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Reliability Approach to the Choice of Dimensions and Materials of Tubes Used in Hydrocarbons Transport Networks

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The growing oil demand requires the construction of new pipes of large diameters, to carry large quantities of oil and natural gas to consumers. This has led industrialists to manufacture high resistance steel tubes.
On the other hand to increase the capacity of pipelines, it is necessary to increase the operating pressure. Ensuring high reliability of pressure pipes requires a significant increase in pipe wall thickness, and the development of high-quality rolled steels.
In this context the choice of pipes for the construction of the oil transporting pipelines require a reliability approach, showing explicitly the dependency between increase in the pipe wall thickness and the pipelines reliability improvement.
This issue is the subject of the current study, which is dedicated to the formulation and analysis of the problem, where by the methods of structures reliability and mathematical statistics, one determines quantitative indices of reliability of pipes which are used in comparing different variants in order to select the best solution. Such an approach allows specifying, at the projection and construction stages, the requirements of proper working of hydrocarbons transport pipelines.

1. Introduction

Main pipelines transporting hydrocarbons over long distances are unique constructions given their large linear dimensions, their transport capacity and their energy powers. Therefore, particular importance is given to their reliability. The problem of reliability of hydrocarbons transport pipelines is multi plan, in which are combined economic, technical, technological ecological and other problems (EL-Shiek, 2013).The ecological aspect in the problem of improving the reliability of hydrocarbons of transport is even so, the peculiarity of this type of transport, which presents a potential danger to the environment (Monier, 1996). One should note the uniqueness and intensive mutual actions between the surrounding medium and these constructions which cross hundreds and even thousands of km sometimes, passing through areas with very harsh climatic and hydrological conditions, as well as the natural and artificial obstacles.
The projection stage is a decisive phase in the life cycle of a hydrocarbons transport pipeline. During this stage its reliability is established by the correct choice of components, of the technological solutions, as well as by the choice of the values of reserve of working safety, taking into account the different influential factors (Abdelbaki et al., 2012). Indeed, hydrocarbons transport pipelines must be not only a safe mode of transport but also respectful of the environment. The design of a good hydrocarbons transport pipeline project is that in which environmental considerations are taken into account, i.e.-the environmental effects of the project, including those caused by failures that can result, i.e. by the non-reliability of the pipeline. During the design of a pipeline, deterministic models defining various technical and economic constraints are often used in which the pipeline reliability is not taken into account. In this context our study focuses on the development of a reliability procedure to the problem of selecting a solution amongst others and that is crucial in terms of the future pipeline working safety. It is considered that the design of hydrocarbons

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transport pipeline projects is placed in a vague and uncertain universe but modelable by a probabilistic hazard, this has been achieved by the use of the coupling between mechanics and probabilities methods to evaluate the pipelines' reliability taking into account their size and materials. In this context, the study of reliability of future pipelines is based on a scenario of failure combining the evaluation of loadings and pipe material strengths, which are functions of the base variables. This scenario is expressed as a function of performance, which reflects the balance between mechanical strength of the pipe and scheduled solicitations (Abdelbaki et al., 2008).

1. Mecano-reliability approach

The illustration of the use of the reliability approach to pipeline design is shown in Figure 1. The first pipeline projection stage is the determination of the influences of the pipeline operating conditions, since those are the most important factors during the working stress and strength calculations.

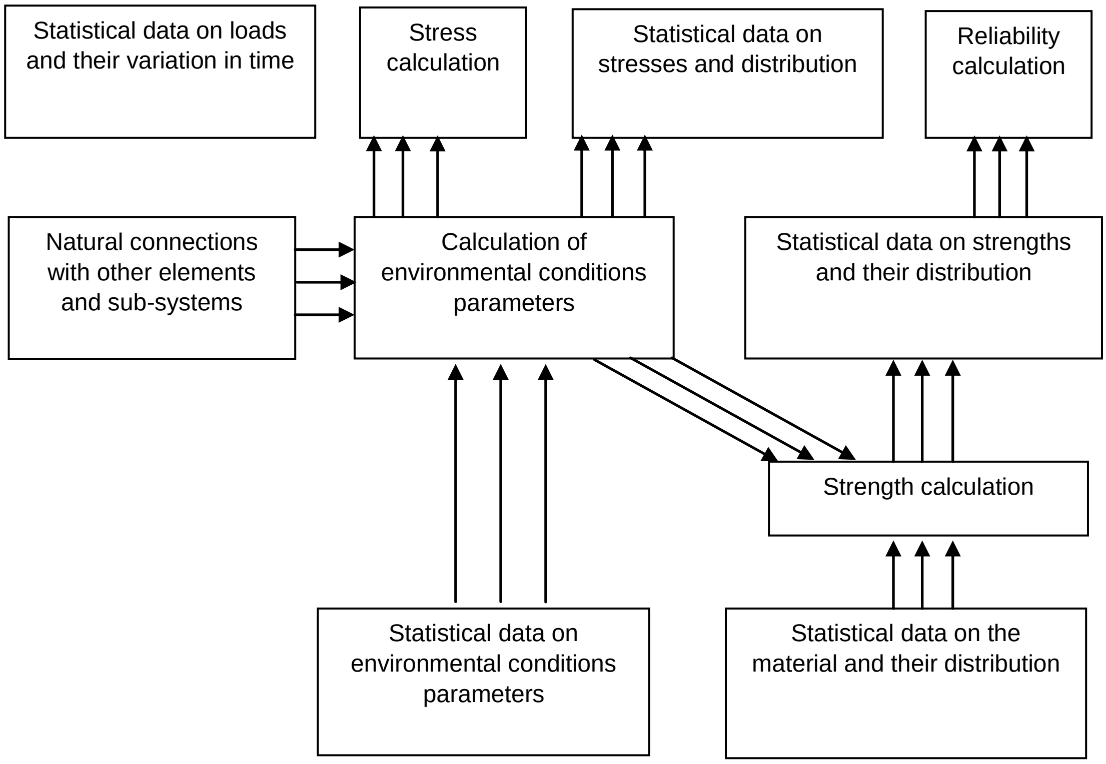

Figure 1: Reliability approach to pipeline design

A pipeline is considered as a system of n components in series whose reliability is given by the relationship :

$$1 - P_f = \prod_{i=1}^{n} \left[1 - P_i\right] \tag{1}$$

Where

P_f - The probability of pipeline failure

P_i - The failure probability of a pipeline section

The mechanical behaviour of a pipeline section is characterized by its bearing capacity and the external load, these quantities are random variables. The probability of good working (Rausand et al., 2004).

$$H = 1 - P_i = \mathrm{Prob}\left\{\sigma_e < \sigma\right\} \tag{2}$$

Where

σ_e - The yield strength of the pipe material

σ - The stress in the considered pipeline section

In a mecano-reliability approach, the failure probability of a pipeline section is given by the expression (Ditlevsen et al., 1996):

$$P_i = \int_0^{\infty} f(\sigma_e) \cdot \left\{ \int_{\sigma_e}^{\infty} f(\sigma) d\sigma \right\} d\sigma_e \tag{3}$$

$f(\cdot)$ - The probability distribution density

The working stress and the yield strength in a section of the pipeline are determined by a combination of adverse factors. They are considered to be random variables of a normal distribution. Expression (2), however taking into account (3) can be put in the form (Wallace et al., 2003):

$$H = \frac{1}{2}\left[1 + \Phi(\gamma)\right] \tag{4}$$

Where

$\gamma = \dfrac{n-1}{\sqrt{V_1^2 + n^2 V_2^2}}$ Working safety characteristic

$V_1 = \dfrac{S_1}{\overline{\sigma}}, V_2 = \dfrac{S_2}{\overline{\sigma}_e}$ Coefficients of variation for the working stress and the yield strength

$\overline{\sigma}$, $\overline{\sigma}_e$ Mathematical expectations of the working stress and the yield strength of the pipe material

S_1, S_2 The average quadratic differences of the working stress of and the pipe material's yield strength

$n = \dfrac{\overline{\sigma}_e}{\overline{\sigma}}$ Working capacity reserve coefficient

If we want to ensure the same level of reliability $P(T)$ in a pipeline section, then it is necessary that the condition is satisfied:

$$\gamma(n, V_1, V_2) \geq \gamma_{ad}\left[H(T)\right] \tag{5}$$

2. Reliability approach to the choice of pipe materials

The choice among existing pipe materials is based on expressions (4) and (5), from which the following criterion is derived:

$$n = \frac{\Delta n}{k-1} \tag{6}$$

Where

Δn - Desired gain in working capacity reserve

$k = \dfrac{\overline{\sigma}_e^{'}}{\overline{\sigma}_e}$ - Ratio between the average yield strengths of the two pipe materials to be compared

3. Reliability criterion of pipe thickness' choice

The choice between the thicknesses of the available pipes is done based on the expressions (4) and (5) from which the expression to be used for comparison between the considered thicknesses is derived:

$$n = \frac{\Delta n}{k_1 + k_2 + k_3} \tag{7}$$

4. Reliability approach to the choice of pipe diameters

The reliability of a hydrocarbons transport pipeline is in this case described by the failure rate (Rausand et al., 2004). In our case the modelling based on statistical data of the failure rate is used to quantify the variation in terms of pipeline diameter. The chosen model is of the type:

$$\lambda(D) = \sum_{i=0}^{n} a_i D^i \tag{8}$$

Where

$\lambda(D)$: Failure rates in terms of the diameter D

D: Pipeline diameter

a_i : Model identifying constants

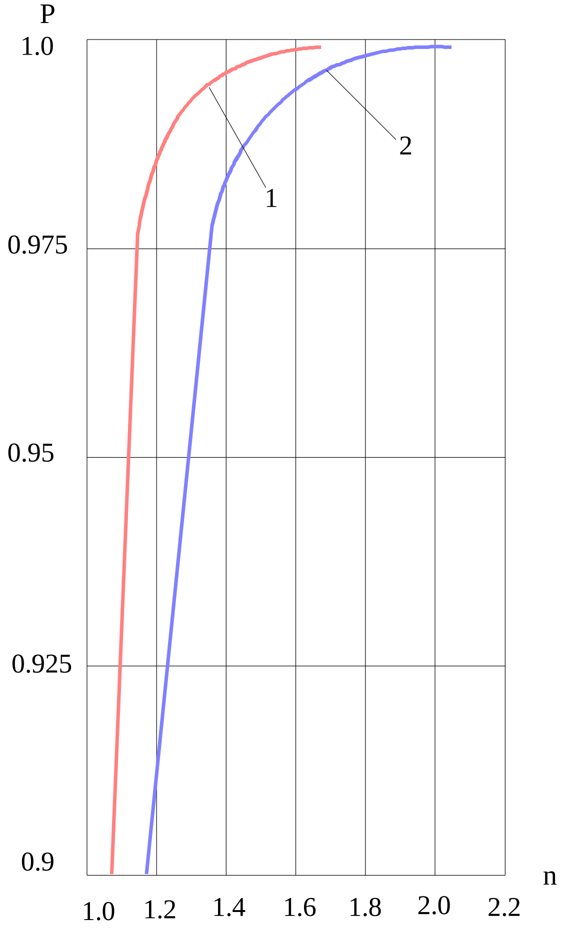

Figure 2: Reliability dependence on pipe material: 1- X60 steel 2- X52 steel

5. Results and discussion

The quantifying of the pipe size and material modifications impact has led to the following results:
a) For comparison purposes, X52 and X60 steel pipes have been considered. The object was to give, explicitly, in the one hand the dependence of pipeline reliability on the chosen pipe material, and on the other hand the influence of pipe size on the pipeline reliability. Mechanical test specimens have been cut out from pipes so that to characterize their material. In an explicit form, are determined the design parameters, from which, the working stress and strength distributions have been determined. Using calculations, it has been found that the working stress and strength distributions follow normal laws and their parameters have been determined; these results have then been used for the calculation of the pipeline reliability indices relative to changes made to the pipe thickness and material.
b) In Figures 2, 3 and 4 are shown the results of the calculations of the impacts of these changes.
c) The treatment of statistical data on failures of hydrocarbons transport pipelines in service, has allowed identifying of expression (8) in the form of a linear dependence between their failure rates and their diameter reduced to one kilometre of pipeline length. This way the expression (8) is of the form (Figure 4):

$$\lambda = 1.2\times10^{-8} + 0.92\times10^{-10} D \qquad (9)$$

Where

λ - Failure rate in 1/km.h
D - Pipeline diameter in mm

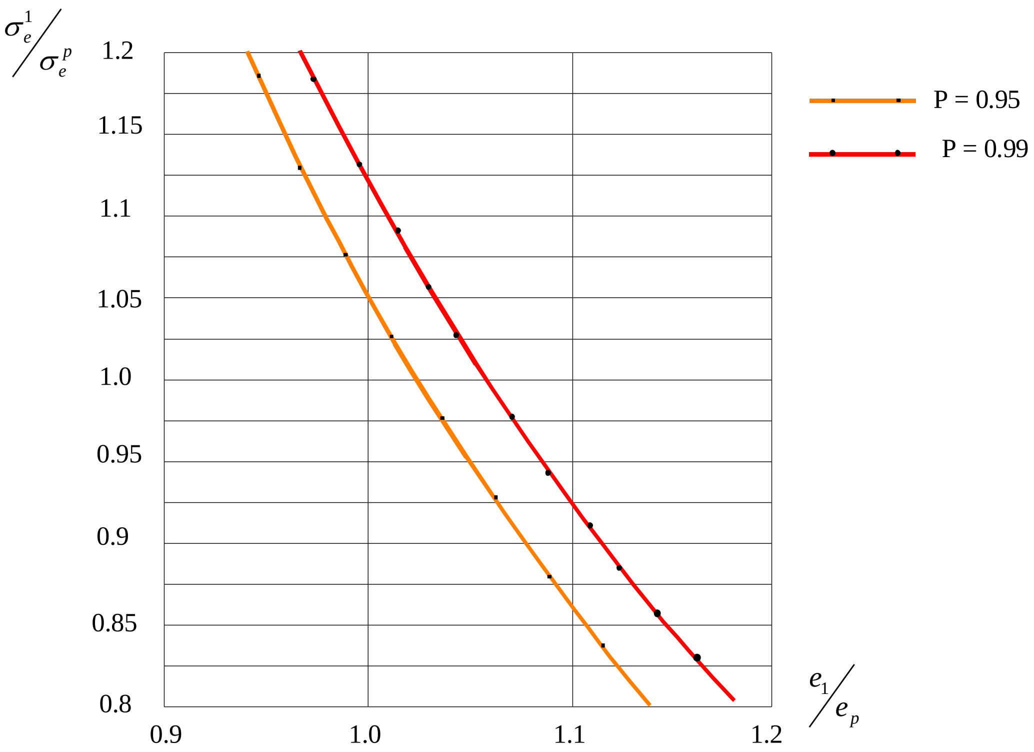

Figure 3: Reliability of pipes during thickness and material modifications

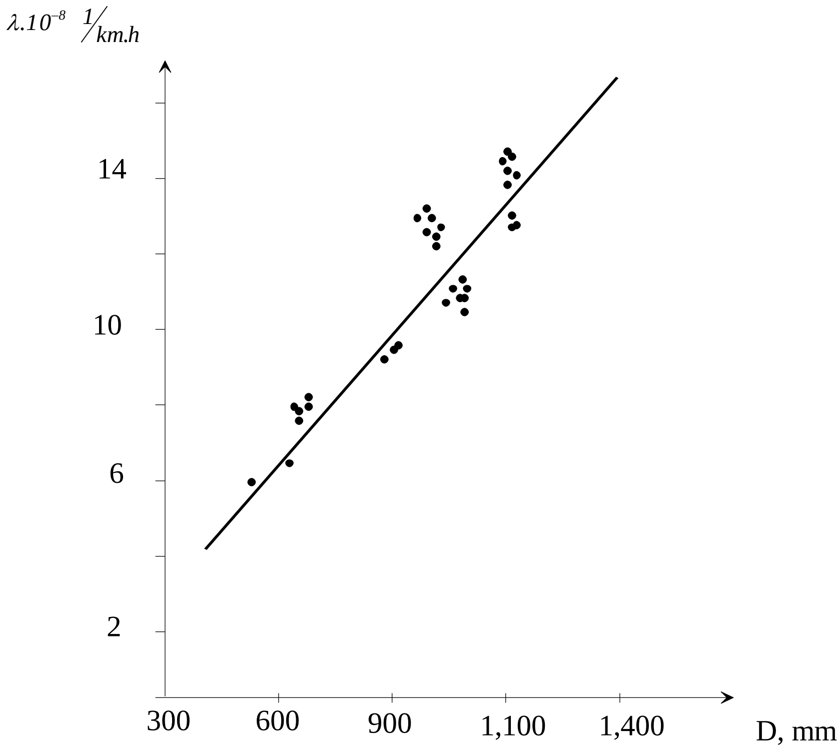

Figure 4: Failure rates dependence on the diameter of the pipelines

6. Conclusion

Analysis of the results obtained (Figures 2 and 3) show quantitatively that the failure rate increases with increase in pipe dimensions and the reliability decreases. With increase in the pipe dimensions, the work of their handling tasks become complicated, the pipeline laying in the trench on the turning points of the plot leading to the further increase in mechanical stresses. As a consequence the pipelines' reliability decreases. This decrease may be balanced by pipe thickness increase (Figure 3) or by the choice of another pipe material (Figure 2).

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