THE INVESTIGATION OF PRESSURE GRADIENTS IN A NONHERMETIC VESSEL

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Abstract: *The process of depressurization of a nonhermetic vessel under a specific law of changing the external pressure has been studies. The ways and methods of decreasing the values of pressure drops rate inside the vessel have been found.*

***KEYWORDS**: VESSEL, PRESSURE, PRESSURE DROP RATE, DRAINAGE DEVICE, AREA.*

1. Introduction

In modern mechanical engineering devices, apparatuses and equipment are usually placed into closed vessels. Outside such a vessel there is variable external pressure.

If the vessel's construction isn't hermetic the change of the external pressure value influences the pressure value inside the vessel.

Due to continuous improvement of various apparatuses the maintenance requirements have increased. The old requirements become more strict, the new ones appear. Some construction elements in modern apparatuses can be sensitive not only to certain dependencies of pressure changes in the place of its location but also to the pressure gradient level. The given maintenance parameter is the criterion of serviceability in many apparatuses.

Under the monotonous decreasing the external pressure the pressure value inside the vessel is decreasing as well. If there is no increasing internal pressure values, it is reasonable to use the term of dishermetization rate instead of the term of pressure gradient. The gradient can have either positive or negative meaning. It reflects mathematical aspect of the phenomenon rather than physical one. When the pressure values decrease not monotonously but undergo a discontinuous change the term of the pressure decrease rate (PDR) was used to describe the physical nature of the phenomenon.

Considerable PDR values are quite possible to be found inside the vessel containing the apparatuses. As a rule, they appear during short time intervals. The loading of apparatus elements at such PDR was characterized as impulse loading (IL). Such a loading may cause a number of problems in providing safe operation of the apparatus.

2. Pre-requisites and means for the problem solution

The actual question is decreasing the maximal levels (PDR).

One of the ways to decrease maximal PDR levels inside the vessel is the arrangement of drainage system (DS). The drainage system is as a rule a complex of drainage devices (DD). The communication between the internal volume with the external environment takes place by means of DD. The drainage systems are characterized by the effective area of DD.

The given paper is aimed at choosing optimal values of the effective areas at which the maximal level of PDR inside vessel is minimal.

To solve the problem the following point were chosen:

- the formulation of the problem about the influence of the external pressure distribution on internal pressure character;
- the elaboration of methods and algorithm for calculating PDR;
- carrying out theoretical research;
- determining rational meanings of the effective DD area;
- finding optimal meanings of the effective DD area, providing minimal PDL level;
- generalizing and analyzing the results of the research carried out;
- practical recommendations.

3. The solution of the problem under study

The studied vessel and the dependencies of the external pressure coefficient on time are presented in Fig. 1.

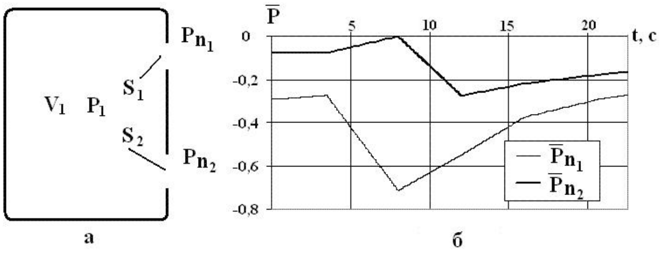

***Fig. 1.** The vessel with drainage holes (a) and the dependencies of external pressure coefficients on time (б)*

Vessel volume is V_1 and internal pressure is P_1. On this stage of research DS consisted of two DD with effective areas S_1 and S_2. On the external side of the vessel in the region S_1 there was the external pressure Pn_1, in the region S_2 – Pn_2.

The peculiarity of the given problem formulation consisted in the laws of the changes of external pressure values against time. Each law is characterized by sharp decrease and increase of its values within a short time interval. Moreover, if the value of one pressure increased those of the other one decreased. Besides, the pressures achieved their minimal and maximal values at the same time. The solution of the problem was reduced to solving a differential equation /1/, /2/

$$\frac{dP_1}{dt} = \frac{RT}{V_1} k \cdot \left(\dot{G}_1 + \dot{G}_2 \right) \tag{1}$$

where

$$\dot{G}_1 = \frac{\mu_1 \cdot S_1 \cdot P_1}{\sqrt{R \cdot T}} \sqrt{\frac{2k}{k-1} \cdot \left[\left(\frac{P_{1н}}{P_1} \right)^{\frac{2}{k}} - \left(\frac{P_{1н}}{P_1} \right)^{\frac{k}{k+1}} \right]},$$

$$\dot{G}_2 = \frac{\mu_2 \cdot S_2 \cdot P_2}{\sqrt{R \cdot T}} \sqrt{\frac{2k}{k-1} \cdot \left[\left(\frac{P_{2н}}{P_2} \right)^{\frac{2}{k}} - \left(\frac{P_{2н}}{P_2} \right)^{\frac{k}{k+1}} \right]}$$

In formula (1) $\dot{G}_1$ and $\dot{G}_2$ are second consumption of atmospheric masses by means of the corresponding DD. The consumption coefficients by means of DD are μ_1, μ_2. For atmosphere $k = 1.4$. R is the universal g

as constant. T is the temperature of atmosphere in the vessel.

The process of vessel drainage takes place due to its discharging or supercharging.

Discharging or supercharging depends on: the DD location, the pressure acting on them and on the external gradient of pressure as well. Both cases of drainage may take place on different DD at the same time. Under supercharging the second discharges in formula (1) have the plus sign. Under discharging they have the minus sign.

4. *Results and discussion*

The results of computing PDR values inside the vessel and depending on time under various values of effective area S_1 are presented in Fig. 2. Under changing S_1 values the area S_2 remained constant. The formation of two consequent peaks I and II was the characteristic feature of the dependencies of PDR values on time that were presented. The values of the peaks are greatly dependent on parameter S_1 values.

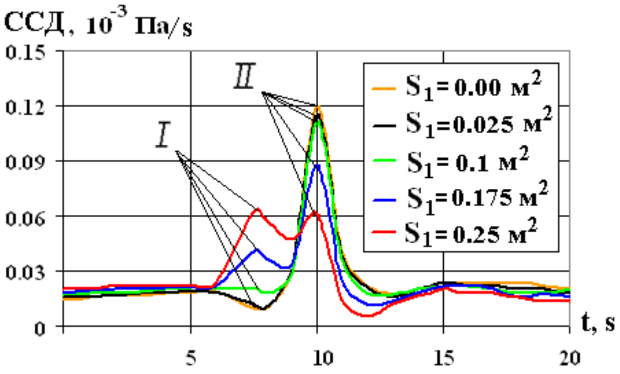

Fig. 2. *The dependence of PDR on time at various values of effective area* S_1

The discussion on the results presented in Fig. 2 made in possible to make the following conclusions.

By the fifth second, when the external pressure values do not change or don't undergo any significant changes (see Fig. 1b), PDR values inside the vessel remain practically unchanged. It is represented by almost horizontal lines in Fig. 2 when time changes from 0 to 5 seconds.

Following the fifth second the changes of the external pressures values influence sufficiently the quantitative and qualitative PDR characteristics inside the vessel. The extent of this influence depends on the effective area S_1 value. In this case the S_1 parameter functions as a regulating, or more precisely, a governing parameter. It is with the help of it that maximal PDR levels inside the vessel can be minimized.

At small values of $0 \leq S_1 \leq 0.1$ m^2 there was some insignificant decrease of PDR values followed by the abrupt increase reaching maximal values. Thus, the maximal level of PDR value is defined for the peak II value.

At $S_1 > 0.1$ m^2 the value of peak I doesn't decrease but increases as compared to the previous region. With S_1 value increased, the value of peak I goes on increasing while the value of peak II is decreasing. At $S_1 = 0.175$ m^2 the value of peak I is less than the value of peak II. At $S_1 = 0.25$ m^2 one can see the reverse picture: the value of peak I is more than the values of peak II. Between these values of S_1 there is its optimal value at which the value of peak I and peak II are equal. The equality of the peaks values realizes the minimal possible PDR level inside the vessel.

Thus, the discussion resulted in the following:

– the area S_1 can act as the governing parameter for changing the values of PDR peaks inside the vessel;

– there is correlation of peaks values, the less the value of one peak, the more the value of the second one. The principle of communicating vessels may be an analogue of the peaks correlation;

– the minimal possible level of the peaks is realized at their balance.

The decrease of maximal PDR values (of peak II) may be treated as damping of impulse loading.

Damping is realized due to the inflow of some additional air masses. If the external pressure decreases abruptly through S_2 occurs the sufficient ablation of the air mass from the vessel. The inflow of the air mass is realized through S_1. At small values of S$_1$ this inflow isn't sufficient to realize damping properly. At the optimal value of S$_1$ area the maximal damping effect is achieved. At S_1 value more than optimal the reverse situation picture is quite possible. The ablation of such quantity of air mass through S$_1$ can not be compensated through S_2.

The results for a single fixed value of S_2 are presented in Fig. 2. The computations were also carried out at other S$_2$ values. There were registered the same quantitative and qualitative laws as in the previous computations. The optimal S_1 value depended on the value of S$_2$.

Fig. 3 shows generalized results of the investigation of PDR dependences on the areas S_1 and S_2. The generalization consisted in the dependencies of the values of two peaks on S$_1$ and S_2 areas being represented not in their absolute values but as the relation of S_1/S_2.

The further discussion as to the results of the investigations presented in Fig. 3 was focused on the following direction.

The whole range of the areas relations was divided into sections. The first section $0 \leq S_1/S_2 \leq 0.4$ m^2 was characterized as the one where the changes of areas relations don't make it possible to influence the peaks values effectively.

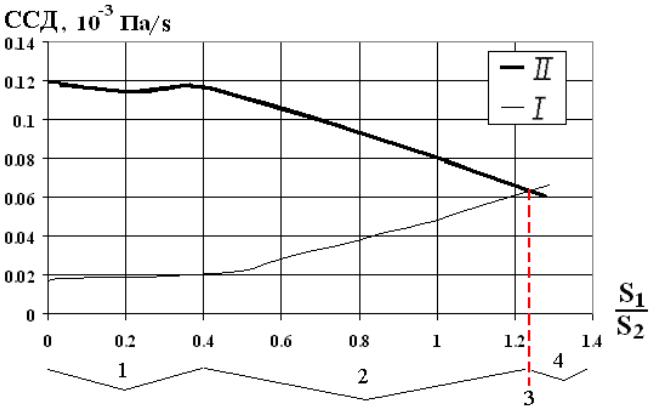

Fig. 3. *The dependence of the peaks I and II values on the areas relations.*

The second section $0.4 \le S_1/S_2 \le 1.22$ m^2 is marked as the rational correlation of the areas. Here, if the correlation increases the value of peak I decreases from the maximal value. The value of peak II increases from the minimal value. It is in this section that the effective control of peaks values takes place.

The third section is only one value, that is $S_1/S_2 = 1.22$. This is the optimal value of areas relations. At this value the balance of peaks I and II values is achieved. It is minimal possible level of PDR values. It is almost twice as little as the minimal possible PDR level (the value of peak II at $S_1/S_2 = 0.4$ m^2).

The fourth section is $S_1/S_2 > 1.22$ m^2. It is a nonrational section. When the value of the areas relation grows the general level of PDR values also grows.

There were undertaken some attempts of the further decreasing the minimal PDR level. For this purpose the construction of the vessel was divided into two unequal vessels.

The volume of the first vessel, where the apparatuses were placed, was four times as large as the volume of the second vessel. The partition dividing the initial vessel into two vessels had DD with effective area S_{12}.

The initial equation (1) was complemented by an analogous equation. A system of two differential equations was obtained.

The results of solving the obtained system are presented in Fig. 4.

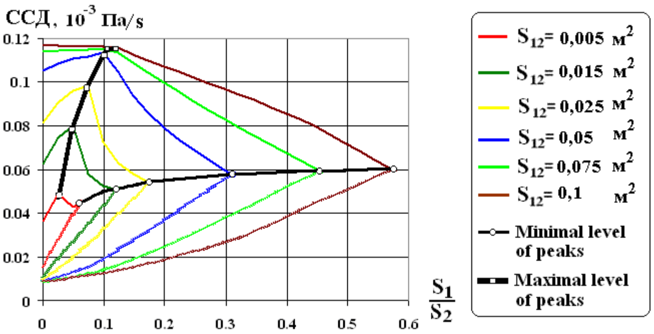

***Fig. 4** The dependence of minimal and maximal of PDR values on the areas relations S_1/S_2 at various areas values S_{12}.*

The discussion about the results of the investigations presented in Fig. 4 showed the following.

At $S_{12} > 0.1$ m^2 the minimal possible PDR level inside the first vessel is practically equal to the level of one vessel. Its order was determined by the value 0.062 Pa/s. When the S_{12} values decrease the minimal possible PDR level also decreases.

At $S_{12} < 0.005$ m^2 the minimal possible PDR level may decrease by 25 % - 35 % as compared to the minimal PDR level for one volume.

Using the results of the investigations presented in Fig. 4 it is possible to point out the correlations between S_1, S_2 and S_{12} at which the maximal possible (black with squares) and the minimal possible (black with circles) PDR levels inside the first vessel.

5. Conclusion

The investigations carried on resulted in the following conclusions.

1. The problem of the PDR level in a nonhermetic vessel has been formulated and solved. The connection of the internal volume of the vessel with the outside atmosphere was realized through drainage devices DD with areas S_1 and S_2.
2. The specific feature of the problem formulation was due to specific laws of the changes of the external pressure within a short time interval.
3. The existence of two PDR peaks inside the vessel has been found out.
4. The PDR peaks inside the vessel occur within short time intervals. The loading of the apparatus elements from such peaks was characterized as impulse loading.
5. Impulse loading on the apparatus elements may cause a number of problems when the attempts are made to provide the safety of operating the equipment.
6. The analysis of the influence of S_1 and S_2 areas values on the peaks values has been made.
7. The correlation of the values of two peaks at the changes areas S_1 and S_2 values has been established. The more the value of one peak, the less the value of the second one. The principle of communicating vessels may be treated as the analogue.
8. The optimal values of S_1, S_2 areas at which the minimal possible level of PDR values have been defined.
9. The minimal possible PDR values level inside the vessel occurred when the values of the peaks were equal.
10. Owning to the balance (equality) of PDR peaks values maximal value can be decreased as much twice.
11. Physical treatment of increasing maximal PDR level has been given. Under abrupt decrease of the external pressure value on one of the DD a great amount of air masses flows out through it. At the same time PDR inside the vessel may reach considerable values. The compensation of the lack of air masses takes place through the second DD. The air mass, the volume of which is defined by the area value of the second DD, flows into the vessel.
12. The process when some quantity of air mass flows in through one DD and some quantity of air mass flows out through the other DD was called damping.
13. The maximal effect of damping occurred at optimal values of the areas S_1 and S_2.
14. The method of the further decreasing PDR minimal level has been suggested. The initial vessel was divided into two vessels of unequal volumes. The connection of air masses between these two obtained vessels was realized through the DD with the area S_{12}. With the help of this method it is possible to decrease additionally minimal possible PDR level by 25 % – 35 %.
15. The results of the investigations have been generalized. On the basis of the given graphs and proceeding from certain relations of areas S_1, S_2 and S_{12} values one can find possible PDR values. Some relations of areas show maximal PDR levels while others show minimal ones.

6. *Литература*

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