**Mini Project**

**Report**

A Study of Transient Analysis in Water Tank and Distribution SystemA logo with a symbol in the middle

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**Submitted to :**

Dr. Sreeja Pekkat

Associate Professor

Water Resources Engineering and Management

Department Of Civil Engineering

Indian Institute of Technology Guwahati

**Submitted by :**

Aalbin Simon (M.Tech)

Roll no:- 234104609

Water Resources Engineering and Management

Department Of Civil Engineering

Indian Institute of Technology Guwahati

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# **1.INTRODUCTION**

An essential component of hydraulic engineering is the study of transients in pipe systems, which makes a thorough grasp of their dynamics necessary to guarantee the dependability and effectiveness of water distribution networks. These transients frequently result from abrupt modifications to the flow conditions, like the abrupt closing of valves, which cause intricate variations in the system's flow rate and pressure. Here, we explore the complex field of transient analysis in pipe after abrupt valve closures, using the method of characteristics as a potent mathematical technique to decipher the underlying processes.

In the field of fluid dynamics, the characteristics technique is a fundamental tool that provides a methodical solution to partial differential equations driving wave propagation processes. This technique, which has its roots in the study of gas dynamics, has been widely applied in a variety of fields, including hydraulics, where it is a useful instrument for examining the transient behaviour of water systems. The characteristics approach allows engineers to study the evolution of pressure and flow rates after transient events by discretizing the governing equations along characteristic curves. This provides insights into the dynamic response of pipe systems.

Using the method of characteristics, a potent analytical tool, we want to clarify the transient response of pipe systems to valve closure events. Through this methodical modelling of the system dynamics and solution of the governing equations, we aim to decipher the complex interactions between hydraulic elements and transient occurrences. We aim to capture the transient evolution of pressure and flow profiles by means of theoretical analysis and numerical simulations, providing insights into the temporal and spatial dynamics of pipe transients.

Our work is important not only for theoretical investigation but also for real-world engineering applications. Transients from pipe can place a great deal of strain on pipeline networks, which could result in operational hiccups, structural damage, or even safety risks. Through a thorough comprehension of the transient reaction of water tank systems, engineers can formulate tactics aimed at alleviating unfavourable consequences, maximising system efficiency, and fortifying the resilience of water distribution networks against sudden occurrences. This report uses the method of characteristics as our analytical compass as we set out to investigate the complex nature of pipe transients. We explain the numerical methods used to solve transient equations, explore the theoretical underpinnings of transient analysis, and provide case examples that illustrate the practical uses of transient analysis in hydraulic engineering. Our goal is to give engineers a comprehensive grasp of pipe transients and the tools they need to efficiently handle problems in water distribution systems by combining theoretical insights with practical concerns.

We explore the theoretical foundations of transient analysis in more detail in the following sections, explaining the characteristics method's mathematical structure and how it applies to pipe systems. Subsequently, we address numerical techniques for resolving transient equations, and then examine case studies that demonstrate the usefulness of transient analysis in hydraulic engineering. By means of these talks, we hope to further the understanding of water tank transients and provide insightful information to scholars, practitioners, and decision-makers involved in the planning, execution, and administration of water distribution infrastructure.

## **2. LITERATURE REVIEW**

Transient analysis in the context of water tanks and pipe valves refers to the study of dynamic behaviour and changes in pressure, flow rate, and other parameters in a fluid system over time. It is particularly important in understanding and predicting phenomena such as water hammer, which occurs when there are sudden changes in flow velocity or direction within a piping system.

Understanding the effects of transient events like water hammer is crucial for ensuring system safety. By conducting transient analysis, engineers can identify potential hazards and vulnerabilities in the system, such as weak points in piping or insufficient pressure relief measures. This information enables the implementation of appropriate safety measures to mitigate risks and prevent accidents such as pipe bursts or equipment failures.

Overall, the effect of transient analysis in water tanks and pipe valves is to enhance system performance, safety, and reliability, leading to more efficient operation and reduced risks for operators and the environment. By leveraging transient analysis techniques, engineers and operators can make informed decisions throughout the lifecycle of fluid systems, from design and construction to operation and maintenance.

### **3. OBJECTIVE**

* Developing a mathematical model to analyse transient in the system for different sections ,time and values of discharge and pressure head.
* Using this model calculating maximum and minimum values of pressure head and discharge at different sections.

### **4. METHODOLOGY**

A pressure surge or wave that happens in a fluid-filled piping system when there is an abrupt change in flow velocity or direction is called a "water hammer," often referred to as a hydraulic shock or surge. If not adequately controlled, this phenomenon, which usually occurs in systems where liquids, like water, are flowing via pipes and valves, can have detrimental repercussions on the infrastructure.

Although water is often thought to be incompressible, modest compressibility effects can still be seen in practice. The water hammer effect is caused by the fluid's inertia and the fluid medium's compressibility. The momentum of the fluid causes it to continue moving temporarily when there is a sudden change in flow velocity or direction, such as the abrupt closing of a valve or the sudden beginning or halting of a pump. This pressure wave then travels through the pipe system.

A mathematical model is developed using Python on the basis of equations of Method of Characteristics. Using these equations, we define the water tank, valve, pipe. With this equation we find the maximum and minimum values of pressure head which will help us to analyse the system for the designing purpose and safety. Different values of Water tank , valve and pipe are taken for the analysis with some initial conditions.

pi = math.pi  
g = 9.80655  
  
**# fluid properties**  
K = 2 \* 10\*\*9 # Pascals  
rho = 1000 # kg/m3

**# pipe properties**  
D = 0.3 # m  
E = 2.15 \* 10\*\*9 # Pascals  
e = 0.01 # m  
L = 100 # length of pipe, m  
f = 0.05 # Darcy's friction factor

A = (pi/4)\*D\*D  
R = f/(2\*D\*A)  
a = sp.sqrt((K/rho)/(1+(D\*K)/(E\*e)))  
  
**# reservoir properties**H\_res = 10  
Cd = 0.8  
Q\_res = Cd \* A \* sp.sqrt(2\*g\*H\_res)  
k\_entry = 0.5

**# Discretization**n = 5 # no. of sections  
del\_x = L/n  
del\_t = del\_x/a

### **4.1BASIC EQUATIONS OF TRANSIENT FLOW ANALYSIS**

**4.1.1 INTRODUCTION**

Early research on water hammer is conducted under the assumption of a single-phase fluid flow. The most popular application of the characteristic’s method is in water hammer modelling. First, a discussion of the basic equations for water hammer analysis.

**4.1.2 METHOD OF CHARACTERISTICS**

The method of characteristics is a mathematical technique used to solve partial differential equations (PDEs) governing wave propagation phenomena. It provides a systematic approach for finding solutions to hyperbolic PDEs by transforming them into sets of ordinary differential equations (ODEs) along characteristic curves.

In the context of fluid dynamics, the method of characteristics is particularly useful for solving problems related to wave propagation, such as those encountered in hydraulic engineering, aerodynamics, and acoustics. It allows engineers and scientists to analyse how waves propagate through a medium and how they interact with boundaries or discontinuities.

The method of characteristics works by transforming the original partial differential equation into a system of ordinary differential equations along characteristic curves. These characteristic curves represent paths along which information propagates through the domain of interest.

The equations are represented below as L1 and L2 .





Linearly combining the equations with the introduction of a constant factor λ





Rearranging terms from the linear combination above



We define a relationship for λ:

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Where:



This relationship between wave speed, time step, and length step must be enforced for this method to work as expected. This is discussed in detail in Pipe Sectioning - Introduction to Method of Characteristics.

Substituting into the above equation:



The terms in the parentheses are simply the total derivatives for P and V.

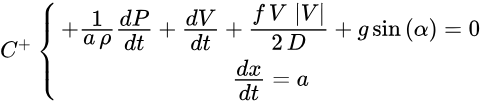


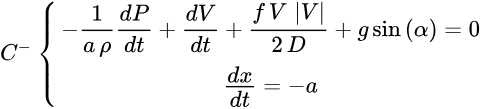


Simplifying the expression to:



This represents the four characteristic equations that we are searching for, paired as positive (C+) and negative (C-) sets of equations:





### **4.2 WATER TANK**

A container or structure designed to store and hold water for various purposes. These tanks come in a variety of shapes, sizes, and materials, depending on their intended use and the specific requirements of the application. Water tanks play a crucial role in water management and distribution systems, serving to store water for domestic, industrial, agricultural, and municipal purposes. The water tank is placed at the upstream with constant water level in it. There can be different types of tanks such as

**Elevated Water Tanks:** These tanks are elevated on supporting structures or towers to create pressure in the distribution system. They are often used in areas with uneven terrain or where gravity flow is not sufficient to meet demand.

**Ground-Level Water Tanks:** These tanks are installed at ground level and are used for storage of treated water before distribution. They can be made of concrete, steel, or plastic and come in various shapes and sizes.

**Underground Water Tanks:** Underground tanks are buried below the ground surface and are used for storage of water in areas where above-ground space is limited, or aesthetic considerations are important. They are commonly made of concrete or fiberglass.

**Reservoirs:** Reservoirs are large artificial lakes or ponds used for storing raw water from natural sources such as rivers, lakes, or reservoirs. They serve as a primary source of water for treatment plants or distribution systems.

**Cisterns:** Cisterns are small-scale tanks used for storing rainwater or harvested runoff water for non-potable purposes such as irrigation, toilet flushing, or firefighting. They can be above ground or underground and are often made of concrete, plastic, or metal.

### **4.3 VALVE**

Considering a valve at the downstream direction of the pipe. The pipe is of length 100 m made of steel with thickness of 0.01 m. The transient analysis is done when the valve at the downstream direction is suddenly closed which produces waves which causes transients in the pipe. This mini project focuses on the analysis of sudden closure of the valve with the intensity or the magnitude of it. But one questions arises what’s the use of valves and how much importance they make to the system.

Some of the main uses of the valve has been written below.

**Flow Regulation:** Valves control the flow of liquids, gases, or slurries within a pipeline. By adjusting the valve opening, operators can regulate the rate of flow through the pipeline. This is essential for maintaining desired process conditions and ensuring efficient operation.

**Isolation:** Valves are used to isolate sections of a pipeline for maintenance, repair, or safety purposes. By closing a valve, operators can stop the flow of fluid through a specific section of the pipeline without affecting the rest of the system.

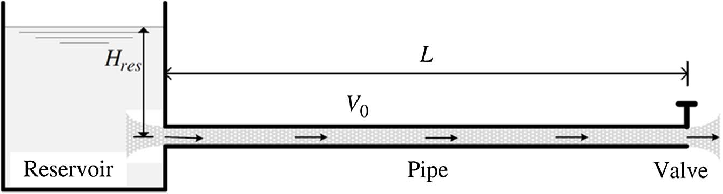
**Pressure Control:** Valves help control pressure within a pipeline system. They can be used to relieve excess pressure by diverting fluid to a different part of the system or by releasing it to the atmosphere.

**Directional Control:** In systems where fluid flow needs to be directed in different directions, valves are used to control the direction of flow. This is commonly seen in systems with multiple pipelines or where fluid needs to be redirected to different processes.

**Safety:** Valves are essential for safety in pipeline systems. They can be equipped with safety features such as pressure relief valves or emergency shutdown valves to prevent overpressure situations, leaks, or other hazardous conditions.

**Metering:** Valves are used in conjunction with flow meters to accurately measure the flow rate of fluids within a pipeline. By adjusting the valve opening, operators can calibrate the flow rate to meet specific requirements.

### **4.4 BOUNDARY CONDITIONS**



At time (t) = t\_0

1. The valve is instantaneously closed

2. Flow through the valve reduces to zero instantly

3. When V = 0 the conversion of the kinetic energy takes place

* The pressure rises at the valve.
* A pressure wave travels in the upstream direction

4. This wave is reflected from the reservoir

5. The wave travels back and forth between the closed valve and the reservoir

6. Due to losses in the system, this wave is dissipated as it travels in the pipeline

7. Finally the flow is completely stopped and the pressure in the entire pipeline becomes same as the reservoir head

### **5. CODE**

import numpy as np  
import math  
import sympy as sp  
import pandas as pd  
  
pi = math.pi  
g = 9.80655  
  
# fluid properties  
K = 2 \* 10\*\*9 # Pascals, Bulk modulus  
rho = 1000 # kg/m3, Density  
  
# pipe properties  
D = 0.3 # m, Diameter   
E = 2.15 \* 10\*\*9 # Pascals, Modulus of Elasticity  
e = 0.01 # m, Thickness   
L = 100 # length of pipe, m  
f = 0.05 # Darcy's friction factor  
  
A = (pi/4)\*D\*D  
R = f/(2\*D\*A)  
a = sp.sqrt((K/rho)/(1+(D\*K)/(E\*e)))  
  
# reservoir properties  
H\_res = 10 #Reservoir head  
Cd = 0.8  
Q\_res = Cd \* A \* sp.sqrt(2\*g\*H\_res)  
k\_entry = 0.5  
  
# Discretization  
n = 5 # no. of sections  
del\_x = L/n  
del\_t = del\_x/a  
  
# initial conditions  
H\_0 = []  
Q\_0 = []  
for node in range(1, 7):  
 H\_0.append(H\_res)  
 Q\_0.append(Q\_res)  
  
H\_matrix = np.array([H\_0])  
Q\_matrix = np.array([Q\_0])  
  
j = 1  
while j\*del\_t <= (8\*L)/a:  
 H\_values = []  
 Q\_values = []  
 for i in range(1, 7):  
 **# Characteristic equations** Ca = (g\*A)/a  
 if i-2 >= 0:  
 Cp = Q\_matrix[j-1, i-2] + Ca\*H\_matrix[j-1, i-2] - R\*Q\_matrix[j-1, i-2]\*abs(Q\_matrix[j-1, i-2])\*del\_t  
 else:  
 Cp = None  
 try:  
 Cn = Q\_matrix[j-1, i] - Ca\*H\_matrix[j-1, i] - R\*Q\_matrix[j-1, i]\*abs(Q\_matrix[j-1, i])\*del\_t  
 except IndexError:  
 Cn = None

**# reservoir boundary**  
 if i == 1:  
 k1 = Ca\*(1 + k\_entry)/(2\*g\*A\*A)  
 Qp = (-1 + sp.sqrt(1 + 4\*k1\*(Cn + Ca\*H\_res)))/(2\*k1)  
 Hp = (Qp - Cn)/Ca  
 H\_values.append(Hp)  
 Q\_values.append(Qp)  
  
 **# valve boundary** elif i == n+1:  
 Cv = 0  
 Qp = 0.5\*(-Cv + sp.sqrt((Cv\*\*2) + (4\*Cp\*Cv)))  
 Hp = (1/Ca)\*(Cp - Qp)  
 H\_values.append(Hp)  
 Q\_values.append(Qp)  
  
 **# MoC** else:  
 Qp = 0.5\*(Cp + Cn)  
 Hp = (Cp - Cn)/(2\*Ca)  
 H\_values.append(Hp)  
 Q\_values.append(Qp)  
  
 H\_values = np.array(H\_values)  
 Q\_values = np.array(Q\_values)  
  
 H\_matrix = np.vstack([H\_matrix, H\_values])  
 Q\_matrix = np.vstack([Q\_matrix, Q\_values])  
  
 j += 1  
  
H\_final = pd.DataFrame(H\_matrix)  
Q\_final = pd.DataFrame(Q\_matrix)

print('OK')

# **6. RESULTS**

After the analysis the maximum and minimum pressure head which was causing the transients in the system has been recorded. These are the results which were found using the model for Discharge and pressure head at different sections.

According to which graphs are also plotted





# **7. CONCLUSION**

With these results that we have got, its easy to design the system as the maximum and minimum values of the pressure head have been seen.

Through improving our knowledge of transient flow dynamics and offering useful insights for maximising system resilience and performance, this work advances the engineering of transient analysis in water system. To guarantee the dependable and effective operation of water supply networks, more study in this field can concentrate on improving modelling techniques, investigating sophisticated control systems, and incorporating real-time monitoring technology.

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