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MODELING, SIMULATION AND CONTROL OF SHELL AND TUBE HEAT EXCHANGER OF BRAZILIAN PRE-SAL FPSO

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Abstract: Brazilian offshore production is greater than onshore production and therefore deserves to be highlighted in its analysis. In recent years, offshore oil exploration in the Brazilian pre-salt has gained prominence due to its volume and social contribution to the country. As it is a complex process, it is important to simulate and model the conditions imposed on the equipment as accurately as possible. The exchangers of FPSOs in platform processes are mostly of the shell and tube type and therefore deserve attention. It was in this scenario that models and simulations were developed to control shell and tube heat exchangers in order to evaluate optimization conditions and possible process stability scenarios. The scheme proposed by Garcia's work was used as a basis and simulated in the Matlab® Simulink® environment in order to validate the models with real data from the studied platform. The results were satisfactory, with deviations of less than 10% for the variables analyzed and it was possible to validate the Gracia model by comparing it with the theoretical and real data available.
Keywords: Shell and tube heat exchanger, process control, simulation and modeling.

INTRODUCTION

The oil industry is essential to modern life. Whether for generating electrical energy, moving vehicles or even as an input for the manufacture of various components, oil consumption can even be used to measure the development of a nation and, therefore, will continue to be essential for many decades until that economically viable substitute products are found for all their applications, (COSTA, 2014).

The technological challenges for oil exploration in ultra-deep waters, the Brazilian pre-salt, permeate conventional exploration and production techniques, Chaves (2018). According to Campos et al. (2017), environments that present extreme situations of temperature, pressure and the presence of contaminants, such as CO2, require new approaches to enable production with reference efficiencies for the processes, thus justifying studies on the equipment used to process this oil.

Heat exchangers are important on oil platforms, as they provide the appropriate temperature variation for the processes to operate. Garcia (2017) propose a new way of carrying out simulation and control of shell and tube heat exchangers that becomes important for the scientific community, because it breaks with conventional models with lumped parameters and presents a way of discretizing the model of systems of equations heat differentials in simulation stages, thus enabling simulation in Matlab®'s Simulink® and thus making it possible to evaluate process control for heat exchangers in various scenarios, Chaves (2021).

Thus, this research will aim to analyze how the model proposed by Garcia (2017) applies to the control of two shell and tube heat exchangers of a real FPSO type platform currently installed in the Brazilian pre-salt, focusing on evaluating the control stability and validation of the model so that scenarios that add value to Petrobras can be evaluated, contributing to a more stable operation of the platform and sustainable industrial development, with a safe working environment and responding to the following research question:

"How to model, simulate and control heat exchangers in the treatment process of an FPSO platform, with the proposal of Garcia (2017), in a valid and safe way?"

METHODOLOGY

The process flowchart used in this work takes into consideration, the current condition of the platform under analysis. Below in figure 1 is a summary flowchart made for this work according to the current situation of the platform. The exchangers studied are P-1223001 and P-1223002, equipped with PID controllers and with only 1 pass in the tubes and 1 pass in the shell for the current moment of operation, with the capacity to operate with up to 160,000 bbl/d.

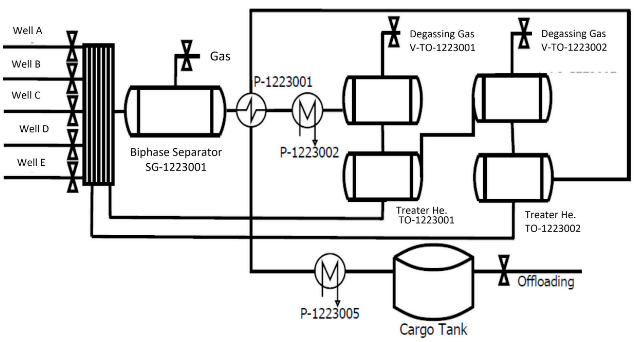

Figure 1 – Oil treatment process flowchart in current configuration.

Source: Author data (2023).

To model the heat transfer system, the following equation was made, based on what is described in the work of Garcia (2017) and already applying the nomenclature to the case under analysis, followed by figure 2 which shows how it is schematized:

$d(T_T$, average)

$$\frac{d(T_{T,média})}{dt} = \frac{\rho_{T,e} Q_{T,e} c_{P,T} (T_{T,e} - T_{T,s}) + UA\Delta T_{CT}}{\rho_T V_T c_{P,T}} \quad (1)$$

$d(T_C$, average)

$$\frac{d(T_{C,média})}{dt} = \frac{\rho_{C,e} Q_{C,e} c_{P,C} (T_{C,e} - T_{C,s}) - UA\Delta T_{CT}}{\rho_C V_C c_{P,C}} \quad (2)$$

$$\Delta T_{CT} = \frac{\Delta T\text{Hull in each section}}{2} - \frac{\Delta T\text{Pipes in each section}}{2} \quad (3)$$

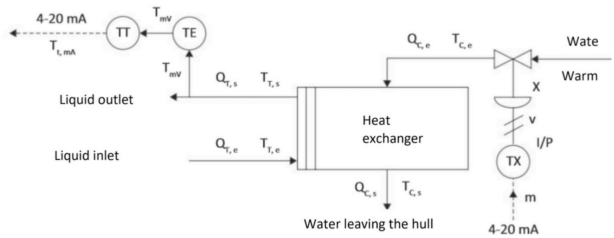

Figure 2 – Schematic of a shell and tube heat exchanger.

Source: Garcia (2017).

TT, average = Average temperature in the tubes (°C) and TC average = Average temperature in the shell (°C);

cPT = Specific heat of the fluid in the tubes (J/ (kg. K));

cP, C = Specific heat of the fluid in the hull (J/ (kg. K);

TT and TTs = Inlet and outlet temperature of the tubes in each section (°C);

TC and TCs = Hull inlet and outlet temperature in each section (°C);

$QT\ e$ = Fluid flow in the tubes (m3/s) and QCe = Fluid flow in the shell (m3/s);

UA = Global heat exchange coefficient (W/K);

$VT\ e\ VC$ = Tube volume and shell volume.

RESULTS AND DISCUSSION

The circuit that represents the equations presented in the methodology, in simulink®, for each section can be seen below:

After implementing the heat transfer equation in Simulink®, it is time to implement the elements necessary to close the control loops, such as meters, controllers, actuators and converters. In addition, elements for measuring controller performance factors were included, which, in this case, were IAE, ISE, ITAE, ITSE and CE. Below is a diagram created to control the temperature of the exchangers for this work in a Simulink® environment. It is worth noting that the level and pressure controls of the separating and treating vessels in this work were also treated as below, however, considering the peculiarities of each type of control and the conditions imposed by the equipment. See figure 4 below.

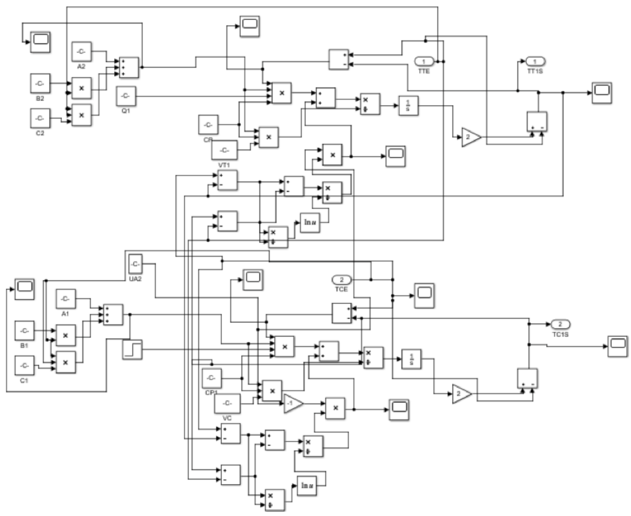

Figure 3 – Scheme prepared by the author – second section.

Source: Prepared by the author, 2023.

In this case, a PID controller was used as recommended by Teixeira et al. (2015). Unlike interface and pressure control, the temperature meter has considerable dynamics in the control process and, therefore, was considered in the control design, being modeled by a first order curve with delay and dead time, but with data hold of order 0 to simplify the analysis instead of order 1 as required for processes that have the derivative term, as, in this case, it had a small absolute value, where the rest of the items were considered purely proportional and the actuators with first order dynamics with delay and dead time with data hold of order 0.

Besides in order to validate the shell and tube heat exchanger model proposed by Garcia (2017) and replicated here under process conditions, a simulation was set up to validate the model with the data present in the example found in Garcia (2017, p. 535). The diagram drawn up in Simulink® can be found in figure 5, where there is the same exchanger repeated twice, with a positive disturbance being applied to one and a negative disturbance to the other in order to display in the same graph and time the response values to the applied step, The result of this can be seen in figure 7 in order to make a comparison between the results shown in figure 6, taken from the book Garcia (2017, p. 535).

It can be seen that the exchangers are in open loop and the disturbance follows what was indicated in the book in relation to a step of 0.48 mA at the controller output and, therefore, evaluating the response of the meter and exchanger output at this disturbance, and both the positive and the negative disturbance can be seen on the same graph.

In figure 8 you can see the result of an open loop test with a step-type disturbance equal to an increase of 0.48 mA at the controller output in order to evaluate its step deformation on the temperature meter and, therefore, analyze the process behavior, showing the validity of the control and models implemented with stability and effectiveness.

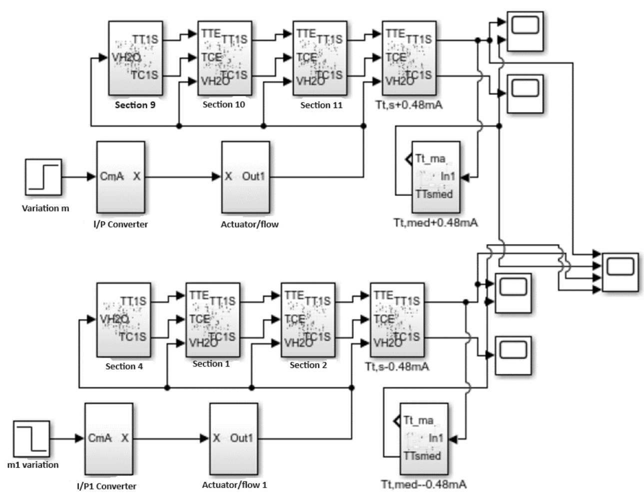

Figure 5 – Simulation scheme for validating the exchanger model.

Source: Prepared by the author, 2023.

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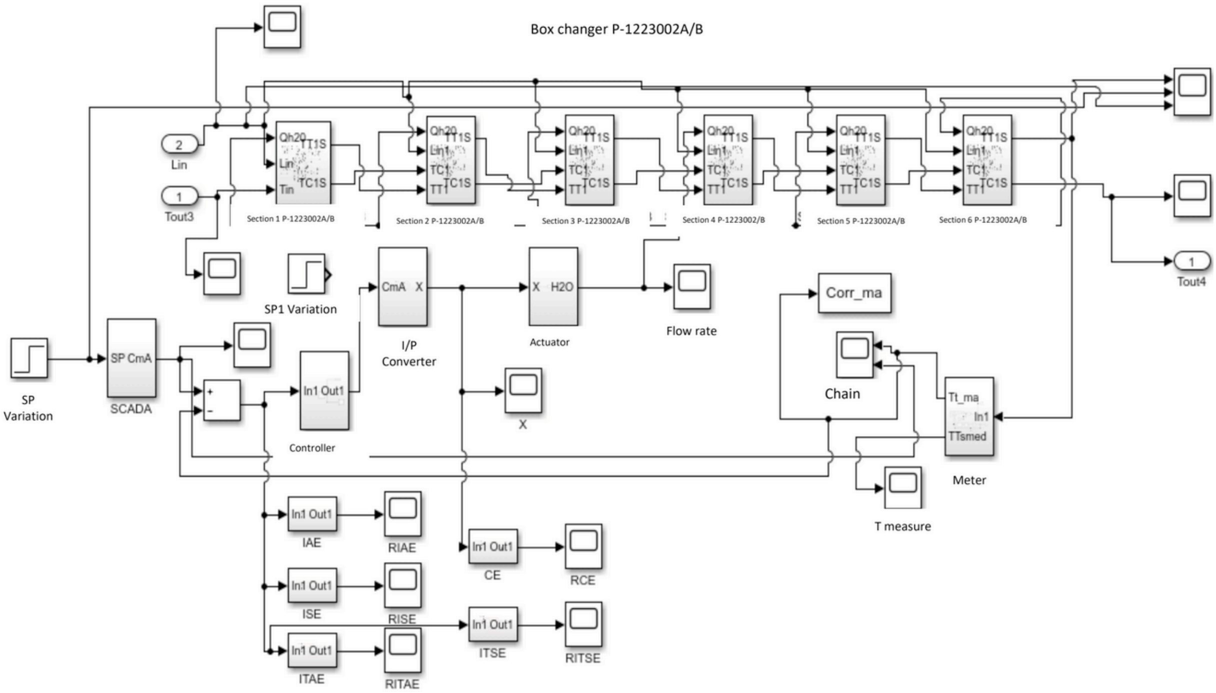
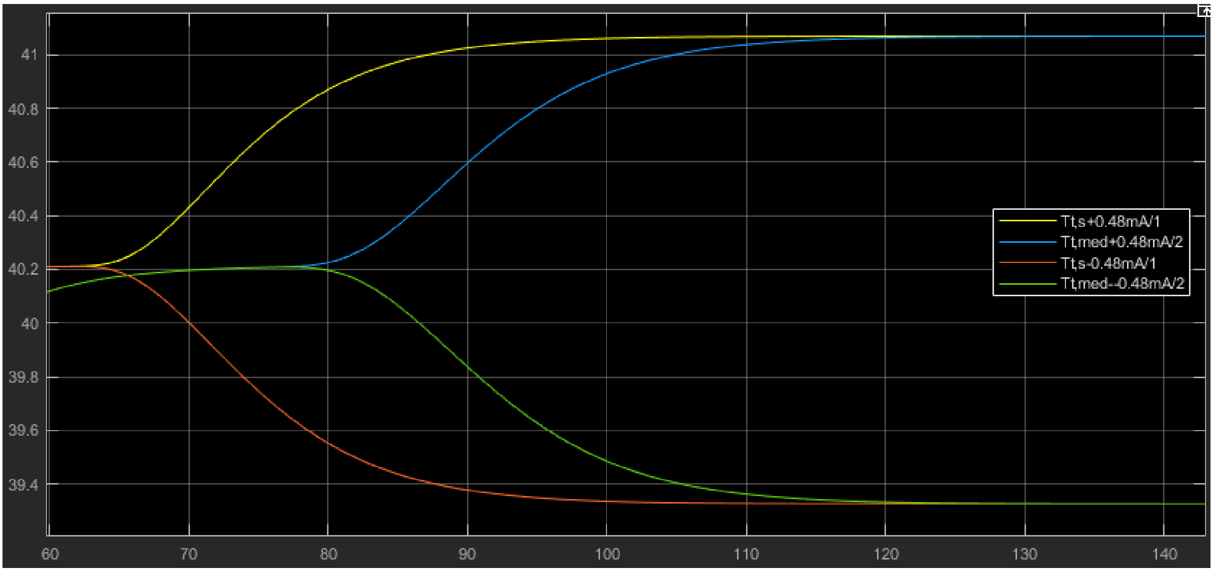


Figure 4 – Shell and tube heat exchanger used in the simulation with controller.

Source: Prepared by the author, 2023.



Temperature (°C) x Time (s)

Figure 7 – Temperature exported in the simulator at a step of 0.48 mA in the controller output current.

Source: Prepared by the author, 2023.

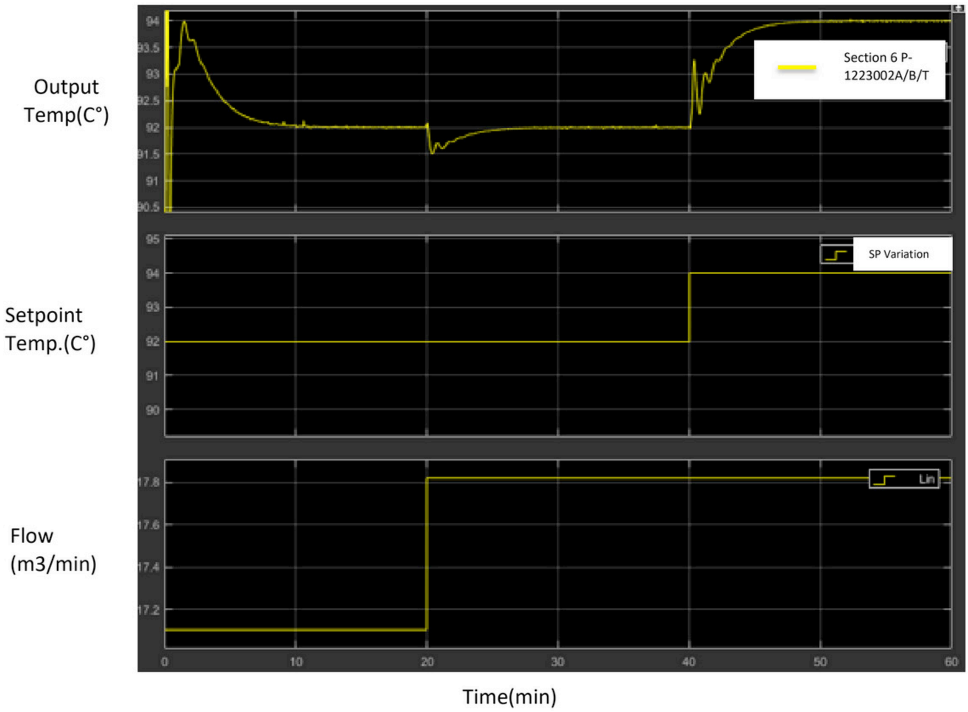


Figure 8 – Temperature control evaluation chart on P-1223002.

Source: Prepared by the author, 2022.

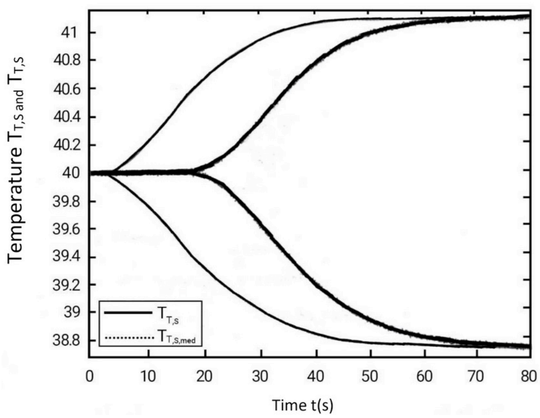


Figure 6 – Temperature graph exported in the book at a step of 0.48mA in the controller output current.

Source: Garcia, 2017.

CONCLUSIONS

It is possible to notice the good correlation between figures 6 and 7 in relation to the openness of the responses, dead time and time delays. The small differences found between the starting value and the final value shown occur due to the variation in the density calculation methodology, where Garcia uses a matrix for its calculation and, in the methodology used here, a correlation based on Racket and Lu. It is worth noting that the initial times between the graphs are different because there is a time necessary for the temperature calculation to stabilize in the simulation carried out by the author, given the numerical method used by Simlunk®, and the processing capacity of the microprocessor of the equipment used for simulation, while in Garcia's graph (2017), the process is already stabilized at time zero and, therefore, does not need to wait for stabilization time. In Garcia, the steps are applied at time 0 and, in this simulation, 4 are applied in 60 seconds of simulation.

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