A Study on Extraction Pipe Insulation for Solidification Prevention of Heavy Crude Oil after Extraction

Arwinder Singh Jigiri Singh[1], Muhammad Izzat Nor Ma'arof*[1], Suresh Akshith[1], Jeyagopi Raman[1], Girma Tadesse Chala[2]

[*1]Faculty of Engineering and Quantity Surveying (FEQS), INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia
[2]International College of Engineering and Management, P.O. Box 2511, C.P.O Seeb 111, Muscat, Oman

***Email:** muhammadIzzat.maarof@newinti.edu.my

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Abstract: Flow assurance is a major issue in offshore pipelines that transport crude oil and gas. Heavy crude oil is causing problems due to its high viscosity during the extraction process. Solidification of crude oil, which occurs below the pour point temperature, must be prevented for efficient transport of crude oil. Thus, the aim of this study was to design a production pipe with an ideal insulation material and optimal thickness such that the crude oil temperature is maintained above the pour point temperature. The benchmark for this study was an extraction pipeline with the length of 24000 m with the outlet temperature of crude oil is 20°C for a thickness of 105mm polypropylene. The 3D models of the extraction pipes were developed using Computer Aided Design (CAD) via INVENTOR software. CFD analysis is performed via ANSYS Fluent software to determine the outlet temperature and the total heat loss from the pipe. The results for the aerogel insulation material with the thickness of 7 mm for the extraction pipe indicated that an outlet temperature of 20.3°C and a total heat loss of 382 kW is obtained. These results indicated with respect to the above benchmark, a better insulation material can be chosen on the above-mentioned criteria. However, the studies have shown, the critical role of sustainability in choosing an insulation material. In order to further improve this project, environmental factors could be considered such as corrosion and further research could be carried out into sustainable viability of solutions, against wax deposition.

Keywords: Heavy crude oil, flow assurance, aerogel insulation

1. Introduction

Flow assurance is a major issue in offshore pipelines that transport crude oil and gas. Heavy crude oil is causing problems due to its high viscosity during the extraction process as noted by Chala et al., (2018) and Sulaiman et al., (2017). The viscosity of heavy crudes is strongly affected by temperature variations (Chala et al., 2017; Sulaiman et al., 2019). Hence, there is the need to further examine flow assurance in relation to heavy crude oil in relation to the extraction process.

Computational Fluid Dynamics (CFD) is the type of computational simulation tool that is used to solve problems involving fluid flow, heat transfer and other physical processes for a given system according to Sofialidis, (2014). In this study, ANSYS Fluent tool was used to perform this CFD simulation of insulation pipeline for offshore subsea pipelines. The scope of this study is to develop a production pipe to obtain an outlet temperature of 15°C within these operating conditions of reservoir temperature of 65°C, sea water temperature of -20°C and the length of the extraction pipeline is 24,000 m.

There are different types of thermal management systems which is mainly categorized in to active and passive insulation. As per a study conducted by (Sunday et al., 2021) - it has been stated that, the maximum distance of sea water depth for passive insulation is 25,000 m and for distances less than 25,000 m passive insulation is more cost effective than active insulation. Hence, in this study only passive insulation is explored. From the study by Mark Chapman, (2012), there are three (3) viable options in passive insulation that is relevant for this application, which are wet insulation, vacuum insulation and pipe in pipe insulation. After conducting a pros and cons analysis on these three (3) types, pipe in pipe insulation method was selected as the best option due to its low chances of breakdown or leakage of crude oil in the sea water due to its protective outer case. In addition, solutions were also found to be more cost friendly.

The aim of this study was to design a pipe in pipe system with optimal insulation thickness and insulation material to maintain the temperature of the crude oil extracted from the reservoir above crude oil's pour point, thereby preventing it from solidifying.

2. Methodology

Table 1. Parameters involved in the experiment

Controlled Variables	**Independent Variables**	**Dependent Variable**
Type of crude oil	Insulation Material	Outlet Temperature
Thickness of Tubing	Thickness of Insulation	Total Heat Loss
Inner Diameter of Tubing		
Thickness of Casing		
Length of Pipe		
Sea Water Temperature		
Inlet Temperature		

The 3D models of the extraction pipes were developed using Computer Aided Design (CAD) via INVENTOR software. CFD analysis is performed via ANSYS Fluent software to determine the outlet temperature and the total heat loss from the pipe. Table 1 shows the parameters involved in the experiment

Material Selection

The list of insulation materials and that were considered in this study were Mineral Wool, Aluminium Silicate, Aerogel, Polyurethane Foam and Syntactic Foam. Operating temperatures of Mineral Wool, Aluminium Silicate and Syntactic Foam do not favor conditions defined in the scope, if an outer casing burst occurs. Thus, after elimination of these materials further analysis was performed on Aerogel and Polyurethane Foam.

The selection of this material is done by first identifying each material's optimum thickness to obtain an outlet temperature higher than the WAT, which is 15°C. MATLAB was used to plot the graphs for the optimum thickness for Aerogel and Polyurethane Foam, which is shown in Figure 1.

The second step in the methodology sought to optimally design an insulated piping system to prevent heat loss to the surrounding. This was done by performing CFD simulations through ANSYS Fluent. The first stage was creating the geometry, this was followed by meshing, setup and running different thicknesses of Aerogel as an insulation material. The last stage of the methodology involved in the validation of CFD simulations using analytical techniques. This was done by computing heat transfer relationships and plotting their effect on the independent variables (Thickness of Insulation material). The next section would present the results of the methodology followed by the discussion of the outcomes.

3. Result and Discussion

Table 2. Benchmark vs Simulated Data for a length of 12m of Aerogel

Resulting variable Manipulated variable	Outlet temperature / °C	Heat loss / W
Benchmark - Insulation Thickness 105 mm (WET INSULATION)	64.967	2632.3
Design 1 - Insulation Thickness 6 mm (PIP INSULATION)	64.963	3136.4
Design 2 - Insulation Thickness 7 mm (PIP INSULATION)	64.968	2711.4
Design 3 - Insulation Thickness 8 mm (PIP INSULATION)	64.972	2389.1
Design 4 - Insulation Thickness 9 mm (PIP INSULATION)	64.975	2136.3
Design 5 - Insulation Thickness 10 mm (PIP INSULATION)	64.977	1932.7

Table 3. Benchmark vs Theoretical Data for a length of 12m of Aerogel

Resulting variable Manipulated variable	Outlet temperature / °C	Heat loss / W
Benchmark - Insulation Thickness 105 mm (WET INSULATION)	64.968	2656.3
Design 1 - Insulation Thickness 6 mm (PIP INSULATION)	64.966	3160.4
Design 2 - Insulation Thickness 7 mm (PIP INSULATION)	64.972	2730.6
Design 3 - Insulation Thickness 8 mm (PIP INSULATION)	64.975	2402.1
Design 4 - Insulation Thickness 9 mm (PIP INSULATION)	64.978	2145.9
Design 5 - Insulation Thickness 10 mm (PIP INSULATION)	64.979	1941.5

Table 4. Benchmark vs Theoretical Data for a length of 24,000m of Aerogel

Resulting variable / Manipulated variable	Outlet temperature / °C	Heat loss / W
Benchmark - Insulation Thickness 105 mm (WET INSULATION)	20.91	377
Design 1 - Insulation Thickness 6 mm (PIP INSULATION)	15.85	420
Design 2 - Insulation Thickness 7 mm (PIP INSULATION)	20.30	382
Design 3 - Insulation Thickness 8 mm (PIP INSULATION)	24.08	350
Design 4 - Insulation Thickness 9 mm (PIP INSULATION)	27.14	323
Design 5 - Insulation Thickness 10 mm (PIP INSULATION)	29.91	299

For the 12m of production pipe, the simulated results were compared with the benchmark from literature of Ahmed and John (2018), as shown in Table 2. From the comparison, the data gathered indicated a similar expectation of result as in the theory, as the thickness of insulation is increased the amount of heat loss is reduced, thus causing the outlet temperature to be reduced. From Table 2 and Table 3, it can be seen that the simulation result in comparison to the theoretical calculation, the results are at most about 0.00115% for Outlet temperature of crude oil (°C) and less than 1% for the total heat loss (W). Thus, since the percentage of difference between the simulation results and the theoretical calculations in Total heat loss are within 15% difference, the results are indeed validated and this theoretical formula can be used to estimate the outlet temperature of the crude oil for a length of 24,000 m according to Ahmed and John (2018) as shown in Table 4.

The total cost of production pipe increases as the insulation thickness increases. Solely from the cost analysis, the optimal design would be one with the minimal cost which is Design 1. However, it is also necessary to consider the performance of the designs in terms of the outlet temperature and the heat loss. According to Ahmed and John (2018), despite the pour point temperature of crude oil being 15°C, due to the consideration towards the effects of multiple connection of pipes, the critical temperature is increased to 20°C which includes acceptable 5°C tolerance. From Table 4 it can be seen that Design 2 to 5 has the thicknesses required in order to obtain an outlet temperature of 20°C at 24,000 m in length. Additionally, as concluded from the cost analysis it is cost effective to choose the design with the minimal thickness that satisfies the temperature criteria. Therefore, Design 2 is chosen to be the optimal design.

When comparing the optimal design with the benchmark, in terms of the price, the Benchmark almost cost twice the amount of chosen design due to the thickness of insulation being much larger for the benchmark. Additionally, in terms of their design, firstly, since the proposed design consists of an outer casing preventing direct contact to the surrounding sea water medium, the expected lifetime of the insulation will be longer. Furthermore, since the benchmark design involves the insulation constantly exposed to the sea water medium, the choice of insulation material will be restricted to wet insulation.

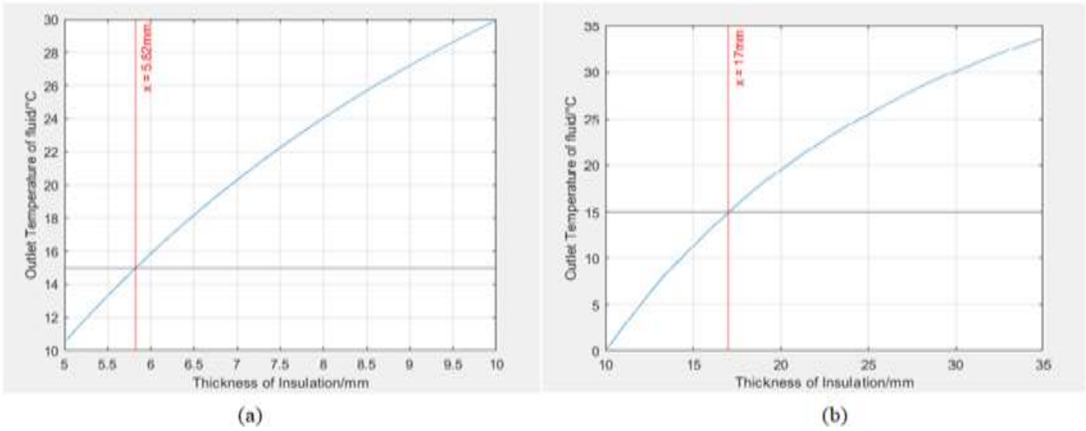

Figure 1: Plot for temperature against thickness - a) Aerogel b) Polyurethane Foam

From Figure 1, it can be seen that the optimum thickness of Aerogel and Polyurethane Foam to be used to get an outlet temperature of 15°C is almost 6mm and 17mm respectively. In order to find which the ideal material to be used is, cost analysis is done using the following equation.

The cost of insulation material used = $2\pi * R_o * L * \$$ ----- (1)
Total Cost for Aerogel Insulation = $2\pi * (0.433/2) * 24{,}000 * 45.14 = \$ 1{,}473{,}705.88$
Total Cost for Polyurethane Insulation = $2\pi * (0.433/2) * 24{,}000 * 90.87 = \$ 2{,}966{,}672.04$

Conclusively, as per the cost analysis performed above, it is clear that Aerogel is nearly half the cost of polyurethane, thus making it a much more economically feasible option. Hence, insulation material Aerogel is chosen to perform the simulation.

4. Conclusions

In summary, due to the wax deposition, the crude oil produced is in lumps of solid which causes costly operational expenses, such as damaging the pipelines and pumps. Solidification of crude oil occurs below the pour point temperature. Thus, the aim of this study was to design a production pipe with an ideal insulation material and optimal thickness such that the crude oil temperature is maintained above the pour point temperature. The selected thermal management was a pipe in pipe (PIP) system where the 3D model was developed using CAD software. Due to the length to diameter ratio of the pipe being extremely large, it is difficult to produce a good mesh quality. Therefore, MATLAB software was used to calculate results for the required design. To justify the calculations, the theoretical results were compared against the simulated results for a shorter length. Based on the cost and outlet temperature achieved, the optimal design proposed was a PIP design with Aerogel insulation of thickness 7mm. These results were also compared with a benchmark to further justify on the performance of the proposed design. To further improve this project, it is also important to consider the other factors which causes solidification other than wax such as hydrates and asphaltenes. Furthermore, it is also important to consider measures to prevent corrosion in the pipes as it could lead to oil spillage.

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