Impact of Excess Roughness on Power Consumption in Pipe Flows

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ABSTRACT

In this study, the effect of excess surface roughness on pump power consumption was investigated for water pipe flows. In fluid distribution systems, the impurities adhering to flow wall or the wall corrosion cause the flow surface being more roughly and as a consequent cause to more frictional drag. Here, an experimental study was carried out with water flows inside aluminium, copper, steel and galvanized pipes which are detached directly from the aging fluid distribution assemblings. Roughness heights of these dated pipes was measured by experimental way. The measured roughness heights were compared with new manufacture values, the dated pipes was found more roughly. An energy consumption analysis was carried out for one meter of pipe flow for the Reynolds number between 15000 < Re < 150000. Determinations showed that the friction existed due to excess surface roughness caused the pump power consumption to increase and cost also, especially at high Reynolds number about Re > 10^5.

Keywords: pipe flow, roughness, friction

Boru Akışında Aşırı Boru Pürüzlülüğünün Pompa Güç Tüketimine Etkisi

ÖZET

Bu çalışmada, artan boru yüzey pürüzlülüğünün pompa güç tüketimine etkisi borulu su akışları için araştırıldı. Akışkan dağıtım sistemlerinde, akış duvarına yapışan kirlilikler veya zamanla oluşan korozyon akış yüzyinin daha pürüzlü olmasına neden olur ve bu da akışa karşı daha fazla sürtünme direnci oluşturur. Burada, alüminyum, bakır, çelik ve galvanizli borulu su akışıyla deneysel bir çalışma gerçekleştirilmiştir. Bu borular çalışmakta olan eskimiş akışkan dağıtım sistemlerinden doğrudan sökülen borulardır. Bu boruların pürüzlülük yükseklikleri deneysel yöntemle ölçüldü ve bulunan pürüzlülük yükseklikleri yeni imal boruların pürüzlülük değerleri ile karşılaştırıldı. Karşılaştırmada aşırı yüzey pürüzlülüğün oluştuğu görüldü. Aşırı pürüzlülük nedeniyle oluşan enerji tüketimi 15000 < Re < 150000 arası Reynolds sayılarında tam gelişmiş türbülanslı yatay boru akışları için gerçekleştirildi. Hesaplamalar artan duvar pürüzlülüğün pompa güç tüketimini ve fatura maliyetini, özellikle yüksek Reynolds sayılarında Re < 10^5, artırdığı tespit edilmiştir.

Anahtar kelimeler: boru akışı, pürüzlülük, sürtünme

1. INTRODUCTION

Energy is crucial for a sustainable life and the demand to energy increases at every other day. Increase in demand will cause the fossil supplies depleted very shortly than predicted. Though some energy demands has been achieved by the renewable energy supplies, it is known that the renewable energy use today are not enough to replace with fossil fuels. Energy becomes very crucials nowadays so it is an obligatory to achieve the energy consumptions efficiently. The context appear clearly in automobiles and power centrals since only one-third of burned fuel are useful and the remaining one is ejected to atmoshere as waste heat. Using the available energy efficiently as well as drop down the exhausts emissions, will extend the lifespan of the fossil fuel resources also.

One of the most important energy consumption component in closed conduits is the frictional losses. So the way to reduce energy consumption in closed conduits pass through directly reducing the frictional losses. The energy losses in closed conduits has been subject to many studies (Lamont, 1954; Haaland,1983; Bagarello et al 1995; Bernuth and Wilson 1989; Romeu et al. 2002; e.g.). Most of these studies has comprised the frictional energy losses (Cabrera et al (2010) has pointed out that an energy audit approach must be applied to water and etc. fluid distribution systems to determine the components having significant effect on the energy losses. According to the results he obtained, the important one is the frictional losses. The study by Boulos and Bros (2010) has reported that a series of eight different networks in a european water utility were found to have friction energy losses ranging from 2.3 to 26.8 percent of the total energy lost in the distribution system, including losses at valves and costume taps. Speight (2013) has conducted that improving pipe roughness for a given flowrate has saved the energy consumption from 7% to 20% and the results were highly dependent on the specific pipes that were replaced or rehabilitated. In water public services, pipe replacement and rehabilitation performings are applied to aging infrastructure. Therefore, the impact on pump power consumption from pipe replacement is primarily associated with the drop in friction and the reduction in flowrate by elimination of leaks. The operating rules that control a pump operation have a significiant influence on the overall energy consumption in a system (Walski, 1993). Pipe replacement applications as well as increase the flow rate, drops the number of fill and drain cycle of elevated tanks and consequently shortens the pump run hour, the overall impact on the system is the save in energy (Filion and Karney, 2003).

2. MATERİAL AND METHOD

Here, the effect of flow friction on energy losses inside pipes is introduced with the empirical correlations. A flow friction exists always inside pipes smooth or roughly. In laminer pipe flows, roughness is not effective on the flow friction so smooth or roughly pipes with the same in diameter flows have the same friction factor for the same flow condition. However, in turbulent flows, the roughness becomes very significant according to smooth pipe flows. In the folllowing two section, the effect of relative roughness on pipe flow friction factor and the empirical correlations for the flow friction has been explained and the experimental study to measure the pipe roughness height for different pipe types are also expressed.

2.1 Frictional Head

In pipe flows, the flow friction and graviational forces must be achieved by the pump. In a fully developed pipe flow, laminar or turbulent, the frictional energy lost can be calculated from the Darcy-Weisbach equation (Equ. 1) as shown below.

$$h = f \frac{L}{D} \frac{U^2}{2g} \tag{1}$$

Here, "h" is the friction head lost, equivalent to hydrostatic pressure by water column height in meter and "f" is the flow friction factor which can be computed from the Moody diagram or from Colebrook equation. L is pipe length (m), D is the pipe inner diameter (m) and U is the bulk mean axial flow velocity. In a fully developed pipe flow horizontal, static pressure drops linearly along the pipe due to flow friction. The frictional head found by Equ. (1) gives the hydrostatic pressure drop along the pipe length L just simply by multiply it with "ρg" term.

Fig.1 shows a plot of friction factor, *f*, as a function of Reynolds number, *Re*, and relative roughness, ϵ/D, as presented by Moody in 1944 which is a simple way to find the empirical factors readily. Moody diagram is seperated into four flow region which is the laminer, critical, transition and full roughly flow regions. This distinction is due to the uncertanities existed in the flow regime or by the roughness and Reynolds effect. To overcome the diffuculties of finding the friction factor from the Moody diyagram, Colebrook and White has developed an empirical correlation. The proposed empirical correlation here is as given in Equ.2.

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right) \tag{2}$$

The correleation given above is called Colebrook-white Equation however mostly called Colebrook Equation by many researchers . Here, ε/D is the relative roughness and ε is the roughness height in meter. *Re* is the Reynolds number based on pipe diameter. Colebrook Equation gives the friction factors in fully developed turbulent flows belong to transition zone.

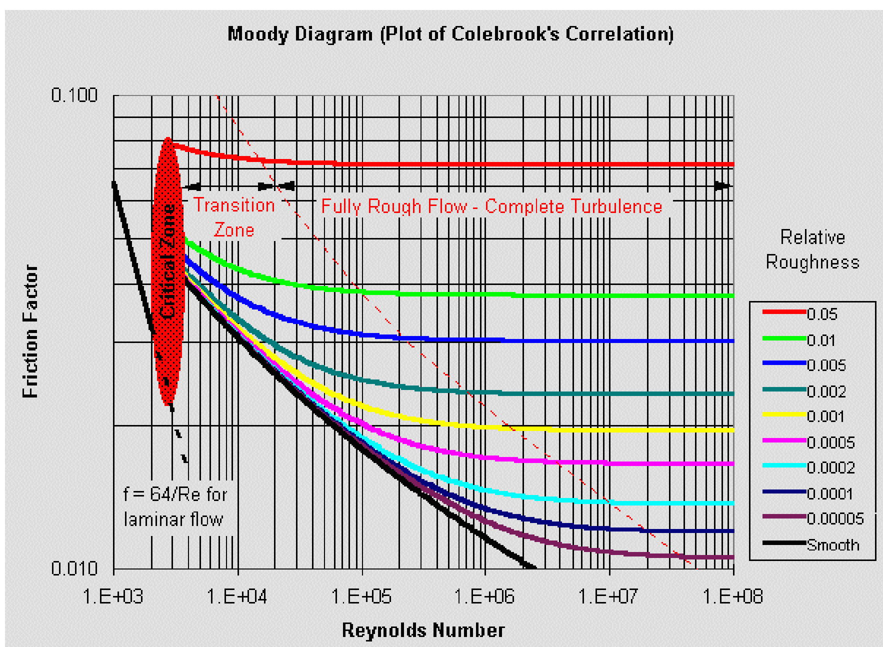

Figure 1. Moody Diagram

The Colebrook-White equation may be decomposed into Karman-Prandtl formulas for smooth-pipes ($\varepsilon/D=0$) (Franzini and Finnemore 1997, Quintela 2000) and can be used for the fully roughly flow, when the second term in pharanthesis disappear as the influence of *Re* decreases on the flow friction factor. the well-known Colebrook-White equation is presented in nearly all current text books of fluid mechanics and hydraulics (e.g. Novais-Barbosa 1986, Franzini and Finnemore 1997, Quintela 2000, among many others). Particularly referenced for the transition turbulent regime, it has been generally accepted in the scientific and academic community, as well as in engineering practice, as one of the most powerful tools for determining the friction factor and continuous head loss throughout the domain of all incompressible uniform turbulent flows in pressure commercial circular conduits. According to the experimental study made by Freire (2014), the Colebrook equation was confirmed as a powerful tool for the determination of head losses inside plastic pipe water flows in turbulent regimes ranging from Re = $4x10^3$ to approximately $6x10^5$.

2.2 Experimental Study

An experimental study of steady water flows horizontal inside four different pipe materials was performed. The four pipe type selected is aluminium, copper, steel and galvanized pipes. These pipes were detached directly from the aging fluid distribution assemblings service on. The aim of the experimental study was to measure the roughness heights of these four different pipe materials. Why four different pipe types selected is due to measure the different roughness effect on energy consumption.

The experimental set-up used consists of a pump, a flow rate measurement tank, a scaled board on which plastic piezometer hoses are assembled for the hydrostatic pressure readings, four experimental pipes and a camera for flow records. A sketch of the flow which depicts the measurement section has given in Fig. 2 below.

As depicted in Fig. 2, pressure taps were welded on pipes at seven stations. Sixth and seventh pressure taps were placed on pipe respectively at a distance of 150 cm and 250 cm, far downstream from pipe inlet. It is determined that the location of sixth pressure tap from pipe inlet is far enough at downstream for the flow to be fully developed according to 60 D entrance length (Özışık, 1985). Entrance length is a distance from pipe inlet to a downstream location where fully developed flow is established. After ensuring that the flow between last two taps is fully developed, the other five pressure taps were welded on the upstream locations of sixth pressure tap, with equal intervals of 10 cm, through which the pressure drop in the flow development section or pipe entry flow, can be measured. For the study performed here which is to investigate the impact of excess roughness on the pressure drops in the fully developed pipe flow, the pressure drop recorded between last two taps were used to determine the friction factors for the fully developed pipe flow investigation. The pressure drops recorded in the development flow section (pipe entry section) are used for other studies regarding the friction factor changes at the pipe entrance.

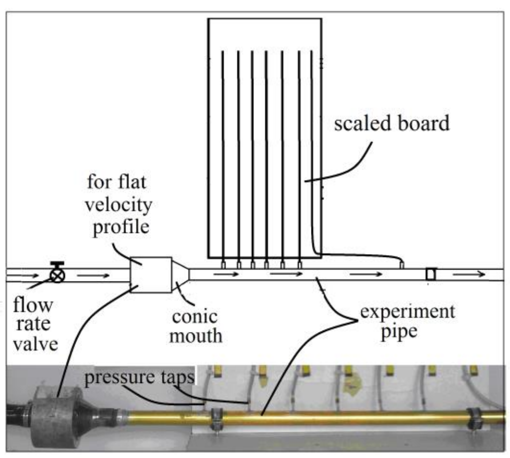

Figure 2. Experimental set-up and flow scheme

The head lost *(h)* between sixth and seven taps were obtained from the difference between both water tap heights. The friction factors of the pipe flow determined through the relation given in Equ.(1) were compared with Colebrook Equation curve at the given flow rates each in experiment. Here the aim was to measure the relative roughness of the pipe materials by comparision with Colebrook Equation curves. Here the relative roughness term in Colebrook equation was changed until a good agreement between colebrook curve and experimental data was maintained. On good coincident, the last relative roughness value written in the Colebrook equation becomes the relative roughness of that pipe material at experiment.

The physical properties of water in experiments were specified according to the average water temperature statistically measured in experiments.

Table 1. Physical properties of water

Mean temperature	28 ºC
Density (ρ)	996 kg/m^3
Dynamic viscosity (μ)	85 x 10^{-5} kg / m.s

To get a flat velocity profiles at pipe inlet, pipe inlet was screwed to a conic mouth. A flow enlargement element welded with conic mouth was also used to calm the flow to a moderate turbulence intensity at pipe inlet. Since, the turbulent fluctuations present in the upstream flow of the pipe inlet are being effective on triggering the laminar flow to a turbulent state. The pipe material and the inner diameters of the pipes used in experiments are given in Table 2.

In experiments, each pipe type was worked with different flow rates from low to high with an adjustable valf until full opening. Mass flow rates of each pipe flow are measured with mass weighted type flowmeter. According to the flow rate readings in the experiments the Reynolds number range performed in that study has been between 3443 and 24317. Seven pressure taps are welded on each pipe with such a manner, 10 cm equal intervals between first five taps which comprise the hydrodynamic entry region and one meter spacing between last two taps which just include the fully developed flow region.

Table 2. Technical properties of pipes used in experiment

Pipe Type	**İnner Pipe Diameter (mm)**
Aluminium	26
copper	26
steel	26
Galvanised	26

The hydrostatic pressures in each tap station are determined through water column heights in piezometre hoses. Due to turbulent flow fluctuation effect the instant readings of water column heights, seven piezometer hoses were recorded for a three minute with a digital camera setting up in the system. From these recordings, the instantaneous hydrostatic pressure at each tap were readed from a snapshot picture through an image processing program at which the record was stopped at five second intervals which is totally hold 21 picture from each record. Mean hydrostatic presures at each tap were obtained by time averaging of that instantaneous hydrostatic pressures readed at each tap seperately. Fig. 3 has shown the variation of instantaneous hydrostatic pressures across time and their time mean value at three different pressure taps for a given flow rate of aluminium pipe flow.

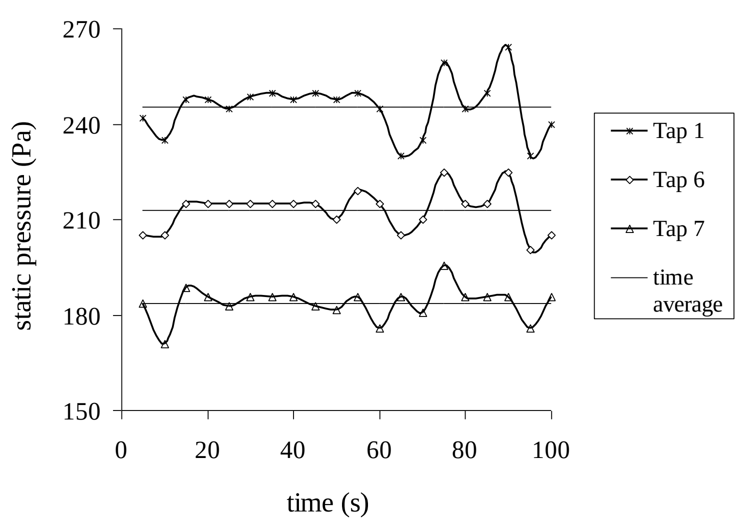

Figure 3. Varitaion of static pressure with time at three different pressure taps and their time average values.

Fully developed Darcy friction factor at each flow rate was determined from the mean hydrostatic pressure diffference between last two pressure taps through the relation given in Equ. (2). The Darcy friction factors determined by this way for each pipe type were compared with Colebrook Equation curves as shown in Fig. 4 below.

As shown from Fig. 4, Colebrook equation curves has been well agree with the experimental data of each pipe type, respectively. Good agreement at high Reynolds numbers has been better according to low Reynolds numbers for Re<15000. Since this situation has been illustrated in Moody diagram by a shaded area, which is named as transition region. Here the relative roughness in Colebrook Equation is changed until a good agreement between Colebrook curve and experimental data catched.

Fig. 4 shows the best one omong the trials made and also shows the last relative roughness value used in the Colebrook equation in paranthesis in the figure definition terms. In this context, the last relative roughness value by which the Colebrook Curve in Fig 4 exists must be the relative roughness of that pipes in experiment. The roughness height of each pipe found by this way are given in Table 3 above.

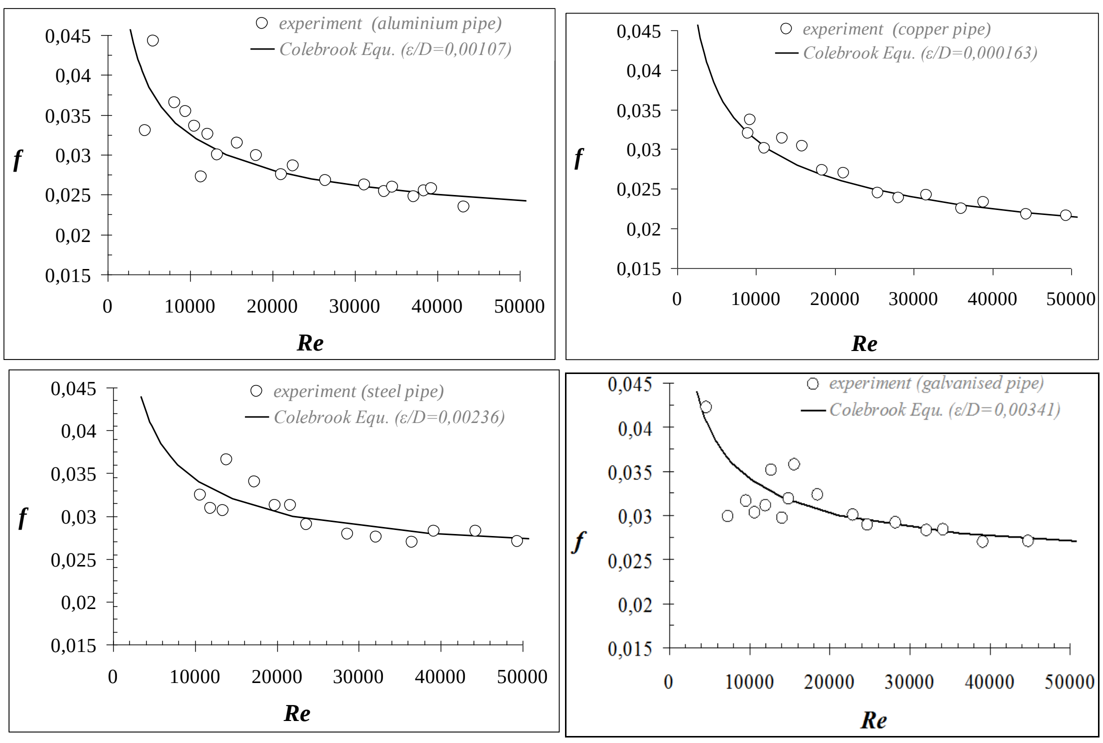

Figure 4. Variation of Darcy friction factor in experiments with Reynolds number and the curves of Colebrook equation equivalent to this variation.

Roughness height of each pipe in experiment must be compared with the new manufacturing pipe values to see the excess roughness existed on pipe material walls. That comparison was illustrated on Table 4 below. The roughness height of new manufacturing pipes was taken as the average value of the same pipe manufactured by different manufacture. As can be seen from Table 4, the roughness heights of pipes in experiment are higher enough considerably than the new manufacturing ones. The roughness ratio of both are given in last column. It is seen that the alumunium pipe ratio is extremely high according to other pipe ratios. However the roughness ratio given in Fig. 4 do not give any description about the energy consumption by the flow inside aging pipe structures. Following section has include the calculations made on energy consumption due to pipe flow friction for the pipes in experiment and for the pipes new manufacture to comparison.

Table 3. Relative roughness and roughness height of each N pipe measured by the experimental method

	Relative roughness	**Roughness height**
Pipe Type	***ε / D***	***ε (mm)***
Aluminium pipe	0,00107	0.0278
Copper pipe	0,000163	0.00424
Steel pipe	0,00236	0.066
Galvanised steel pipe	0,00341	0.0954

Table 4. Comparision of pipes in experiment with new manufacturing pipes in terms of roughness heights

Pipe type	Pipes in experiment	New manufacture pipe	Ratio
	ε (mm)	ε'' (mm)	$\varepsilon/\varepsilon''$
Aluminium pipe	0.027	0.0015	18
Copper pipe	0.0042	0.0015	2,8
Steel pipe	0.066	0.046	1,43
Galvanizednsteel pipe	0,0954	0.078	1,223

3. FRİCTIONAL ENERGY CONSUMPTION AND COST

Increase in surface roughness cause much more frictional energy lost in turbulent flows. Much more energy losts due to flow friction means much pump power required to drive the same flow rate inside pipe or a reduction in flow rate will occur over the time in case the same pump runs. So the replacement or rehabilitation applications to roughly pipes in the fluid distribution systems is very siginificant to energy savings. To see the impact of excess roughness on frictional energy losses in pipe flows, an energy consumption and cost analysis must be performed.

Pump power required to overcome frictional and gravitational head in closed conduit flows can be determined from the relation given below as Equ. 3.

$$\dot{W}_p = \rho g \dot{Q} h_p \tag{3}$$

Where, $\dot{W}_p$ (W) is the pump power required to drive the fluid in closed conduit, $\dot{Q}$ (m^3/s) is the volume flow rate and h_p is the pump head which include the frictional and gravitational head together. Here, the head means the water height column in meter, for friction it can be computed from the Equ.1 and for gravitational, it shows the meter height of the water must be pumped by the pump to a given height. Whereas the electrical energy consumption by the pump motor can be determined from the Equ.(4).

$$\dot{W}_p = \frac{\rho g \dot{Q} h_p}{\eta_p \eta_e} \tag{4}$$

Here, η_p *and* η_e is the efficiency of pump and electrical motor, respectively.

The pump head required just to overcome the friction in a fully developed pipe flows was evaluated in the case of a pipe replacement considered with new manufacture pipes. To perform that calculation, two pipe flows was considered which one belong to pipe in experiment and other belong to new manufacture pipe. Both pipes have the same diameter and the same length. For the same mass flow rate, the pump power required to overcome the friction in each pipes can be rated as below.

$$\frac{\dot{W}_p}{\dot{W}_p''} = \frac{\rho g \dot{Q} h_p}{\rho g \dot{Q} h_p''} = \frac{h_p}{h_p''} = \frac{f \frac{L}{D}\frac{U^2}{2g}}{f''\frac{L}{D}\frac{U^2}{2g}} = \frac{f}{f''} \tag{5}$$

Where, $\dot{W}_p$ is the pump power required to achieve the friction in the pipes of experiments and f is the friction factor of that flows. $\dot{W}_p''$ is the pump power required to achieve friction in the new manufacture pipe and f'' is the friction factor of that pipe flow. According to Equ. (5), the ratio of the pump powers has given the friction factor ratio. In this case, the friction factor ratio can be taken as a criteria to evaluate the pipe replacements with new ones due to more energy lost. To see the effect of friction factor on pump power consumption, the pipe flows in the broad range of Reynolds numbers must be examined. Friction factors at each pipe flow can be determined from the Colebrook Equation according to the values given in Table 1&2&4.

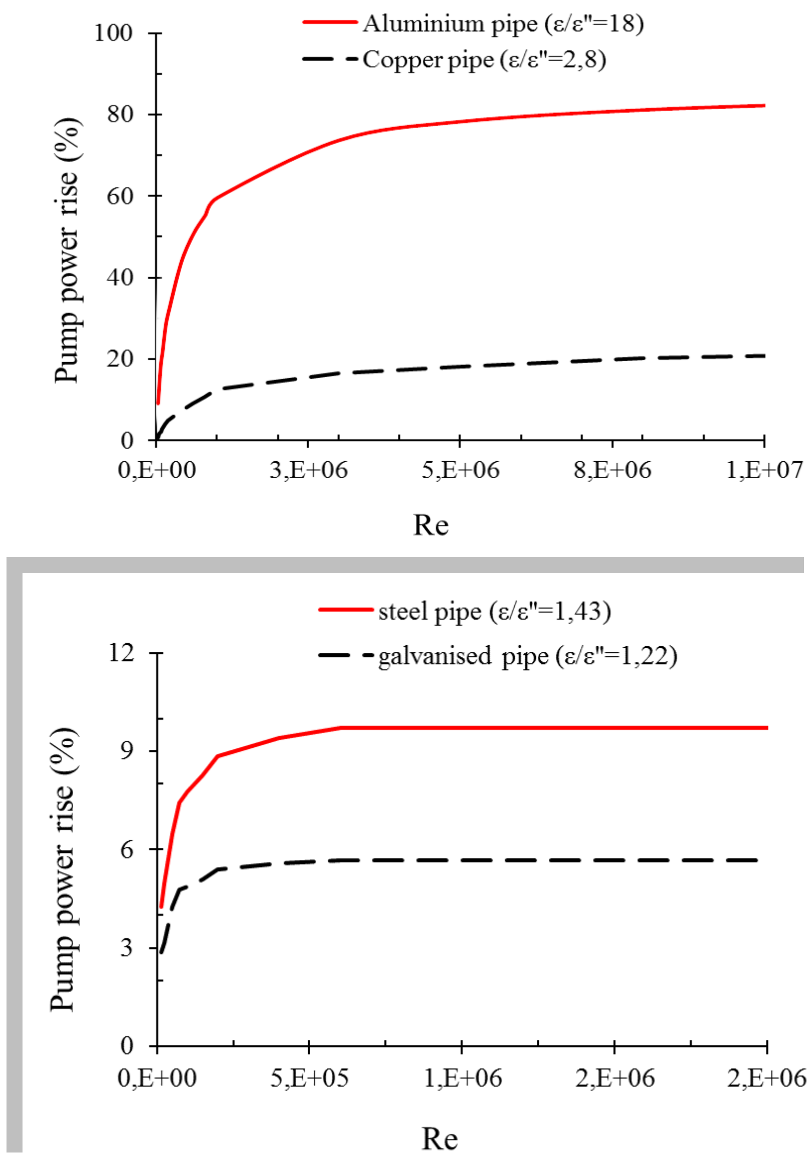

Figure 5 Percent rise in pump power across Reynolds numbers due to excess roughness

Percent rise in the friction factors according to Equ.6 means the percent rise in pump power consumption in the pipe flows in experiment according to the power consumption in New manufacture pipe flows. That percent rise in pump power has been given in Fig. 5 above.

As can be seen from Fig. 5, the percent rise in pump power consumption increases as the Reynolds number increases untill a constant value of friction factor reached at there the flow regime becomes fully rough flow. Since the friction factors becomes free of Reynolds number in fully rough flows as shown on Moody diagram. According to Fig.5, aluminium pipe flows, which have the highest excess roughness ratio than others, has also shown the highest percent rise in the pump power. Upon the examination on the low Reynolds number flows, e.g at Re = 25000, aluminium, copper, steel and galvanised pipe flows has shown 9%, 0.78%, 5% and 3% rise in the pump power, respectively. However at very high Reynolds numbers, e.g. at fully rough flow, the same pipes have the values of 81%, 21%, 9.7% and 5.7% rise in the pump power, respectively. As shown in Fig. 5, the pump power rise in steel pipe and galvanised pipe has reached the asymptotic constant value at very early Reynolds numbers about Re = 5x10^5 but the same case for aluminium and copper pipes has been at very high Reynolds number about Re = 8 x 10^6. The situation here can be explained with the effect of relative roughness value on pipe flows since the pipe flows have high relative roughness becomes fully rough flow very early according to low relative roughness flows according to Moody Diagram.

The best way to see the effect of excess roughness on pipe flow assemblings is to analysis the annual energy consumption and cost. Since the decisions made on pipe replacement or rehabilitation applications are mostly based on the annual energy saving analysis. So, in this study an energy saving analysis was made to see the effect of excess roughness on the pipe flows. In the analysis, the annual energy consumption and cost were evaluated over the one meter of pipe flow for the Reynolds numbers until Re = 16 x 10^4. The pump that drive the flow in pipe consume electrical energy. The pump efficiency and electrical motor efficiency was assumed as 100% to simplify the calculations. The prediction of annual energy consumption and cost was determined from the relation given below as Equ. (6).

$$W_e = \frac{\rho g \dot{Q} h_p}{\eta_p \eta_e} * N \qquad (kWh) \tag{6}$$

Where, N is the annual pump operating hours. The pump head term (h_p) in Equ. (6) can be estimated from Equ.(1) since the pump head just include the frictional head no any gravitational head in it. Pipe diameters, fluid properties and pipe roughness heights given in Table 1&2&3 were used in calculations. The result obtained are graphed on Fig. 6.

As shown in Fig. 6, the more electrical power consumption for the one meter of pipe flow due to friction in the fully developed turbulent state have graphed across the Reynolds numbers between 15000 and 160000. The reason why these Reynolds number range selected is due to we know that many pipe flows in most applications operate in this Reynolds number range.

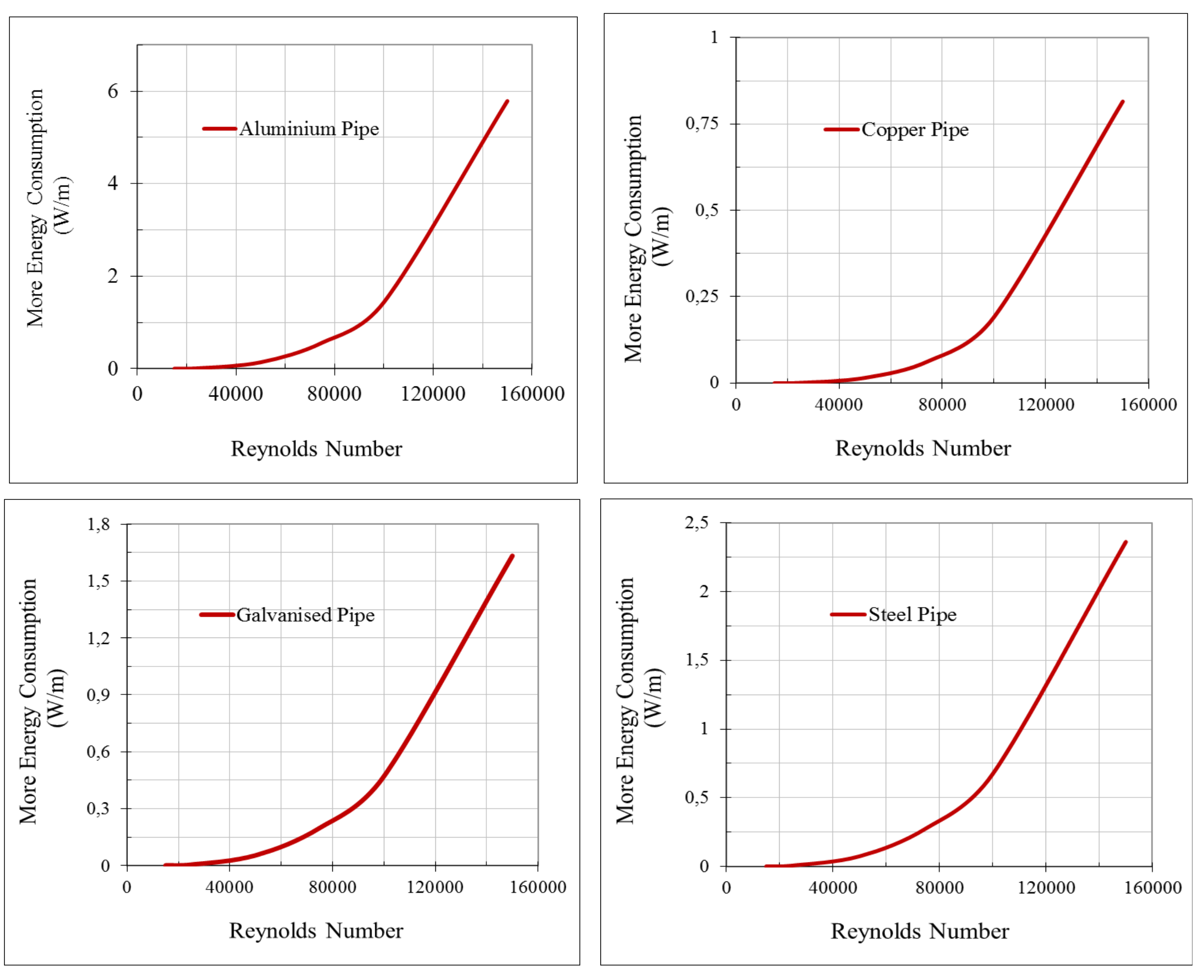

Figure 6. The more power cosumption per one meter of the pipe flow across Reynolds numbers due to friction existed by the excess roughness

When Fig.6 is reviewed well enough, it is seen that the more power consumption increases exponentially with the Reynolds number until about Re = 10^5 then increases linearly with the Reynolds numbers. Due to aluminium pipe have highest roughness ratio, its curve have shown higher more power consumption among others. But the same case is not true for copper pipe since though it has a higher roughness ratio than steel and galvanised pipe, nearly two times higher but its more power consumption is lower than both pipes. This can be explained as since the relative roughness value of steel and galvanised pipe is very high than copper, nearly thirty times higher, and also than aluminium pipe (can look to Table 4). Aluminium pipe have very high roughness ratio than both pipes so the more power consumption in aluminium pipe flows has became higher about two times than steel and galvanised pipes.

By the realization that the annual more energy consumption and cost analysis becomes significant for the decisions made on the pipe replacement, an energy saving analysis and a payback time must be determined before a pipe replacement program was applied. So an annual more energy consumption and cost analysis due to more friction generated by the excess roughness was considered here also for the Reynolds numbers range given in Fig. 6. The electrical unit cost was specified as 0.25 TL/kWh according to the unit cost paid in Turkey in 2016. Here, the annual energy consumption and cost analysis were carried out for a pipe flow assembly considered in 100 m long pipes and operate 5000 hour annually. The calculation results were represented in Table 5.

As can be seen from Table 5, the more cost paid increases as the Reynolds number increase. Except for the Reynolds number in the last two array, annual more cost paid is low enough to launch a pipe replacement program. But at the Reynolds number of 150000, more cost paid is high enough, especialy in aluminium pipe which has a highest value with a more cost paid of 723 TL annually. Except copper pipe, the other pipes also have more cost paid enough at that Reynolds number. As a result, at high Reynolds number flows, pipe rehabilitation program can be considered. Before any decision made, the other statements must be considered well enough before the pipe flow assembly is stopped for a while for the pipe replacement or rehabilitation. The time consume during pipe replacement or rehabilitation application will cause to many money to lost for the facility due to the production is stopped. So when a pipe replacement aplication is considered, all the effects possible on the system economy must be determined before a decision made.

Table 5. Annual more cost paid due excess roughness for a pipe flow assembly in different Reynolds number

ANNUAL MORE ENERGY COST (TL) (a pipe flow assembly with 100 m pipe length and 5000 pump hour annual)				
Re	**Aluminium (*D=26mm*)**	**Copper (*D=26mm*)**	**Steel pipe (*D=28mm*)**	**Galvanised pipe (*D=28mm*)**
15000	0,28	0,02	0,20	0,14
25000	1,57	0,13	0,98	0,67
50000	17,52	1,91	9,32	6,74
75000	70,66	8,10	34,74	24,85
100000	180,18	23,81	84,16	58,86
150000	723,64	101,87	295,23	204,13

4. RESULT

Here the effect of excess roughness existed on pipe walls timely was evaluated on the energy consumption due to more flow friction created. Four different pipe type were selected from the aging fluid distribution systems. Pipe inner surface roughness of that pipes were measured through the experimental method in which Darcy friction factors were compared with Colebrook equation curves.

Pipe roughnesses found by the experimental way were compared with new manufacture pipe roughness values and excess roughness was found at a considerable amount. The division of the pump power required in the aging pipes to the new manufacture pipe ones is resulted with a Darcy friction factor ratio. The percent rise in the pump power due to excess surface roughness can be determined from the Darcy friction factor ratio.

According to Fig. 5, the order scale in the percent rise in pump power to achieve the friction is the same with order scale of the pipe roughness ratios which is a roughness heights ratio betweeen aging pipe and new manufacture pipe. Since aluminium pipe has a highest roughness ratio than others, also has shown a highest value in percent rise in the pump power. But the same case is not true according to Fig. 6 in which more energy consumption due to excess roughness was curved across Reynolds number. Though copper pipe has a high roughness ratio than steel and galvanised pipe, more energy consumption in copper pipe has became lower than both pipe values. This is because of the roughness height of steel or galvanised pipe are nearly thirty times than copper pipe.

An annual more energy consumption and cost due to excess roughnes were determined for a pipe assembly considered 100 m in length and 5000 annual pump hour. Annual determinations were evaluated for Re = $15x10^3$ to $15x10^4$. According to Table 5, it was seen that annual more cost paid was high enough at Reynolds number range bigger than $1x10^5$. So the pipe flows at that Reynolds numbers can be considered for a pipe replacement program. Before a pipe replacement program was launched, all the effects possible on the system economy due to pipe replacement must be determined before a decision made. This includes the money lost and e.g other efffects due to production is stopped during pipe replacement.

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