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A MATHEMATICAL MODEL FOR CONVEYING WATER THROUGH A LONG PIPE LINE

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DEDICATION

To Kheloud, source of kindness that inexhaustible, which without her what I was able to be what I am today.

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I heard once before that when you reach a significant achievement in your life, you should stop and take time to thank the people who helped along the way. I don't remember where I heard this but I feel it is a wise saying. So, first and above all, I praise ***ALLAH***, the almighty for providing me this opportunity and granting me the capability to proceed successfully and enabling me to accomplish this stage of my life.

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ABSTRACT

Transportation by pipeline is the means most frequently used to transport water for their safe and economical properties and also for their ability to maintain a high quality of life. A pipelines flow condition where the velocity and pressure change rapidly with time is called hydraulic transient. It can collapse a water pipeline system if that system is not equipped with adequate transient protection device(s). A hydraulic transient normally occurs when a flow control component changes situation (for example, a pump stopping or valve closing), and this flow changes through the system as a pressure wave is called water hammer phenomenon. The water hammer transient is a non-uniform flow which is a change in the pressure resulting from a sudden change in the flow.

In this study, governing equations of water hammer are numerically simulated using MATLAB software based on method of characteristics. The mathematical model has been verified with several published data namely (Elbashir and Amoah (2007), Gubashi and Kubba (2010) and Mansuri et al. (2014)). It is found that the developed mathematical model agree very well with these previous studies and can rely on it for simulation a transient water flow in pipes. The developed model was used to simulate the water transport from region called Five Bridges to Wadi abi-Naft (within the villages of Clans Neda) in the outskirts of Mandali city, Diyala governorate, Iraq. The total length of pipeline path is 54km. The simulation results showed that the pipeline path need three pumping stations

in order to transport water to Mandali City. The pipeline used unplasticized polyvinyl chloride (PVC-U) with diameter is equal to 1200mm. Each pumping station was simulated separately under transient flow condition. The required remediation to overcome the water hammer phenomenon is suggested. A surge tanks with different capacities namely $1700m^3$, $1530m^3$ and $1475m^3$ for first, second and third stage respectively are suggested.

Sensitivity analysis has been performed using several variables such as pipe diameter, wave's velocity and friction factor. It has been found that the diameter of the pipe has a significant effect on the results of water hammer compared to the effect of both velocity wave and frication factor. Also, it has been found that the ending section of pipe is the critical zone for the water hammer effect. In the present study, it has been found that pumps failure has relatively smaller effect in increasing the negative pressure compared with the valve closure effect.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

CFD	Computational Fluid Dynamics
DIN	Deutsches Institute for Normung
FDM	Finite Difference Method
FEM	Finite Element Method
FVM	Finite Volume Method
HAM	Homotopy Analysis Method
MOC	The Method of Characteristics
PDE	Partial Differential Equations
PPFS	Parallel Pump Feedwater System
PVC-U	Unplasticized Polyvinyl Chloride
WCM	Wave Characteristics Method
WKB	Wentzel–Kramers–Brillouin

Symbols

h_L	The head loss in valves (m)
h_f	Friction head loss (m)
C^-	Negative characteristic line
C^+	Positive characteristic line
K_L	The valve loss coefficient
P_0	The initial population
P_t	The population at time(t)
R_e	Reynolds number
T_c	The required time for valve closure (sec)
At	The area of the surge tank ($m2$)
C	Coefficient that accounts for the pipe support conditions
D	Inner diameter of pipe work (m)
E	The Young modulus (modulus of elasticity) of the pipe material (pa)
H	Pressure head of water in pipes (m)
K	The bulk modulus of elasticity of the fluid (pa)
L	Length of pipe work (m)
N	Number of sections of pipe

Q	Discharge of pipes ($m3/sec$)
S	The maximum elevation within a cylindrical surge tank (m)
V	velocity of water in pipes (m/sec)
a	Wave celerity (m/sec)
e	The thickness of the pipe (m)
f	Darcy-Weisbach coefficient
g	Acceleration due to gravity (m/s^2)
k	Unsteady fiction coefficient
p	Pressure of water in pipes (Pa)
r	The rate change of Arithmetic growth
z	Elevation head or potential energy (m)
ρ	The bulk modulus of density of the fluid ($kg/m3$)
μ	Poisson ratio

CHAPTER ONE
INTRODUCTION

1.1 General

Appropriate quality and quantity of necessary water supply is one of the most important issues in human history. Most ancient civilizations began near the water source. The challenge to meet user demands increased when the populations grew (Chung, 2007). Water generally is not present at the locations and times where and when it is most needed. As a result, engineering works of all sizes have been constructed to transport water from places of abundance to places of need (Winter, 1998). The hydraulic systems, which are used to transport water either gravitational systems such as open channels or pumping systems such as pipeline systems.

In open channel, upper surface of the water flow exposed to atmosphere and the flow is due to gravity. Thus, the flow conditions are extremely influenced by the slope of the channels. The gravitational method used when the source of water at such a height that the desired pressure can be available for transport to the reservoir (French, 1985)

The benefits of open channels included: lower capital cost, potential to generate electricity, potential recharge of aquifers, warmer water and perceived easier future expansion. But, the disadvantages of open channel transportation include: land loss, poor safety, poor access, less harmonious community process especially land purchases from unwilling sellers, community disruption during construction, high cost of land purchase, poorer water quality and vulnerability to pollution, water loss through leakage and evaporation, higher maintenance, contamination and sabotage, dry channels in summer, and no water in summer for community use (French, 1985).

While that pipeline system not exposed to atmosphere and the flow due to pressure. The pipeline systems ranging from the very simple systems to very large and complex systems. These systems may contain any of the types of pumps at the end of the pipe or in an intermediate point, the mission of these pumps is to deliver water to or from the reservoir (Larock, et al., 1999).

The benefits of water transport in pipelines include: the land utilization, energy saving, less delay of existing activities, environmental, aesthetics, safety, quality, flexibility, and the acceptance of the community have easier. But, the disadvantages of the pipes includes: the high upfront cost, possible disruption to farming operation during installation and higher earthquake risk, and when replacing open channels with pipeline systems gets the loss of biodiversity. The overall conclusion is that the pipeline system is more sustainable systems (Larock, et al., 1999).

Therefore, and based on the above advantages and disadvantages, it has been suggested to design and analyze a project of transport water using pipeline system.

1.2 Flow Regimes in Pipes

During the fluid flow within the pipe, the internal roughness (e) of the pipe wall creates an eddy that add resistance to the flow of fluid in the pipe. Pipes with smooth walls have little effect on the frictional resistance such as glass, copper and polyethylene pipes. But the pipes walls with less smoothness such as iron, concrete and steel generate larger eddy currents. In some cases these eddies have a large effect on the frictional resistance (Metzner and Reed, 1955). Laminar flow occurs when the Reynolds number is less than about 2300 and at this point the resistance of the flow doesn't depend on the pipe wall roughness. Internal roughness of the pipe in laminar flow does not have any effect on the frictional resistance (White and Corfield, 2006).

But, when the Reynolds number is larger than about 4000, the turbulent flow occurs. Eddy currents occur within the flow, and to determine the friction factor of the pipe needs to find the ratio of the internal roughness height to the internal diameter of the pipe which is called relative roughness (e/D). The total effect of the eddy currents is less important in the case of large diameter pipes. But the internal roughness have a significant effect on the friction factor in the case of small diameters pipes. The Darcy-Weisbach formula can be used for calculating the frictional resistance in pipes (White and Corfield, 2006).

The flow in pipeline systems can be classified into steady and unsteady flow depending on changing velocity and pressure with time.

1.3 Flow in Pipes under Steady State

The definition of steady state flow is that the fluid characteristics at any point in the system do not change with time. These characteristics include velocity, pressure and temperature. The system mass flow rate is one of the most important properties in the pipeline system, which remains constant in a steady state flow. This means that there is no accumulation of mass in any component in the system. Bernoulli equation is the basic equation developed to explain steady-state fluid flow, which assumes that the overall mechanical energy is protected for a steady, isothermal and incompressible and without heat transfer or work done. (Larock, et al., 1999).

1.4 Flow in Pipes under Transient Flow

A hydraulic transient is a flow condition where the velocity and pressure change rapidly with time (Elbashir, and Amoah, 2007). In fact, transient flow occurs in all fluid, which it occurs in confined and unconfined fluids that causes a disturbance to the flow (Batterton, 2006).

A quasi-steady flow is the first type of transient, which is distinguished by the absence of elastic or inertial effects on the flow conduct. In this type of flow the pressures and discharges change gradually over time, and over a short time periods the flow up to steady-state. True transient flow is the second kind of transient. In this type, the effect of the elasticity of the fluid and the inertia of the pipe and/or the fluid is an fundamental factor in the flow behavior and must be taken into consideration. If the effects of inertia are large, but the effects of compressibility in pipe and fluid are small or non-existent, then a true transient flow will be referred to as a rigid-column flow. Additionally, it must be retained the effects of the elasticity of the pipe and the fluid in order to get an accurate description of the transient and this is called water hammer (Larock, et al., 1999).

1.5 Water Hammer Phenomenon

In closed systems, such as pipeline system, any sudden change occurring to the flow caused large pressure fluctuations inside the pipe this is called water hammer phenomenon (Batterton, 2006). The name of water hammer comes from the hammering sound that occasionally occurs during the phenomenon (Gubashi and Kubba, 2010). Water hammer is a transient flow in pipes that was created by abrupt changes of velocity in pipe lines (Mansuri, and et al., 2014). The Italian engineer Lorenzo Allievi was the first person explained water hammer problem successfully. Water hammer phenomenon can be analyzed in two different ways, the first one is rigid column theory in which the compressibility of the fluid is neglected and the second is the elasticity of the walls of the pipe which includes elasticity (Choon, et al., 2012). The water hammer phenomenon can be explained as shown in Figure (1.1)

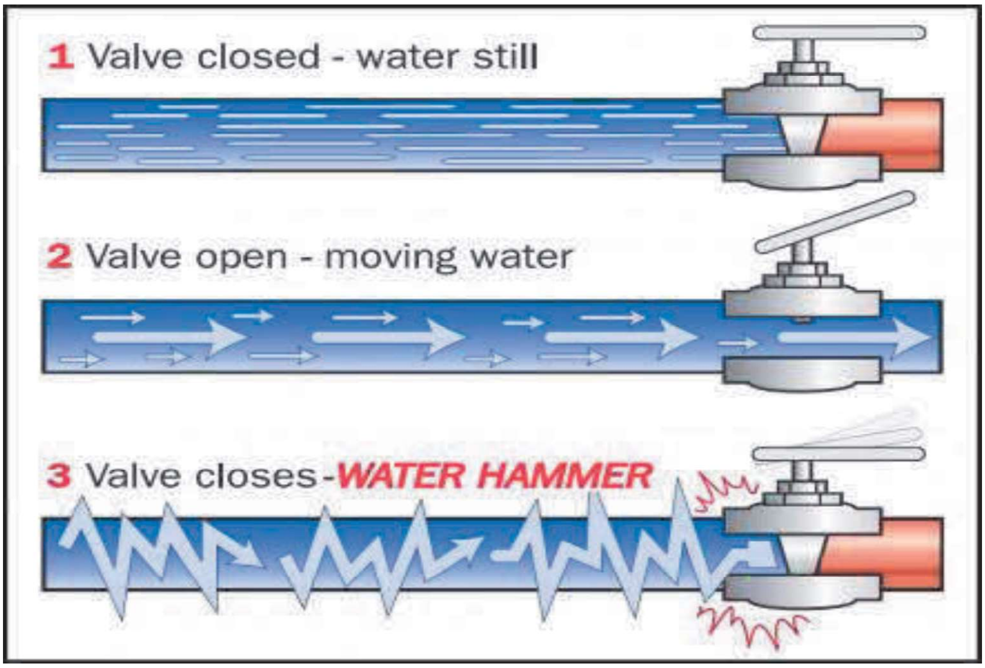

Figure (1.1) Water hammer phenomenon

The causes of water hammer are varied. There are four common causes that typically make large changes in pressure: sudden power failure at pump station, starting or stopping of pumps, rapid changes in valve setting and unstable pump characteristic curve. Hydraulic systems must be designed to absorb both normal and abnormal operations. (Jalut and Ikheneifer, 2010).

Water hammer waves transmit with the velocity of sound (celerity), which depends on the elasticity of the water and the elastic properties of the pipe (Jalut and Ikheneifer, 2010). Sometimes the power of pressure waves are too high that resulted destructive forces which caused rupturing and breaking of pipelines in conveying and distributing systems, breaking valves, control valves and pumps (Mansuri, and et al., 2014).

Over time, the waves are reduced by friction and damping actions until the system stabilizes at a new steady state conditions (Jalut Ikheneifer, 2010).

There are several methods in which water hammer effect can be prevented. First, based on lower liquid velocities the discharge pipe will be designed. Water hammer effect will be decreased through the reduction of the flow velocity. In addition, it can reduce water hammer effect by increment the moment of inertia of the pump. Restrain the excess pressure increase or decrease, by adding a flywheel on the rotating axis of the driving motor, this would prohibit the rotational speed of the decline sharply. One of the known ways to prevent the influence of the water hammer is installing a by-pass pipe with a non-return valve. To prevent pressure reduction, a non-return valve will be applied that opens and lets the water enters to the pipe. For preventing the serious effect of water hammer, it also can be install air chamber in pipeline system or surge tanks. Additionally, one of the good ways to reduce the effect of water hammer is adding the pressure control valves (Choon, and et al., 2012).

To simulate the water hammer phenomenon in pipes a set of momentum and continuity equations. These equations form a set of hyperbolic, non-linear, partial differential equations which is very difficult to solve analytically. A numerical method with a two boundary conditions and initial condition are needed. (Gubashi and Kubba, 2010).

The Method of Characteristics (MOC) is a technique most often used to solve these equations. The method of characteristics solves these two equations by first converting them into ordinary differential equations, which are then solved by a finite difference method. This solution technique can be easily programmed into computer software allowing rapid analysis, which overcomes the limitations of graphical methods (Jalut and Ikheneifer, 2010).

The choice of material for a water pipelines depends on the characteristics of the conveyed water, Factors that affecting on the pipes are the external loads, work pressure (transient condition) and seismicity and also from the special local conditions, such as heavily populated areas, crossing roads and waterways etc. Also, the cost has a great significance not only the pipes costs, but the installation costs, custom duties costs, transport costs and to delivery times (Larock, et al., 1999).

Pipes that will be used in this study are unplasticized polyvinyl chloride (PVC-U) for many reasons including: light weight, strong to weight ratio, low coefficient of friction, long-term tensile strength, watertight joints, high impact strength, flexibility, abrasion/wear resistance, corrosion resistance, chemical resistance, maintain water quality, energy efficient, recyclable so ECO friendly and favorable cost.

1.6 Research Objective

The main objective of this study is carrying out the Mandali irrigation project with using pipeline system for the purpose of providing drinking and irrigation water to the city that suffers from water scarcity. A mathematical model has been used to simulate water flow in pipeline for a long distance taking water hammer phenomenon in consideration. These mathematical model is applied to simulate transport water in pipeline from Diyala River up to Mandali City. Also, the sensitivity analysis is carrying out to understand the behavior of some parameters.

1.7 Research Methodology

1- Developing mathematical model to simulate transport water in pipeline.
2- Verifying the developed model.
3- Collection field data of the case study.
4- Calibration model of the case study and sensitivity analysis.