SIMULATION OF MULTI PRODUCT PIPELINE
(OPTIMUM PUMPING STATION AND HYDRAULIC PROFILE)

Submitted By

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SIMULATION OF MULTI PRODUCT PIPELINE
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A thesis submitted in partial fulfillment of the requirements for the Degree of

Master of Technology

(Pipeline Engineering)

By

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April, 2009

CERTIFICATE

This is to certify that the work contained in this thesis titled **"SIMULATION OF MULTI PRODUCT PIPELINE (OPTIMUM PUMPING STATION AND HYDRAULIC PROFILE)"** has been carried out by **SOMASHEKHAR ANDELI** under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

The objective of this project to locate the optimum pumping stations, hydraulic profile generation and interface length is calculated for various pipe diameter, wall thickness, pipe grade, elevation and throughput considering batches of products. The Darcy-Weisbach and Moody friction factor empirical formula equations are used for computing the friction loss. The program is written in MATLAB-2008a to generate the graph for hydraulic profile, interface length and to locate the optimum pumping station. The simulation considers the product properties like density and viscosity. The elevation, outer diameter, wall thickness and pipe grade are fed into the excel worksheet, which is used as input in the program. Enabling the user to easily modify the parameters.

The optimum pumping stations are found for various diameter and throughput. Similarly the interface length is calculated for various throughput. The ground temperature effect is not considered.

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Nomenclature

τ = shear stress, N/m^2

μ = dynamic viscosity, centipoises

γ = specific weight of the liquid

R= Reynolds number, dimensionless

ρ = Density of fluid, kg/m^3

ν = Kinematic viscosity, cSt

f=Darcy friction factor, dimensionless

g=Acceleration due to gravity, $9.81 m/s^2$

e=absolute pipe roughness

P=Pipe internal design pressure, kPa

S=Specified minimum yield strength (SMYS) of pipe material, kPa

E=Seam joint factor

V= Volume of pipeline, m^3

C= Length of the Interface, m

CHAPTER 1

1. INTRODUCTION

The pipeline transport is the transportation of various goods through a pipe. Most commonly, liquid and gases are sent, but pneumatic tubes that transport solid capsules using compressed air have also been used.

As for gases and liquids, any chemically stable substance can be sent through a pipeline. Therefore sewage, slurry, water, or even beer pipelines exist; but arguably the most important are those transporting oil and natural gas.

It was Dmitri Mendeleev, who first proposed this idea in 1863. He suggested using pipe for transporting Petroleum. He explained how it should be done and why it should be done.

A comparison of share of petroleum products carried by various modes of transportation in India in 2003-04 is shown below:

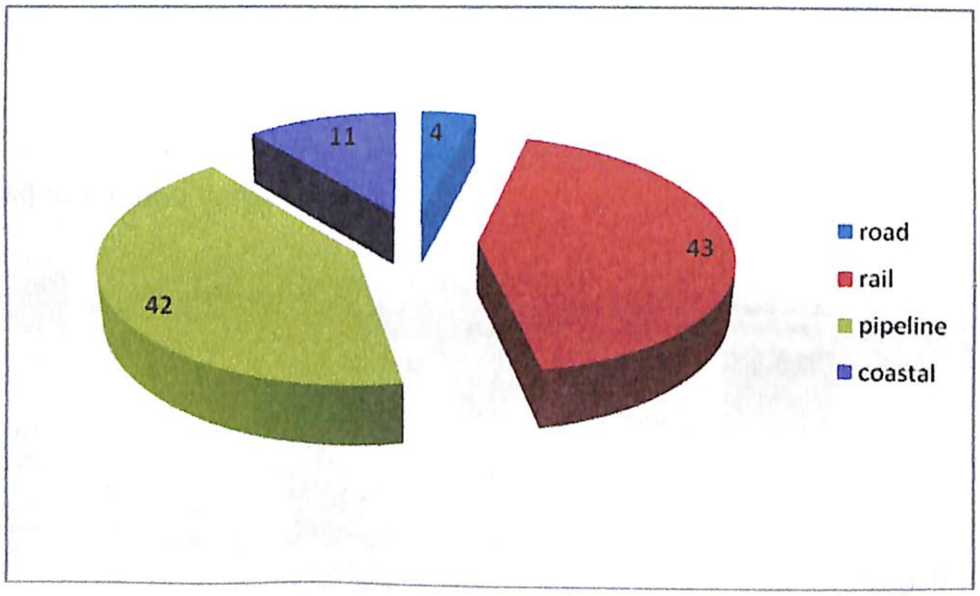


Figure 1.1: Share of petroleum products carried by various modes of transportation in India in 2003-04

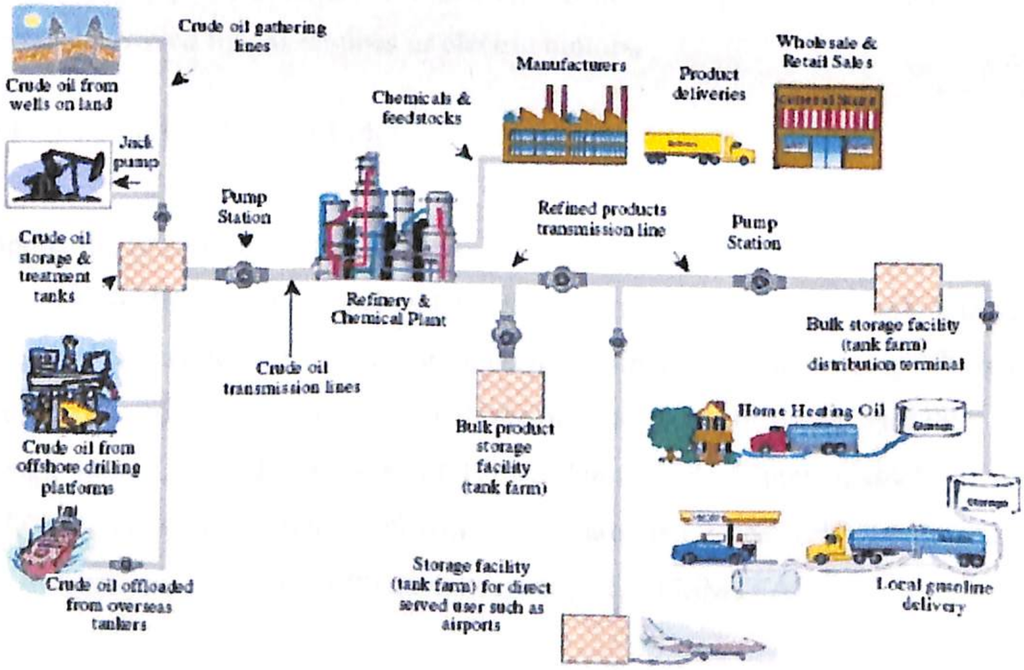
1.1 Pipeline System

Pipeline networks first transport crude oil from onshore and offshore oil fields to refineries. Pipeline "gathering systems" are designed to collect the oil from the onshore and offshore producing fields. Gathering systems connect into "trunk" lines which transport the crude oil to refineries.

Coastal shipping terminals are used to receive crude oil from tankers originating in foreign countries, mostly from the Middle East and South America. At these terminals, crude oil is stored in large tanks, and then is transported by pipeline to refineries.

Refineries, which are mostly located in coastal areas and in the mid-continent area, refine or process the oil into many intermediate and final hydrocarbon products. Intermediate products include the raw materials for plastics, fertilizer, chemicals, and pharmaceuticals, which are further processed by chemical companies into many of the products we use in and around our home. Final products include gasoline, jet fuel, heating oil, and diesel fuel. Pipelines handle the second part of the transportation journey - transporting the final products - gasoline, jet fuel, heating oil, diesel and other refined products to distribution centers. At the distribution centers, the products are then transported to market, such as your local gas station or to your home, generally by tanker trucks.

Given below is a typical schematic illustrating a pipeline system from the wellhead to the end consumer.



Many different kinds of oil and oil products are shipped back-to-back through pipelines in "batches." The physical principles of hydraulics keep the batches of liquid from blending and contaminating one another except where they actually touch. These "interfaces" between different product shipments are separated out when they arrive at their destination and are reprocessed. Batches are sometimes separated by "pigs" or plugs that keep the batches from touching. Pigs are also used for cleaning the interior surfaces of pipelines to help prevent corrosion. Specially developed "smart" pigs containing instrumentation packages are used to check pipeline integrity. To learn more about Shell Pipeline Company's pipeline integrity and safety, click on Pipeline Safety.

Petroleum product moves through pipelines driven by pumps that apply pressure to the product to force it down the pipeline. The pressure is needed to overcome friction between the product and the inside wall of the pipeline. An originating pump station is needed at the beginning of every pipeline to get it started. After that, pump stations are generally spaced at 30-50 mile intervals. The spacing and horsepower required to drive the pumps is based on a number of parameters, including: desired pipeline flow rate, pipeline diameter, physical properties of the product, and elevation changes. The pumps that drive the pipelines are most often centrifugal pumps driven by electric motors. Natural Gas pipelines utilize compressors instead of pumps. The compressors are generally powered by gas engines or electric motors.

1.2 Petroleum pipelines in India

In India, the first crude oil pipeline was built between Nahorkatiya (Assam) to Barauni in 1960s and the first product pipeline between Guwahati – Siliguri in 1964. The success of these pipelines led to implementation of lot more pipelines in the country. Currently there is a network of 3 nos crude oil pipelines of total capacity of 34 MMTPA traversing through 4000 Kms and a network of 17 petroleum product lines of total capacity of 62 MMTPA traversing through 6600 Kms. There are also 2 nos. LPG pipelines owned by Gas Authority of India Ltd. with a total capacity of 3.8 MMTPA.

The above paragraphs convince the vital role of pipeline in the modern society. It is the challenging task for the engineering and construction to provide this infrastructure for growing energy demand. In this thesis the effort is done to find the optimum pumping station, hydraulic profile for multiproduct pipeline considering the physical properties of the product to be transported. The programming is done in MATLAB-2008a.

1.4 Introduction about MATLAB-2008a:

MATLAB® is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and Fortran.

You can use MATLAB in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas.

MATLAB provides a number of features for documenting and sharing your work. You can integrate your MATLAB code with other languages and applications, and distribute your MATLAB algorithms and applications.

Key Features

- High-level language for technical computing
- Development environment for managing code, files, and data
- Interactive tools for iterative exploration, design, and problem solving
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration
- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces

- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java, COM, and Microsoft Excel

Developing Algorithms and Applications

MATLAB® provides a high-level language and development tools that let you quickly develop and analyze your algorithms and applications.

The MATLAB® Language

The MATLAB® language supports the vector and matrix operations that are fundamental to engineering and scientific problems. It enables fast development and execution.

With the MATLAB language, you can program and develop algorithms faster than with traditional languages because you do not need to perform low-level administrative tasks, such as declaring variables, specifying data types, and allocating memory. In many cases, MATLAB eliminates the need for 'for' loops. As a result, one line of MATLAB code can often replace several lines of C or C++ code.

At the same time, MATLAB provides all the features of a traditional programming language, including arithmetic operators, flow control, data structures, data types, object-oriented programming (OOP), and debugging features.

Analyzing and Accessing Data

MATLAB® supports the entire data analysis process, from acquiring data from external devices and databases, through preprocessing, visualization, and numerical analysis, to producing presentation-quality output.

Data Analysis

The MATLAB product provides interactive tools and command-line functions for data analysis operations, including:

- Interpolating and decimating

- Extracting sections of data, scaling, and averaging
- Thresholding and smoothing
- Correlation, Fourier analysis, and filtering
- 1-D peak, valley, and zero finding
- Basic statistics and curve fitting
- Matrix analysis

Data Access

MATLAB is an efficient platform for accessing data from files, other applications, databases, and external devices. You can read data from popular file formats, such as Microsoft Excel; ASCII text or binary files; image, sound, and video files; and scientific files, such as HDF and HDF5. Low-level binary file I/O functions let you work with data files in any format. Additional functions let you read data from Web pages and XML.

You can call other applications and languages, such as C, C++, COM objects, DLLs, Java, Fortran, and Microsoft Excel, and access FTP sites and Web services. Using the Database Toolbox™, you can also access data from ODBC/JDBC-compliant databases.

You can acquire data from hardware devices, such as your computer's serial port or sound card. Using the Data Acquisition Toolbox™ , you can stream live, measured data directly into MATLAB for analysis and visualization. The Instrument Control Toolbox™ (available separately) enables communication with GPIB and VXI hardware.

Performing Numeric Computation

MATLAB® contains mathematical, statistical, and engineering functions to support all common engineering and science operations. These functions, developed by experts in mathematics, are the foundation of the MATLAB language. The core math functions use the LAPACK and BLAS linear algebra subroutine libraries and the FFTW Discrete Fourier Transform library. Because these processor-dependent libraries are optimized to the different platforms that MATLAB supports, they execute faster than the equivalent C or C++ code.

MATLAB provides the following types of functions for performing mathematical operations and analyzing data:

- Matrix manipulation and linear algebra
- Polynomials and interpolation
- Fourier analysis and filtering
- Data analysis and statistics
- Optimization and numerical integration

- Ordinary differential equations (ODEs)
- Partial differential equations (PDEs)
- Sparse matrix operations

CHAPTER 2

2. LITERATURE REVIEW

The purpose of this work is to find the optimum pumping stations and generate hydraulic profile for the multiproduct pipeline.

Drago Matko, Saˇso Blaˇziˇc, and Gerhard Geiger (2003) addressed the problem of modelling and simulating pipelines that are used for transporting different fluids . The problem is solved by including fluid density in the model beside pressure and velocity of the medium. First, the system of nonlinear partial differential equations is derived. Then, the obtained model is linearised and transformed into the transfer function form with three inputs and three outputs. Four different forms of model description are presented in the paper. Since transfer functions are transcendent, they cannot be simulated using classical tools. Rational transfer function approximation of the modelwas found and that simple model was validated on the real industrial pipeline. It was also compared to the model that does not take the changes in fluid density into account. The latter model cannot cope with batch changes whereas the proposed one can.

Edgardo J. Garcia James F. Steffe has found the method for determining optimum pipe diameter, for which total pumping system cost is minimum, has been derived for the transport of Herschel-Bulkley (H-B) fluids (power-law fluids with a yield stress) in laminar flow. The method accounts for pipe system cost as a function of diameter, and pump station and operating costs as a function of power requirements. The optimum diameter can be estimated given rheological properties, fluid density, mass flow rate and economic parameters.

Pipeline Optimization by Computer Simulation by Tony Cleveland and Mike Milinusic (2000) developed the simulation program which is intended to provide optimum solutions to the design pipeline system and to permit the rapid investigation of the effects of significant variables on the optimum design. The optimization of the design of a pipeline to transmit fluids involves a number of variables, which include pipe diameter, pressure, temperature, line length, space between pumping or compressor stations, required inlet and delivery pressures and delivery quantity.

CHAPTER 3

3. THEORETICAL DEVELOPMENT

3.1 Single-Phase Incompressible Flow of Newtonian Fluid

A multiphase flow contains at least two separate phases, such as a liquid and a solid, a gas and a solid, a liquid and a gas, or two immiscible liquids. A singlephase flow, on the other hand, contains either a single liquid or gas without solids in it, or without any other immiscible liquid or gas. The flows of water, oil, natural gas, air, etc. are all examples of single-phase flow. Water laden with sediment particles or air bubbles is a two-phase flow. If the flow of water contains both air bubbles and sediment, it is a three-phase flow and so forth. A liquid with dissolved gas or another dissolved liquid, or with homogeneous suspension of very fine particles of solids, can be considered and treated as a single-phase flow, although in reality two phases are involved.

A flow is said to be incompressible if the density of any particle in the flow, be it a fluid or a solid particle, remains constant as the particle travels with the flow. A flow is said to be homogeneous if the density is constant throughout the flow. A single-phase incompressible flow is a homogeneous flow, whereas a multiphase incompressible flow is not homogeneous. For instance, for a pipe flow of water carrying gravel, the density of the flow is not the same everywhere at a given time, depending on whether water or gravel exists at the location at a given time. Normally, both liquid and gas are treated as incompressible flow. However, when the speed of a gas approaches, equals to, or exceeds the velocity of sound, large density changes occur in the flow within short distances and the flow can no longer be treated as incompressible. Also, when any gas is flowing through a long pipeline, there can be substantial change of the density of the gas over a long distance due to pressure change along the pipe even when the speed involved is low. Therefore, not all gas pipelines can be treated as incompressible, even when the velocity is low.

From elementary fluid mechanics, the shear τ stress in a two-dimensional laminar flow in the x direction as shown in Figure 3.1 is

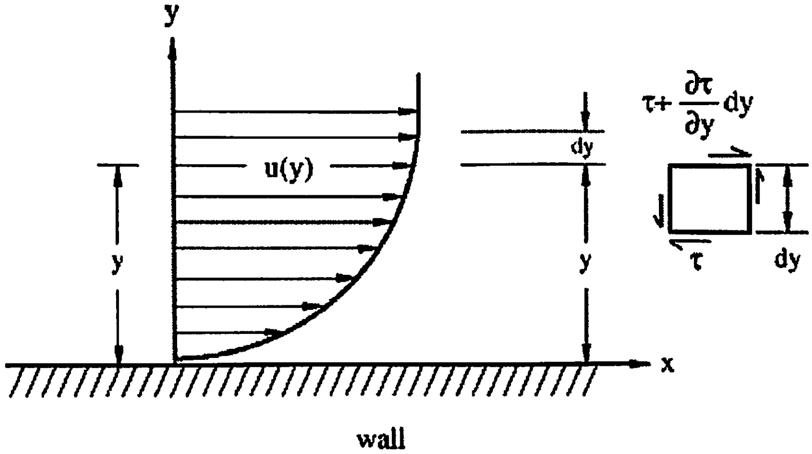


Figure 3.1 Velocity variations from wall and shear stress for a parallel flow.

$$\tau = \mu \ (du/dy) \tag{3.1}$$

where τ is the shear stress; u is the velocity at a distance y from the wall; du/dy is the derivative of u with y; and μ is the dynamic viscosity. Equation 3.1 is often referred to as Newton's law of viscosity.

3.2 Flow equations for One-Dimensional analysis

3.2.1 Continuity Equation

The continuity equation for incompressible flow in a pipe is

$$V_1A_1=V_2A_2 \tag{3.2}$$

where A_1 and A_2 are the cross-sectional areas of the pipe at sections 1 and 2; V_1 and V_2 are the cross-sectional average velocities (mean velocities) at sections 1 and 2; and Q is the discharge (i.e., volumetric flow rate) at either section. Note that Equation 3.2 is applicable to not only steady flow but also unsteady flow through pipes.

The pipe can have a cross section of circular or any other shape. Even when the fluid is non-Newtonian or multiphase, the equation still holds as long as the velocity V refers to the average velocity of the different phases at any pipe cross section, and when the flow is incompressible. The equation does not hold if the fluid leaves or enters the pipe between sections 1 and 2, as for instance when a branch exists between the two sections.

3.2.2 Energy Equation

The basic principle of conservation of energy applied to liquid hydraulics is embodied in Bernoulli's equation, which simply states that the total energy of the fluid contained in the pipeline at any point is a constant. Obviously, this is an extension of the principle of conservation of energy which states that energy is neither created nor destroyed, but transformed from one form to another.

Consider the pipeline shown in Figure 3.2 that depicts flow from point A to point B with the elevation of point A being Z_A and elevation at B being Z_B above some chosen datum. The pressure in the liquid at point A is P_A and that at B is P_B. Assuming a general case, where the pipe diameter at A may be different from that at B, we will designate the velocities at A and B to be V_A and V_B respectively. Consider a particle of the liquid of weight W at point A in the pipeline.

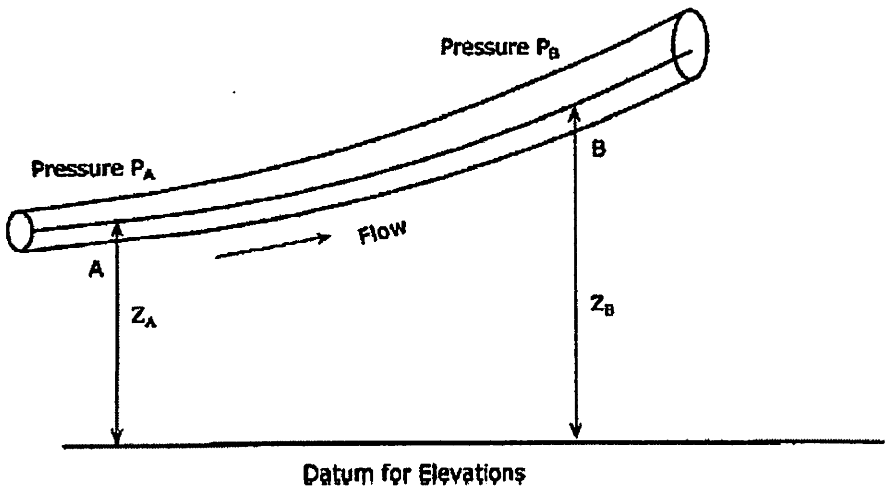


Figure 3.2 Energy of a liquid in pipe flow.

This liquid particle at A may be considered to possess a total energy E that consists of three components:

$$\textbf{Energy due to position, or potential energy} = WZ_A \quad (3.3)$$

$$\textbf{Energy due to pressure, or pressure energy} = WP_A/\gamma \quad (3.4)$$

$$\textbf{Energy due to velocity or Kinetic energy} = WV_A^2/2g \quad (3.5)$$

where

γ=Specific weight of the liquid

We can thus state that

$$E = WZA + WPA/\gamma + WVA^2/2g \quad (3.6)$$

Dividing by W throughout, we get the total energy per unit weight of liquid as

$$H_A = Z_A + P_A/\gamma + V_A^2/2g \quad (3.7)$$

Where,

H_A=total energy per unit weight at point A

Considering the same liquid particle as it arrives at point B, the total energy per unit weight at B is

$$H_B = Z_B + P_B/\gamma + V_B^2/2g \quad (3.8)$$

Due to conservation of energy

$$H_A = H_B \quad (3.9)$$

Therefore,

$$Z_A + P_A/\gamma + V_A^2/2g = Z_B + P_B/\gamma + V_B^2/2g \quad (3.10)$$

Equation (3.10) is one form of Bernoulli's equation for fluid flow.

In real-world pipeline transportation, there is energy loss between point A and point B, due to friction in the pipe. We include the energy loss due to friction by modifying Equation (3.10) as follows:

$$Z_A + P_A/\gamma + V_A^2/2g = Z_B + P_B/\gamma + V_B^2/2g + \Sigma hL \quad (3.11)$$

Where,

ΣhL=all the head losses between points A and B, due to friction. In Bernoulli's equation (3.10), we must also include any energy added to the liquid, such as when there is a pump between points A and B. Thus the left-hand side of the equation will have a positive term added to it that will represent the energy generated by a pump. Equation (3.11) will be modified as follows to include a pump at point A that will add a certain amount of pump head to the liquid:

$$Z_A + P_A/\gamma + V_A^2/2g + H_P = Z_B + P_B/\gamma + V_B^2/2g + \Sigma hL \quad (3.12)$$

Where,

H_P = pump head added to the liquid at point A

3.3 Pressure Drop due to friction

Reynolds Number

Flow in a liquid pipeline may be smooth, laminar flow (also known as viscous or streamline flow). In this type of flow the liquid flows in layers or laminations without causing eddies or turbulence. As the liquid flow rate is increased, the velocity increases and the flow will change from laminar flow to turbulent flow with eddies and disturbances. An important dimensionless parameter called the Reynolds number is used in classifying the type of flow in pipelines. The Reynolds number of flow, R, is calculated as follows:

$$R=VD\rho/\mu \qquad (3.13)$$

V = Flow rate, m/sec

D = Internal diameter, m

ρ = Density of fluid, kg/m^3.

ν = Kinematic viscosity, cSt

Flow Regimes

The three flow regimes may be distinguished as follows:

Laminar: Reynolds number<2000

Critical: Reynolds number>2000 and Reynolds number<4000

Turbulent: Reynolds number>4000

As liquid flows through a pipeline, energy is lost due to friction between the pipe surface and the liquid and due to the interaction between liquid molecules. This energy lost is at the expense of liquid pressure.

The pressure drop due to friction in a pipeline depends on the flow rate, pipe diameter, pipe roughness, liquid specific gravity, and viscosity. In addition, the frictional pressure drop depends on the Reynolds number (and hence the flow regime).

The pressure drop due to friction in a given length of pipe, expressed in feet of liquid head (h), can be calculated using the Darcy-Weisbach equation as follows:

$$h=f(L/D)(V^2/2g) \qquad (3.14)$$

where

f=Darcy friction factor, dimensionless, usually a number between 0.008 and 0.10

L=Pipe length, m

D=Pipe internal diameter, m

V=Average liquid velocity, m/s

g=Acceleration due to gravity, 9.81m/s^2

In laminar flow, the friction factor f depends only on the Reynolds number. In turbulent flow f depends on pipe diameter, internal pipe roughness, and Reynolds number, as we will see shortly.

Friction Factor

For laminar flow, with Reynolds number R<2000, the Darcy friction factor f is calculated from the simple relationship

$$f=64/R \qquad (3.15)$$

For turbulent flow, when the Reynolds number R>4000, the friction factor f depends not only on R but also on the internal roughness of the pipe. As the pipe roughness increases, so does the friction factor.

Therefore, smooth pipes have a smaller friction factor compared with rough pipes. More correctly, friction factor depends on the relative roughness

$$\text{Relative roughness}=(e/D) \qquad (3.16)$$

e=absolute pipe roughness

D=Inside diameter, m

For turbulent flow the friction loss are calculated on the basis of Moody friction factor empirical formula

$$f= 1.325/(\ln((e/3.7\,D)+(5.74/Re^{0.9})))^2 \qquad (3.17)$$

3.3.1 Minor Losses

In most long-distance pipelines, such as trunk lines, the pressure drop due to friction in the straight lengths of pipe forms the significant proportion of the total frictional pressure drop. Valves and fittings contribute very little to the total pressure drop in the entire pipeline. Hence, in such cases, pressure losses through valves, fittings, and other restrictions are generally classified as *"minor losses"*. Minor losses include energy losses resulting from rapid changes in the direction or magnitude of liquid velocity in the pipeline. Thus pipe enlargements, contractions, bends, and restrictions such as check valves and gate valves are included in minor losses.

Valve or fitting

Pressure drop in a valve or fitting is calculated as follows:

$$h=KV^2/2g \tag{3.18}$$

where

h=Head loss due to valve or fitting, m

K=Head loss coefficient for the valve or fitting, dimensionless

V=Velocity of liquid through valve or fitting, m/s

g=Acceleration due to gravity, 9.81 m/s^2

Gradual Enlargement

Consider liquid flowing through a pipe of diameter D1. If at a certain point the diameter enlarges to D2, the energy loss that occurs due to the enlargement can be calculated as follows:

$$h=K(V_1-V_2)^2/2g \tag{3.19}$$

where V_1 and V_2 are the velocity of the liquid in the smaller-diameter and the larger-diameter pipe respectively. The value of K depends upon the diameter ratio D_1/D_2 and the different cone angle due to the enlargement.

3.4 Permissible/Allowable Operating Pressure

To transport a liquid through a pipeline, the liquid must be under sufficient pressure so that the pressure loss due to friction and the pressure required for any elevation changes can be accommodated. The longer the pipeline and the higher the flow rate, the higher the friction drop will be, requiring a corresponding increase in liquid pressure at the beginning of the pipeline.

In gravity flow systems, flow occurs due to elevation difference without any additional pump pressure. Thus, a pipeline from a storage tank on a hill to a delivery terminus below may not need any pump pressure at the tank.

However, the pipeline still needs to be designed to withstand pressure generated due to the static elevation difference.

The allowable operating pressure in a pipeline is defined as the maximum safe continuous pressure that the pipeline can be operated at. At this internal pressure the pipe material is stressed to some safe value below the yield strength of the pipe material. The stress in the pipe material consists of circumferential (or hoop) stress and longitudinal (or axial) stress.

This is shown in Figure 3.3.

To ensure that the pipeline can be safely operated at a particular maximum allowable operating pressure (MAOP) we must test the pipeline using water, at a higher pressure.

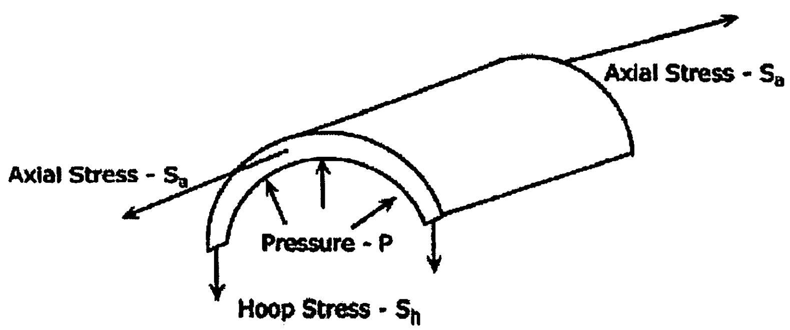


Figure 3.3 Hoop stress and axial stress in a pipe.

Permissible Pressure

$$P=2t \times S \times E \times F/D \qquad (3.20)$$

where

P=Pipe internal design pressure, kPa

D=Nominal pipe outside diameter, mm

T=Nominal pipe wall thickness, mm

S=Specified minimum yield strength (SMYS) of pipe material, kPa

E=Seam joint factor, 1.0 for seamless and submerged arc welded (SAW) pipes

F=Design factor, usually 0.72 for liquid pipelines, except that a design factor of 0.60 is used for pipe, including risers, on a platform located off shore or on a platform in inland navigable waters, and 0.54 is used for pipe that has been subjected to cold expansion to meet the SMYS and subsequently heated, other than by welding or stress-relieving as a part of the welding, to a temperature higher than 900°F (482°C) for any period of time or to over 600°F (316°C) for more than 1 hr.

3.5 Line Fill Volume and Batches

It is necessary to know how much liquid is contained in a pipeline between two points along its length, such as between valves or pump stations.

For a circular pipe, we can calculate the volume of a given length of pipe by multiplying the internal cross-sectional area by the pipe length.

$$V=(\pi/4) \times D^2 \times L \tag{3.21}$$

V= Volume of pipeline, m^3

D= Internal diameter of pipe, m

L= Length if pipe, m

3.6 Hydraulic Pressure Gradient

The total pressure P_T required at the beginning of a pipeline to transport a given flow rate from dispatch station to terminal station will depend on

- Pipe diameter, wall thickness, and roughness
- Pipe length
- Pipeline elevation changes from dispatch to delivery station
- Liquid specific gravity and viscosity
- Flow rate

If we increase the pipe diameter, keeping all other items above constant, we know that the frictional pressure drop will decrease and hence the total pressure P_T will also decrease. Increasing pipe wall thickness or pipe roughness will cause increased frictional pressure drop and thus increase the value of P_T. On the other hand, if only the pipe length is increased, the pressure drop for the entire length of the pipeline will increase and so will the total pressure P_T.

If the pipeline were laid in a flat terrain, with no appreciable elevation difference between the beginning of the pipeline and the terminus, the total pressure P_T will not be affected. But if the elevation difference between delivery and terminus were substantial, and terminus was at a higher elevation than delivery station, P_T will be higher than that for the pipeline in flat terrain. The higher the liquid specific gravity and viscosity, the higher will be the pressure drop due to friction and hence the larger the value of P_T. Finally, increasing the flow rate will result in a higher frictional pressure drop and therefore a higher value for P_T. In general, the total pressure required can be divided into three main components as follows:

- Friction head
- Elevation head
- Delivery pressure at terminus

Therefore total pressure required is,

$$P_T = P_{friction} + P_{elevation} + P_{del} \tag{3.22}$$

Considering the two pump station (dispatch and intermediate), the elevation profile of the route, the hydraulic gradient will be as shown in below figure.

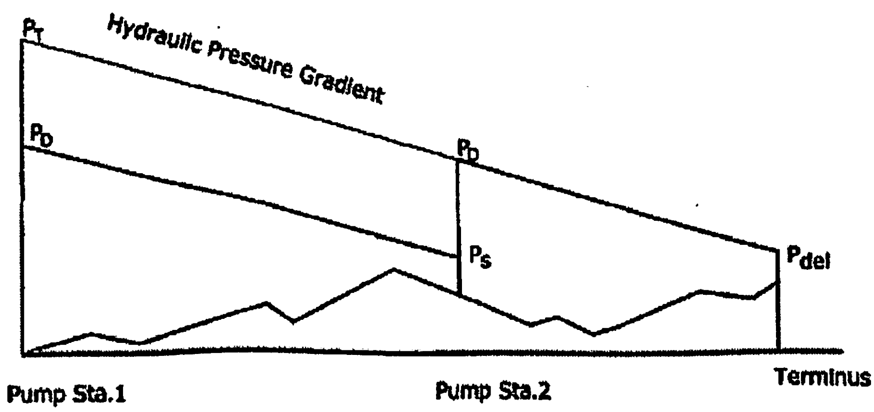


Figure 3.4 Hydraulic pressure gradient: two pump stations.

3.7 Multiproduct Pipeline

Operation of the multi-product pipelines is based on tight line principle wherein the Pipeline is always kept under certain pressure to minimize intermixing of the two different adjacent products moving in the line simultaneously. Pipeline receives products from the refineries/port at the initial pump station and transfers the same to the storage tanks at the terminals in the form of batches.

Batch

Batches are means by which product movement can be tracked .A batch always starts out as a continuous stream of products. It may be split, partially delivered, or stored in one or more locations. A batch interface is the region where two batches meet in a pipeline and where some mixing of the products occur

Type of batches

Batches are mainly two types

- Fungible batches
- Segregated batches

Fungible batches

A Fungible batch is defined as a batch of petroleum products meeting carrier's established specifications, which may be commingled with other quantities of petroleum products meeting the same specifications. Fungible product specifications are established based on industry standards.

Segregated batches

A segregated batch is defined as a batch of petroleum products meeting carrier's established specifications, which may not be commingled with other quantities. A batch may be segregated because it has properties that differ from the fungible specifications.

Batch Sequencing

Liquid pipeline operators transport various liquid petroleum products or grades of the same products in sequence through pipeline, with each product or batch distinct from the preceding or following .One refined product is injected and begins its journey , then subsequent other products are injected and shipped.

Products are pumped in sequential batches depending on the following criteria.

- Product compatibility and ability to blend with successive products.
- The minimum batch volume necessary to absorb the interface quantity of the adjacent products without compromising the product specifications.

3.7.1 Interface Calculation

For determining the optimum batch size of each product, we also need to decide where to receive the interface, when more than one location receives product from same batch.

Let us first understand the formula for interface generation.

Formula for Length of the Interface generated in a Pipeline is

$$C = 11.75 \times D^{0.5} \times L^{0.5} \times Re^{-0.1} \qquad (3.23)$$

where

D = diameter, m

L = length of the pipeline, m

Re is the dimensionless Reynolds no. of the interface.

CHAPTER 4

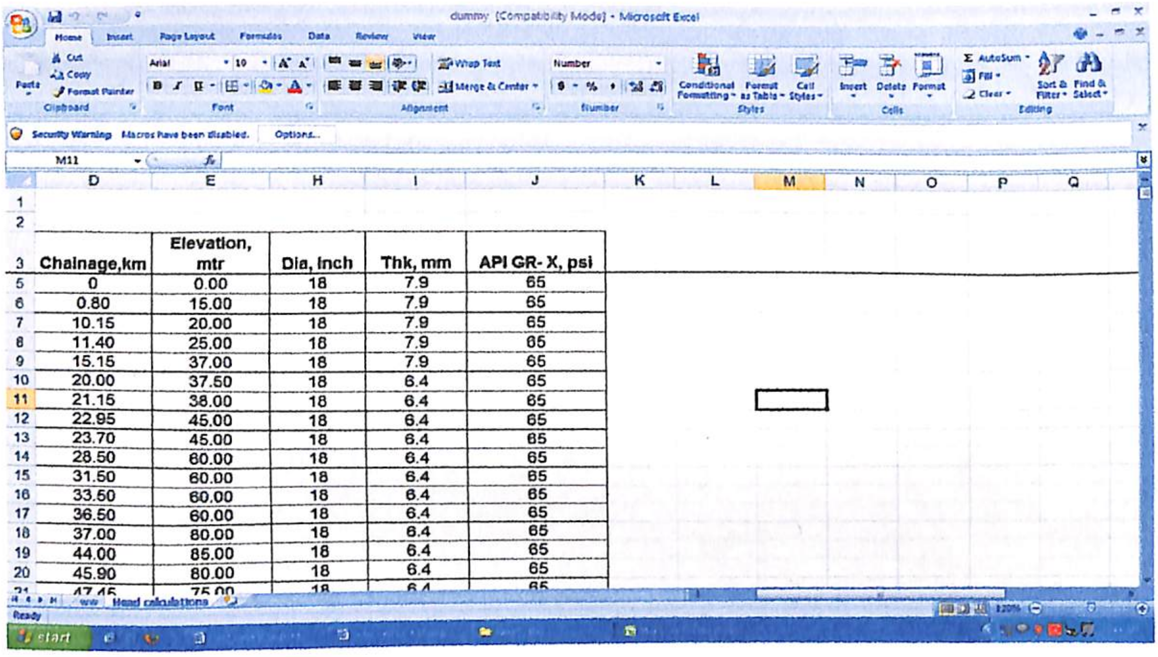
4. DEVELOPMENT OF PROGRAM

4.1 Assumption:

- The ground temperature is not considered.
- The minor losses like head loss due to sectionalizing valve, variation in thickness and bends is not considered, for nullifying this error the back pressure is equated to 60m.

The elevation profile, pipeline specifications of Mundra-Delhi pipeline* is collected. The data like elevation, pipe thickness, pipe diameter, pipe grade are fed into the Microsoft Excel sheet with respective to the chainage.

The Excel sheet is shown in below figure:



Chainage,km	Elevation, mtr	Dia, Inch	Thk, mm	API GR- X, psi
0	0.00	18	7.9	65
0.80	15.00	18	7.9	65
10.15	20.00	18	7.9	65
11.40	25.00	18	7.9	65
15.15	37.00	18	7.9	65
20.00	37.50	18	6.4	65
21.15	38.00	18	6.4	65
22.95	45.00	18	6.4	65
23.70	45.00	18	6.4	65
28.50	60.00	18	6.4	65
31.50	60.00	18	6.4	65
33.60	60.00	18	6.4	65
36.50	60.00	18	6.4	65
37.00	80.00	18	6.4	65
44.00	85.00	18	6.4	65
45.90	80.00	18	6.4	65

Figure 4.1 Data Excel sheet

The data are arranged in the form of matrix in excel sheet. The excel worksheet can be read in the MATLAB as matrix.

In the programming the Excel worksheet serves as input.

Open MATLAB from the desktop by double click on the icon 

Go to open in tool bar select M file.

Then we get the Editor where the programming can be done.

*The data is got by the courtesy of MDPL, Mundra.

The set of equations are properly used in the loop to find the permissible pressure, friction loss, elevation loss, interface length and batch length. The other parameters like design safety factor, station back pressure, seam joint factor are taken as constants in program. In finding interface the sequence is read from the Excel sheet.

The code for single product written in MATLAB Editor is typed below for the reference.

```
ChainageKm = xlsread('C:\Documents and Settings\somu\Desktop\Somu
Projects\Project.xls', 3, 'E5:E472');
Elevation = xlsread('C:\Documents and Settings\somu\Desktop\Somu
Projects\Project.xls', 3, 'F5:F472');
O_DiaInch = xlsread('C:\Documents and Settings\somu\Desktop\Somu
Projects\Project.xls', 3, 'I5:I472');
Thk_mm = xlsread('C:\Documents and Settings\somu\Desktop\Somu
Projects\Project.xls', 3, 'J5:J472');
API_GRX = xlsread('C:\Documents and Settings\somu\Desktop\Somu
Projects\Project.xls', 3, 'K5:K472');

CorAllmm = 0.5; %corrosion allowance
MMTPA = 6;      %throughput
Viscosity = 8.4; %kinematic viscosity
SpGr = 0.8718;   %specific gravity
A_Rghs = 0.00015; % absolute roughness
FS = 0.72;        %design factor
MAOP = 0.9;       % maximum allowable pressure
StatBack_m = 60;  %station back pressure
operating_hour=8000;

N = size(ChainageKm);
Rows = N(1,1);

for i = 1:Rows
    I_DiaInch(i) = (O_DiaInch(i)-(Thk_mm(i) * 2 / 25.4))/12;
end

for i = 1:Rows
    R_Rghs(i) = (A_Rghs / I_DiaInch(i));
end

for i = 1:Rows
    Flow(i) = (MMTPA * 1000000 / (SpGr * operating_hour)) * (1000000 /
(3600 * 30 * 30 * 30));
end
```

```
for i = 1:Rows
    area(i)= (22/28)* I_DiaInch(i) * I_DiaInch(i) ;
end

for i = 1:Rows
    vel(i)= Flow(i)/ area(i);
end

for i = 1:Rows
    rey_no(i)= (vel(i)* I_DiaInch(i))/( Viscosity/(100*30*30));
end

for i=1:Rows
    %h_perm=permissible pressure
    h_perm(i)=(API_GRX(i)*1000*FS*MAOP*2*(Thk_mm(i)/(O_DiaInch(i)*25.4-
Thk_mm(i)))*(10/SpGr)* (0.454/(2.54^2)));
end

for i=1:Rows
    h_permtotal(i)= h_perm(i)+ Elevation(i);
end

for i=1:Rows
    %f_factor=friction factor
    f_factor(i) = 1.325/(log((R_Rghs(i)/3.7)+(5.74/
rey_no(i)^(0.9)))^2);
end

%if length=0 then hf=0
hf(1) = 0;
for i=2:Rows
    %hf=head loss due to friction
    hf(i) = (f_factor(i)* ((ChainageKm(i)- ChainageKm(i-1))*1000/0.3)*
(vel(i)^2)/(2 * 32.7 * I_DiaInch(i)) * 0.3);
end

%if length=0 then he=0
he(1) = 0;
```

```
for i=2:Rows
    %he=head due to elevation
    he(i)= Elevation(i)- Elevation(i-1);
end

%if length=0 then hg(i)= h_permtotal
% if [hg(i-1)-(hf(i)+he(i)+hf(i+1)+he(i+1))]< StatBack_m then hg(i) =
h_perm(i)
hg(1) = h_perm(1);
for i=2:Rows
    if(i<(Rows - 1))
        temp = hg(i-1) - (hf(i)+he(i)+hf(i+1)+he(i+1));
    else
        temp=hg(i-1) - hf(i) - he(i);
    end

    if (temp<=StatBack_m)
        hg(i) = h_perm(i);
    else
        hg(i) = hg(i-1)-((hf(i)+he(i)));
    end
end

for i=1:Rows
    h_total(i)= hg(i)+Elevation(i);
end

for i=1:Rows
    check(i)= h_perm(i)-hg(i);
end
 plot(ChainageKm, Elevation);
hold all;
plot(ChainageKm, hg);
hold all;
plot(ChainageKm, h_total);
hold all;
plot(ChainageKm, h_permtotal);
hold all;
```

The code for multiproduct written in MATLAB Editor is typed below for the reference.

```
ChainageKm = xlsread('D:\e-books\novels\somu\project\Somu Projects\new
program\Project.xls', 3, 'E5:E472');
Elevation = xlsread('D:\e-books\novels\somu\project\Somu Projects\new
program\Project.xls', 3, 'F5:F472');
O_DiaInch = xlsread('D:\e-books\novels\somu\project\Somu Projects\new
program\Project.xls', 3, 'I5:I472');
Thk_mm = xlsread('D:\e-books\novels\somu\project\Somu Projects\new
program\Project.xls', 3, 'J5:J472');
API_GRX = xlsread('D:\e-books\novels\somu\project\Somu Projects\new
program\Project.xls', 3, 'K5:K472');

CorAllmm = 0.5;      % corrosion allowance
MMTPA = 6;            % throughput
A_Rghs = 0.00015;    %Absolute Roughness
FS = 0.72;            %Design factor
MAOP = 0.9;           %Maximum allowable operating pressure
StatBack_m = 60;     %station back pressure
operating_hour=8000;

Viscosity = xlsread('D:\e-books\novels\somu\project\Somu Projects\new
program\Project.xls', 1, 'C2:C7');
SpGr = xlsread('D:\e-books\novels\somu\project\Somu Projects\new
program\Project.xls', 1, 'B2:B7');
batch_volume = xlsread('D:\e-books\novels\somu\project\Somu
Projects\new program\Project.xls', 1, 'D2:D7');

N = size(Viscosity);
R = N(1,1);
j = R;
len = batch_volume(j);



N = size(ChainageKm);
Rows = N(1,1);
for i = 1:(Rows+1)
    if(i    <    (Rows+1))
```

```
I_DiaInch(i) = (O_DiaInch(i)-(Thk_mm(i) * 2 / 25.4))/12;

R_Rghs(i) = (A_Rghs / I_DiaInch(i));

Flow(i) = (MMTPA * 1000000 / (SpGr(j) * operating_hour)) *
(1000000 / (3600 * 30 * 30 * 30));

area(i)= (22/28)* I_DiaInch(i) * I_DiaInch(i) ;

vel(i)= Flow(i)/ area(i);

rey_no(i)= (vel(i)* I_DiaInch(i))/( Viscosity(j)/(100*30*30));

%h_perm=permissible pressure

h_perm(i)=(API_GRX(i)*1000*FS*MAOP*2*(Thk_mm(i)/(O_DiaInch(i)*25.4-
Thk_mm(i)))*(10/SpGr(j))* (0.454/(2.54^2)));

h_permtotal(i)= h_perm(i)+ Elevation(i);

f_factor(i) = 1.325/(log((R_Rghs(i)/3.7)+(5.74/
rey_no(i)^(0.9)))^2);

if (i == 1)
    %hf=head loss due to friction
    hf(i) = 0;
    length(i) = 0;
    volume(i) = 0;
    TotVolume(i) = 0;
else
    hf(i) = (f_factor(i)* ((ChainageKm(i)- ChainageKm(i-
1))*1000/0.3)* (vel(i)^2)/(2 * 32.7 * I_DiaInch(i)) * 0.3);
    length(i) = ChainageKm(i)- ChainageKm(i-1);
    volume(i) = length(i) * area(i) * (0.3048^2) * 1000;
    TotVolume(i) = volume(i) + TotVolume(i-1);
end

if(i == 1)
```

```
            he(i) = 0;
        else
            he(i)= Elevation(i)- Elevation(i-1); % head loss due to
elevation
        end
    end

    if(i>1)
        if (i-1 == 1)
            hg(i-1) = h_perm(i-1);
        else
            if(i-1<(Rows - 1))
                temp = hg(i-1-1) - (hf(i-1)+he(i-1)+hf(i-1+1)+he(i-
1+1));
            else
                temp=hg(i-1-1) - hf(i-1) - he(i-1);
            end
            if (temp<=StatBack_m)
                hg(i-1) = h_perm(i-1);
            else
                hg(i-1) = hg(i-1-1)-((hf(i-1)+he(i-1)));
            end
        end
        h_total(i-1)= hg(i-1)+Elevation(i-1);
        check(i-1)= h_perm(i-1)-hg(i-1);
        if ( i-1 < Rows)
            if (TotVolume(i-1 + 1) > len)
                j = j-1;
                if(j == 0)
                    j = R;
                end
                len = len + batch_volume(j);
            end
            rho(i-1) = SpGr(j) * 1000;
        else
            rho(i-1) = SpGr(j) * 1000;
        end
    end
```

```
end

plot(ChainageKm, Elevation);
hold all;
plot(ChainageKm, hg);
hold all;
plot(ChainageKm, h_total);
hold all;
plot(ChainageKm, h_permtotal);
hold all;
plot(ChainageKm, rho);
hold all;
```

The code for interface written in MATLAB Editor is typed below for the reference.

```
ChainageKm = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 3, 'E5:E472');
Elevation = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 3, 'F5:F472');
O_DiaInch = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 3, 'I5:I472');
Thk_mm = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 3, 'J5:J472');
API_GRX = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 3, 'K5:K472');

CorAllmm = 0.5;     % corrosion allowance
MMTPA = 9;          % throughput
operating_hour=8000;
A_Rghs = 0.00015; %Absolute Roughness
FS = 0.72;        %Design factor
MAOP = 0.9;       %Maximum allowable operating pressure
StatBack_m = 60;  %station back pressure

Viscosity = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 1, 'C2:C7');
SpGr = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 1, 'B2:B7');
batch_volume = xlsread('D:\e-books\novels\somu\project\Somu Projects\new program\Project.xls', 1, 'D2:D7');

N = size(Viscosity);
R = N(1,1);
j = R;
len = batch_volume(j);


x = 1;
N = size(ChainageKm);
Rows = N(1,1);

for i = 1:(Rows+1)
```

```
    if(i    <    (Rows+1))
        I_DiaInch(i) = (O_DiaInch(i)-(Thk_mm(i) * 2 / 25.4))/12;
        R_Rghs(i) = (A_Rghs / I_DiaInch(i));
        Flow(i)  =  (MMTPA  *  1000000  /  (SpGr(j)  *  operating_hour))  *
(1000000 / (3600 * 30 * 30 * 30));
        area(i)= (22/28)* I_DiaInch(i) * I_DiaInch(i) ;
        vel(i)= Flow(i)/ area(i);
        rey_no(i)= (vel(i)* I_DiaInch(i))/( Viscosity(j)/(100*30*30));
        %h_perm=permissible pressure

h_perm(i)=(API_GRX(i)*1000*FS*MAOP*2*(Thk_mm(i)/(O_DiaInch(i)*25.4-
Thk_mm(i)))*(10/SpGr(j))* (0.454/(2.54^2)));
        h_permtotal(i)= h_perm(i)+ Elevation(i);
        f_factor(i)          =          1.325/(log((R_Rghs(i)/3.7)+(5.74/
rey_no(i)^(0.9)))^2);
        if (i == 1)
            hf(i) = 0;
            length(i) = 0;
            cumLength(i) = 0;
            volume(i) = 0;
            TotVolume(i) = 0;
        else
            %hf=head loss due to friction
            hf(i)    =    (f_factor(i)*    ((ChainageKm(i)-    ChainageKm(i-
1))*1000/0.3)* (vel(i)^2)/(2 * 32.7 * I_DiaInch(i)) * 0.3);
            length(i) = ChainageKm(i)- ChainageKm(i-1);
            cumLength(i) =  cumLength(i-1)  +  length(i);
            volume(i) = length(i) * area(i) * (0.3048^2) * 1000;
            TotVolume(i) = volume(i) + TotVolume(i-1);
        end
        if(i == 1)
            he(i) = 0;
        else
            he(i)= Elevation(i)- Elevation(i-1);  % head loss due to
elevation
        end
    end
    if(i>1)
```

```
if (i-1 == 1)
    hg(i-1) = h_perm(i-1);
else
    if(i-1<(Rows - 1))
        temp = hg(i-1-1) - (hf(i-1)+he(i-1)+hf(i)+he(i));
    else
        temp=hg(i-2) - hf(i-1) - he(i-1);
    end
    if (temp<=StatBack_m)
        hg(i-1) = h_perm(i-1);
    else
        hg(i-1) = hg(i-2)-((hf(i-1)+he(i-1)));
    end
end
h_total(i-1)= hg(i-1)+Elevation(i-1);
check(i-1)= h_perm(i-1)-hg(i-1);
if ( i-1 < Rows)
    if (TotVolume(i) > len)
        j = j-1;
        if(j == 0)
            j = R;
        end
        len = len + batch_volume(j);

        IntLen  =  11.75  *  ((I_DiaInch(i-1)*0.3048)^0.5)    *
((cumLength(i-1)*1000)^0.5)   *   (rey_no(i-1)^(-0.1));
        Y(x) =   IntLen;
        han = rey_no(i-1);
        han
        han1 = I_DiaInch(i-1);
        han1
        X(x) =   cumLength(i-1);
        IntLen
        han2 = cumLength(i-1);
        han2
        x = x +1;
    end
    rho(i-1) = SpGr(j) * 1000;
```

```
        else
            rho(i-1) = SpGr(j) * 1000;
        end

    end
end


plot(ChainageKm, rho);
hold all;
plot(X, Y);
hold all;
```

CHAPTER 5

5. RESULT

Case 1: Finding the optimum pumping station for different pipe diameter for single product.

For 18 inch diameter pipeline.

The density of the fluid is kept constant

```
MMTPA = 6;
Viscosity = 8.4;
SpGr = 0.8718;
A_Rghs = 0.00015;
FS = 0.72;
MAOP = 0.9;
StatBack_m = 60;
```

The output for the above data is shown in below graph generated in MATLAB

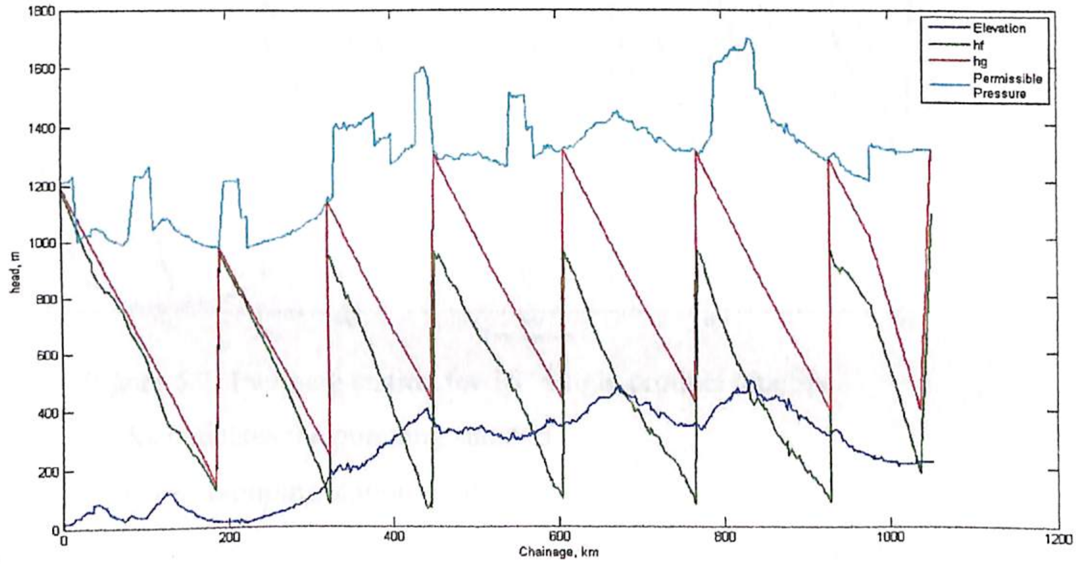


Figure 5.1: Pumping station for 18" single product pipeline

The number of peaks indicates the pumping stations.

Therefore the number of pumping station = 6

For 16 inch diameter pipeline.

The density of the fluid is kept constant

```
MMTPA = 6;
Viscosity = 8.4;
SpGr = 0.8718;
A_Rghs = 0.00015;
FS = 0.72;
MAOP = 0.9;
StatBack_m = 60;
```

The output for the above data is shown in below graph generated in MATLAB

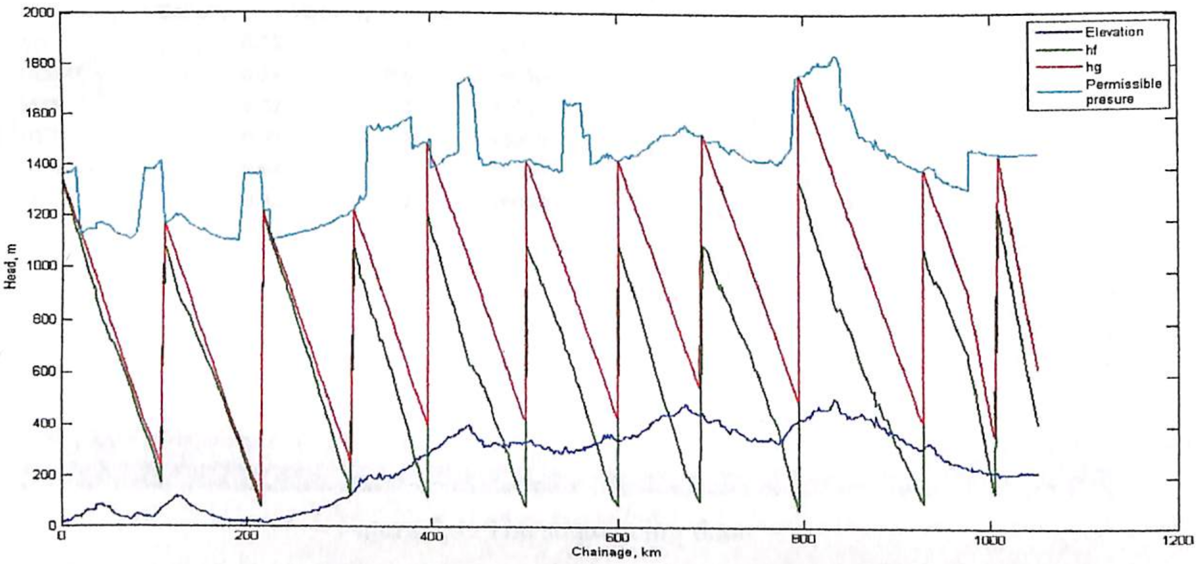


Figure 5.2: Pumping station for 16" single product pipeline

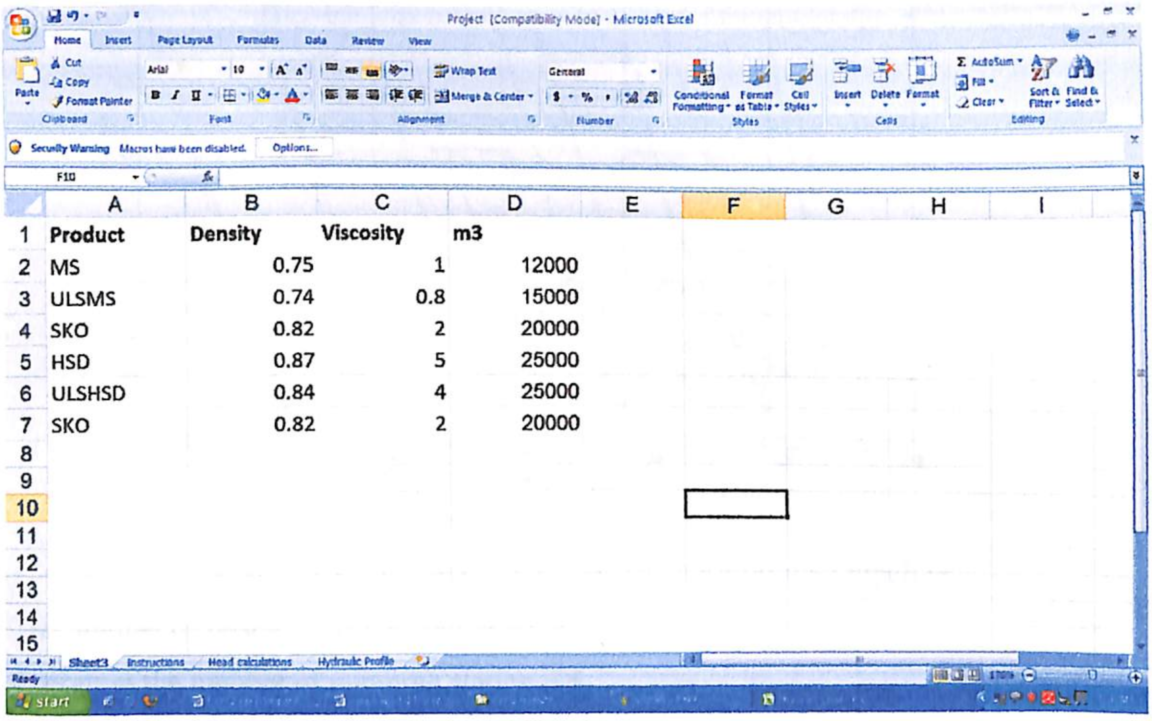
The number of peaks indicates the pumping stations.

Therefore the number of pumping station = 10

Case 2: Finding the optimum pumping station for different pipe diameter for the same sequence of batches.

The sequence of batches are mentioned in excel worksheet their physical properties like density and viscosity should be mentioned.

The sequencing data is shown in below figure



Product	Density	Viscosity	m3
MS	0.75	1	12000
ULSMS	0.74	0.8	15000
SKO	0.82	2	20000
HSD	0.87	5	25000
ULSHSD	0.84	4	25000
SKO	0.82	2	20000

Figure 5.3: The sequencing data

For 18 inch diameter pipeline.

```
MMTPA = 6;
A_Rghs = 0.00015;
FS = 0.72;
MAOP = 0.9;
StatBack_m = 60;
```

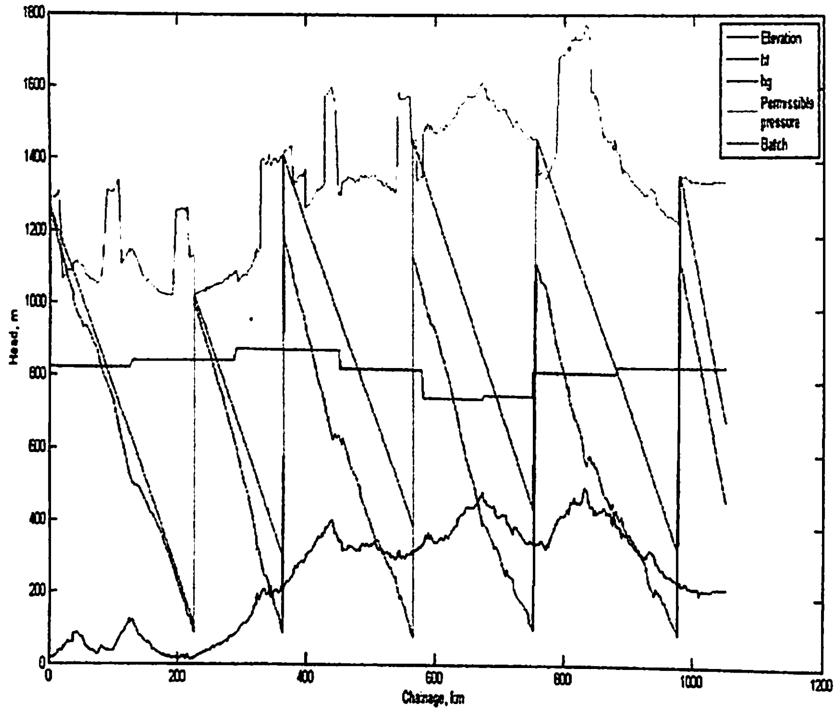


Figure 5.4: Pumping station for 18" multiproduct pipeline

The number of peaks indicates the pumping stations.

Therefore the number of pumping station = 5

For 16 inch diameter pipeline.

```
MMTPA = 6;
A_Rghs = 0.00015;
FS = 0.72;
MAOP = 0.9;
StatBack_m = 60;
```

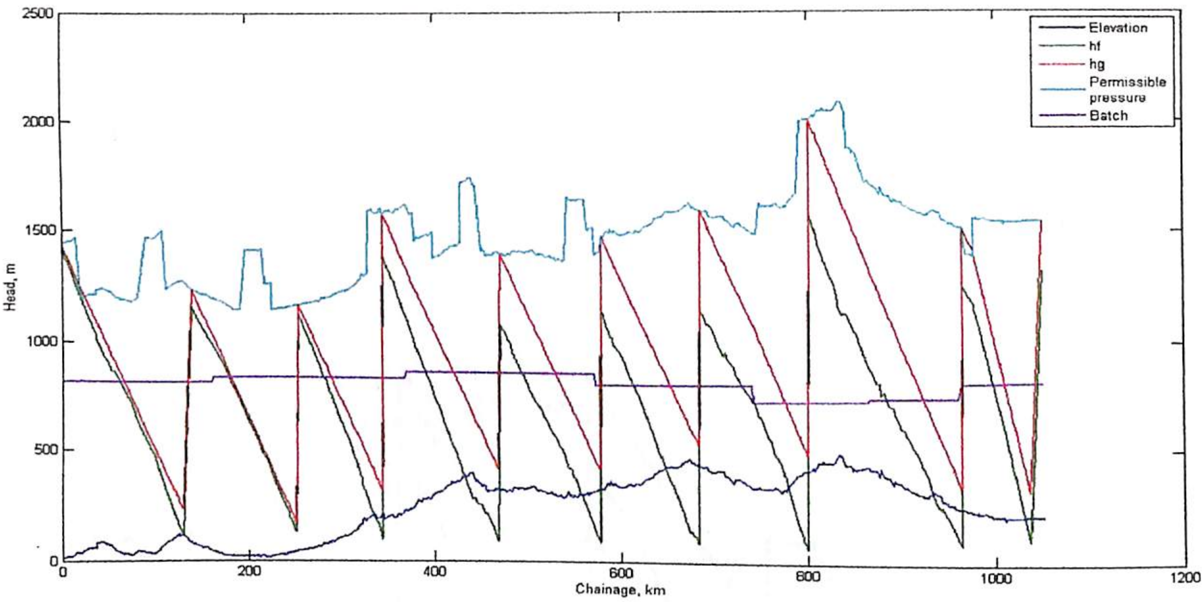


Figure 5.5: Pumping station for 16" multiproduct pipeline

The number of peaks indicates the pumping stations.

Therefore the number of pumping station = 9

Case 3: Finding the optimum pumping station for different throughput.

For Throughput=6 MMTPA

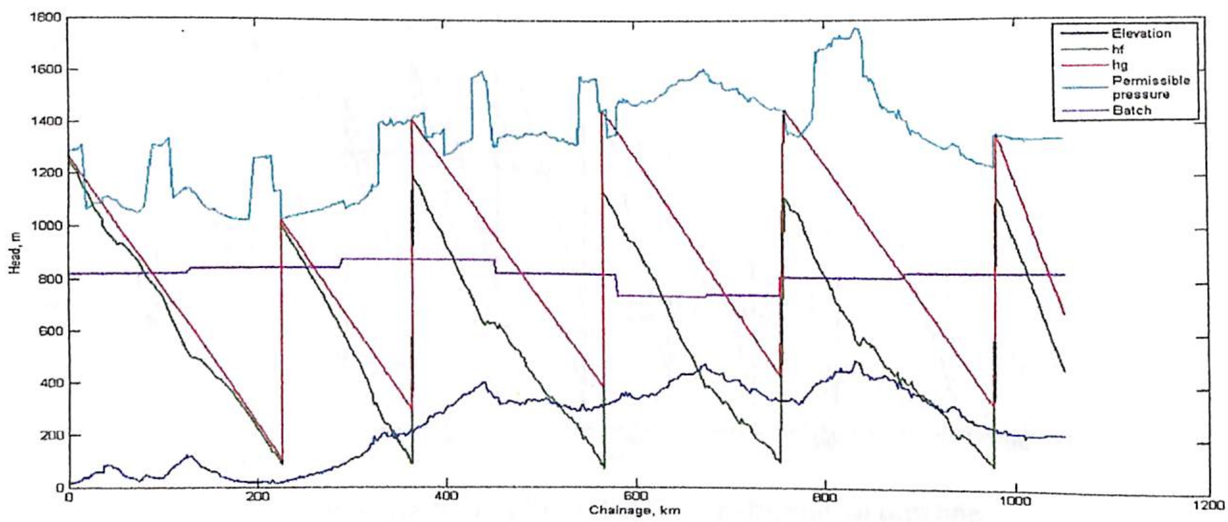


Figure 5.6: Pumping station for 6 MMTPA multiproduct pipeline

The number of peaks indicates the pumping stations.

Therefore the number of pumping station = 5

For Throughput=9 MMTPA

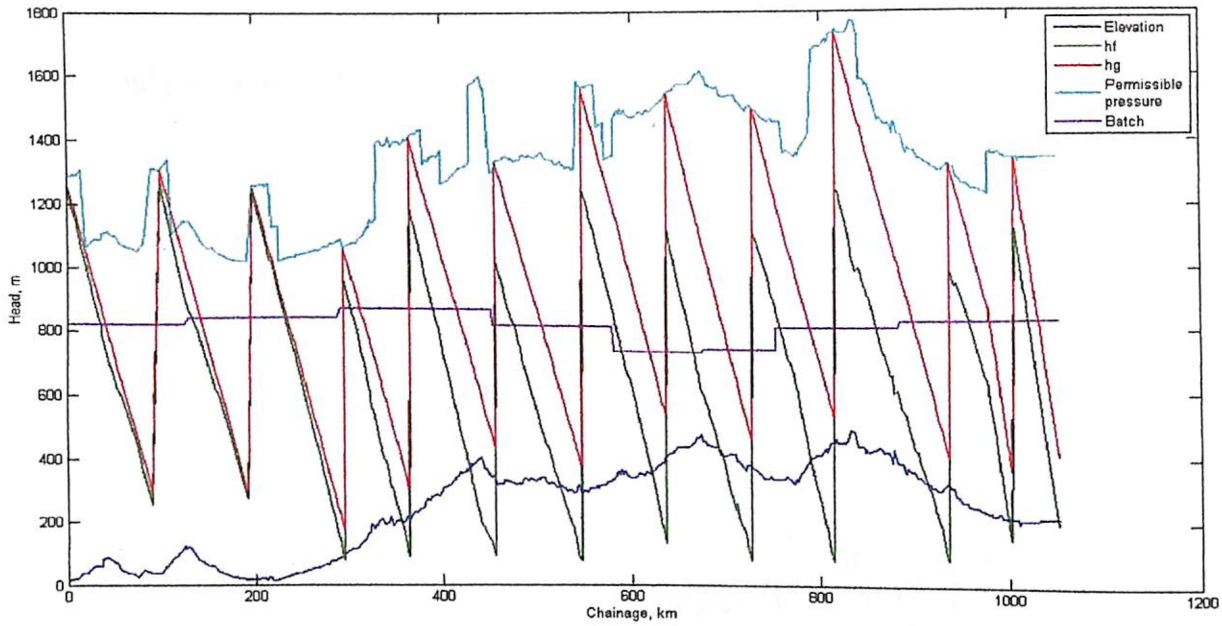


Figure 5.7: Pumping station for 9MMTPA multiproduct pipeline

The number of peaks indicates the pumping stations.

Therefore the number of pumping station = 11

Case 4: Finding the interface length for different throughput considering the same sequence of batches.

For Throughput=6 MMTPA

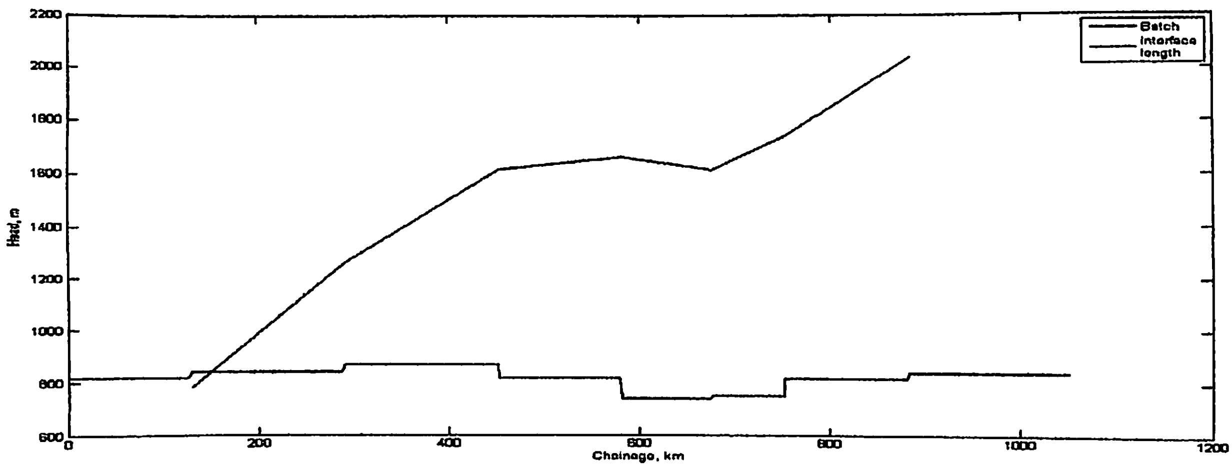


Figure 5.8: Interface length for 6 MMTPA multiproduct pipeline

For Throughput=9 MMTPA

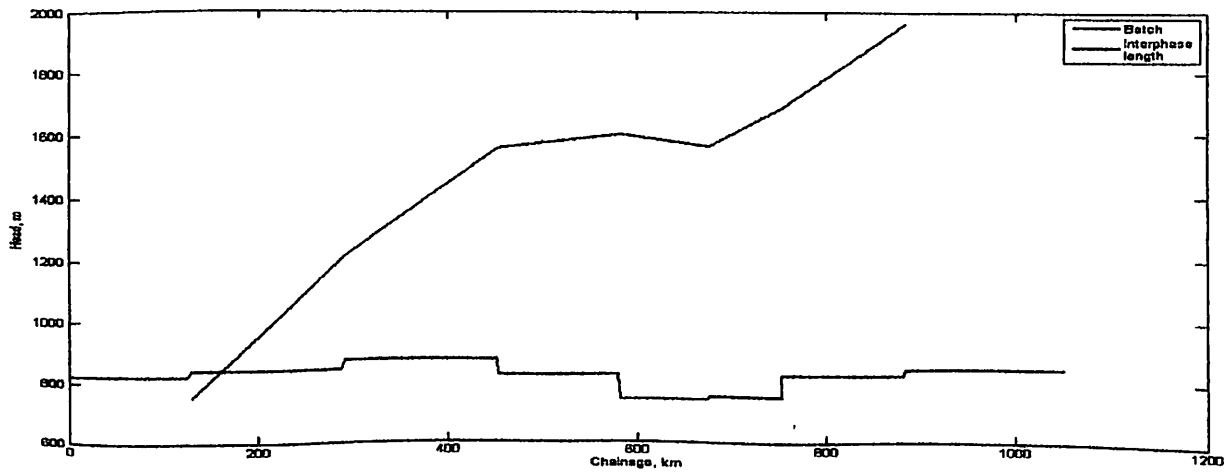
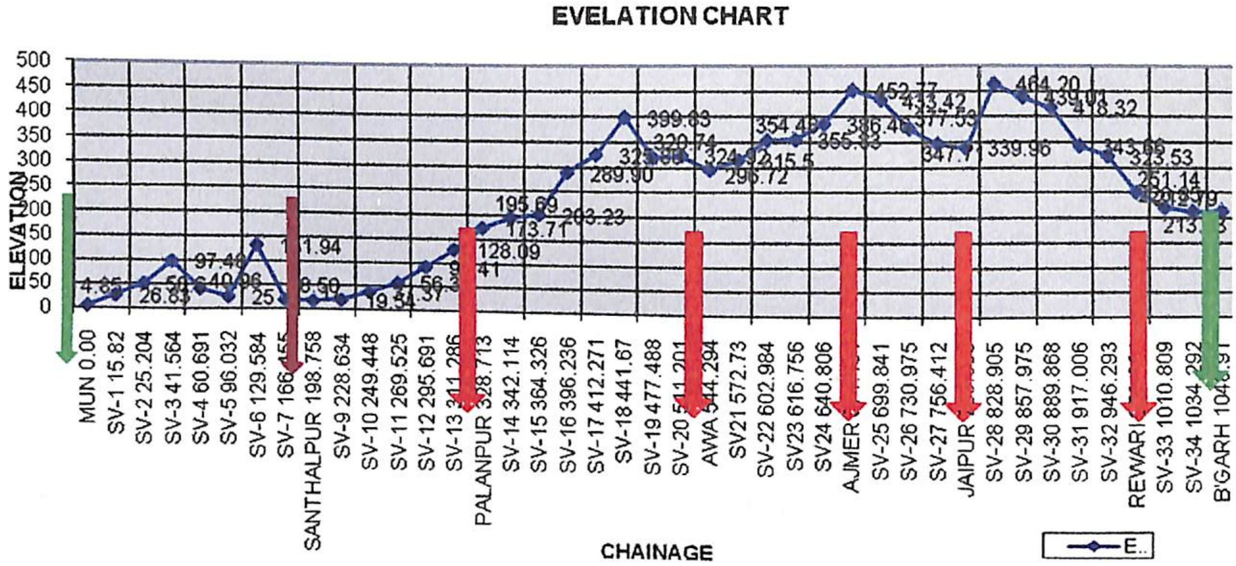


Figure 5.9: Interface length for 9 MMTPA multiproduct pipeline

5.1 Summary of Result:

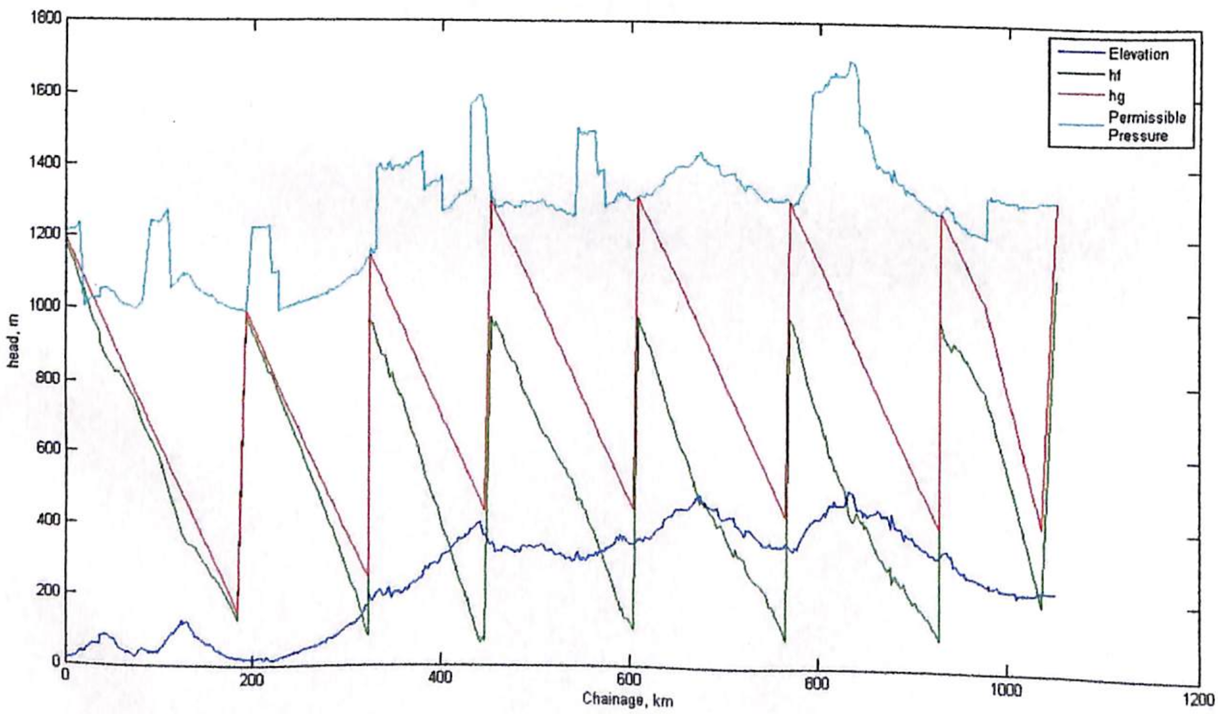
Variable	No. of Pumping Station
Single Product	
16'' Diameter	10
18'' Diameter	06
Multi Product	
16'' Diameter,	08
18'' Diameter	05
6 MMTPA, 18'' Diameter	05
9 MMTPA, 18'' Diameter	11

5.2 Comparison of MDPL pumping station v/s Simulated Result



Number intermediate pumping stations = 06

MODEL



Number intermediate pumping stations = 06

CHAPTER 6

6. CONCLUSION AND RECOMMENDATIONS

The program is created to find the optimum pumping station and hydraulic profile. It computes the interface length along the pipeline and tracks the batch according to the density.

The result shows the reasonable outcome in which the number of pumping stations increases as the throughput increase and when pipe diameter reduced.

This can be used for crude oil pipeline when scheduling is not done. It was recommended that the optimum pumping station is found for the worst condition considering heavy fluid like diesel.

As the extension of this work, horsepower necessary for the pipeline can be calculated.

Reference

1. ASME B31.4, Liquid Transmission and distribution, the American society for mechanical engineers, 1999
2. E. Shashi Menon, Liquid pipeline hydraulics, Taylor & Francis Group, 2005
3. Henry Liu, Pipeline Engineering, Lewis publishers, 2003
4. Drago Matko, Saˇso Blaˇziˇc, and Gerhard Geiger, Simulation of Multi-product Pipelines, International Journal of Mathematical Models and Methods in Applied Sciences, Issue 2, Volume 1, 2007

APPENDIX

Laminar Flow and Turbulent Flow of Fluids

Resistance to flow in a pipe

When a fluid flows through a pipe the internal roughness (e) of the pipe wall can create local eddy currents within the fluid adding a resistance to flow of the fluid. Pipes with smooth walls such as glass, copper, brass and polyethylene have only a small effect on the frictional resistance. Pipes with less smooth walls such as concrete, cast iron and steel will create larger eddy currents which will sometimes have a significant effect on the frictional resistance.

The velocity profile in a pipe will show that the fluid at the centre of the stream will move more quickly than the fluid towards the edge of the stream. Therefore friction will occur between layers within the fluid.

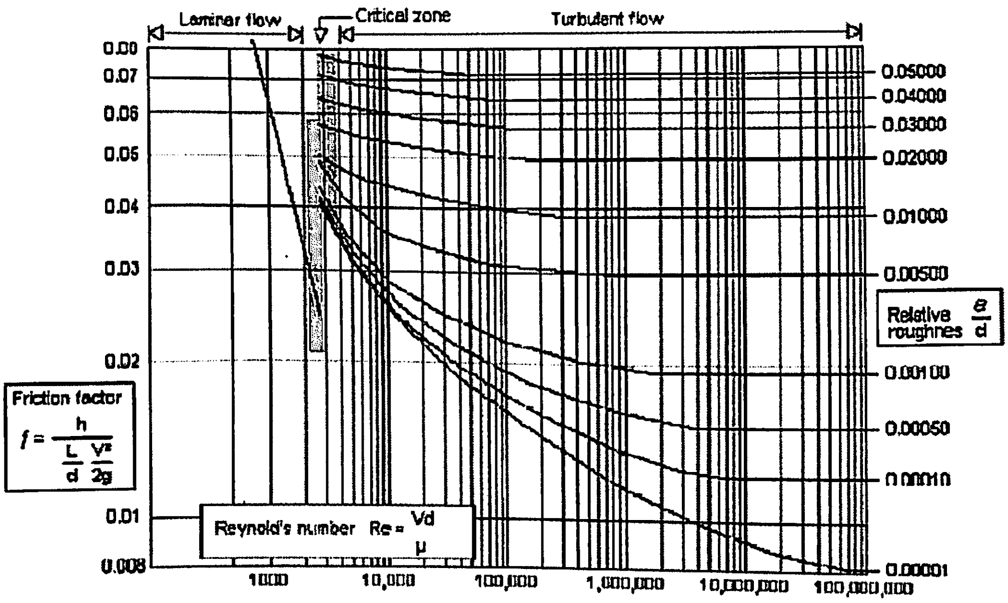
Fluids with a high viscosity will flow more slowly and will generally not support eddy currents and therefore the internal roughness of the pipe will have no effect on the frictional resistance. This condition is known as laminar flow.

Laminar Flow

Where the Reynolds number is less than 2300 laminar flow will occur and the resistance to flow will be independent of the pipe wall roughness. The friction factor for laminar flow can be calculated from 64 / Re.

Turbulent Flow

Turbulent flow occurs when the Reynolds number exceeds 4000.



Eddy currents are present within the flow and the ratio of the internal roughness of the pipe to the internal diameter of the pipe needs to be considered to be able to determine the friction factor. In large diameter pipes the overall effect of the eddy currents is less significant. In small diameter pipes the internal roughness can have a major influence on the friction factor.

The 'relative roughness' of the pipe and the Reynolds number can be used to plot the friction factor on a friction factor chart.

The friction factor can be used with the **Darcy-Weisbach formula** to calculate the frictional resistance in the pipe.

Between the Laminar and Turbulent flow conditions (Re 2300 to Re 4000) the flow condition is known as critical. The flow is neither wholly laminar nor wholly turbulent. It may be considered as a combination of the two flow conditions.

Internal roughness (e) of common pipe materials.

Cast iron (Asphalt dipped)	0.1220 mm	0.004800"
Cast iron	0.4000 mm	0.001575"
Concrete	0.3000 mm	0.011811"

Copper	0.0015 mm	0.000059”
PVC	0.0050 mm	0.000197”
Steel	0.0450 mm	0.001811”
Steel (Galvanized)	0.1500 mm	0.005906”