Design and optimization of the cost of a crude oil pipeline by Genetic Algorithm technique

A Project Report

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CANDIDATE'S DECLARATION

I/We hereby declare that this submission is our own and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other Degree or Diploma of the University or other Institute of Higher learning, except where due acknowledgement has been made in the text.

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CERTIFICATE

This is to certify that the thesis titled **Design and optimization of the cost of a crude oil pipeline by Genetic Algorithm technique** submitted by AKSHAY DEEP KANDA (R900213005), RISHI BRAHMA (R900213035), SHRIYA KOHLI (R900213042) and SAHIL KHURANA (R900213037), to the University of Petroleum and Energy Studies, for the award of the degree of **BACHELOR OF TECHNOLOGY** in Chemical Engineering with Specialization in Refining and Petrochemicals is a bonafide record of project work carried out by them under my supervision and guidance. The content of the thesis, in full or parts have not been submitted to any other Institute or University for the award of any other degree or diploma.

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NOMENCLATURE

Symbol	Description	Units
Q	Volumetric Flow rate	m^3/hr
D	Internal Diameter	in.
VL	Line Volume Fill	m^3/hr
Re	Reynolds Number	-
f	Friction Factor	-
e	Absolute Roughness	mm
P(km)	Pressure loss due to friction	kPa/km
P_e	Pressure loss due to elevation	kPa
T	Pipe Wall Thickness	in.
PMC	Pipe Material Cost	$
S	Specific Gravity	-
V	Kinematic Viscosity	cSt
F	Transmission factor	-
LFC	Line Fill Cost	₹
PSC	Pump Station Cost	₹
OPC	Operating Cost	₹
PC	Pipe Material Cost	₹

ABSTRACT

The optimization of the design of a pipeline involves a number of variables, which include pipe diameter, pressure, temperature, line length, required inlet and delivery pressures and delivery quantity. The cost elements include the physical parameters: Cost of material, pipe, cost of fuel and energy, cost of construction, cost of operation, (fuel maintenance; utilization), total life cycle cost, etc.

Each of these parameters influences the overall construction and operating cost in some degree and the selection of one or more will determine the economics of the construction and operation of the system. This is as true for the design of a system from a clean sheet of paper (grass roots) as it is for the development and upgrading of an existing system, the only real difference between these two examples is the extent to which some of the variables are already fixed.

The program we shall use for optimization is the Genetic Algorithm Technique. Genetic Algorithm (GA) is a powerful technique for solving optimization problems in hydraulic engineering. It is a method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. GA uses the main three operations, the selection, crossover and mutation to produce new generations from the old ones.

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Chapter 1
Introduction

In most of the world, a crisis related to energy is going-on in the present scenario. Many countries have actively participated in the field of research to control the prevailing crisis. India is also one of the countries which are working in the field of this arena. Many research scholars of India have put their days and nights to eradicate present ongoing problem. This report is also somehow focused on to the current prevailing problem. The Report talks about the techniques of **design and optimization of the cost of a crude oil pipeline.**

Crude oil transmission pipelines convey crude oil from production locations, such as conventional crude oil deposits and shale formations containing tight oil, to processing locations, such as refineries. From there, specialty pipelines carry the refined products to customers, including manufacturers that use refined products as an intermediate input, and final consumers.

The network of pipeline system taken into consideration here is the **Petronet MHB Limited Pipeline** which is presently operating between **Mangalore**, **Hassan** & **Bangalore** which is to be 362.373 km in the length and the value of inner and outer diameter of pipeline is 20” and 24” respectively. That pipeline in future may extend up-to **Bommidi**, so if the pipeline would extend from Bangalore to **Bommidi**, the additional length would be 128.395 km. This report will reveal size of appropriate diameter to be used for the best optimization and minimization in terms of cost.

Optimization (1)is maximizing or minimizing some function relative to some set, often representing a range of choices available in a certain situation. The function allows comparison of the different choices for determining which might be “best.” These are basically of two types:-

Linear Programming: A linear programming problem is characterized, as the name implies, by linear functions of the unknowns; the objective is linear in the unknowns, and the constraints are linear equalities or linear inequalities.

Non-Linear Programming: Nonlinear programming (NP) involves minimizing or maximizing a nonlinear objective function subject to bound constraints, linear constraints, or nonlinear constraints, where the constraints can be inequalities or equalities.

Our aim is to minimize the cost of the **Petronet MHB Limited Pipeline** using the Genetic algorithm in MATLAB (2).

We use MATLAB because it has several advantages over other methods or languages:

1. Its basic data element is the matrix. A simple integer is considered a matrix of one row and one column. Several mathematical operations that work on arrays or matrices are built-in to the MATLAB environment.
2. Vectorized operations. Adding two arrays together needs only one command, instead of a 'for' or 'while' loop.
3. The graphical output is optimized for interaction. One can plot your data very easily, and then change colors, sizes, scales, etc. by using the graphical interactive tools.
4. MATLAB's functionality can be greatly expanded by the addition of toolboxes. These are sets of specific functions that provided more specialized functionality.

The minimization of total cost of pipeline would depend on the mentioned factors i.e.

a) **Pipe Material Cost**
b) **Operation Cost of Pumps**,
c) **Pump Station Cost**
d) **Line fill cost**.

Optimization will be done by analyzing two parameters -:

i. **Variation of Diameter of pipeline**
ii. **Pressure profile along the pipeline.**

The optimization tool is used to optimize the overall cost of pipeline which includes pipe material Cost, Operating Cost, Pump Station Cost & fuel cost inside the pipeline.

A **Genetic Algorithm (GA)** is a search procedure based on natural selection and on the genetic population mechanisms, as well as the biological processes of survival and adaptation. The GA object of this project is specifically designed to optimize the hydraulic systems, where the operators are applied to two parents selected from the population elements, through a certain scheme, which in turn generates a new individual that replaces an existing one, through a replacement strategy.

Since the cost of the pipeline has to be optimized, we take it as the objective function (i.e., the function that it is desired to maximize or minimize) subjected to diameter and pressure constraints.

The GA operates on a simulation model of pressured flow lines developed by Narváez (1999), which allows for sizing hydraulic systems made up of pipelines, consumer and supply nodes, tanks, centrifugal and positive displacement pumps, nozzles, control valves, processing equipment and accessories, and on the operational costs stated by Narváez and Galeano (2002), which takes into consideration, among other aspects, the costs of installation, maintenance and operation, including the pumping equipment.

Chapter 2

Literature Review

For an oil or gas pipeline, cost optimization is as important as optimization of the characteristic parameters. In this age of high competition in the several industries, it becomes necessary to cut down capital and operating costs as much as possible. Specifically in case of Chemical industries, the main focus is on reducing the processing costs, which include heating, cooling, transfer of various streams involved in any operational unit. The oil/gas transmission network, which forms a considerable fraction of the operating cost, is also one of the focus areas. Broadly, a crude oil pipeline system includes source of oil, delivery sites with the pipeline segments and pumping stations used to achieve desired pressure at the delivery site.

As the design of an efficient and economical oil/gas transmission network involves a lot of design parameters which directly/indirectly affect the capital and operating costs, this topic deserves special attention.

Over the years, various aspects of the problem have been addressed:

1. Goldberg and Kuo [1987] applied the traditional GA to the optimization of the operation of a steady state serial gas pipeline consisting of 10 pipes and 10 compressor stations each containing 4 pumps in series. The objective in that study was to minimize power while supplying a specified flow and maintaining allowable pressures.

2. Davidson and Goulter [1994] used GAs to optimize the layout of a branched rectilinear network, such as a rural natural gas or water distribution system. The optimal layout in that case was assumed to be the one of least length. The layout solutions were represented by blocks of binary code, and new GA operators of recombination and perturbation were introduced to reduce the number of infeasible solutions created by the traditional GA operators of crossover and mutation.
3. Walters and Lohbeck [1993] studied the case of pipe networks with one demand pattern and no constraints on minimum pipe diameter. They showed that GA effectively converges to near optimal branched network layouts, as selected from a directed base graph which defines a set of possible layouts. In that study the nodal connectivity within the trial branched network solution was represented by the string of code. Alternative GA coding schemes, including a binary representation and an integer representation, were also investigated in that study.
4. Walters and Cembrowicz 1993[53] extended these concepts using linear programming for the optimal selection of pipe sizes for branched pipe networks generated by GA. The combination of Gas, graph theory, and linear programming was found by Walters and Cembrowicz 1993[53] to be the basis for an effective search for near optimal branched pipe network design.

Genetic algorithms (GAs) are receiving increasing application in a variety of search and optimization problems. These efforts have been greatly aided by the existence of theory that explains what GAs are processing and how they are processing it.

Genetic algorithms are different from the normal search methods encountered in engineering optimization in the following ways:

1. GA's work with a coding of the parameter set, not the parameters themselves.
2. GA's search from a population of points, not a single point.
3. GA's use probabilistic transition rules, not deterministic transition rules. Genetic algorithms require the natural parameter set of the optimization problem to be coded as a finite length string.

Optimization of a crude oil pipeline using Genetic Algorithm is subject to various variables and constraints.

The variables we consider are:

Diameter:

Diameter is the important variable that decides the cost of pipeline. So an optimal diameter should be chosen to minimize the cost.

Pressure:

Based on pressure product delivery can be achieved by choosing an optimal diameter. So pressure is an important variable in deciding the diameter to be chosen.

2.1 Cost Estimation

E. Shashi Menon (3) suggests the following criteria to calculate Pipeline network costs, including Capital costs and Operating costs.

2.1.1 Capital Costs

i. Pipeline
ii. Pump Station
iii. Tanks and manifold piping
iv. Valves, fittings
v. Meter station
vi. SCADA and telecommunication
vii. Engineering and Construction management
viii. Environmental and permitting

2.1.2 Operating Costs

i. Pump station equipment maintenance costs (equipment overhaul, repairs, etc.)
ii. Pipeline maintenance cost including line rider, aerial patrol, pipe replacements, relocations, etc.
iii. SCADA and telecommunication costs
iv. Valve and meter station maintenance
v. Tank farm operation and maintenance
vi. Utility costs: water, natural gas, etc.
vii. Ongoing environmental and permitting costs
viii. Right-of-way lease costs
ix. Rentals and lease costs
x. General and administrative costs including payroll

a) Pipeline Costs:

Pipe material cost (4) = $10.68(D-t)t \times 2.64 \times L \times$cost per ton

PMC $=$ 28.1952 L(D-t)t(Cpt)

Pipe Labor cost= $15,000x 1600 x 100= $24 million

b) Pump Station:

Installed cost of $1500 per HP

For a 5000 HP station

$1500 x 5000= $ 7.5 million

c) Tanks and Manifold:

Tank costs in $/bbl

Increase in Total tankage cost by a factor of 10-20%

d) Valves and Fittings:

It can be estimated as a percentage of total pipe cost.

e) Meter Station:

It is estimated as a lump sum fixed price for a complete site.

A 10in. meter station with valves, meter and piping instrumentation cost = $25,000

f) SCADA and Telecommunication:

SCADA system includes facilities for monitoring, operation and control of the pipeline from a central control center.

Estimated cost 2% - 5% of the total project cost.

2.2 Background

2.2.1 Pipelines

There are two general types of energy pipelines (5) – **liquid petroleum pipelines** and **natural gas pipelines**.

Within the liquid petroleum pipeline network there are crude oil lines, refined product lines, highly volatile liquids (HVL) lines, and carbon dioxide lines (CO_2). Crude oil is also subdivided in to 'Gathering Lines' and ’Transmission Lines”.

First, gathering lines are very small pipelines usually from 2 to 8 inches in diameter in the areas of the country where crude oil is found deep within the earth.

The larger cross-country crude oil transmission pipelines or trunk lines bring crude oil from producing areas to refineries.

The next group of liquid petroleum pipelines is one that carries refined petroleum products – gasoline, jet fuel, home heating oil and diesel fuel. These refined product pipelines vary in size from relatively small, 8 to 12 inch diameter lines, to much larger ones that go up to 42 inches in diameter. There are approximately 63,000 miles of refined products pipelines nationwide. They are found in almost every state in the U.S. These pipelines deliver petroleum products to large fuel terminals with storage tanks that are then loaded into tanker trucks. Trucks cover the last few miles to make local deliveries to gas stations and homes. Major industries, airports and electrical power generation plants are supplied directly by pipeline.

Highly volatile liquid (HVL) lines and carbon dioxide (CO_2) lines are also a part of the liquid petroleum pipeline network. These liquids turn to gas once exposed to the atmosphere. They include ethane, butane and propane.

Steel pipe is used in most pipelines transporting hydrocarbons. It is manufactured according to the specifications of the American Petroleum Institute (API 1994, 2000), the American Society of Mechanical Engineers (ASME), the American National Standards Institute (ANSI), and the American Society of Testing Materials (ASTM).

Various grades of line pipe are specified, based on yield strength.4 Grade A line pipe has a minimum yield strength of 30,000 pounds per square inch (psi), with Grade B having a minimum yield strength of 35,000 psi. Other grade categories may indicate special fabrication methods. For example, Grade X42 indicates a pipe made of steel with 42,000 psi minimum yield strength; X60 pipe has minimum yield strength of 60,000 psi, etc. Newer pipe grades X70 and X805 are available, but are typically used in offshore or high-pressure gas pipelines for large-diameter or high-pressure applications.

Line pipe is manufactured as either seamless or welded. These designations refer to how each length, or joint, of pipe is manufactured, not how the joints are connected in the field to form a continuous pipeline. Seamless steel pipe is made without a longitudinal weld by hot working lengths of steel to produce pipe of the desired size and properties. Welded pipe is made using several manufacturing processes. The two types of pipe differ both by the number of longitudinal weld seams in the pipe and the type of welding equipment used. Welded pipe is the most common pipe used in petroleum pipeline service. The individual lengths of pipe are normally joined by welding sections of pipe together (20 or more feet in length). Pipe made of materials other than steel, including fiberglass, various plastics, and cement asbestos, has been used for special applications involving corrosive liquids, such as saltwater disposal or the transport of highly corrosive crude oils.

2.2.2 Piping types

2.2.2.1 Flowlines

Flowlines are used as part of a crude gathering system in production areas to move produced oil from individual wells to a central point in the field for treating and storage. Flowlines are generally small-diameter pipelines operating at relatively low pressure. Typical in the United States flowlines are between 2 and 4 inches in diameters. The size required varies according to the capacity of the well being served, the length of the line, and the pressure available at the producing well to force the oil through the line. Some wells are not pressurized and require pumping to collection systems. Flowlines typically operate at pressures below 100 psi.

Flowlines are normally made of steel, although various types of plastic have been used in a limited number of applications. Pipelines used for oil flowlines typically operate at low pressures, and therefore could be made of materials other than steel. Flowline pipe wall thicknesses of 0.216 inch for a 3-inch-diameter pipe are not uncommon, corresponding to a weight of 7.58 lb/linear foot for a 3-inch-diameter pipe.

2.2.2.2 Crude Trunk Lines

Crude is moved from central storage facilities over long-distance trunk lines to refineries or other storage facilities. Crude trunk lines operate at higher pressures than flowlines and could vary in size from 6 inches in diameter to as large as 4 feet, as in the TAPS in Alaska.

2.2.2.3 Product Pipelines

Pipelines carrying products that are liquid at ambient temperatures and pressures do not have to operate at excessive pressures in order to maintain the product in a liquid state. However, liquids that vaporize at ambient temperatures must be shipped at higher pressures. For instance, ethane pipelines can operate at pressures up to 1,440 psi. Product pipelines usually are 12 to 24 inches in diameter, but can be as large as 40 inches in the case of the Colonial Pipeline, which carries gasoline and distillate from the Gulf Coast to northeast markets. Product pipelines are unique, since they are typically used to transport a variety of petroleum distillate products concurrently in a batch-wise manner. The petroleum products jointly carried in the same pipeline are always chemically compatible with each other, but may differ in physical properties such as density. Some intermixing occurs at the interface of two products sequentially introduced into the pipeline. Operating methods allow for minimizing the interface between products. Regardless of how the commodities are separated while in the pipeline, any mixtures of two commodities are segregated from the rest of the flow at terminals and handled by downgrading (i.e. marketing them as product mixtures of lower quality than the original individual products) or by recovering and fractionating each mixture into the two original petroleum products. In some instances, a sphere or a specially designed pig can be inserted between batches to reduce the amount of mixing.

2.2.2.4 Pumping Stations

As with storage tanks, pump stations require an infrastructure of their own. They require waste handling, such as nearby sewer facilities or holding facilities for transfer in batches to an off-site waste-handling facility. Also, the handling and injection of additives, such as for viscosity reduction, often occurs at pump stations. Pumps are typically driven by electric motors; however, engines operating on a variety of fuels (but typically obtained from sources other than the pipeline itself) can also be used to drive the pumps. Depending on location, power may be an issue. In the event of power failures or other significant upset conditions, pump stations are typically equipped with sufficient emergency power generation to support monitoring and control systems to accomplish an immediate safe shutdown.

2.2.2.5 Metering Stations

Although primarily utilized to measure the volume, quality, and consistency of product for billing purposes and delivery receipts, storage tank monitoring and product metering can be used with line pressure monitors to verify that pipeline integrity has not been compromised. Any discrepancy could indicate some sort of system leak. Typically there is some “shrinkage” in volume when products are transferred from pipeline to tanks to pipeline. Systems and processes are in place to determine when the shrinkage observed is outside expected values. An expanded discussion on how SCADA systems are used to monitor and control the operations of a pipeline.

2.2.3 Optimization

Optimization, also referred to as mathematical programming, formally encompasses several stages described by OR, namely (a) understanding and formulation of the problem; (b) design, implementation and evaluation of solution methodologies; and (c) validation and interpretation of the outcome. It can be considered as a scientific research field that creates a narrow link between computer science and applied mathematics, i.e. its major focus is placed on the study of the theory of mathematical modeling and algorithmic design.

An **optimization** problem in its simplest form refers to the theory of minimizing or maximizing an objective function, i.e., a real-valued function of several variables. The domain of the objective may be subject to a wide range of (equality or inequality) constraints, which define the set of feasible choices. Thus, an optimization technique solves the problem by systematically selecting a solution that is within the feasible set and improves the objective.

Table 2.1 Main Components of Optimization Model

Objective Function	Quantitative component of the problem that we want to maximize or minimize.
Decision Variable	Elements of the problem that can be manipulated (adjusted) by the optimizer to achieve a given objective.
Constraints	Equalize or in equalize relating variables and parameters of the problem that have to be satisfied while looking for the best performance in the objective (Note that there may exist implicit or explicit constraints).
Parameters	Input data that provide the values required, e.g., the coefficient of the decision variables or the right hand side of the constraints.

2.2.3.1 Types of optimization model

There are basically two types of optimization models:-

i. **Linear Programming Model**

ii. **Non Linear Programming Model**

Linear Programming (6) is a very simple model. The components of an LP model share a specific characteristic, i.e., both objective function and constraints are linear. The canonical form of an LP model can be put in the following way:

$$\textbf{(}\boldsymbol{LP}\textbf{): min } \boldsymbol{f(x)} = \boldsymbol{\{cT\ x|Ax \geq b,\ x \geq 0\}}$$

where f: Rn → R is the real-valued objective function, i.e., the mathematical expression indicating what it needs to be improved (here in terms of minimizing its value); R denotes the set of real numbers; $x = (x_1, \cdots, x_n)T$ is a nonnegative real vector representing the decision variables of the problem, i.e., the components that must be manipulated to achieve the objective f; c and b are real vectors of known coefficients; and A is a known matrix of coefficients.

Several assumptions must be satisfied when using a linear programming model. These are:

Proportionality Assumption: A problem can be phrased as a linear program only if the contribution to the objective function and the left-hand-side of each constraint by each decision variable ($x_1, \ldots, x_n$) is proportional to the value of the decision variable.

Additivity Assumption: A problem can be phrased as a linear programming problem only if the contribution to the objective function and the left-hand-side of each constraint by any decision variable x_i (i = 1, n) is completely independent of any other decision variable x_j (j 6= i) and additive.

Divisibility Assumption: A problem can be phrased as a linear programming problem only if the quantities represented by each decision variable are infinitely divisible (i.e., fractional answers make sense).

Certainty Assumption: A problem can be phrased as a linear programming problem only if the coefficients in the objective function and constraints are known with certainty.

When certain applications require integrality of variables, or nonlinearities in relationships, or uncertainty in the data, LP formulations are not suitable and other more sophisticated models may be required. Nonetheless, these other models as well as their solution methodologies are heavily influenced by the structure, theory, and algorithms aligned with LP.

A model is **Non Linear** (7)when the objective function, the constraints or both contain a nonlinear term.

For a program:

Minimize **f (x)**

subject to **g_j(x) <= 0** for j = I... m

h_i(x) = 0 for i = I... t

x belongs to **X**.

The function **f** is usually called the **objective function**, or the criterion function. Each of the constraints g(x) <= 0 for i = 1 ,..., m is called an **inequality constraint**, and each of the constraints h,(x) = 0 for i = 1, ...,t is called an **equality constraint**. The set X might typically include lower and upper bounds on the variables, which even if implied by the other constraints can play a useful role in some algorithms. Alternatively, this set might represent some specially structured constraints that are highlighted to be exploited by the optimization routine, or it might represent certain regional containment or other complicating constraints that are to be handled separately via a special mechanism. A **vector** x belongs to X satisfying all the constraints is called a **feasible solution** to the problem. The collection of all such solutions forms the **feasible region**. The nonlinear programming problem, then, is to find a feasible point X such that f (x) >= f (X) for each feasible point x. Such a point is called an **optimal solution**, or simply a solution, to the problem. If more than one optimum exists, they are referred to collectively as **alternative optimal solutions.**

2.2.4 Our pipeline system

2.2.4.1 Pipeline route map of Bangalore-Bommidi pipeline

The optimal pipeline route is selected based on ground profile, by avoiding industrial areas, forests, institutions, rivers, railway stations, lakes, mountains etc. based on the maps & satellite views obtained from internet. So these routes may not be the authentic routes if geotechnical surveys, soil surveys, etc. are taken, but it may be the approximate route and one of the shortest possible routes.

Three maps considering different outlooks are shown.

Figure 2.1 Route Map

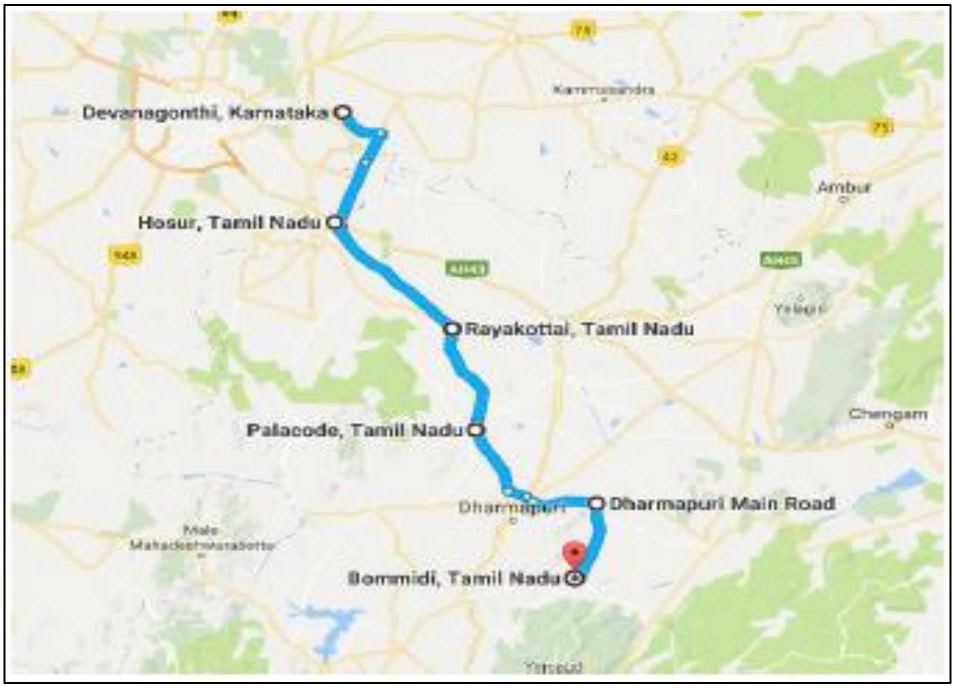


Figure 2.2 Satellite View

Figure 2.3 Satellite View

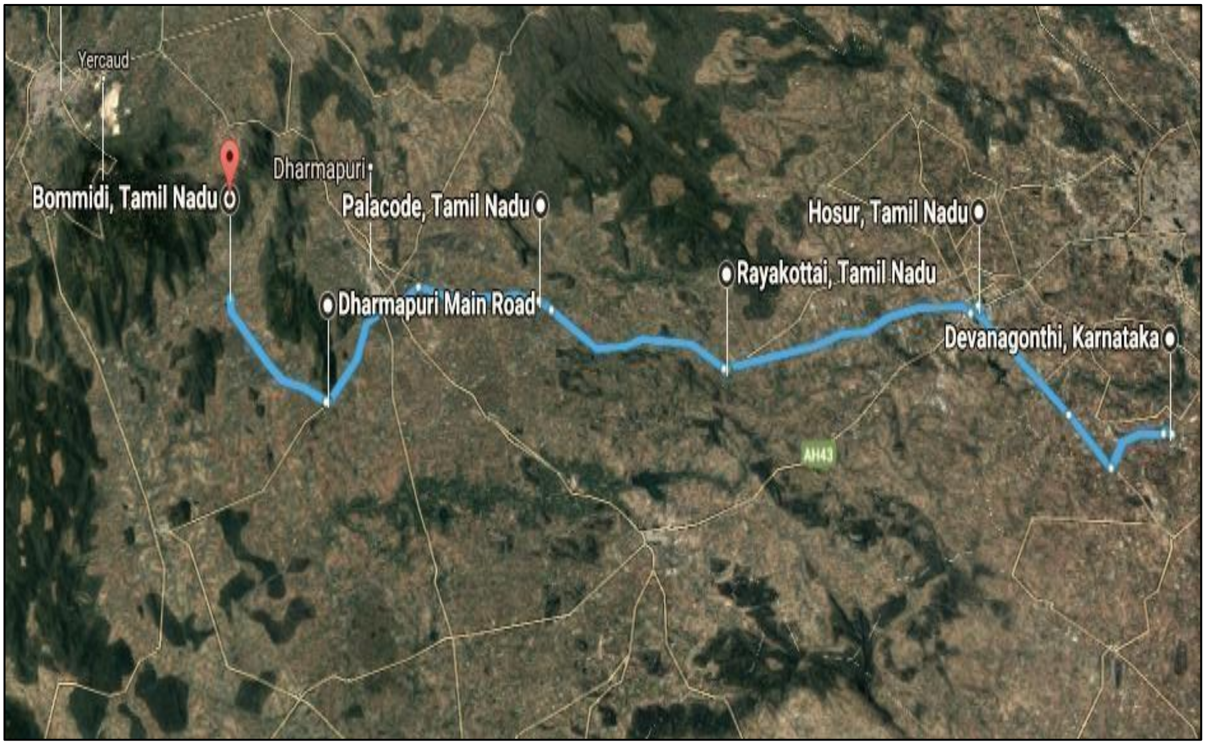


Figure 2.4 Topographical View in 3-D

2.2.4.2 Value of Elevation & Chainage of Operating Pipeline

Petronet MHB Limited Pipeline is **presently operating** between Mangalore, Hassan & Bangalore which is to be 362.373 km in the length and the value of inner and outer diameter of pipeline is 20" and 24" respectively.

Table 2.2 Elevation and Chainage of Pipeline

S.NO.	Station/Location	Elevation(m) above sea level	Chainage(km)
1	Mangalore Station (St.)	4.39	0
2	SV – 1 (Sectionalizing Valve)	9.53	15.497
3	SV – 2	89.12	44.201
4	SV – 3	80.27	66.036
5	Neriya IPS	125	79.5
6	Neriya Saddle	914.61	93.349
7	Hulukamale Halla	769.61	96.771

8	Gutti Saddle	1127.53	98.90
9	SV – 4	924	119.558
10	SV – 5	950	150.854
11	Hassan P&R Station	951	165.5
12	SV – 6	923.82	192.852
13	SV – 7	852.09	220.308
14	SV – 8	784.82	256.379
15	IP Station	808.61	266.757
16	SV – 9	876.87	297.504
17	SV – 10	923.99	327.34
18	Devangonthi St	890.66	362.373

2.2.4.3 Value of Elevation & Chainage of Future Anticipated Pipeline

The pipeline, in future may extend up-to Bommidi therefore, if the pipeline extends from Bangalore to Bommidi then additional length would be 128.395 km and appropriate diameter would be revealed by optimization technique used in this project.

The numerals obtained for Chainage and Elevation are approximate. The elevation values give the height of corresponding locations above sea level, these are not the ideal values through which pipeline is passing. But as of the profile taken from Google maps along the pipeline route, the elevation is gradually decreasing (except a slight rise in few places which is being neglected according to this report).

Table 2.3 Elevation and Chainage of Anticipated Pipeline

S.No.	**Station/Location**	**Elevation above sea level (in meter)**	**Chainage (in km)**
1	Devanagonthi (Tap-off Station)	890	0
2	Chikka Tirupathi	905	11.298
3	Hosur (Tap-off Station)	895	32.692
4	Royakottai (SV Station – 1)	804	57.733
5	Palacode (SV Station – 2 cum intermediate Pigging station)	503	83.476

6	Jakkupatti,Dharmapuri(SV Station – 3)	467	104.193
7	Bommidi(Receiving Terminal)	442	128.395

In the above table, it is shown that the elevation of Chikka Tirupathi is 905 meters, this is the altitude of Chikka Tirupathi above sea level. As the pipeline route shown is not passing through the actual Chikka Tirupathi city, the approximate elevation of the selected route is gradually decreasing. But, we consider the maximum elevation to overcome any undesirable circumstances which may arise while laying the pipeline.

The anticipated pipeline route between Bangalore-Bommidi will have the following stations:-

1. Devanagonthi (Tap-off Station)
2. Hosur (Tap-off Station)
3. Royakottai (SV Station – 1)
4. Palacode (SV Station – 2 cum intermediate Pigging Station)
5. Jakkupatti, Dharmapuri(SV Station – 3)
6. Bommidi (Receiving Terminal)

2.2.4.4 Ground Profile along Pipeline Route

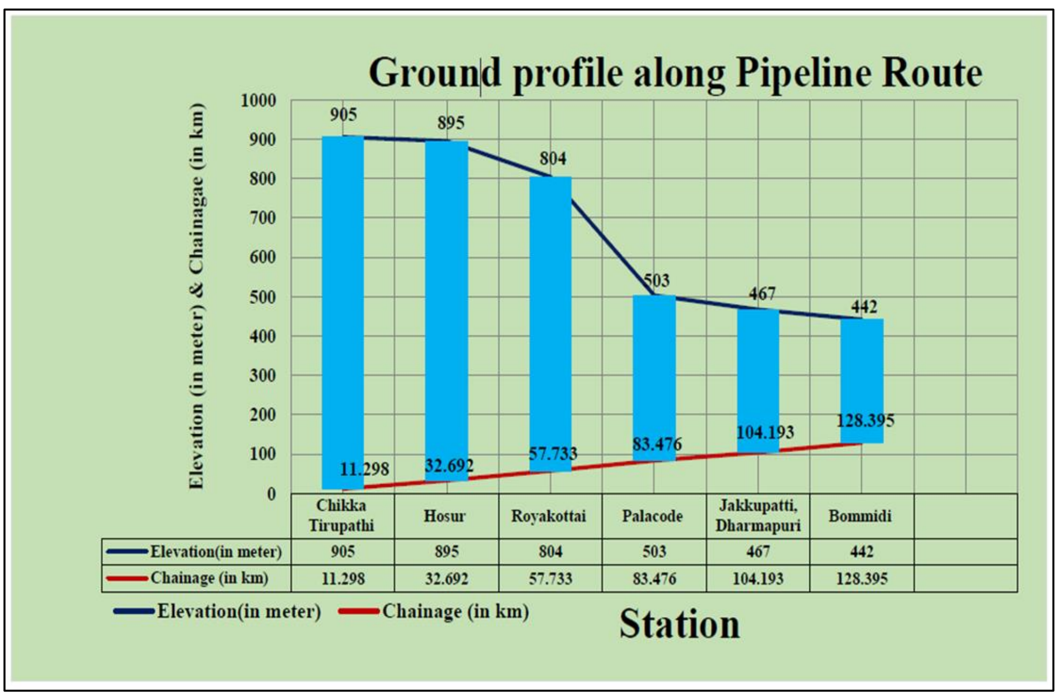


Figure 2.5 Ground Profile along Pipeline Route

2.2.4.5 Pressure at Bangalore Terminal for Existing Pipeline

The following calculation is made according to the outlet pressure from Neriya. From reference it seen that outlet pressure from Neriya is nearly 90 kg/cm^2. According to the outlet pressure from Neriya and by assuming two different flow rates 520 m^3/hr. & 640 m^3/hr. The inlet pressure to Bangalore terminal will be shown in the table.

Pressure at Bangalore (Pressure from Neriya)	3.8620	-6.9278

So it is seen that even if the flow rate is increased to 640 m^3/hr. there will be a stipulation to run Hassan pumps in order to make the product reach Bangalore terminal.

2.2.4.6 Particulars of Pumps at Hassan

Mainline Pumps- 3 pumps (2 running and one standby)

a. Make- M/s IDP UK
b. Flow Capacity of each pumps 328m^3/hr.
c. Differential Head- 445m
d. Motor- 6.6KV Motor
e. Motor Capacity- 470KW
f. Discharge Pressure- 32.7kg/cm^2

The three mainline pumps at Hassan are connected in parallel and are mainly used for increasing the flow rate. So if single pump can increase the pressure up to 38.7kg/cm2, it will be the same case even if all the three pumps are running.

2.2.4.7 Pressure at Bangalore after commissioning Hassan Pumps

Once the Hassan pumps are considered and if the current flow rate of 520m^3/hr. or maximum flow rate of 640m^3/hr. is maintained then the product reaching Bangalore will be at the following pressure.

Pressure at DKN (If Pressure from Hassan= 32.7 kg/cm^2)	19.9713	10.9531

2.2.5 Genetic Algorithm

In computer science and operations research a genetic algorithm (GA) is a met heuristic inspired by the process of selection that belongs to the larger class of evolutionary algorithms (EA). Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection.

It is better than conventional AI in that it is more robust. Unlike older AI systems, they do not break easily even if the inputs changed slightly, or in the presence of reasonable noise. Also, in searching a large state-space, multi-modal state-space, or n-dimensional surface, a genetic algorithm may offer significant benefits over more typical search of optimization techniques.

2.2.5.1 Representation

Each individual in the populations is a parametric representation of a fluid transportation system that uses whole numbers. Each individual is codified with two chains of whole numbers, where the first part represents the diameters of each of the pipes in the network, and the second one is equivalent to the pumping equipment. The chains pick up the values of the set of whole numbers symbolizing the feasible diameters and pumping equipment.

The adjustment of each individual is based on the hydraulic system's evaluation costs and on a penalty function. The penalty function is linked to violation of the restrictions imposed on the hydraulic system and it is defined by the following equation:

$$Adjustment = \frac{1}{\left(Cost \text{ of the network + Penalty}\right)}$$

2.2.5.2 Penalty Function

The penalty function is related to violations to the restrictions of the hydraulic system numbered in the mathematical formulation of the problem. The simulation algorithm ensures compliance with the matter and energy conservation laws for each individual generated and the diameters of the pipes are chosen from a set of possible values in the codification system of each individual.

An important feature of the GA is its ability to adjust the magnitude of each of the penalty coefficients depending on the situation, taking into account that it is better to use a modest penalty in the initial states in order to ensure the adequate sampling in the search space and then, gradually increase the penalty to force optimization convergence to a feasible solution.

The coefficient is the function of the generation number that allows a gradual increase of the penalty term.

$$p = p_{initial} \times \left(\frac{\#\_ \, population}{\#\_ \, generations} \right)^{n}$$

Where $p_{initial}$ and n are constant, so that the penalty coefficient is an increasing monotonous function that guarantees that after final execution of the GA, the penalty coefficient has a value that prevents the best non-feasible solution to be superior to any of the population's feasible solutions.

2.2.5.3 Initializing strategy

In order to initialize the evolution process of the GA, an initial population of solution vector must be generated. The method used is that of random initializing, where the initial population contains random vectors uniformly distributed in the search space, which are formed through designation of numbers randomly selected within a set of possible values for each of the two chains that constitute the individual.

2.2.5.4 Selection strategy

The selection strategy decides on how to choose individuals to convert them into parents of the following generation. The prototype allows the selection of any of the following strategies: by roulette, tournament with roulette, by chance, by expected value, by deterministic sampling, stochastic without reposition, stochastic with reposition and binary tournament.

2.2.5.5 Genetic operators

The genetic operators are used to generate new individuals in the population, by applying to the selected parents any of the selection schemes. These operators may be grouped in two: binary crossover operators which take two parents and produce new individuals based on their chains and individual operators (mutation) which take one individual and produced a perturbed version of it.

2.2.5.6 Crossover operators

The basic operation of a GA is the crossover that combines the merits of several individual to produce a better one. The possible crossover operations for the GA that were implemented in the prototype software are: simple one-point, simple two-points, interspersed, uniform, whole arithmetical, simple arithmetical, based on position, by partial adjustment and by orderly partial adjustment.

2.2.5.7 Mutation operators

This operation introduces new genetic information to the population, with the purpose of exploring new regions and maintaining the diversity. The mutation operators who fit the prototype are: simple uniform, simple non-uniform, by interchange and by proximity.

2.2.5.8 Replacement strategy

The GA allows the overlap between populations in a way similar to De Jong's proposal as stated by Goldberg (1989), who proposes the overlap in an amount estimated by the user. In each generation the GA creates a temporary population of individuals which add themselves to the previous population, soon to eliminate the worse individuals so that the population will be equal size to the original one.

2.2.5.9 Scaling strategies

At the beginning of the evolution it is common to have a small number of extraordinary individuals in the middle of a population of bad individuals, and if the rule of normal selection is used, first they will take the population in few generations, causing the premature convergence of the algorithm. In addition, in the later stages of the evolution, sufficient diversity must be ensured, to obtain optimums closer to a global optimal. The scaling aims at preventing these situations, through the normalization of the adjustment values. The prototype has strategies of linear and exponential scaling.

2.3 Motivation

Transportation of crude oil is a very important aspect of the oil and gas industry and as such, it must be done efficiently. Pipelines have been recognized as the most economic, effective and safest way of transporting oil. A lot of capital is needed, due to cost of pipeline, pumping stations and also in its maintenance. Therefore in order to minimizing cost, optimization of crude oil transportation processes is necessary. With the increasing competition, it has become imperative for industries to improve their technology and optimize various parameters including cost. Over the years, many methods have been applied to optimize both the design and operation of pipeline systems. Some methods, like dynamic - programming, require an unholy mixture of model and optimization procedure which thwarts the construction of modular programs. Other methods such as calculus-based gradient techniques require the construction or approximation of derivative information, and even then these methods can only hope to achieve local optima. As a result, there is still a need for optimization procedures which

i. Are free from a particular program structure,
ii. Require a minimum of auxiliary information to guide the search, and
iii. Have a more global perspective than many of the techniques in common usage.
iv. Genetic Algorithm has these characteristics-:

It is better than conventional Artificial Intelligence (AI) in a way that it is more robust. Unlike older AI systems, they do not break easily even if the inputs are changed slightly, or in the presence of reasonable noise. Also, in searching a large state-space, multi-modal state-space, or n-dimensional surface, a genetic algorithm may offer significant benefits over more typical search of optimization techniques. (Linear programming, heuristic, depth-first, breath-first, and praxis).

The pipeline we are considering is the Petronet MHB Limited Pipeline is presently operating between Mangalore, Hassan & Bangalore. It was incorporated on 31.07.1998 on common carrier principle to provide petroleum product transportation facility from Mangalore Refinery at Mangalore to the Oil Marketing Company Terminals at Hassan & Devangonthi (Bangalore).

PMHBL pipeline was envisaged to transport the petroleum products such as MS commonly known as petrol, HSD commonly known as diesel, SKO commonly known as Kerosene, Naphtha and aviation turbine fuel to meet the needs of various districts viz. Hassan, Mysore, Mandya, Tumkur, Chikmangalore, Chitradurga, Shimoga, Kolar, Bellary, Raichur, Ramanagara, Bangalore Rural & Bangalore Urban districts of Karnataka State.

The motivation is to transport petroleum product with high standard of quality measure and to render the best quality product to the customers through Oil Marketing Companies in order to reduce road / rail transportation and environmental pollution and also de-congestion of traffic in the highway.

2.4 Objectives

The design of pipeline network has two main objectives:

i. The hydraulic objective is to secure the desired pressure and flow rate at specific locations in the system. For a given wellhead flowing pressure at the top of the well, a relationship between flowing bottom hole pressure and production rate can be calculated.
ii. The economic objective is to meet the hydraulic requirements with minimum expense.

Chapter 3
Methodology

The pipeline network chosen, i.e., the Petronet MHB Limited Pipeline is presently operating between Mangalore, Hassan & Bangalore. This is because all the information required for optimization, such as the variables and the constraints could be easily acquired from authentic sources. The analysis for this semester would include a thorough study of this pipeline network using Genetic Algorithm. Moreover this analysis can be used for further expansion of the pipeline till Tamil Nadu.

We use **Genetic Algorithm** (8) because it is robust and has been proven theoretically and empirically to be able to efficiently search complex solution spaces. GA is much less likely to restrict the search to a local optimum compared with point to point movement optimization techniques.

Genetic algorithms have a number of advantages over other mathematical programming techniques (Goldberg 1989). In the context of optimization of pipe network design some advantages include the following.

i. GAs deal directly with a population of solutions at any one time. These are spread throughout the solution space, so the chance of reaching the global optimum is increased significantly.
ii. Each solution consists of a set of discrete pipe sizes. One does not have to round diameters up or down to obtain the final solution.

iii. GA’s identify a set of solutions of pipe network configurations that are close to the minimum cost solution. These configurations may correspond to quite different designs that can be then compared in terms of other important but non-quantifiable objectives.
iv. GA’s use objective function or fitness information only, compared with the more traditional methods that rely on existence and continuity of derivatives or other auxiliary information.

Steps taken for optimization of the Petronet MHB Limited Pipeline using Genetic Algorithm:

3.1 Determining the objective function

This is the function to be minimized (or maximized). Here, we use cost as the objective function. The minimization of total cost of pipeline would depend on the mentioned factor i.e. (i) Pipe Material Cost, (ii) Operation Cost of Pumps, (iii) Pump Station Cost and (iv) Line fill cost. Optimization will be done by analyzing two parameters i.e. (i) Variation of Diameter of pipeline and (ii) Pressure profile along the pipeline. The optimization tool used to optimize the overall cost of pipeline which includes pipe material Cost, Operating Cost, Pump Station Cost & fuel cost inside the pipeline.

3.2 Selecting a pipeline network

As mentioned above, we have selected the Petronet MHB Limited Pipeline. This project consists of 4 main Stations, 10 Sectionalizing valve stations, 1 Intermediate Pigging Station and 362.373 KMS long 20inch /24inch diameter pipeline which passes through 238 villages / 17 Taluks / 8 districts in Karnataka and designed for transportation of petroleum products viz. Petrol, Diesel, Kerosene, Naphtha, Aviation Fuel for catering to the requirement of different consumption zones in Karnataka viz. Hassan, Mysore, Mandya, Tumkur, Chikmagalur, Chitradurga, Shimoga, Bangalore, Kolar, Bellary and Raichur.

3.3 Determining the constraints

1. Volumetric flow rate

The volumetric flow rate (Q) of a system is a measure of the volume of fluid passing a point in the system per unit time. The volumetric flow rate can be calculated as the product of cross sectional area (A) for flow and the average flow velocity (v).

$Q = A \times v$

Where,

Q is in m^3/hour (S.I.)

A is in m^2

v is in m/hour

2. Pipe diameter

The larger the inside diameter of the pipeline, the more fluid can be moved through it, assuming that other variables are held constant. It is expressed **in mm**.

Internal Diameter = Outer Diameter – 2*thickness

$I.D. = O.D. - (2t)$

3. Line Fill Volume

The quantity of the product which is present in the pipeline at a specific time is called line fill volume. It may be multi **product line fill** (9)which provides the information about the different batches in pipeline.

From the line fill we can find the quantities of different batches of product and their exact locations. For every pipe size the line fill quantity per km is constant irrespective of the product.

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.

If the pipe internal diameter is D, in. and the length is L Feet, the volume of this length of pipe is

$$V = \frac{\pi}{4} \times \frac{D^2}{144} \times L$$

$V = 0.7854 \times \frac{D^2}{144} \times L$ (Where, 1/144 is the conversion factor)

V=Volume, ft^3

Simplifying,

$$V = 5.4542 \times 10^{-3} \times D^2 L$$

This equation is restated in terms of conventional pipeline units, such as the volume in bbl in a mile of pipe. The quantity of liquid contained in a mile of pipe, also called the line fill volume, is calculated as follows:

$$V_L = 5.129\left(D^2\right)$$

Where

V_L=Line fill volume of pipe, bbl/mile
D=Pipe internal diameter, in.

In SI units we can express the line fill volume per km of pipe as follows:

$$V_L = 7.855 \times 10^{-4} D^2$$

Where,
V_L=Line fill volume, m^3/km
D=Pipe internal diameter, m

4. Reynolds Number

This dimensionless number is used to describe the type of flow exhibited by a flowing liquid in laminar flow, the molecules move parallel to the axis of flow. In turbulent flow, molecules move back and forth across the flow axis. Other types of flow are also possible, and the Reynolds Number (10). can be used to determine which type is likely to occur under specified conditions. In turn, the type of flow exhibited by a fluid affects pressure drop in the pipeline.

Reynolds number is thus, the ratio of inertial force by viscous force.
It can also be interpreted as ratio of dynamic pressure and the shearing stress.
Dynamic pressure is ρu^2
Shearing Stress is $\mu u / L$

$$\mathrm{Re} = \frac{(\rho \times u^2)}{(\mu \times u)/L}$$

$$\mathrm{Re} = \frac{\rho \times u \times L}{\mu}$$

$$\mathrm{Re} = \frac{u \times L}{\nu}$$

Therefore, Reynolds no. can be calculated for any given liquid and pipe size as follows:

$$\mathrm{Re} = \frac{\rho v D}{\mu}$$

ρ = Liquid density, slugs/ft^3

$\boldsymbol{v}$ = Average velocity, ft./s

$\boldsymbol{D}$ = Pipe internal diameter, ft.

It has been shown that for values of Re less than approximately 2000 the flow is laminar. Above 4000 the flow is considered turbulent and for 2000 – 4000 the value of flow lies in 'critical Zone' where the flow is unpredictable.

It is more practical to express the calculations of Reynolds no. in oil field unit (SI unit) as follows:-

$$\mathrm{Re} = \frac{353678Q}{vD}$$

Q=Flow rate, m^3/hr.
D=Internal diameter, mm
ν=Kinematic viscosity, cSt

5. Friction factor

A variety of friction factors (11)are used in pipeline equations. They are determined empirically and are related to the roughness of the inside pipe wall. For laminar flow conditions (Re< 2000), the friction factor of the Reynolds no., (Re) and is given by:

$$f = \frac{64}{\mathrm{Re}}$$

For turbulent flow condition (Re>4000), the friction factor (f) is a function of the Reynolds no. (Re) and the surface roughness of the pipe wall. The value of f is usually obtained from a chart developed by Moody. More correctly, friction factor depends on the relative roughness (e/ID) rather than absolute pipe roughness (e).

The **Colebrook-White equation** to calculate friction factor (f) in turbulent flow is as follows:

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\left(\frac{e}{3.7D}\right) + \frac{2.51}{R\sqrt{f}}\right]$$

f=Darcy friction factor, dimensionless

D=Pipe internal diameter, in.

e=Absolute pipe roughness, in

6. Transmission factor

The transmission factor F is directly proportional to the volume that can be transmitted through the pipeline and therefore has an inverse relationship with the friction factor f. The transmission factor F is calculated from the following equation:

$$F = \frac{2}{\sqrt{f}}$$

Since the friction factor f ranges from 0.008 to 0.10 it can be observed that the transmission factor F ranges from 6 to 22 approximately.

Transmission factor is used only in case of turbulent flow. Transportation of products through pipeline will always be in turbulent state.

For turbulent flow Re>4000

$$F = -4\log_{10}\left[\left(\frac{e}{3.7D}\right) + \left(\frac{1.255F}{\text{Re}}\right)\right]$$

F=Transmission factor, dimensionless

D=Pipe internal diameter, in.

e=Absolute pipe roughness, in.

7. Pressure at a point

If product is being transferred from station 1 to station 2 the inlet pressure at station 2 will be given by the following formula:

$$P_{total} = P_{friction} \pm P_{elevation} + P_{flow}$$

Where,

P_{flow} = Existing pressure of flow

$P_{friction}$= Total friction pressure drop between two point

$P_{elevation}$ = Pressure loss/gain due to elevation

8. Pressure Loss/Gain due to Elevation

There is a relationship between loss/gain of pressure due to elevation & Head. But in our case as we know the head difference between each station in meters, we will consider the formula:

$$Head = \frac{2.31 Pe \text{ (psig)}}{S.G.} \, ft \qquad \textbf{(English units)}$$

The factor 2.31 comes from the ratio Sizing of Gas Pipelines (144 in.^{2}/ft^2)/62.34 lb/ft^3

Where 62.34 lb/ft^3 is the specific weight of water.

For SI units:

$$Head = \frac{0.102 \text{ Pe (KPa)}}{S.G. \text{ (m)}} \qquad \textbf{(SI units)}$$

9. Pressure Drop to due to friction

Friction is force of resistance between the adjacent layers within a fluid that are moving relative to each other. For calculating pressure drop due to friction (12)we have to use the value of friction factor which can be calculated using formulae already mentioned.

Therefore,

$$P \text{ (km)} = \frac{6.2475 \times 10^{10} \text{ f } Q^2 \text{ SG}}{D^5} \qquad \textbf{Darcy friction}$$

$$P \text{ (km)} = \frac{24.99 \times 10^{10} \left(Q/F\right)^2 \text{ SG}}{D^5} \qquad \textbf{Transmission factor}$$

Where,

P (km) =Pressure drop due to friction, kPa/km

Q=Liquid flow rate, m^3 /hr

f=Darcy friction factor, dimensionless

F=Transmission factor, dimensionless

SG=Liquid specific gravity

10. Pipe material cost

The capital cost of a pipeline consists of material and labor for installation. To estimate the material cost (3) we will use the following method:

Pipe material cost $= 10.68(D - t)t \times 2.64 \times L \times Cpt$

Hence,

$$\text{PMC} = 28.1952\ \text{L}\left(D - t\right)\text{t (Cpt)}$$

Where,

PMC=Pipe material cost, $

L=Pipe length, miles

D=Pipe outside diameter, in.

t=Pipe wall thickness, in.

Cpt=Pipe cost, $/ton

In SI units, it can be written as:

$$\text{PMC} = 0.02463\ \text{L}\left(D - t\right)\text{t (Cpt)}$$

Where,

PMC=Pipe material cost, $

L=Pipe length, km

D=Pipe outside diameter, mm

t=Pipe wall thickness, mm

Cpt=Pipe cost, $/metric ton

11. Pump station cost

It has been found rom references that a detailed analysis consist of preparing a material from its take off from the pump station drawings and getting vendor quotes on major material equipment such as pumps, drivers, switchgear, valves, instrumentation, etc., and estimating the station labour costs. An approximate cost of pump station is then estimates using a value of cost in dollars per estimated horse power. It is told that it is an all- inclusive number considering all facilities associated with pump station. Pump station cost is given by:-

PSC = $1500 per HP

Where HP= Horse power

12. Operating Cost

Operating cost of the pumps is calculated by considering that the pumps are running at 80% of its capacity, electrical power is used to run the pumps, the pumps are running 24 hours for 350 days and for 30 years. The rest of the days are left for maintenance or shut down purpose & 30 years is taken as the life of pipeline should a minimum 30 years. Using BHP calculated for pumps and 8 cents/kWh of electrical cost and converting it to rupees the cost is calculated using

OPC= BHP*24*350*0.08*0.746*60*30

BHP= Brake Horse Power

3.4 Matlab Program

3.4.1 Steps taken to build the program

i. Diameter and pressure are taken as unknowns.

ii. Pressure loss equations are taken as constraint, this problem contains both equality and inequality constraints.

iii. Thickness is assumed to be constant of 6.35mm for all the diameter pipelines.

iv. Based on the diameter within the bounds it will calculate the pressure at 7 points along the anticipated pipeline route.

v. In the constraint function the equality and inequality constraint function are given.

vi. It should be noted that nowhere along the pipeline route the pressure should go below $3 kg/cm^2$. This is done to avoid loss due to interface mix.

vii. It should be checked whether the delivery can be achieved by running Hassan Pumps.

viii. For diameters below 16 inches it is seen that even by running Hassan Pumps it is impossible to achieve product delivery.

ix. In such cases a pump station should be structured at Bangalore. Always the pumps will operate at 80% of its maximum capacity. So HP rating in station cost and operation cost will vary.

x. For smaller diameter pipeline in that total cost, pump station cost will also be added up.

xi. Operating costs of the pumps may be either due to Hassan pumps or the pumps to be structured at Bangalore.

xii. Operating cost is calculated for 30 years, as this is considered as the life span of a normal pipeline.

xiii. The cost of product inside the pipeline will also get added up as the initial cost. So based on the line fill volume of each diameter pipeline the cost of product filling the line is calculated.

xiv. The total cost for laying a pipeline includes pump station cost, pipe material cost, operating cost, and line fill cost.

xv. Optimization is done to choose an appropriate diameter so that cost will be minimal.

xvi. Optimization is done to using genetic algorithm.

3.4.2 Program Files

One Objective function file and one constraint equations file is created.

Function file **costopti ( )**

Constraint file **progconstraint ( )**

3.4.2.1 Function file

```
function [TC]=costopti(x)
D=x(1);
%Diameter to be optimized

L=[11.298,21.394,25.0410,25.743,20.717,24.203];

TC=0;

%distance between sv stations along the pipeline route in (km).Also includes the highest point

e=.045;

%internal roughness of the pipeline in (nm)
```

```
Qo=640;

MAOP=1000;

%Design factor of offshore liquid pipelines

SMYS=60000;

T=6.35;

DI=D-(2*T);

%thickness of the pipelines in (mm)

V=4.7290;

%Kinematic Viscosity at 40?C, V (cst)

S=0.8359;

%Specific Gravity at 40?C, (no units)

F=15;

%Transmission factor (no units)

H=[15,-10,-91,-301,-36,-25];

%Elevation along the pipeline route in (meter)

P1(1,1)=x(2);

%Inlet pressure to the pipeline in (kg/m^2) considering the possible diameters to find the pressure provide along the pipeline

Re=(353678*Qo)/(V*DI);

%Reynolds number for all possible diameters (no units)

F=-4*log10(e/(3.7*DI)+(1.255*(F/Re)));

%Finding the transmission factor by trial and error method for each diameters taken(no units)
```

```
Pkm=24.99*(10^10*((Qo/F)^2)*(S/DI^5));

%Pressure drop per km in kPa due to friction for the possible diameter for each diameter pressure loss due to friction and pressure loss due to elevation changes is to be found

for i=1:6

Pf(i,1)=Pkm*L(i)*0.0102;

%Pressure drop due to friction along the pipelines route (kg/cm^2)

Pe(1,i)=(H(i)*S/.102)*0.0102;

%Pressure drop due to elevation along the pipeline route

P1(i+1,1)=P1(i,1)-Pe(1,i)-Pf(i,1);

PL(i,1)=(P1(i+1,1)-P1(i,1));

%pressure loss between stations in (kg/cm^2)

totalPL1=sum(PL);

Prloss=-[totalPL1];

%Pressure profile along the pipelines route for 12 inch diameter pipeline

end

Le=128.396;

%Total length of pipelines in Km

Cpt=600;

%Cost of carbon steel per tonne in USD

PMC=0.02463*Le*(D-T)*T*(Cpt);

%Pipe Material Cost for the whole length of pipeline in USD

PC=PMC*60;
```

```
%Pipe material cost in rupees

V1=7.855*(10^-4)*(DI^2);

VL=V1*128.396;

LFC=VL*1000*55;

b=3.8620;

if x(2)-b>=0;

%by calculations it is known that if Hassan pumps are commissioned the product will be delivered at a pressure of 3.8620 kg/cm2 at Bangalore

Pr=x(2);

%operating cost is calculated by considering Bangalore outlet pressure

PPr=1.2*x(2);

%Mostly pumps run at 80 percent of its maximum capacity

Psig1=Pr*14.2233;

%kg/cm2 to psig conversion

Head1=2.31*Psig1/S;

%head necessary for operation in (ft)

Q=16924.45;

%flow rate in (lb/min)

HP1=(Q*Head1)/33000;

%Horse power required while operation

Psig=PPr*14.2233;

Head=2.31*Psig/S;
```

```
HP=(Q*Head)/33000;

%Horse Power required for structuring pump

PSC=1500*HP*60;

%Pump station cost by considering a multiplication factor

BHP=HP1/(.80*.90*.95);

%Brake Horse of Bangalore pumps power by considering pump efficiency ,motor or driver efficiency ,mechanical efficiency

OpC=BHP*24*350*0.08*0.746*60*30;

%Operating cost of Bangalore pumps by considering 30 years of operation

 TC=PC+PSC+OpC+LFC;

%total cost by considering pipeline cost, pumps station cost, operation cost of Bangalore pumps

else

Pr=x(2)-5.0438+26.9421;

%Outlet pressure from Bangalore if Hassan pumps are commissioned by considering pressure loss/gain due to elevation and friction

Psig1=Pr*14.2233;

Head1=2.31*Psig1/S;

Q=16924.45;

HP1=(Q*Head1)/33000;

BHP=HP1/(.80*.90*.95);

OpC=BHP*24*350*0.08*0.746*60*30;

%Operating cost of Hassan Pumps by considering 30 years of operation

TC=PC+OpC+LFC;
```

```
disp('Total Cost')

disp(TC)

%total cost by considering pipe cost & operation cost Of Hassan pumps

end
```

3.4.2.2 Constraint Equation

```
function [gineq geq]=progconstraint(x)

D=x(1);

P1=x(2);

P2=x(3);

P3=x(4);

P4=x(5);

P5=x(6);

P6=x(7);

P7=x(8);

L=[11.298,21.394,25.0410,25.743,20.717,24.203];

e=.045;

%internal roughness in nm.

Qo=640;

%Maximum flow rate

T=6.35;

DI=D-(2*T);

V=4.7290;

S=0.8359;
```

```
F=15;
H=[15,-10,-91,-301,-36,-25];
Re=(353678*Qo)/(V*DI);
F=-4*log10((e/(3.7*DI)+1.255*(F/Re)));
Pkm=24.99*(10^10*((Qo/F^2)*(S/DI^5)));
for i=1:6;
Pf(1,i)=Pkm*L(i)*0.0102;
Pe(1,i)=(H(i)*S/.102)*0.0102;
end
geq(1)=P2-(P1-Pe(1,1)-Pf(1,1));
geq(2)=P3-(P2-Pe(1,2)-Pf(1,2));
geq(3)=P4-(P3-Pe(1,3)-Pf(1,3));
geq(4)=P5-(P4-Pe(1,4)-Pf(1,4));
geq(5)=P6-(P5-Pe(1,5)-Pf(1,5));
geq(6)=P7-(P6-Pe(1,6)-Pf(1,6));
%equality constraints
gineq(1)=3-P1;
gineq(2)=3-P2;
gineq(3)=3-P3;
gineq(4)=3-P4;
gineq(5)=3-P5;
gineq(6)=3-P6;
```

```
gineq(7)=3-P7;

%In equality constraints .Pressure at any points along the pipeline should be more than 3kg/cm2 to avoid loss due to interface mix

end
```

3.5 Observations

Optimization Toolbox Settings for running the code

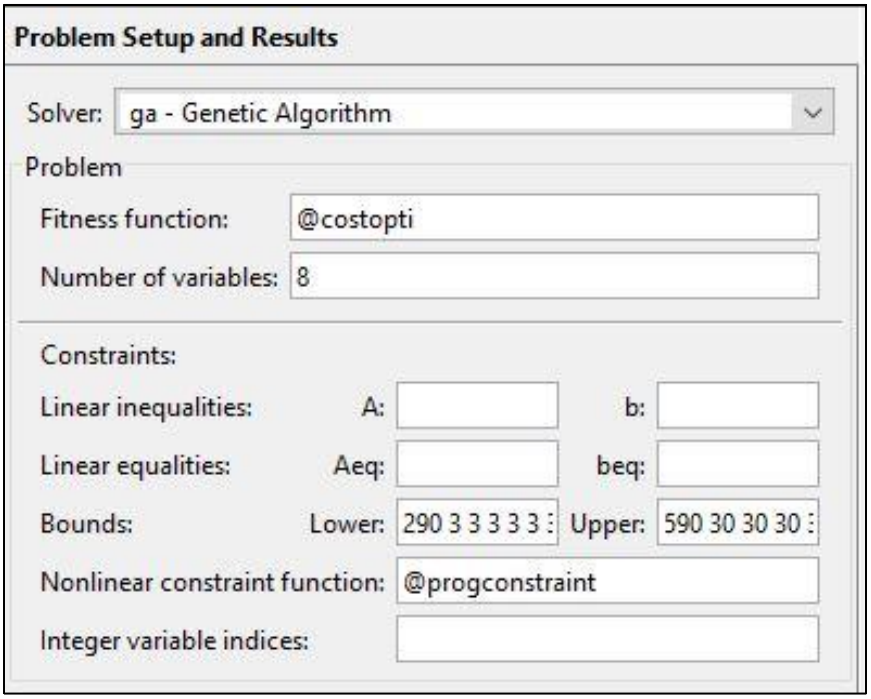
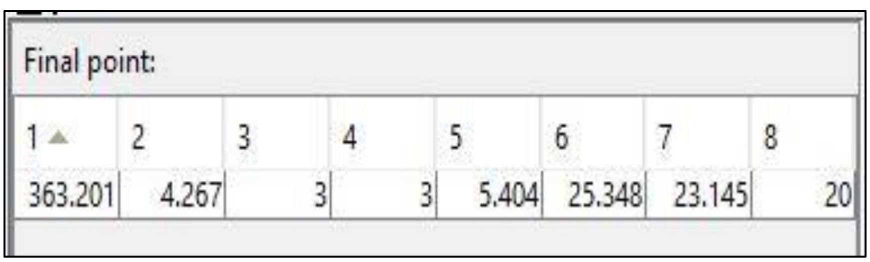


Figure 3.1 Optimization Toolbox

When the program code was run in MATLAB, using optimtool we got an optimized value of the Diameter D = x(1) = 363.201 mm



Final point:

1	2	3	4	5	6	7	8
363.201	4.267	3	3	5.404	25.348	23.145	20

Figure 3.2 Final Point Values

The value of the variables x(2), x(3),…x(8) are the values of the pressure at 7 different points of the pipeline considered.

x(2) = 4.267 kg/cm^2

x(3) = 3 kg/cm^2

x(4) = 3 kg/cm^2

x(5) = 5.404 kg/cm^2

x(6) = 25.348 kg/cm^2

x(7) = 23.145 kg/cm^2

x(8) = 20 kg/cm^2

The value of TC (total cost) for the optimized Diameter is obtained as 8.056×10^8 (**Fig.9**)

Hence, the minimum total cost for the network is ₹800 million.

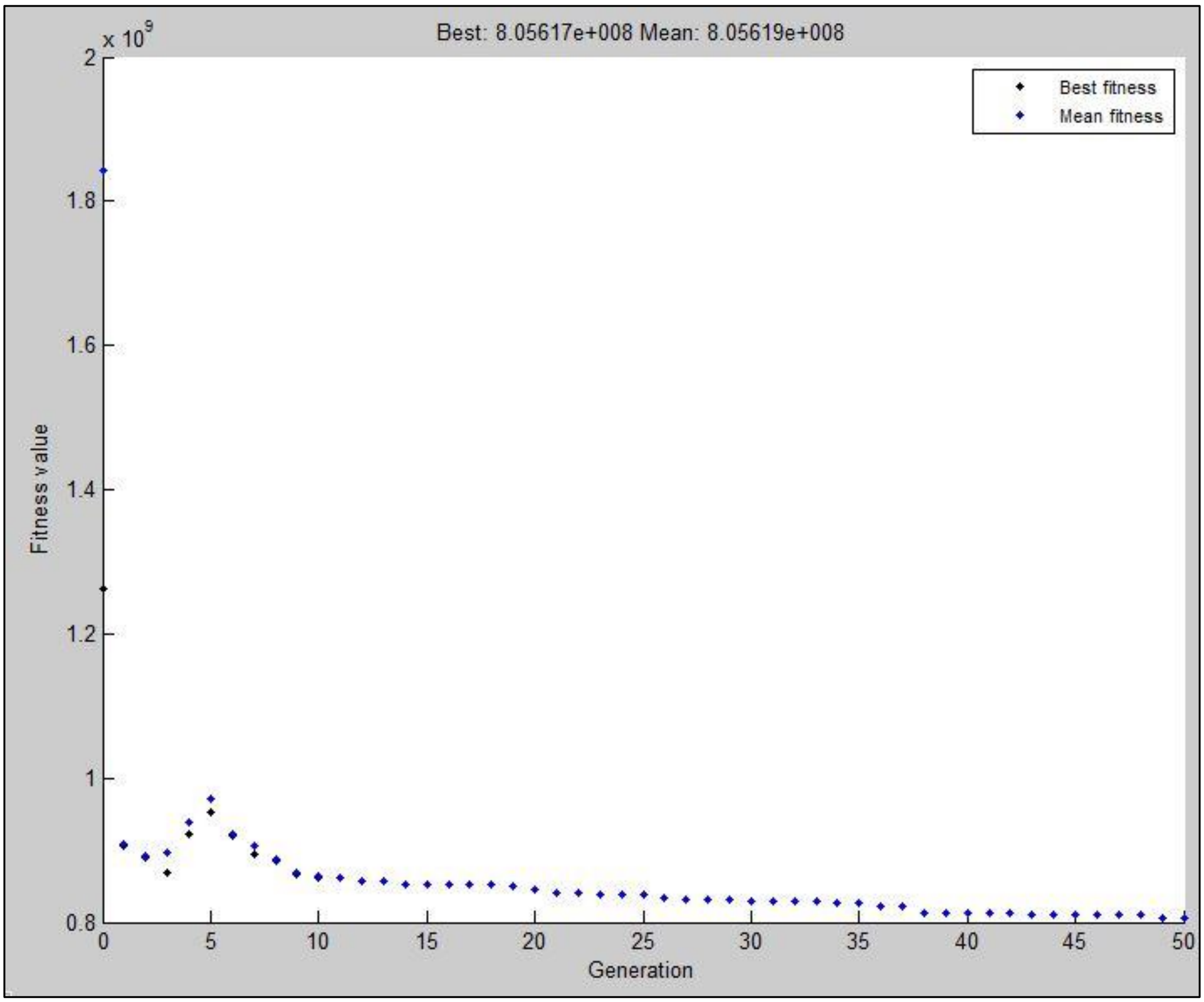


Figure 3.3 Fitness value vs Generations

Chapter 4
Results

The program code was run in MATLAB using Genetic Algorithm solver in the Optimization Toolbox. The number of variables was set to 8 and the range of diameter specified between 290 mm to 590 mm.

For number of generations set to 50 and other options set to default, the value of Optimized Diameter was obtained as 363.201 mm (**Fig. 3.1**).

As per the ASME standards the closest nominal pipe size is 350mm of 14 inch with an outer diameter of 355.6 mm.

The values of pressure at the seven different points of the pipeline was also obtained as x(2), x(3),…x(8).

A graph between Fitness value and Number of generations (**Fig.3.2)** gives an optimized fitness value of 8.056×10^{8}

This fitness value specifies the minimum total cost for the network for the optimized diameter.

Hence the total cost value for the pipeline network is **₹800 million**

Chapter 5
Conclusion

Pipelines are the most convenient, efficient and economical mode of transporting fluids like petroleum, petroleum products, natural gas, etc. Pipelines have relieved the increasing pressure on the existing surface transport system (railways and roadways). Transportation by pipelines is a relatively new development in India. India has a total pipeline network of 35,676 km and is still growing.

Present day pipelines are designed and operated by consideration of economics, environmental protection and high safety. A thorough analysis of all the parameters is required for construction and maintenance of pipelines. In any pipeline investment project we must perform an economic analysis of the pipeline system to ensure that we have the right equipment and materials at the right cost to perform the necessary service and provide a profitable income for the venture. Therefore, cost optimization of the pipeline is of utmost significance.

The pipeline considered is the Petronet MHB Limited Pipeline, presently operating between Mangalore, Hassan & Bangalore. All variables and constraints are collected and studied, along with the equations. The optimal pipeline route is selected based on ground profile, by avoiding industrial areas, forests, institutions, rivers, railway stations, lakes, mountains etc. based on the maps & satellite views. We have reviewed the major cost components of this pipeline system consisting of pipe, pump station, etc., and illustrated methods of estimating the capital costs of these items. Pipe diameter is used for encoding of parameters, as various types of parameters like frictional losses etc. and thereby cost depends on diameters.

Various methods for optimization have been discussed and Genetic Algorithm has been chosen (due to its advantages over others). Genetic algorithms are extremely powerful techniques which are capable of finding the least cost solution in relatively few simulations. In addition, a genetic algorithm can generate near optimal solutions for the designer.

MATLAB program is constructed in view of the objectives of the project. Seven points on the anticipated pipeline network are considered and the pressure constraints have been applied. The program generates random populations of variables, values of diameter in the range of 290 mm to 590 mm and constraint equations are evaluated at the seven locations.

If all the constraints are satisfied for the value of diameter between 290 mm to 590 mm, the total cost of the network is evaluated for that set of variables. This process is repeated for several times, and a number of generations (default 100) are evaluated. A graph between fitness values (from the objective function) vs. Generations (**Fig. 3.2**) is plotted.

Our objective to determine minimum expense for the network is met by selecting the least of the fitness value from the set of 50 generations. The least value of the fitness functions is the minimum total cost of the network.

The benefit of using MATLAB code for evaluating the total cost is the re-usability of the code. The same code can be used to evaluate different pipeline networks, by changing the values of the parameters and constraints for the given network.

The value of the optimized diameter obtained can be used to select the nearest available standard diameter values from the ASME standards and costs can be further calculated with much greater precision.

Chapter 6
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