Temperature Modeling and Simulation of the Asphaltic Emulsion in an Industrial Tank

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Abstract—In this paper, a solution for the modeling-simulation of the temperature propagation phenomenon in the asphaltic emulsion from an industrial tank is presented. The heating process of the asphaltic emulsion is a distributed parameter one, its model being expressed using a partial differential equation. The modeling-simulation procedure is based on the matrix of partial derivatives of the state vector (Mpdx) associated with Taylor series. Some suggestive 2D and 3D graphical representations are presented in order to show the temperature distribution inside the tank. Also, a solution for the designing of the emulsion’s temperature control system is proposed in the end of the paper.

I. INTRODUCTION

The asphaltic emulsion is stored in an industrial tank of big sizes and cylindrical form. A very important parameter that has to be monitored and controlled is the emulsion temperature in the tank. The temperature of the solution has to be maintained at lower value than 80°C, respectively at higher value than 50°C. Under the imposed low limit (50°C) of the temperature, the asphaltic emulsion passes progressively to the solid state of aggregation. Also the imposed high limit of the temperature represents the evaporation point of the hydrochloric acid from the chemical composition of the emulsion. Another restriction is imposed by the necessity that the emulsion should be delivered in the tank cars at a temperature value as high as possible in order to compensate the temperature losses from the transport period. Only in this manner, the asphaltic emulsion will be in liquid state of aggregation when it is delivered to the customer because the tank cars are not equipped with self-heating sources.

II. THE TECHNOLOGICAL PLANT

The considered tank containing asphaltic emulsion is presented in Fig. 1. In the industrial tank 1 the asphaltic emulsion 9 is stored, h being the level of the solution. In normal conditions h = 0.95·L, where L is the height of the tank. Also the tank is a covered one. The technical characteristics of the tank are presented in Table I.

<table>
<thead>
<tr>
<th>The Technical Characteristics of the Tank</th>
<th>The height (L)</th>
<th>The diameter (D); The radius (R)</th>
<th>The volume (V)</th>
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<tr>
<td>7 m</td>
<td>3 m ; 1.5 m</td>
<td>50 m³</td>
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The asphaltic emulsion is introduced in the tank in its upper part through the pipe 7 and it is delivered to the tank cars in its lower part (at 10 cm over the heat exchangers) through the pipe 10. The heating source is composed by two shell and coil heat exchangers [1] (2 and 12 in Fig. 1) placed in the lower part of the tank, being disposed in horizontal plane. The used heat carrier is the thermal oil that is heated outside the tank. The hot oil is circulated through the exchangers, the input, respectively the output points in the tank being opposite in relation to the symmetry plane of the tank in relation to its height, plane that divides each heat exchanger in two equal parts. The oil is introduced in the heat exchanger 2 through pipe 3 and it exits from it through the pipe 16. Also the oil enters the heat exchanger 12 through the pipe 14 and it exits from it through the pipe 6. The arrows show the oil’s circulation direction in each heat exchanger. As it can be remarked, the directions of the thermal oil circulation in the two heat exchangers are opposite. Considering this aspect, through some approximations, the thermal power generated by the heating source (the heat exchangers) can be considered homogeneous (uniformly distributed on the transversal section of the tank).
On all the pipes from Fig. 1, electro-valves are installed (electro-valves 4, 5, 8, 11, 13 and 15).

In this paper, the case of temperature distribution and control is considered in the emulsion’s storage case (h = const. = 0.95·L). Also in this application the tank is considered isolated with cinder wool and the temperature of the environment is considered 0°C. The initial temperature of the emulsion that is introduced in the tank is approximately 60°C, temperature resulted at the end of the production process. Due to the isolation, if the tank were not heated, the emulsion average temperature would decrease with 2°C/h. In this case, in order to maintain the initial conditions (presented in the following chapter), the heat given off by the emulsion stored in the tank in the hypothesis that the tank is not heated has to be compensated with the heat generated by the heating source. The heat given off by the solution from the tank in an hour has the expression:

\[ Q_{ced} = m_{ae} \cdot c_{ae} \cdot \Delta T_{ae} / 3600 \ [J/s] \]  

(1)

where \( m_{ae} = 47500 \) kg (0.95·50t) is the mass of the asphaltic emulsion from the tank (the density of the asphaltic emulsion \( \rho_{ae} = 1000 \) kg/m³), \( c_{ae} \) is the specific heat of the asphaltic emulsion and the difference of the emulsion’s temperature is \( \Delta T_{ae} = 2^\circ C = 2 \) K. After making the calculus it resulted \( Q_{ced} = 55.232 \) kJ/s (kW). Also the heat given off from the heating source to the asphaltic emulsion from the tank has the relation:

\[ Q_{ced1} = 1.8 \cdot F_{to} \cdot \rho_{to} \cdot c_{to} \cdot \Delta T_{to} / [J/s] \]  

(2)

where 1.8 is a constant (2·0.9; 2 derives from the fact that two heat exchangers are used for heating the tank, respectively 0.9 derives from the heating efficiency), \( F_{to} \) represents the flow of the thermal oil, \( \rho_{to} = 900 \) kg/m³ represents the density of the thermal oil, \( c_{to} \) is the specific heat of the thermal oil, respectively \( \Delta T_{to} = 20.3^\circ C = 20.3 \) K is the oil’s difference of temperature between its input and its output point in the heat exchangers (\( \Delta T_{to} \) is considered the same for the both heat exchangers).

The equality \( Q_{ced} = Q_{ced1} \) is satisfied if a flow of thermal oil of \( F_{to} = 0.8 \) l/s, is assured. The emulsion’s temperature will be increased adjusting only the flow of the thermal agent from the heat exchangers. In this case the value of the oil flow previously calculated represents the initial condition. In some cases the difference of temperature \( \Delta T_{to} \) can be considered 20.3 K, too, and in the cases when it has other values, this variation comparing with the value 20.3 K can be introduced in the simulation as a disturbance. The value \( \Delta T_{to} = 20.3^\circ C \) derives from the difference: (100.3 – 80)^\circ C. In the neighborhood of the pipes, due to the thermal agitation, a circulation of the solution from the tank appears, fact that implies the avoidance of the emulsion’s temperature increasing over the limit value of 80°C.

III. THE PROCESS MODELING

The technological heating process of the asphaltic emulsion from the tank is a distributed parameter process [2] because the temperature of the solution mathematically depends both on the time independent variable (t) and on the position in the tank. The position in the tank can be determined considering the three axes of the Cartesian space 0p, 0q and 0r (Fig. 1) and associating an independent variable to each axis (p, q, respectively r). In this case, the emulsion temperature in the tank is a function of four independent variables. Also the temperature variation in the tank volume is due to some major factors that are exposed below.

Considering these aspects, the highest temperature of the solution from the tank, in relation to its height (on the 0r axis), can be measured in the close neighbourhood of the heat exchanger, respectively the lowest temperature can be measured in the upper part of the tank, at the separation limit between the solution and the gas. Another factor that introduces temperature variations on the 0p and 0q axes is the influence of environment temperature. The generated effect consists in a decreasing evolution of the temperature between the region of the symmetry axis of the tank in relation to its height (that corresponds to the 0r axis) and the tank walls.

In Fig. 1 the origin of the Cartesian system 0 is placed in the center of the tank (on the symmetry axis of the tank in relation to its height) and in the neighborhood of the heat exchangers (at 10cm over these). The 0r point is a projection of the origin point in the height of the tank made in order to make the representation more suggestive (it is avoided the agglomeration of the elements in the lower part of the figure). As it has previously mentioned, the temperature variation on the 0r axis corresponds to the temperature variation on the tank height. Also the temperature variations on the 0p, respectively 0q axes (these being vertical lines) correspond to the temperature variations on the radius of the tank section perpendicular to its height. Due to the fact that the thermal power generated by the heating source is considered homogeneous, on both 0p and 0q axes, the temperature has the same variation form. With other words, at a certain height, in all points from the tank that belong to a circle from the corresponding section of the tank perpendicular to the 0r axis (0r is the vertical line on the plane generated by 0p and 0q), the same temperature can be measured.

Considering the previous remarks, in the model of the process, as space independent variable is considered only r (corresponding to the 0r axis). The influence of the temperature variation on 0p, respectively 0q axes is introduced in the model as a constant depending on the values of the variables p and q in the point where the temperature simulation is made. The approach modeling procedure is valid for the case of the temperature evolution over the initial conditions maintained according to the procedure presented in the previous chapter.

The general partial differential equation of second order with two independent variables (time and height r) (PDE II-2) [3,4] that describes the process work is presented in relation (3).

\[ a_{00} \cdot y_{00} + a_{10} \cdot y_{10} + a_{01} \cdot y_{01} + a_{20} \cdot y_{20} + a_{11} \cdot y_{11} + a_{02} \cdot y_{02} = Q_{00} . \]  

(3)

In (3) the a... coefficients are constant and the functions \( y(t,r) \) (the temperature value of the asphaltic emulsion from the tank) and \( \phi(t,r) \) respect Cauchy conditions of continuity... In (3), the notation \( \frac{\partial y}{\partial r} = \frac{\partial T^R \cdot y}{\partial t} \) was made, where \( T=0,1,2,..... \), and \( R=0,1,2,..... \). This notation is valid for \( \phi \) function, too.
In order to identify the structure parameters of the process, some experimental data are used. If the flow \( F_{0w} = 0.8 \text{ l/s} \) is used as it was presented in the previous chapter, the initial condition temperature of \( 60^\circ\text{C} \) is assured in the origin of the Cartesian system from Fig. 1. In the same time, due to the exterior influences and due to the non-perfect isolation, the temperature decreases according to some exponential evolutions, from the point \( 0 \) (origin) to the tank walls, both on the tank height and in its transversal section. In steady state regime, the emulsion temperature near the separation limit between the liquid and the gas from the tank (\( h = 0.95\cdot L \)), on the 0r axis, has the value \( 54^\circ\text{C} \). Also the temperature of the emulsion near the lateral walls of the tank, in the same transversal section that contains the origin \( 0 \) (on both the \( 0p \) and \( 0q \) axes) has the value of \( 58^\circ\text{C} \). Finally, the emulsion temperature that can be measured near the separation limit between the liquid and the gas from the tank, near the lateral wall has the value \( 52^\circ\text{C} \). The difference of temperature of \( 6^\circ\text{C} \), between the emulsion temperature in the transversal section of the tank that contains the origin \( 0 \) and the circular section from \( h = 0.95\cdot L \) is maintained for any correspondent points from the section (for any value of \( p \) and \( q \) independent variables). Also, the difference of temperature of \( 2^\circ\text{C} \), between the symmetry axis of the tank in relation to its height (the \( 0r \) axis) and the tank lateral walls is maintained for any value of the height (for any value of the \( r \) independent variable). The presented values represent the set of the initial values of the temperature in the tank.

For the calculation of the structure parameters, an experiment based on a positive step signal (in this case the thermal power) applied at the input of the process is made. The process is considered linear near the working point given by the initial conditions of the temperature. If the used step signal has the value \( 82.848 \text{ kW} \) over the initial value of \( 55.232 \text{ kW} \), the temperature in the origin \( 0 \) of the Cartesian system gets steady to the value \( 65.3^\circ\text{C} \). Also the differences of \( 6^\circ\text{C} \) between the emulsion’s temperature in the lower part of the tank and the upper part of the tank, respectively do differences of \( 2^\circ\text{C} \) between the emulsion’s temperature in the central part and the lateral walls of the tank are kept. The steady state regime appears after 50 min in the origin point, respectively after 70 min at \( h = 0.95\cdot L \). The steady state regime appears slower in the upper part of the tank due to the longer distance of this zone in relation to the heating source.

The approximating analytical solution that verifies relation (3) is:

\[
y_{00.0V}(t,r) = K_y \cdot F_{0T}(t) \cdot u_0(t) + F_{0R}(r) + C. \tag{4}
\]

In (4), the \( F_{0T}(t) \) increasing exponential function is given by the relation:

\[
F_{0T}(t) = 1 - \frac{T_1}{T_1 - T_2} e^{-\frac{t}{T_1}} - \frac{T_2}{T_2 - T_1} e^{-\frac{t}{T_2}}, \tag{5}
\]

where \( T_1 \) and \( T_2 \) are the time constants of the process. The time constants were identified using the tangent method to the curve that marks the temperature evolution in relation to time, in the origin point \( 0 \), resulted in the previous experiment. After calculation, the values \( T_{10} = 4 \text{ min} \), respectively \( T_{20} = 6 \text{ min} \) resulted. The same procedure is applied to the experimental curve resulted at \( h = 0.95\cdot L \), resulting the values \( T_{1B} = 5.6 \text{ min} \), respectively \( T_{2B} = 8.4 \text{ min} \). The value of the time constants is the same in each transversal section of the tank, but differs from a transversal section to another. Considering a linear variation of the time constants in relation to the independent variable \( r \), the general form of the time constants of the process resulted:

\[
T_1 = T_{10} + \frac{T_{1B} - T_{10}}{r_f - r_0} r_f, \quad T_2 = T_{20} + \frac{T_{2B} - T_{20}}{r_f - r_0} r_f, \quad r_f = 0, \quad r_0 = 0, \quad \text{corresponding to the origin} \ 0, \ \text{respectively} \ r_f = h = 0.95\cdot L. \tag{6}
\]

The proportionality constant of the process can be calculated using the following relation:

\[
K_y = \frac{y_{st} - y_i}{u_{st} - u_i} = \frac{5.3}{82.848} = 0.064 \text{ K/W}. \tag{7}
\]

The values \( u_{st} \) and \( u_i \) correspond to the steady state regime, respectively to the initial value of the input step signal. Also \( y_{st} \) and \( y_i \) correspond to the steady state regime, respectively to the initial value of the temperature in the origin point \( 0 \).

The input signal \( u_0(t) \) represents the thermal power generated by the heating source. Only one subscript attached to the signal \( u \) signifies the differentiation order of this signal in relation to the independent variable time \( t \). The input signal can be obtained as it is presented in Fig. 2.

\[
\begin{align*}
\Delta T_{sd}(t) \times u_0'(t) & = 1.8 \cdot y_{st}c_m \cdot u_0(t) \\
F_{sd}(t) & = \text{input signal (thermal power)}
\end{align*}
\]

Figure 2. The generating of the input signal (the thermal power)

In Fig. 2, the implementation of relation (2) is made. The intermediary signal \( u_0(t) \) results if we multiply the values of the thermal oil flow and of the thermal oil difference of temperature between the input and the output points in/from the tank. The relation between signals \( u_0(t) \) and \( u_0(t) \) is made through a constant. \( u_0(t) \) results introducing the same oil flow in both heat exchangers and considering the value \( \Delta T_{in} \) the same in both cases, too.

In (4), the \( F_{0B}(r) \) decreasing exponential function is given by the relation:

\[
F_{0B}(r) = (-6) \cdot \left( 1 - \frac{R_1}{R_1 - R_2} e^{-\frac{r}{R_1}} - \frac{R_2}{R_2 - R_1} e^{-\frac{r}{R_2}} \right). \tag{7}
\]

In (7) the constant \( -6 \) represents the difference of temperature (the temperature drop) between the transversal section from \( h = 0.95\cdot L \) and the transversal section of the tank that contains the origin \( 0 \). Also \( R_1 \) and \( R_2 \) can be called “the length constants” of the process associated to the temperature propagation on the \( 0r \) axis.
Their values are determined using a method based on interpolation, resulting \( R_1 = 0.64 \text{m} \) and \( R_2 = 0.96 \text{m} \).

Having the previously calculated parameters of the process, the a... coefficients from (3) can be determined: \( a_{00} = 1, \ a_{01} = T_1 + T_2, \ a_{20} = T_1 \cdot T_2, \ a_{01} = R_1 + R_2, \ a_{02} = R_1 \cdot R_2 \) and \( a_{11} = (T_1 + T_2) \cdot (R_1 + R_2) \).

In (4), the constant \( C \) has the purpose to shift the value of the analytical solution \( Y_{00,n} \) with a value that depends on the position in the transversal section of the tank where the simulation is made. Due to the fact that on any circle from the circular sections of the tank with the center on the \( 0r \) axis, the temperature is constant, it results that the length constants \( P_1 \) and \( P_2 \) are equal as value with the length constants \( Q_1 \) and \( Q_2 \). In this case the exponential decreasing function that models the temperature propagation between the \( 0r \) axis and the lateral walls of the tank can be expressed, for example, in relation only to the independent variable \( p \). The constant \( C \) has the following expression:

\[
C = F_0(p_c) = (-2) \cdot (1 - \frac{P_1}{P_1 - P_2} \cdot e^{\frac{P_1}{T_1}} - \frac{P_2}{P_2 - P_1} \cdot e^{\frac{P_2}{T_2}}).
\]

In (8) the constant \((-2)\) represents the difference of temperature between the lateral walls of the tank and the \( 0r \) axis. Also, \( p_c \) represents the considered value for the independent variable \( p \), more exactly the radius of the circle with the center on the \( 0r \) axis. In this case, the simulation can be made on a cylinder or on a spiral of radius \( p_c \) and of height \( h = 0.95 \text{L} \). Using the same interpolation method as in the case of the length constants \( R_1 \) and \( R_2 \), after calculus the values \( P_1 = Q_1 = 0.2 \text{m} \), respectively \( P_2 = Q_2 = 0.3 \text{m} \) resulted.

The analogue modeling of the process starts from the equation (3) rewritten as:

\[
\begin{bmatrix}
y_{00} \\
y_{10} \\
y_{20} = \frac{1}{a_{20}} \cdot \left[ \varphi_{00} - (a_{00} \cdot y_{00} + a_{10} \cdot y_{10} + \right. \\
\left. + a_{01} \cdot y_{01} + a_{11} \cdot y_{11} + a_{02} \cdot y_{02}) \right]
\end{bmatrix}
\]

From the relation (9) the elements of the state vector \( x \) are obtained which in transposed form is being presented in relation (10):

\[
x^T = \begin{bmatrix} y_{00} & y_{10} \end{bmatrix}
\]

If we consider that the values M=8 and N=5 are definitive for the dimension of matrix \( M_{p\beta} \) (the matrix of partial derivatives of the state vector) [4], the matrix is presented in relation (11). The matrices and vectors that occur in relation (11) are [4]: the state vector \( x \) of the system with dimension \( x(2 \times 1) \); the vector of partial derivatives related to time \( t \) of the state vector \( x_0 \) with dimension \( x_0(5 \times 1) \); the matrix of partial derivatives related to independent variable \( r \) of the state vector \( x_R \) with dimension \( x_R(2 \times 8) \); the matrix of partial derivatives related to time \( t \) and to the independent variable \( r \) of the state vector \( x_{TR} \) with the dimension \( x_{TR}(5 \times 8) \).

Thus it results that the matrix \( M_{p\beta} \) has the dimension \( (M_{p\beta}(7 \times 9)) \).

IV. THE NUMERICAL SIMULATION

To start the numerical simulation, the initial conditions of the elements of the \( M_{p\beta} \) matrix are needed to be known or calculated. A possibility to calculate them is to use the analytical solution of the process. First, using the analytical solution, the values of the elements of \( x \) and \( x_R \) are calculated, for the moment \( t = 0 \). Then, using the resulted values and the relation of the pivot element, the values of the elements of \( x_T \) and \( x_{TR} \) can be also calculated. After doing the calculations, we can obtain the matrix \( (M_{p\beta}) \) for the initial conditions ((\( M_{p\beta}(h) \)) that correspond to the start sequence (k-1). In general (in the majority of the applications) the initial conditions are null values (with the exception of the \( Y_{00,n} \) signal). In order to advance from sequence (k-1) to sequence \( k \) we need to use the Taylor series [4]. The numerical simulation is finished when \( t \geq t_{\beta} \) (final simulation time \( \beta \)). The final simulation time \( t_{\beta} \) corresponds to the period after the steady state regime appears for the value of the independent variable \( r = h = 0.95 \text{L} \).

In all the relations implemented in the simulation application, we used the value \( \Delta t = 0.01 \text{min} \) for the integration step. In this case, \( (\Delta t) \) has a value that is small enough, so that the numerical integration is being done correctly.

V. THE SIMULATION RESULTS

The simulation applications are developed in MATLAB environment [5]. After simulation we compare the response that results through numerical integration and the analytical response of the system, through the calculus of the cumulated relative error in percentage (CREP) [4].

The first treated case is the case of the experiment made in order to identify the structure parameters of the process, experiment described in chapter III. The experiment, as it was previously mentioned, is based on the applying of an input step signal (thermal power) at the input of the process, having the value 82.848 kW over the initial value of 55.232 kW and on measuring the process response (the temperature of the emulsion from the tank). In Fig. 3 is presented the comparative graph between the numerical step response of the process, if the simulation is made for the values of independents variables \( p = p_c = 0 \text{m} \) and \( r = 0 \text{m} \) (in the origin of the Cartesian space) and the numerical response of the process, if the simulation is made for the values of the independent variables \( p = p_c = 0 \text{m} \) and \( r = h = 0.95 \text{L} \) (on the \( 0r \) axis at the separation limit between the liquid and the gas from the tank). From Fig. 3, it can be remarked that the temperature difference of 6°C between the initial values of the two responses is preserved in the steady state regime, too (the
steady state values of the two responses are 65.3°C, respectively 59.3°C. The dashed line drawn on the figure, shows the effect of the increasing of the two time constants \( T_1 \) and \( T_2 \) from \( r = 0 \) m to \( r = h = 0.95 \) L, as it was shown in chapter III. This line highlights the fact that, when, for \( r = 0 \) m, the response tends to be steady, for \( r = h = 0.95 \) L, the response is still in transitory regime.

From Fig. 4, it can be remarked that the temperature responses in two different points on the 0r axis has the same value as in the previous case.

The comparative graph between two numerical step responses of the process in two different points on the 0r axis is presented between the numerical step response of the process in the origin of the Cartesian system and in the point from the tank volume determined by the following values of the independent variables: \( p = p_c = 0.75 \) m, \( r = 4.34 \) m. In this case the value of the input step signal that is used is 207.12 kW over the initial condition. The transitory regime is longer in the case of the point from the tank volume \( (p=p_c = 0.75 \) m, \( r = 4.34 \) m) due to higher values of the time constants, respectively the value of the steady state regime is smaller due to the fact that this point is positioned at a longer distance than the origin, both in relation to the heating source.

Using the model of the process expressed using the partial differential equation from (3), the simulation can be made in any point from the tank. In Fig. 5, a comparative graph is presented between the numerical step response of the process in the origin of the Cartesian system and in the point from the tank volume determined by the following values of the independent variables: \( p = p_c = 0.75 \) m, \( r = 4.34 \) m. The used input signal (thermal power) for this simulation is 289.968 kW over the value associated to the initial condition. The simulation follows the trajectory of a spiral with the radius \( p_c = 1.5 \) m (the neighborhood zone from the lateral walls of the tank) with the period of a complete rotation \( T^\rho = 1.8 \) min.

The numerical simulation of the emulsion temperature variation near the walls of the tank both in relation to \( t \) and to \( r \) is performed. The used input signal (thermal power) for this simulation is 289.968 kW over the value associated to the initial condition, respectively the step of the spiral is \( \Delta r = 9.31 \cdot 10^{-4} \) m. The process response starts from the initial condition associated to the value of the independent variable \( r = 0 \) (58°C), it varies in relation to both independent variables \( t \) and \( r \) and it gets steady to the value 70.54°C (associated to \( r = h \)). The steady state regime can be remarked from Fig. 6 in the upper part of
the graph where the last complete rotations of the spiral are very close one compared to the other. This simulation can be made for any value of \( p_c \) (0 < \( p_c \) < 1.5 m). A very important aspect is the fact that the numerical simulation method generates very high accuracy when both the independent variables present variations. Another important aspect is to introduce the disturbance in the process. A possible disturbance can be the thermal oil temperature variation \( \Delta T_{\text{to}} \). If the value of \( \Delta T_{\text{to}} \) decreases with a quarter (1/4) comparing with the value considered in chapter two, the comparative graph between the numerical step response of the process in the case with and without disturbance, for \( r = h \) and \( p = 1.5 \) m, is presented in Fig. 7. The value of the input step signal is considered the same as in the case of Figs. 3 and 4.

![Figure 7](image)

Figure 7. The comparative graph between the numerical step response of the process between the case with and without disturbance.

The effect of the disturbance can be remarked through the smaller values of the emulsion temperature comparing to the case without disturbance. The steady state value of the process response in the case without disturbance is 57.3°C, respectively in the case with disturbance 56°C, a difference of 1.3°C. This fact is relevant because, for example, if the disturbance appears in the case of maintaining the initial conditions, the temperature at the separation limit between the liquid and the gas from the tank, near the tank walls, has the possibility to decrease under the imposed lower limit of 50°C.

VI. THE TEMPERATURE CONTROL STRUCTURE

The proposed temperature control structure is treated in a fundamentally manner, being presented in Fig. 8 (the modeling was made in order that the process to be included in a control structure).

![Figure 8](image)

Figure 8. The proposed temperature control structure.

In Fig. 8 the significance of the new notations is: C—controller of PID type; A—actuator (the electro-valve); MT—temperature transducer; \( a(t) \)—error signal; \( c(t) \)—control signal; \( u(t) \)—reference signal; \( F_{\text{ud}}(t) \)—acting signal representing the flow of the thermal oil, after the actuation generated by the controller; \( m(t) \)—measurement signal; \( u_\text{ud}(t) \)—disturbance signal that affects the process, independent of the heating source; \( u_\text{fd}(t) \)—the final input signal in the process. The purpose of the control structure [6] is to maintain the temperature \( y(t,r) \) at the imposed value and to reject the effect of the two main disturbances \( \Delta T_{\text{to}} \) and \( u_\text{ud}(t) \). In order to obtain the measurement signal, the transducer can be installed in any point of the tank. In this case only one of the arrows from Fig. 8 that enters in the accolade is valid. In Fig. 8, the case of measuring the temperature in any point on the tank height is presented. The control structure can be generalized because we consider \( p \) and \( q \) independent variables in the model. The temperature control can be made in two stages: in the normal conditions (storage conditions) the temperature has to be maintained at a value as low as possible in order to reduce the plant energy consume, but avoiding the solidification temperature (the transducer should be placed, considering the most unfavorable case at \( r = h \) and \( p = 1.5 \) m). When the emulsion is prepared to be delivered the temperature has to be maintained at a value as high as possible, but avoiding the hydrochloric acid evaporation limit (the transducer should be placed, considering the most unfavorable case in the origin of the Cartesian system).

VII. CONCLUSIONS

In this paper, a method for the modeling-simulation of the temperature evolution in an asphaltic emulsion tank is presented. The process, being a distributed parameter one, is modeled using partial differential equations. The obtained model, being a very precise one, permits the user to have access to the temperature value in any point from the tank volume. In this case the monitoring process can be made indifferent the position of the transducer from the tank. The numerical simulation method is a very accurate one, the obtained values of the cumulative error in percentage (CREP) being smaller than 10⁻8% for all treated cases. The analytical responses of the process are avoided to be graphically figured because these would be superposed over the numerical responses and could not be distinguished from them with the eye. The proposed control structure can be used to control the temperature in any point from the tank volume, the accurate model of the process permitting to avoid the limit temperatures.

REFERENCES


