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MODELING OF TRANSIENT FLUID FLOW IN THE SIMPLE PIPELINE SYSTEM

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ABSTRACT

Temporary hydraulic fluid flow regimes, using the characteristic method, are applied based on the simplified theory of water hammer theory for a simple pipe system. Based on the model as a simple pipeline system, the tank-tube valve, a water hammer program was developed the WH program (water hammer) whose results are compared to current programs from the literature used. Numerical analysis in the transition process of the selected model is made by changing the spatial and temporal steps of integration, such as the time change of the pipe in the system and the closing time of the valve, respectively depending on the time for the shut-off valve: a number of hydraulic shocks - water hammer are analyzed. The frontal movement of the fluid pressure was also analyzed, depending on the speed of interruption, pressure and time. The obtained results are presented in tabular form and in diagrams.

Keywords: closing times, simple pipeline, unsteady fluid flow, velocity, water hammer.

1. INTRODUCTION

During the hydraulic shock (water hammer) in the metal pipe, the velocity *c*of the pressure disturbance is usually three times greater than the velocity *v* of the flow, which, therefore, may be ignored in the characteristic equations, then [1], [2], [3]:

$$\frac{dx}{dt} = c \ , \ \frac{dx}{dt} = -c \tag{1}$$

In the simplified analysis, fluid viscosity is neglected, which means that in the equation:

$$\pm \frac{g}{c}\frac{dh}{dt} + \frac{dv}{dt} + \frac{\lambda v|dv|}{2d} = 0 \tag{2}$$

The last member is cancelled, i.e. $\lambda v|dv|/2d = 0$. Considering the reductions mentioned, below, we will analyze the simple pipeline system shown in Figure-1 [4], [5], [6].

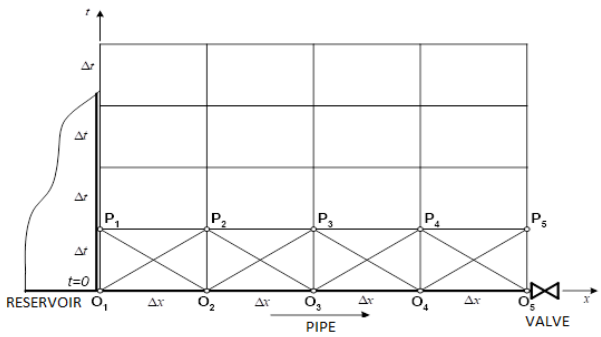

Figure-1. Diagram x-t for the basic version of the simple pipeline.

Up to the moment *t=0*, non-viscous fluid, stationary, swings with velocity v_0 through the horizontal pipeline with constant diameter d and length *lin m*, from the large reservoir with constant piezometric head *h in m*, to the valve mounted at the end of the pipeline [7].

In the analysis of the changes of velocity and the piezometric head, which are constant during the stationary flow, the overall L length of the pipeline divide into n equals pieces, with *Δx=L/n*, and, by equation (2), we also choose the time step of Integration, *Δt=Δx/c*. The positional diagram for the given situation is shown in Figure-2 (1. Reservoir, 2.Pipeline, 3.Valve) [8], [9], [10].

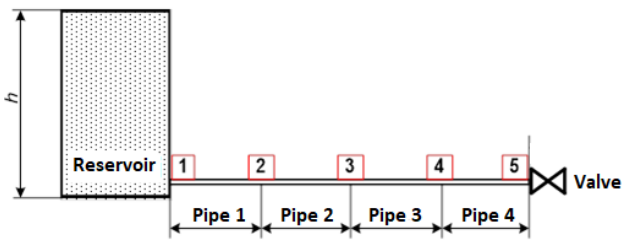

Figure-2. Modeled grids of the simple pipeline.

The equations (1) and (2) will become [1], [2], [5]:

$$\left.\begin{aligned} dh + \frac{c}{g}dv = 0 \\ \frac{dx}{dt} = c \end{aligned}\right\} \quad C^{+} \tag{3}$$

And

$$\left.\begin{aligned} dh - \frac{c}{g}dv = 0 \\ \frac{dx}{dt} = -c \end{aligned}\right\} \quad C^{-} \tag{4}$$

From the equation (4) follows Allievi's expression, this determines the change of pressure versus the velocity in the valve [5]:

$$\Delta h = -\frac{c}{g}\Delta v \quad or \quad \Delta p = -\rho c \Delta v \tag{5}$$

The exact solution of the equation system (3) and (4) for the described situation is shown in Figure-1, in which for the front point of the valve appears the time difference of pressure in function of the various valve closure times. For this case, the linear change of the closing speed of the valve is assumed.

With the letter, p_0 we have marked the pressure on the steady flow regime with speed v_0; while with a full line we have shown the change of pressure during the sudden closing of the valve. At the moment $t=0$, the valve closes suddenly, while the speed $v_0$drops to zero, where the pressure increase occurs according to the expression (5). At the point where the fluid hits the closed valve, from which he, with speedv_0 and pressure p_0, still flows to the valve, pressure disorder from the left occurs.

Right to the front of the disorder, the fluid stays quiet when the pressure is increased toop_0+Δp. The front, with velocity c, moves to the reservoir. When it arrives there, it will remain quiet all over the pipeline, but with a greater piezometric head than the fluid in the tank. Under these conditions, the flow occurs in the opposite direction, i.e., from the pipeline to the reservoir.

Lack of friction, It makes the speed to be equated withv_0. At this moment, the disorder front is again occurring from the left, but with pressure p_0 (the difference of piezometric head converted to kinetic energy of the opposite stream), when the fluid is still under increased pressure from its right [5].

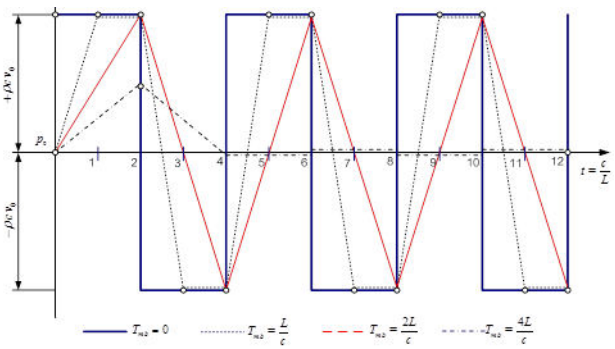

Figure-3. Time shifting of the pressure in front of the valve depending on the closing time T_{mb}.

From Figure-3, substantial conclusion can be drawn about the valve closing speed. During the period for which the closing time T_m is less than $2L/c$, the maximum increase or decrease of the pressure will occur in front of the valve, while after the closing time is increased the size of maximum or minimum pressure will be reduced according to the expression [3], [5]:

$$\left.\begin{aligned} T_{mb} \le \frac{2L}{c} \quad \Delta p = \Delta p_{\max} = \rho c v_0 \\ T_{mb} > \frac{2L}{c} \quad \Delta p = \Delta p_{\max} \cdot \frac{2L}{cT_{mb}} = \frac{2\rho v_0 L}{T_{mb}} \end{aligned}\right\} \tag{6}$$

Similar analysis can also be used for pressure change curves for other timing closure models.

2. ANALYSIS WITH NUMEROUS METHOD FOR TRANSIENT FLUID FLOW IN THE SIMPLIFIED PIPELINE SYSTEM

Testing the Program for the Analysis of Non-Stationary Occurrences in the Simple Pipeline System

The Simple Pipeline System (Figure-2) will serve to test the GH program of analysis of stationary working regimes in the nets [10], [11], [12].

Data on the above system are:

- The height of the water pressure in the tank, $h = 100$ m
- The length of the pipe, $l = 12000$ m
- Number of pipes in the system, $n = 4$
- Pipe diameter, $D = 900m$ m
- Speed of sound, $c = 1200$ m/s
- Coefficient of friction resistance, $\lambda = 0.022$.

The closing of the valve will be simulated for these cases:

- With the product $C_v A_v$ (local loss coefficient in valves with open valve surface) at any time of integration (Figure-4), when the valve is fully closed,
- With the suddenly closing and an opening of the valve($T_m=0$) for some characteristic cases (Figure-5). These cases will be defined in the following analysis carried out.

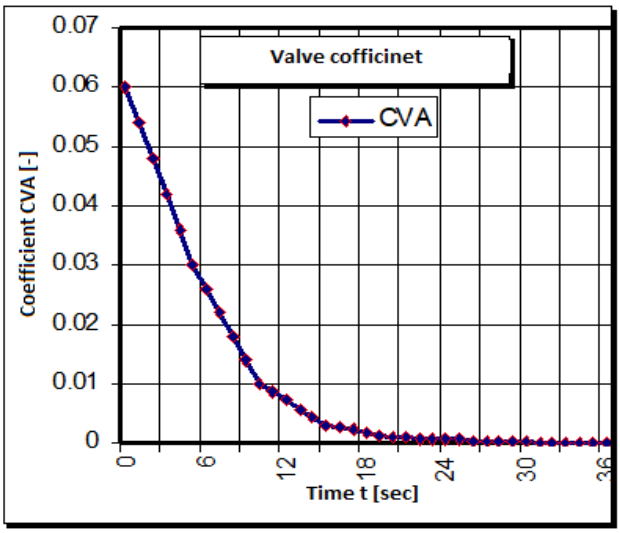

Figure-4. Linear valve closure.

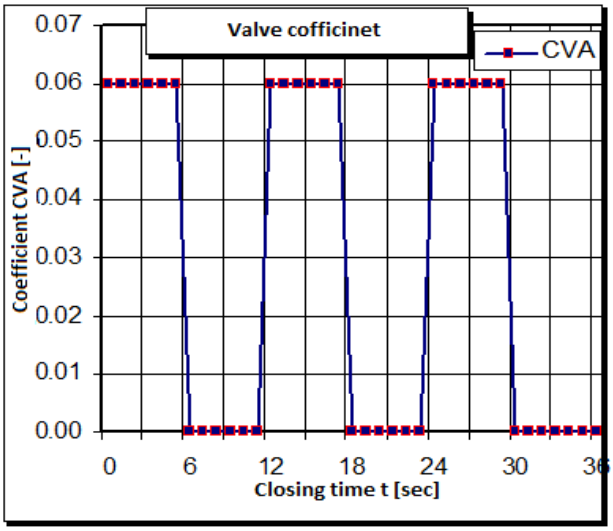

Figure-5. Suddenly closing of the valve.

Assuming non-viscous fluid (λ=0), the integration time is accepted 36 s.

For transient fluid flow regimes, using the method of characteristics, and the Hardy Cross program in FORTRAN, the WH program (WH - water hammer program) was developed [6], [13]. Testing the WH program for the analysis of stationary working regimes in stationary state maintenance is carried out with fully open valves throughout the entire integration time. This means that, in the input file, for all integration time steps, the product $C_v A_v$ is the same as that of the moment *t=0 sec*; thus, the start time of the valve closure is greater than the integration times T_{in}> 36 sec, as shown in Table-1, [14], [15].

Table-1. Simulation results according to the WH Program - transient state of calculation.

Piezometric head h (m) **in the node**						
T [s]	**CVA[-]**	**h_1**	**h_2**	**h_3**	**h_4**	**h_5**
0	0.06	100	99.53	99.06	98.58	98.11
6	0.026	100	115.3	130.7	140.1	146.7
12	0.072	100	110	118.9	121.5	125.9
18	0.018	100	91.68	79.02	72.21	66.94
24	0.0006	100	111.7	120.2	123.8	128.8
30	0.0002	100	96.67	93.16	93.9	94.64
36	0	100	91.59	86.05	86.76	86.24

Fluid flow in the node V (m^3/s)						
T [s]	**CVA[-]**	**V_1**	**V_2**	**V_3**	**V_4**	**V_5**
0	0.06	2.63	2.63	2.63	2.63	2.6
6	0.026	1.89	1.87	1.82	1.57	1.4
12	0.072	-0.6	-0.4	-0.3	0	0.4
18	0.018	0.2	0.22	0.23	0.15	0.1
24	0.0006	0.39	0.37	0.39	0.25	0
30	0.0002	-0.9	-0.7	-0.5	-0.2	0
36	0	0.71	0.59	0.5	0.29	0

Changing spatial and temporal steps during integration

The impact of the spatial and temporal integration steps on the accuracy of the HC program will be tested in these directions:

- The pipe location in the grid system of piping, and
- The closing time of the valve.

The impact of the pipe location in the grid system of pipeline

We have shown the impact of the pipe location in the row in the pipeline system in Figure-6(a), which shows that the Node 1 (the outlet node from the reservoir) has constant rates of pressure and flow fluid during all the time.

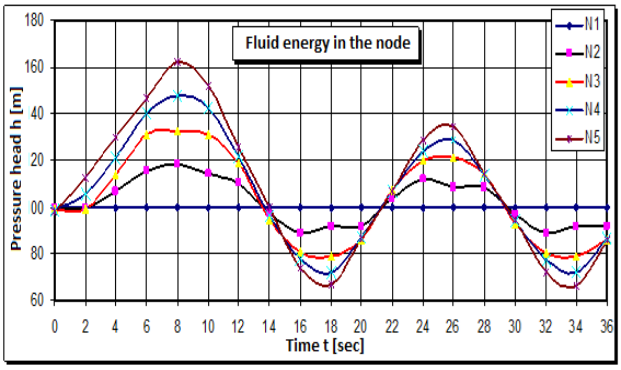

Figure-6(a). Influence of the fluid energy in the pipeline.

The most critical element is the one at the bottom of the pipeline, that is, the one connected to the valve in that position, which in our case belongs to the number 5, namely, its end or the entrance to the valve.

From these figures, Figure-6.a and Figure-6.b, it is concluded that in element 5, the maximum pressure is reached after eight seconds from the closing of the valve. Further, we have the beginning of the amortization of hydraulic shock. For its part, the striking return wave will be more active after about 14 and 30 seconds. These results prove that, with increased distance from the power source, the hydraulic shock is more likely.

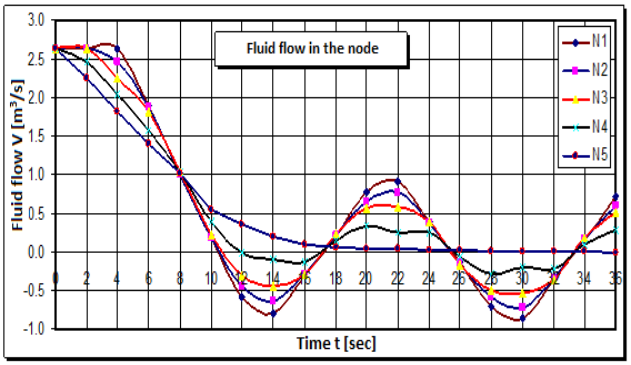

Figure-6(b). Influence of the fluid flow in the pipeline.

Valve closing time

The influence of the closing time of the valve will be checked in the system according to Figure-2 with different closing times: t = 6 s; t = 12 s; t = 18 s and t = 24 s, assuming linear and instantaneous change of speeds. The simulation calculation results, according to the current valve closing model presented in Figure-5, are shown for the closing time: t = 12 s and t = 24 s, in figures 7.a to 8.b.

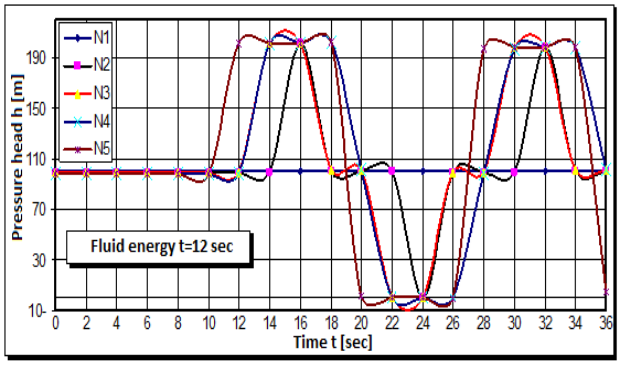

Figure-7(a). The pressure head in the node, depending on the closing valve time, after t = 12 s.

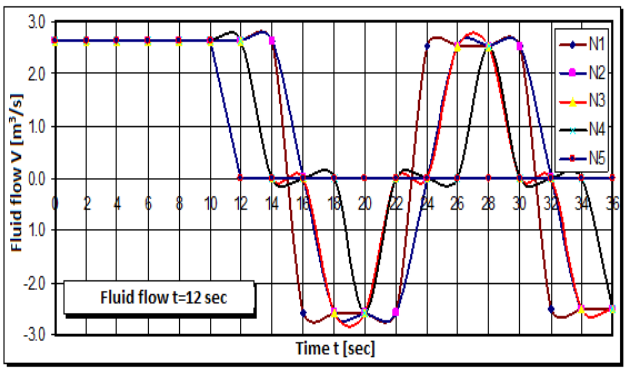

Figure-7(b). The fluid flow in the node, depending on the closing valve time, after t = 12 s.

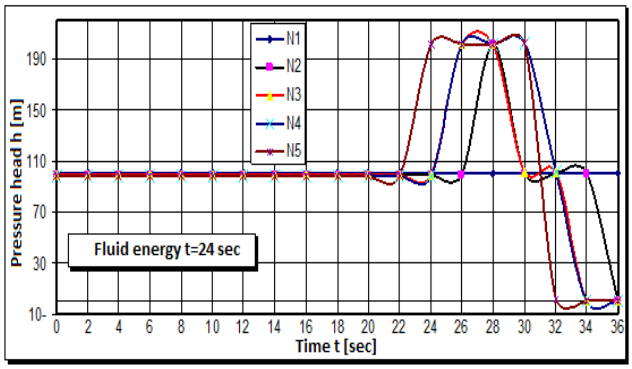

Figure-8(a). The pressure head in the node, depending on the closing valve time, after t = 24 s.

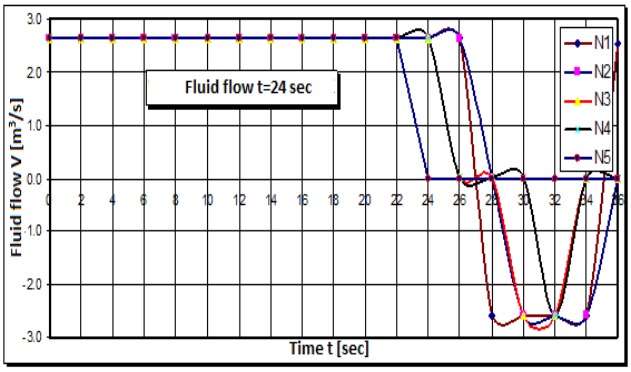

Figure-8(b). The fluid flow in the node, depending on the closing valve time, after t = 24 s.

We can see that after the valve's suddenly closing, the hydraulic shock wave, is distributed according to the "sawmill" model, where the most striking point is the valve itself, and that is why the choice of its type should be taken care off.

Also, the hydraulic shock wave is distributed according to the "saw" model, where the most striking point is the valve itself. The opening-closing time is simulated with different closing times: t=6 s; t=12 s; t=18 s; t=24 s and t=36 s, while the results are presented only for t=6 s and t=18 s.

Even the sudden closing and opening of the valve in synchronized mode is shown in the following figures, Figure-10(a) to Figure-11(b).

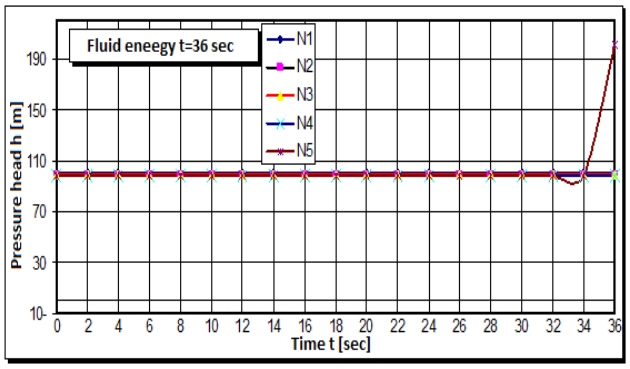

Figure-9(a). The pressure head in the node, depending on the closing valve time, after t = 36 s.

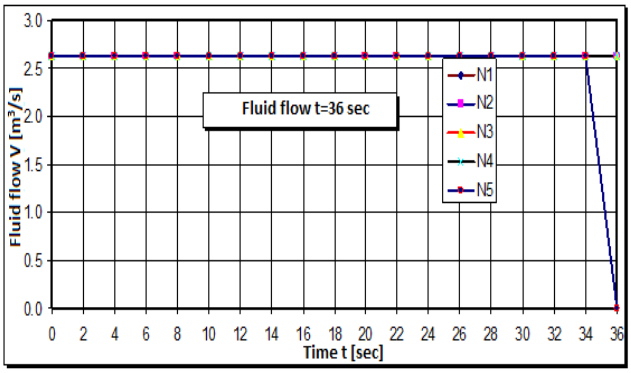

Figure-9(b). The fluid flow in the node, depending on the closing valve time, after t = 36 s.

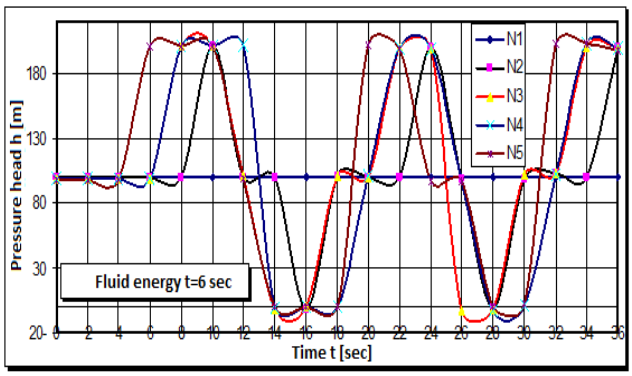

Figure-10(a). The pressure head in the node, depending on the closing and opening valve time, each t = 6 s.

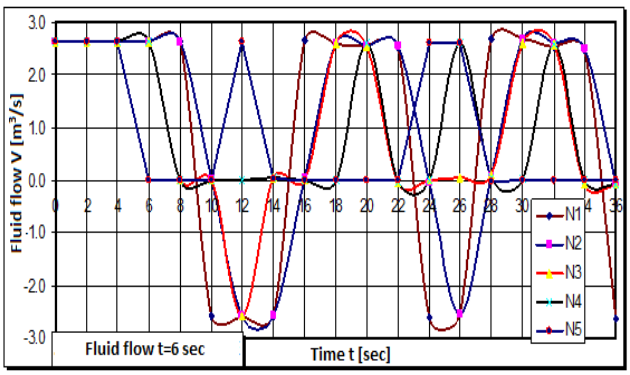

Figure-10(b). The fluid flow in the node, depending on the closing and opening valve time, each t = 6 s.

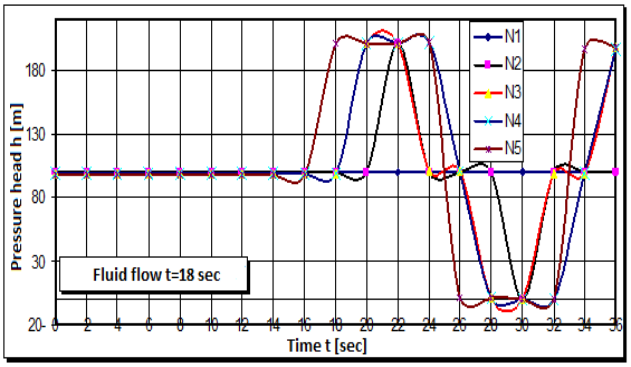

Figure-11(a). The pressure head in the node, depending on the closing and opening valve time, each t = 18 s.

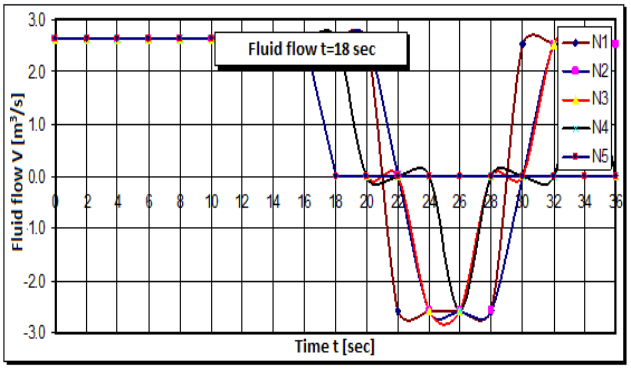

Figure-11(b). The fluid flow in the node, depending on the closing and opening valve time, each t = 18 s.

3. RESULTS AND DISCUSSIONS

For the transient fluid flow, according to the method of characteristics, in the FORTRAN language, the WH (water hammer) program was developed based on the Hardy - Cross program HC, for stable fluid flows. It consists of main and sub-programs for reading the values of the pipeline geometry (diameter and length) and the parameters of the initial state (stationary) of the fluid flow. The main program, for editing the hydraulic calculation results of hydrodynamic, calls the exit sub-program. The accuracy and regularity of the programs, HC and WH, is tested with the examples taken from the literature [1], [2]. We have applied the method of characteristics, namely the program transient fluid flows, for the simple pipeline system, reservoir-pipeline-valve. For this, depending on the changing time of the closing valve, some cases of hydraulic shocks have been analyzed. Movement of fluid pressure front, depending on the speed of deregulation, pressure and time, is presented in Figure-4.

The analysis of the results for non-stationary fluid flows (Table-1), has been done while changing, during integration, spatial and temporal steps. The impact of these changes, e.g. the location of the pipe in the system, the stability of the numerical method, the viscosity, the closing time of the valve, the energy and flow of the fluid, are provided in Figures 6(a) and 6(b), which show that the last element has the highest hydraulic shocks and largest flow oscillations. Specific importance was given on the impact of the closing time of the valve during hydraulic shocks. The used time for the closing valve simulation was t = 6 s; t = 12 s; t = 24 s and t = 36 s. The results of the calculations are presented in figures 7.a to 11.b. These figures reflect the symmetry between obtained and theoretical results, outlined in Figure-3. We can see from them that disturbances begin to emerge from the moment that valve closure begins. For all cases, the strongest shocks and their durations happen in the last node of the pipeline.

4. CONCLUSIONS

The construction of reliable and efficient piping systems represents a large investment cost due to the number of protective elements to be installed to keep the system safe from non-stationary phenomena. The terms for one-dimensional fluid flow, with the introduction of assumptions and simplifications, are quite complex, therefore computer programs are used to calculate fluid flow parameters. Computer programs for the simulation of stationary and non-stationary fluid flow have made great progress in the construction and protection of piping systems precisely due to the possibility of calculating impact parameters due to non-stationary phenomena. By installing the pressure vessel into the system, the desired effect of hydraulic shock reduction has been achieved, but it is necessary to pay attention to the correct dimensioning of the hydraulic shock.

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