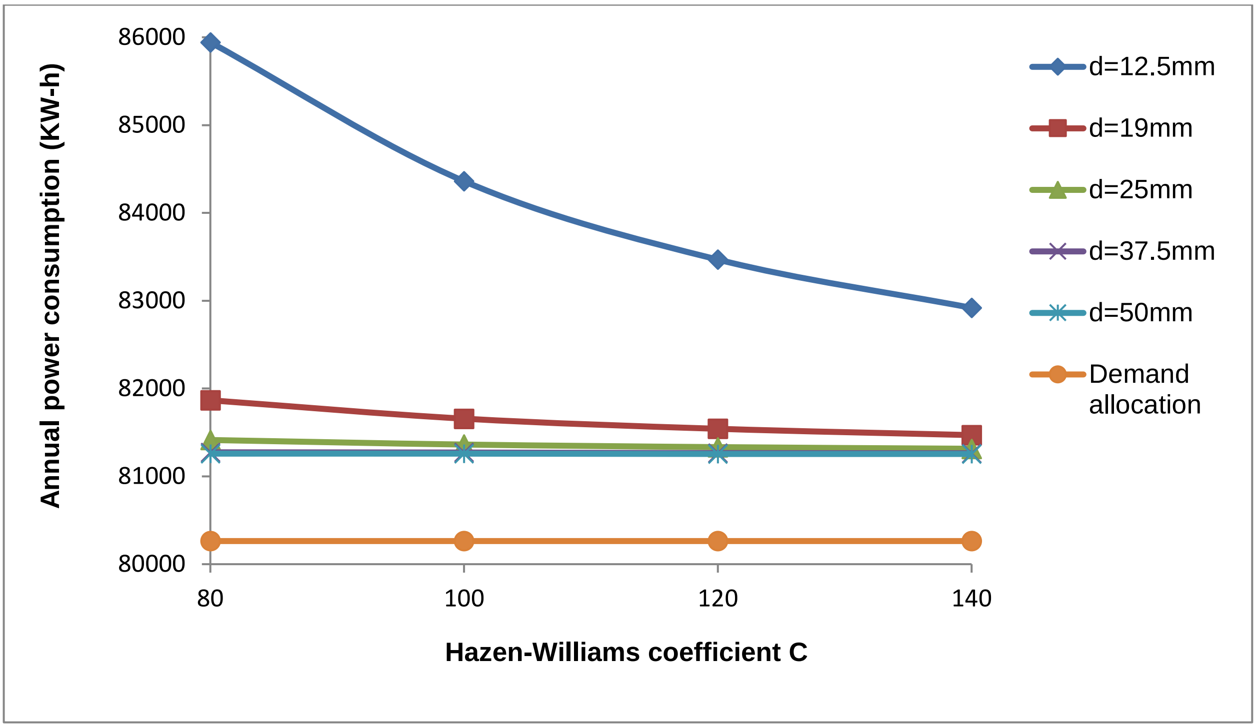

Fig. 8. Effect of diameter and Hazen Williams coefficient of the service pipe on the annual power consumption (C=140 for other network pipes)

3.1 Effect of Diameter of the Service Pipe

As shown in any one of the four figures, the annual power consumption reduces with increasing the diameter value of pipe at any value of C-coefficient. So, the highest value is with 12.5 mm diameter pipe and the lowest value is with 50 mm diameter. At the same time, the effect of diameter on annual power consumption reduces with the increasing in diameter value at any value of C-coefficient. So, the line of 37.5 mm diameter approximately coincides to the line of 50 mm diameter.

3.1.1 The interpretation

The variation of annual power consumption with the variation of service pipe diameter is interpreted from equation (1) for head loss calculation in pipe:

$$h_L = 10.67 \times (\frac{Q}{C})^{1.85} \times \frac{L}{d^{4.87}} \tag{1}$$

The equation revealed that there is inverse relationship between head loss and diameter of pipe. The lead loss in service pipe for different diameters can be computed at maximum hourly consumption 0.0568L/s. The results and the corresponding reduction in head loss with increasing in diameter are listed in table 1.

Table 1. Head loss in service pipe during maximum hourly consumption for different values of pipe diameters for each C-coefficient and corresponding reduction in head loss with pipe diameter increasing (L=20m, Q=0.0568L/s)

Pipe diameter (in)	Pipe diameter (mm)	C-coefficient	Head loss (m)	Reduction in head loss (∆HL) (m)
0.5	12.5	80	1.6675	
0.75	19		0.2170	1.4505
1.0	25		0.0570	0.1599
1.5	37.5		0.0079	0.0491
2	50		0.0019	0.0059
0.5	12.5	100	1.1035	
0.75	19		0.1436	0.96
1.0	25		0.0377	0.1058
1.5	37.5		0.0052	0.0325
2	50		0.0013	0.0039
0.5	12.5	120	0.7876	
0.75	19		0.1025	0.6851
1.0	25		0.0269	0.0755
1.5	37.5		0.0037	0.0232
2	50		0.0009	0.0028
0.5	12.5	140	0.5922	
0.75	19		0.0770	0.5151
1.0	25		0.0202	0.0568
1.5	37.5		0.0028	0.0174
2	50		0.0007	0.0021

The last column of table can be read as follows: for example, if the diameter of service pipe – with C=120 - increase from 12.5mm to 19mm, the head loss in the pipe reduces by 0.6851m.

The reducing in head loss due to increasing in diameter will be subtracted from the head of pump that must be delivered by it to overcome the new head loss. Also, the increasing in head loss due to decreasing in diameter will be added to the head of pump that must be delivered by it to overcome the new head loss. This concept is proved as follows:

The head of pump is computed by application of Bernoulli equation between the surface water in the reservoir and the node at end point of the most remote service pipe [Fig. 9]:

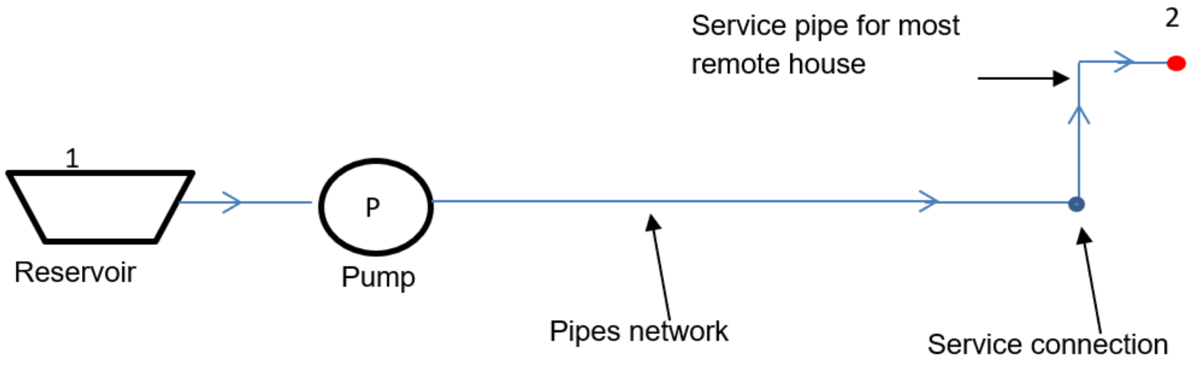

Fig. 9. Pipes line from reservoir to the node at the end point of the most remote service pipe

$$\frac{P1}{\gamma} + \frac{V1^2}{2g} + Z1 + Hp = \frac{P2}{\gamma} + \frac{V2^2}{2g} + Z2 + HL(n.p) + HL(s.p) \qquad (7)$$

Where:

$\frac{P1}{\gamma}, \frac{P2}{\gamma}$: pressure head at point 1 and 2 respectively, (m).

$\frac{V1^2}{2g}, \frac{V2^2}{2g}$: velocity head at point 1 and 2 respectively, (m).

Z1, Z2: elevation head at point 1 and 2 respectively, (m).

Hp: head of pump (m).

HL(n.p): head loss in network pipes from point 1 to point 2, (m)

HL(s.p): head loss in service pipe, (m).

$\frac{P1}{\gamma} = 0$; $\frac{P2}{\gamma} = 0$; $\frac{V1^2}{2g} = 0$, $\frac{V2^2}{2g}$ is ignored due to its small value, so

$$Hp = \Delta Z + HL(n.p) + HL(s.p) \qquad (8)$$

During any hour (i) of the day:

$Hpi = \Delta Z + HL(n.p)i + HL(s.p)I$

Using equation (2) where:

$$Ppi = Qpi \times Hpi \times \gamma \qquad (2)$$

So,

$$Qpi = Qpi \times \gamma \times [\Delta Z + HL(n.p)i + HL(s.p)i\,)] \qquad (9)$$

Using equation (6) where:

$$Py = 365 \sum_{i=1}^{i=24} (Qpi \times Hpi \times \gamma \times 1\,hour) \qquad (6)$$

So,

$$Pd = 365 \sum_{i=1}^{i=24} [Qpi \times \gamma(\Delta Z + HL(n.p)i + HL(s.p)i)] \qquad (10)$$

It can be concluded from equation 8, that the effect of head loss in service pipe HLs.p) on the head of the pump Hp. This effect reflects on the annual power consumption as indicated from equation 10. As a resultant, any reduction in head loss of service pipe due to increasing in the pipe diameter, will leads to reduction in annual power consumption.

It can be noticed from table 1 that there is reducing in ∆H as the diameter of service pipe increase. Consequently, a reduction in the annual power consumption will decreases as the pipe diameter increases. This interprets the reduction in gabs among the curves – at any value of C-coefficient - in figures from 5 to 8 as the diameter of service pipe increase.

3.1.2 Estimation of Annual Power Consumption

According to equation 6, the annual power consumption for network has service pipe with (x) diameter:

$$Py(d = x) = 365 \sum_{i=1}^{i=24} (Qpi \times Hpi \times \gamma \times 1\,hour) \qquad (6)$$

When the diameter of the service pipe reduces from (x) diameter to (y) diameter, then the head of pump Hpi increases by ∆Hi, so the annual power consumption for network has service pipe with (y) diameter:

$$Py(d{=}y) = 365\sum_{i=1}^{i=24}[Qpi\ \times \Upsilon(Hpi\ + \Delta Hi)] \qquad (11)$$

$$Py(d{=}y) = 365\sum_{i=1}^{i=24}(\,Qpi\ \times\ \Upsilon\ \times Hpi\,) + 365\ \sum_{i=1}^{i=24}\ (Qpi\ \times\ \Upsilon\ \times \Delta Hi)$$

Since

$$Py(d{=}x) = 365\sum_{i=1}^{i=24}(Qpi\ \times Hpi\ \times \Upsilon \times 1\,hour) \qquad (6)$$

Therefore:

$$Py(d{=}y) =\ \ Py(d{=}x) + 365\ \sum_{i=1}^{i=24}\ (Qpi\ \times\ \Upsilon\ \times \Delta Hi)$$

$$Py(d{=}y) =\ \ Py(d{=}x) + 3577\ \sum_{i=1}^{i=24}\ (Qpi\ \times \Delta Hi) \qquad (12)$$

From equation 12:

$$\sum_{i=1}^{i=24}\ (Qpi\ \times \Delta Hi) = Qpi\,[\,HLi(d{=}x) - HLi(d{=}y)]$$

$$\sum_{i=1}^{i=24}(Qpi\ \times \Delta Hi) = Qpi\,[\,10.67\times(\frac{Qsi}{C})^{1.85}\times\frac{20}{(d{=}x)^{4.87}} - 10.67\times(\frac{Qsi}{C})^{1.85}\times\frac{20}{(d{=}y)^{4.87}}\,] \qquad (13)$$

Where:

HLi(d=x): head loss in service pipe of diameter (x) during (i) hour of day, with pump flow rate *Qpi* during this hour, (m).

HLi(d=y): head loss in service pipe of diameter (y) during (i) hour of day, with pump flow rate *Qpi* during this hour, (m).

Qsi: water flow rate in service pipe during (i) hour of day, (m^3/s).

$$\sum_{i=1}^{i=24}(Qpi\ \times \Delta Hi) = Qp1[10.67\times(\frac{Qs1}{C})^{1.85}\times\frac{20}{(d{=}x)^{4.87}} - 10.67\times(\frac{Qs1}{C})^{1.85}\times\frac{20}{(d{=}y)^{4.87}}]$$

$$+\ Qp2[10.67\times(\frac{Qs2}{C})^{1.85}\times\frac{20}{(d{=}x)^{4.87}} - 10.67\times(\frac{Qs2}{C})^{1.85}\times\frac{20}{(d{=}y)^{4.87}}]$$

$$+\ Qp3[10.67\times(\frac{Qs3}{C})^{1.85}\times\frac{20}{(d{=}x)^{4.87}} - 10.67\times(\frac{Qs3}{C})^{1.85}\times\frac{20}{(d{=}y)^{4.87}}]$$

$$+\ Qp24[10.67\times(\frac{Qs24}{C})^{1.85}\times\frac{20}{(d{=}x)^{4.87}} - 10.67\times(\frac{Qs24}{C})^{1.85}\times\frac{20}{(d{=}y)^{4.87}}]$$

$$\sum_{i=1}^{i=24}\ (Qpi\ \times \Delta Hi) = [\,Qp1\times Qs1^{1.85}\times 10.67\times 20\times(\frac{1}{C})^{1.85}$$

$$+\ Qp2\times Qs2^{1.85}\times 10.67\times 20\times(\frac{1}{C})^{1.85}$$

$$+\ Qp3\times Qs3^{1.85}\times 10.67\times 20\times(\frac{1}{C})^{1.85}$$

$$+\ Qp24\times Qs24^{1.85}\times 10.67\times 20\times(\frac{1}{C})^{1.85}\,]\ \times [\frac{1}{(d{=}x)^{4.87}} - \frac{1}{(d{=}y)^{4.87}}]$$

$$\sum_{i=1}^{i=24}\ (Qpi\ \times \Delta Hi) = [\,Qp1\times Qs1^{1.85} + Qp2\times Qs2^{1.85} + Qp3\times Qs3^{1.85} + Qp24\times Qs24^{1.85}] \times [10.67\times 20\times(\frac{1}{C})^{1.85} \times (\frac{1}{(d{=}x)^{4.87}} - \frac{1}{(d{=}y)^{4.87}})\,]$$

$$\sum_{i=1}^{i=24}(Qpi\ \times \Delta Hi) = [\sum_{i=1}^{i=24}(Qpi)\,(Qsi^{1.85})\times[10.67\times 20\times(\frac{1}{C})^{1.85}\times(\frac{1}{(d{=}x)^{4.87}} - \frac{1}{(d{=}y)^{4.87}})] \qquad (14)$$

Substituting equation (14) in equation (12) yields:

$$Py(d{=}y) = Py(d{=}x) + 3577[\sum_{i=1}^{i=24}(Qpi)\,(Qsi^{1.85})]\times[10.67\times 20\times(\frac{1}{C})^{1.85}\times(\frac{1}{(d{=}x)^{4.87}} - \frac{1}{(d{=}y)^{4.87}})] \qquad (15)$$

For research network: $\sum_{i=1}^{i=24}(Qpi)\,(Qsi^{1.85}) = 4.76247\times 10^{-9}$

$$Py(d{=}y) = Py(d{=}x) + 3577\ \times 4.76247\times 10\text{-}9\,[10.67\times 20\times(\frac{1}{C})^{1.85}\times(\frac{1}{(d{=}x)^{4.87}} - \frac{1}{(d{=}y)^{4.87}})]$$

$$Py(d{=}y) = Py(d{=}x) + 0.0036353\,[\,(\frac{1}{C})^{1.85}\times(\frac{1}{(d{=}x)^{4.87}} - \frac{1}{(d{=}y)^{4.87}})\,] \qquad (16)$$

The last equation can be used to estimate the annual power consumption of network have a service pipe with any value diameter representing by (y), based on the annual power consumption of the same network have the same service pipe but with different value of diameter representing by (x).

For example, if it is required to find the annual power consumption of network with service pipe of diameter 25mm and C=120. The annual power consumption of network with service pipe of diameter 50mm and C=120 is known, then:

$$Py(d{=}0.025) = Py(d{=}0.05) + 0.0036353\,[\,(\frac{1}{120})^{1.85} \times (\frac{1}{(d{=}0.05)^{4.87}} - \frac{1}{(d{=}0.025)^{4.87}})\,]$$

$$Py_{d=25mm} = Py_{d=50mm} + 31.7$$

3.2 Effect of C-Coefficient of the Service Pipe

Effect of C-coefficient of service pipe on the annual power consumption can be noticed from the fig.5 to fig. 8. Four values of C-coefficient are adopted, 80, 100, 120, and 140. Each figure concerns with network have pipes of certain value of C-coefficient, but the C-coefficient of service pipe varies. Each figure shows that at any value of service pipe diameter, the annual power consumption decreases as the C-coefficient increase. As was explanation for the effect of diameter of pipe, there is inversely relationship between C-coefficient and head loss in pipe as inferred from Hazen-Williams equation. Moreover, as C-increasers, the reduction value in annual power consumption decreases for each value of service pipe diameter. This case can be explanation by rearranging the table 1 as shown in the table 2.

Table 2. Head loss in service pipe during maximum hourly consumption for different values of C-coefficient for each pipe diameter and corresponding reduction in head loss with C-coefficient increases (L=20m, Q=0.0568L/s)

C-coefficient	Pipe diameter (mm)	Head loss (m)	Change in head loss (∆HL) (m)
80	12.5	1.6675	
100		1.1035	0.5640
120		0.7876	0.3159
140		0.5921	0.1954
80	19	0.2170	
100		0.1436	0.0734
120		0.1025	0.0411
140		0.0771	0.0254
80	25	0.0570	
100		0.0377	0.0193
120		0.0269	0.0108
140		0.0202	0.0067
80	37.5	0.0079	
100		0.0052	0.0026
120		0.0037	0.0015
140		0.0028	0.0009
80	50	0.0019	
100		0.0013	0.0006
120		0.0009	0.00037
140		0.0007	0.00023

It can be concluded from the results listed in the table 2, that there is reduction in head loss changing as the C-coefficient of service pipe increasing. This condition reflects on the pump head as the same manner, since any reducing in head loss will lead to same reducing in the head of pump. Consequently, the annual power consumption will reduce by value decreasing as the C-coefficient increasing.

3.2.1 Estimation of Annual Power Consumption

The equation that can be used to estimate the annual power consumption for networks have different C-coefficient for service pipe, is derived using the same procedure for deriving equation 16, the product of derivation:

$$Py(C{=}n) = Py(C{=}m) + 0.0036353\,[\frac{1}{d^{4.87}} \times ((\frac{1}{C{=}n})^{1.85} - (\frac{1}{C{=}m})^{1.85}] \qquad (17)$$

For example, if it is required to find the annual power consumption of network with service pipe of C-coefficient equal to 120 and diameter equal to 37.5mm. The annual power consumption of network with service pipe of C-coefficient equal to 140 and diameter equal to 37.5mm is known, then:

$$Py(C{=}120) = Py(C{=}140) + 0.0036353\, [\frac{1}{(0.0375)^{4.87}} \times ((\frac{1}{120})^{1.85} - (\frac{1}{140})^{1.85}] = Py(C{=}m) + 1.1$$

3.3 Effect of C-Coefficient of Network Pipes

The effect of C-coefficient of network pipes on annual power consumption is studied through using the same four values of C that have been used for service pipes. Each figure from 5 to 8 represents a network with pipes have specified value of C, while the service pipe has different values of diameter. It can see from the figures that the annual power consumption increases – for each value of service pipe diameter – as the C-coefficient of network pipes decreases. Therefore, the minimum power is consumed by pump for network of C-coefficient equal to 140, and maximum power is consumed by pump for network of C-coefficient equal to 80. The reason belongs to augment in head loss in pipes network that must be compensate by the pump to achieve the required pressure. The augmentation results from the reduction in C-coefficient value as revealed from Hazen-Williams equation.

3.4 Effect of Demand Allocation

The application of demand allocation principles on the water supply network do not represent the actual hydraulic state of network. This can be concluded when a comparison is carried out between the annual power consumption for the network with demand allocation application and the annual power consumption for the network without demand allocation application. The lower lines in the figures from 5 through 8 are for networks with demand allocation application. The lines have straight form since all service pipes with their service connections are eliminated as seen in figure 9. The figures [5 through 8] indicated that there are differences of annual power consumption among two cases. The application of demand allocation leads to decrease the real value of annual power consumption. The percentage of reduction in power is calculated and listed in the table 3.

As seen from the table 3, that the range of reduction percentage in annual power consumption reduces as follows:

1) When C-coefficient for pipes network increases at each service pipe diameter.
2) When C-coefficient for service pipe increases at each service pipe diameter.
3) When service pipe diameter increases at each C-coefficient for pipes network.

The reasons of above points are explained in previous paragraphs. The annual power consumption reduces as: C-coefficient for pipes network increases, C-coefficient for service pipe increases, and as service pipe diameter increases. All that lead to near of curves in the figures 6 to 9 from the lowest straight line.

Table 3. Range of reduction percentage in annual power consumption when demand allocation is applied on the network with various values of service pipe diameter, service pipe C-coefficient, and network pipes C-coefficient

C-coefficient for pipes network	Range of reduction percentage %				
	Service pipe characteristics				
	D=12.5mm, C from 80 to 140	D=19mm, C from 80 to 140	D=25mm, C from 80 to 140	D=37.5mm, C from 80 to 140	D=50mm, C from 80 to 140
80	3.89-6.97	2.95-3.32	2.8-2.89	2.75-2.76	2.74-2.75
100	3.78-6.80	2.28-2.71	2.12-2.23	2.07-2.08	2.060-2.065
120	3.43-6.68	1.80-2.25	1.62-1.74	1.56-1.57	1.55-1.559
140	3.20-6.61	1.48-1.95	1.29-1.41	1.23-1.24	1.220-1.225

Based on above explanation, it can be suggested a model of simplified network that simulates that actual network and at the same time gives the real results on power consumption of water network. The model of suggested network is shown in the fig. 10. This model is develoved in EPAnet sofware. The parameter called (base demand) which introduced in the model for nodes with red color - in the figure -will represent the average daily consumption for the house, while the (base demand) for nodes with blue color will represent the the summation of average daily consumption for the 15 houses that locate on the street.

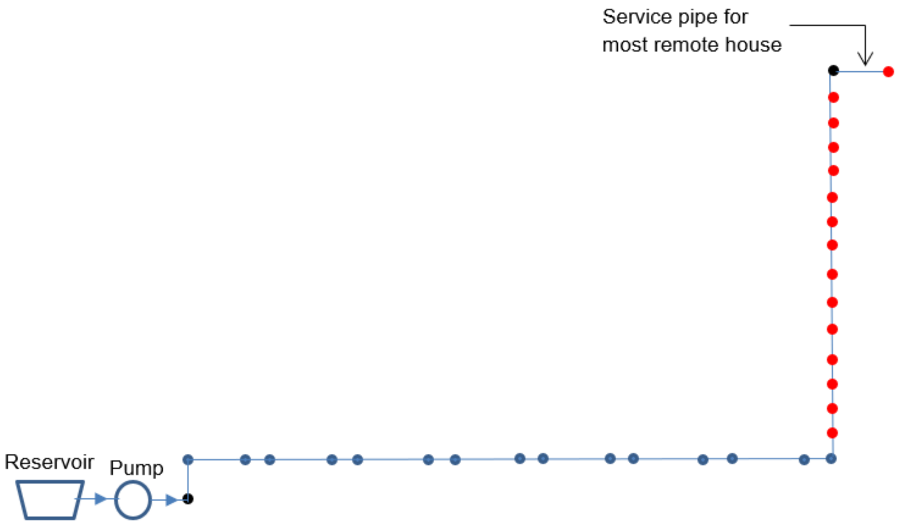

Fig. 10. Model of proposed simplified network

3.5 Statistical model

To evaluate the significance of relationship between the annual power consumption as dependent variable with service pipe C-coefficient, service pipe diameter, and network pipes C-coefficient as independents variables, a statistical model is developed using multiple regression method by SSPS software. The ANOVA technique is applied and the main results of the technique and statistical characteristics of model are listed in the table 4. The developed model is:

$$APC = 132724 - 55.85 \times dsp - 6.15 \times Csp - 358.84 \times Cnp \quad (18)$$

Where:

APC: Annual power consumption (KW.h).

dsp: diameter of service pipe (mm).

Csp: C-coefficient of service pipe.

Cnp: C-coefficient of networks pipes.

Model properties		Independent variables properties	Independent variables		
			dsp	Csp	Cnp
P-value	0.000	P-value	0.003	0.57	0.000
R^2	0.936	Unstandardized coefficient of beta	-0.090	-0.017	-0.963

The result of analysis can be summarized through the following points:

1) The model is very significance (P<0.0001). This indicated that the relationship among the independent variables and dependent variable was very high strength.
2) The high value of the coefficient of determination R2 indicating that good representation of research results by the model and display the high magnitude of effect that caused by the overall independent variables on dependent variable values.
3) Based on P-values for independent variables, each of one of service pipe diameter and network pipes C-coefficient has very significance relationship with annual power consumption, while the service pipe C-coefficient has very low significance relationship.
4) The unstandardized coefficient of beta revealed that the C-coefficient of pipes network has the major effect on annual power consumption. Its effect higher than the effect of service pipe diameter and service pipe C-coefficient by 10.7 and 56.6 respectively.

4 CONCLUSIONS

1) There are effects of service pipe properties with respect of diameter and C-coefficient on the annual power consumption of pump station of water supply network.
2) The annual power consumption decreasing with increasing either service pipe diameter or service pipe C-coefficient.
3) The reduction rate in annual power consumption due to increasing in diameter of service pipe, decreases as the service pipe diameter increase.

4) The application of demand allocation principle causes to obtain magnitude of annual power consumption less than actual magnitude. The difference between them reduces with service pipe diameter increasing, service pipe C-coefficient increasing, and pipes network C-coefficient increasing.
5) From knowledge of annual power consumption for network with certain value of service pipe diameter and certain value of service pipe C-coefficient, it can be estimated the annual power consumption for network with another value of service pipe diameter and another value of service pipe C-coefficient.
6) It can be suggested a simplified model of networks that overcomes the effect of application of demand allocation in all network, so the new model gives the real magnitude of annual power consumption.
7) The analysis of statistical model of annual power consumption as dependent variable with independents variables indicate the high significance of relationship among them, and show that the C-coefficient of network pipes has more effect on annual power consumption than C-coefficient of service pipe. At the same time, the C-coefficient of service pipe has more effect on annual power consumption than the diameter of service pipe.

5 REFERNCES

[1] Mallios Z, Siarkos I., Karagiannopoulos P. and Tsiarapas A., (2022). Pumping energy consumption inimization through simulation-optimization modelling. *Journal of Hydrology*, vol. *612*, p.128062.

[2] Chen W., Tao T., Zhou A., Zhang L., Liao L., Wu X., Yang K., Li C., Zhang T. C. and Li Z., (2021). Genetic optimization toward operation of water intake-supply pump stations system. *Journal of Cleaner Production*, vol. *279*, p.123573.

[3] Omaha NE, (2001). *Handbook of public water system*, 2nd edition, John Wiley and Sons.

[4] Zhou Y., Lee E. W., Wong L.T. and Mui K. W., (2021). Environmental evaluation of pump replacement period in water supply systems of buildings. *Journal of Building Engineering*, vol. *40*, p.102750.

[5] Cheung C. T., Mui K. W. and Wong L. T., (2013). Energy efficiency of elevated water supply tanks for high-rise buildings. *Applied energy*, volo. *103*, pp.685-691.

[6] Patelis M., Kanakoudis V. and Gonelas K., (2017). Combining pressure management and energy recovery benefits in a water distribution system installing PATs. *Journal of Water Supply: Research and Technology—AQUA*, vol. *66, no.* 7, pp.520-527.

[7] Ramos H. M., Vieira F.and Covas D. I., (2010). Energy efficiency in a water supply system: Energy consumption and CO_2 emission. *Water Science and Engineering*, vol.3, no *3*, pp.331-340.

[8] American Water Works Association, (2010). *Water Transmission and Distribution*, 4th edition, American Water Works Association.

[9] Houghtalen R. J., Akan A. O., and Hwang H. C., (2010). *Fundamentals of Hydraulic Engineering Systems*, 4th edition, Prentice Hall.

[10] Brandt M. J., Johnson K. M., Elphinston A. J. and Ratnayaka D. D., (2017). *Twort's water supply*, 7th edition, Butterworth-Heinemann.

[11] Davis M. L., (2010). *Water and wastewater engineering: design principles and practice*. McGraw-Hill Companies.

[12] McGhee T. J. and Steel E. W., (1991). *Water supply and sewerage,* New York: McGraw-Hill.

[13] Al-Tamir M. A., (2019). The Situation Of Water Treatment Plant In Mosul City, *Al-Rafidain Engineering Journal*, vol. 24, pp. 138-145.(In Arabic).

[14] Hammer M. J., (2008). Water and wastewater technology. Prentice hall.

[15] Rossman L. A., (2000). *EPAnet User Manual*, Environmental Protection Agency.

[16] Cengel Y and Cimbala J., (2014). *Fluid Mechanics Fundamentals and Applications,* 4th edition, McGraw Hill.

[17] Swamee P. K. and Sharma A. K., (2008). *Design of water supply pipe networks,* John Wiley & Sons.

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