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EXPERIMENTAL STUDY OF THE POLYTROPIC COEFFICIENT IN A HYDRAULIC HAMMER WITH AIR-WATER FLOW

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Annotation

The article presents the results of analytical and experimental study of the polytropic coefficient in the process of hydraulic shock with an air-water pressure flow. At the same time, a reliable coincidence of the results of calculating the polytropic coefficient by the proposed method with experimental data is obtained, which also confirms the variability of the polytropic coefficient during hydraulic shock in the air-water flow. The conducted experiments prove that the coefficient of polytropes is strictly polytropic in nature.

Key words

polytropic coefficient, hydraulic shock, air-water pressure flow, pressure system, law of air compression-expansion, velocity of impact wave propagation, isothermal process, adiabatic process.

Аннотация

В статье приведены результаты аналитическое и экспериментальное исследование коэффициента политропы при процессе гидравлическом ударе с воздушно водяном напорном потоке. При этом получено достоверное совпадение результатов расчетов коэффициента политропы по предлагаемой методике с опытными данными, что также подтверждает изменчивости значение коэффициента политропы при гидравлическом ударе в воздушно-водяном потоке. Проведенные эксперименты доказывают, что коэффициент политропы имеет строго политропического характера.

Ключевые слова

коэффициент политропы, гидравлический удар, воздушно-водяной напорный поток, напорная система, закон сжатия-расширения воздуха, скорости распространения волны удара, изотермический процесс, адиабатический процесс.

Аннотация

Мақолада политропа коэффициентининг гидравлик зарба жараёнида напорли ҳаволи суюқлик оқимида аналитик ва экспериментал тадқиқоти натижалари келтирилган. Бунда таклиф этилаётган усул бўйича политропа коэффициентининг ҳисобий қийматлари тажриба маълумотлари билан ишончли мос келиши олинганки, шунингдек политропа коэффициенти қиймати ўзгарувчанлиги тасдиқланади. Утказилган тажрибалар политропа коэффициентининг политропик характерга эга эканлигини исботлайди.

Tayanch so'zlar

politropa koeffitsiyenti, gidravlik zarba, bosimli havo-suv oqimi, bosim tizimi, havoning siqilish-kengayish qonuni, zarba to'lqinining tarqalish tezligi, izotermik jarayon, adiabatik jarayon.

Currently, there is no consensus on the selection of the numerical value of the polytropic coefficient n, which takes into account the law of compression-expansion of air in a gas-liquid pressure system. In works [1,2,3,4,5] the authors recommend accepting the law of compression-expansion of air in a gas-liquid pressure flow as adiabatic n=1.41, while other authors [6,7,8,9,10] accept n=1.0, considering that the process of compression-expansion of air in the system is isothermal. At the same time, in the works [11,12,13,14,15,16] it is stated that the process of compression and expansion of air in the system proceeds according to the polytropic law. Therefore, the justification of the correct choice of the numerical value of the polytropic coefficient when calculating pressure gas-liquid systems for hydraulic shock is very important, since the reliability of determining the speed of propagation of the shock wave, as well as the minimum and maximum pressures in the pressure system, depends on this.

The speed of propagation of the impact wave is the most important parameter when calculating water hammer. When deriving the dependence for determining the speed of propagation of the impact wave, changes in the mass of the gas-liquid pressure flow in an elementary section of the pipeline over time Δt were adopted. The following assumptions were made:

1) the average speeds of the components of the air-water flow (air and water) are equal to the average speed of the flow mixture;

2) the components of the air-water flow are mixed fairly well with each other;

3) the mass transfer equation is broken down into independent mass transfer equations for each component of the air-water flow;

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4) during the impact, neither absorption nor release of air occurs, that is, the mass of air in the air-water flow is constant;

5) the volume concentration of air is insignificant φ=0.03;

6) the process of changing the volume of air is considered adiabatic, that is, n=1.4.

The dependencies obtained in accordance with the described methodology are reduced by equivalent transformations to an equation of the form (1) [3].

We compared the experimental values of the propagation speed of a hydraulic shock wave in an air-water flow C_{ex} with the values C_{cal} calculated using dependence (1) [3]. The results of experiments conducted by D.N. Smirnov, A.G.Dzhvarsheishvili and G.I. Kirmelashvili, V.S. Dikarevsky and A.A. Markin, N.G. Zubkova were used.

To experimentally determine the numerical value of the polytropic coefficient n in a gas-liquid pressure flow, special experiments were carried out in the laboratory, consisting of several series, the methodology for which is described in [3]. The standard deviation of the experimental values of C_{ex} from those calculated using formula (1) [3] is 12.7%. Presumably, one of the possible reasons for these discrepancies is that the process of gas compression during hydraulic shock in an air-water flow is not exactly adiabatic. In all likelihood, the value of the polytropic coefficient *n* lies in the range from 1 to 1.4.

To obtain the value of n corresponding to the experimental data, we will use the least squares method and find the minimum value of the expression:

$$F = \sum_{1}^{i} \left(\frac{C_p - C_{on}}{C_{on}}\right)^2,$$

Where $C_p = f_1(P_c, V_p, \varphi, n)$ - calculated values of the propagation speed of the hydraulic shock wave according to formula (1) [3];

$C_{on} = f_2(P_c, V_0, \varphi, n)$- the speed of propagation of a hydraulic shock wave according to experimental data; i - number of experiments.

We will look for n - corresponding to the minimum value of F with an accuracy of ±0.5% and the expression itself according to the "minimax" plan. The problem is to solve a system of difference equations in the range x′ = 1 ≤ n ≤ x″ = 1.4 with an accuracy of η=±0.5%, that is it should be

$$\eta \le \frac{mes[x', x'']}{U_n + 2},$$

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Where $x' = 1$ and $x'' = 1{,}4$ - boundaries of the interval of the desired n; U_{n+2} - Fibonacci number defined by the following ratio $U_{n+2}=U_{n+1}+U_n$; n - number of steps.

If $\eta \le \frac{1.4-1.0}{80} \approx 0{,}5\,\%$, that $U_{n+2} \ge \frac{4}{0.005} = 80.$

We'll find it $U_{n+2} \ge 80$. The table of Fibonacci numbers is written as follows: $U_0=0$, $U_1=1$, $U_2=1$, $U_3=2$, $U_4=3$, $U_5=5$, $U_6=8$, $U_7=13$, $U_8=21$, $U_9=34$, $U_{10}=55$, $U_{11}=89$, that is $U_{12}=89$ and therefore, to determine the value of F with an accuracy of η=±0.5%, it will be necessary to calculate the expression η=11-2=9 times.

The polytropic indices n, at which the values of F were calculated, and the values of the expression F themselves are given in Table I.

Table I

Values of the polytropic exponent n and the expression F

n	1,152	1,163	1,174	1,183	1,192	1,201	1,212
F* 10^4	14859	14690	13958	14504	11197	10905	10256

Thus, the minimum value of the expression F=1.0256 corresponds to n_0 equal to 1.212. This result was obtained by analyzing several series of experimental values of the propagation speed of a hydraulic shock wave in natural and laboratory conditions with an air content of up to 3% by volume at atmospheric pressure. However, the experiments conducted did not aim to study the influence of the air-water flow structure on the values of the propagation velocity of the hydraulic shock wave.

In conclusion, it can be noted that the research results (Table No. 1) show that the value of the polytropic coefficient n is not constant. The average value of the polytropic coefficient obtained in the experiments is n=1.182. In calculations of pressure pipeline systems for hydraulic shock with gas-liquid flow, take n=1.20 with some reserve, which also proves the reliability of the recommendation of D.A. Fox [12].

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