SURGE ANALYSIS OF WATER PUMPING PIPELINE SYSTEM (CASE STUDY: AJALLI RAW WATER PUMPING PIPELINE SYSTEM) IN EZEAGU LOCAL GOVERNMENT AREA, ENUGU STATE, SOUTHERN NIGERIA.

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Abstract: Generally, water transmission systems are inherently pressure transients, since the systems must be operated either programmed or unprogrammed. The resulting pressure transients could be destructive to the hydraulic systems, depending on its magnitude. The study concerns surge analysis of pumping water pipeline system using Ajalli raw water pumping pipeline system in Ezeagu Local Government Area of Enugu State, Nigeria as a case study. The method employed in the analysis is varying the number of pumps in operation from 1 - 6, that is the flow rate (Q1-Q6) using a mathematical model with the help of an Excel software to determine the magnitude of surge pressures at selected key points along the pipeline as well as determining the minimum thickness of the pipeline required for safe and efficient operations of the system, since thickness governs the design of pipeline system against surge and the adequacy of the surge allowances provision (ramp up and ramp down times) for an electrically induced transient pressures. The analysis of these three parameters, surge pressure, minimum pipe wall thickness required and period of vibrations were carried out with as well as without functional anti- water hammer devices. The results obtained show that the actual pipe wall thickness did not satisfy the minimum thickness required for safe and efficient operation of the system when more than three pumps are simultaneously in operation. However, the surge pressure developed at the key points of the pipelinesystem are well below the test pressure of 41.5 bar when five pumps are in operation but are slightly above the test pressure of 41.5 bar when more than five pumps are in operation from drainage 00m to 210m and from chainage 3+930m to 4+470m. Moreover, the calculated period of vibrations for an electrically induced transient pressure is very well below the actual ramp up and ramp down allowances. For the pipeline to operate safely, efficiently and maximally as designed- six duty and one standby, it was recommended to increase the pipeline wall thickness from 7.10mm to 10.8mm from drainage 00m to chainage 3+930m to 4+470m. Moreover, additional anti-water hammer protection devices are also recommended to improve the operational efficiency and safety of the pipeline against inadmissible surge pressures in an event of electromechanically induced surge pressures in view of poor quality and inadequate poweravailability in Nigeria in general and Ajalli water scheme in particular.

Keywords: Surge, hydraulic systems, Chainage, Water hammer,

INTRODUCTION

In general, water delivery system provides a link between the point source of water and the point of usage. There are three types of this delivery system. Pumpingsystem, Gravity system and Combination of pumping and gravity systems. A pumping pipeline is one that is used to convey water from points at lower elevations to those at higher elevations. The use of pumps is the only way to overcome the difference in elevation, usually of a centrifugal type as regards water and wastewater applications. The design of this type of system is usually performed under steady flow conditions, i.e., variations in hydraulics related conditions such as pump’s rotational speed variations or changes in the percent opening of valves installed in the pipeline will not occur throughout the system’s operational life (Garg, Santash, 2004). During pipeline design, the movement of fluid is based on steady state calculations of the static head and frictional head losses, using the maximum operating pressure plus a small safety factor (Lokesh K., Phanindra V, Adarsh K. 2015). On the other hand, surge pressure or water hammer in pumping pipeline systems, are referring to an unsteady flow phenomenon (hydraulic transients) in which the variations in hydraulics related conditions such as pump’s rotational speed variations or changes in the percent opening of valves installed in the pipeline will occur throughout the system’s operational life as “disturbances” are generated, leading, eventually, to higher hydraulic head levels than those that would occur under steady flow conditions (Lokesh K. et al. 2015). In this case, pipeline pressuresurges are occurred by a sudden increase in pressure which is produced by a change in velocity of the moving fluid in a pipeline.

A pressure surge or wave that occurs when there is a sudden momentum change of a fluid (the motion of a fluid is abruptly forced to stop or change direction)within a closed conduit is called Water Hammer. Water hammer can lead toadmissible pressures that could cause pipeline to burst in case of positive or upsurge pressures and vacuum condition leading to intrusion of contaminated water into the conduit in cases of negative or down surge pressures. Some of the more common causes of primary and secondary pressure surges in a closed conduit are as follows: Primary surge transients which include, Pump startup or shutdown, pump trip, Load changes (in hydropower plants), Valves operations (opening and closing of valves, full or partial), Check valve slam etc. The Secondary surge transients include, Discharge of air through air vent, valves, Excitation of resonant vibrations, improperly sized pressure reducing valves, Water column separation at high spots etc. (Lokesh K., Phanindra V, Adarsh K. 2015).

The most unfavorable situation (in terms of the maximum possible head pressures in the system) is when sudden or an unexpected stoppage of pumping equipment generates the occurrence of water hammer. This sudden stop is normally associated with failure in
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the electrical energy supply to Pumping Station’s drives. This situation is the worst, since it is precisely the one that cannot be controlled by system operators or personnel or by any special device, thus creating major disturbances in the system’s hydraulic conditions and causing not only a significant pressure upsurge but also a pressure down surge that might lead to pipe collapsing as a vacuum, i.e. column separation can occur under this condition. The aforementioned considerations indicate that the speed at which the equipment stops plays an important role in the analysis of Water Hammer in pumping pipelines. The detention speed of pumping equipment mainly depends on the moment of inertia of the rotating parts of the motor and the pump itself, yielding to the extent that as the higher this value is, the higher the detention time for the pump will be, which will lead to minor perturbations in the pipeline system. Many times, the surge pressure is as much high that it can damage or fracture the pipes at one or more places in the pipe line system. Therefore, the proper and considerable attention must be paid to study the physics of water hammer (Hanmer, G., Bachman, S., & Lind, G. 2014). It is a truism that efficient water supply is very crucial to the sustenance of economic activity, alleviating poverty and attaining food security in any country. However, it is also a known fact that in most developing countries, having sufficient water supply even in cities is still a problem. In Nigeria, it has become common for citizens to solely provide basic amenities, especially water, electricity and even security for themselves, all because the government falls short of expectation in that regard. The problem is not that there is no infrastructure to sustain water supply in the country, but that there is no known plan or, if there is, it has not been implemented, to maintain the structures already in place to supply water appropriately. There are scores of dams and reservoir scattered all over the country. What seems to be missing right from when these dams were constructed was a working policy on how they are to be maintained. This lack of maintenance has been seen to the dilapidation of those multi-million dollar projects and the strife thereof in the purposes for which they were originally designed to serve, including the most important need which is providing water for residents in the states they are located and beyond (Leadership 2017). Today, most state governments have no functioning water boards. Where the facility still exists, it is operating below capacity because of lack of maintenance. This has, in turn, gone on to affect several other public establishments like hospitals and schools. In this study, the pumping pipeline system will be analyzed to determine the likely parameters that will affect pipeline performance efficiency.

STUDY AREA

The Ajalli Water Scheme is geographically located in Ngwo, Udi Local Government Area of Enugu State Nigeria and lies between Latitude 6°25’N - 6°29’N and longitudes 7°23’30´´E - 7°25’30´´E (figure 1.1). The Ajalli water scheme was commissioned in 1985. This scheme was developed to supply Enugu urban and environs. Though this supplies Enugu metropolis, it equally supplies other satellite towns of Ngwo, Emene, Iji-Nike, Edem Nike, Nsude and Eke (figure 1.2). The source of water to this scheme is Ajalli River at Owa-Imezi town at Ezeagu Local Government Area, about 38km west of Enugu. The design capacity of this scheme is about 77,000m³/day and about 80% of water is meant to be distributed to the service areas of Enugu and environs. This scheme basically comprises of: the intake and weir, Abonuzu headwork, trunk and rising mains, booster station and reservoirs. The water is abstracted through weir and intake structures. It is then lifted to the Abonuzu Headwork where the treatment is done and from there the water is pumped to the Nsude break pressure tanks. After this, the water is then allowed to flow by gravity through a number of reservoirs into the distribution network. The sub-division of the Ajalli water scheme are thus: The weir, intake structure, wet pit, seven vertical pumps with control panels and a 2300KVA generating set as alternative power source. The weir is constructed just downstream of the intake as free flow concrete structure. However, during the flood period, a gate is used as flood regulator. The radial gate completes the span of the weir across the width of the river. There is a lift pumping station that houses the seven vertical pumps. These pumps have a delivery capacity of 580m³/hr each of raw water to the Abonuzu Headworks, some 5.55km away. The intake can accommodate up to 3,500m³/hr. but under design condition, only five of the pumps run simultaneously with total discharge of 69, 600m³/day, while two are on standby. The water from the pumps moves down from the wet pit to the Abonuzu headwork via a nominal diameter -DN- 1000/900mm ductile/steel pipeline.

Topographical details of the Study Area

The table 1.1 below indicates the drainages, natural ground from the Ajalli river weir and intake (sump) to the flash mixer from where the treatment starts. To capture the data well, the elevations have been taken at a uniform difference of chainage of 30m and at locations of bends and other important fittings and appurtenances -table 1.1. The plan and longitudinal section of the pipeline (pipeline profile) for surge analysis are drawn as shown in figure 1.1

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Table 1.1: Drainages and Natural Ground from the Ajalli River Weir and Intake (Sump) to the Flash Mixer.
Table 1.1: Elevation of the Natural Ground Level with Chainage along the existing Raw Water Transmission Pipeline from the Ajalli River to the Flash Mixer at the High lift.

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Fig 1.1: The plan and longitudinal section of the pipeline (pipeline profile) of the study area.
Figure 1.2 and 1.3 show the locations of Udi LGA and the Ajalli water works in the Udi LGA. Figure 1.2: location of Udi LGA in Nigeria.
Figure 1.3: Location of Ajalli water work in the Udi LGA.

**Materials and Methods**

This chapter focused on methods adopted in data collection and analysis. It also dealt with the engineering methods applying in the work. In the same vein, the description of the method and instruments that was used for data collection and presentation were highlighted.

The study adopted experimental research design approach. The experimental design was adopted because it involves monitoring of water velocity and pressure in the pipeline using different number of pumps, maximum seven (7) pumps which translate to using varying flow rates. As the number of pump running increases, the discharge is increased and the pressure surge is analyzed to determine the magnitude of the pressure surge and velocity at the key points along the pipeline without as well as with the existing anti-hammer protection devices which will be compared with the allowable or withstood test pressure of the pipe. The thickness of the pipe is also checked under varying flow conditions to compare with the allowable wall thickness of the pipe since thickness...
governs the design of pipe against surge. The time (t) it takes a wave when perturbation is generated electrically to travel from chainage 00+00 to the flash mixer tank (boundary condition) at chainage 5+550m and back (t=2L/C), where L is the length of pipeline and C is the wave velocity is compared with pump ramp-up or ramp-down time of the electrical equipment (pumpstart and stop time) to provide a decision support system (DSS) for operators of the water scheme as regards the safety of the electrical equipment and its associated pipeline system.

**Sources of Data**

Two data sources were used; the secondary data source and the primary datasource.

**Secondary data source**

This include data that were collected both from published and unpublished sources such as textbooks, journals, magazines, newspaper, internet, online publication etc.

**Primary data source**

This includes data that were generated from the experimental survey. The experiment survey was adopted on the field to record the velocity and pressure at different starting/stopping of pumps conditions. The Ajalli raw water Transmission pipeline map of the study area, the construction drawings, water consumption records, pipe rupture records and other water supply network related information, the physical information of the pipe network were also collected from Enugu State Water Corporation.

**Grouping of data for convenience of surge analysis**

For the purpose of clarity of this surge analysis of Ajallli pumping water pipeline, the data required for the analysis is grouped into four:

**Geometric group**

In this group, the geometrical parameters such as the pipeline outside diameter(D), wall thickness (t) and the Hazen-William friction coefficient (C) are listed and are used to calculate the friction losses in the pipe system.

The pipe’s diameter and thickness specification is quite important in order to calculate the pressure wave speed required for the water hammer analysis.

**Longitudinal profile group**

In this group, the values of chainages and elevations for the pipeline’s longitudinal profile are tabulated in excel format.

**Transient Analysis Parameters group**

The required water hammer calculation parameters are defined in this group.

Here, the data required are:

1. The pressure wave speed.
2. Hydraulic transient simulation
3. The number of key points on which the analysis is performed.

**Maximum Allowable pressure in pipes group**

This is the ability to plot the pipeline’s maximum allowable hydraulic grade (piezometric head) envelope accordingly to the rating of pressure of the used pipes.

It is possible to indicate in this group for each section between control points, the rating pressures allowed for the pipe under the different analysis. In this case, we seek the mechanical and geometrical pipeline properties in an easy and very practical way.

**Population of the Study**

Ajalli Water Supply Scheme is owned by Enugu State Government, operated by Enugu State Water Corporation and has a design output of 77,000 m³/day. The scheme has principal components such as intake, Low Lift Pumping Station, Treatment Process and High Lift Pumping Station. This study analyses pressure surges at the potential locations along the raw water transmission pipeline experiencing frequent pipe bursts from the low lift pumping station to the flash mixer tank at a distance of 5550m. All the Ajalli components and specification information are obtained from Engineering department, Enugu State Water Corporation, Headquarters, Enugu, The Low Lift Pumping Station comprises the following components and specifications:

**Pump**: 7 identical vertical multi-stage pumps operating 5 duties and 2 stand by. The pumps are currently peerless and Adoli Pumps with specifications as follows: RPM – 1480, head – 178m, flow rate – 580 m³/hour, Power – 400 kW, and efficiency 80%. These pumps were supplied by Nasting Engineering Limited and Eauxwell Nigeria Ltd. respectively in the year 2010 and have the same specification with the scheme’s original Betbow pumps at the inception of the scheme in 1985.

**Transmission pipeline**: The pipeline has a total length of 5550m comprising 3,650m length of ductile iron pipe of 1000mm diameter and 1,900m length of steel pipe of 900mm diameter. The thickness of ductile iron and steel pipes is 7mm each. The transmission pipeline has design/test pressure of 41.5 bars (4150m). Surge Chambers: The water transmission pipeline has 2.0m³ and 4.0m³ surge chambers with double orifice air valve on top of each situated at chainages 1+350m and 2+850m respectively along the pipeline.

**Sampling size**

Random sampling was employed in the study. The selection of seven (7) stratified random sampling pumps were applied to represent the entire population of the study. Seven (7) pumps were used to monitor the surge along (5550m) Ajalli raw transmission pipeline.

**Sample and Sampling Technique**
The setup consists of intake sump housing seven vertical pumps, 5550m rawwater ductile/steel pipeline with air valves, non-return, butterfly valves, surgechambers, pump pressure gauges from the intake sump to the flash mixer thank where raw water treatment starts.

The seven raw water pumps have their respective starter panels, some equipped with soft start and thyristors and some with star delta. The function of these soft starter is to reduce the surge generation effect by gradually allowing the control voltage of the pump to start (more time allowed), while the function of the thyristors is to control electric power and current by acting as a switch. The star delta takes less time to start and increases the surge effect and this should be discouraged if we really wish to avoid excessive pressure surges.

The experimental method involves putting on one pump and calculating the velocity and Pressure at the key points along the pipeline, the remaining pumps are added one by one till the six pumps are running.

The project is a 5550m long Ductile iron/ steel raw water transmission pipeline – Ductile iron 3,650 and steel 1,900 designed for an ultimate capacity of 83,520 m$^3$/day.

The profile of the pipeline is shown in figure 1.1. Water is being pumped from the intake sump at the low lift pumping station to a semi underground level raw water receiving flash mixer tank with a maximum water level of 4m from the floor. The center line of the discharge and of the main at the tie-in to the flash mixer tank is 1.5m below the tank floor.

Key stations and their elevations along the pipeline are as shown in figure 1.1. The objective of the surge analysis is to determine the surge pressure heads along the key stations with varying flow rates/ number of pumps in operation until all the pumps are in operation.

The key determinant of D/steel pressure design is the internal pressure. The exact pipe dimensions are required to determine the flow velocity while the pipeline mechanical properties are required to determine the wave velocity.

The total pressure in the pipeline at any point is the sum of the static head, the friction and the pressure rise (internal pressure/surge pressure) as a result of sudden velocity changes.

**Instrument for Data Collection**

The following tools were used to collect data for surge analysis: Tape for measuring the length of pipeline and size of flash mixer; vernier caliper was used to measure the thickness of the existing pipe to confirm the thickness stated in the as “built drawing” and pressure gauge to measure the output pressure of the pump.

**Method of Data Analysis**

The problem of surge phenomenon in Ajallli water system is associated with pumps as a results of frequent power failures and hence was analyzed as a result of power failure of pumps or pump trips. Power failure of pumps, sudden valve actions and operations of automatic control systems among others may cause water hammer problems in a liquid service pipelines or water delivery systems. These operations (events) normally generate steep pressure increases or decreases otherwise known as pressure variations in the pipeline which propagates over the associated pipeline system by converting kinetic energy of the fluid to potential or pressure energy until the fluid comes to steady state again due to the action of friction.

The maximum or increasing pressure propagation may cause over pressure problem, while the minimum, negative or decreasing pressure propagation may lead to vacuum problem and sometimes include secondary pressure upset due to vapor cavity formation and collapse (vaporization and condensation) at high and low points in the systems, etc.

The problem of surge is solved by formulation of mathematical model which consists of a set of partial differential equation of hyperbolic nature which are transformed by the method of characteristics into ordinary differential equations which are solved by the predictor-corrector, finite difference methods among others. The method of characteristics is used to find the pressure increase and decreases along the pipeline at various finite times and distances and hence help decision makers to decide the kind of anti-hammer protective devices required in the water main for safety operations and optimal performance of the associated pipeline system.

In most recent times, interactive commercial software is developed that provide user to draw the network structure of pipelines with components or appurtenances like valves, pumps, reservoir, etc. and also obtain the results in tabular or graphical format. This allows the operators of the pipeline system or users of the software to not only detect faults but also provides information about which anti-surge devices are to be installed in order to increase the life expectancy of the associated water supply delivery systems.

In Equations 7 and 8, $H$ denotes the piezometric head at the centerline of the pipeline at location $x$ and time $t$, $V$ is the average velocity of flow, $D$ is the pipe diameter, $f$ is the friction factor in the Darcy-Weisbach formula, $x$ is the distance along the centerline of the pipe, $\alpha$ is the angle between the horizontal and the centerline of the pipe, taken as positive for the pipe sloping downwards in the direction of positive $x$, $g$ is the gravitational constant; and $a$ is the celerity of the pressure surge, i.e. the velocity with which the surge is propagated relative to the liquid. The positive direction for $V$ coincides with that for $x$. The Equations 7 and 8 are a simultaneous pair of partial differential Equations which relate the two dependent variables, $H$ and $V$.

However, this method is beyond the scope of this study since it will not be applied in this study, rather analytical solution is obtained by the help of Willian Hezan equations supported by water hammer calculator.

**Surge Analysis Assumption**

- The flow is a one directional model
- The pipeline is in full flow condition at all times.
- The elasticity of the pipe wall as well as the compressibility of the fluid are not taken into consideration. The maximum surge pressure will be equal to an instantaneous stoppage of flow at full velocity.
The existing anti-hammer protection devices are assumed to be fully functional during the analysis of the pipeline with anti-hammer protection devices. All the seven pumps are operating at 580 m³/h at 178 m total dynamic head. Both the 1000 mm diameter ductile iron and 900 mm diameter steel pipelines are hydraulically connected. In this project, the analysis was carried out at the identified locations along the pipeline at varying flow rates/number of pumps in operation using the data collected from Enugu State Water Corporation. The analysis has been done manually using Microsoft excel with the help of Hazen Williams formula, taken from American Water Works Association (AWWA) Manual. The table below shows the data extracted from “as built” drawing of Ajalli raw water pipeline.

Table 2 - Data extracted from “as built” drawing of Ajalli raw water pipeline.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>RAW WATER PUMPING MAIN</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Pumping Main</td>
<td>5550m</td>
<td>Profile data</td>
</tr>
<tr>
<td>Material of Pipes</td>
<td>(1.) Ductile iron Pipes with cement mortar in lining and out coating from chainage 0+00m to 3+650m. (2.) Mild Steel Pipes from 3+650m to 5+550m with the same in lining and out coating</td>
<td>Geometric data</td>
</tr>
<tr>
<td>Internal Diameter of pipeline</td>
<td>1000mm for ductile iron pipe and 900mm for Steel Pipe</td>
<td>Geometric data</td>
</tr>
<tr>
<td>Thickness of both pipes</td>
<td>7.10mm</td>
<td>Geometric data</td>
</tr>
<tr>
<td>Pump Discharge Head</td>
<td>178m</td>
<td>Profile data</td>
</tr>
<tr>
<td>Maximum flow rate of each pump</td>
<td>580m³/hr.</td>
<td>Geometric data</td>
</tr>
<tr>
<td>Pressure wave Velocity</td>
<td>2241 m/s from chainage 0+00 to 3650m and 2174 m/s from chainage 3650m to 5550m</td>
<td>Transient Analysis data</td>
</tr>
<tr>
<td>Laying condition</td>
<td>Under Ground</td>
<td>Profile data</td>
</tr>
<tr>
<td>pump Velocity</td>
<td>1480 RPM</td>
<td>Geometric data</td>
</tr>
<tr>
<td>Pump power</td>
<td>400 KW</td>
<td>Geometric data</td>
</tr>
<tr>
<td>Pump type</td>
<td>Vertical Turbine Type</td>
<td>Geometric data</td>
</tr>
<tr>
<td>Number of key points</td>
<td>14</td>
<td>Transient Analysis data</td>
</tr>
<tr>
<td>Hazen-William friction coefficient (C)</td>
<td>140</td>
<td>Geometric data</td>
</tr>
</tbody>
</table>

Source: Engineering department, Enugu State Water Corporation, Head Quarters, Enugu.

Flow characteristics of Ductile iron and steel pipe

The flow characteristics via cement-mortar-lined ductile iron and steel pipe is usually computed by widely used Hazen-Williams formula (ANSI/AWWA C104/A21.4, Denver, Colo.), in metric units

\[ Q = 6.756 \times 10^{-3} \times C \times D^{2.63} \times H^{0.54} \] ...

\[ Q = \text{discharge in m} \]
\[ C = \text{Hazen-Williams flow coefficient} \]
\[ D = \text{actual pipe inside diameter in m}. \]
\[ H = \text{head loss, m/1,000m} \]
A = cross sectional area of pipe in m²

Determine the maximum flow velocity.

\[ V_o = \frac{Q}{A} \]

\[ A = \frac{\pi d^2}{4} \]

Where \( d \) is pipe inside diameter

Determine pressure wave velocity (a) (Wylie, et al., 1993):

\[ a = k (1 + \frac{k}{0.5}) \]

\[ \frac{D}{-0.5} \times C_1 \]

\[ \frac{\rho}{E} \times t \]

Where:

\( D = \) Internal diameter of pipe
\n\( K = \) bulk modulus of liquid in the pipe = 2.67 x 108 kg/m²
\n\( E = \) young modulus = 1.7 x 1010 kg/m²
\n\( \mu = \) Poison’s ratio of the pipe walls material
\n\( C_1 = \) equivalent thickness of the pipe wall

The types of axial restraint commonly encountered in Engineering of this nature are:

Case a: the pipe is restrained throughout its length against axial movement = \( C_1 = 1 - u^2 \)
Case b: The pipe has frequent expansion joints throughout its movement = \( C_1 = 1 \)
Case c: The pipe is restrained at its upstream and only \( C_1 = 5/4 - u \)

In most engineering applications case a or b or some conditions intermediate between them would apply.

For the case of water in a Steel/D1 pipe, (Wylie, et al., 1993):

\[ e = 1438 (1 + 0.01 \times \frac{C_1}{d}) \]

\[ \frac{\rho}{E} \times t \]

Determine the surge pressure (internal Pressure)

In a water transmission pipeline, the amplitude and location of the surge envelope will often be analyzed by computer. In this study, it has been assumed that the maximum surge pressure will be equal to an instantaneous stoppage of flow at full velocity.

The pressure rise resulting from instantaneous velocity change in Ductile/steel pressure pipes can be determined using Joukowski equation as shown below (Wylie, et al., 1993):

\[ V_o a g \]

(14)
Determine the friction loss under full flow condition. The Hazen–William equation is convenient to use. Metric (Wylie, et al., 1993):

\[
Friction = \frac{10.7\times L\times Q^{1.852}}{C\times 1.852\times D^{4.87}}
\]

where \( f \) is frictional pressure drop,
\( Q \) is the volumetric flow rate \( \text{m}^3/\text{s} \),
\( L \) is length of pipe, \( \text{m} \),
\( D \) is the pipe internal diameter, \( \text{m} \),
\( C \) is factor or Hazen–William constant for the pipe.

\( C \) values ranges from 90 to 140 depending on the diameter and velocity. In this study, \( C \) is taken as 140.

Determine the pressure at key locations in the pipeline underunsteady full flow condition.

Note: The pressure \( P \), at any point in the pipeline is the sum of the static heads a result of difference in elevations, the friction loss and the internal pressure as a result of change in the fluid flow velocity

\[
P = H_{static} + Dh_{Hazen} + Dh_{Friction}
\]

Determine Design Pressure Conditions as per AWWA Guidelines.

1.5times maximum sustained operating head
1.5 times maximum pipeline static head
Sum of maximum sustained operating head and maximum surge head
Sum of maximum pipeline static head and maximum surge head Design Pressure (Maximum of above).


\[
t_1 = \frac{p(D - t_1)SF}{2Rm}
\]

\( P \) = Internal Pressure (in Mpa), \( SF = \) Safety Factor
\( Rm = \) Minimum tensile strength (in Mpa), \( D = \) Outside Diameter of pipe (in mm), \( t_1 = \) Minimum thickness required (in mm)

Compare the pressures at minimum tensile strength with pipe nominal or operating or test pressures and the calculated minimum thicknesses with the wall thickness of pipe as per IS 8329:2000 (Ct) or applicable standards and draw your conclusions on the safety of the pipeline operating under these conditions.

The time \( t \) it takes a wave when perturbation is generated electrically to travel from chainage 00+00 to the flash mixer tank (boundary condition) at chainage 5+500m and back \( (t=2L/C) \), where \( L \) is the length of pipeline and \( C \) is the wave velocity is also compared with pump rampup or rampdown time of the electrical equipment (pump start and stop time) to provide a decision support system (DSS) for operators of the water scheme as regards the safety of the electrical equipment and its
associated pipeline system.

As early as said, this analysis has been carried out manually in Excel sheet and with the help of Hazen William formula taken from AWWA manual. The result is displayed both in tabular and graphical formats with the help of Excel software.

**DISCUSSION OF FINDINGS, CONCLUSION AND RECOMMENDATION**

**Discussion of Findings**

The plan shows the spatial location of surge incidences along Ajjalli raw water transmission pipeline. The following are three potential surge locations. 0+000 chainage: the surge occurred at non return valve location at 170 m of elevation. At 1+350m chainage, the surge occurred where 2.0m surge chamber is located and at 2+850m chainage, the surge occurred where 4.0m2 surge chamber is located. The experimental method involves putting on one pump and calculating the velocity and pressure (Table 4.1). The rest of the pumps are added one by one till the six pumps are. The experimental study of the pressure (Table 4.2), revealed that when four pumps are in real operation, the pipeline is completely safe from the surge pressure generated but is not safe at the above mentioned locations when five and above number of pumps are running at the same time. This implies that the pipeline can operate safely and efficiently when five pumps are operating under 100% efficiency of the pipeline. It is also revealed that if the pipeline is to operate under safety and efficient condition, the surge pressures are not supposed to exceed the withstood test pressure. But in real life, the pipeline cannot operate at 100% efficiency and considering that the test pressure is about 1.5 times the static or operating pressure, the pipeline could be assumed to operate at 80% efficiency. In that case, the admissible pressure should be 80% times the test pressure, equal to 80% * 415m = 332m. This implies that the pipeline can operate safely and efficiently when all six pumps are running at the same time as regards pressure transients and it is not safe when more than three pumps are running at the same time as regards minimum thickness. The figure (4.4) also revealed that since the pipeline is designed for six pumps to run at the same time, this 7.10mm thickness of the existing pipe is not meeting the minimum thickness required for safety operations. This could be added as one of the factors responsible for the frequent failures of the pipeline and its associated mechanical and electrical machineries as well the cause of persistent water scarcity in Enugu metropolis. The minimum thickness calculations when one, two, three, four, five and six pumps are in operation are 4.727mm, 6.028mm, 7.201mm, 8.375mm, 9.548mm and 11.768mm respectively, while the actual thickness of the pipeline is 7.10mm as per data available. This implies that the pipeline can only operate safely and efficiently when only three out of the six pumps are running at the same time without optimization. If the pipeline is to be optimized economically, four pumps can run safely and efficiently on the condition that the pipe with about 8.40mm thickness can be laid as from chainages from 00+00 to 00+210. According to field experience, the 1000mm/900mm ductile iron/steel pipeline has been found to be safe when five pumps are in operation and unsafe as per surge pressure generated when more than five pumps are running at the same time, since six pumps are meant to operate to meet the capacity utilization of the water treatment plant (WTP) as well as the water requirement of Enugu Metropolis, the pipeline thickness can be varied by segment to meet up the criterion for the purpose of best economic choice of pipe dimension ratio (DR). The study has revealed from the analysis that the operation of the system must satisfy the over pressure system, thickness as well as the electrically induced surge transient allowances specifications. On that framework, a minimum thickness of 10.8mm is recommended to eliminate all aspects and magnitudes of surges in the system in addition to provision of additional anti-hammer protective device at strategic location. This thickness is also considered very economical in relation to the existing thickness used in the main transmission and distribution systems within Enugu Metropolis which ranges up to 12.5mm.

Further analysis carried out with respect to the electrically induced transients (Power loss) revealed and affirmed that the period of vibration upon power loss is calculated to be 5.028 seconds which is less than 10 seconds and 15 seconds respectively for pump ramp-up and ramp-down (pump manufacturer’s installation and operational manual surge allowance provision). The aforementioned shows apparently that the manufacturer’s minimum standard surge allowance is sufficient (10 seconds > 5.028 secs) and that the critical time for pump ramp-up is 10 secs. A slower ramping would diminish the surge pressure.

Moreover, it appears that the existing anti-water hammer protecting devices are not adequate for efficient hydraulic response of the raw water pipeline systems.

**Conclusions**

The Ajjali raw water pipeline has been analyzed as per the design and hydraulic data available especially in the as “built drawing”. The calculated maximum pressure levels including surge at key points along the pipeline when one, two, three, four, five and six pumps are in operation are about 193.944m, 240.827m, 287.711m, 334.595m, 381.478m and 428.362m respectively, while the test pressures as per the data available is 415m. This implies that the pipeline can operate safely and efficiently when five pumps are operating under 80% efficiency of the pipeline. Similarly, the minimum thickness calculations when one, two, three, four, five and six pumps are in operation are 4.727mm, 6.028mm, 7.201mm, 8.375mm, 9.548mm and 10.768mm respectively, while the actual thickness of the pipeline is 7.10mm as per data available. This implies that the pipeline can only operate safely and efficiently when three out of the six pumps are running at the same time. If the pipeline is to be optimized economically, four pumps can run safely and efficiently on the condition that the pipe with about 8.40mm thickness can be laid as from chainages from 00+00 to 00+210. According to field experience, the 1000mm/900mm ductile iron/steel pipeline has been found to be safe when five pumps are in operation and unsafe as per surge pressure generated when more than five pumps are running at the same time. Furthermore, the pump manufacturer’s installation and operational minimum surge allowance provision is sufficient enough to obviate the risk of water hammer in the valves and pipework when an electrically induced transient (power loss) occurs.

**Recommendation**

Proper training should be conducted to educate the operators on the safety condition of running water pumps in the Ajjali Waterworks Station.
• The 1000mm ductile iron pipeline with at least 10.8mm thickness from chainage 00+000m to 5+550m should be recommended for the raw water transmission system to eliminate all aspects and magnitudes of surge pressures in the system arising from under thickness design if the system is to be safely, efficiently and maximally operated as designed-six duty and one stand by.

• Moreover, it appears that the existing anti-water hammer protecting devices, 2m³ and 4m³ are not adequate for efficient hydraulics of the raw water pipeline systems and should be recommended to install one more 6m³ surge chamber or air vessel and or zero velocity valve at chainage 00+210m or pump discharge end with an isolation valve which will allow the smooth start up and stopping of the centrifugal pump without any complicated and expensive maintenance. This is discernible from the calculated value of ±0.073m head surge pressure difference when analyzed the pipeline system with and without the existing surge protection devices installed at different locations along the pipeline.

• The damaged trust bocks anchoring the pipeline and its appurtenances during previous water hammer events should be properly repaired to provide restraints against pipeline longitudinal or axial movement which was one of the condition for the analysis.

• Finally, I affirm that if all these recommendations are implemented especially as Ajalli Water Scheme is slated for rehabilitation under the Agence Franchaise de Development (AFD) support to 3rd National Urban Water Sector Reform Project, the system will be operating safely, efficiently and maximally and the persistent challenges of scarcity of water supply experiences in Enugu Metropolis for the past years will be a thing of the past.

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