# THE STUDY OF THE POSSIBILITIES TO MODEL AND SIMULATE THE OPERATION OF MAIN PIPE TRANSPORT SYSTEMS

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**Abstract:** When conceiving, designing and realising main pipe petroleum products transport systems, in order to find the optimum choice concerning their architecture and structure, the most modern and efficient research method is represented by the modelling and simulation of the considered system. The research focused on conceiving mathematical models which describe the construction and operation of main pipes, pumping groups and the entire network.

**Key words:** pipe modelling and simulation, resistive tube model

## 1. GENERAL CONSIDERATIONS

For the improvement of the parameters of an oil transport system through main pipes, researching based on scientific approaches of complex phenomena defining the continuous processes inside the installations destined for this scope of operations is compulsory.

Research may be approached in various instances starting from analytical determinations, experimental research, modelling, simulation, etc. Considering that the operation of such a system is influenced by an important number of constructive and functional parameters, some having a random characteristic, the analytical determinations lead to solutions with a high degree of approximation determining a weak conformance during industrial exploitation. Experimental research ensure better precision and accordance but they are hard to realize, require highly trained personnel, a lot of expenses, ant they are hard to generalise for architectures and different

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structures of the transport systems.

Therefore, research has been focused on conceiving mathematical models which describe the construction of main pipes, pumping groups and that of the system

## 2. MAIN PIPE MODELLING AND SIMULATION

In order to realise the mathematical model it is approximated that a main pipe with length $L$ is a resistive tube. Considering all these, the stationary equation defining the pressure drop on this resistive tube is:

$$\Delta p = \frac{\rho F^2}{2\alpha A^2} \tag{1}$$

where: $F$ the resistive tube flow; $\Delta P$ pressure drop on the resistive tube; $\alpha$ flow coefficient; $\rho$ represents the density of the fluid.

In relation (1) the flow coefficient is determined according to the following relation:

$$\alpha = \frac{D_H}{f \cdot \left(L + L_{eq}\right)} \tag{2}$$

where: $D_H$ is the internal diameter of the tube; $L$ is the length of the resistive tube**;** $L_{eq}$ is the equivalent length of local resistances; $f$ is the friction factor determined based on relation (3).

$$\begin{aligned}
&f = \frac{K_s}{R_e} \quad daca \quad R_e \le R_{eL} \\
&f = f_L + \frac{f_T - f_L}{R_{eT} - R_{eL}} \cdot \left(R_e - R_{eL}\right) \quad daca \quad R_{eL} < R_e < R_{eT} \\
&f = \frac{1}{\left\{-1.8 \cdot \log_{10}\left[\frac{6.9}{R_e} + \left(\frac{\frac{r}{D_H}}{3.7}\right)^{1.11}\right]\right\}^2} \quad daca \quad R_e \ge R_{eT}
\end{aligned} \tag{3}$$

where: $R_e = \frac{F \cdot D_H}{A \cdot \upsilon}$ is the Reynolds number; $Ks$ is the form factor characterising transversal pipes; $f_L$ is the friction factor in a laminar regime; $f_T$ is a friction factor in a turbulent regime; $R_{eL}$ is the maximum of Reynolds number in a laminar regime; $R_{eT}$ is the maximum of Reynolds number in a turbulent regime; $A$ is the area of the transversal section of the resistive pipe; $r$ is the ruggedness coefficient of the internal surface of the resistive tube; υ is the cinematic viscosity of the fluid.

The forces acting in a system are balanced for the stationary flowing regime and the following relation results:

$$\Delta P_0 A - \frac{F_0^2 \rho}{2\alpha A^2} \cdot A = 0 \tag{4}$$

where: $\Delta P_0 A$ is the active force pushing on the liquid inside the pipe; $\frac{F_0^2 \rho}{2\alpha A^2} \cdot A$ is the reaction force due to the restriction.

In a dynamic regime the difference between the two forces is compensated by the time variation of the impulse in the system:

$$\Delta P(t) A - \frac{F^2(t)\rho}{2\alpha A^2} A = \frac{d}{dt}(M\omega(t)) \tag{5}$$

In relation (5), $M$ is the liquid quantity in the pipe, and $\omega$ is its speed (flow).

From the above relation we will consider that $M = \rho LA$ and $F(t)=A\omega(t)$ is:

$$\Delta P(t) A - \frac{F^2(t)\rho}{2\alpha A^2} A = \rho L \frac{d}{dt}(F(t)) \tag{6}$$

The measures depending on the time $t$ in relation (6) are obtaines if arbitrary variations are given above the values of the stationary regime, therefore:

$$\begin{aligned} \Delta P(t) &= \Delta P_0 + \Delta(\Delta P(t)) = \Delta P_0 + \Delta p(t) \\ F(t) &= F_0 + \Delta F(t) \end{aligned} \tag{7}$$

From relations (6) and (7) the following is obtained:

$$\left(\Delta P_0 + \Delta p(t)\right) A - \frac{\rho\left(F_0 + \Delta F(t)\right)^2}{2\alpha A^2} A = \rho L \frac{d}{dt}\left(F_0 + \Delta F(t)\right) \tag{8}$$

If the stationary regime expressed through relation (4) is extracted from relation (8), and the square term $\Delta F^2(t)$ is neglected, the following is obtained:

$$\Delta p(t) A - \frac{\rho F_0 \Delta F(t)}{\alpha A} = \rho L \frac{d}{dt}\left(\Delta F(t)\right) \tag{9}$$

In the following, if we turn to Laplace transform in initial conditions nul in relation (7), we obtain:

$$A\Delta p(s) = \left( \rho L \cdot s + \frac{\rho F_0}{\alpha A} \right) \Delta F(s) \tag{10}$$

From the differential equation (10), the transfer function of the resistive tube is easily obtained:

$$H_{pa}(s) = \frac{\dfrac{\Delta F(s)}{F_0}}{\dfrac{\Delta p(s)}{\Delta P_0}} = \frac{k_p}{\tau_{pa} s + 1} \tag{11}$$

where: $k_p$ is the amplification factor ($k_p$=1/2); $\tau_{pa}=\alpha AL/F_0$ is the delay constancy of the resistive tube.

In the following we are going to present an example where we suppose that the diameter of the pipe is 8 inches. Therefore, the diameter of the pipe is $D_H$=0.2032 m and the distance for the flow transducer is $L$=1 m. The diagram presented in figure 5.1 will be used for the determination of the friction parameter.

For the determination of this friction coefficient Reynolds number will be calculated $R_e = \frac{F \cdot D_H}{A \cdot \upsilon}$ where υ is the cinematic viscosity of oil (API40°) with the density ρ=825 kg/m$^3$ obtained at a 60°$F$ temperature, $F$ is the flow of the pumped oil $F$=80 m$^3$/h.

The cinematic density of the above presented oil is $\upsilon=3.8\cdot10^{-6}$ m$^2$/sec. Considering these conditions Reynolds number is $R_e=3.6642\cdot10^4$ what indicates the existence of a turbulent flowing regime. For the determination of the friction coefficient we have considered a ruggedness coefficient $r/D_H$=0.00005. Therefore from figure 1 or from the relation (3) we may read/calculate the value of the friction coefficient $f$=0.023.

In these conditions, the constancies defining the mathematical model are:

$$k_p = \frac{1}{2} \quad and \quad \tau_{Pb} = 13.268\ sec \tag{12}$$

Where we have considered $L_{eq}$=0 m.

In these conditions the mathematicalmodel of the technological pipe is completely defined.

The transfer function (11) is used for the design of the flow regulator. For a more exact simulation formula (6) defining the dynamic regime equation of the technological pipe will be implemented using SimHydraulics toolbox in Matlab.

The block diagram of the element simulating several pipe lengths sections L and their internal structure in presented in figure 2.

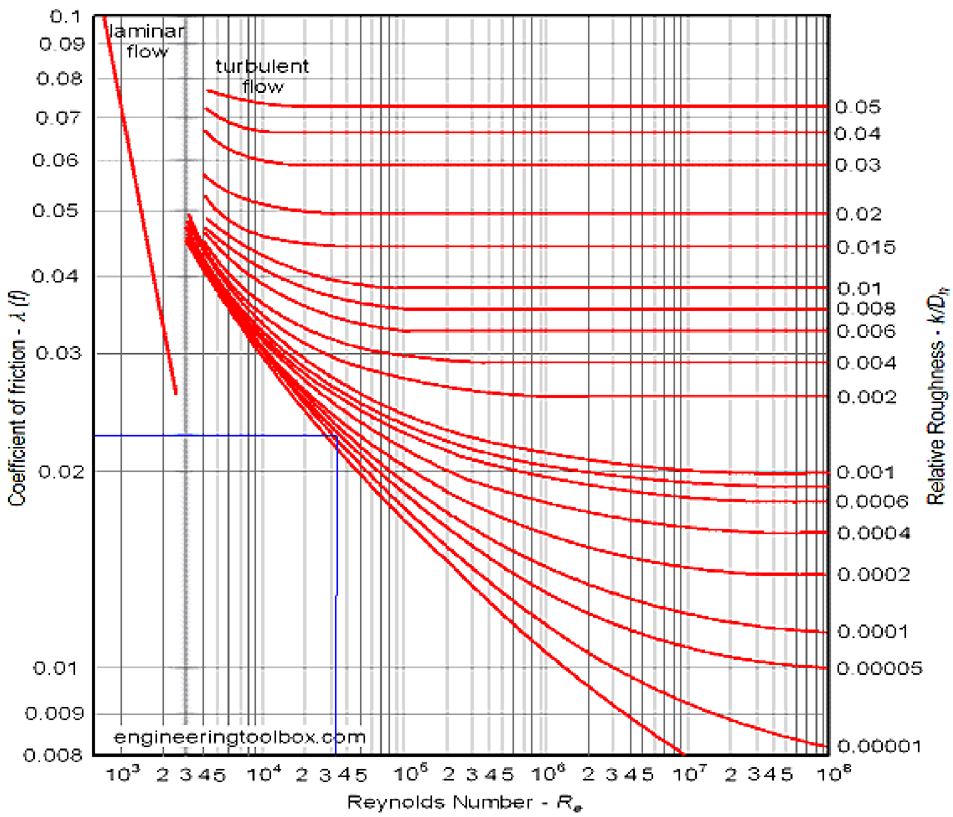


**Fig. 1.** Friction coefficient dependency on the Reynolds number

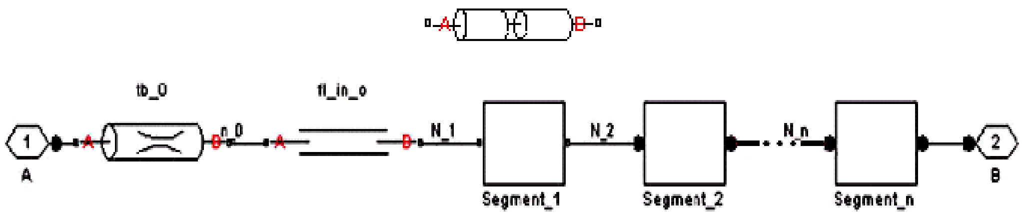


**Fig. 2.** The mathematical model of the technological pipe using the SimHydraulics toolbox elements in Matlab

The above presented model implements relation (6), nonlinear, for each pipe segment. On the other hand, the resistive tube is defined by equation (1) and is implemented within the block presented in figure 3.

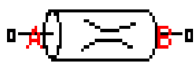


**Fig. 3.** SimHydraulics Matlab resistive tube model

SimHydraulics Matlab block of fluid inertia is presented in figure 4.


**Fig. 4**. SimHydraulics Matlab inertia fluid model

### 3. Centrifugal pump modelling and simulation

The mathematical model of the centrifugal pump, the internal structure of which is presented in figure 5, is realised based on the main blocks of SimHydraulics Matlab toolbox. Therefore, based on the “Lookup Table” block, the two characteristics of a centrifugal pump are introduced, namely the pressure [Pa] – flow [m3/h], respectively *consumed energy* [KW]- *flow* [m3/h]. These blocks are marked with PQ respectively NQ.

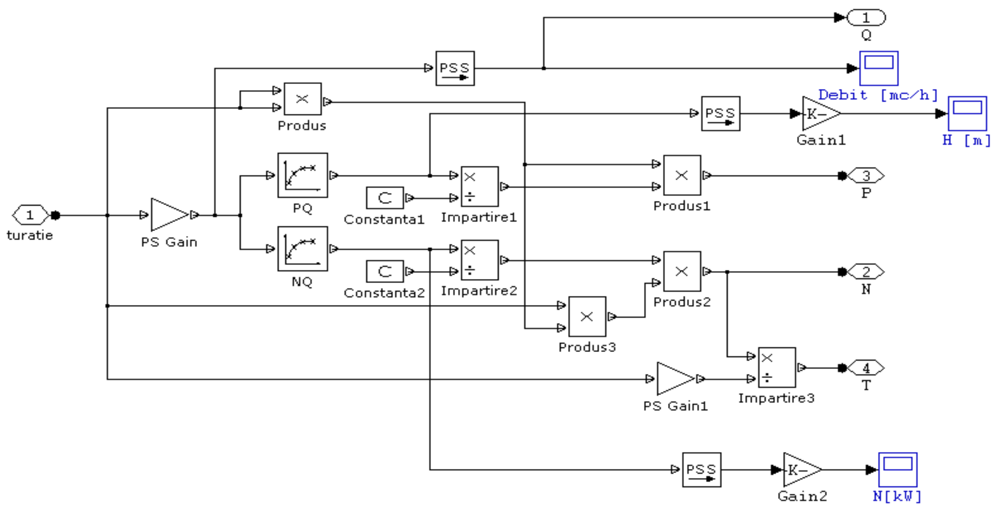


**Fig. 5.** Centrifugal pump internal structure

The rotation of the induction motor of the centrifugal pump is considered as an input data in the mathematical model of the pump. For the determination of the inlet flow necessary for the determination of pressure and respectively of consumed energy in the “Lookup Table” made tables relation (13) is used and is implemented within the “PS Gain” block in the internal structure of the centrifugal pump.

$$Q = \frac{Q_N}{n_n} \cdot n \tag{13}$$

where $Q_N$ is the normal flow of the centrifugal pump obtained at a nominal speed $n_n$.

Considering these conditions, the new pressure and consumed energy values of the centrifugal pump will be determined based on the following relation:

$$p = \frac{p^*}{n_n^2} n^2 \text{ and } N = \frac{N^*}{n_n^3} n^3 \tag{14}$$

The two characteristics of the centrifugal pump are introduced the same as in figure 6.

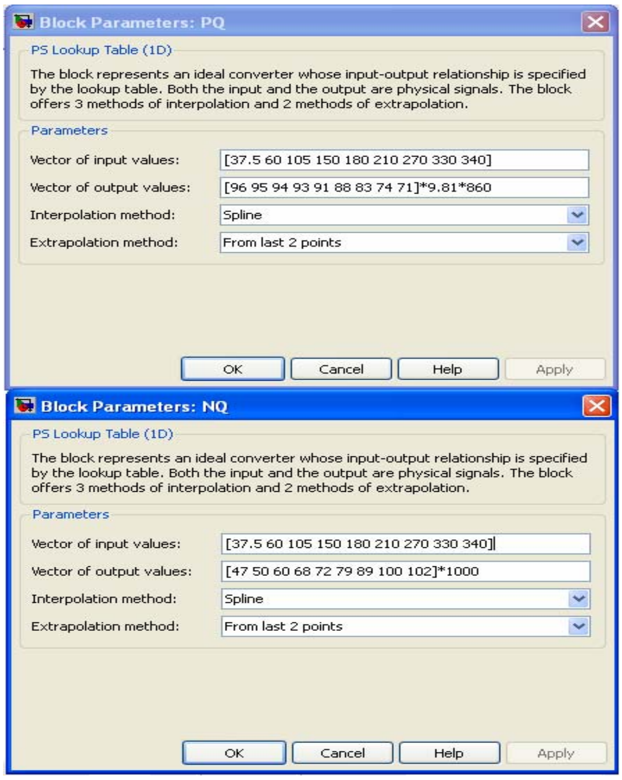


**Fig. 6.** Centrifugal Pump PQ and NQ characteristics input method

Where $p^*$ şi $N^*$ are the pressure and consumed energy of the centrifugal pump, obtained from the PQ and NQ characteristics, but $n_n$ is the nominal speed at which the nominal flow is obtained.

On the other hand, the momentum developed by the centrifugal pump is defined by the following mathematical relation:

$$T = \frac{N}{\omega_N} \text{ where } \omega_N = \frac{2\pi n_N}{60} \tag{15}$$

In order for the mathematical model of the centrifugal pump to be defined completely the SimHydraulics Matlab toolbox "pressure source" block will be installed on its outlet. These are better observed in figure 7.

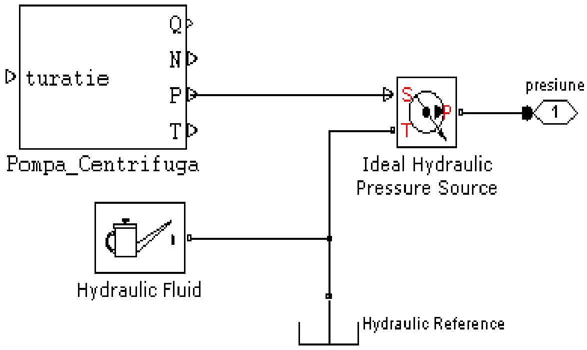


**Fig. 7.** Centrifugal pump model using SimHydraulics Matlab toolbox blocks

## 4. SINGLE MAIN PIPE FLOW REGULATION SYSTEM MODELLING

The model developed to emphasise the operation of the transport system may be used in various instances. In this case a simulation is presented for the situation in which the transportation of oil is made through one single main pipe. The flow regulating system through the modification of the speed of the centrifugal pump is presented in figure 8.

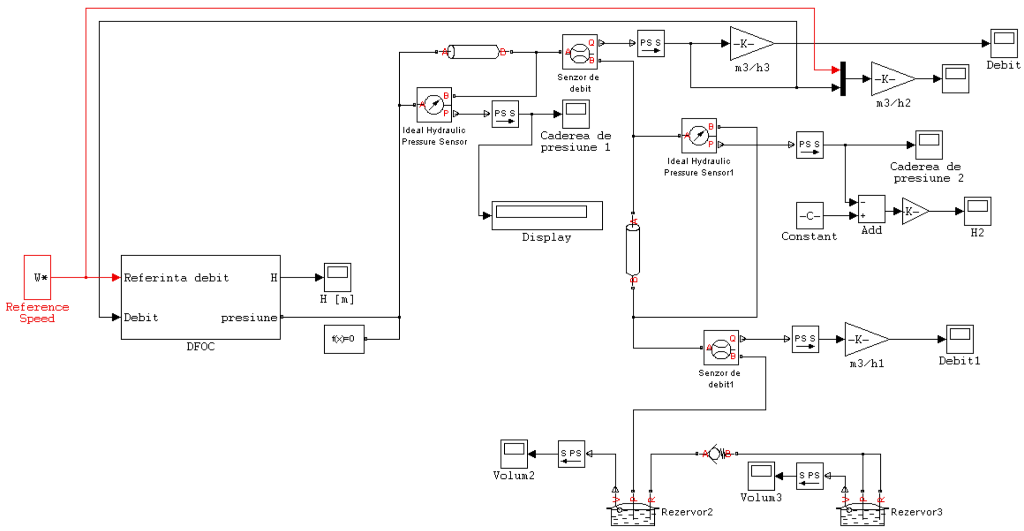


**Fig. 8.** Flow regulating system through the modification of the speed of the centrifugal pump when the main stream is composed of one single pipe

For the simulation of the flow regulating process through speed modification of the centrifugal pump, there have been different values for the flow *Q* respectively 50, 80, 150 and 200 [$m^3$/h] and for the operating temperature 20$^o$C. For the operation of the pump the 160kW power motor 1487 rpm and 3000 rpm is used. The length equivalent to that of the main pipe for petroleum product transportation has been considered being equal to 1000m and the interior diameter of 0,2m. If the system operates at the prescribed parameters then there has to be a good correspondence between the imposed flow and the realised flow. Figure 9 presents the flow variation in time in the simulated transport system.

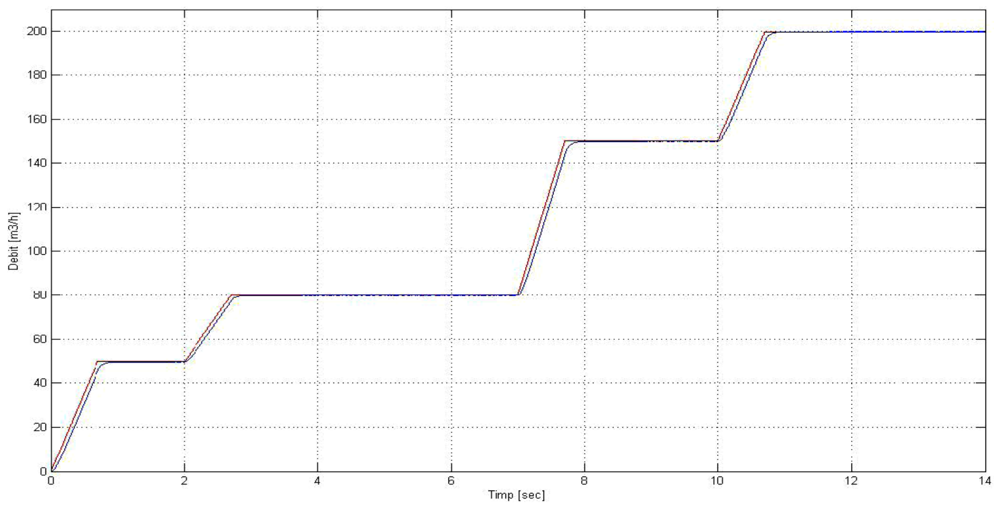


**Fig. 9.** Time proportioned flow variation

It is observed that between the prescribed flow (in red) and the realised flow (in blue) there is a significant overlap. This proves that the flow regulation system meets the functional requirements.

The flow regulation system behaves as a first order aperiodic system with a reduced transitional process time and a stationary error going for zero.

## 5. CONCLUSIONS

The research has been focused on conceiving several mathematical models which describe the construction and the operation of main pipes, pumping groups and the entire system.

All models refer to transport systems for which the modification of capacity parameters is realised by modifying the speed of the centrifugal pumps either inside the main pumping station or inside intermediate pumping stations placed on the trajectory of the pipe. The analysis of the entire simulation process proves that the conceived flow regulation system is functionally satisfactory.

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