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RESEARCH ARTICLE

Simulation and evaluation of fuel distribution line from fuel terminal Tuban into integrated terminal Surabaya at PT Pertamina MOR V through ASPEN Plus® modeling

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OBJECTIVES This research aims to 1) to determine operating conditions that correspond to the amount of fuel needed to be distributed, 2) visualize the profile of pressure changes with pipe distance, and 3) carry out simulation of techno-economic analysis to estimaste the overall costs of fuel distribution process through pipeline. METHODS The research method consists of simulation of energy loss in the form of pressure drop for each type of fuel oil (gasoline and gasoil) using ASPEN Plus® software. RESULTS Research results show that a greater pump pressure of 87 bar is required to distribute gasoil, compared to gasoline which only uses 82 bar to reach ideal atmospheric pressure at 750 m3/hour. Reduction in fuel pumping pressure is close to linearity, where pumping pressure will continue to decrease as piping distribution distance increases. Based on the economic analysis of cost requirements for fuel distribution from FT Tuban to IT Surabaya, it takes a larger cost to distribute gasoil than gasoline. CONCLUSIONS This research has been in accordance with the real conditions in the field, so it can predict the right conditions to maximize the process.

KEYWORDS fuel distribution; piping line; pressure drop; process simulation

1. INTRODUCTION

Fuel is a substance that can be used to produce energy through combustion or chemical reactions (Sanni et al. 2024). Fuels are generally used in the combustion process to produce heat or energy and can be classified into several types, including fossil fuels and renewable fuels (Xu et al. 2023). Fossil fuels involve natural resources such as oil, coal, and natural gas (Cheng et al. 2022), while renewable fuels include renewable energy sources such as solar, wind, water, and biomass (Paraschiv and Paraschiv 2023). Based on data from the Ministry of Transportation of Republic Indonesia in 2023, there will be 97% of fuel oil demand in private vehicles, with the remaining 3% used for utilities and public facilities. Changes in Indonesia's oil supply and demand conditions cause the costs required to intervene in fuel prices to increase. Forecasting through simulations shows that starting in 2025 the supply of fuel cannot meet domestic fuel needs which are predicted to reach 651,092 million barrels and fuel consumption to reach 719,048 million barrels (Sa'adah et al. 2017). This is supported by many factors, one of which is the fuel distribution process.

The development of new technologies in fuel storage and distribution continues to drive the evolution of the energy sector, one of which is applied by the distribution of Fuel Terminal (FT) Tuban into Integrated Terminal (IT) Surabaya pipeline distribution line. Fuel sources in the form of gasoline and gasoil are obtained from FT Tuban through a distribution line using pipes to IT Surabaya. The fuel transfer process is carried out using underground pipe through a pump from FT Tuban which is adjusted based on needs. Based on the problems that often occur in the field, FT Tuban has not been able to estimate the appropriate pump pressure when needed to distribute fuel in quantities different from the standard. Often the pressure to IT Surabaya is excessive, which can reduce process efficiency and increase operating costs.

In this study, a petroleum distribution simulation was carried out at PT Pertamina MOR (Marketing Operation Re-

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FIGURE 1. Fuel distribution line of FT Tuban to IT Surabaya.

gion) V covering the area of East Java, Bali, and Nusa Tenggara. This study simulates and evaluates energy loss in the form of pressure drop for each type of fuel in the FT Tuban to IT Surabaya fuel distribution line equipped with sensitivity analysis features through ASPEN Plus® software to get the best operating conditions. The main objectives of this study are: 1) to determine operating conditions that correspond to the amount of fuel needed to be distributed, 2) visualize the profile of pressure changes with pipe distance, and 3) carry out simulation of techno-economic analysis to estimaste the overall costs of fuel distribution process through pipeline.

Related studies are reviewed based on simulation modeling and parameters adapted from several researchers. Herman et al. (2020) conducted a pressure drop analysis in natural gas piping systems. In a study by Luo et al. (2014), simulations were carried out on the CO_2 distribution process in the petroleum industry based on techno-economic evaluation for different main pipeline design variations. In another study, Mohamed Bey et al. (2021) designed a simulation on a natural gas pipeline network using different software, namely PIPSYS. Amer et al. (2024) also analyzed the effect of hydrogen blending ratio on gas compression in natural gas distribution pipes. However, a few studies only discuss gas distribution simulations in piping systems. Reviewing the lack of references for fuel distribution simulations, this research is presented with a novelty discussion which includes: 1). flow rate efficiency opportunities for each destination pressure difference, 2). flow rate that must be maintained to meet the pressure at the destination (atmospheric), 3). pressure required by Tuban to Surabaya at each flow rate, 4) distribution pressure profile over a certain distance, 5) Influence of Underwater Environment on Fuel Distribution Process, and 6) Techno-Economics Analysis.

2. RESEARCH METODOLOGY

TABLE 1. Physical properties simulation of fuel variations (Huth and Heilos 2013; Yaws 1999; Jakkula et al. 2012).

Parameters	Pertalite	Pertamax	Diesel Fuel
Phase	Liquid	Liquid	Liquid
Hydrocarbon Chain Content	C8H18 (90%)	C8H18 (92%)	C12H24 (75%)
Aromatic Content Hydrocarbons	C7H16, (10%)	C7H16, (8%)	C6H6, (25%)
Additive Content	-	-	-
Material Density (kg/m3)	706,48	707,46	747,51
Boiling Point (K)	377,89	378,2	412,98
Material Viscosity (kg/m.s)	49 x 10-4	5 x 10-4	6 x 10-4
Total Flow Rate (m3/jam)	750	750	750
Temperature of Operation (K)	308,15	308,15	308,15
Suction Pressure (bar)	4,43	4,43	4,43
Number of Elbows 90o	25	25	25
Number of Elbows 45o	50	50	50
Number of Elbows 22.5o	163	163	163
Roughness of Pipe (meter)	4.57E-05	4.57E-05	4.57E-05
Number of Valves	14	14	14
Discharge Pressure (bar)	82	82	87

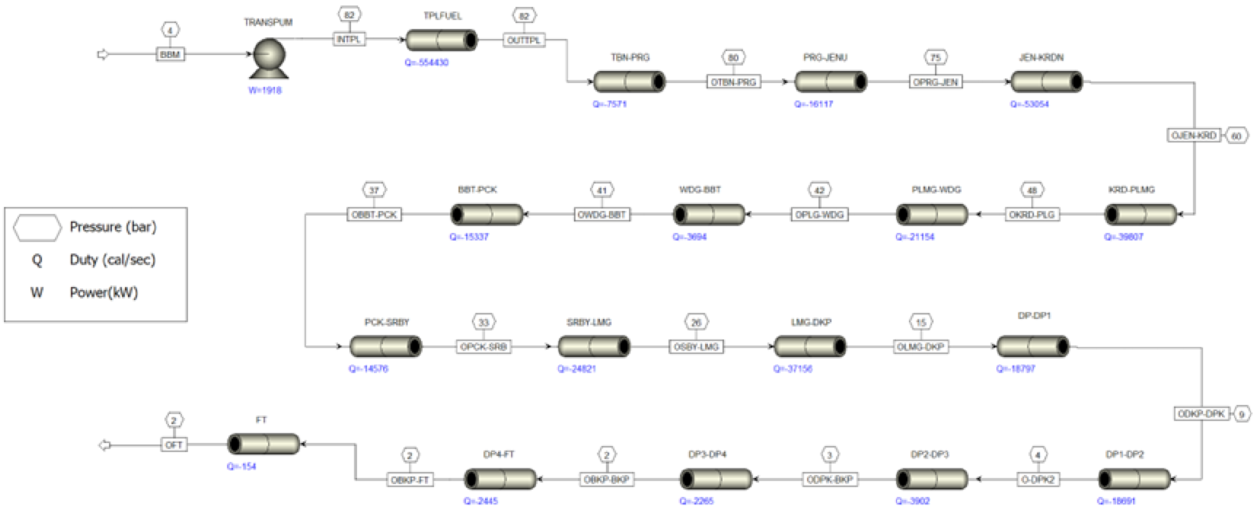

FIGURE 2. ASPEN Plus® flowsheet, based on fuel distribution line from FT Tuban into IT Surabaya.

2.1 Instrument

ASPEN® stands for Advanced Simulation and Process Engineering Environment. It is a highly advanced and integrated software used in the chemical engineering industry. This software enables engineers and process and engineering professionals to perform process simulation, process design, and reliability analysis of process systems. This software has several features and uses, including: 1). Process Simulation, 2). Process Design, 3). Performance Analysis, 4). Process Optimization, 5). Thermodynamic Modeling, 6). Process Data Management, 7). Training and Education (Aspen Technology 2000). ASPEN® is software that uses an official paid license, where the author uses the system name: SYS918942.5 with key serial number of 918942 which provided by Laboratory of Computing and Simulation at Universitas Islam Indonesia to avoid software piracy.

2.2 Fuel distribution line

Distribution line of the three types of fuel supplied by FT Tuban to IT Surabaya is channeled through 18" (inch) diameter of pipes with a total distance of 140.8 KM that passes through 4 cities, 14 villages, and 14 sub-districts which is illustrated in Figure 1. The distribution line is equipped with 14 Emergency Shutdown Valves (ESDV) that function to secure the distribution line from leakage and theft. ESDV is a common component in safety instrumented systems (SIS) that is often used in securing industrial processes and autonomous detection of potential hazards (Cameron et al. 2023). ESDV works by providing a minimal pressure difference when the valve is in the fully open position (A. Wells 2021). In operation, ESDV is equipped with a controller that has a setpoint pressure which is the maximum limit of operating pressure, if the operating pressure exceeds the set point pressure, the valve will automatically close fully and reduce the process pressure (Demissie et al. 2017). Some parts of the pipeline pass through the Java Sea between ESDV 2 and ESDV 3, this is planned because there are residential areas that cannot be passed by the pipeline.

Fuel distribution process is carried out by flowing 3 types of fuel sequentially at certain intervals to reduce the oc-

TABLE 2. Actual length of pipe in each section.

Pipe Section Name	Brief Code	Actual Length of Pipe (meter)
TPL Fuel Terminal Tuban	TPLFUEL	130
FT Tuban – Pereng	TBN-PRG	5040
Pereng - Jenu KP 15	PRG-JENU	10918
Jenu KP 15 - Kradengan KP 33	JEN-KRDN	18556
Kradenan KP 33 - Plumpang KP 47	KRD-PLMG	14005
Plumpang KP 47 - Widang KP 62	PLMG-WDG	14591
Widang KP 62 - Babat KP 64	WDG-BBT	2422
Babat KP 64 - Pucuk KP 75	BBT-PCK	10568
Pucuk KP 75 - Surabayan KP 85	PCK-SRBY	10058
Surabayan KP 85 - Lamongan KP 94	SRBY-LMG	8814
Lamongan KP 94 - Duduk KP 107	LMG-DKP	13304
Duduk KP 107 - Dupak Bunker KP 134	DP-DP1	13175
Dupak Bunker KP 134 – Dupak Bunker KP 136	DP1-DP2	13144
Dupak Bunker KP 136 – Dupak Bunker KP 137	DP2-DP3	2601
Dupak Bunker KP 137 – Dupak Bunker KP 138	DP3-DP4	1438
Dupak Bunker KP 138 – FT ISG KP 139	DP4-FT	1573
FT ISG KP 139	FT	174

TABLE 3. Actual length of pipe in each section.

Parameter	Fuel Type		
	Pertalite	Pertamax	Diesel Fuel
Total Capital Cost [USD]	$ 2.775.060,00	$ 2.774.780,00	$ 2.896.450,00
Total Operating Cost [USD/Year]	$ 2.626.640,00	$ 2.626.640,00	$ 2.903.680,00
Total Utilities Cost [USD/Year]	$ 1.555.960,00	$ 1.555.960,00	$ 1.809.370,00
Equipment Cost [USD]	$ 516.100,00	$ 515.800,00	$ 565.100,00
Desired Rate of Return [Percent/Year]	$ 20,00	$ 20,00	$ 20,00
Total Installed Cost [USD]	$ 773.800,00	$ 773.500,00	$ 833.900,00

currence of fuel interface products with the help of high-pressure pumps by assuming 85% efficiency located at FT Tuban and operated with a certain pressure according to the type of fuel flowing. The flow rate distributed by FT Tuban is also adjusted to the needs of customers determined by PT Pertamina MOR V. The output of the pipeline distribution process will be forwarded by PT Pertamina MOR V to be re-distributed by land using trucks on the JATIMBALINUS route (East Java Province, Bali Island, and Nusa Tenggara Island).

2.3 Boundary condition of simulation

Analysis was conducted by testing several parameters through three common fuel types distributed by FT Tuban to IT Surabaya, including: 1). Gasoline (Pertalite and Pertamax), 2). Gasoil (Diesel Fuel). After obtaining the parameters of the three types of fuel, data processing is carried out in the form of graphs and tables that represent the differences between the three of them. Based on several sources, the three types of fuel have compositions depending on the needs of a company at a certain atomic chain range. However, in general, fuels consist of hydrocarbon and aromatic groups. As a sampling, the lowest atomic chain range was determined, whose physical parameter values are known based on calculations through ASPEN Plus® software, because there is no literature that describes the specific carbon chain length. The literature describes a general range of carbon chain-length for gasoline ranging from C7 - C11 and gasoil ranging from C12 – C15 (Wang et al. 2015). The three fuels mentioned above have specifications in the form of carbon chain length, mole fraction, and additive content that determine the physical properties of a particular type of fuel which is presented in Table 1. Table 1 presents the data inputted in the simulation software as boundary conditions.

Figure 2 illustrates the flowsheet that simulates fuel distribution process. In addition, the specific determination of flowsheet properties is also made. The flowsheet properties contain the tools used in the process and their operating conditions. In general, based on field conditions, there are several tools, including: 1). Pump, 2). Pipes. More tools are needed that must resemble field conditions. Due to the limited data and tools available in the software, the author simplifies the simulation model by only displaying pumps and pipes, where in the pipe specific settings are made on the number of valves, fittings, elbow 90, length, diameter, material, and height of the pipe against the ground surface. The flowsheet in Figure 2 is prepared using multiple piping, where each section is adjusted based on the actual pipe length. This is important to consider, because using multiple pipes can be adjusted to the number of valves and fittings that have a pressure drop. If only using a single pipe, the pressure drop is equivalent to zero, so the pressure drop cannot be predicted correctly. In addition, the actual data regarding the actual length of pipe in each section is presented in Table 2.

3. RESULT AND DISCUSSION

3.1 The correlation between initial flow rate and destination pressure on fuel distribution line from FT Tuban into IT Surabaya

Flow rate efficiency opportunity calculation analysis is aimed at obtaining an appropriate flow rate so that the fuel can flow naturally from FT Tuban to IT Surabaya, where the expected final pressure at IT Surabaya is atmospheric (assumed to be 1.5 - 2 bar). Determination of the initial pressure at initial pumping was carried out with a fixed test of 82 bar for gasoline and gasoil fuel. Based on log sheet data by PT Pertamina MOR V, standard amount of flow that is often used is between 700 - 750 m^3/hour to reach the destination pressure at atmospheric pressure.

Figure 3 shows profile the initial flow rate and the pressure on Fuel Distribution Line from FT Tuban into IT Surabaya. Based on Figure 3, the data shows that to achieve atmospheric pressure at the destination, an initial flowrate of 750 m^3/hour is required. It is considered that pipe roughness influences pressure drop, resulting in a reduction in fuel pressure during the distribution process. Looking at the flowrate of 650 m^3/hour, this creates an anomaly. Where the pressure drop will be drastically reduced, which causes an increase in the destination pressure. Sudden changes in fuel flow rate can occur due to flow resonance (Khan et al. 2022). At certain flowrates, the natural frequency of the system or pipeline can resonate with the fuel flow, causing regular or sudden pressure changes. This resonance can result in unstable pressure fluctuations. In addition, cavitation can occur when the local pressure drops below the fuel vapor pressure, causing the formation of vapor bubbles (Khoo et al. 2023). When these bubbles collapse, they can cause significant pressure fluctuations. At certain flowrates, both flow velocity and pressure can cause cavitation.

The correlation between initial flow rate and destination pressure on fuel distribution line from FT Tuban into IT Surabaya was according to the Bernouli's Law. The Bernouli's law states that energy losses due to friction with pipe walls and changes in flow direction can occur (Schäfle and Kautz 2021). These losses can cause a larger pressure drop than predicted. In addition, when the fuel flow changes through the fitting, it will cause changes in pressure and flow velocity (Kim et al. 2024). Fluid velocity and pressure can increase on the inside of the turn and decrease on the outside, so the velocity and pressure fluctuate. In the Bernouli Equation, the density parameter (ρ) is very influential. Fluids with greater density cause greater changes in flow velocity and pressure. This shows that in the case of a flow with a greater density, the pressure can decrease significantly compared to a fluid with a lower density at the same initial flowrate.

3.2 The correlation between flow rate efficiency and destination pressure on fuel distribution line from FT Tuban into IT Surabaya

From the data in Figure 3, it can be seen the destination pressure data against the initial flow rate, where the best results of desired destination pressure are in the range of 1.5 - 2 bar shown at an initial flow rate of 750 m^3/hour for gasoline fuel types (Pertalite, Pertamax). Meanwhile, at the same initial flow rate for the type of gasoil fuel (Diesel Fuel) shows that the pressure has run out, almost close to vacuum pressure (<1 atm). This is because gasoil has a greater density and heavier content compared to gasoline, so that when tested at the same pressure, gasoline and gasoil will certainly show different results, where gasoil will experience a greater pressure drop so that a greater pressure is needed to flow gasoil in order to reach the ideal destination pressure. Figure 3 can be described regarding the variation in efficiency of using the appropriate flow rate based on different types of fuel presented in figure 4 through trial and error at a pressure of 82 bar.

Figure 4 shows the result that the less destination pressure between the range of 1.5 - 2 bar indicates high efficiency. This means that it does not cost much to dispose of some of the remaining pressure in IT Surabaya, because the fuel will be stored at atmospheric conditions in the tank. With the ideal destination pressure remaining in IT Surabaya, it will produce an ideal process because in that pressure range it will be stored in the tank to keep the material from evaporating excessively. Unlike the case that leaves > 2 bar in IT Surabaya, it is necessary to reduce the pressure that is too high to be the ideal pressure, so it is a waste to release high pressure that will only be disposed of without benefit. Cost losses will also occur due to issuing discharge pressure on pumps that are too high without significant benefits. Compared on research by Koor et al. (2016), the use of a single pump tends to be easier to achieve the highest efficiency in the flow rate range of 200 - 250 liters/second. This is in accordance with the field conditions at FT Tuban, which only uses one pump with a flow rate of 750 equivalent to 208 liters/second.

Efficiency is key to the results of this study. The higher the efficiency of the process, the better the results. Figure 4 tests the same initial fuel pressure of 82 bar. Based on the simulation results, Pertalite and Pertamax (Gasoline) achieved the highest efficiency, 55.16 and 59.07 respectively. Meanwhile, Diesel fuel has a low efficiency of 14.07. Thus, to increase diesel efficiency, it is necessary to increase the initial flowrate that can overcome the pressure drop and produce atmospheric pressure at the destination. In this study, it is recommended to use an initial flowrate to flow gasoil of 87 bar. It will be more interesting to provide the equation to calculate the efficiency. The process distribution efficiency is presented in the equation below. Where, (Cdp) is the current destination pressure and (Ddp) is the desired destination pressure. Closer difference between Lpc and Lpd will provide the better process efficiency.

$$\%\text{ Efficiency of Process} = \frac{C_{dp}}{D_{dp}} \quad (1)$$

3.3 The correlation between required pressure and flow rate on fuel distribution line from FT Tuban into IT Surabaya

From the data in Figure 4, it can be seen the destination pressure data against the initial flow rate, where the best results of ideal destination pressure are in the range of 1.5 - 2 bar shown at an initial flow rate of 750 m^3/hour for gasoline fuel types (Pertalite, Pertamax). Looking at the efficiency that has been described in Figure 4 and Figure 5, it can be seen that the ideal initial flow rate is at 750 m^3/hour in order to get the ideal destination pressure between the ranges of 1.5 - 2 bar. This is in accordance with the company standard of PT Pertamina MOR V which maintains discharge pressure in the range of 70 - 90 bar at an initial flow rate of 700 - 750 m^3/hour. Distribution to PT Pertamina Patra Niaga is highly dependent on demand which is not always the same. Thus, if the demand is below the initial flow rate, the researcher conducts testing through numerical methods to determine the pres-

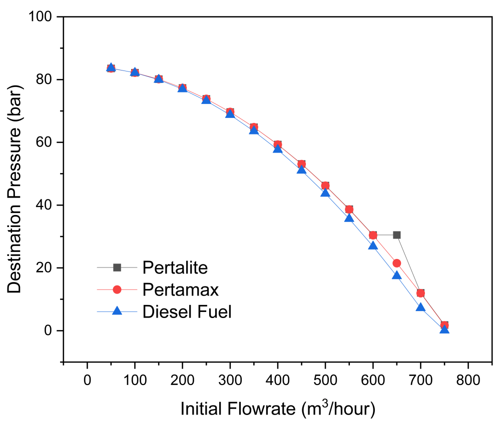

FIGURE 3. Initial flow rate profile vs destination pressure.

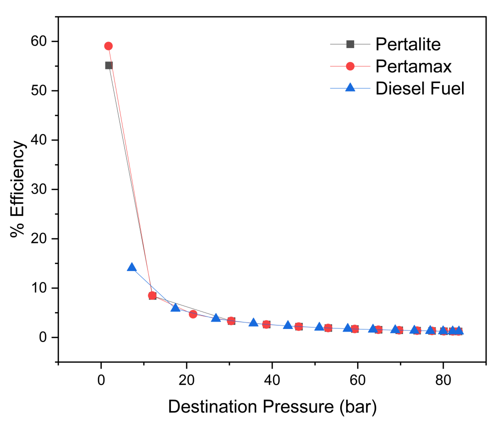

FIGURE 4. Destination pressure vs % efficiency profile.

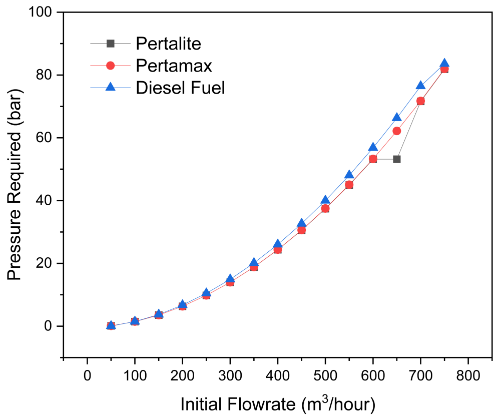

FIGURE 5. Pressure demand profile at initial flow rate variation.

sure required for FT Tuban into IT Surabaya. Figure 5 shows the same anomaly as Figure 3, where pertalite has a significant difference at a flowrate of 650 m^3/hour. Both of these have the same discussion regarding sudden changes can occur due to flow resonancea at certain flowrates.

The data in Figure 5 was collected by trial and error testing the initial flow rate with increments of 50 m^3/hour and paying attention to the destination pressure at each increment. The graph in Figure 5 shows the same thing as in discussion point about flow rate efficiency opportunity at destination pressure difference, when tested with the same initial pressure, gasoil will certainly produce a vacuum destination pressure (<0.1 atm). This is influenced by density due to longer hydrocarbon chains and more additives than gasoline (Jakkula et al. 2012; Qian et al. 2017), so higher pressures are needed compared to gasoline which only uses an initial pressure trial of 82 bar to reach the ideal destination pressure (1.5 - 2 bar).

3.4 Distribution pressure profile over a certain distance

In order to know the pressure profile at a certain distance, the author also compares the data of the three types of fuel through the graph presented in Figure 6. The graph presents the significance of the fuel pumping pressure reduction to the piping distribution line at a certain distance. The initial pumping process (Initial Pressure) is carried out at different pressures, where the initial pressure for gasoline is 82 bar and gasoil is 87 bar, where the pressure is the ideal pressure presented in Figure 5, to be able to flow fuel with a flowrate of 750 m^3/hour as a standard used by PT Pertamina MOR V. The difference in initial pressure is considered considering the high content and density of gasoline and gasoil as explained in discussion point about required pressure of FT Tuban into IT Surabaya at variation of flow rate.

In Figure 6, it can be seen that the reduction in fuel pumping pressure is close to linearity, this is in accordance with field conditions where the pumping pressure will continue to decrease as the piping distribution distance increases. This is influenced by the pressure drop caused by friction due to pipeline roughness, fluid friction against fittings, head loss due to fluid height increase, as well as shaft work (for example from turbines) and turbulence due to sudden changes in direction or cross-sectional area (Coker 1995). It can also be seen that gasoline (Pertalite, Pertamax) only produces a slight difference in pressure drop, so it does not have a significant difference between the three.

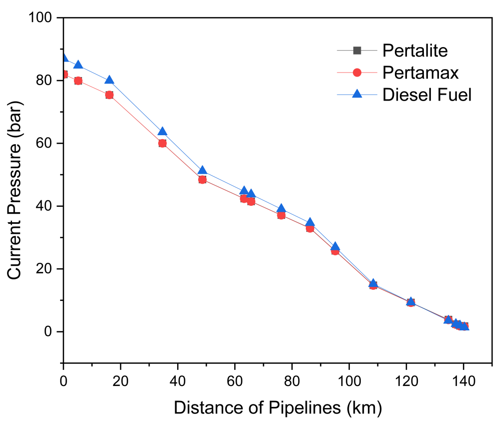

FIGURE 6. Fuel pressure reduction profile against piping distance.

3.5 Influence of underwater environment on fuel distribution process

The distribution pipeline has several sections that pass through the North Sea of Java. This is intended to obtain adequate distribution space, due to population density which makes it difficult for workers to carry out the pipe dismantling process if there is a problem in fuel distribution. In general, the installation of subsea pipelines has an effect on the temperature and pressure of fuel distribution. Below sea level, temperature tends to decrease as sea depth increases. This phenomenon is known as a temperature gradient or thermal stratification (A. Wells 2021). In addition, the pressure underwater increases as the depth of the ocean increases. Generally, every 10 meters of depth will increase the pressure by 1 atmosphere.

Subsea-mounted pipelines are designed with very specific strength and durability to handle extreme subsea environmental conditions. Based on research by Surojo et al. (2022), Subsea pipes are designed with strong and thick materials such as carbon steel or special metal alloys. In addition, the pipelines are coated with reinforcing materials that are equipped with additional structures to prevent deformation or damage due to extreme pressure. In order to reduce the effects of subsea pipeline installation, the pipeline is provided with an insulating layer to keep the temperature stable during the fuel distribution process. It is important to note that fuel is a temperature-sensitive substance, so without insulation, it will cause an increase in viscosity that can increase pressure drop, resulting in energy loss that can reduce the overall efficiency of the distribution system.

(Szablowski and Morosuk 2022) defines that the fuel distribution pipe is a pipe that has adiabatic properties, which in this condition allows no heat exchange between the system and the environment. In adiabatic conditions, the entire system will be closed so that all energy entering or leaving the system is only work, so the fluid temperature in the pipe does not change due to heat exchange with the outside environment. In fact, a fluid flowing very quickly will cause a very small change in fluid temperature due to heat exchange, so this is often ignored in the system.

3.6 Techno-economics analysis of distribution Process

In this study the cost of pump power during the fuel distribution from FT Tuban to IT Surabaya was evaluated based on each fuel type. The economic analyzer feature on ASPEN Plus® software is applied to estimate of the amount of costs required during the operating process. The initial flowrate is 750 m^3/hour. Costs are expressed in USD units following the standards in ASPEN Process Economic Analyzer® software as follows.

The overall cost required by the company to be able to distribute fuel along with energy loss that may occur due to design fittings and operating conditions is capital cost. While operating cost is the cost required without calculating the energy loss that may occur. Table 3 shows the costs required by each fuel variation are different. In the gasoline type distribution, it is found that the cost required by Pertamax is less than Pertalite. When compared to all fuel variations, it is shown that the total cost required is greater for gasoil type fuel followed by gasoline. This is influenced by the chemical characteristics of fuel in the form of density that the greater the density will make the flow pattern turbulent so as to increase the friction between the fluid and the pipe wall. So that at the same initial flowrate, more pump power is needed to distribute gasoil than other fuels.

4. CONCLUSIONS

Simulation of fuel distribution piping from FT Tuban into IT Surabaya at PT Pertamina MOR (Marketing Operation Region) V has been conducted using ASPEN® software. Simulations were conducted to determine the ideal conditions of initial pressure, initial flow rate, and destination pressure for three types of fuel: Gasoline (Pertalite, Pertamax) and Gasoil (Diesel Fuel). Standard initial flow rate that needs to be maintained is 750 m^3/hour to achieve the ideal destination pressure (1.5 - 2 bar) for all tested fuel types. Gasoil has a greater density than gasoline, so a greater pump pressure of 87 bar is required compared to gasoline which only uses 82 bar to reach the ideal destination pressure. When using the same pressure as gasoline, gasoil distribution process will experience a very large pressure drop, so that the pressure will reach vacuum before reaching IT Surabaya. Reduction in fuel pumping pressure is close to linearity, this is relevant with field conditions where pumping pressure will continue to decrease as the piping distribution distance increases. Based on the economic analysis of cost requirements for fuel distribution from FT Tuban to IT Surabaya, it takes a larger cost to distribute gasoil than gasoline.

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