SURVEY REGARDING THE HYDRAULIC DETERMINATION OF A MAIN PIPE TRANSPORT SYSTEM

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Abstract: Petroleum products main pipes transport systems have to be dimensioned based on technical-economical determinations with the help of which the best solution will be determined. The possibilities of increasing the glow of the transported liquid through the main pipe by different methods, as well as those of decreasing the viscosity of the transported liquid have been analysed. All the theoretical, technical and economical aspects are analysed in order for all advantageous applications, either independent or combined, may be established.

Key words: pipes transport systems, pumps, flow model.

1. GENERALITIES

Petroleum products main pipe transport systems have to be dimensioned based on technical-economical calculations with the help of which the optimal solution will be determine. This becomes a compulsory operation where expensive materials, large diameter and long pipes are used, consequently supposing the use of considerable quantities of materials respectively increased costs.

Pipe dimensioning is based in the hydraulic, mechanical and thermal calculation.

Figure 1 represents the block diagram allowing the division on phases of the operational and construction parameters correlation methodology considering the realisation of operational safety and economical use of materials and energy. The main condition is that the transportation should be made in good conditions in a inhomogeneous fluid environment in order for the mechanical impurities to be

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transported in a suspended state to avoid their settlement and formation of clogs. In the case of a horizontal pipe transport this condition is realised in a turbulent flow where the speed of transversal currents needs to be greater or at least equal to speed of falling materials composing the mechanical impurities comprised by raw oil. The falling speed limit increases with the material size. In the same time, the proportion between the average flow speed and transversal turbidity currents increases together with the diameter of the pipe.

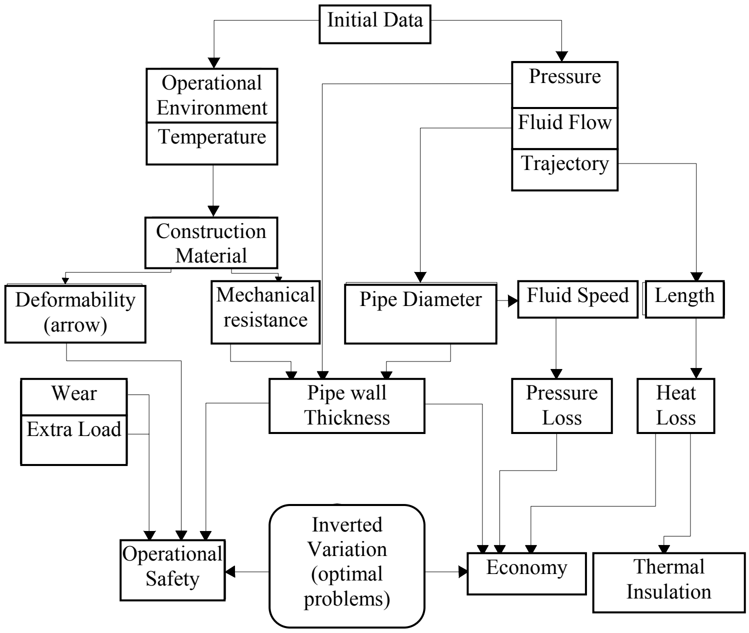

Fig. 1. Operational and construction parameters correlation diagram during pipe exploitation and that of material and energy economy

2. PIPE PRESSURE LOSS DETERMINATION

Friction caused pipe pressure loss determination is made accordind to the following relation:

$$\Delta p_f = \rho \frac{v_m^2}{2} \frac{l}{d} \lambda \text{, bar} \tag{1}$$

where: v_m represents the average flow of the fluid in a transversal section of the pipe; *d,* the interior diameter of the pipe; *l* the length of the pipe and λ is the resistance coefficient of the pipe related to the flow, being a function of the flow regime.

In order to establish the flowing regime through the pipe the Reynolds number determination is necessary:

$$\mathrm{Re} = \frac{v_m d}{\nu} = \frac{4Q}{\pi d\ \nu} \tag{2}$$

where: Q represents the transported flow implied as a design parameter, and ν is the cinematic viscosity.

3. HYDRAULIC DETERMINATION OF PIPES USED FOR FLUID TRANSPORTATION

The starting point of the hydraulic determination is constituted by the following relation:

$$\rho\alpha_1 \frac{v_{m1}^2}{2} + p_1 + \rho g z_1 = \rho\alpha_2 \frac{v_{m2}^2}{2} + p_2 + \rho g z_2 + \Delta p \tag{3}$$

Obtained through Bernoulli's equation by introducing the pressure losses Δp. Index (1) refers to the pipe inlet section, and index (2) to the outlet section.

Generally, relation (3) is applied to a pipe with a constant transversal section, making the average speeds v_{m1} si v_{m2} equal. Therefore, the relation becomes:

$$p_1 - p_2 = \Delta p + \rho g (z_2 - z_1) \tag{4}$$

The term Δp comprises both the pressure drop due to friction as well as local pressure losses, with the following relation:

$$\Delta p = \rho \frac{v_m^2}{2} \left(\frac{l}{d}\lambda + \sum_{i=1}^{n} \xi_{l_i} \right) \tag{5}$$

where, ξ_{li} represents the local loss coefficient. If it is not possible for the later to be neglected, the equivalent length (l_e) is introduced, determined by the following relation:

$$l_e = \frac{d}{\lambda} \sum_{i=1}^{n} \xi_{l_i} \tag{6}$$

If we consider the length l_e to be included in the total length l, then relation (5) becomes:

$$\Delta p = \rho \frac{v_m^2}{2} \frac{l + l_e}{d} \lambda \tag{7}$$

Adimensional measure:

$$i = \frac{v_m^2}{2g}\frac{\lambda}{d} \tag{8}$$

For the determination of the relations previously presented it has been considered that the temperature of the transported liquid is constant.

4. FREE FALL LIQUID TRANSPORTATION

In the practices of liquid transportation, there are situations where they can be transported through free fall. The condition that a pipe has to meet in this case is that the starting point should be placed at higher grounds than the final point and between these two points there should not be any other intermediate point situated at a higher ground than the starting point.

From the relations presented previously, it results that free fall transportation is possible when the following condition is met:

$$\frac{8Q^2\lambda}{\pi^2 g d^5} l \leq z_1 - z_2 - \frac{p_2}{\rho g} \tag{9}$$

For a pipe with the given length and interior diameter, supposing that we know the benchmarks z_1, z_2 and pressure p_2 necessary in the final point, it results that the flow Q has to satisfy the following inequation:

$$Q^2\lambda \leq \frac{\pi^2 g d^5}{8l}\left(z_1 - z_2 - \frac{p_2}{\rho g}\right) \tag{10}$$

These considerations apply when realizing a free fall flow of the liquid, after the highest point on the final part of the pipe.

5. ASPECTS REGARDING THE INCREASE OF A MAIN PIPE TRANSPORTATION CAPACITY

For a pipe destined to transport liquids, designed and built in a certain manner for a certain flow, the problem of realizing a greater transport capacity may arise, therefore a flow increase.

5.1. Transport capacity increase by installing an intercalation

The increase of the transport capacity by this method, presented in figure 2, implies the installation of an intercalation with an interior diameter (d_1) greater than the diameter of the pipe. (d).

Therefore, the following relation may be written for the modified pipe with the flow Q':

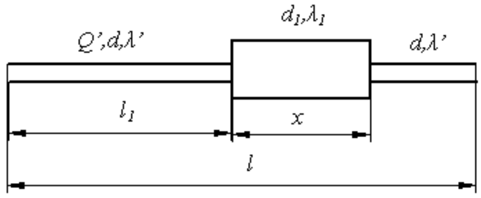

Fig. 2. Intercalation installation

$$p_1 - p_2 = \frac{8\rho Q'^2\lambda'}{\pi^2 d^5} l_1 + \frac{8\rho Q^2\lambda}{\pi^2 d_1^5} x + \frac{8\rho Q'^2\lambda'}{\pi^2 d^5}\left[l - (l_1 + x)\right] + \rho g(z_2 - z_1) \tag{11}$$

where, λ' corresponds to diameter d and flow Q' and λ_1 diameter d_1 and flow Q.

From relation (11) it results:

$$p_1 - p_2 = \frac{8\rho Q'^2\lambda'}{\pi^2 d^5}(l - x) + \frac{8\rho Q^2\lambda_1}{\pi^2 d_1^5} x + \rho g(z_2 - z_1) \tag{12}$$

Showing that the intercalation may be installed anywhere on the pipe trajectory

5.2. Transport capacity increase by installing a derivation

The transport capacity of a pipe may be increased, keeping the pressures p_1 and p_2 unchanged by the installation of a derivation with the interior diameter d_1 diffrebt from d (larger or smaller) or equal to it, as shown in figure 3.

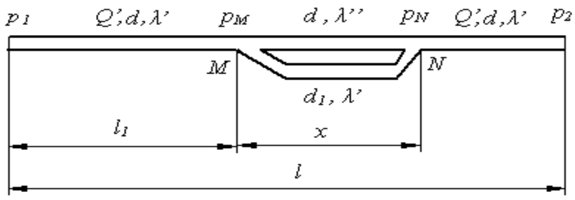

Fig. 3. Installation of a derivation

If the general case is considered where $d_1 \# d$ is known and the length x of the derivation, supposed to be equal to the length of the main pipe section along which the derivation is installed, the following determination results:

$$p_M - p_N = \frac{8\rho Q'^2}{\pi^2\left(\sqrt{\frac{d^5}{\lambda''}} + \sqrt{\frac{d_1^5}{\lambda_1'}}\right)^2} x + \rho g(z_N - z_M) \tag{13}$$

And for the entire pipe it is obtained:

$$p_1 - p_2 = \frac{8\rho Q'^2}{\pi^2}\left[\frac{\lambda' l}{d^5} - \frac{\lambda' x}{d^5} + \frac{x}{\pi^2\left(\sqrt{\frac{d^5}{\lambda''}} + \sqrt{\frac{d_1^5}{\lambda_1'}}\right)^2} x + \frac{\lambda'(l - l_1 - x)}{d^5}\right] \tag{14}$$

Analyzing relation (14) it is determined that the position of the derivation along the pipe may be chosen arbitrarily.

The length of the derivation is determined with the following relation:

$$x = \frac{1 - \frac{Q^2}{Q'^2}\frac{\lambda}{\lambda'}}{1 - \frac{1}{\left(\sqrt{\frac{\lambda'}{\lambda''}} + \sqrt{\frac{d_1^5}{d^5}\frac{\lambda''}{\lambda_1'}}\right)^2}} l \tag{15}$$

5.3. Transport capacity increase by decreasing the viscosity of the transported liquid

If the resistance coefficient depends on the Reynolds number, the increase of the pumping capacity may be also realised by decreasing the viscosity of the transported liquid. The Reynolds number increases when viscosity decreases therefore the resistance coefficient decreases. If pressures p_1 and p_2 are kept unchanged then the following relation is obtained:

$$\frac{Q'}{Q} = \sqrt{\frac{\lambda}{\lambda'}} \tag{16}$$

We may notice that flow increases when the resistance coefficient decreases. The greatest effectiveness is obtained during a laminar regime where the resistance coefficient is inversely proportional to the cinematic viscosity.

Considering these conditions, the following may be written:

$$\frac{Q'}{Q} = \frac{\nu}{\nu'} \tag{17}$$

In a turbulent regime, for smooth pipes with Re < 10^5 the following relation is valid:

$$\frac{Q'}{Q} = \left(\frac{\nu}{\nu'}\right)^{0,143} \tag{18}$$

This procedure is less effective than in a laminar regime. It is observed that in a turbulent regime for rugged pipes where $\lambda=\lambda'$, this procedure has no kind of effectiveness.

6. REALISATION OF A MATHLAB FREE FLOW MODEL

Figure 4 presents the model for a fluid free flow simulation. For a free flow simulation the MATHLAB utility software has been used, and from the Simulink library of the software, pipe, tank and the display of flow parameter models have been implemented.

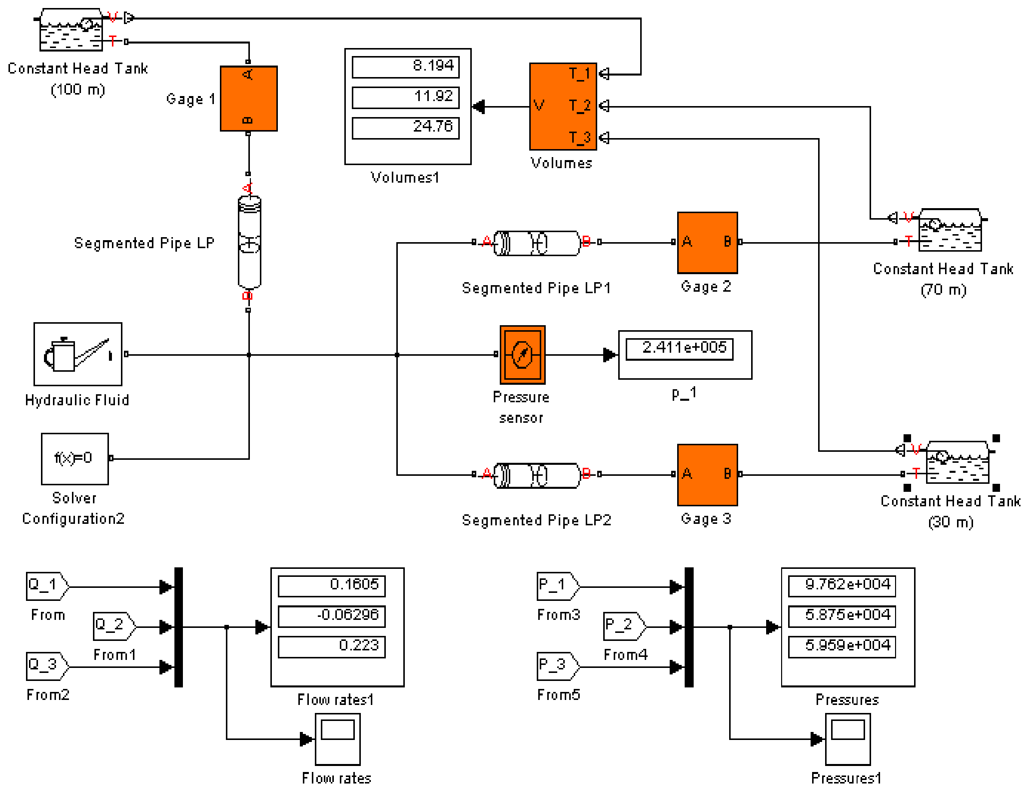

Fig. 4. Free flow simulation model

From the variation diagram of the flow during a free flow in main pipes presented in figure 5, it is observed that the flow of the transported fluid depends on the benchmark of the inlet of the pipe in proportion to the benchmark of the overflow, on one hand, and on the other hand in the beginning of the flowing process there is a transitional phenomenon determined by the necessity to fill the pipe. It is observed that the flow in the end of the transitional phenomena stabilizes and the sum of the flows from the secondary pipes represents the liquid flowing free through the main pipe.

Figure 5, the variation diagram of the main pipe flow represented in yellow, the variation diagram of the secondary pipe flow with the smallest benchmark of the overflow is represented in purple.

The simulation with this model ensures multiple analysis possibilities, starting from the free flow installation schematics and from their constructive and operational parameters.

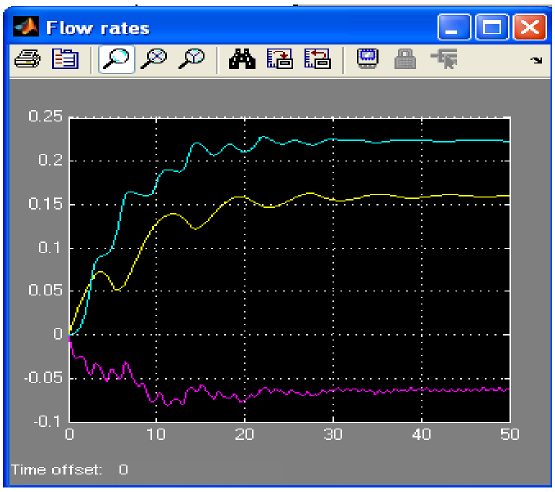

Fig. 5. Variation diagram of free flow

7. FLOW DETERMINATION INSIDE PARALLEL CONNECTED PIPES

In order to make this determination a special application has been developed using the Mathcad software. Therefore the input data, scalar and vector measures are defined for two cases representing the symmetrical and asymmetrical bond in parallel. It has been developed software which ensures the determination of the flow for a parallel bond for each branch of the considered installation.

Input data:

- the lengths of the parallel pipes (ramifications of the main pipe);
- the length of the connection pipes between the main pipe and the parallel pipes;
- the diameter of the main pipe;
- the diameters of the pipes tied in parallel;
- the ruggedness of the parallel pipes;
- flow coefficients of connection valves between the main pipe and its ramifications;
- the fluid flow in the main pipe;
- cinematic viscosity of the fluid;
- convergence applied deviation.

CASE I, represents the parallel symmetrical installation of main pipes, figure 6.

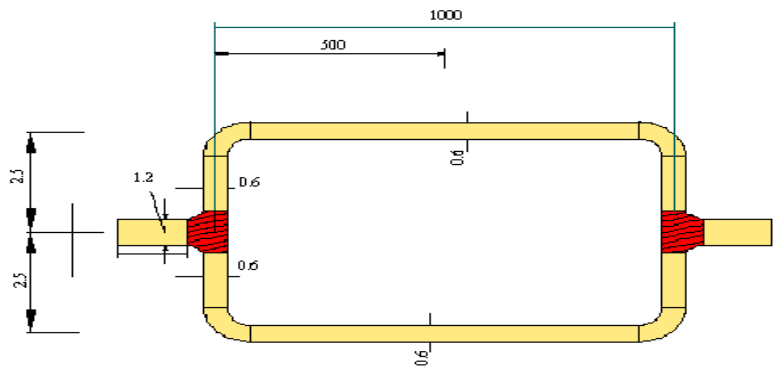

Fig. 6. Parallel Symmetrical main pipes connection schematics

CASE II, represents the parallel asymmetrical installation of main pipes, figure 7.

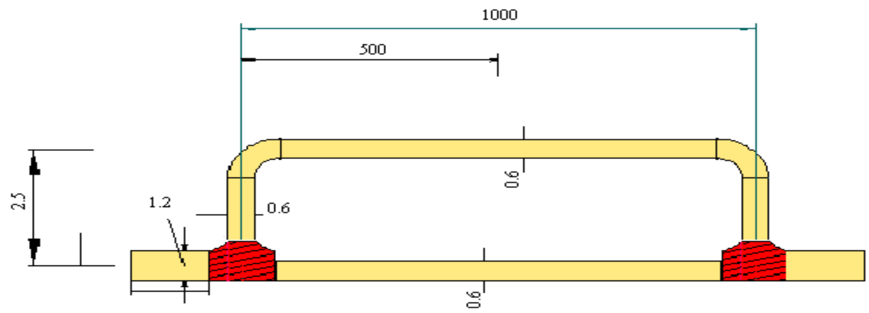

Fig. 7. Parallel asymmetrical main pipes connection schematics

It is observed that in the case of parallel symmetrical connection the flows through the 2 branches are equal (figure 8), and in the case of parallel asymmetrical connection the flows through the two branches are different (figure 9).

8. CONCLUSIONS

The main pipe transportation systems of petroleum based products have to be dimensioned based on technical-economical determinations, with the help of which the best solution will be determined.

For the simulation of a free fluid flow through main pipes the MATHLAB software has been used and from the Simulink library of the software pipe, tank and the display of flow parameters models have been implemented. From the tank the liquid flows through a main pipe up to a division point to two pipes which overflow at different benchmarks in proportion to the tank's benchmark. All three pipes have the same constructive and operational parameters. The simulation within the created model ensures multiple analysis possibilities starting from a free flow installation design and from their constructive and operational parameters.

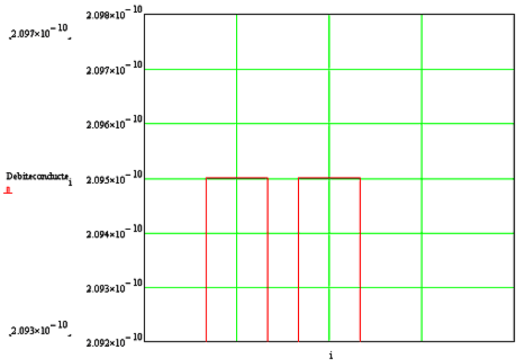

Fig. 8. Flow variation diagram for the two branches

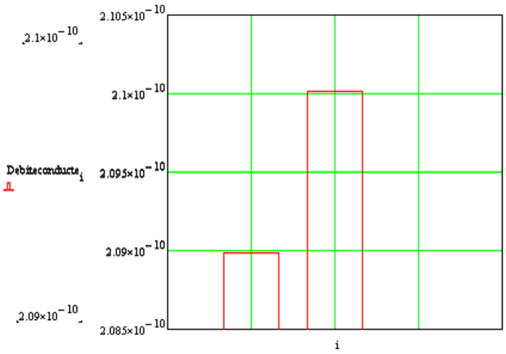

Fig. 9. Flow variation diagram for the two branches

For the determination of the flow from parallel connected main pipes, a Mathcad application has been developed. The input data, scalar and vector measures have been defined in the software for two cases, the symmetrical and respectively asymmetrical parallel connection.

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