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DEPARTMENT OF ENVIRONMENTAL AND LAND ENGINEERING
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MASTER'S THESIS

ANALYSIS OF OIL TRANSPORTATION PIPELINE USING ASPEN PLUS AND OLGA SOFTWARE

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Abstract

The target of this thesis is to simulate the hydrocarbon transportation system and the behavior of the pressure profile, during the movement through a pipeline. This work includes Aspen and Olga software to plan the model and dive deep into the process factors to anticipate the capacity of our system and examine the different variables that influence the pressure profiles.

My vision in this thesis is to examine the different factor can cause energy loss along the hydrocarbon pipeline, I will concentrate on four primary elements, Hydrocarbon flow rate, intel and ambient temperature, pipeline diameter and pipeline material, these components are investigated in Aspen and Olga software that every one of them has its exceptional computation parameter, I will investigate the experimental information to compare the outcome with software. In order to characterize the oil properties in Software condition and plan precisely the development which included different conditions, geography of the site, Proper property technique and examining the ideal activity that change in pressure drop profiles which are influenced by various factors such as hydrocarbon flow rate, pipeline diameter and material, inlet temperature, pump head requirement have been considered.

Acknowledgements

I like to express my thanks to my professor Guido Sassi for his significant help during this thesis, I want to give an extraordinary thank you to the Petroleum department staff for all their assistance and backing.

Finally, I wish to offer my genuine thanks to my family, and friends for their love. Without their steady help I would not be the place I am today.

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Chapter One: **Introduction**

1.1 Background of Study

Hydrocarbon transportation system comprised of various methods and each method has its specific equipment, Petroleum extracted site is generally far from the refinery processing region, according to geography of this distance various transportation method has been considered.

one the most common and safest method is Transportation of oil through the pipeline and is required much less energy and cost compare with others method' [1] climate change does not much affect in this method of transportation and it goes on continuously, also a rapid movement of fluid and carry large volume of hydrocarbon are another advantages of pipeline, the pipeline has a less harmful effect for the environment with respect to the other methods' [2],

In 2013 the pipeline under construction is about 188,108 km and the length of complete building is 53,180 and this is 11.4 percent more than previous year, though the global economy has undergone a slowdown, the construction of oil-gas pipelines continues to flourish around the world. [3].

In order to set up the oil transportation system, designer should consider proper material of pipeline which is vary in inside diameter and wall thickness, Sizing a pump station is essential process to compensate energy loss and head requirement in our system and respectively to control the flow valve installation is necessary for our system, topography of the site represents the different elevation in a pipeline route which has huge effect on pressure profile and the flow rate and velocity of petroleum also should be considered.

In the last few decades, a lot of work have been dedicated by researchers to design the pipeline system and optimizing the equipment so there are several pipeline modeling tools that developers have created to build and analyze the oil and gas distribution pipeline like Aspen plus and Olga Software.

Simulation modeling Software such as Aspen plus and Olga are a mathematical Modeling devices for an analyzer to anticipate the behavior of the system, these two software are provide easy access environment and simulate and optimize a complex system that comprise of modeling, development and improves operation within a short time, also the design briefly thorough process is another outstanding feature of these two software.

In other words, energy, momentum and continuity equation for each phases have been solved in Aspen and Olga software provide huge, in addition they suggest various methods proper to your process, physical and chemical properties of compositions have been obtained, and also they predict phase behavior of fluids, design, and size the plant to get the desired purpose, and in order to regulate the pressure of system they offer and determine process optimization and equipment configuration.

Specifically, in our simulation model aspen plus allows us to determine the oil properties as a complex oil characterization or assay that required the numerous properties such as true boiling point, API gravity, light end fraction, this information which obtain from Aspen oil characterization should be an input of Olga software. in addition, we can choose the best property method in wide variety options in order to have convenient thermodynamic and transport equations for our system, also flow sheet in aspen plus and Olga provide streams that we can input oil composition, flow rate, inlet pressure, and temperature and specific equipment such as a pipeline that contains the pipe parameters such as length, diameter, material and grade of the pipe, the elevation of pipes, etc., another options that we are dealing with in this thesis are pump and valves that each of them required the special configuration.

1.2 Problem Statement

During hydrocarbon transport in pipeline due to fraction factor, elevation, and fittings pressure drop in the pipeline may occur. Pressure drop is a major problem to remember when constructing the transport pipeline. Designer will not be able to do the requisite studies on pressure drop If this is not researched, it may fail to generate the amount of pressure and flow needed by customers which may result in a loss of the significant amount of project benefit. This project proposes variables to be explored such as pipeline configuration (pipeline wall thickness, pipeline type, and material), phase envelope, different equations to estimate pressure drops.

Chapter Two: **Literature Review**

2.1 Topography of the pipeline route

Constructing the pipeline is the first step to determine the topography of the pipeline route; It could be very complicated to evaluate various areas simultaneously and requiring many different criteria.

The open source model of Digital Elevation Model (DEM) data provided through the Google Shuttle Radar Topography Mission (SRTM) model. The accurate, high-quality, near-global elevation data provided by digital elevation data and collection of the Shuttle Radar Topography Mission (SRTM). This version of SRTM digital elevation data was processed to fill data voids and promote their user-friendliness.

2.2 Oil Characterization

Crude oil appearance and properties differ from each other and they are not treated equally, in order to recover from the reservoir and convert it to the saleable product in the refinery it is not follow the same rule, black or dark brown are the general color of oil although it may be yellowish or even greenish, because of the degree of processing and conversion for achieve what a refiner sees as an optimal product is very important to identify crude oil mixture, because of the natural qualities of crude oils, their density measured as American Petroleum Institute or API gravity and their sulfur content typically distinguish between crude oil types different types of crude oil yield a different product mix.

2.2.1 Specific Gravity or Density

Based on SG (specific gravity), the gravity of API (American Petroleum Institute), and the percentage of sulfur Crude oil classified differently. To assess crude oil performance, the specific gravity has been evaluated which is the most critical of commercial criteria. The low specific gravity gives the lighter fractions of crude oil quality and vice versa. Gravity of measured

API can be classified crude oil into light, medium, or heavy. API gravity below 10 is considered to Bitumen and extra heavy oil. API normally describes heavy oil from 10 to 22.3, medium oil from 22.3 to 31.1 and light oil higher than 31.1. [4] The crude oil SG (Specific gravity) is reversed by the API values and gives an initial estimation of the (heavy or light) hydrocarbon forms, the lower the specific gravity has a higher quality and the higher gravity of the API. The API gravity formula can be stated as [5]

$$API = \frac{141.5}{SG} - 131.5 \quad \text{Eq. 1}$$

2.2.2 Distillation Curve

One of the most significant parameters to assess the complicated fluid mixture is the distillation curve or boiling curve, graphical plot of a fluid boiling point against the volume fraction distilled is represent the distillation curve, and this proportion of the volume is usually represented as a combined portion of the overall amount. [6]

There are several approach in order to investigate distillation curve and one of the usual methods to specify the distillation curve and assess the crude oils is True boiling point (TBP), true boiling point determine the amount of distilled fraction of each component, the composition of crude oil and its fractions is expressed in terms of 'cuts' which is between a range of boiling points and because of the component of crude oil is not be separated into individual chemical compounds we use cut for each specific range. [7] Each cut represents the specific boiling point which demonstrates as the average True Boiling Point.

2.2.3 Bubble Pressure

Maximum pressure of fluid mixture that the first bubble of gas released is represented by bubble pressure; constant composition test can help us experimentally calculated this essential aspect for fluid by. bubble point is a strong function of API, System Temperature, gas and oil gravity, and gas solubility. [8]

2.2.4 Fluid Phase Behavior: Pressure-Temperature Diagram (P-T Diagram)

In a wide range of temperatures and pressures hydrocarbons represent multi-phase behavior. Gaseous, liquid, solid or mixed phase are the various Hydrocarbon state, this different state is essential to predict of the phase behavior of hydrocarbon fluids for designing the optimum transportation process along a pipeline. For the single and pure compound is easier to investigate the phase behavior than mixture of hydrocarbon because of involving more details, although hydrocarbons are predominately composed of a molecule with the same structure, so their phase behavior is not generally complicated. For a multi-component with a fixed overall composition, the phase envelope figure illustrates an idealized P-T diagram. there is a transition zone between the complete liquid phase and the complete vapor phase. In other word go against the pure substance, phase change from liquid to vapor appears.

On a phase envelope line, there is a region that two phases are at equilibrium. Liquid and gaseous regions that is bounded by the bubble point and dew point curves are called “phase envelope”. The bubble point and dew point curves meet at a critical point. In Aspen software simulation, bubble point pressure of crude oil can be defined through the pressure-temperature diagram.

2.3 Pipeline flow profile

Fluid behavior can be changed due to the two major parameter, viscosity and velocity of a hydrocarbon through the pipeline; different flow rate generally causes various flow profiles through the pipeline.

To estimate the pattern of the fluid behavior Reynolds numbers play a major part. Reynolds is dimensionless and calculates whether liquid flows are laminar or turbulent, and it depends on various factors, including speed, length, viscosity, and flow kinds. Laminar flow is representing that there are no eddies, current and swirls, and flow goes on a parallel layer.

high speed, light fluids, causing irregular flow patterns, and swirls which characterize by turbulent flow. Reynolds numbers are given as the following:

$$Re = \frac{\rho V D}{\mu} \quad \text{Eq.3}$$

The model of laminar flow is Reynolds below the 2300 number. And the turbulent flow is characterized by the number Reynolds greater than 4000.

2.4 pipeline characterization

The main purpose of pipeline is to move fluid from one site to another, the industries usually collect hydrocarbon from wellheads and transport product through the pipeline to processing platform, Pipelines classified into small and large with diameters of up to 48 inches. The main part of pipeline system generally buried underground but some part of it such as pump station is above the ground. Pipeline can be very short or long enough up to 1000 kilometers.

In Selecting and constructing a pipeline must take into consideration many factors such as material and grade of the pipeline, the inner and outer diameter of the pipeline, maximum allowable pressure in the pipeline.

2.4.1 Pipeline material

Due to internal and external pressures and laying techniques and maintenance frequency or impermeability ,the material of the pipeline should be different, Carbon steel and stainless steel are found in most hydrocarbon system, Carbon steel and stainless steel pipes are comprised of bimetallic tubing which has titanium alloy steel, copper or aluminum. high mechanical performance, high corrosion resistance, high operational convenience, and high safety are the properties of this kind of pipes. The properties of material of pipe are standardized by the American Petroleum Institute (API 5L 2004) and other organization. They offer nominal diameter, inside diameter, wall thickness and maximum allowable pressure up to 80 inches pipes. [9]

2.4.2 Pipeline sizing

The amount of the fluid which could be carry through the pipeline is depends on the size of a pipeline. Designer For high mass flow usually consider large diameter of pipes based on intent and application region. The diameter in some region could be large up to 0.5 meter.

The maximum and minimum pipeline diameters can be stated with the following formulas:

$$D_{max} = \sqrt{\frac{4Q}{V_{min}\pi}} \qquad D_{min} = \sqrt{\frac{4Q}{V_{max}\pi}} \qquad \text{Eq.4}$$

2.4.3 Absolute and Relative Roughness of pipe

The pipe wall irregularity is measured by absolute Pipe Roughness (ε). The unit of pipe roughness is usually expressed in millimeters or feet. If you have higher number of absolute roughness it leads to the frictional head loss. Another parameter that we are dealing with in this project is a pipe's relative roughness which is the ratio of absolute roughness to the inside diameter of the pipe (ε/D). in order to calculate pressure, drop per unit of length in a pipeline we use relative roughness. Based on the amount of Reynolds number for flow in a pipe and relative roughness we can investigate the friction factor.

2.5 Pressure profile in pipes

Flow resistance along the pipeline leads the pressure drop in each section of pipe. Elevation is another factor that arise the pressure drop. In addition, different inside diameter and various flow rate have the major effect on pressure drop, also Loss of energy as the fluid passes through fittings, valves of the pipe, can be occurred. [10]

2.5.1 Friction Factor

Interaction between the fluid and pipe's wall leads to pressure decrease of fluid along the pipeline, in other words movement of a fluid through a pipe cause friction factor changing. There are several approaches to measure the friction factor one of them is graphical diagram. The Moody Diagram or Moody Chart with considering various factor such as Reynolds number to know about the laminar and turbulent flow, relative roughness and absolute roughness of pipe provide a friction factor.

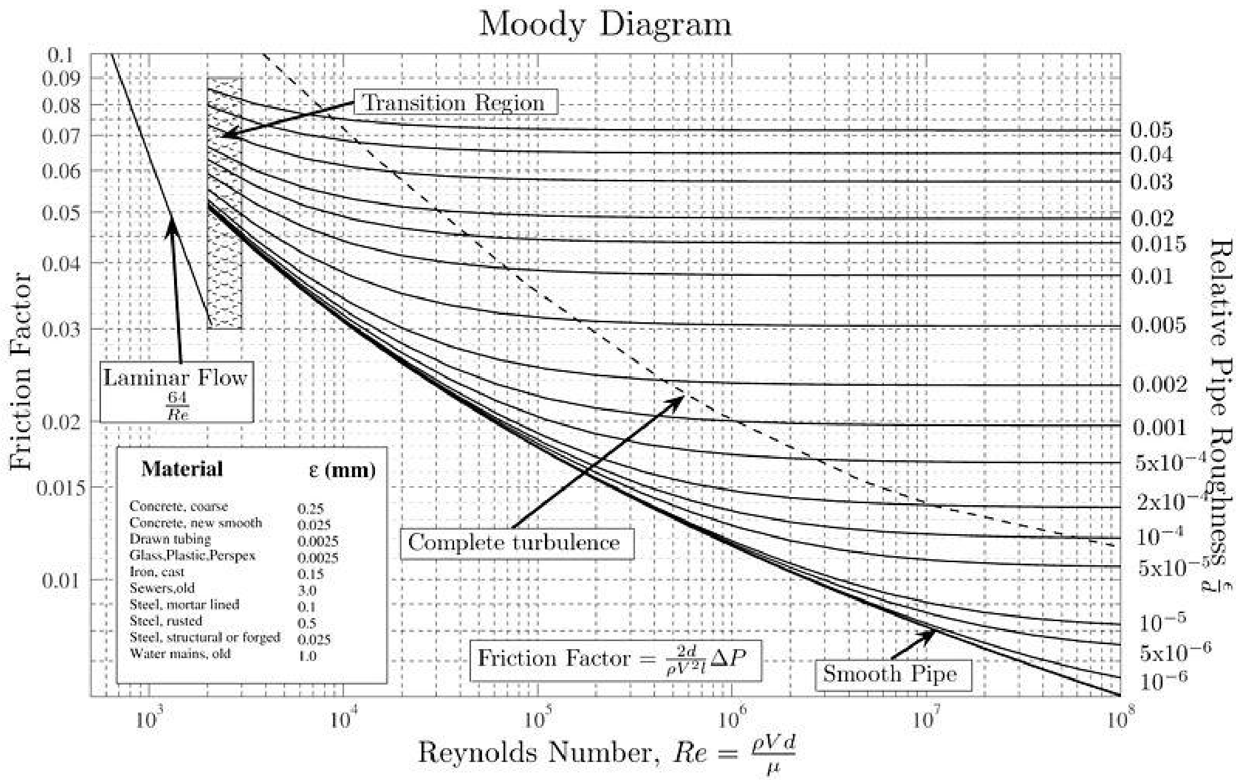


Figure 2.1 Moody diagram

Mathematical approach of moody diagram is the Colebrook correlation in order to calculate the friction factor of turbulent flow, ASPEN and OLGA software also follow this correlation:

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\frac{\mathcal{E}}{3.7} + \frac{2.51}{Re\sqrt{f}}\right] \quad \text{Eq.5}$$

2.5.2 Pressure drop per unit of length (Momentum Balance equation)

Pressure drop due to the friction in a pipeline system refers to energy loss and it can be calculated with the momentum balance equation. Pressure drop per unit of length accounts for the overall energy loss due to the length of a pipe it could be due to the fittings, valves, and other device structures. In order to develop energy balance equation, it is necessary to investigate momentum balance. General Fanning equation offers the head loss per unit length due to friction as follows:

$$\left(\frac{dp}{dz}\right) = \frac{2\rho f v^2}{144\, g_c\, D} \quad \text{Eq. 6}$$

2.5.3 Energy Balance Equation

In order to investigate the energy balance equation in Aspen and Olga software environment, the simplified version known as Bernoulli equation should be defined. Some assumption should be considered to develop Bernoulli Equation.

1) The density of fluid remains constant along the pipeline so we follow the incompressible fluid rules even though pressure varies along the pipe.

2) If the distance of transportation is short the viscous effects of fluid is minimized so we assume inviscid fluid during movement

3) We assume steady state condition, it means that the flow rate does not change during time,[11]

$$\mathrm{P}= P_A - g\rho(H - H_a) - \frac{\Delta P}{L} * \mathrm{L} \quad \textbf{Eq.7}$$

Multiphase pressure loss is more complex than the single phase, if we want to make the single-phase calculation applicable to wider condition, we should consider each phase hydrostatic pressure differential and use modification to friction pressure loss measurement.

Fluid nature should be considered for each single phases and interaction of each phase leads to have good understanding to multiphase pressure drop. The percentage of gaseous phase should be calculated in order to know about the velocity of each section of the fluid. We consider to phase correlation in order to investigate multiphase behavior. Oil and water include in one pseudo phase and we calculate gas in separate phase. [12]

Beggs and Brill correlation uses three different factors such as frictional, elevation and acceleration in order to calculate pressure drop in our system. This equation is used in Aspen plus software as a one of reliable approach in energy balance equation. Olga also use momentum, continuity, and energy balance for each phase separately [13]. three components friction, elevation and acceleration, it is expressed in the form below:

$$\left(\frac{dp}{dL}\right)_{tp} = \left(\frac{dp}{dL}\right)_{f} + \left(\frac{dp}{dL}\right)_{ele} + \left(\frac{dp}{dL}\right)_{acc} \quad \text{Eq.8}$$

$$\left(\frac{dp}{dL}\right)_{tp} = \frac{\rho f v^2}{2d} + g\rho \sin\theta + \frac{\rho v dv}{dL} \qquad \text{Eq.9}$$

Chapter Three: **Case Study**

3.1 Pipeline Coordinate and length

Intended area: from Tehran to Semnan in Iran

Length (km)	Elevation (m)	X Easting (m)	Y Northing (m)
0	1019	545124.25	3934755.48
20	1194	564746.49	3932429.41
40	1707	584369.28	3930103.4
60	1632	603992.81	3927777.4
80	1941	623617.27	3925451.37
100	2408	643780.53	3923061.53
120	2508	663138.54	3920767.16
140	1236	683035.76	3918408.99
160	989	702665.78	3916082.27
180	915	722566.57	3913723.52
200	931	741662.53	3911460.11
220	1004	761567.58	3909100.71
240	1069	234847.48	3906367.11
273	1037	267634.48	3900452.94

Table 3.1 Pipeline Length and Coordinates

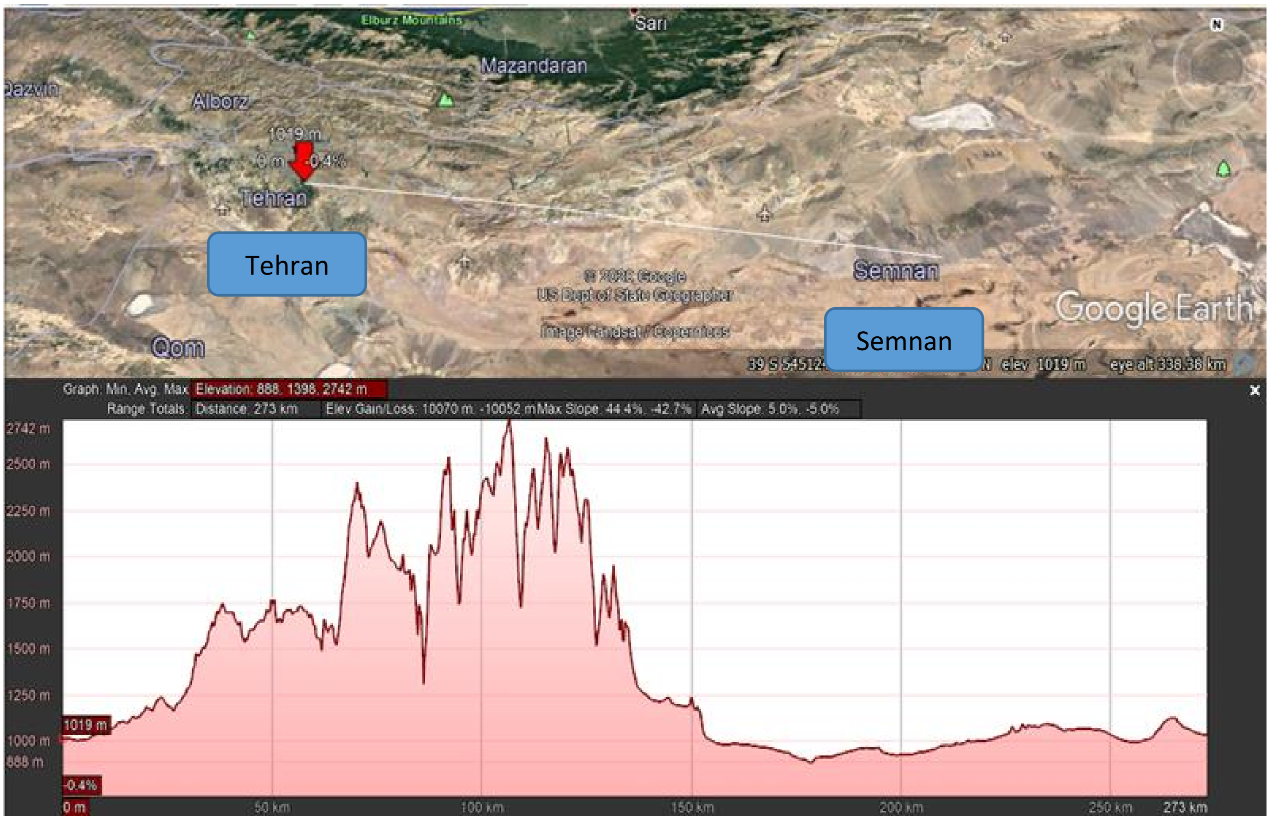


Figure 3.1 Distance between Tehran and Semnan

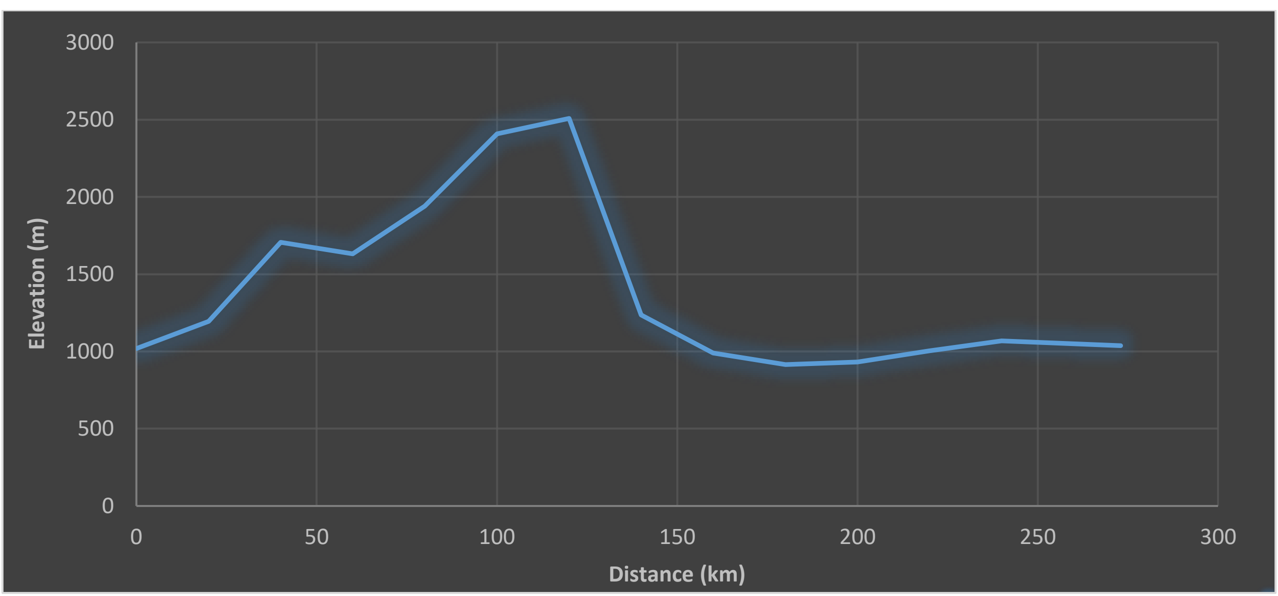


Figure 3.2 Intended Elevation

3.2 Oil Properties

One of the most reliable approaches, in order to model the petroleum in aspen plus, is to consider laboratory data of crude oil which contains a piece of tested information such as True boiling point for the determination of a distillation curve, Light ends fraction, API gravity, etc., In our case, we are following the official laboratory data of the Light oil that is comprised of two groups with different fractional properties as an assay ("Assay is a Complex characterization of crude oil which comprised of different hydrocarbon component"[14])

Assay 1

Component	Light Ends Fraction	API Gravity		TBP Distillation	
Methane	0.001	Distilled Vol. %	Gravity	Liq. Vol. %	Temp. (F)
Ethane	0.0015	5	90	6.8	130
Propane	0.009	10	68	10	180
Isobutane	0.004	15	59.7	30	418
N-butane	0.016	20	52	50	650
2-Methyl-butane	0.012	30	42	62	800
N-pentane	0.017	40	35	70	903
API = 31.4	Standard volume fraction of Assay 1 in a mix oil = 0.2	45	32	76	1000
		50	28.5	90	1255
		60	23		
		70	18		
		80	13.5		

Table 3.2 Oil properties of Assay 1

Assay 2

Component	Light Ends Fraction	API Gravity		TBP Distillation	
Methane	0.002	Distilled Vol. %	Gravity	Liq. Vol. %	Temp. (F)
Ethane	0.005	2	150	6.5	120
Propane	0.005	5	95	10	200
Isobutane	0.01	10	65	20	300
N-butane	0.01	20	45	30	400
2-Methyl-butane	0.005	30	40	40	470
N-pentane	0.025	40	38	50	550
Water	0.001	50	33	60	650
API = 34.8	Standard volume fraction of Assay 2 in a mix oil = 0.8	60	30	70	750
		70	25	80	850
		80	20	90	1100
		90	15	95	1300
		95	10	98	1475
		98	5	100	1670

Table 3.3 Oil properties of Assay 2

Oil Mixture at 22°C

API	Viscosity (cp)	Density (Kg/m3)	Specific Gravity
34.1	2.33347	742.308	0.854444

Table 3.4 Properties of Mix oil

3.3 Average Temperature in pipeline

Due to annual temperature of intended area from Tehran to Semnan we consider 30°C for the summer months and 16°C for the winter and the average annual temperature of the this site, we assume temperature of 22°C in the pipeline. [15]

3.4 Fluid velocity

Due to the Different pressure along the pipeline, elevation of the intended area viscosity of oil, flow rate of the fluid and the inside dimeter of pipeline, fluid velocity could be changed during the transportation, for light crude oil usually maximum (2m/s) and minimum (1m/s) velocities has been considered. If the velocity of oil is too high, it causes severe damage such as corrosion in it produces excess noise. and in order to prevent the surging the minimal velocity should be considered

3.5 Pipeline Diameter

Maximum Diameter	Minimum Diameter
Q = 0.1104 m3/s	Q = 0.1288 m3/s
$V_{min} = 1$ m/s	$V_{max} = 2$ m/s
$D_{max} = 15.7$ in	$D_{min} = 10.2$ in

Table 3.5 minimum and maximum Diameter of Pipeline

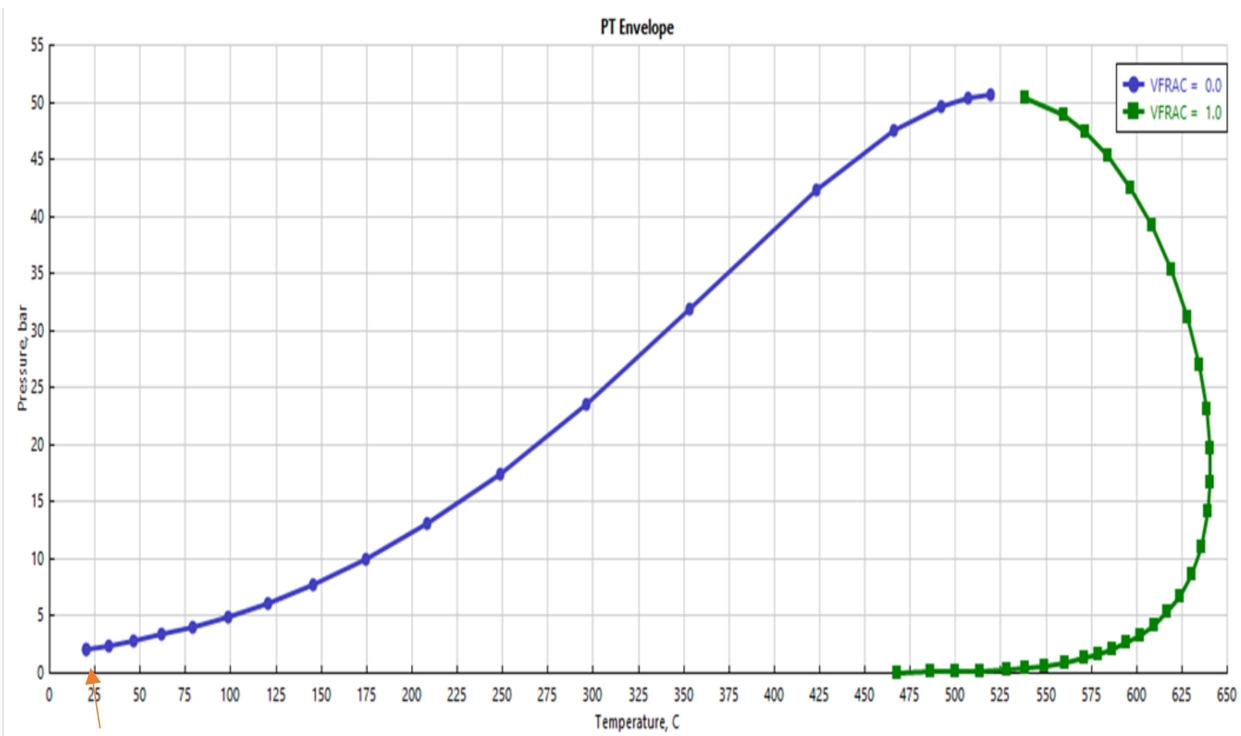
3.6 Maximum Allowable Pressure in the Pipeline

Inner Diameter (in)	Wall Thickness (in)	MAP Carbon Steel Pipeline (Psi)	MAP Stainless Steel Pipeline (Psi)
10.250	1.250	3000	2800
11.500	1.250	3000	2800
12.376	0.812	3000	2090
13.500	1.250	3000	2800
14	1	3000	2250
15.624	1.188	3000	2380

Table 3.6 Maximum Allowable Pressure in the Pipeline according to API 5L

3.7 Minimum Allowable Pressure in the Pipeline

In order to prevent corrosion along the pipeline, it is necessary to determine that in which pressure and temperature fluid is in multi-phase region [16], in this case study 2.1 bar at 22°C is the minimum pressure which lower than this amount, we have two phase hydrocarbon .



At 22°C, Pressure equals to 2.1 bar

Figure 3.3 Pressure-Temperature Diagram of Mix oil

Chapter Four: **Simulation Parameters**

4.1 Component Properties

There are several approaches exist in aspen plus environment in order to select the hydrocarbon composition, in this project we are dealing with light mix oil, thus some definition and parameters should have been considered for this purpose:

"Conventional component: single compound of chemical fraction which characterize by specific properties such molecular weight,

Blend: mixture of assays" [17]

Select components

Component ID	Type	Component name	Alias
C1	Conventional	METHANE	CH4
C2	Conventional	ETHANE	C2H6
C3	Conventional	PROPANE	C3H8
IC4	Conventional	ISOBUTANE	C4H10-2
NC4	Conventional	N-BUTANE	C4H10-1
IC5	Conventional	2-METHYL-BUTANE	C5H12-2
NC5	Conventional	N-PENTANE	C5H12-1
WATER	Conventional	WATER	H2O
ASSAY1	Assay		
ASSAY2	Assay		
MIXOIL	Blend		

Figure 4.1 Selection of Component in Aspen

Distilled percentage of assays with respect to the various temperature.

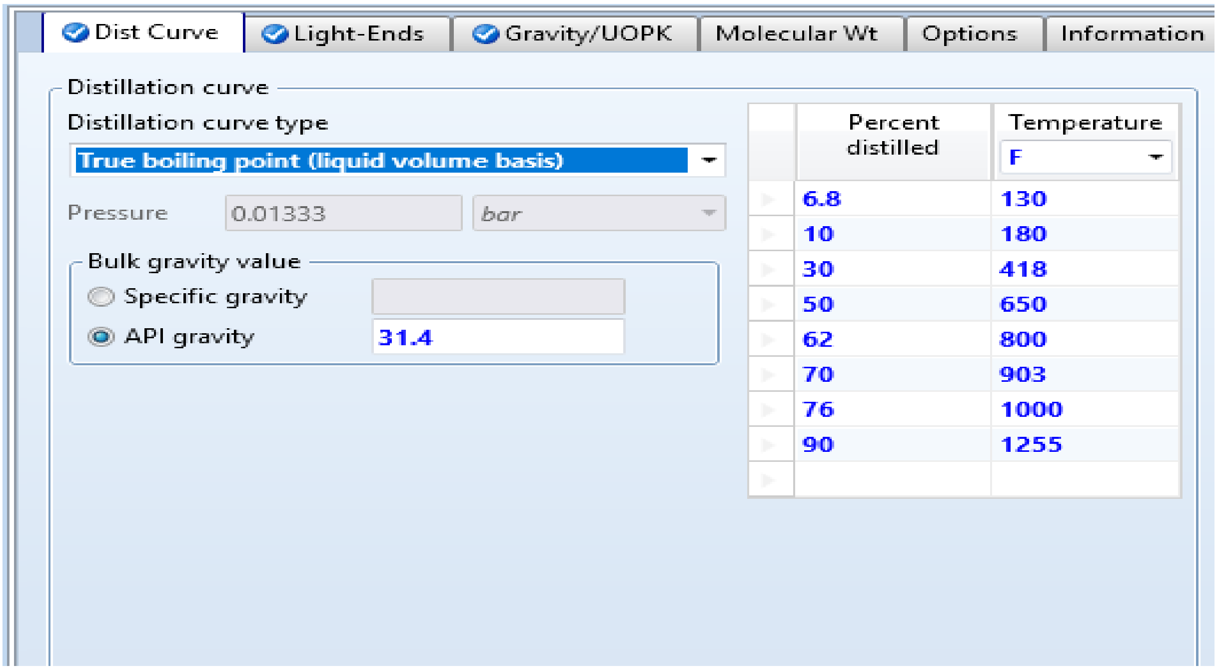


Figure 4.2 True boiling point properties of Assay 1 in Aspen

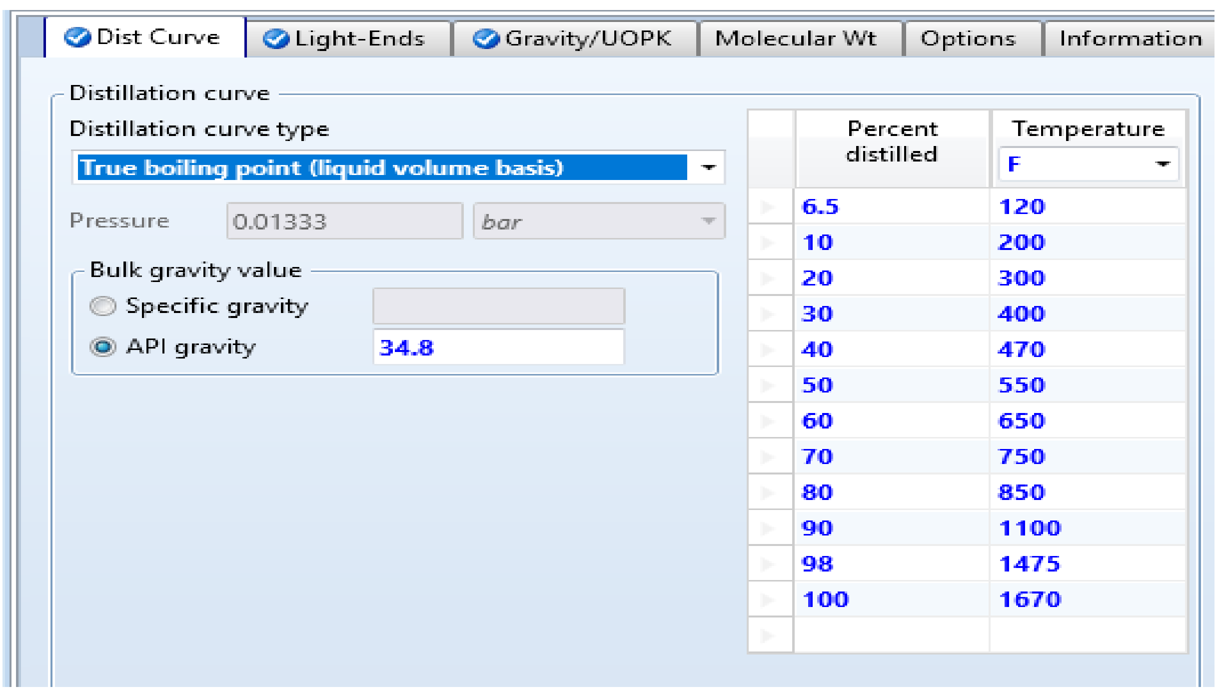
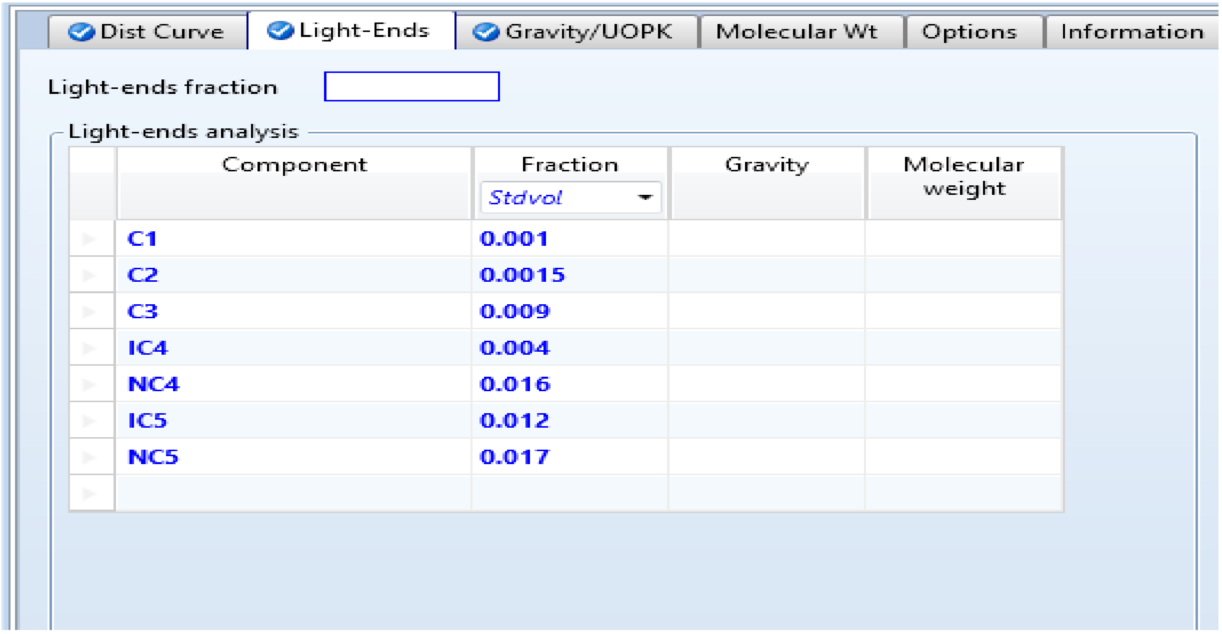


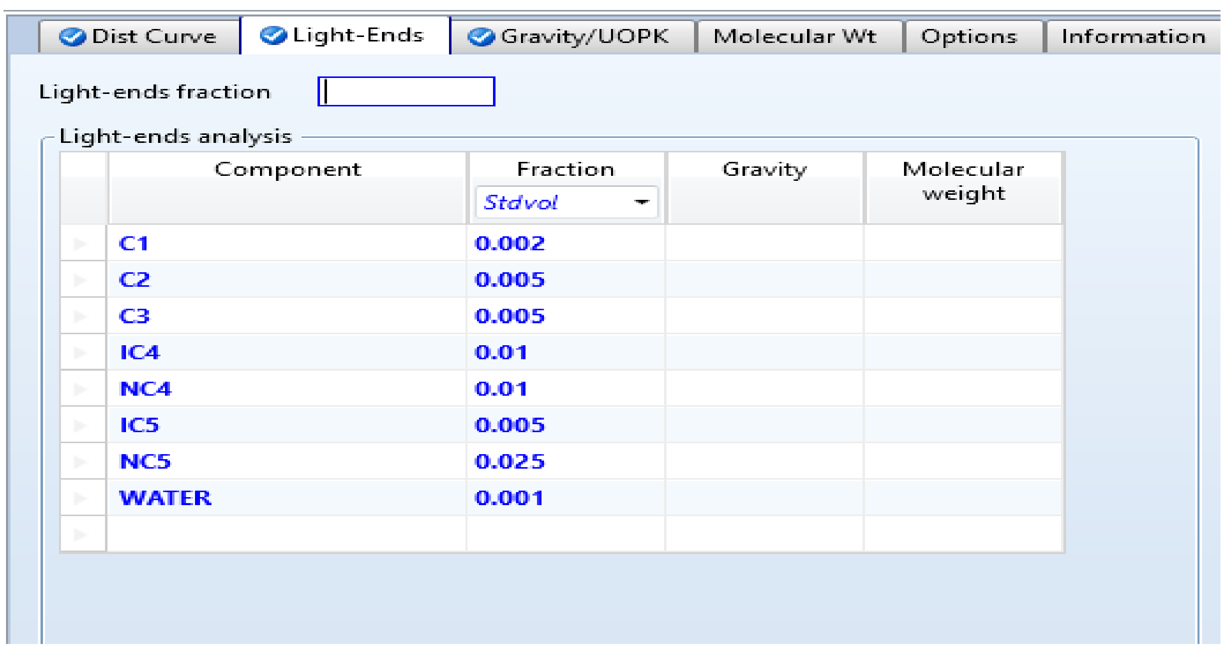
Figure 4.3 True boiling point properties of Assay 2 in Aspen

Light ends fraction of two assays with consideration of standard volume fraction are represented below:



Component	Fraction (Stdvol)	Gravity	Molecular weight
C1	0.001		
C2	0.0015		
C3	0.009		
IC4	0.004		
NC4	0.016		
IC5	0.012		
NC5	0.017		

Figure 4.4 Light-ends Fraction of Assay 1 in Aspen



Component	Fraction (Stdvol)	Gravity	Molecular weight
C1	0.002		
C2	0.005		
C3	0.005		
IC4	0.01		
NC4	0.01		
IC5	0.005		
NC5	0.025		
WATER	0.001		

Figure 4.5 Light-ends fraction of Assay 2 in Aspen

Each cut of the petroleum has the specific density and API gravity, we can demonstrate it from TBP [18] here we can see that API gravity of the first assay is 31.4 and for the second on is 34.8

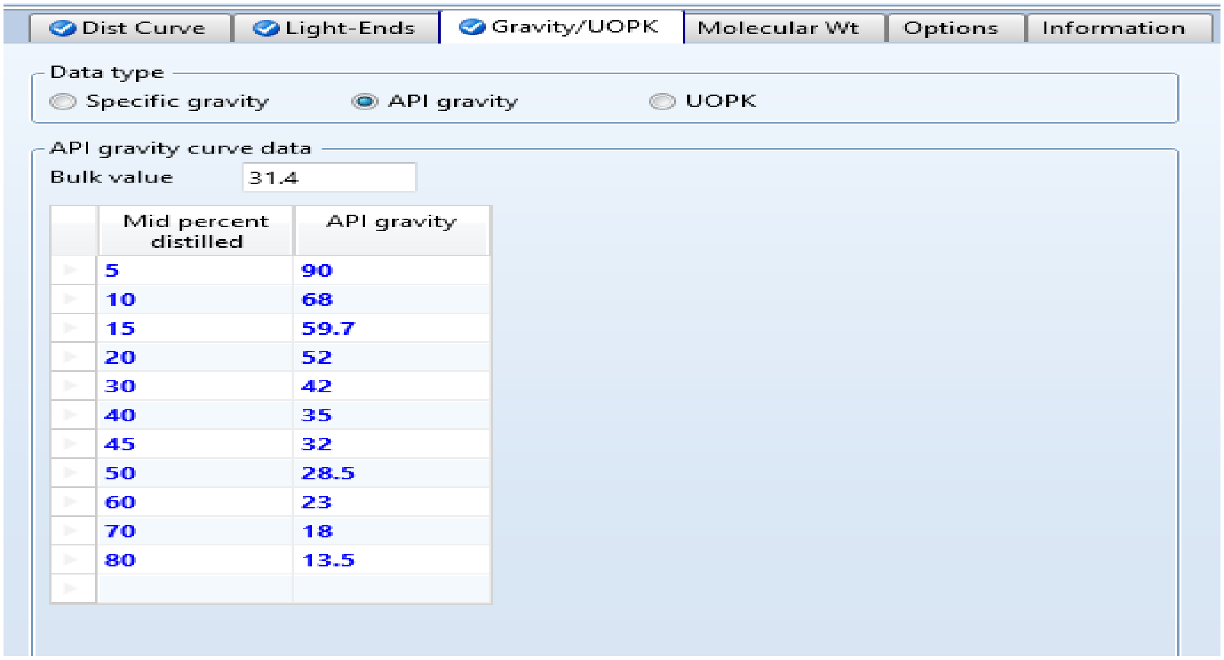


Figure 4.6 API gravity data of Assay 1 in Aspen

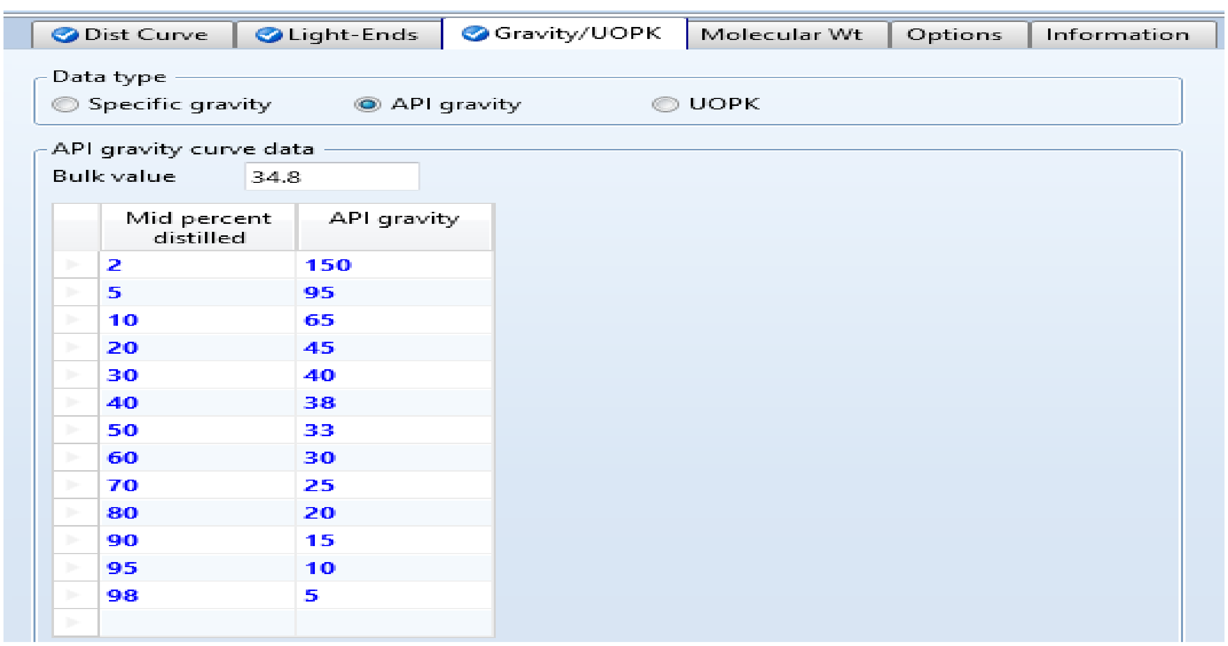


Figure 4.7 API gravity data of Assay 2 in Aspen

Next step is to consider each assay as a blending fraction in order to mix this to petroleum fraction and use the unique properties of hydrocarbon,

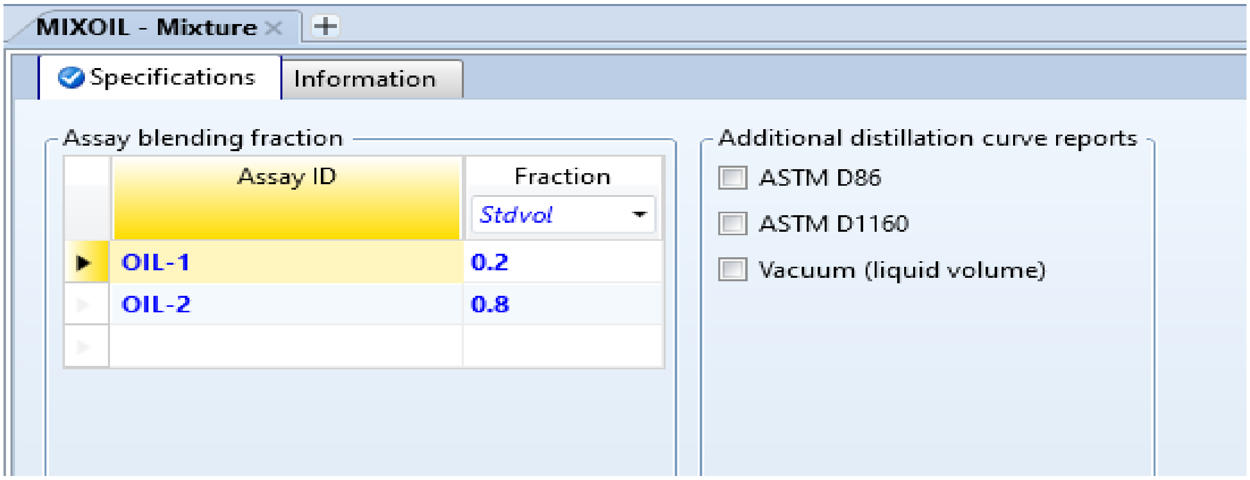


Figure 4.8 Standard Volume fraction of Mix oil in Aspen

In OLGA Software environment, in order to select feed characterization, we are dealing with each phase properties; Oil specific gravity, Gas specific gravity, Gas Oil Ratio, Water cut, H2S CO2 N2 Fraction Should be defined.

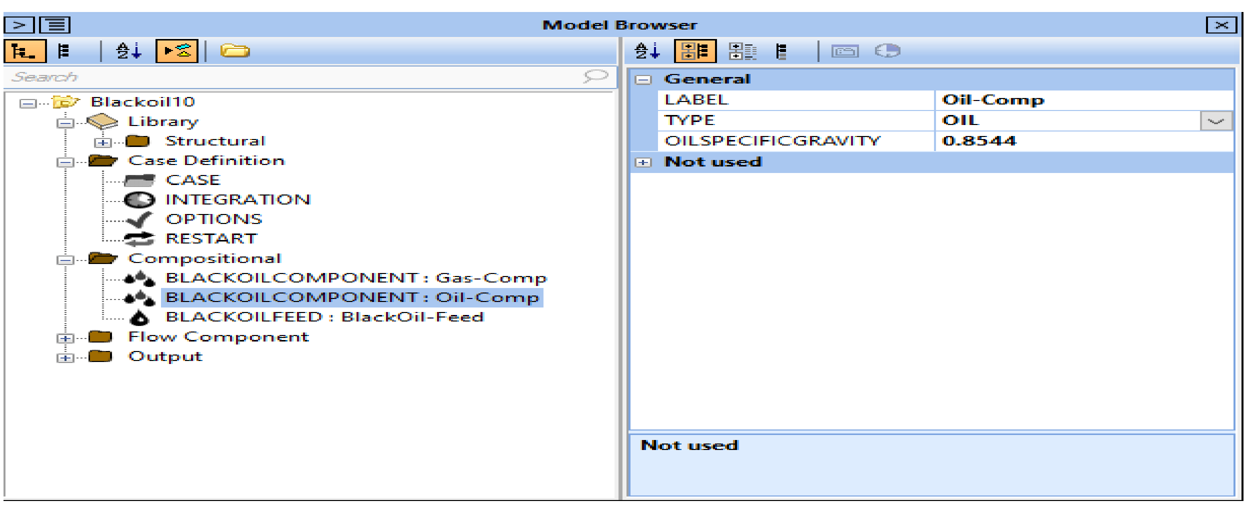


Figure 4.9 Oil characterizations in OLGA

4.2 Property Method

In simulation environment of aspen plus it is important to select proper approach to consider the pure component and the mixture properties of chemical composition. In order to estimate various factor which, effect the chemical composition Aspen offers different method for each specific chemical process. For measuring the thermodynamic data such as enthalpy, entropy , grade of freedom, Aspen introduce property method which is set of calculation in order to have proper process. [19]

One of the most common approach to determine the thermodynamic properties of hydrocarbon during transportation is he Peng-Robinson model which uses for low, medium, and high pressure (e.g. oil, gas, and petrochemical) processes. In fact, it can estimate the multiphase behavior of oil and help designer to investigate vapor liquid equilibrium calculation. Some transport and thermodynamic calculation method which we are dealing with in this project as follows

Equation of State	Peng Robinson
Density	Peng Robinson
Viscosity	Ely and Hanley
Enthalpy	Peng Robinson
Entropy	Peng Robinson

Heat Capacity	Peng Robinson
Thermal Conductivity	Misic, Thodos & Chung
Vapor Isentropic Coefficient	Peng Robinson
Friction Factor	Colebrook-White, Darcy
Energy loss per unit of length	General fanning equation
Energy balance	Beggs and Brill method

Table 4.1 Property Methods in Aspen

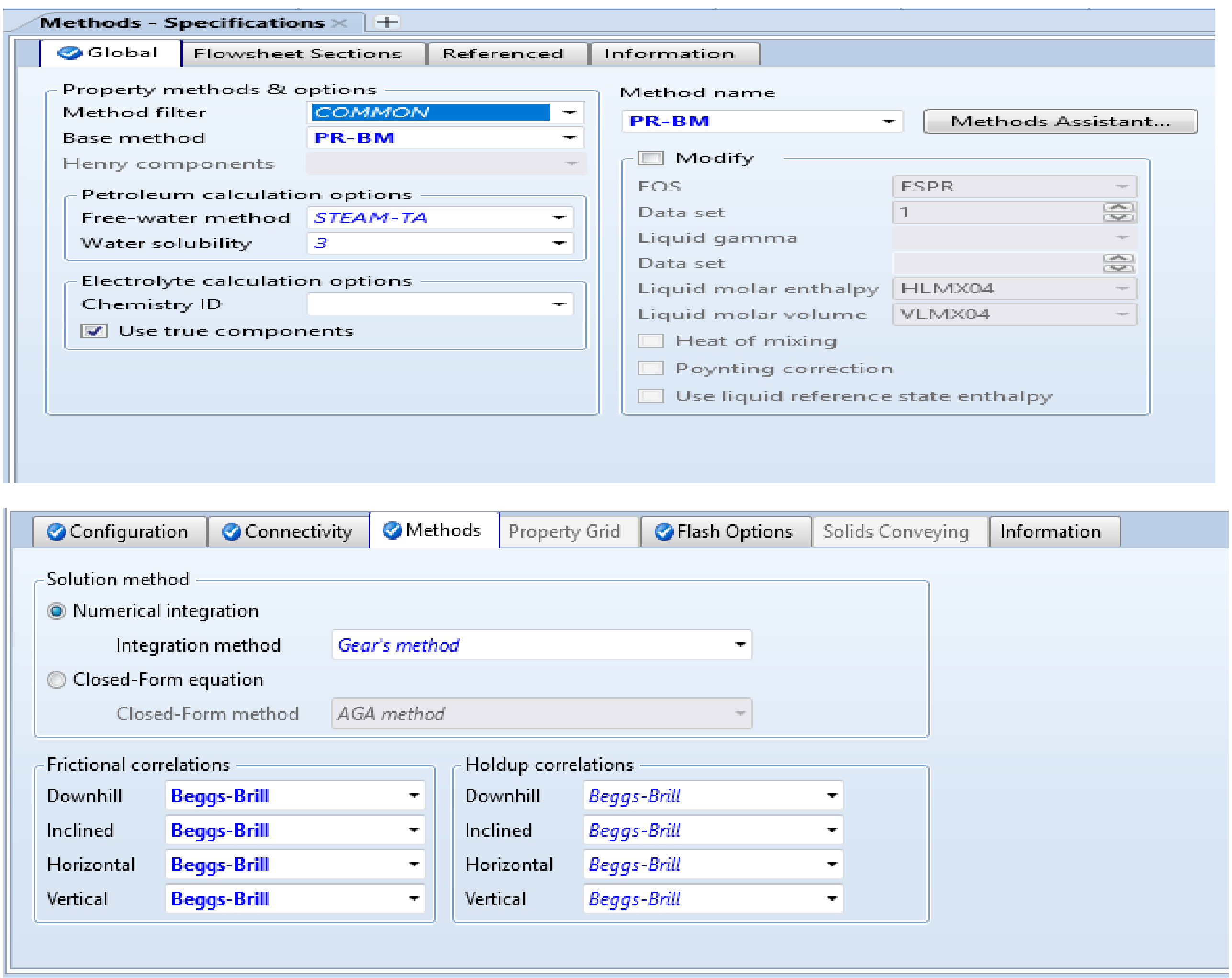


Figure 4.9 Selection of property method and Equations in Aspen

4.3 pipeline segment operation

In order to develop energy balance equation precisely 14 different segments have been selected that each of them has the specific coordinate and length, and for each segment Aspen and Olga provide geometry profile, temperature specification, inside diameter and wall thickness selection, pipeline material and absolute roughness, here we can see the software procedure for calculating the pressure profile;

Figure 4.10 Selection of first pipeline segment length and Coordinate

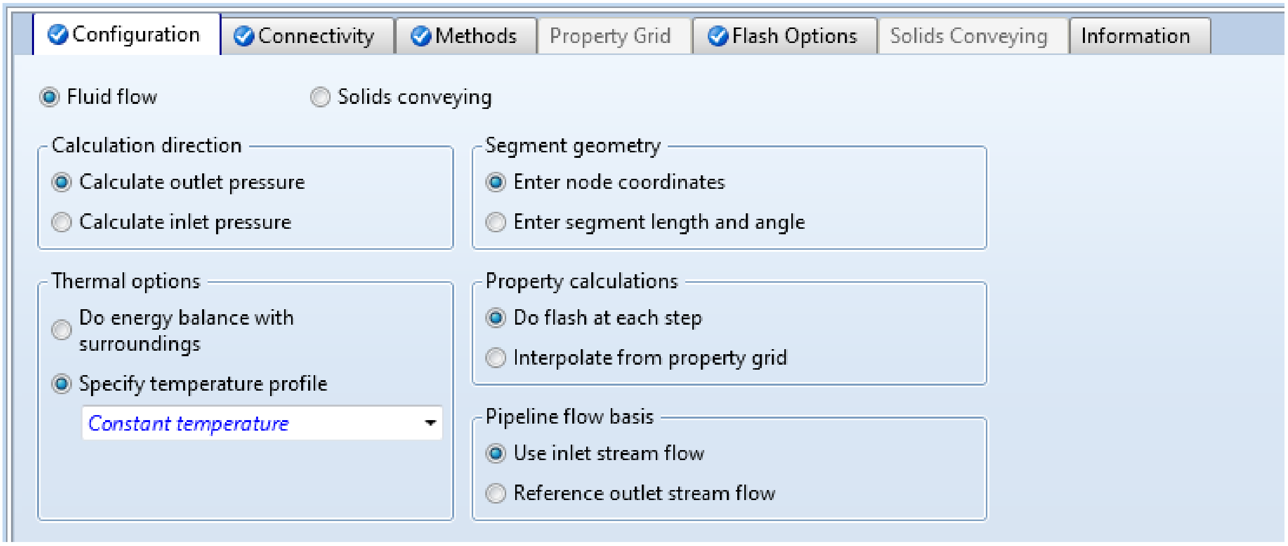
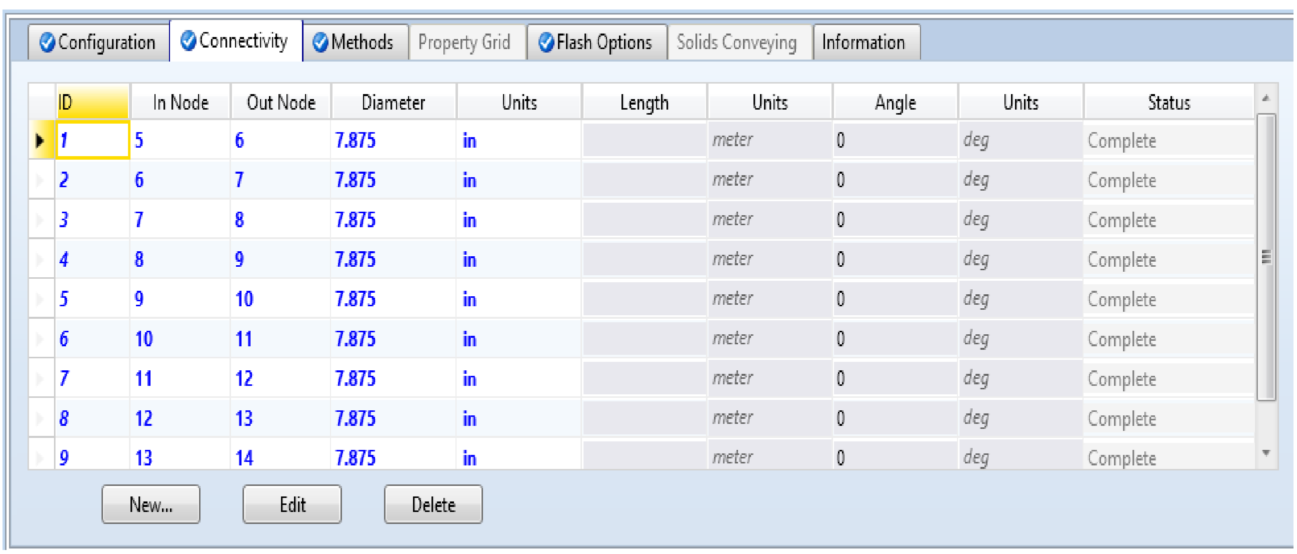


Figure 4.11 Configuration of Pipeline segment in Aspen



ID	In Node	Out Node	Diameter	Units	Length	Units	Angle	Units	Status
1	5	6	7.875	in		meter	0	deg	Complete
2	6	7	7.875	in		meter	0	deg	Complete
3	7	8	7.875	in		meter	0	deg	Complete
4	8	9	7.875	in		meter	0	deg	Complete
5	9	10	7.875	in		meter	0	deg	Complete
6	10	11	7.875	in		meter	0	deg	Complete
7	11	12	7.875	in		meter	0	deg	Complete
8	12	13	7.875	in		meter	0	deg	Complete
9	13	14	7.875	in		meter	0	deg	Complete

Figure 4.12 Representation of Connectivity of Pipeline segment in Aspen

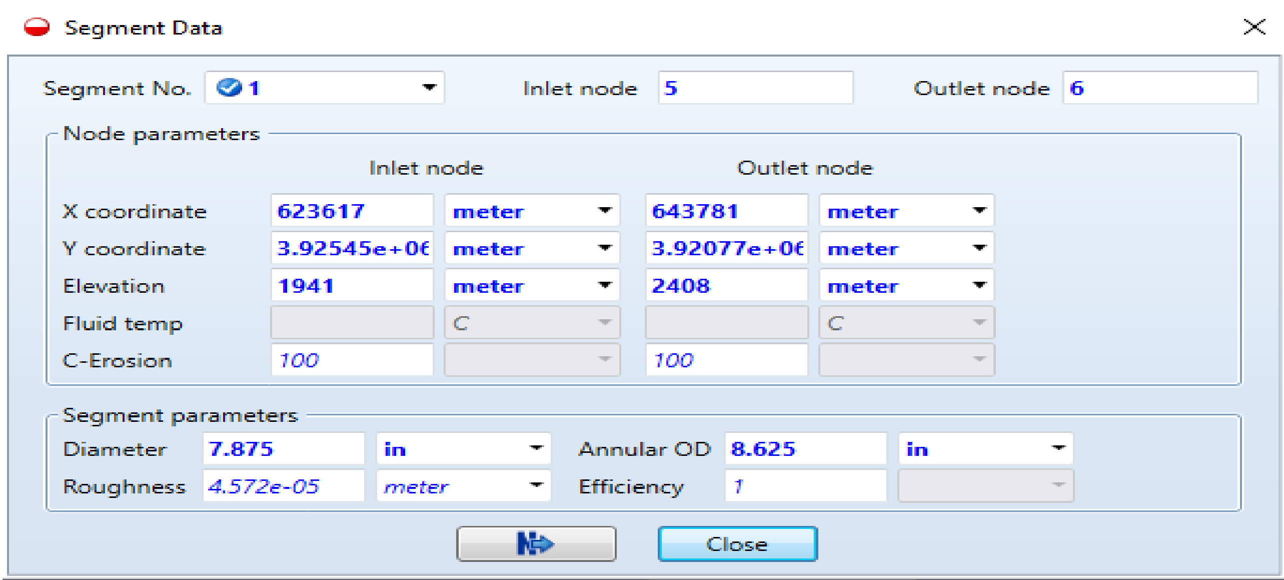


Figure 4.13 Representation of Segment input parameters in Aspen

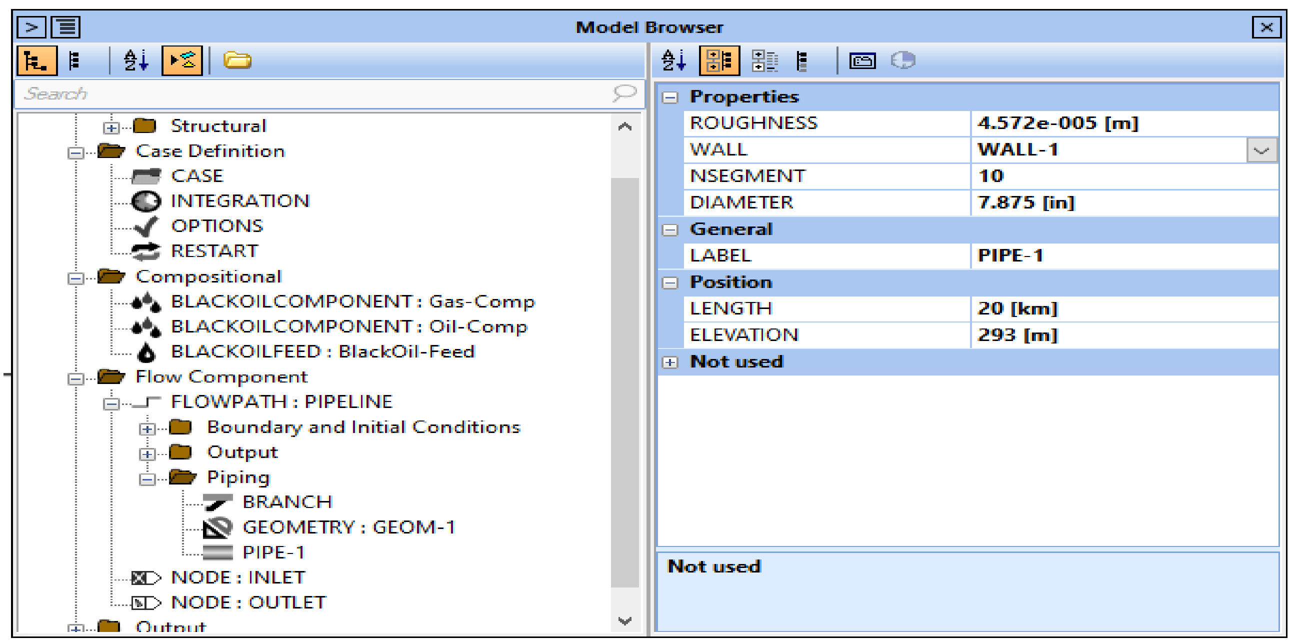


Figure 4.14 Representation of Segment input parameters in OLGA

4.4 Pumps

In order to compensate energy loss during the movement along the pipeline, pumping station should be installed, there are various pumps model to discharge pressure into the system, the calculation of pump head which is summarize of head required and fitting is necessary to select the proper pump.

Pump characteristic curve and dynamic and static head loss provide information to investigate the sizing of the pump station, usually several pumps are considered in parallel and series to meet the head requirement for the system

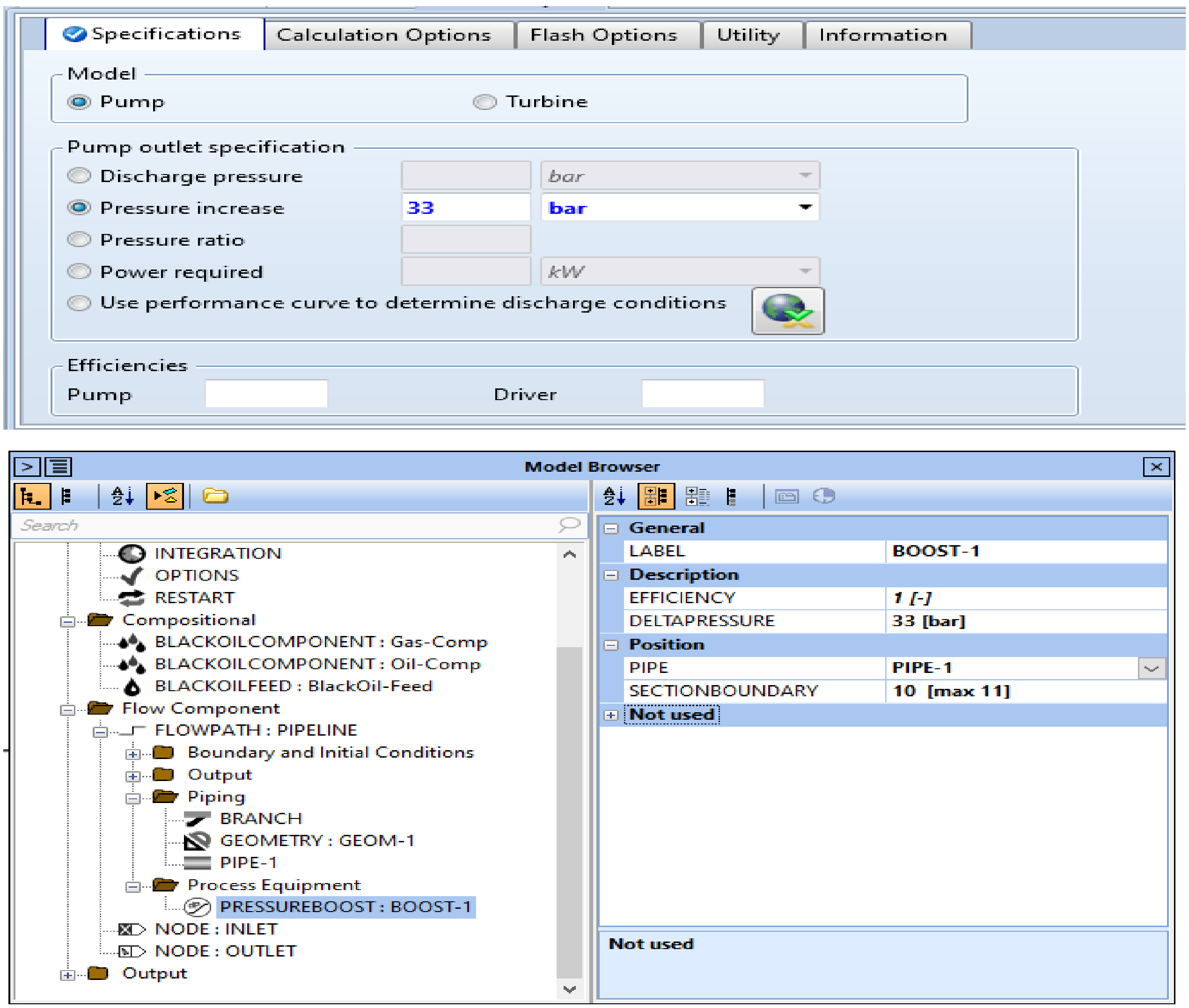
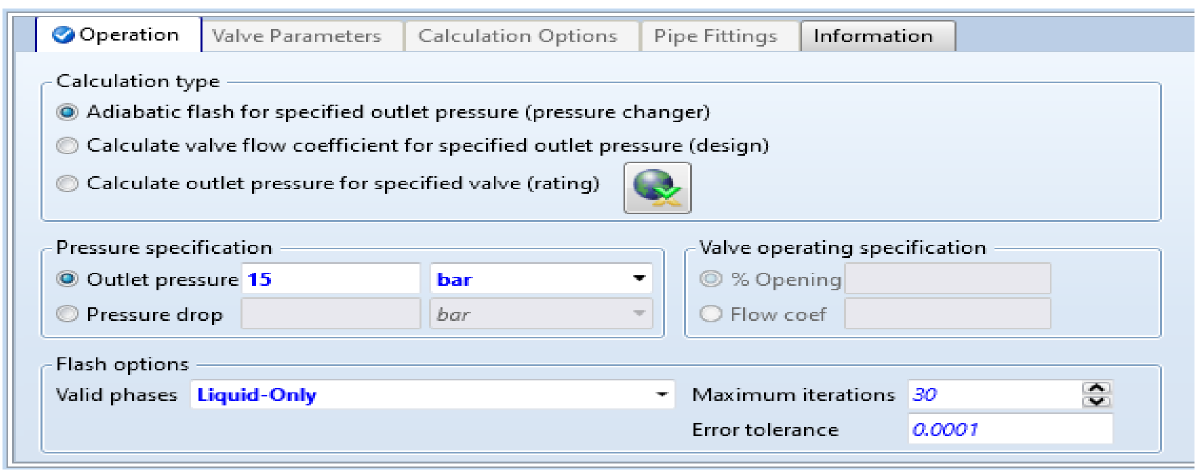
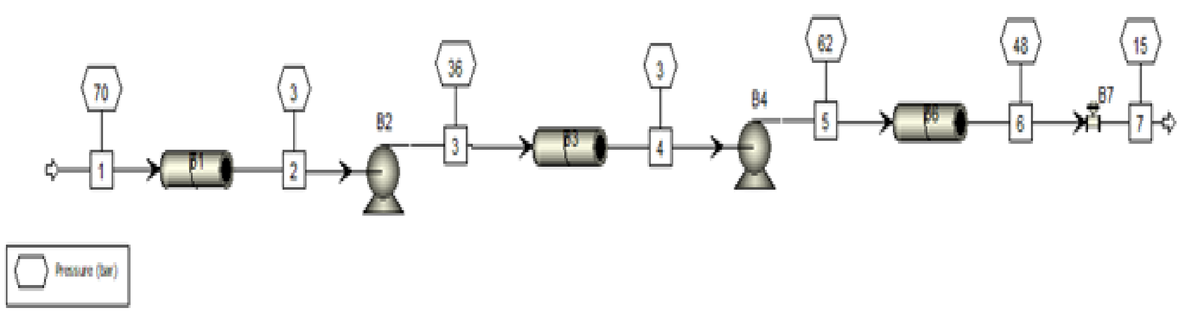


Figure 4.15 Specification of pump in Aspen and Olga

4.5 valves

Flow control is a major part of pipeline system for preventing the excess of pressure, when the pressure of the oil goes beyond the maximum allowable pressure we use valve to control the flow, in this project to meet the desired pressure of the end point we use valve to decrease the pressure,





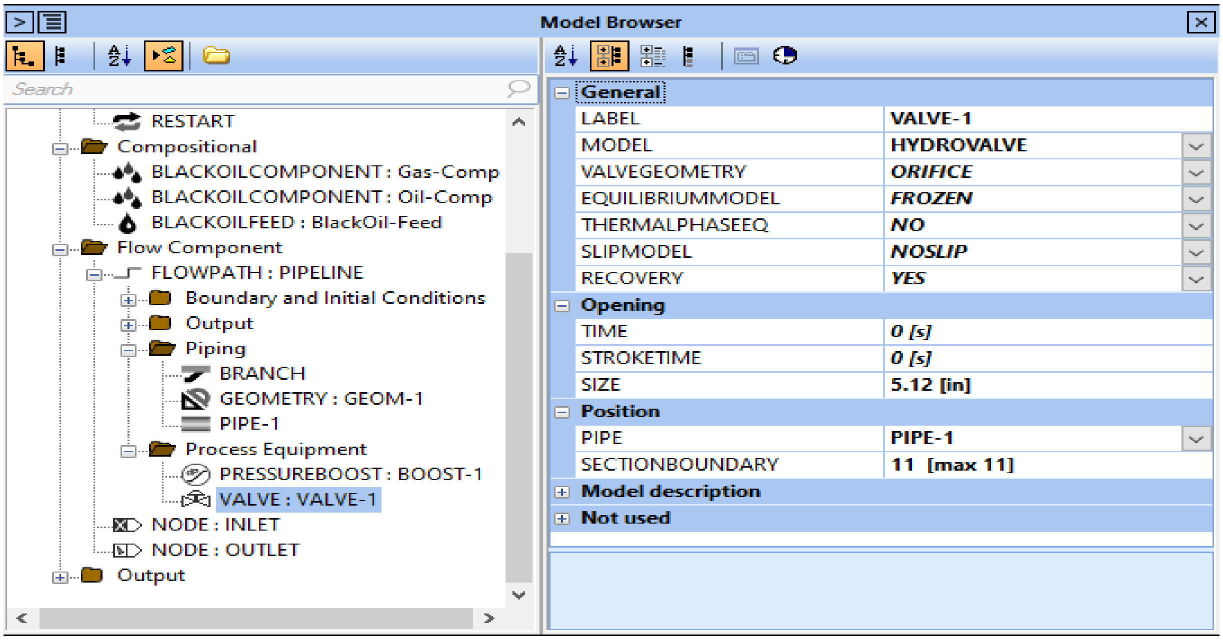


Figure 4.16 Specification of Valve in Aspen and Olga

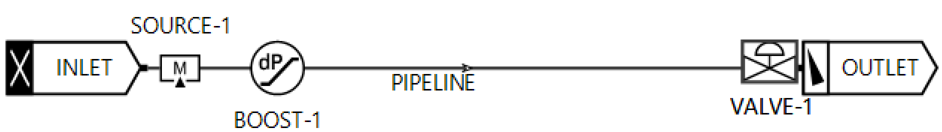


Figure 4.17 Schematic representation of pipeline design in Aspen and Olga flowsheet

Chapter Five: **Pipeline Design Measurement**

5.1 Friction Factor Calculation

Inner Diameter (in)	ε/D Stainless Steel	Friction Factor (Qmax)	Friction Factor (Qmin)	ε/D Carbon Steel	Friction Factor (Qmax)	Friction Factor (Qmin)
10.250	5.76147E-08	0.015594	0.016077	1.75533E-07	0.015595	0.016078
11.500	5.13523E-08	0.015955	0.016449	1.56453E-07	0.015956	0.016449
12.376	4.77175E-08	0.016185	0.016693	1.45379E-07	0.016184	0.016694
13.500	4.37445E-08	0.01648	0.016991	1.33275E-07	0.016481	0.016992
14	4.21822E-08	0.016608	0.017116	1.28515E-07	0.016608	0.01711
15.624	3.77977E-08	0.016967	0.0175061	1.15157E-07	0.016967	0.017506

Table 5.1 Friction Factor Calculation

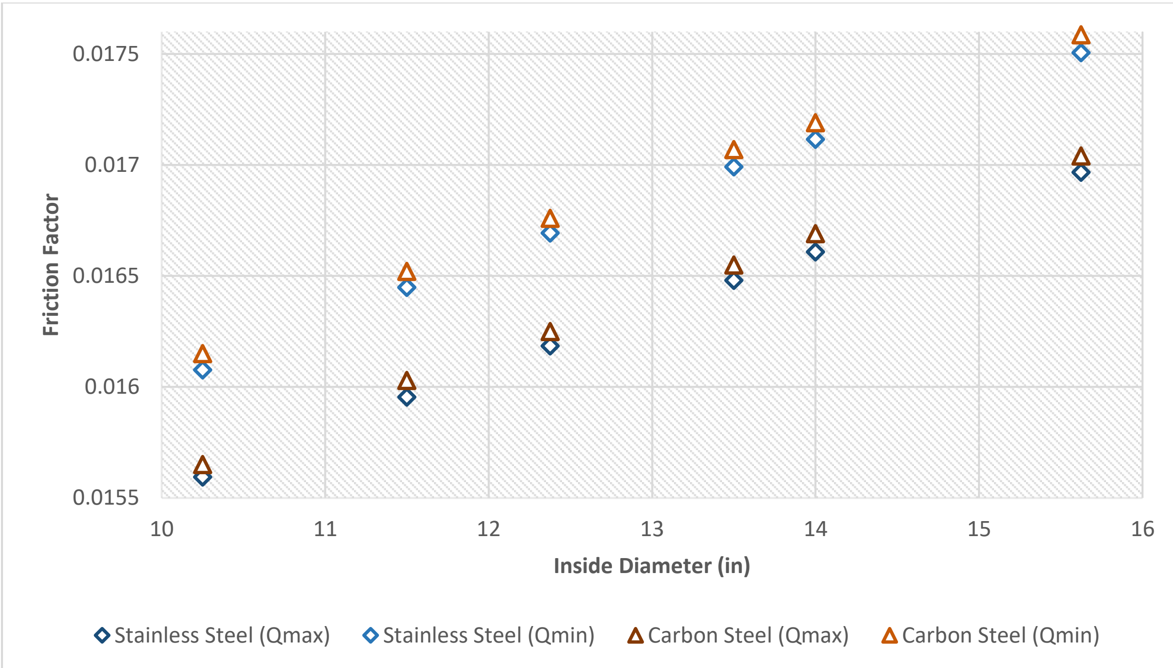


Figure 5.1 Friction Factor-Relative Roughness

5.2 Reynolds Number Calculation

Inner Diameter (in)	Reynolds Number (Qmax)	Reynold's Number (Qmin)
10.250	202854.4	173767.42
11.500	180569.44	154932.34
12.376	167982.46	143989.3
13.500	153459.49	131931.004
14	147694.03	127268.74
15.624	132866.8	114048.26

Table 5.2 Reynolds Number Calculation

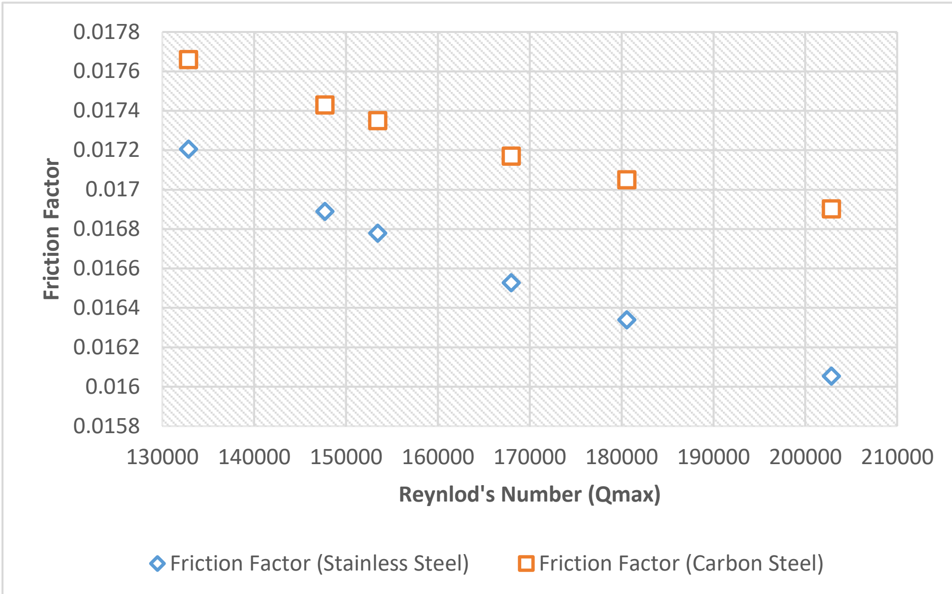


Figure 5.2 Friction Factor-Reynolds Number of maximum flow rate

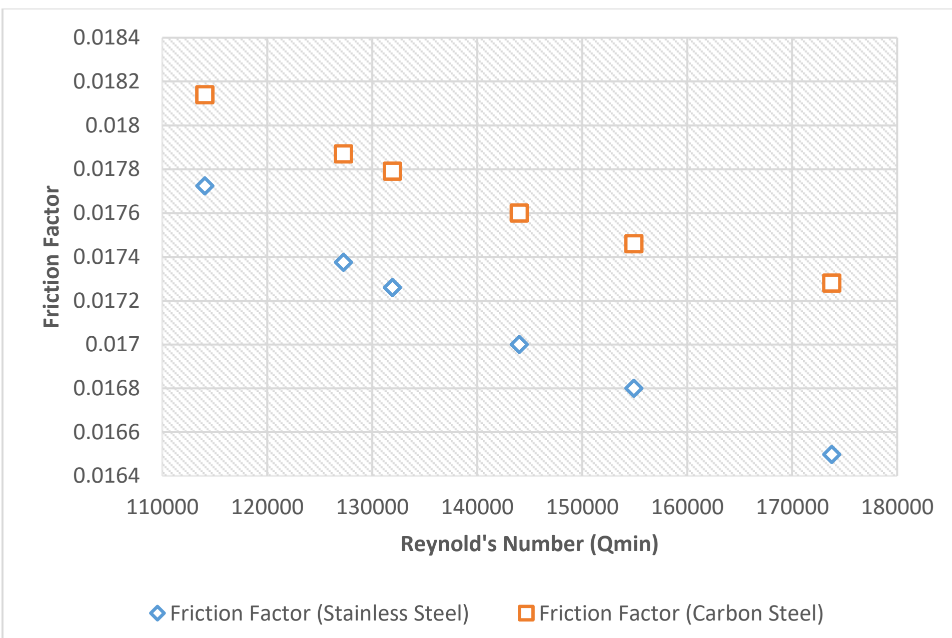


Figure 5.3 Friction Factor-Reynolds Number of minimum flow rate

5.3 Pressure drop per unit of length

5.3.1 Comparison of Experimental data and Simulation data

The second column of the table below is the values of the experimental data to the temperature of 69,8 ºC, which were obtained from the hydraulic slope and velocity relationship of heavy crude oil (API 11) through a PVC pipeline taking in consideration the and piping diameter is 0,2m. The friction factor was determined considering constant temperature values and the experimental results obtained.[20]

$$\boldsymbol{E_P} = \left|\frac{X_{exp} - X_{sim}}{X_{exp}}\right| .100 \qquad \textbf{Eq.10}$$

Q (m3/s)	dp/dz (pa/m) Exp	dp/dz (pa/m) OLG	dp/dz (pa/m) ASP	Relative Point Error
0.005	162.13	152.57	160.25	5.9-1.16
0.01	314.03	303.83	302.66	3.2-3.62
0.015	456.72	440.89	419.98	3.4-8.04
0.02	612.11	592.39	567.85	3.2-7.23
0.025	766.57	742.79	734.58	3.1-4.17
0.03	898.4	872.62	862.02	2.9-4.04
0.04	1189.06	1121	1128.02	5.7-5.13
0.044	1297.15	1227.44	1222.1	5.3-5.7

Table 5.3 Relative point error of pressure drop per unit of length

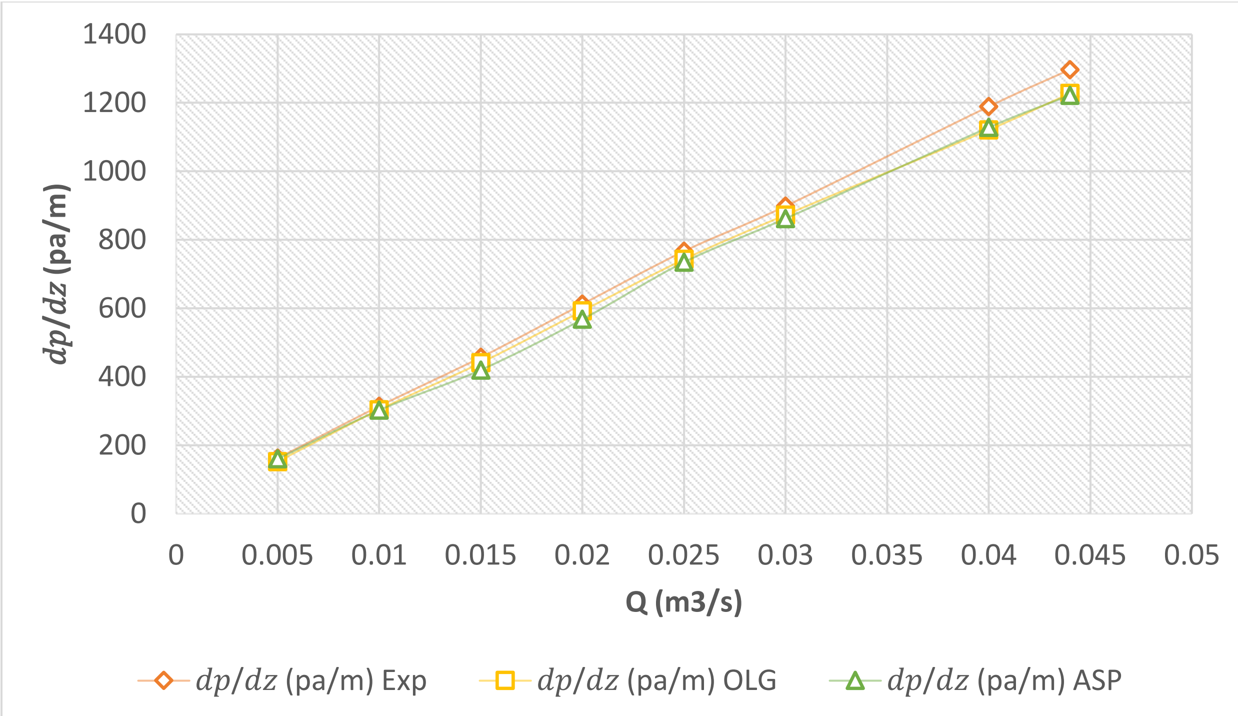


Figure 5.4 Pressure drop per unit of length of different simulation method

5.3.2 Different Ambient Temperature

	T= 16◦C		T= 22◦C		T= 30◦C	
Flow Rate (m3/s)	ASPEN (T= 16◦C)	OLGA (T= 16◦C)	ASPEN (T= 22◦C)	OLGA (T= 22◦C)	ASPEN (T= 30◦C)	OLGA (T= 30◦C)
0.1288	0.2305	0.2206	0.2249	0.2133	0.2198	0.2066
0.1104	0.1746	0.1692	0.1703	0.1636	0.1662	0.1583

Table 5.4 Pressure drop per unit of length for different ambient Temperature

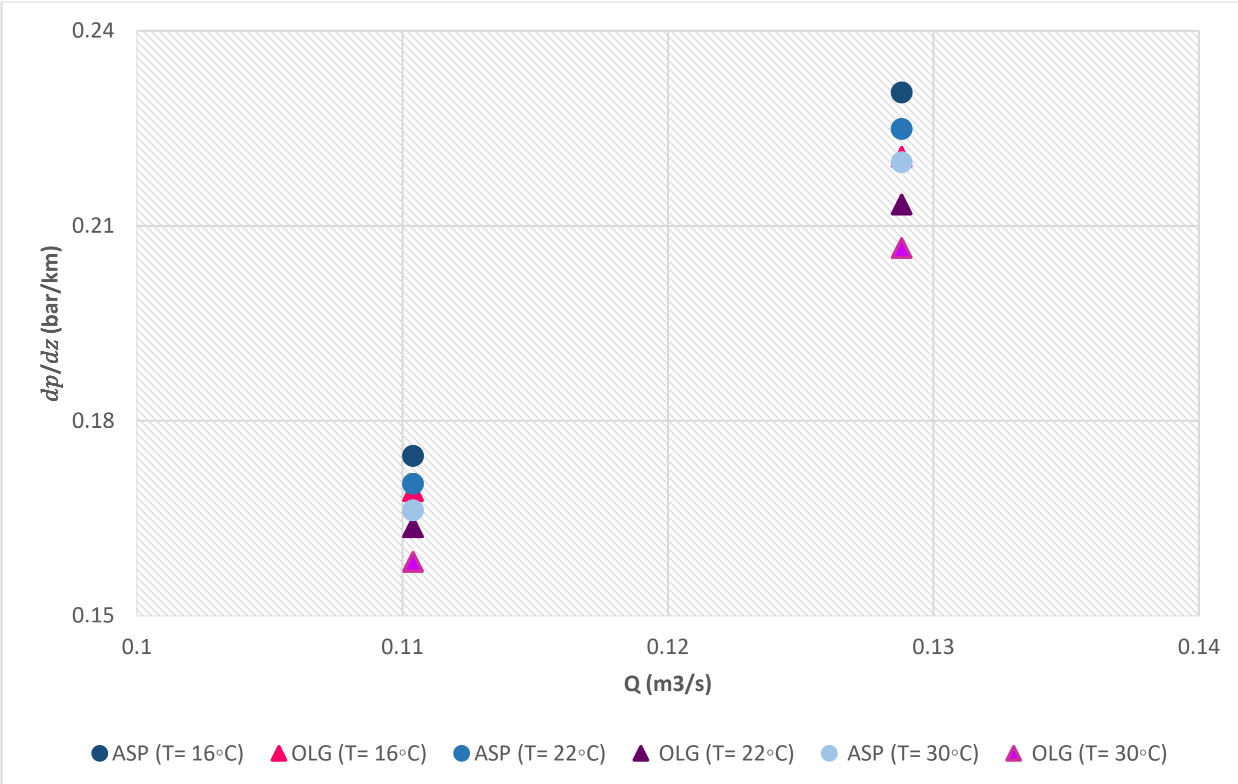


Figure 5.5 Pressure drop per unit of length for different ambient Temperature

5.3.3 Different Inside Diameter

Inside Diameter (in)	ASP (Qmax)	ASP (Qmin)	OLG (Qmax)	OLG (Qmin)
10.25	1.7319	1.3065	1.7986	1.3627
11.5	0.9906	0.748	1.0593	0.7822
12.376	0.694	0.5243	0.7557	0.5739
13.5	0.4556	0.3444	0.5232	0.3722

14	0.3822	0.2889	0.4569	0.3114
15.624	0.2249	0.1703	0.3133	0.2036

Table 5.5 Pressure drop per unit of length for different Inside Diameter

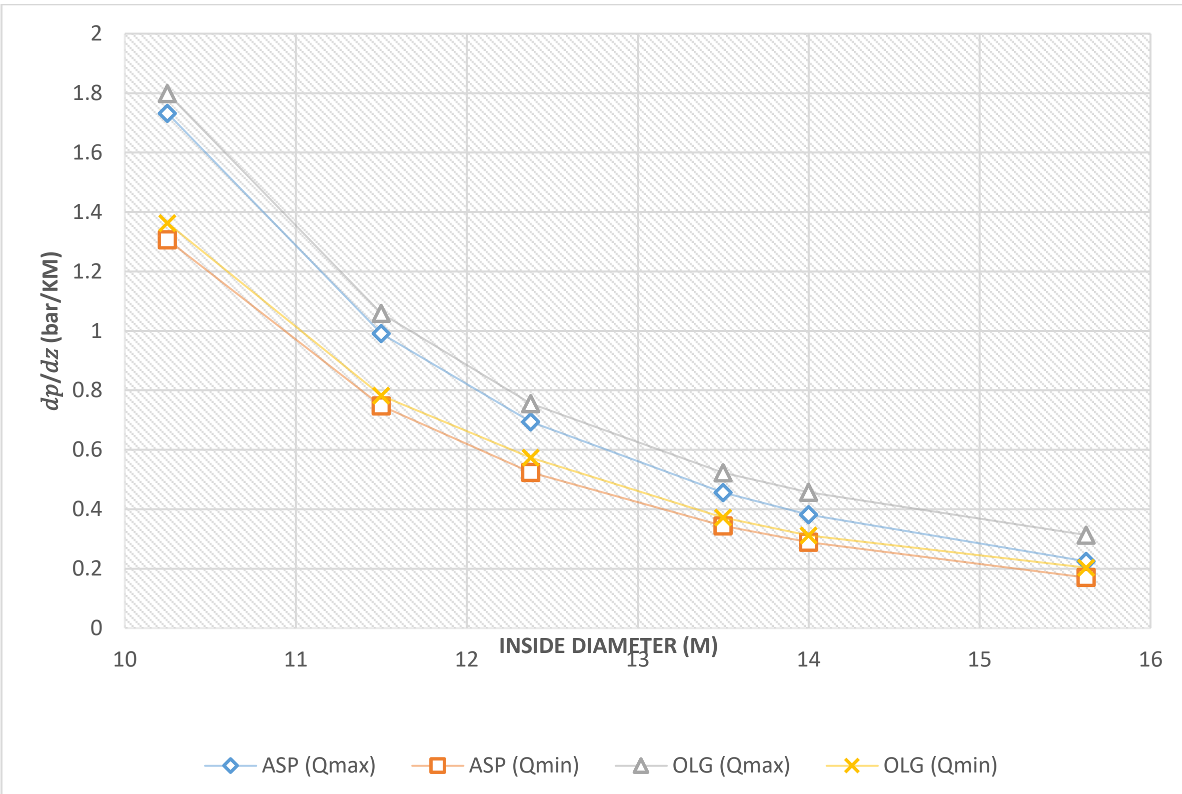


Figure 5.6 Pressure drop per unit of length for different Inside Diameter

5.3.4 Different Pipeline Material

Flow Rate (m3/s)	ASP (CARBON STEEL)	ASP (STAINLESS STEEL)	OLG (CARBON STEEL)	OLG (STAINLESS STEEL)
0.1288	0.232	0.228	0.302	0.298
0.1104	0.175	0.171	0.233	0.23

Table 5.6 Pressure drop per unit of length for different Material of Pipeline

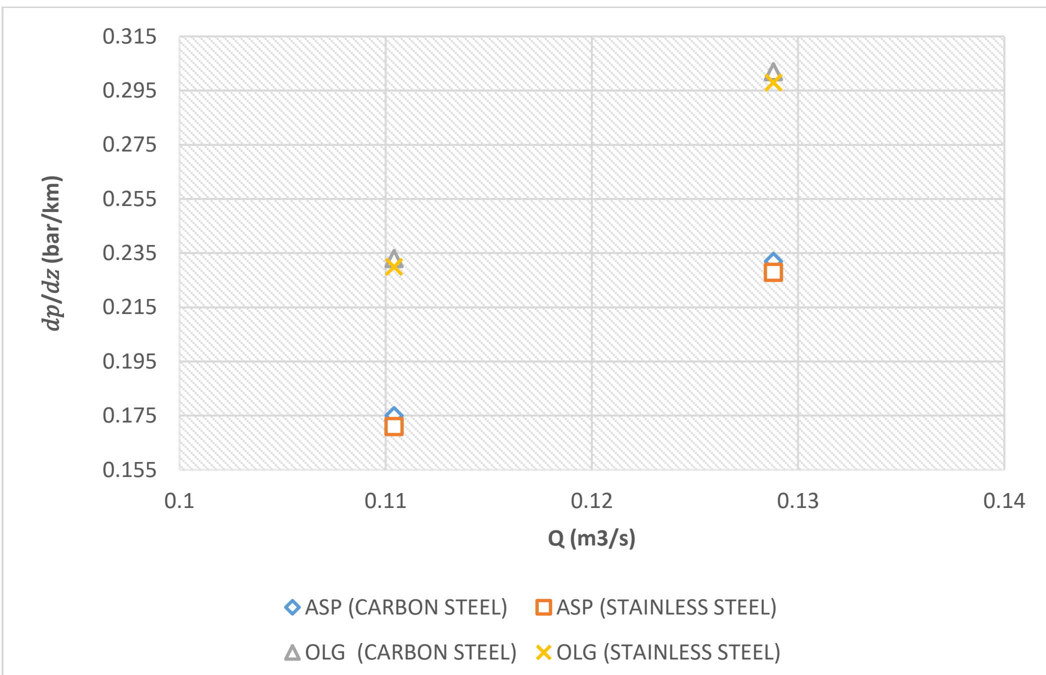


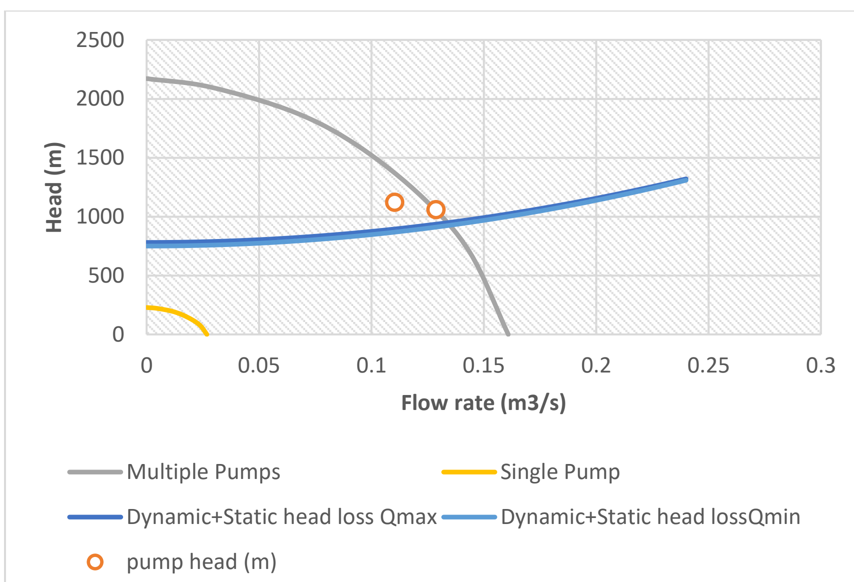
Figure 5.7 Pressure drop per unit of length for different Material of Pipeline

5.3.5 Pump head calculation (ASPEN)

Q(m3/s)	pump head (m)
0.1104	1120.16
0.1288	1058.08

Pumps in Parallel 6	Pumps in Series 9
Q(m3/s)	Multiple Pumps
0	2171.726
0.028391	2099.336
0.066245	1882.163
0.094635	1592.599
0.123026	1158.254
0.143846	694.9525
0.16088	0

Pump characteristic curve					
Q (gpm)	Total Q (gpm)	Head (ft)	Total Head (ft)	Q(m3/s)	Single Pump
0	0	150	750	0	228.6028
15	75	145	725	0.004732	220.9827
35	175	130	650	0.011041	198.1224
50	250	110	550	0.015773	167.642
65	325	80	400	0.020504	121.9215
76	380	48	240	0.023974	73.15289
85	425	0	0	0.026813	0

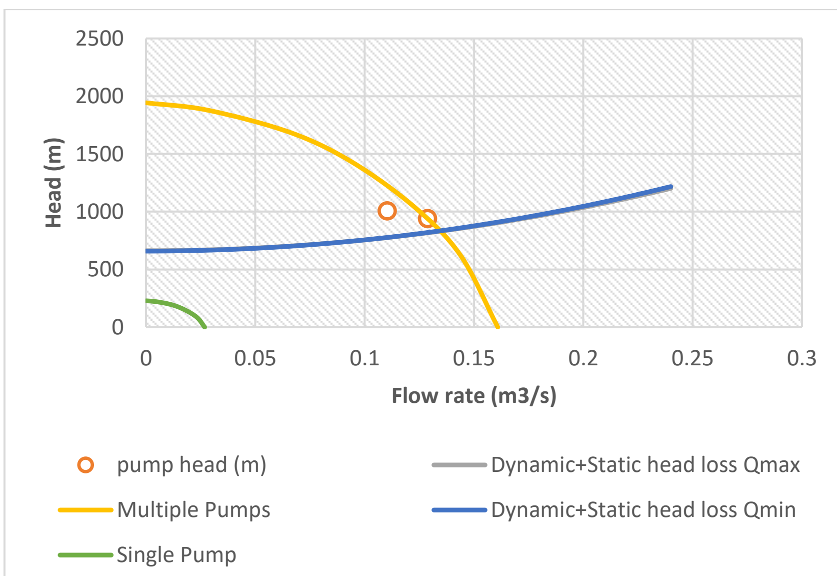


5.3.5 Pump head calculation (ASPEN)

Q(m3/s)	pump head (m)
0.1104	1005.55
0.1288	939.087

Pumps in Parallel 6	Pumps in Series 8
Q(m3/s)	Multiple Pumps
0	1943.124
0.028391	1878.353
0.066245	1684.04
0.094635	1424.957
0.123026	1036.333
0.143846	621.7996
0.16088	0

Pump characteristic curve					
Q (gpm)	Total Q (gpm)	Head (ft)	Total Head (ft)	Q(m3/s)	Single Pump
0	0	150	750	0	228.6028
15	75	145	725	0.004732	220.9827
35	175	130	650	0.011041	198.1224
50	250	110	550	0.015773	167.642
65	325	80	400	0.020504	121.9215
76	380	48	240	0.023974	73.15289
85	425	0	0	0.026813	0



5.4 Pressure Profile

Inside Diameter 15.624 in, Stainless Steel Pipeline, Minimum flow rate

Wall thickness 1.188 in

Length (km)	Pressure (bar) ASPEN	Pressure (bar) OLGA
0	60	60
20	43.9195577	44.7205
40	3.36466194	11.69102
60	5.42936652	12.06292
60	77	77
80	51.2098695	52.5463
100	13.9278498	19.5827
120	3.39639802	8.97342
140	92.2996676	96.09732
160	106.940137	110.55152
180	108.936926	112.7385
200	104.513817	108.8445
220	95.8042636	100.9505
240	87.6581757	93.617
273	82.4579806	86.8809
273	20	20

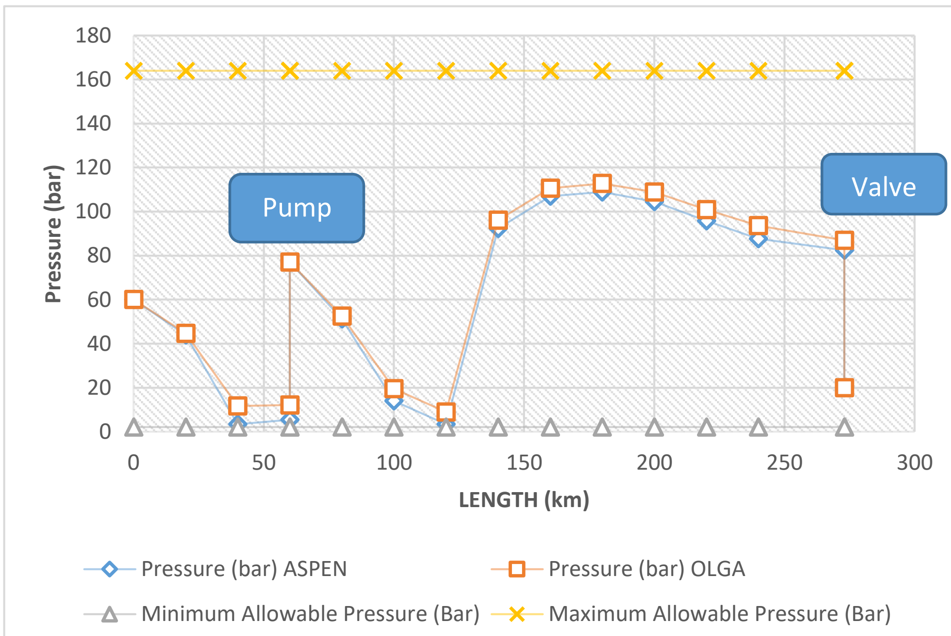


Figure 5.8 Pressure Profile 15.624 in, Stainless Steel Pipeline

Inside Diameter 15.624 in, Stainless Steel Pipeline, Maximum flow rate

Length	Pressure (bar) ASPEN	Pressure (bar) OLGA
0	60	60
20	43.8406549	44.64159
40	2.20717044	10.533528
60	3.19086339	11.824416
60	80	80
80	53.1318192	54.46825
100	14.7429336	20.39778
120	3.15130926	8.728331
140	90.9548326	94.75248
160	104.519081	108.1305
180	105.428354	109.23
200	99.9632354	104.29394
220	90.1674847	95.31372
240	80.9258347	86.88465
273	74.5903902	79.01331
273	20	20

Wall thickness 1.188 in

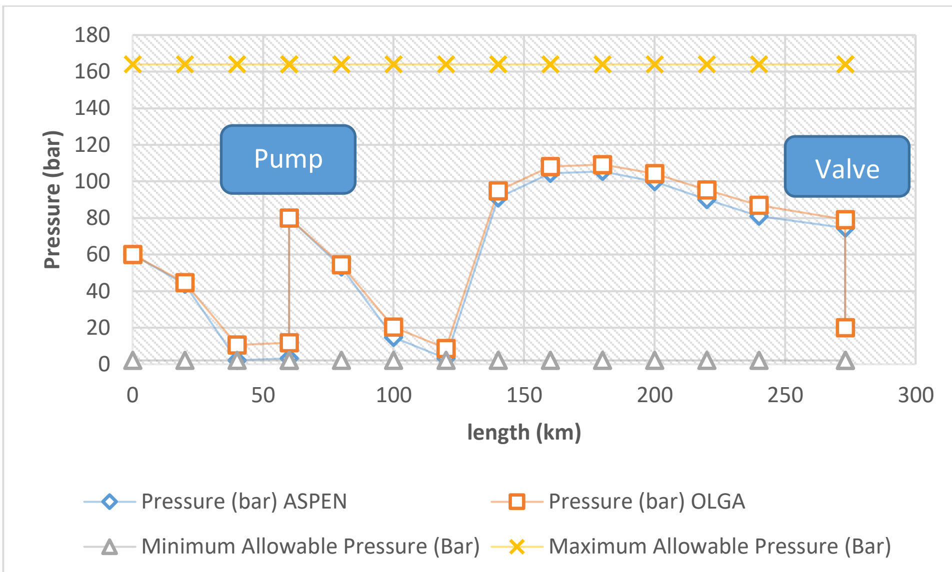
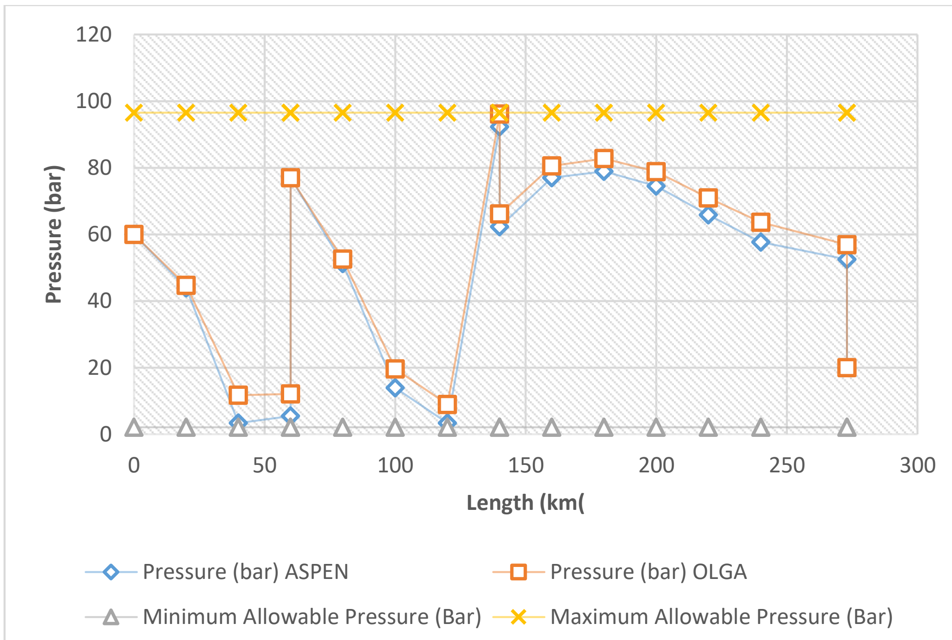


Figure 5.9 Pressure Profile 15.624 in, Stainless Steel Pipeline

Inside Diameter 15.624 in, Stainless Steel Pipeline, Minimum flow rate

Length (km)	Pressure (bar) ASPEN	Pressure (bar) OLGA
0	60	60
20	43.91956	44.7205
40	3.364662	11.69102
60	5.429367	12.06292
60	77	77
80	51.20987	52.5463
100	13.92785	19.5827
120	3.396398	8.97342
140	92.29967	96.09732
140	62.29967	66.09732
160	76.94014	80.55152
180	78.93693	82.7385
200	74.51382	78.8445
220	65.80426	70.9505
240	57.65818	63.617
273	52.45798	56.8809
273	20	20

Wall thickness0.188 in

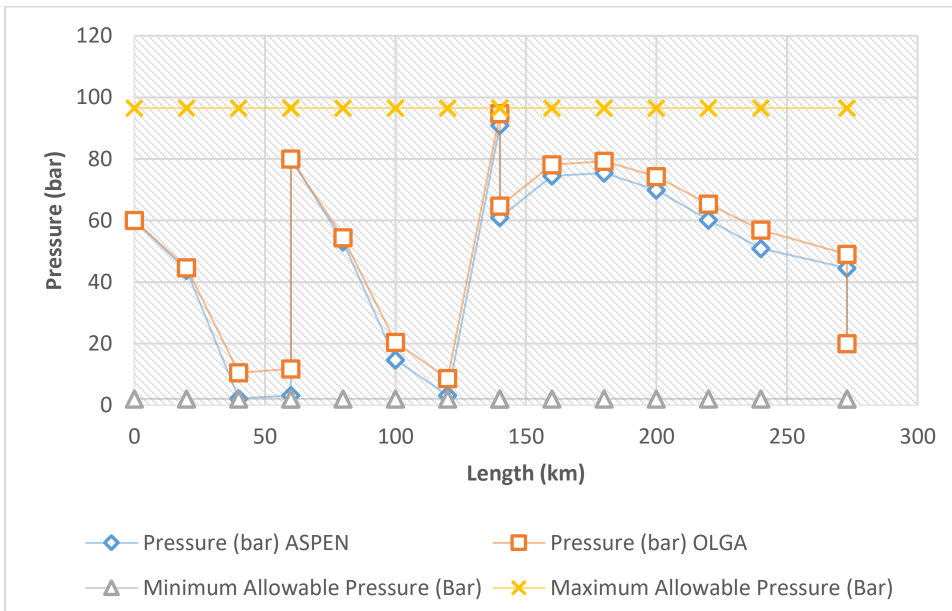


Pressure Profile 15.624 in, Stainless Steel Pipeline

Inside Diameter 15.624 in, Stainless Steel Pipeline, Minimum flow rate

Length	Pressure (bar) ASPEN	Pressure (bar) OLGA
0	60	60
20	43.84065	44.64159
40	2.20717	10.53353
60	3.190863	11.82442
60	80	80
80	53.13182	54.46825
100	14.74293	20.39778
120	3.151309	8.728331
140	90.95483	94.75248
140	60.95483	64.75248
160	74.51908	78.1305
180	75.42835	79.23
200	69.96324	74.29394
220	60.16748	65.31372
240	50.92583	56.88465
273	44.59039	49.01331
273	20	20

Wall thickness0.188 in



Pressure Profile 15.624 in, Stainless Steel Pipeline

Chapter Six: **Summary and Conclusion**

In this thesis project, the Oil transportation pipeline from Tehran to Semnan which has a distance 273 kilometers (figure 3.1) has been designed. Aspen plus and Olga software provide simulation environment in order to assess various factors that affect the pressure profile of a light crude oil through a Pipeline.

With respect to the minimum and maximum flow rate and velocity of a light crude oil (table 3.5), Six different inside diameter of carbon steel and Stainless steel pipeline from 10.250 to 15.624 inches have been considered and according to API 5l, maximum allowable pressure (table 3.6) has selected, the phase diagram of a light crude oil (figure 3.3) the minimum allowable pressure inside the pipeline is equal to 2.1 bar at an average temperature 22°C.

With increasing the inside diameter of the pipeline, reynolds number has increased respectively, and the friction factor goes downward, So higher inside diameter causes lower pressure drop through a pipeline. (figure 5.7) In other word the smaller diameter causes higher velocity through a pipeline thus the energy loss is higher because of higher frictional loss.

According to the ambient temperature of a intended area maximum (30°C) and minimum (16°C) temperature are considered, Analysis shows that

Pressure drop per unit of length and total pressure drop respectively for the minimum flow rate and the higher temperature (figure 5.6) is lower than the maximum flow rate and the lower temperature for each specific diameter.

Result obtained from Carbon Steel and Stainless steel (figure 5.8) demonstrates that for both the relative roughness is decreasing with increasing the inside diameter and the total pressure pressure drop for carbon steel is higher than stainless steel.

Comparison of pressure drop per unit of length for experimental data of crude oil through a pipeline with the same hydrocarbon and pipeline properties in Aspen and Olga software environment (table 5.3) demonstrates that relative point error for Olga software is lower than Aspen. Precisely With respect to the experimental data, average relative point error for OLGA software is 4.08 and for Aspen is 4.88. Pressure drop predicted by OLGA fairly matched the experimental data for a wide range of oil flow rates.

Result of 15.624 (in) Stainless steel pipeline represents that the total pressure drop during the movement of oil through a pipeline is much lower than the other selected inside diameter, so there is low energy needed to increase by pump with respect to the other diameters.

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