INFLUENCE OF TEMPERATURE ON TIGHTNESS OF FLANGED JOINTS UNDER FATIGUE CONDITIONS

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Abstract: This paper presents the results of an experimental research on the properties of "It" gaskets, which are used to ensure the tightness of flanged joints at pressured vessels. In this work, were considered the vessels working at variable pressure and high temperature. Experimental data are used to determine a general relation for calculating the endurance reduction factor of the flanged joints. This factor is recommended for determining the safe lifetime of the gasket, which is the most sensitive constructive element of flanged joints.

Keywords: fatigue, lifetime, flanged joint, gasket, tightness.

1. INTRODUCTION

The tightness is a complex phenomenon which has a particular importance for the safe operation of many industrial types of equipment. At the same time, it should be noted that the equipments lack of tightness has major implications for the environment by the pollution it can generate. According to statistics, the most important loss of liquids or gases from the equipments appear on the seals of pumps, compressors and mixing devices, at flanged joints, valves and safety valves.

With regard to flanged joints, it should be noted that, without these subassemblies, it would not be possible to operate the various equipments in the chemical, food, metallurgical, energy industries, and from other spheres of activity. Practically, it can be said that the flanged joints are used in structures of equipments and installations from all industrial fields. A flanged joint is composed of very different structural elements (flanges, screws, nuts, washers, gasket) and each of these elements can be the cause for a loss of tightness. Moreover, the behavior of these constructive elements is influenced both by the working fluid properties, and by the working conditions (pressure, temperature).

On the other hand, it should be underlined that, during its operation, a flanged joint can pass through various stress stages. For example, the flanged joint between the cover and the body of a pressure vessel runs through the following steps: assembling (screws tightening, without inner pressure), pressure tests, transitory conditions of work (increase or decrease of pressure and temperature), exploitation (operation at the work temperature and pressure). In these operational phases, the pressure and temperature of flanged joint take different values, which can vary according to different stress cycles. Since this cycle is repeated with some frequency along the equipment lifetime, the components of a flanged joint will be tested in terms of their fatigue resistance; this will contribute to the premature loss of tightness [1, 2].

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As can be seen from the above mentioned, the durability of a flanged joint may be influenced by many factors. For this reason, experimental measurements presented in this paper were limited to studying the endurance of the gasket, under fatigue and high temperature conditions.

2. THEORETICAL

The resistance to variable requirements (fatigue resistance) of the mechanical structures is a complex characteristic, which depends on many factors. Some of the factors are taken into account in the quantitative calculations of resistance and the others are taken into account when choosing the material, shape and manufacturing technology [3].

In general, these factors can be classified into three categories:

- construction factors: size, element's shape, stress concentrators;
- technological factors: the composition and structure of the material; surface quality, thermal treatments, the surfaces protection type etc.;
- factors which take account of the exploitation conditions: the type of application, temperature, pressure, aggressiveness of working environment etc.

In the concrete case of the flanged joints, fatigue endurance assessment is a difficult operation, because the effect of these factors on the endurance of all components has to be taken into account. Thus, as can be seen, very different aspects of this problem are tackled in the specialty literature: screw's endurance, gasket's endurance, durability of welded joint between the vessel body and the flange, durability of the whole assembly with flanges etc.

In many of these works is noted that in terms of the phenomenon of fatigue, the gasket is the most sensitive element of a flanged joint. In this context, it should be noted that, from the experimental study performed on gaskets of marsit (SR 3498-1:2000), tested for their resistance to fatigue, a relation was obtained, which has been proposed for evaluating the endurance of this type of gasket [4].

The relation, which was determined by the statistical processing of the experimental data, has the following expression:

$$\Delta p = 4.92 \cdot \frac{A_e}{A_i} \cdot N^{-0.443} \tag{1}$$

where:

Δp is the domain of pressure variation;

N – the number of cycles of pressure variation up to the tightness loss of the flanged joint (the appearance of first droplets of liquid);

A_e - outer area of the gasket;

A_i - inner area of the gasket;

d, D - inner and, respectively, outer diameter;

h - thickness of the gasket.

Equation (1) can be written under the form:

$$N = \left(4.92 \cdot \frac{A_e}{A_i} \cdot \frac{1}{\Delta p}\right)^{\frac{1}{0.443}} \tag{2}$$

which allows the determination of the number of cycles possible until the tightness is lost, depending on gasket's geometrical parameters and amplitude of the stress cycle. It should be noted that this relation was derived from the fatigue tests performed at 20 ^{0}C, so it is not reflecting the temperature effect on tightness. For this reason, in the present paper, the authors intended to study the temperature's influence on the number of internal pressure variation cycles until the tightness loss of the flanged joints.

3. EXPERIMENTAL

The experimental set-up for gaskets testing has been designed so as to simulate the functioning of a gasket mounted between two flanges with flat sealing surfaces (Figure 1). By the help of this, it can be determined the number of cycles until the tightness loss of the flanged joints, depending on the working temperature and on the amplitude of the internal pressure variation cycle [5].

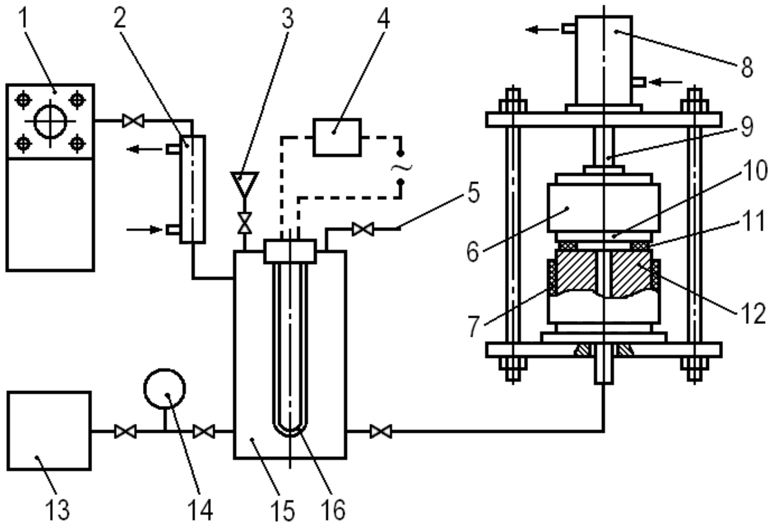

Fig. 1. Experimental set-up.

Gasket 11 is compressed between parts 10 and 12 with the help of piston 9, which slides in the hydraulic cylinder 8. This experimental instalation ensure a uniform and controlled gasket compression, with forces ranging between 4,000 and 40,000 Newton.

The gaskets used were made of asbestos-free marsit plates [6]. In accordance with the classification made by the European Sealing Association, studied gaskets are part of the so-called "soft-gaskets" (non-metallic ones). They are manufactured by the “It” calendering process, whereby a mixture of fibers, fillers and binders is compressed between two rollers under load [7].

Taking into account the size of the experimental equipment, the geometric parameters of all the tested gaskets were limited to the following values: outer diameter D = 100 mm, inner diameter d = 80 mm and thickness h = 3 mm. The massive pieces, between which the gasket is compressed, eliminate the characteristic deformations of a real flanged joint. Thus, the behavior of the gasket may be revealed only from the tightness point of view.

In accordance with the regulations in force, the specific pressure on the gasket was set to the value of q = 8 N/mm^2. After compression, in the inner gap of gasket 11, hot water is introduced, which is first obtained in tank 15, by means of the electrical resistance 16. To ensure the necessary working temperature value, the facility is equipped with thermostat 4. Pieces 10 and 12 are also heated by means of resistors 6 and 7, controlled by the thermostat.

By means of pipes 3 and 5 - vessel 15 is provided with - it is ensured the filling of the installation with water, once with air elimination from it. Volumetric pump 13 serves to raise the pressure of the hot water at the minimum value, measured with manometer 14 and set according to the operating temperature.

Variation in pressure between pieces 10 and 12 is achieved through the pressure pulsating equipment 1. It provides the fatigue stress of the gasket after a cycle whose frequency and amplitude can be adjusted to the working conditions [5].

Heat exchanger 2 is intended to protect the pressure pulsating equipment from the contact with the hot liquid in the installation. The warm water pipelines were thermally isolated.

In order to determine the influence of temperature over the number of cycles to tightness loss of flanged joints, experimental determinations were made at three values of temperature: 100 ^{0}C, 150 ^{0}C and 200 ^{0}C. Keeping each of these temperatures constant, the amplitude has been modified for the cycle of pressure variation. Thus, at each value of temperature, three values of the cycle amplitude were taken into account, which are adjusted by means of the pressure pulsating equipment 1. To eliminate the measurement errors, at each value of the amplitude of the cycle, five gaskets were tested; so, a total of 45 gaskets have been subjected to trial.

The cycle limits are established taking into account that, for the temperatures of 150 ^{0}C and 200 ^{0}C, the minimum pressure of hot water must be 0.5 MPa and, respectively, 1.6 MPa. The frequency of the stress cycle was kept constant for all experimental investigations (12 cycles/min).

Gasket testing under fatigue condition is stopped when steam leakage is observed between the gasket and the parts between which it is compressed. At this moment, it is recorded the number of cycles to tightness loss, which is indicated by the pulsating pressure equipment.

It should be noted that experimental studies under fatigue conditions and high temperature are very difficult. The difficulties are caused by the following aspects: the need to coordinate the operation of all equipments that make up the experimental facility; the long duration requested by the experimental determinations; the danger arising from the possibility of gaskets breaking during the experimentations.

4. RESULTS AND DISCUSSIONS

After the statistical processing of experimental data [4, 8, 9], the curves of average durability were obtained for the gaskets, according to temperature and to the amplitude of the stress cycle (Figure 2).

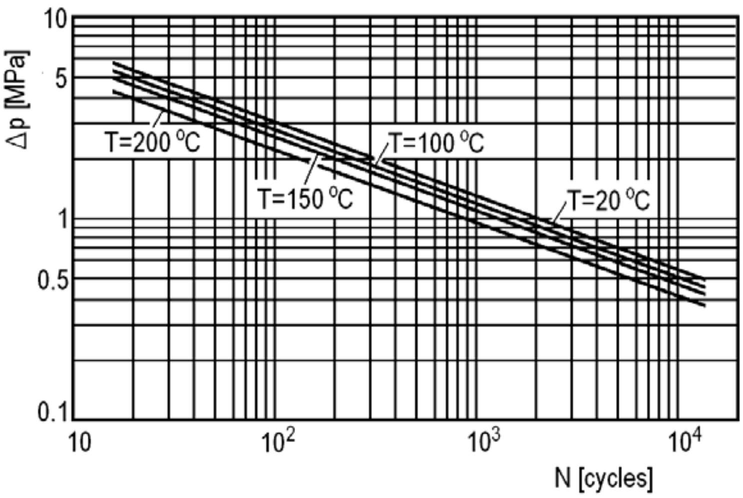

Fig. 2. Gasket's average durability according to temperature and to the stress cycle amplitude.

As can be seen, once with increasing temperature this leads to gasket durability decreasing; that is the decrease in the number of cycles, *N*, until tightness loss of flanged joints takes place.

Further-on, comparing the experimental results obtained at a temperature of 20 ^{0}C with those obtained at high temperatures, the effect of temperature could have been quantified over the number of cycles to tightness loss of flanged joints, when the gaskets if of marsit.

This influence is represented by a durability decrease factor, α, whose evolution according to temperature is described by a second degree parabolic equation (Figure 3).

$$\alpha = a + b \cdot T + c \cdot T^2 . \tag{3}$$

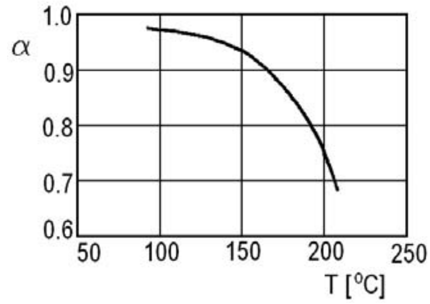

Fig. 3. Temperature influence over the gaskets durability reduction factor.

The coefficients *a*, *b* and *c* are obtained through the regression of experimental data, using the least squares method [6]. To this end, Expression (3) is minimized, thus equaling to zero the partial derivatives depending on regression coefficients, taking to:

$$\begin{cases} n \cdot a + b \cdot \sum_{i=1}^{n} T_i + c \cdot \sum_{i=1}^{n} T_i^2 = \sum_{i=1}^{n} \alpha_i \\ a \cdot \sum_{i=1}^{n} T_i + b \cdot \sum_{i=1}^{n} T_i^2 + c \cdot \sum_{i=1}^{n} T_i^3 = \sum_{i=1}^{n} T_i \cdot \alpha_i \\ a \cdot \sum_{i=1}^{n} T_i^2 + b \cdot \sum_{i=1}^{n} T_i^3 + c \cdot \sum_{i=1}^{n} T_i^4 = \sum_{i=1}^{n} T_i^2 \cdot \alpha_i \end{cases} \tag{4}$$

In previous relations, *n* is the number of experimental measurements and *T* is the working temperature. After solving the system of Equations (4), the final form of regression Equation (3) is obtained, which expresses the relation between the gasket durability reduction factor of temperature:

$$\alpha = 1.16 - 8.20 \cdot 10^{-3} \cdot T - 3.14 \cdot 10^{-5} \cdot T^2 \tag{5}$$

So, in the case of gaskets made of marsit subjected to pulsating internal pressure and temperatures between 100 ^{0}C and 200 ^{0}C, the number of cycles to tightness loss can be determined by the relation:

$$N_T = \alpha \cdot N \tag{6}$$

where *N* is the value obtained by solving Equation (2).

Finally, the admissible number of cycles to tightness loss of gaskets made of marsit can be calculated, with the relation:

$$N_a = \frac{N_T}{C_{NE} \cdot C_R} \tag{7}$$

where the safety factor of the number of cycles to tightness loss $C_{NE} = 5$, and the risk coefficient $C_R = 1.371$, in the case of tightness loss probability $P_A = 0.01\%$.

5. CONCLUSIONS

Within the present paper, presented are the results of an experimental research on the properties of gaskets made from marsit, used to ensure the tightness of flanged joints.

Based on numerous and complicated experimental measurements, it was set the diagram showing the dependence between the cycle amplitude of the internal pressure variation and the number of work cycles to tightness loss of the flanged joint.
These measurements were made at different temperatures, to reveal the influence of temperature on the tightness of the flanged joint.

Thus, it could be demonstrated that, as the temperature rises, the tightness loss occurs at a smaller number of working cycles.

Further, comparing the experimental results obtained at a temperature of 20 ^{0}C with those obtained at high temperatures, it was established expression of the durability reduction factor for the flanged joint. This factor can be used in the design stage to determine the safe working lifetime of the flanged joint operating at high temperatures.

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