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DIMENSIONING OIL PIPELINES TAKING INTO ACCOUNT THE ENTROPY GENERATION PROCESS

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Abstract: *The losses in warm liquid transportation processes, respectively mechanical losses due to friction processes and viscous dissipation, as well as the thermal ones represented by the heat lost by the liquid in the environment, lead to increased entropy of the system. Therefore, a optimal dimensioning criterion for transport pipelines may be minimization of the entropy generated by the system.*

Key words: *pipelines, entropy, transportation, dimension.*

1. Introduction

A modern procedure of thermo-dynamic process optimization can be achieved through the minimization of the entropy generated during the process. The losses in a transport process represented by the mechanical losses due to friction and viscous dissipation as well as the thermal losses represented by the heat lost by the crude oil towards the environment determine the increase of the system entropy. Therefore a criterion through which the losses can be minimized can be the minimization of the entropy generated in the system.

2. The Analysis of the Process of Entropy Generation

The pipe through which crude oil is transported in non-isothermal conditions can be considered an open system though which hot crude oil flows, tightly connected to the environment in which this pipe is built. The flux and energetic interactions of the pipe with the environment are emphasized for a pipe segment of a length Δl in figure 1.

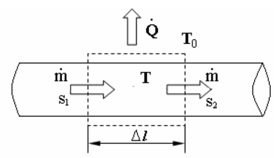

Fig. 1.

We used the notations: T – the crude oil temperature, s_1 – the specific entropy when entering the segment Δx, s_2 – the specific entropy when getting out of segment Δx, T_0 – the environment temperature and $\dot{Q}$ - the lost thermal power.

According to *Gouy-Stodola* theorem, the available power lost in the systems is proportional with the entropy generated in the system, the constant being the environment temperature. If we use $\dot{S}_{gen}$ for the entropy generated in the system, this can be defined for the pipe segment Δx.

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$$\dot{S}_{gen} = \frac{\partial S}{\partial \zeta} - \frac{\dot{Q}}{T_0} - m(s_1 - s_2) \tag{1}$$

According to *Gouy-Stodola* theorem the available power lost in the system that we designate as P_p has the expression:

$$P_p = T_0 \dot{S}_{gen} \,. \tag{2}$$

The expression further down contains a term relatively constant, T_0, the environment temperature in which the pipe is fixed and the second term with a complex expression, $\dot{S}_{gen}$ the entropy generated in the pipe that depends on more factors tightly connected by the movement of the fluid through the pipe. The expression of the lost available power (2) offers a criterion of the transport process optimization. If we can find a minimum for the generated entropy then the lost available power in the system will be minimum, therefore the transport process becomes highly economical.

3. Defining the Model for the Calculus of the Entropy Generated in the Pipe

In the case of the pipes transporting crude oil in non-isothermal conditions, the thermo-dynamic parameters of the crude oil strongly vary from one end to the other of the pipe. In order to limit this variation of the parameters we will divide the pipe in segments with a constant length Δx. We will sum up all these values in order to obtain the value of the entropy generated on the entire pipe.

Figure 2 presents the geometry of the model of entropy generation on a pipe segment of finite length Δl, in which a length segment dx was emphasized.

On it we apply the second principle of thermodynamics for open systems, obtaining the equation:

$$d\dot{S}_{gen} = \dot{m} ds - \frac{\dot{q} dx}{T + \Delta T} \tag{3}$$

where $\dot{q}$ is the lost heat on the length unit $\Delta T = T - T_p$, T – temperature on the left face of element dx, and $T + \Delta T$ – the temperature on the right face of element dx.

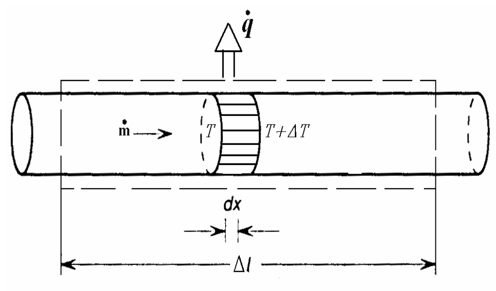

Fig. 2.

The fundamental equation of thermodynamics for open systems can be written:

$$T ds = dh - \frac{1}{\rho} dp \tag{4}$$

and particularized on the segment dx it gets the form:

$$\frac{dh}{dx} = T \frac{ds}{dx} + \frac{1}{\rho} \frac{dp}{dx} \tag{5}$$

The variation of the enthalpy of the elementary volume dx is due to the heat loss towards the external environment. In this situation the thermal balance for the elementary volume becomes:

$$\dot{m} dh = \dot{q} dx \tag{6}$$

Replacing the expression ds in relation (5) in relation (3) taking into account the elementary enthalpy variation dh from relation 6) we obtain the relation for the generated entropy:

$$\dot{S}_{gen} = \frac{\dot{q}\Delta T}{T^2(1+\delta)} + \frac{\dot{m}}{\rho T}\left(-\frac{dp}{dx}\right) \quad (7)$$

in which $\dot{S}_{gen} = \frac{dS_{gen}}{dx}$, $\delta = \frac{\Delta T}{T}$.

The value of δ is very small in comparison with the unit and because of this we can neglect it. There follows the relation:

$$\dot{S}_{gen} = \frac{\dot{q}\Delta T}{T^2} + \frac{\dot{m}}{\rho T}\left(-\frac{\mathrm{d}p}{\mathrm{d}x}\right) \quad (8)$$

If we designate G as the mass speed defined by the expression:

$$G = \frac{\dot{m}}{A} \quad (9)$$

in which A represents the pipe section and f is the friction term defined by the relation:

$$f = \frac{fD}{2G^2}\left(-\frac{\mathrm{d}p}{\mathrm{d}x}\right) \quad (10)$$

For cylindrical pipes with the diameter D the expression of the generated entropy is:

$$\dot{S}_{gen} = \frac{\dot{q}^2}{\pi\lambda T^2 \mathrm{Nu}} + \frac{32\dot{m}^3}{\pi^2\rho^2 T}\frac{f}{D^5} \quad (11)$$

which λ is the conductivity of the ground around the pipe, Nu – *Nusselt*'s criterion, calculated with the formula $\mathrm{Nu} = 0{,}023\,\mathrm{Re}^{0,8}\,\mathrm{Pr}^{0,4}$, Re –*Reynolds* criterion, Pr –*Prandtl* criterion, and ρ – the crude oil density. We introduce the notations:

$$\dot{S}_Q = \frac{\dot{q}^2}{\pi\lambda T^2 \mathrm{Nu}},\ \dot{S}_f = \frac{32\dot{m}^3}{\pi^2\rho^2 T}\frac{f}{D^5} \quad (12)$$

and we can easily notice that the generated entropy can be expressed in the relation:

$$\dot{S}_{gen} = \dot{S}_Q + \dot{S}_f \quad (13)$$

This expression explains the mechanism of entropy generation. For a pipe transporting crude oil in non-isothermal conditions the entropy production is due to the heat exchange between the crude oil and the ground from the outside of the pipe, defined by the S_Q and by the viscous dissipations that took place in the crude oil mass combined with its friction against the pipe wall, respectively the term S_f.

In order to calculate the entropy generated on the entire pipe we consider the pipe divided in equal segments of length Δl (figure 3) for which the properties of the crude oil are considered regionally constant.

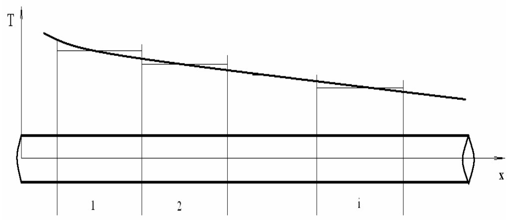

Fig. 3.

For the entire pipe the expression of the generated entropy is:

$$\dot{S}_{gen}\Big|_{cond} = \sum_{i=1}^{N} \dot{S}_{gen,\,i} \quad (14)$$

3. The Analysis of Results concerning the Entropy Generation

The relation (14) allows us to calculate the entropy generated on the entire transport pipe. If we consider that the flow of the crude oil is constant, the thermal state represented by the temperature variation curve along the pipe unchanged, but the pipe diameter (designated as D) variable the minimum of the relation (14) was numerically determined.

This calculation can be done only numerically as the relation (14) must be simultaneously integrated with the flow in equations and Fourier's equation that describes the temperature field around the pipe. This allows the calculation of the heat lost by the crude oil for each segment Δl.

The results of the calculations showed that the two terms that compose the generated entropy expression S_Q and S_f have opposed variations once the diameter is changed. Thus, with the increase of the pipe diameter the entropy production decreases and the production of entropy due to the heat exchange between the crude oil and the external environment increases.

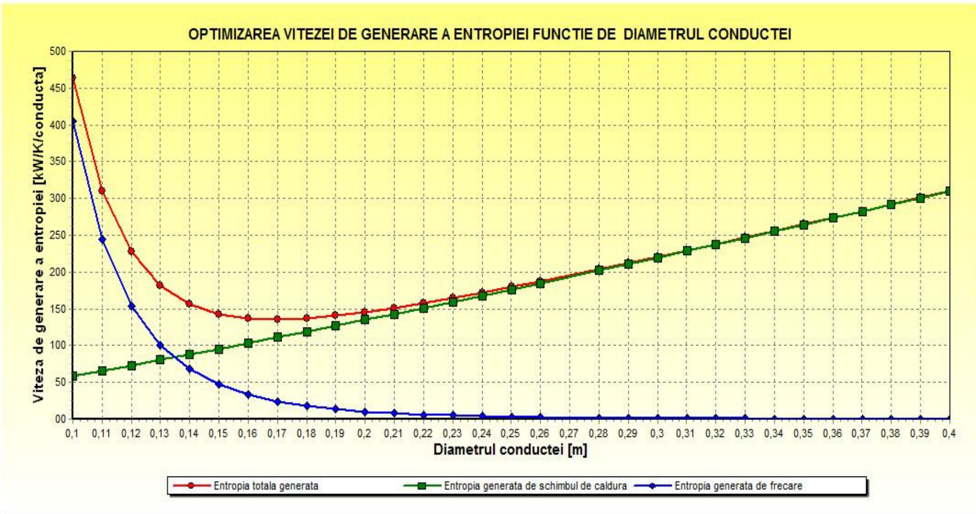

Fig. 4.

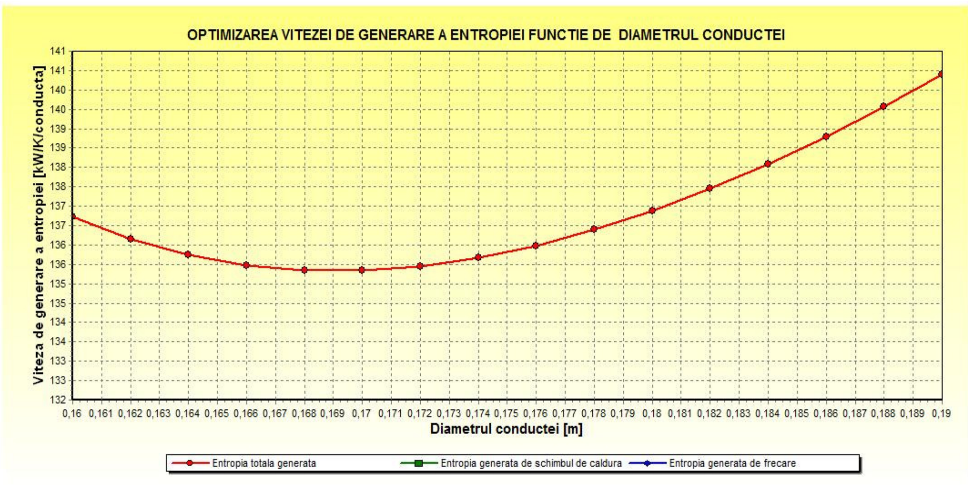

Fig. 5.

These opposed types of behaviour determine the existence of a bigger diameter which minimizes the entropy generated on the transport pipe. The results of the calculations are graphically represented in figures 4 and 5. For the case considered the minimum was numerically determined starting from a diameter of 0,1m and finishing at 0,4 m with a pace of 0,01 m.

In figure 4 the red curve represents the total entropy generated on the pipe taking into account the calculation diameter. We can easily notice the existence of a minimum.

The blue colour was used for the total production of entropy due to friction $\left(\sum S_f\right)$ on the entire pipe taking into account the pipe diameter, and the green colour was used to represent the production of entropy due to the thermal exchange between the crude oil and the ground for the entire pipe $\left(\sum S_Q\right)$.

The graphics show the intimate mechanism of the process of entropy generation. The existence of a minimum of the process of entropy generation shows that there is an energetically optimum diameter for which the lost available power is minimum.

Figure 5 presents in detail the region of the minimum for which we could identify the value of the energetically optimum diameter. From calculations we get that the entropy production for the analysed case is minimum for the diameter D_{opt} = 170 mm.

4. Conclusions

In conclusion we can assert that in the case of transporting crude oil in non-isothermal conditions there is an energetically optimum diameter for which the lost power during the process becomes minimum.

By the term „power" we understand the sum of thermal and mechanical powers that are dissipated during the transport process.

If we compare the energetically optimum diameter obtained by the calculation of the entropic optimization we can conclude that this is the smaller than the diameter established through the pipe design. Using pipes with such small diameters in the transport process determines big flowing speeds and unacceptable pumping pressures on the entire pipe.

This thing can be explained through the fact that the energetically optimum diameter was numerically determined through summing up local processes in certain simplifying hypotheses that allowed the integration of the model.

The optimization methodology of the transport process through the calculation of the energetically optimum diameter determined through the minimization of the entropy generated on the entire pipe shows the inimate mechanisms of entropy production, the existence of a minimum value of it, therefore the real possibility to optimize the process.

Through perfecting and developing an analysis and calculation method we can get to the optimization of the crude oil transport processes in non-isothermal conditions from which economically optimum diameters that can be used in projecting result.

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