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WATER HAMMER CALCULATION WITH A BREAK IN THE CONTINUITY OF THE FLOW

Aybek Muhamedjanovich Arifjanov,
Doctor of Technical Sciences, National Research University "TIIAME"
https://orcid.org/0000-0003-2599-4892

Alisher Mirzatillaevich Fatkhulloev
Doctor of Technical Sciences, National Research University "TIIAME"
https://orcid.org/0000-0002-9813-1513

Bektemir Ulugmuradovich Jonkobilov
Karshi state technical university
https://orcid.org/0009-0003-7523-897X

Ulugmurad Umbarovich Jonkobilov
Doctor of Technical Sciences, Karshi state technical university
https://orcid.org/0000-0003-0871-0317

Shuhrat Panjievich Xushiev
Karshi state technical university
https://orcid.org/0009-0001-5198-8958

Abstract: This article is devoted to the study of direct hydraulic shock with a decrease in pressure in pressure systems, taking into account the pressure loss along the length of the pressure pipeline.

The article presents an analysis of scientific works devoted to determining the maximum possible pressure of negative direct hydraulic shock affecting the strength characteristics of pressure pipelines, taking into account the energy loss along the length of pressure systems.

The article presents an analytical study on determining the maximum pressure of a hydraulic shock with a decrease in pressure , which provides an accurate assessment of the optimal parameters of pressure pipelines.

The article presents a relationship for calculating the maximum pressure of negative hydraulic shock, taking into account energy loss along the pipeline length. It improves and ensures the reliability of the pressure system and resource conservation in the design of pressure pipelines.

The results of theoretical studies were compared with experimental data from ongoing research. Reliable agreement was achieved between the results of pressure pipeline calculations using the proposed relationship for hydraulic shock with decreasing pressure and the experimental data.

Keywords: hydraulic hammer, hydraulic hammer with rupture of flow continuity, check valve, pressure pipeline, hydraulic hammer with pressure drop , pipeline strength.

Аннотация. Статья посвящена к исследованию прямого гидравлического удара с понижения давления в напорных системах с учетом потери напора по длине напорного трубопровода.

В статье приведены анализ научных работ, посвященных к определению максимального возможного напора отрицательного прямого

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гидравлического удара влияющих на прочностных показателей напорных трубопроводов с учетом потери энергии по длине напорных систем.
В статье приведено аналитическое исследование по определино максимального напора гидравлического удара с понижения давления, который обеспечивает точную оценку оптимальных параметров напорных трубопроводов.

В статье получена зависимость для расчета максимального напора отрицательного гидравлического удара с учетом потери энергии по длине трубопровода, она повышает и обеспесивает надежность напорной системы и ресурсосбережение при проектировании напорных трубопроводов.

Результаты теоретических исследований сопоставлены с опытными данными проводимых исследований. При этом получено надежное совпадение результатов расчетов напорных трубопроводов по предлагаемой зависимости на гидравлический удар с понижения давления с опытными данными.

Ключевые слова: гидравлический удар, гидравлический удар с разрывом сплошности потока, обратный клапан, напорный трубопровод, гидравлический удар с понижения давления, прочность трубопровода.

Annotatsiya. Maqolada bosim quvurlari uzunligi bo'ylab bosim yo'qolishini hisobga olgan holda bosim tizimlarida bosimning pasayishi bilan to'g'ridan-to'g'ri gidravlik zarbani o'rganishga bag'ishlangan.

Maqolada bosim tizimlarining uzunligi bo'ylab energiya yo'qotilishini hisobga olgan holda bosim quvurlarining quvvat ko'rsatkichlariga ta'sir qiluvchi salbiy to'g'ridan-to'g'ri gidravlik zarbaning maksimal mumkin bo'lgan bosimini aniqlashga bag'ishlangan ilmiy ishlarning tahlili keltirilgan.

Maqolada bosim quvurlarining optimal parametrlarini aniq baholashni ta'minlaydigan bosimni pasaytirishdan gidravlik ta'sirning maksimal bosimini aniqlash bo'yicha tahliliy tadqiqotlar keltirilgan.

Maqolada quvur liniyasi uzunligi bo'ylab energiya yo'qotilishini hisobga olgan holda salbiy gidravlik zarbaning maksimal bosimini hisoblash uchun bog'liqlik mavjud bo'lib, u bosim quvurlarini loyihalashda bosim tizimining ishonchliligini va resurslarni tejashni oshiradi va ta'minlaydi.

Nazariy tadqiqotlar natijalari olib borilayotgan tadqiqotlarning eksperimental ma'lumotlari bilan mos keladi. Bunday holda, bosim quvurlari hisob-kitoblari natijalarining bosimni pasaytirishdan gidravlik zarbaga bog'liqligi bo'yicha eksperimental ma'lumotlar bilan ishonchli muvofiqligi olinadi.

Kalit so‘zlar: gidravlik zarba, oqim uzluksizligi bilan gidravlik zarba, nazorat valfi, bosim quvuri, bosimni pasaytiradigan gidravlik zarba, quvur liniyasi kuchi.

Introduction.

When the flow rate of a fluid in a pressure pipeline changes abruptly, the pressure increases or decreases. This phenomenon is called water hammer [1,2,3]. Water hammer poses a threat to the normal operation of any pressure system [1,2,3,4-6].

ISSN 3030-3907

The article is devoted to the study of hydraulic shock in a pumping unit with a decrease in pressure, taking into account the fracture and without the fracture of the pressure pipeline profile. [7,8,9,10].

The article presents an analysis of scientific works devoted to determining the main parameters of hydraulic shock affecting the strength indicators of pressure pipelines under the above conditions.

The article presents analytical and experimental studies to determine the main parameters of hydraulic shock that ensure the normal operation of the pumping unit. [11,12,13,14].

The article presents dependencies for calculating the maximum pressure of a hydraulic shock with a decrease in pressure, taking into account a fracture and without a fracture in the profile of a pressure pipeline; they increase the reliability of the pressure system and ensure resource conservation in the design of pressure pipelines.

Calculating pressure pipelines for hydraulic shock with increasing and decreasing pressure is currently of great importance. More accurate calculations allow for the use of pipes without excessive safety margins and for more appropriate selection of protective equipment [4].

The task of refining existing and developing new methods for calculating hydraulic shock requires conducting new theoretical and experimental studies of the unsteady motion of a real (viscous) liquid.

The aim of the research in this work is a theoretical and experimental study of hydraulic shock in simple water pipelines taking into account friction forces and the development of a method for calculating it that is simple enough for practical application [4-9].

At present, it can be considered that the theory of hydraulic hammer without discontinuity of an ideal flow has been developed sufficiently. We do not yet have a sufficiently developed theory of hydraulic hammer for a real fluid [4]. The latter is explained by certain mathematical difficulties that arise in solving various problems on hydraulic hammer after introducing viscous forces into the initial differential equations of unsteady fluid motion. Such issues as accounting for energy losses during the "recovery" of friction pressure in the impact phase, the attenuation of impact oscillations over time, etc. remain unresolved [4-9].

A hydraulic hammer with a discontinuity of flow is one of the most complex problems in the theory of unsteady flow of a real liquid in pipes [1]. Analysis of studies of hydraulic hammer with a discontinuity of flow by A.F. Mostovsky, D.N. Smirnov, L.F. Moshnina [2,3,11] and a number of other authors shows that there is still no consensus not only on the magnitude, but even on the possibility of increasing the shock pressure above the value determined by N.E. Zhukovsky's formula [1,5].

Research Methodology. The paper uses differential equations for the unsteady motion of a low-viscosity real fluid under a quadratic friction law to address the problem of accounting for energy losses during the "recovery" of friction pressure during the impact phase.

ISSN 3030-3907

The issue of maximum pressure during hydraulic shock with a rupture of flow continuity is considered [4-9] .

To assess the accuracy of the obtained solutions, their results are compared with the data of experiments carried out on pressure pipelines [4-9].

This paper examines the solution to the problem of accounting for frictional pressure losses during a direct hydraulic shock, which is caused by the instantaneous closure of a valve, beginning with a pressure increase. An analysis of existing solutions shows that they are not mathematically sound, and the final results are contradictory.

The initial equations are the hydromechanics equations of a real fluid [4-9]

$$\left.\begin{aligned} -\frac{\partial H}{\partial x} &= \frac{1}{g}\left(\frac{\partial \vartheta}{\partial t}+\frac{\lambda}{2d}\vartheta^2\right) \\ -\frac{\partial H}{\partial x} &= \frac{c^2}{g}\frac{\partial \vartheta}{\partial x} \end{aligned}\right\}, \qquad (1)$$

Where H is the pressure; ϑ is the water velocity; λ is the hydraulic resistance coefficient; g is the acceleration due to gravity; d is the pipeline diameter; c is the shock wave propagation velocity; x is the longitudinal coordinate; t is time.

Equations (1) are integrated under the initial condition

$$0<x\leq l \quad \vartheta = \vartheta_0, H = H_0 \text{ at } t \leq 0$$

and boundary conditions

$$x = 0 \; H = H_0 = \text{const for any } t;$$

$$x = |l - ct| \vartheta = \frac{g}{c} h_m \left(\frac{l-x}{l}\right) \text{ at } 0 \leq t \leq 2\, l/s, \qquad (2)$$

Where : ϑ_0 is the initial velocity of water movement; H_0 is the static pressure; h_t is the pressure loss due to friction along the entire length of the pipeline at the initial velocity of water movement, determined by the Darcy-Weisbach formula.

Boundary condition (2) is obtained from the equality of the live force that determines the speed of water movement during unsteady motion, and the work that is expended on the deformation of the pipeline and water by the pressure difference that occurs during a hydraulic shock in two adjacent sections of the pipeline due to pressure losses due to friction before the shock.

As a result of solving the equation of hydromechanics of a real fluid under the above initial and boundary conditions, it was determined that [4-9]

$$H = H_0 + \frac{c\vartheta_0}{g} - \frac{\alpha^2}{3} h_m, \qquad (3)$$

Where: $\alpha = h_t\, g\, (c\vartheta_0)^{-1}$ – the ratio of pressure losses due to friction under steady-state flow conditions to the magnitude of the pressure increase upon impact according to the formula of N.E. Zhukovsky.

In dependence (3), the last term expresses the energy loss due to friction during the impact phase. From this dependence, it is easy to establish that for values $0 < \alpha \leq 0.5$, with practically acceptable accuracy, the maximum possible pressure during impact can be determined with some reserve using the formula of N.E.Zhukovsky [1]

ISSN 3030-3907

$$H = H_0 + \frac{c\vartheta_0}{g}.$$

Thus, when calculating a direct hydraulic shock, starting with an increase in pressure, when the relative friction losses (α) do not exceed 0.5, the shock pressure can be determined with practically acceptable accuracy using the formula of N.E. Zhukovsky, i.e., energy losses during the "recovery" of friction pressure in the shock phase can be neglected. [4-9].

It should be noted that many water supply system pipelines meet the α≤0.5 condition. Experimental data from various authors and our own (with a discrepancy of up to 5%) confirm the validity of our solution.

The paper also presents the results of a theoretical and experimental study of the maximum possible pressure during a hydraulic shock with a rupture of the flow continuity.

Hydraulic hammer accompanied by flow cavitation should be considered a type of unsteady motion of a two-phase medium (liquid + gas). However, hydraulics currently lacks any closed-loop differential control system describing this fluid flow regime. Therefore, when deriving analytical relationships for calculating hydraulic hammer with flow discontinuity, one must resort to simplifications and schematizations of this complex phenomenon.

When solving the problem, the following conditions were initially adopted [4-9]

$$0 \le x \le l \qquad \vartheta = \vartheta_0 \qquad H = H_0 \text{ at } t \le 0;$$
$$x = l \qquad H = H_0 = \text{const for any } t \ge 0, \qquad (4)$$

where h_{in} is the magnitude of the vacuum in the pipeline during a hydraulic shock in the pressure reduction phase.

The physical meaning of condition (4) is that during a hydraulic shock, the velocity of water flow in the opposite direction, achieved by filling the voids in the rupture zone, at the boundary with this zone can only be equal to or less than the velocity of water flow in the forward direction. This limitation follows from the law of conservation of energy and the physical condition that during a shock, the pressure in the pipeline cannot fall below a certain limit.

Based on N.E. Zhukovsky's general integral, a solution is given to the problem under consideration for the case of pressure wave motion of an elastic ideal fluid. It is assumed that the interface between the discontinuity zone and the continuous flow is a vertical plane , and the transitional cavitation region is absent.

According to this solution, the maximum pressure during a hydraulic shock with a rupture of the flow continuity, measured from the atmospheric pressure, is [4-9]

$$H = H_0 + \frac{c\vartheta_0}{g} + \Delta h, \qquad (5)$$

where, $0 \le \Delta h \le H_0$ – pressure increase due to the elasticity of water and the pipeline in excess of the value determined by the formula of N.E. Zhukovsky [1] .

In real conditions, due to pressure losses due to friction in the pipelines, the impact movement is reduced compared to the value calculated according to (5).

ISSN 3030-3907

Taking into account pressure losses due to friction according to A.F. Mostovsky [3] , the boundary condition (4) is represented as [4-9]

$$x=0 \quad \vartheta \le \left| \vartheta_0 \sqrt{\frac{H_0 + h_в}{H_0 + h_m + h_в}} \right|, \; H \ge h_{in} = \text{const} \quad \text{at } t>0. \qquad (6)$$

Research results. During operation, the hydraulic characteristics of the water pipeline change, and the water supply mode may also change. Since the pressure during hydraulic shock is pulsating in nature and can both increase and decrease with changes in the water velocity, in dependence (5) the value of Δ h is taken as the maximum possible and equal to H_0. In this case, neglecting the energy losses that occur during the restoration of static pressure and with an increase in the return velocity in the pipeline above the value determined by (6), from (5) we obtained [4-9]

$$H = (H_0 - h_в) + \frac{c\vartheta_0}{g} \sqrt{\frac{H_0 + h_в}{H_0 + h_m + h_в}} + (H_0 + h_в) \frac{H_0 + h_в}{H_0 + h_m + h_в}. \qquad (7)$$

Dependence (7) takes into account the elasticity of water, the pipeline and viscous forces and makes it possible to determine the maximum pressure during a hydraulic shock with a break in the continuity of the flow.

The results of calculations according to dependence (7) are compared with the experiments of L.F.Moshnin [2]. The agreement between experimental data and theoretical data has sufficient convergence.

The above-mentioned researchers conducted an experimental study of hydraulic shock with a discontinuity in flow continuity using installations with horizontal pipelines. To study this shock in a sloping pipeline, a pilot installation was mounted. This installation consisted of a steel pipeline with a diameter of 200 mm, a length of 1720 m, and static heads of 21.9 m and 35.2 m, respectively. At a distance of 5.6 m from the pump, the steel pipeline was connected to the steel pipeline via a three-way plug valve, allowing the pump to switch the water supply to one of the two pipelines. The initial section of the steel pipeline, 171 m long, had no pronounced bends and was laid with a steep incline to +22.0 m; the remaining section, without bends, had a relatively slight incline of +11.3 m. The installation was designed to generate hydraulic shock with both decreasing and increasing pressure. Scientific studies were conducted at steady-state water flow rates in a steel pipeline ranging from 0.1 m/s to 2.2 m/s, and in a glass pipeline from 0.1 m/s to 2.6 m/s. Water hammer was created by practically instantaneous (0.02–0.05 sec) closure of the plug valve. Recording of pressure fluctuations during transient processes was carried out using strain gauge pressure sensors [4–9]. During the experiments, discontinuities in the flow in the pipeline were observed visually (in the steel pipeline, through transparent inserts near the plug valve and at the fracture). The methodology for conducting the experiments and processing the experimental data is given in [4–9].

A total of four series of experiments were conducted. Two of them simulated hydraulic shock beginning with an increase in pressure, and the other two simulated a decrease in pressure. Both increasing and decreasing pressure shocks were studied on a steel pipeline.

ISSN 3030-3907

The final length of the pressure pipeline was chosen so that the upper part of the pipeline after the 94 m long break would be almost horizontal.

The experimental data showed that in all series except the last, within a certain range of velocities where a discontinuity in the flow was observed, the shock pressure exceeded the value determined by N.E. Zhukovsky's formula. This range of velocities, depending on the hydraulic characteristics of the pipeline and the height of the water column above the discontinuity, varied between 0.1 m/s and 1.8 m/s. The maximum excess of the shock pressure over the value calculated by N.E. Zhukovsky's formula for pipelines without breaks was equal to the static pressure. For pipelines with a break, this excess was equal to the difference between the break point (the location of the upper discontinuity in the flow) and the water level in the upstream pool. As the water velocity before the impact increased, the shock pressure became less than the value determined by N.E. Zhukovsky's formula due to the action of viscous forces.

Excess of impact pressure over the value according to the solution of A.F. Mostovsky [3] occurs across the entire range of speeds at which the discontinuity of the flow was observed. The maximum value of this excess on pipelines without breaks is equal to the static pressure, while on pipelines with a break, it is equal to the height of the water column above the location of the upper break, i.e., the difference between the break point and the water level in the tank. As the water velocity increases before the impact, under the influence of frictional forces, the increase in impact pressure, arising due to the elasticity of the water and the pipeline (in formula (5), the value Δ h), decreases.

The calculated curves according to dependence (7) quite satisfactorily cover the data from experiments on pipelines without fractures [4-9] .

In experiments on pipelines with a fracture, the pressure resulting from the impact of the settling lower column on the closed plug valve was always less than the pressure determined by N.E. Zhukovsky [1]. The maximum pressure fluctuation was always a consequence of the collision of the upper column with the lower one. Therefore, by analogy with the dependence (7) for pipelines with a bend, we obtained [4-9]

$$H = (H_0 - h_в) + \frac{c\vartheta_0}{g}\sqrt{\frac{h + h_в}{h + h_m^{/} + h_в}} + (h + h_в)\frac{h + h_в}{h + h_m^{/} + h_в}, \qquad (8)$$

where h is the height of the upper column (the difference between the elevations of the breaking point and the water level in the upper pool);

$$h_m^{/} = \frac{\lambda l^{/}}{d}\frac{\vartheta_0^2}{2g}$$

$l^{/}$ - the length of the pipeline from the fracture point to the end of the pipeline.

The calculated curves according to dependence (8) satisfactorily cover the data of experiments on pipelines with a fracture.

The calculated data for dependencies (7) and (8) are in satisfactory agreement with the experimental data of hydraulic shock, beginning with both an increase and a decrease in pressure (Table 1).

ISSN 3030-3907

Since the upper part of the 265-meter-long pipeline after the fracture was practically horizontal, i.e., the height of the water column above the upper fracture was 3.4 m, in the experiments of this series, there was practically no excess of the shock pressure above the value according to A.F. Mostovsky's solution. The experimental points were located according to A.F. Mostovsky's solution, which follows from the theoretical dependence (8) for h → 0.

In some experiments on pipelines with low hydraulic resistance, an interesting finding is the increase in shock oscillation in the subsequent phase of pressure increase compared to the previous one. This can be explained by the pulsating nature of the pressure increase due to the elasticity of the pipeline and water during hydraulic shock with a rupture of the flow continuity. Since the hydraulic resistance is relatively small, the pressure losses due to friction during the shock phase are also small [4].

Table 1

Comparison of calculated data with experiments on hydraulic shock, starting with a decrease in pressure and accompanied by a rupture of the flow continuity

The speed of water movemen, m/sec.	Static pressure	The difference between the elevations of the end of the pipeline and the point of its fracture	Friction pressure losses	Pressure according to N.E. Zhukovsky's formula	Maximum pressure		
					Experienced	by dependency (7)	by dependency (8)
	in meters						
Inclined pipeline without fractures							
0.60	40.6	-	0.9	122.9	159.0	161.8	-
1.00	40.6	-	2.5	178.3	212.0	212.0	-
1.40	40.6	-	4.9	232.9	253.0	260.4	-
1.80	40.6	-	8.1	288.4	306.0	314.1	-
2.20	40.6	-	12.1	343.6	334.0	342.1	-
Inclined pipeline with a bend							
0.20	51.8	11.2	0.3	79.3	90.0	-	90.2
0.90	51.8	11.2	5.4	175.8	173.0	-	174.6
2.10	51.8	11.2	29.4	340.8	264.0	-	260.0
0.50	44.0	3.4	1.0	112.8	114.0	-	114.4
1.20	44.0	3.4	5.5	209.0	200.0	-	197.7

ISSN 3030-3907

2.0	44.0	3.4	15.2	319.4	270.0	-	270.2

The reduction in the reverse water velocity due to friction in the subsequent phase sometimes leads to an increase in pressure gain due to the elasticity of the pipeline and water. This increase not only covers the energy loss due to friction but also increases the impact vibration.

Visual observation and analysis of experimental data made it possible to establish certain provisions that qualitatively characterize the complex process of formation and development of a cavitation cavity in a pipeline during a hydraulic shock.

Thus, during a hydraulic shock with a break in the continuity of the flow both in a horizontal pipeline and in an inclined one without breaks, the highest total pressure can be determined using dependence (7) [4-9].

In an inclined pipeline with a fracture during the rupture of a water column impact at the fracture point, the total pressure from the collision of the upper column of liquid with the lower one, which is at rest, can be determined using dependence (8) [4-9].

The magnitude of the pressure increase that occurs due to the elasticity of the pipeline and water during a hydraulic shock with a rupture of the liquid column, all other things being equal, depends on the geometric and hydraulic parameters of the pipeline [4-9].

Conclusion. Based on the above, the following conclusions can be drawn:

1. As a result of the theoretical solution, boundary condition (2) was obtained, and by solving the differential equations for the unsteady motion of a real low-viscosity fluid under a quadratic friction law, the calculated dependence (3) was obtained. The latter allows for the energy loss caused by additional local water displacements during the "recovery" of friction pressure during the impact phase.

2. By studying the solution (3) and comparing it with experimental data, it was established that when calculating a direct hydraulic shock, beginning with an increase and a decrease in pressure and proceeding without breaking the continuity of the flow, the shock pressure can be determined with practically acceptable accuracy using the formula of N.E.Zhukovsky, when the relative friction losses do not exceed 0.5. Many pressure pipelines of water supply and irrigation systems meet this condition.

3. Based on the energy balance, the following boundary condition is proposed: without taking into account viscous forces (4); with taking into account viscous forces (6). Using the general solution of differential equations of unsteady motion by N.E.Zhukovsky based on conditions (4) and (6) to determine the maximum pressure during a direct hydraulic hammer with a rupture of flow continuity, the following dependencies are obtained: without taking into account viscous forces (5); with taking into account viscous forces in pipelines without bends (7) and in pipelines with a bend (8).

4. As a result of the conducted theoretical and experimental studies, the limits and nature of the change in the magnitude of the pressure increase arising due to the elasticity of the pipeline and liquid during a hydraulic shock with a rupture of

ISSN 3030-3907

the flow continuity were established, depending on the change in the speed of the liquid before the shock, and the geometric and hydraulic parameters of the pipeline.

5. Comparison of the calculated data according to dependencies (7) and (8) and the experimental maximum values of impact pressures shows their good agreement.

6. The obtained calculation dependencies allow for a fairly accurate engineering calculation of the possible impact pressure and, consequently, the correct selection of means of protecting water pipelines from hydraulic shock.

REFERENCES

1. Жуковский Н.Е. О гидравлическом ударе в водопроводных трубах. – М., Гостехиздат, 1949. – 104 с.
2. Мошнин Л.Ф., Тимофеева Е.Т. Указания по защите водоводов от гидравлического удара. – М., Стройиздат, 1961, - 227 с.
3. Мостовский А.Ф. Исследования гидравлического удара в трубах при малых напорах. – Труды МИИТа, М., 1929, вып.11, с.263-304.
4. Арифжонив.А.М, Жонқобилов.У.У., Фатхуллоев.А.М., Жонқобилов С.У., Жонқобилов.Б.У. Суюқликнинг беқарор ҳаракатида напорли қувурнинг гидравлик ҳисобини такомиллаштириш бўйича тавсиялар. Қарши .ҚДТУ. 2025,-32 б.
5. Жонкобилов У.У., Хушиев Ш.П., Жонкобилов Б.У., Рузимурадов З.Ҳ., Баходиров Ш.Б. Насос станцияси напорли қувурларида ва тизимларда сув зарби ва унинг сўндиргичи ҳисоблари (Монография). Кар ИЭИ., Intellekt nashriyot. – К., 2024, 130 с.
6. Jonkobilov S.U., Chuliev M.N., Jonkobilov B.U., Baxodirov Sh.B. Расчет гидравлического удара с учётом разрыва сплошности потока. “Innovatsion texnologiyalar” jurnali maxsus son, Qarshi 2022, 61-67 bet.
7. Jonkobilov U.U., Dusmatov X. A., Jonkobilov S.U., Jonkobilov B.U. Максимальное давление гидравлического удара в напорных трубапроводах. O‘zbekiston Respublikasi Oliy harbiy aviatsiya bilim yurti, Samo qalqonlari ilmiy-axborot jurnali, 3(7) 2023 y. s.80-84.
8. Jonkobilov U., Dusmatov X., Jonkobilov S., Ruzikulov J., Jonkobilov B. Отрицательный гидроудар с разрывом неразрывности потока. O‘zbekiston Respublikasi Oliy harbiy aviatsiya bilim yurti, Samo qalqonlari ilmiy-axborot jurnali, 3(7) 2023 y. s.31-38. (ОАК раёсатининг 30.04.2022 йилдаги қарори 315/1).
9. Jonkobilov U., Rajabov U., Xushiev Sh., Jonkobilov B., Ulugmurodov M. Максимально возможный напор в трубопроводе при прямом гидроударе с повышения давления. O‘zbekiston Respublikasi Oliy harbiy aviatsiya bilim yurti, Samo qalqonlari ilmiy-axborot jurnali, 3(7) 2023 y. s.12-21.
10. Блохин В.И. К вопросу о практических расчетах гидравлического удара в напорных оросительных сетях. Автоматизация закрытых оросительных систем, том XB, выпуск 9, сборник Новочеркасского инженерно – мелиоративного института, 1976. с.29-34.

ISSN 3030-3907

11. Смирнов Д.Н., Зубов Л.Б. Гидравлический удар в напорных водоводах. – М., Стройиздат, 1975. – 125 с.
12. Jonkobilov U.U.About calculation of a hydraulic hitting absorber - –ir-hydraulic cap with diaphragm.//European Sciencce review Scientific journal Austria, Vienna. № 9-10. 2018-P.192-194(05.00.00; № 3).
13. P.F. Boulos, B.W. Karney, D.J. Wood, S. Lingireddy, Hydraulic transient guidelines for protecting water distribution systems, Am. Water Works Assoc. 97 (5) (2005) 111–124.
14. A. Triki, Further investigation on water-hammer control inline strategy in watersupply systems, J. Water Supply Res. Technol. Aqua 67 (1) (2018) 30–43.

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