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VALIDATION OF THERMO-HYDRAULIC SIMULATION MODEL FOR OIL PIPELINE TRANSPORTING HEATED FLUIDS

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Abstract

The study of operations and security conditions at the transport of oil and derivatives in pipelines is strongly leaned on thermo-hydraulic computational simulations. Due to characteristics of oil production or derivatives refining, they can be presented with temperatures above the environment. However, in other situations, typically in the marine fuel case, it is necessary the fluid to be heated, and with its viscosity reduced, be easily transported. When the goal is defining operational conditions, it is desirable to check the impact of the temperature, mostly, in the transport rate. On the other hand, when the aim is the operational security, the minimum and maximum temperatures of the process are the subject. The minimum temperature may be due to fluidity point, which, if reached, may cause a pipeline blockage. The maximum temperature is limited by the temperature of the pipeline's mechanical design. The pipeline simulation process used in the temperature computation involves physical and mathematical modeling that introduces simplifications. However, these formulations are established in the literature and the uncertainties introduced in the results are known. On the other hand, to complete the formulation, it is needed information about the thermophysical properties (thermal conductivity and specific heat) of the material (fluid, pipeline, thermal isolation, and ground) and about the environment temperature. Since the uncertainties on these data can be high, this paper carries out a sensibility analysis applied to real pipelines, in order to define which parameters should be acquired with higher precision. In addition to these variables, the correlations used for the calculation of the internal heat transfer coefficient present great impact on the results. For heavy crude oil and fuel oil, the flow may happen in the laminar band with high Prandtl numbers, producing situations where there is a high thermal development length, reducing the reliability of the correlations. Some correlations found in the literature are used in this study to determine which one produces the best results. With the stage set, a computer simulation of a real pipeline transporting heated fluids was conducted, using the history of process variables as input data and the key variables identified in the study of sensitivity were adjusted to reproduce, as faithfully as possible, the temperature variation along the pipeline.

1 Introduction

Due to the oil and derivatives production characteristics, these products can enter the pipeline system at temperatures above the environmental temperature. Typically, for marine oil, it must be warmed up, to reach a lower viscosity and flows more easily. So, to define the operating pipeline conditions, the influence of the temperature on the flow must be especially evaluated. On the other hand, when the focus is the operational security, the higher and lower fluid temperatures must be observed. The minimum temperature must be a restriction given the limit for the fluid's fluidity point, which, if reached, may cause a pipeline blockage. The maximum temperature is limited by the pipeline's mechanical design temperature.

Nowadays, pipeline fluid flow computational simulators are extensively used on new oil and gas systems design, as well as in the production evaluation of operating systems. These simulators solve nonlinear differential equations of mass, momentum and energy conservation applied to pipelines. To fulfill the analysis of a specific case, input data, such as geometric data and products and material properties, is needed to configure the computational model. Frequently, these data come with high or unknown uncertainty. The uncertainties on these data reflects on the uncertainty of the focused variables calculated by the simulator. Furthermore, the nonlinear nature of the problem can amplify the uncertainty levels of the input variables on the output data making the analysis unfaithful.

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Hence, it is a fundamental information to the analyst, the knowledge of the uncertainty levels associated to the variables calculated by the computer codes and a methodology for measuring uncertainties.

The focus of this paper is to evaluate the uncertainty in the calculation of the variables of heated fluids flowing in the pipelines.

2 Sensibility Analysis

2.1 Conservation Equations

To solve a fluid flow in pipelines, counting the heat exchange with the environment, mass, momentum and energy conservation equations are usually worked to reflect this specific situation. (Stoner Pipeline Simulator (SPS) 10.1.0,, 2014; Incropera, DeWitt, Bergman, & Lavine, 2007)

The mass conservation is given by

$$\frac{\partial(v\rho)}{\partial x}+\frac{\partial(\rho)}{\partial t}=0 \tag{1}$$

Where, v is the fluid velocity, ρ is the density, t is the time, and x is the distance. The momentum conservation equation is

$$\frac{\partial(vA\rho v)}{\partial x}+\frac{\partial(A\rho v)}{\partial t}+g_c A\frac{\partial P}{\partial x}+\frac{A\rho f|v|v}{2D_{int}}+A\rho\frac{\partial h}{\partial x}\ =0 \tag{2}$$

Where, A is the area, g is the acceleration due to gravity, g_c is a dimensional constant, P is the pressure, f is the friction factor, D_{int} is the inside diameter and h is the height. The energy conservation equation is

$$\frac{\partial\left(A\rho\left(g_c U+\frac{v^2}{2}\right)\right)}{\partial x}+\frac{\partial\left(A\rho\left(g_c U+\frac{v^2}{2}\right)\right)}{\partial t}+g_c\left(\frac{\partial(vPA)}{\partial x}+P\frac{\partial A}{\partial t}\right)+A\rho vg\frac{\partial h}{\partial x}+g_c\pi d h_1(T-T_0)=0 \tag{3}$$

Where, U is the intern energy, h_1 is the film coefficient for heat transfer, T is the temperature

The commercial software Stoner Pipeline Simulator DNV (SPS) was used to solve the conservation equations. The film coefficient for heat transfer between the fluid and the pipeline is defined on the simulator as:

$$Nu=\alpha(A_C Re^{Bc}\mathrm{Pr}_c^{\mathrm{C}})+(1-\alpha)A_g\left(\left(\frac{\mu_m}{\mu_w}\right)\left(\frac{\rho_w}{\rho_m}\right)\right)^{B_{g_i}}\left(\left(\left(\frac{\pi}{4}\right)(C_g)RePr\right)^{D_g}+E_g(GrPr)^{F_g}(C_g)G_g\right)^{H_g} \tag{4}$$

Where μ_m and ρ_m is the fluid's viscosity and density in the main temperature, μ_w and $\rho_w$is the fluid's viscosity and density in the wall temperature and the Nusselt number, Nu, is defined as:

$$Nu=\frac{h_1\,D_{int}}{k} \tag{5}$$

Re is Reynolds and Pr is Prandtl numbers.

$$Re=\frac{\rho u D_{int}}{\mu} \qquad Pr=\frac{C_p\mu}{k} \tag{6}$$

Where C_p is the fluid thermal capacity, k is the fluid thermal conductivity.

The $Ac, Bc\ and\ Cc$ values used by the software are, respectively, 0.023, 0.800, and 0.300 that transforms the equation (4) on the Dittus-Boelter equation for a turbulent flow.

$$Nu=0.023\ Re^{0.8}Pr^{0.3} \tag{7}$$

The simulator using equation (8) calculates the heat conduction on the pipeline, coating and ground:

$$k\left(\frac{d}{dr}\left(\frac{r\partial T}{\partial r}\right)\right)=C_p\rho\left(\frac{\partial T}{\partial t}\right) \tag{8}$$

Considering that, the ground has an equivalent radius defined as function of the burial depth as

$$t_{solo} = R_1\left(\frac{2b}{D} + \left(\left(\frac{2b}{D}\right)^2 - 1\right)^{\frac{1}{2}} - 1\right) \tag{9}$$

Where, t_{solo} is the ground's thickness for the radially symmetric model; R_1 is the radius from pipe center to the ground layer, b is the actual burial depth to center line of pipe, and D is the pipeline outside diameter

The viscosity as a function of temperature is defined by:

$$\mu(T) = \mu_0 \exp\bigl(VTMI(T - T_0)\bigr) \tag{10}$$

Where VTMI is the temperature coefficient of viscosity and T_0 is the temperature where the viscosity μ_o is known. The equation of state is:

$$V = V_0\left(1 - \frac{\Delta P}{PM_0} - \frac{\Delta T}{TM_0} - \frac{\alpha \Delta P \Delta T}{PM_0 TM_0} + \frac{\eta(\Delta P)^2}{PM_0^2} + \frac{\nu(\Delta T)^2}{(TM)^2}\right) \tag{11}$$

V_0 is the fluid's specific volume, P_0 is the base pressure, T_0 is the base temperature, PM_0 is the bulk modulus and TM_0 is the temperature modulus both at P_0 and T_0

2.2 Study Case Selection

The selected study case is a transport pipeline for heated fluids with 35.2 km of length, 12" of nominal diameter and 0.252" of thickness. The pipeline is buried and has a thermal insulation coating through all its length. The fluid flows at turbulent regime. The fluid is pumped from a tank farm and is sent in a tank with constant pressure at the end of the pipeline. Table 1 shows the pipeline layers thermal properties and Table 2, the fluids characteristics.

Table 1 – Pipeline's layers properties

Layers	Density [kg/m³]	C_P [kJ/kg.K]	K [kJ/h.m.K]	Thickness [in]
Steel	7846	0.434	219.6	0.252
Insulation (PU)	35	1.045	0.75	2 3
Ground	1396	3.2322	6.6855	111.4

Table 2 – Fluids characteristics

Fluid name	**Diluent**
Flow regime	Turbulent
Pressure P0 [kgf/cm²]	1.033
Temperature T0 [°C]	40
Density @T0 e P0 [kg/m³]	1000.0
Viscosity @ T0 e P0 [cP]	18.0
Thermal Capacity @ T0 e P0 [kJ/kg.K]	1.9259
Thermal Conductivity @ T0 e P0 [kJ/h.m.K]	0.3863
Bulk Modulus @ T0 e P0 [kgf/cm²]	21660
VTMI * [°C-1]	-0.05626

* Temperature coefficient for viscosity's variation

2.3 Parameters Selection for the Case Study

The acquired experience in several real world case studies helped to select the input and output variables, considered as the most relevant to the current study. Table 3 shows the input variables studied, the difficulty of gathering its actual value and its uncertainty. The so-called "design uncertainty" can typically be divided in two major groups, the first is the variable uncertainty obtained in ideal conditions (laboratory conditions), and the second is composed of uncertainties due to lack of information (soil composition) or approximations needed to gather those values.

As the outlet pipeline pressure is controlled, the inlet pipeline pressure is an open variable depending upon the flow rate and temperature and pumps curves. As an open variable, the outlet temperature is chosen since the inlet pipeline temperature is used as an input parameter. The selected output variables are the inlet pipeline pressure (P_{ENV}), the oulet pipeline temperature (T_{REC}) and the flow (Q_{REC}).

Table 3 – Uncertainty variables studied

Studied Variables		Obtaining Difficulty	Design’s Uncertainty
μ	Fluids viscosity	Medium	0.25%
VTMI	Temperature coefficient for viscosity	Low	0.25%
T_{fluid}	Fluids inlet temperature	Low	0.50%
ρ	Fluid’s density	Low	1.00%
ρ_A	Steel’s density	Low	1.00%
ρ_I	Insulation’s density	Low	1.00%
Cp	Fluids thermal capacity	Low	1.00%
k	Fluids heat conductivity	Medium	1.00%
k_A	Steel’s heat conductivity coefficient	Old: high New: Low	1.00%
k_I	Insulation’s heat conductivity coefficient	Old: high New: Low	1.00%
Cp_A	Steel’s thermal capacity	Old: high New: Low	1.00%
Cp_I	Insulation’s thermal capacity	Old: high New: Low	1.00%
ESP_A	Pipeline’s steel thickness	Low	10.00%
ESP_I	Insulation thickness	Medium	20.00%
MB	Bulk modulus	High	20.00%
k_S	Ground’s heat conductivity coefficient	High	30.00%
Cp_S	Ground’s thermal capacity	High	30.00%
ρ_S	Ground’s density	High	30.00%
T_{grnd}	Ground’s temperature	High	30.00%
ESP_S	Depth of Burial (ground’s thickness)	High	33.33%
Ac	Colburn coefficient	Low	15.00%
Bc	Colburn coefficient for Reynolds exponential	Low	15.00%
Cc	Colburn coefficient for Prandlt exponential	Low	15.00%

2.4 Uncertainty Measurements and the difficult in obtaining the “real value”

Primarily, was performed a literature search seeking for a better input uncertainties estimation. According to Marvin (Marvin, 1971) the fluid’s viscosity measurement uncertainty is 0.25%. According to (ASTM D 5002, 1999), the fluid’s density measurement uncertainty is 0.043%. According to (API 5L, 2010), the density’s steel has an uncertainty of 1.35%. The (Joint Industry Foam, 1994) states that its uncertainty is about 0.5% for the polyurethane foam density (API 5L, 2010) accepts an error of 10% for the steel thickness measurement, and (PETROBRAS N-0556, 1989), 20% for the PU’s thickness. The measurement uncertainty of the fluids temperature was estimated as 0.5%, according to (JM Industrial, 2013).

For grounds properties, such as density, thermal capacity and thermal conductivity, there are many estimated values for different kinds of grounds, as sandy, loam, and rocky, wet and dry. As the pipeline runs thru kilometers of land, it is usually used an average value, which can generate a large uncertainty, so a 30% uncertainty was chosen for these values. For the depth of the ground, a 33.33% uncertainty was used as a default value of a depth of 1.5m. For depths greater than 0.3m the temperatures variation throughout the days does not vary widely with the air temperature. (Azevedo & Galvani, 2003) It was considered a range of 20°C to 30°C and approximately a 20% uncertainty, considering a standard temperature of 25°C.

Despite not enough information was found to estimate the uncertainty of thermal conductivity and heat capacity of PU, fluid and steel, these properties can be measured with 1% of. It is known that in old pipelines the insulation may be much degraded due to water absorption and other agents. Specifically to the thermal conductivity of the insulation, and despite of not finding any references, this uncertainty can reach up to 1200%.

No reference was found to the bulk modulus uncertainty, so it was used at first a value of 10%, and others values assessed to determine their relevance to the study. A summary of the uncertainties and the difficulty in obtaining the actual value of the input variables are shown in Table 3.

2.5 Identification of the relevant parameters

The total uncertainty of a variable was calculated using the Partial Derivative Method This method was used to assess the contribution of each uncertainty parameter, where only one was disturbed at a time, while all the others are held constant at their default values. Thus, the influence of the disturbance of this parameter is monitored at the output results of the SPS (P_{ENV}, Q_{REC} and T_{REC}) for the study case. This procedure is repeated for each of the parameters listed in Table 3.

This method is commonly used to estimate uncertainties in experiments of a single sample, as shown in the research of (Moffat, 1982). On that methodology the δR uncertainty is estimated based in an output R from an experiment that depends on n independent variables, x_i, being δx_i is the uncertainty associated to each one. Thereby, using the equation (12), the δR uncertainty was calculated. (Azevedo, Lopes, Cabanillas, Kubrusly, & Dias, 2008)

$$\delta R = \sqrt{\left(\frac{\partial R}{\partial x_1}\delta x_1\right)^2 + \left(\frac{\partial R}{\partial x_2}\delta x_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n}\delta x_n\right)^2} \qquad (12)$$

For the sensitivity and uncertainty analysis, the index of sensitivity, S (eq 13) was used. It is a ratio between the global and the local variation to a given input, or which indicates the impact of the diversion of an entry in an output deviation, in other words, dividing each sum corresponds to the term of equation (12) by δR^2. (Bresolin, 2005)

$$S_i = \left(\frac{\partial R}{\partial x_i}\right)^{\mathbf{2}} \frac{\delta x_i^2}{\delta R^2} \qquad (13)$$

The disturbance generated for each variable was a 5% reduction from the default value. As it was considered that the influence of each variable can be identified with the variation caused, others disorders were not investigated. It were not investigated others influences of the variations of several variables simultaneously, which can be nonlinear. Thus, this procedure becomes valid to estimate the magnitude of the comparative importance of each input variable.

An uncertainty of 10% was considered for all input variables on the beginning of the calculations. The most important variables can be identified using equation (13) to calculate the derivative from a perturbation of 5% and an uncertainty of 10%.

3 Sensibility and Uncertainty analysis results

The results obtained for the base case, which uses inputs from Table 1 and Table 2, were divided as follows:

- Sensitivity Analysis Results of thermal parameters of the fluid
- Sensitivity Analysis Results of the parameters of the pipeline layers (steel, insulation and ground)
- Sensitivity Analysis Results of SPS’s correlation parameters for the Nusselt calculation.

First, a sensitivity analysis with 10% uncertainty for all input parameters and their importance were evaluated in the output variables. Second, the output variables sensitivities, regarding the input variables, were evaluated considering the design and pipeline operation uncertainties (Table 3). This analysis is based on a steady state flow regime.

3.1 Fluids Thermal Parameters

The sensitivity index of outlet temperature and flow to a uniform 10% uncertainty and design uncertainty are shown in **Figure 1** and **Figure 2**. **Figure 1** shows that, considered a plain uncertainty of 10%, the most important variables, to the outlet temperature are mostly the inlet temperature, and the fluid’s density and thermal capacity with a mild participation, although when considered the uncertainties of Table 3, the bulk modulus appears as the most important variable. In the case of the outlet flow, **Figure 2** shows that when considering a plain uncertainty of 10% the most important variables are: inlet temperature, fluid density and VTMI, but when considering the uncertainties of Table 3, the most important variable is the fluid density. Table 4 shows the absolute uncertainty of the output variables, considering the design input variables uncertainty.

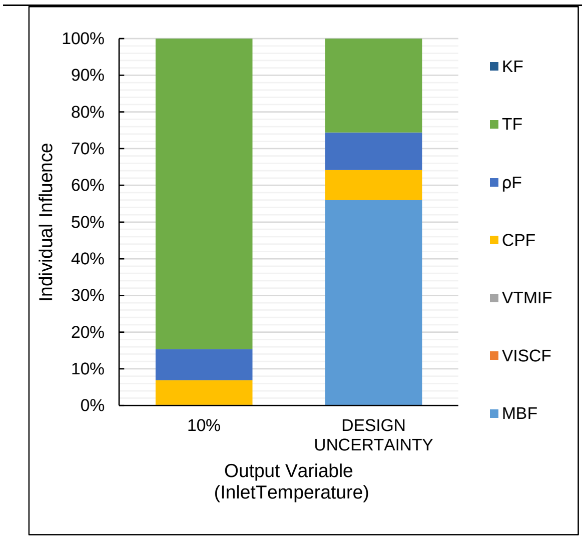

Figure 1 – The sensibilities for the outlet temperature graph (Individual influence) for the fluids thermal parameters

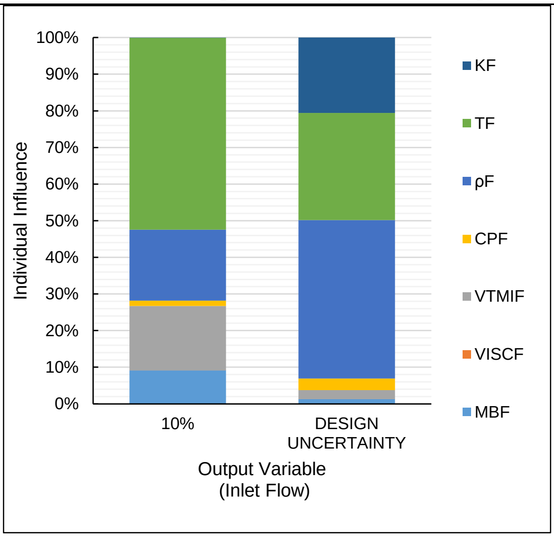

Figure 2 – The sensibilities for the outlet flow graph (Individual influence) for the fluids thermal parameters

Table 4 – Output variables absolute and percent uncertainty

Output	**Absolute uncertainty**	**Percent uncertainty**
Inlet Pressure	0.19 kgf/cm²	0.9%
Outlet Temperature	0.37°C	0.6%
Outlet Flow	0.42 m³/h	0.1%

Therefore, it can be noticed that, due to the uncertainties of the fluid thermal properties, the uncertainties of the study case variables are very small. This way, it is easy to figure out that this group of characteristics does not have great influence in the overall model's validation.

3.2 Pipeline Layers Thermal Parameters

The sensitivity index of outlet temperature to a uniform 10% uncertainty, design uncertainty and real uncertainty (considering PU degradation) is shown in **Figure 3**. As stated in section 2.4, to an old pipeline, the sensibility analysis calculations were accomplished considering an uncertainty of 1233% for the insulation thermal conductivity.

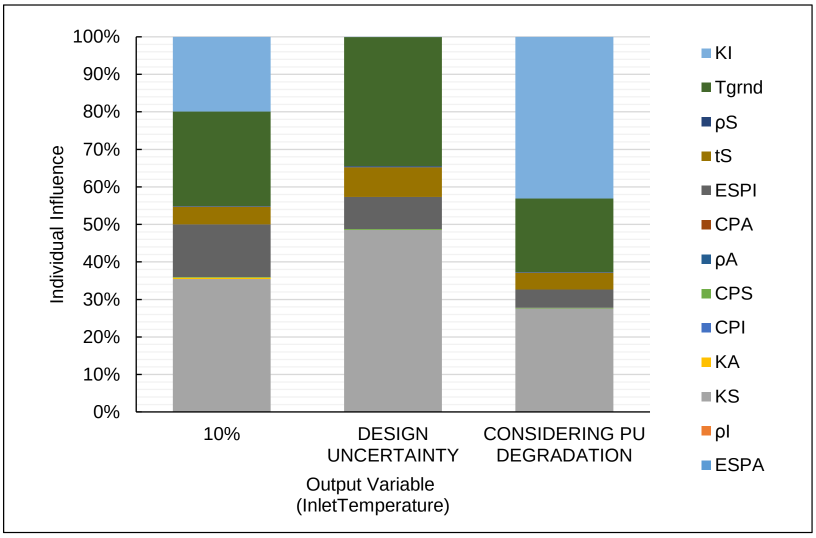

Figure 3 - The sensibilities for the outlet temperature graph (Individual influence) for the pipeline thermal parameters

Figure 3 shows that, considered a plain uncertainty of 10%, the most important variables, to the outlet temperature are: the inlet temperature, and the fluid's density and thermal capacity with a mild participation, although when considered the uncertainties of Table 3, the bulk modulus show up as the most important variable. Table 5 shows the absolute uncertainty of the output variables, considering the design input variables uncertainty.

To the outlet temperature, as to the outlet flow and inlet pressure, considering a plain uncertainty of 10%, the most important property is the ground temperature, followed by the ground thickness, the insulation thermal conductivity and the ground density. **Figure 3** shows that, considering the design uncertainties, the insulation thermal conductivity is not relevant. Nevertheless, when considering the uncertainty of the insulation degradation, the insulation thermal conductivity is the most important one.

Table 5 – Output variables absolute and percent uncertainty

Output Variables	Absolute Uncertainty	Percent Uncertainty
Inlet Pressure	0,13 kgf/cm²	0.6%
Outlet Temperature	3,50°C	6.1%
Outlet Flow	2,08 m³/h	0,7%

The pipeline layers thermal properties uncertainties, mainly the ground temperature and the insulation thermal conductivity, generate uncertainties on the output variables significantly higher that the fluid thermal properties uncertainties. Therefore, those variables are the ones that need more information and research to achieve a better real case approximation.

3.3 Nusselt Equation Parameters

The sensitivity index for uniform uncertainty of 10% and design uncertainty is shown in Figure 4.

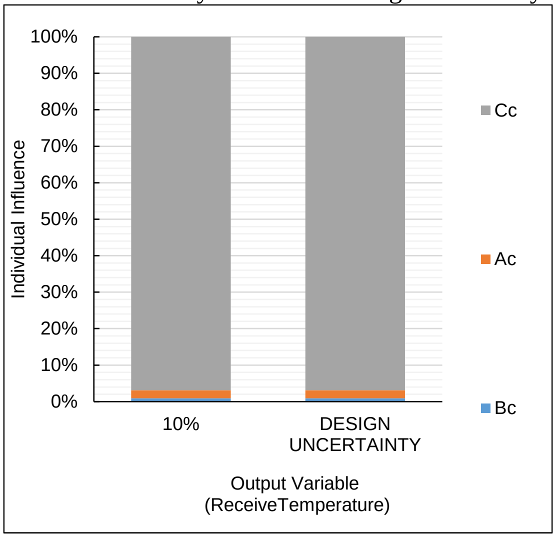

Figure 4 - The sensibilities for the outlet temperature graph (Individual influence) for the Nusselt equation parameters

Figure 4 shows that the Colburn coefficient Bc, the Reynolds Number exponential, has the higher influence over the outlet temperature. It was also observed with the inlet pressure and flow. However, when considered the fluid and pipeline layers properties, its influence becomes non-relevant.

3.4 Global Uncertainty

Table 6 shows the global uncertainty, when considering the variables of Table 3, and can be noticed that the outlet temperature is the most sensible variable, among the studied variables.

Table 6 –Output variables uncertainty to the given input variables

Output Variables	Absolute Uncertainty	Percent Uncertainty
Inlet pressure	0.23 kgf/cm²	1.1%

Outlet temperature	3.53 °C	6.2%
Flow	2.13 m³/h	0.7%

4 Methodology for validation of pipeline simulation model

As noticed in section 3, the most influent input variables are K_I and T_{grnd} which will be tweaked in the model so that values close to the operational log can be achieved. In this step, a simplified model was used and the pumps were replaced by a pressure setpoint, taken from the log, in the inlet tank. The geometry and materials used in this study case are presented in Table 7, Table 8, and Table 9.

Table 7 – Pipeline physical characteristics

Length [km]	Nominal Diameter [in]	Thickness (in)	Material
99.490	16	0.250 0.375 0.406	API 5L X52

Table 8 – Pipeline layers properties

Layers	Density (kg/m³)	C_P [kJ/kg.K]	K [kJ/h.m.K]	Thickness (in)
Steel	8,131¹	0.434¹	147.6¹	0.250³ 0.375³ 0.406³
Insulation	40²	1.045¹	0.075²	2³
Ground	1,396	3.2322	6.6855	214.55³

¹ (Incropera, DeWitt, Bergman, & Lavine, 2007)
² (PETROBRAS N-1618, 1998)
³ design values given by TRANSPETRO

The density, thermal capacity and conductivity of the steel were taken from (Incropera, DeWitt, Bergman, & Lavine, 2007) for a carbon-manganese-silicon steel (1%<Mn<=1.65% and 0.1%<Si<=0.6%), similar to API 5L X52. The insulation properties were taken from (PETROBRAS N-0556, 1989) and (PETROBRAS N-1618, 1998), and the ground properties from the experience. A 25°C temperature was considered. The operational log gave the fluids characteristics.

Table 9 – Fluids Characteristics

Fluid	Diluent
Flow	Turbulent
Pressure P0 [kgf/cm²]	1.033
Temperature T0 [°C]	60
Density @T0 e P0 [kg/m³]	921.2
Viscosity @ T0 e P0 [cP]	26.3975
Thermal Capacity @ T0 e P0 [kJ/kg.K]	1.9259
Thermal Conductivity @ T0 e P0 [kJ/h.m.K]	0.3863
Bulk Modulus @ T0 e P0 [kgf/cm²]	21,660
VTMI * [°C-1]	-0.04343

From the operational log, the inlet pressure, inlet temperature, density, and outlet pressure were used as input in the model. The calculated outlet temperature and inlet flow and outlet flow, were compared with the operational log. During the validating process, some input pipeline thermo-mechanics characteristics were gradually tweaked until the output data stay inside a 10% tolerance range.

5 Model Validation

The input variables original and final adjusted values used to validate the model are shown in Table 10. Table 11 shows the real pipeline situation analyzed, the simulated values and the error between them. The current fluid in the pipeline was Diluent, and its properties are found in Table 9, taken from the pipeline's operational log.

Table 10 – Design and adjusted input values

Input Parameters	Design Value	Adjusted Value	Difference (%)
T_{grnd} (°C)	25	20	20%
K_I(kJ/h.m.K)	0.075	0.75	900%

Table 11 – Real pipeline and simulated operational conditions

Case	Inlet pressure (kgf/cm²)	Inlet Temperature (°C)	Inlet flow (m³/h)	Density (kg/m³)	Outlet pressure (kgf/cm²)	Outlet temperature (°C)	Outlet flow (m³/h)
Real pipeline	43.32	78.52	339	0.9149	1.2	37.49	343
Simulated	43.32	312.89	78.52	0.9212	1.2	38.744	312.89
Error	0.0%	0.0%	-7.8%	0.7%	0.0%	-0.5%	-8.7%

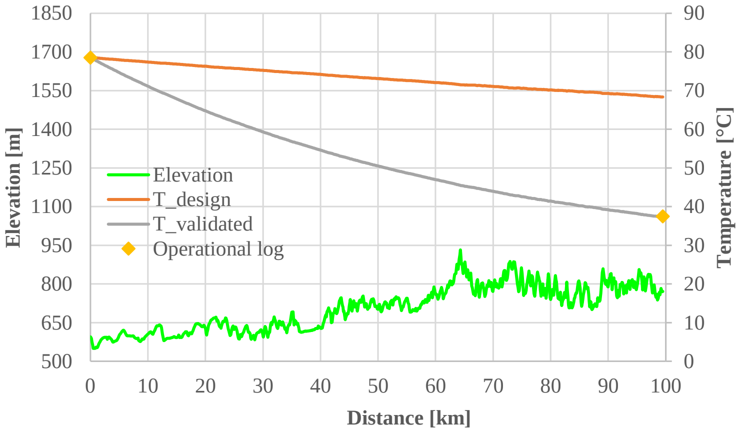

Figure 5 - Temperature distribution through the distance

Figure 5 shows the temperature distribution through the pipeline length. It can be observed that, when using the design data (T_design) the pipeline has a smaller temperature decrease than the adjusted data (T_validated), which matches the log data. It confirms the pipeline thermal insulation condition is degraded. Table 12 shows the output variables uncertainty to the given input variables.

Table 12 –Output variables uncertainty to the given input variables

Comparison of the uncertainties	$\delta K_{I_{Design}}\ vs\ \delta K_{I_{Ajusted}}$		$\delta K_{I_{Real}}\ world\ vs\ \delta K_{I_{Ajusted}}$	
Output Variables	**Absolute Uncertainty**	**Percent Uncertainty**	**Absolute Uncertainty**	**Percent Uncertainty**
Inlet pressure	2.21 kgf/cm²	5.1%	0.26	0.6%
Outlet temperature	54.92 °C	146.5%	4.66	12.4%
Flow	35.88 m³/h	10.5%	2.91	0.8%

It is difficult to determine the change of a specific variable value due to material degradation, typically thermal insulation aging. When comparing the values adjusted with the values from the design data, the temperature uncertainty is too high, indicating that the insulation is degraded, and the design data is no longer valid. The insulation thermal conductivity uncertainty was settled to 50% to counterweight the insulation degradation. As a result an uncertainty of 12.4% was reached, which is still a high uncertainty, suggesting that further studies must look for a more precise value to accomplish a better validation model.

6 Conclusion

In situations related to heated fluids flow in pipelines it was noted a strong dependency of the output data on the uncertainty of the input data. Thus, given the widespread use of fluid flow in pipeline computational simulators, which provide results that are independent of the input data quality, it becomes evident that the analyst must have the caution when evaluating the output data. The input data uncertainty can be fostered from the measurement, the pipeline degradation or the fluid specs, to say the few.

It was possible to pinpoint the most important input variables, which are the insulator thermal conductivity, the ground thickness and the fluid's density. Considering the output variables, the most sensible one to the input variables is the outlet temperature. So further studies are encouraged to reach data that are more precise.

This work is in continuous development and it will consider scenarios with laminar flow and thermal transient. A future study must consider the effect of multiple input variables simultaneous changes, as it is a scenario even closer to the real world one.

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