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Thermal Analysis Impact for Hydrates Formation in Oil & Gas Pipelines

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A R T I C L E I N F O

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Pipelines,
Industry,
Formation.

The Oil & Gas industry has grown and new discoveries and technologies have risen in order to accommodate the dynamics of such industry. With investments ranging billions of US Dollars is mandatory to create measures to avoid pressure vs temperature related issues during the extraction, transportation and of the crude in order to minimize losses and maximize the profit (Borsani, 2001). Hydrates in oil& gas pipelines poses a very big issue to the industry. Hydrates are normally formed when the adequate conditions (gas, water, compatible pressures and temperature ranges) are present. They are in the market several methodologies to prevent the evolution or emerging of hydrates. An adequate thermal study during the design of the pipeline and its insulation layers, constitutes a greater value on the path to avoid hydrates formation during the pipeline operating life. On This paper the study is dedicated on the impact of thermal analysis in one of the pipelines operating in one of the Angolans Offshore fields. COSMOS Geostar is the tool used for the investigation. The study was conducted in a pipeline considering the thermal conduction through a normal pipe section and the thermal conduction through a field joint. This project has proven the efficiency of COSMOS in assisting on the determination of a proper type, nature and size of insulation to be applied in a certain piping system for crude oil production and/or transport.

1. Introduction

Despite many recommendations from regulation bodies around the planet to preserve the environment, in the use of green energy, the exploitation of oil is still performed in an environmentally unacceptable way. However, because of its predominance in the energy market to the present day, this resource forms the basis of the global energy matrix. As a result, demand for oil has increased, thus forcing production companies to engage in studies for the exploitation of crude oil in hard-to-reach areas such as deep and ultra-deep waters.

With the revolutionizing of oil exploration in ultra-deep waters, in this industry the greater need of studies that guarantee the adequate flow of crude appears in this industry. It is of extreme responsibility to ensure the flow of hydrocarbons to the production facilities, as large sums of money are invested and the objective is to recover the hydrocarbon to guarantee the investment.

During the initial phase of the project, costs should be analyzed and evaluated in terms of CAPEX vs. OPEX. Flow assurance problems significantly influence operating costs. For this reason, it is appropriate to invest in the acquisition of methodologies and the use of equipment to prevent possible problems and/or mitigate their effects. Among the measures to be taken, injection of inhibitors has been one of the most effective for both prevention and mitigation. However, in many fields of exploitation, the quantities of inhibitors to be injected, significantly increase operating costs (OPEX). For this, it is advisable to increase the incidence of CAPEX investments by selecting efficient equipment and an adequate dimensioning of the production lines as well as thermal and anticorrosive insulation. Crude Oil is a mixture of liquid and gaseous hydrocarbons, water and contaminates. The flow of all these components through the same duct, will eventually cause flow problems duo to the pressure and temperature changes along the pipeline, thus a cautious pipeline design is required. Multiphase flow is very complex due to is ease of organic deposits formation such as paraffin, asfatene and hydrates.

Due to the complexity of subsea fields (shallow, deep and ultra-deep waters), it is vital to foresee and tackle the main possible issues during the initial project stages avoiding several interventions during the field operation, injection of a huge amount of chemicals, risks of production reduction or shutdown.

Thermal insulation, is one of the methods to be used to prevent hydrates formation in pipelines, with the main purpose to reduce the heat flow from the cold sea water around the pipe to the warm crude inside the pipe, eliminating this way one of the hydrates formation elements (Low temperature) out of the hydrate formation envelope as well as allowing the system to have a high cool down time.

According to Makongon[1], pipe insulation is not supposed to be uniform all along, since the temperature changes and the stresses experienced are different on each section of the pipeline. However, if good calculations are performed for each of the sections, it is usual to find an average design to suit the whole length of the pipeline, thus saving time, material and money.

Amongst all pipe insulation methods available, it is suggested that the use of pipe-in-pipe method should be recommended for oil and gas pipelines, since it allows the conservation of the insulation for much more time then when it is exposed to various external forces and circumstances [2].

Ferreira [2] suggests that flow assurance scope of study, is to investigate measures to prevent any issues during the process of crude Oil extraction from the well to the treatment and/or storage facility.

Hydrates are solid crystals ice kind appearance. Its formation depends essentially upon the presence of water and natural gas, high pressures and low temperatures. A molecular structure of water with hydrogen bonds holding the gas molecule within. Hydrates pose in hazard to Oil & gas production systems. In presence of hydrates, the production may drop significantly, some important equipment such as Separators and pumps may damage during the course of the fluid. In many occasions, to remediate the appearance of hydrates, companies use Chemical inhibitors. However, is not always cost effective to use them, due to the quantities to be injected, the availability of such chemicals in the market and the correctness and effectiveness of the specific chemical to be used.

This paper fringes its study objectives on the use of thermal analysis to optimize hydrates formation prevention in a pipeline and the significance of U-Value to determine the insulation design for a given pipeline.

2. The Research Problem

Due to the chain size, lighter gases such as methane and ethane are more likely to form Hydrates than the heavier ones. Ferreira [2] further suggests that there is a higher tendency of Hydrates formation in a pipeline with the presence H_2S and CO_2 due to the solubility in water of these contaminants.

Hydrates formation normally occurs in pipe bends, low points, pipe joints and valves since these are the most common points of water concentration. Hydrates, amongst other issues, they cause the blockage of valves and pipes segments, obstruction ion of the pipeline, causing, equipment damage, high energy consumption and even a complete shutdown of the operations.

To avoid the issues mentioned above, many are the methods to be used. However, in the selection process of which method to be used, it is necessary to take into account the effectiveness of such method, the stage (engineering design or operation) to be applied, the cost and risks involved using such method.

Many are the methods that are used today to solve the problem of hydrate formation, but for this work the method in development is the thermal analysis in order to obtain the best thermal insulation aiming to keep the temperature away from the HFT for longer, making it possible to solve the problem more effectively and reduce costs.

For this paper, the method to be used will be the thermal study of the pipeline during the design phase in order to avoid problems during its Operation. No specific problem is considered, but a cost effective and almost free of physical risks method will be evaluated to accommodate our client´s expectation.

3. Methodology

The data used for this study were collected form a realistic project ran by SAIPEM Luxembourg/ Angola Branch. It was possible to have access to situations experienced in one of the projects and to analyze the effectiveness of the thermal analyzes in the prevention of the formation of hydrates. Several analyzes were carried out in order to obtain the best thermal case and a retention time normally expected by the customer, which facilitates the production stop and restart operations, optimizing productivity.

Many experiments were performed in order to understand the importance of thermal analysis in preventing the hydrates formation in pipelines.

To conduct such studies, COSMOS Geostar software was used, a software developed by SRAC (Structural Research Analysis Corporation), that helps to represent graphically the pipe structure and analyses the physical characteristics of the fluid being transported as well as the outside environment around the pipe. And the end of each simulation, the software is able to provide us with the rate of heat transfers from one end to another, the U-Value and the CDT (Cool down Time) for the system.

3.1. U Value and CDT Analytical Calculations

For a typical pipe cross section as depicted below (Fig.1 and Fig. 2), the analytical calculation for the U-value and Cool down Time.

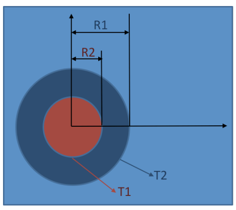

Fig.1: Pipe cross Section

$$U = \frac{\Phi_{tot}}{\pi \times ID \times \Delta T} \quad (1)$$

Where

$$\Phi_{tot} = \sum_{i=1}^{n} \varphi_i \quad (2)$$

$$\Delta T = T_{in} - T_{sea} \quad (3)$$

Where Φ, represents the thermal flux; R1/R2, represents the sectional thermal resistances; T1, represents the fluid temperature and T2, represents the external environment temperature.

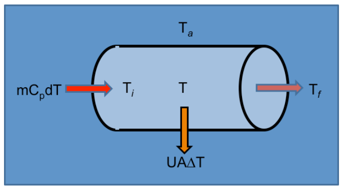

Fig 2: Pipe longitudinal view

$$mC_P dT = UA\Delta T \quad (4)$$

$$CDT = \frac{mC_p}{UA} ln \frac{T_f - T_a}{T_i - T_a} \quad (5)$$

Where: C_p is the specific heat of the fluid; m is the mass of the fluid; T_i is the temperature at which the fluid enters the pipe segment; T_f is the temperature at which the fluid exits the pipe segment; T_a is the ambient temperature around the pipe and; A, is the cross section area of the pipe.

3.2. Software Description

COSMOSM for Windows is a complete, modular, full-fledged, self-contained finite element system developed by Structural Research and Analysis Corporation (SRAC). Geometries are built in GEOSTAR, the pre- and post-processor of COSMOSM, but could also be imported from CAD system. The COSMOSM system consists of a pre- and postprocessor, various analysis modules, interfaces, translators and utilities. The program is completely modular and allows the following types of problems to be solved: Structural Problems, Heat Transfer Problems, Fluid Flow Problems and Electromagnetic. The Heat Transfer Analysis Module (HSTAR) module solves heat transfer problems involving conduction, convection and radiation.

The U-Value is calculated considering a stationary case with a constant internal fluid temperature and external seawater temperature. On the other hand, the CDT is calculate taking into account the transient state, where the whole pipe length and its insulation are studied.

For geometry reasons, several insulation simulations were done in a standard section of piping and in a field joint in order to obtain a U-value suitable to the functionality of the system, to know the temperatures and time of hydrate formation as well as the cooling time.

After the analyzes were obtained solutions for the prevention of the problem in the project under study and that are presented in this work.

3.3. Hydrates

Researches [3],[4],[1],[5] illustrate that hydrates are stable in a pressure-temperature region. The pressure and exact temperature range from gas to gas. An equilibrium curve is made with all pressure-temperature pairs where there is hydrate formation, there may be water and gas together for an indeterminate period. The hydrate formation region is located above the curve, region in which the hydrate is thermodynamically stable. This curve is adjustable depending only on the density of the gas i.e. the type of gas (Fig.3).

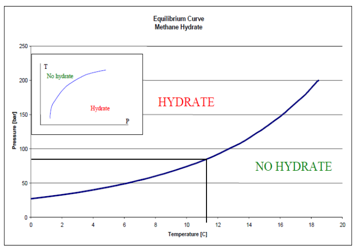

Fig. 3: Hydrate balance curve. The curve represents the stability region for a methane hydrate, the equilibrium line was simulated by the PVT simulator (Adapted by Total Fina Elf [4]).

The left part of the curve is the stable region. It is assumed that we have a gas under constant pressure cooling, P = 80 bar. Furthermore, suppose the free water is present, possibly from the gas phase due to the reduction in temperature, or was produced directly from the reservoir. Observe the intersection in the equilibrium curve at T = 11.5ºC when the pressure is 80 bars. It means that when the temperature is below 11.5 ° C there is a risk of formation of methane hydrate, when the pressure is 80 bar.

In order to delay the formation of the hydrate the conditions of thermodynamic equilibrium must be changed thus displacing the curve of the hydrate and only to give continuity to other procedures that will be approached throughout this paper.

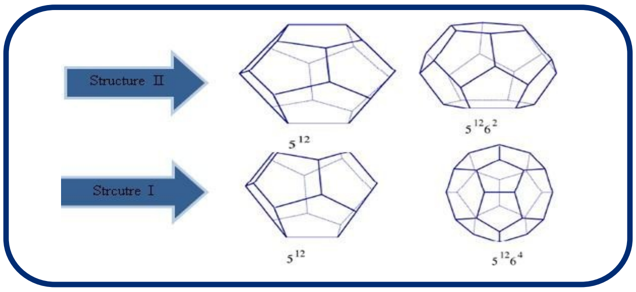

Fig. 4. Hydrates Structure (Adapted de Total Fina Elf [7])

The consistency of the hydrate is varied due to its chemical composition and physical properties. Hydrate buffers may also contain a large amount of compounds such as waxes and asphaltenes, sands, oil and gas boxes. This is due to the similarity of the formation conditions of each of the compounds with the hydrate formation conditions [6].

If we know the quantity of each fraction (both for water and gas) we can predict the ease of hydrate formation according to the standard percentages which are: 87% water and 13% gas [7].

According to Peytavy[8], the structure of the molecule of water that forms are united by connections of the type of hydrogen bridge, thus being found in the petroleum industry two types of structures constituted by two types of cavity (small and large cavity) as depicted in Fig. 4.

The formation of these depends on the type of substance present in the gas. The structure I is formed by molecules of gases smaller than propane because it is the cavity of smaller size thus being less stable in comparison to the structure II.

Structure II is formed by gas molecules larger than ethane and smaller than pentane. This is the structure that is most found in the oil industry.

The gases which may form hydrates are limited in size of the chain due to the cavities in which they fit. For natural gases, methane and iso-butane fit into the wells, but there are other gases that also fit together and can form hydrates, so the natural gases are not the only hydrate formers. Air can also form hydrates under high pressure conditions such as carbon dioxide [9].

Hydrates cause an increase in viscosity of the fluid, its accumulation facilitates the creation of hydraulic plugs and consequent blocking of the piping. These buffers are formed during the flow of the oil or gas necessarily containing water and gas. Its formation normally occurs in curves and low points of the pipes, connections and valves because they are the most propitious points of accumulation of water. Hydrates can be formed during the production of the oil, during gas flow ad during drilling phase and completion.

According to Lingelem [10], hydrate formation begins in the aqueous phase emulsified in the oil. The water present in contact with the gas forms a hydrate film which isolates the water phase of the oil phase which over time becomes firmer.

There are numerous problems caused by hydrate buffers. They cause great damage to the production of a field as clogging of valves and pipes, immobilization of the drilling column due to hydrate formation and pipe obstruction

These problems imply loss of productivity, damage to equipment, higher energy consumption and it is often necessary to stop drilling operations to remove hydrate, and these interventions are costly.

Prevention is the most important point of operations. There are several techniques used and these are grouped in many bibliographies into two categories:

- **Chemical and physical treatment**

This includes the use of thermodynamics inhibitors, kinetics inhibitors, agglomerating, dehydration, heating, inert gas treatment, thermal insulation and depressurization.

- **Thermodynamic Inhibitors**

This method is usually the first choice whenever there is a need to develop a strategy for solving the problem. This is proven technology with excellent results [11].

The most commonly used inhibitors are methanol and monoethylene glycol (MEG). But other alcohols, glycols and salts (NaCl, $CaCl_2$, KCl) may be used.

- **Kinetic and anti-agglomerating inhibitors**

Kinetic inhibitors are water-soluble polymers that serve to retard the formation of hydrates. They decrease the rate of growth of hydrate crystals. They act in a predetermined period of time, depending on the sub cooling to which the fluid is exposed and also depending on the residence time of the fluid in the hydrate formation zone. The most commonly used kinetic inhibitors in fluid testing are N-vinylpyrrolidone, N-vinylcaprolactan and their copolymers.

- **Dehydration**

In dehydration the idea is to remove the water. An alternative to displace the hydrate curve. If there is no free water, there will be no formation of hydrate. This gives a certain flexibility as it is possible to operate within the hydrate region in terms of pressure and temperature. The gas usually stays dry when in contact with glycol. What happens is that water is transferred from its vapour state into natural gas.

- **Thermal insulation and Depressurization**

The main objective of the insulation is to ensure that there is less heat loss possible to the external environment thereby keeping the temperature outside the hydrate envelope for longer thereby enabling the operators to stop and resume production in an even suitable system and possibly to prepare the system for a longer stop.

Among the thermal insulation methods for pipes, Cardoso & Ferreira[2] defend that the use of pipe-in-pipe allows the application of different insulating materials depending on the location and properties of the fluid to be produced.

The level of protection of the insulation will depend on the temperature of the reservoir, the production flow, the size of the tieback and especially on the type of insulation chosen and this project has as main objective to prove that it is possible to increase this protection by a strict thermal analysis using the COSMOS software.

4. Case study

The Blue Pearl Project is located in the southern portion of Block 19, in the province of Cabinda, Republic of Angola. The project's main objectives include the development of oil and gas from the Black Diamond field. The scope of this study is based on determining the U-Value in a standard pipe section and a field joint, and the production system CDT. For this, COSMOS software was used where several isolation simulations were made.

The project consists of the proper dimensioning of the insulation system of the oil extraction pipelines with a piping system of about 4391 meters of piping and about 760 meters of field joints.

The piping section was analyzed, and the field joint was obtained solutions to prevent the problem in the project presented in this work.

Usually, the operating companies provide us the U-value they expect to have and the cool down time. We need to know the characteristics of the pipe, the operating temperature and the sea temperature as well as the design life of the project.

The purpose of the research is to define or verify the different insulation material and associated thicknesses needed to provide to the production line of 18” the required thermal performances. The work covers the standard section and the field joints.

The Table 1 show a 1.0-Btu.hr^{-1}.ft^{-2}.°F^{-1} [5.68-W.m^{-2}.K^{-1}] (at pipe ID) overall heat transfer coefficient (U-value) is required from the top of the inlet riser to the top of the outlet riser, to meet the arrival temperature criteria as weel as Table 2 shows the anticorrosion coating insulation.

Table 1: Fluid Thermal Data

U-value	$W.m^{-2}.K^{-1}$ [$Btu.hr^{-1}.ft^{-2}.°F^{-1}$]	5.68 [1.0]
Arrival Temperature	^{0}C [ºF]	65.56 [150]

To calculate the required insulation thickness to comply with the U-value requirement, the thermal resistance of the seawater and of the production fluid are neglected.

The following temperature on the external surface in contact with Seawater is imposed:

- T = Minimal Sea Water Temperature 14.4°C [57.20ºF].
- T=Maximum seawater temperature of 29.7ºC [85.46ºF] for PU max temperature calculation.

In order to guaranty an overall U-value respecting the above requirements, the standard section shall have a U-value less or equal to 5.5 $W.m^{-2}.K^{-1}$ or 0.969 $Btu.hr^{-1}.ft^{-2}.°F^{-1}$ (aged value).

Table 2: Insulation material typical characteristics

Material	Heat conductivity	Density	Heat capacity
	$W.m^{-1}.K^{-1}$ [$Btu.hr^{-1}.ft^{-1}.°F^{-1}$]	$kg.m^{-3}$ [$lb.ft^{-3}$]	$J.kg^{-1}.°C^{-1}$ [$Btu.lb^{-1}.°F^{-1}$]
FBE	0.3 [0.173]	1300 [81.16]	1500 [0.359]
		1300 [81.16]*	
Hybrid HSS	0.223 [0.129]	903 [56.39]	1610 [0.385]

Table 3: Resumes U-values and associated insulation thickness

Material	Heat conductivity $W.m^{-1}.K^{-1}$ [$Btu.hr^{-1}.ft^{-1}.°F^{-1}$]
PP adhesive	0.220 [0.127]
Solid PP	0.219 [0.127]
PP Foam (Start Of Life)	0.173 [0.100]
PP Foam (End Of Life)	0.179 [0.103]
Solid PP	0.222 [0.128]
Solid PU (FJ)	0.208 [0.120]
IMPP	0.222 [0.128]

The thermal requirement is fulfilled for the production line. With the obtained results, is very well observed that there is a very solid path to mitigate the Hydrates formation in the system, since the heat transfer across the pipe walls is greatly reduced, consequently eliminating on of the elements on the Hydrates formation set (low *temperature*). The chances of having a significant drop in temperature during operation or shut down are reduced significantly.

Is also observed that with the configuration obtained for the insulation, it is possible to have a CDT of *27 hours*, which is really considerable time for the production system preservation operation, in case it takes place.

It is verified through this experiment, the importance of the correct insulation design for the pipelines. A good insulation constitutes directly a high hydrates prevention performance for the respective system. Many other methods such as electrical heating, chemicals injection and other thermodynamics means of avoiding hydrates may be considered to assist the effect of the insulation on the hydrates prevention, since the insulation layer, depending on the deep sea conditions and umpredicteness, may suffer damages and loose its efficiency.

Table 4: Simulation from NF model of Block B

Description	Steam	Gas	CO_2	Polymer	Combustion
NDEI≤10%	X	√	X	√	√
10<NDEI≤20%	X	√	X	√	√
20<NDEI≤30%	X	√	X	√	√

5. Conclusions

A five layer feedforward-backpropagation model based on TSK and Mamdani has been trained and validated to obtain the optimal model for testing oilfield data from Block B in offshore Angola. The sensitivity analysis of the two approaches was employed using the successful EOR data and the least RMSE from the trained and validated model for each parameter and NDEI was used in the testing process with TSK approach being more accurate than Mamdani approach.

The results obtained from the NF model show that this model presents strengths that can be considered as robustness required for screening reservoir candidates. Several advantages compared to other models have been identified due to the fact of the model uses raw data and no assumptions needed but matches the pattern from the data under investigation.

The result of the screening process within the five EOR techniques presented miscible gas, polymer and combustion as the most suitable techniques whereas CO_2 and steam injection were not suitable within the investigated range. Therefore, additional investigation such as laboratory tests, simulation and pilot tests are recommended to confirm the results obtained from the model.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

[1] Makogon, Yuri F. Hydrates of Hydrocarbons,. Editora: PennWell Books. Tulsa (Oklahoma), United Stats of America. (1997).

[2] Ferreira, S. Importância da Prevenção de Hidratos para o Processamento de Gás Natural (Importance of preventing hydrates for natural gas Processing). Dissertação de Mestrado. Centro Universitário Augusto Motta. Rio de Janeiro, Brasil. (2011).

[3] MARTINS, Luís. R.. Hidratos de Metano: Um Interesse Crescente. Book. Editora: GRAVEL. Porto Alegre, Brasil. (2003).

[4] Total Fina Elf. “Hydrates Manuel formation”, vol. 26, pág. 06-42. (s,d)

[5] Ross, Luciano. F. S.; Formação de Hidratos em Sistemas de Gás Natural. Dissertação de Mestrado. Universidade Estadual de Campinas, São Paulo, Brasil. (1990).

[6] Sloan, E. Dendy; Bloys, J. Ben. Hydrate Engineerin. Society of Petroleum Engineers. Editora: Richardson, Tex Henry L. Doherty Fund of AIME. Society of Petroleum Engineers 2000. Book. (2000).

[7] Vinatovskaja, Tanja. Cold Flow in the Arctic: a Feasibility Study. Master´s Thesis. University of Stavanger. (2015).

[8] Lingelem, M. N.; Majeed, A. I. hydrate formation and control in long distances submarine pipelines. Chemical Engineering Research & Design Journal. vol. 70, pág 38-42. (1992).

[9] Peytavy, J. L.; Glenat, P.; Bourg, P.; SPE, TOTAL S.A.. Kinetic Hydrate Inhibitors: Sensitive Towards Pressure and Corrosion Inhibitors. International Petroleum Technology Conference. Dubai. (2007).

[10] Sloan, Jr. E. D. Offshore Hydrate Engineering Handbook. ARCO Exploration and Production Technology. New York. United Stat of America. (1998).

[11] Andrade, A. R. Hidratos no Âmbito de Perfuração: Histórico, Mecanismos de Inibição e Técnicas para Análises de Hidrato. Monografia. Universidade Católica, Rio de Janeiro. (2009).