# Dynamic modeling of the water pumping station in water treatment plant using the bond graph method

Mohammadmasoud Maghzi[1], Ehsan Hadizadeh[2]

[1]*Department of Mechanic, Abadan branch, Islamic Azad University Abadan, Iran*

[2]*Department of Mechanic, Ahvaz branch, Islamic Azad University Ahvaz, Iran*

mohammadmasoud_maghzi@yahoo.com[1], Hadizadeh.ehsan@gmail.com[2]

## Abstract

Pump stations play an important role in providing drinking water in cities. They are mainly composed of fluid, hydraulic, chemical, and electrical subsystems. The purpose of this work is to investigate performance of the pump station in Ahvaz city based on its dynamic model; some instructions are proposed to improve the performance of this pump station. To this end, based on available technical information, the dynamic model of the pump station was first constructed using the bond graph method and 20sim software. Then, the performance of the system was evaluated under different working conditions. According to the investigations, it was found that replacing the outlet pipeline of the raw water section resulted in a decrease not only in the amount of electricity consumed by the pumps, but in hydraulic wastes in circuit. What's more, different types of pumps were studied to achieve a model in which the energy consumption and hydraulic wastes is minimum. According to this study and based on results it is available to replacing any type of pump by knowing the dynamic model of electro pump.

**Keywords:** Pump station, Dynamic modeling, The bond graph method, Optimization on energy consumption, Water treatment

## 1. Introduction

One way to improve countries and leading them toward civilization and commonwealth is efficient use of natural sources. In many countries such as third world countries, healthy and sanitary water is not available for more than the half of the people. The bond graph method was first introduced by Paynter on the basis of systems identification as power bonds for the physical systems (Paynter, 1961; Karnopp, 1968; Rosenberg, 1968) and (Thoma, 1971) developed this method to hydraulic, mechatronics, thermodynamic, electrical and economical systems. Among the modeling methods, the bond graph possesses the unique capability of modeling multi-disciplinary physical systems in a unified model. Worm discussed the hydraulic elements for drinking pump station (Worm et al., 2009). Verbrek researched on governing principals on water purification systems (Verberk et al., 2006).

Water treatment plant management of this place will provide availability to see the effects of each part on the other available parts and, in spite of that the complex manager will find a better idea about function effect of each factor and can make better decisions at the incidence of failure. Even to increase production and efficiency of each factor and the entire complex can present more comprehensive and exact instruction with the systematic view that he got. In the modeling part presented the process of providing raw water pumping station complete bond graph model. Then in modeling part and presenting the results part, the system quite and passing treatment observed. Cause of disability in some parts of raw water pumping station and the effect on the entire system function observed. At the end, the main conclusion and suggestion to improve the function of the raw water pumping station presented.

## 2. Materials and Methods

Bond Graph model is used for dynamic modeling in this research. The type of view that we have about dynamic system is based on power and energy flow from one system or neighbor system. In this method, desired system simulated with bond graph factors and system change to different stimulation can be finding. To extract water from river, centrifuge pumps were used. The placement of the pumps is as follows: in one phase three centrifuge pumps located in raw water station which sucking pump were attached to the bottom part of waterfront which is used to extract raw water. Second phase made according to first phase. For first step of modeling three pumps located in one phase. Pump station modeled and then the conclusion was generalized, so we will present different factors in modeling there:

### 2.1 Model of Resistance factor in hydraulic system

All the factors locate at the place where there is fluid flow resistance and pressure drop and all porous filters and their functions which there all fluid is forced through several pores is called resistance factor. A usual pipe has the same resistance property which there the relation between pressure and the linear resistance element is as mentioned below. There R shows resistance .

$$P = R \times Q \; P = R \times Q \quad (1)$$

Each line used in piping is considered as one element of resistance as the fluid is passing, the fluid pressure decreases considers as a factor of the resistance. In spite of pipes resistance, existence of any check and gate valves as they cause pressure drop in the flow path, are considered as the factor of resistance ($R_{gate\ valve}$ and $R_{check\ valve}$).

As the picture showed, an active bond entered on resistance factor. As gate valve opens and closes by hand, resistance is changeable and is based on the number of opening and closing. To analyze the issue a linear relation can be find between the number of opening and closing and resistance which can be shown in this way: $R=R_{max}$ X, so $R_{max}$ shows the valve resistance in closed position. As the reducing the expansion and contraction is gradual, drop can be observed in a gradual expansion cone. It will be also for pipe according to the length: There are two positions for one way valve. While the flow is positive, valve is completely open; on the other hand it is close with $R_{max}$ (Fig 1, 2 & 3).

*Figure 1. The way of arranging pumps in water pumping station*

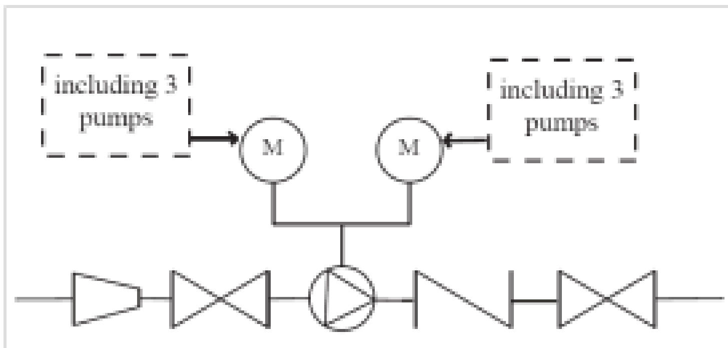



*Figure 2.Schematic picture of gate valve and bond graph diagram*

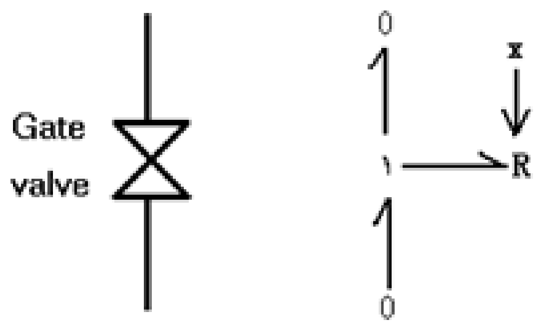
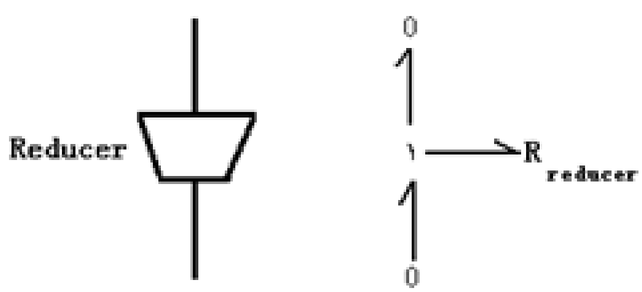



Figure.3.Reducer schematic and bond graph diagram




## 2.2 Model of capacitor factor in hydraulic system

Is a factor which there is a linear relation between pressure and flow integral (capacity). In hydraulic systems capacitor is the most striking element which is modeled by capacitor factor and also fluid and transmitter modeled by capacitor factor under conditions. In fluid transfer under its pressure and effect of the line high pressure density happens. In this position, capacity caused by the fluid compressibility is as following:

$$C = \frac{V_0}{\beta} \quad (2)$$

We should know that the transmitter can change the volume of the fluid so, a capacity to change the pipe size is equal to

$$C = \frac{2V_0R_0}{Et_w} \quad C = \frac{2V_0R_0}{Et_w}$$

So there are two capacities for pipe, one for changes in the volume of fluid and another for change in pipe volume, as following:

$$C = V_0\left(\frac{1}{\beta} + \frac{2r_0}{E_w}\right) \quad (3)$$

## 2.3 Model of inertia factor in hydraulic system

It is a factor which there is relation between pressure and derived flow which is linear.

$$P = IQ^{\cdot} \; P = IQ^{\cdot} \quad (4)$$

Now we have pipe with constant cross section of A and length of L . Lets imagine that pressure cap is P.

$$(5)$$

So inertia value is equal to:

$$F = ma \; F = ma$$

$$I = \frac{\rho l}{A} \quad I = \frac{\rho l}{A} \quad (6)$$

We can see that the pipe has a lower level might have more inertia

Input pump power is supplied by an electric motor. For modeling and electro motor pump setting, power input to engine is considered as a power source, is considered as a source of power and it is circular pump output and applied angel speed to the pump shaft. Current Power diagram is showed as following:

Power source Electrical motor Shaft Pump

To convert electrical current range in to mechanical we should use Gyrator factor. To convert mechanical current in to, transformer factor is used to speed shaft angel to the flow. To model shaft inertia and capacitor factors are used. After identifying subsystem factors, and calculating the factors numerical bond graph is made from system sub branch. The entire made model for a row of pump is shown in (Fig. 4, 5).

*Figure.4 Schematic picture of pipe and bond graph diagram*

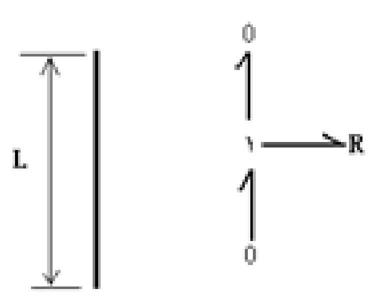
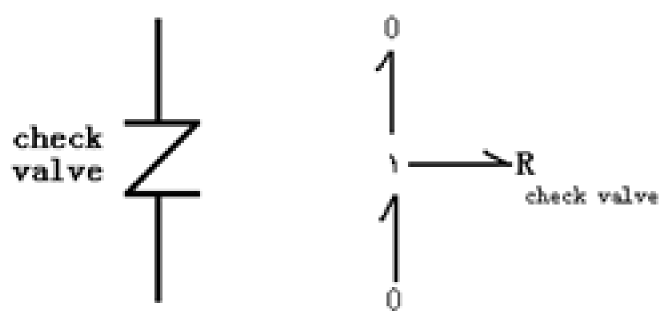



*Figure.5 Shematic picture of one way valve and bond graph*




## 2.4 Simulation

By gathering the mentioned model we will reach the bond graph model of the entire system. As this model is bulky, is avoided to present the whole parts. In this part obtained analyze and diagrams from refinery system simulation is used. This numbers are obtained with assumptions and methods in references. It's noteworthy that the differential equations are solved by the second order Euler method (Carnahan, 1996).

## 2.5 The pump model verification

The pump's power consumption rate for various flow rates calculated from the simulated model is compared to the power characteristic graph provided by the manufacturer (Pumpiran, 2012) and the results is shown in the (Fig. 6, 7). It is concluded that the hydro-mechanical behavior of the pump can be successfully predicted with the proposed model.

*Figure 6. Schematic picture of pipe and bond graph diagram- inertia factor*

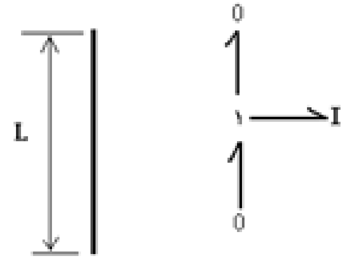
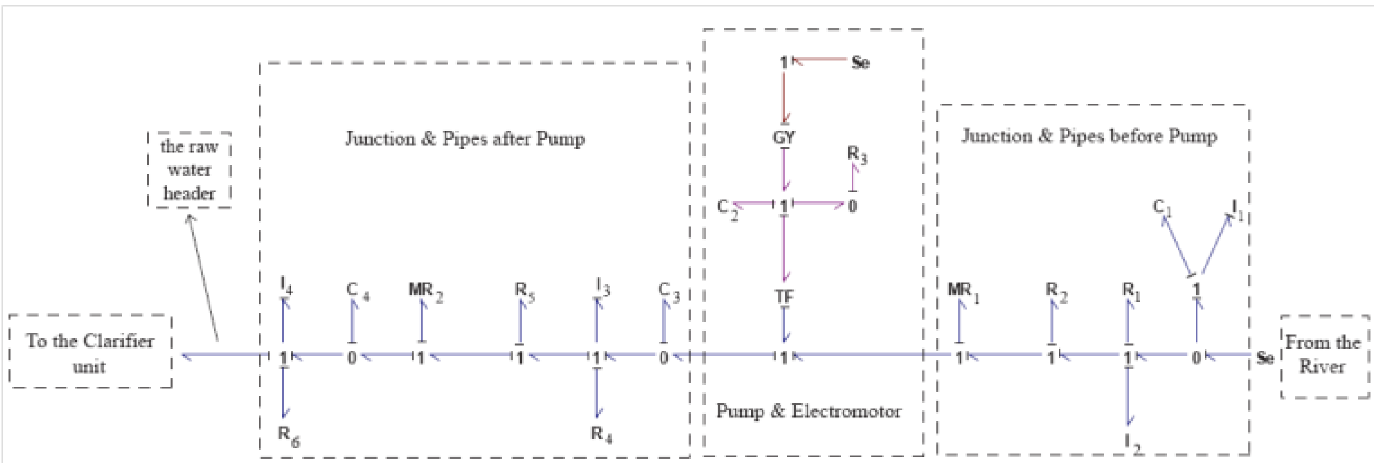


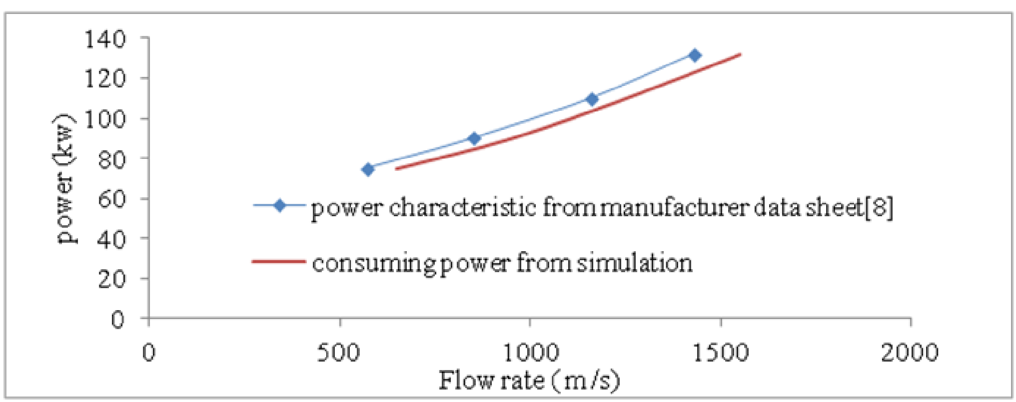

*Figure. 7 Bond graph model for a row of pumps*




## 2.6 The final state and transient behavior of the system

Figure 8 & 9, Shows the system's start up time needed to reach a steady flow rate. It is seen that the pump station undergoes the steady-state behavior about 650 seconds after the system starts to operate.

*Figure 8. Comparison between power characteristic from manufacture data sheet and consuming power from simulation.*




## 2.7 The transient behavior of each unit

The transient behavior of each unites are shown in (Fig. 10). Consequently, the rise time corresponding to different subsystems are shown.

Figure 9. The transient behavior of the pump station:

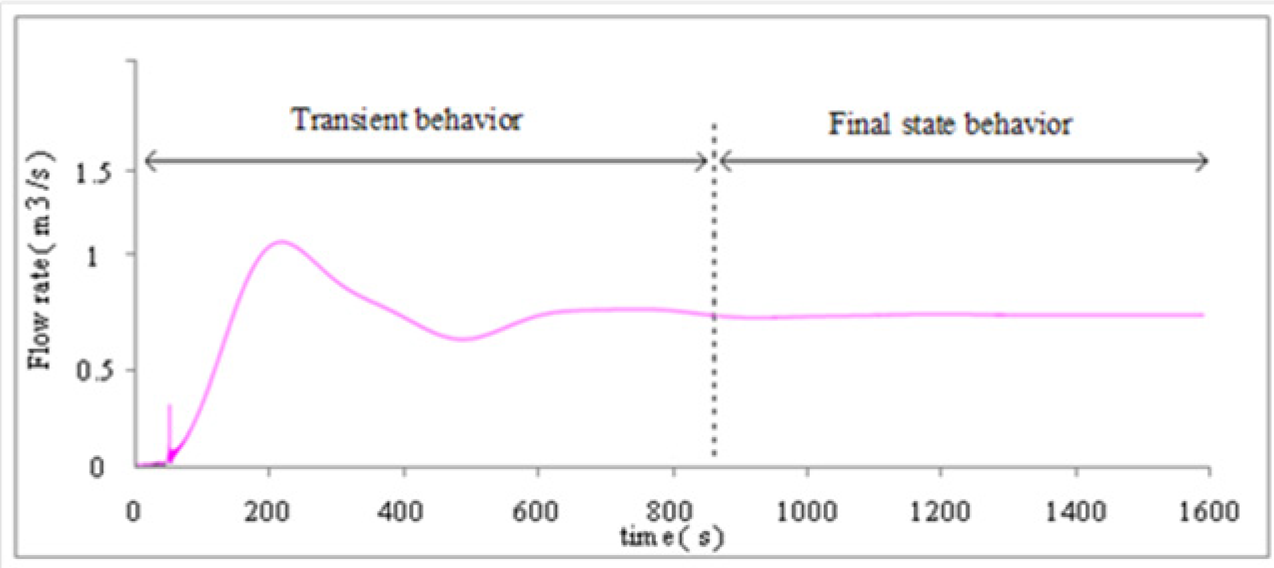
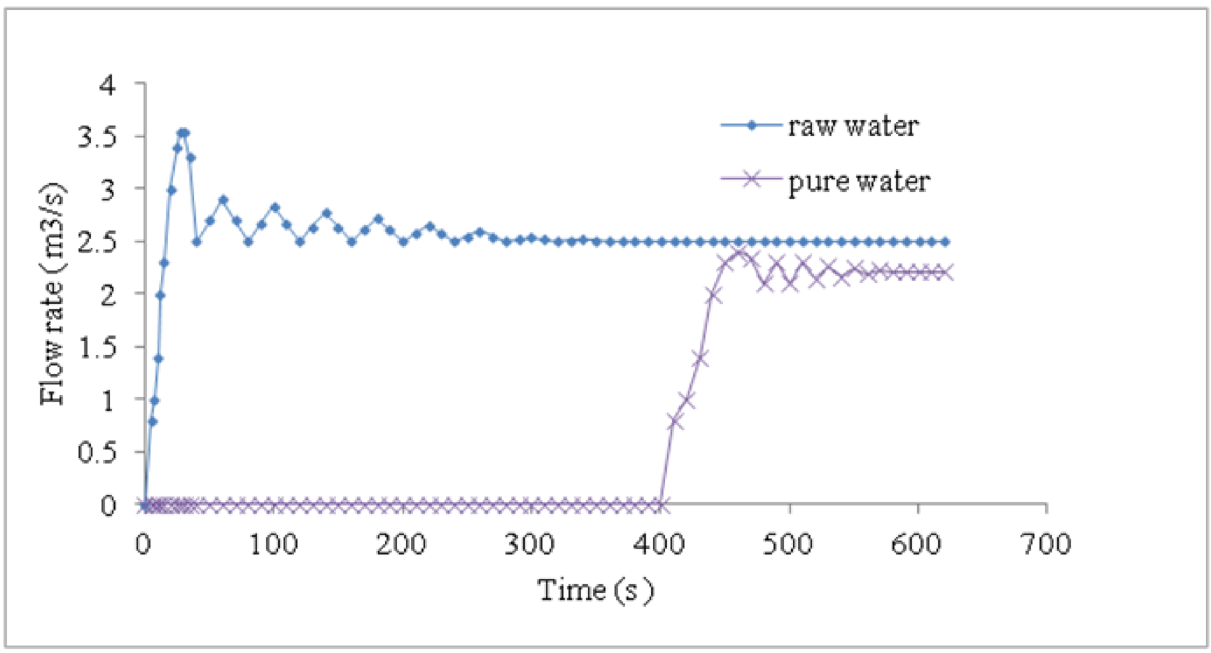



*Figure.10. The transient behavior of each sub system*




## 3. Result and discussion

### 3.1 Changing the raw water header (System performance improvement)

One of the investigations made by the model is the effect of changing the diameter of the raw water header. The raw water header. In this investigation, the diameter of the header varies between 400 mm to 600 mm. In addition, for rather than five pumps are considered to be present in the raw water subsystem for this part of the study. The results of the study shows that although the flow rate decreases by 4.5% (see Fig. 11.), the energy consumption decreases by almost 16%.

## 4. Fault generation in system

Figure 12, shows the response of the PUMP STATION when one of the raw water pumps is broken down at t=200 s. It is seen that after 300 seconds, a steady flow rate in the output is achieved with 30% lower in the level compared to the case when all the three pumps are in the circuit.

*Figure 11. Comparison between the present exit flow rate and the modified one in the pump station.*

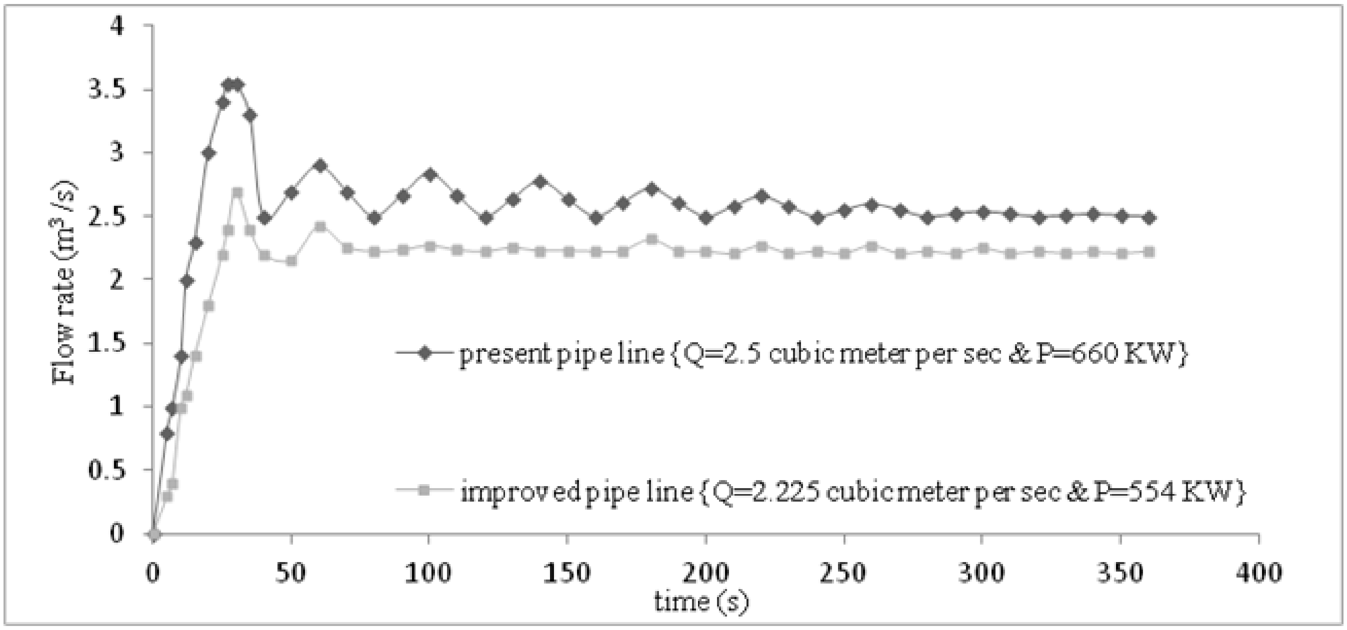
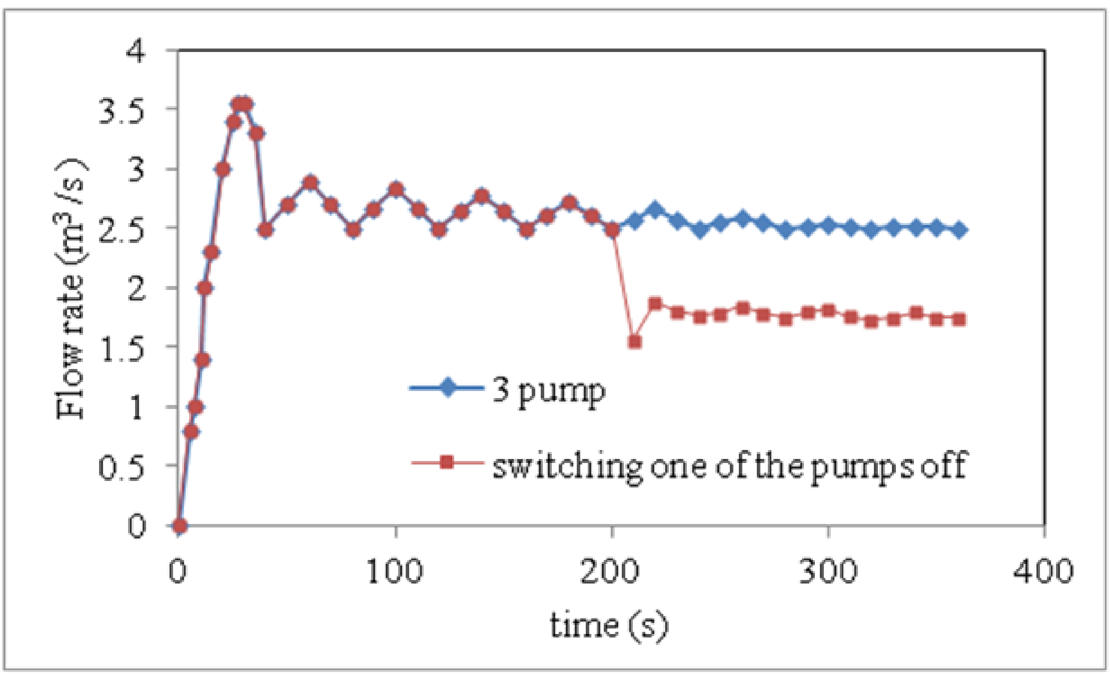



*Figure.12. Effect of turning off one of the raw water pump*




## 5. Conclusion

The results from research showed: the effect of some factors causes big changes in system function. By changing output pipe from raw water and increase the pipe diameter we can decrease 19% hydraulic system waste, refinery raw water pumping station consuming electricity decrease by more than 3000 kilowatt in per day. According to the current situation in refinery raw water part which can't provide extra pumps this change can cause one pump be in reserve and in the case of pump failure or disorder in the other pumps, there will be enough time to solve the pumps problems and there is no need to worry about keep and maintenance of pumps because of not having extra pumps. By having pump model and electromotor it will be possible to replace the other pumps in complex and by making a software modeling in computer, simulating and analyze and do the required editions.

## 6. Acknowledgment

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