International Journal of Innovative Technology and Interdisciplinary Sciences
www.IJITIS.org
ISSN:2613-7305
Volume 3, Issue 3, pp. 457-466, 2020
DOI: https://doi.org/10.15157/IJITIS.2020.3.3.457-466
Received July 10, 2020; Accepted August 31, 2020

Hydraulic Modeling of Operating Modes in the Mihaliq Main Pipe-Water Treatment Plant

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ABSTRACT

Hydraulic water hammer has been a serious problem in hydraulic drinking water treatment systems. This potentially can cause additional stresses and strain on pipes, joints and other equipment. In closed hydraulic systems, the phenomenon of water hammer usually occurs in cases when it passes from a steady state to an unstable state. In these cases, the kinetic energy of the fluid mass was immediately converted to pressure energy. The name hydraulic water hammer comes from the sound emitted by the phenomenon, the hammer-knock sound that sometimes occurs during this phenomenon. The phenomenon of water hammer is an important element that must be considered when constructing many hydraulic structures due to the extreme changes in pressure it causes. Based on it, our research work will be focused on the hydraulic modeling of operating modes in the Mihallaq main pipe-water treatment plant.

Keywords: Water distribution systems; Regional Water Company "PRISHTINA"; water hammer; hydraulic water hammer software WHAMO.

1. INTRODUCTION

Water distribution systems are vital in supplying communities with their water demand include pipes, pumps, valves and reservoirs and are designed to deliver water at adequate discharge and pressures according to demands and with quality for human use [1]. Hydraulic modelling provides an effective tool in this regard where the hydraulic calibration can be defined as the process of comparing a model results to field observations. The hydraulic water hammer simulation in this scenario was executed by using the hydraulic water hammer software (WHAMO). Simulations provide information on fluid parameters in stationary and non-stationary situations such as static and dynamic pressure, fluid velocity and flow [2].

In closed hydraulic systems, as is our case, the phenomenon of hydraulic shock usually occurs in cases when it passes from a steady state to an unstable state. In these cases, the kinetic energy of the fluid mass is immediately converted to pressure energy. The phenomenon of water hammer is an important element that must be considered when constructing many hydraulic structures due to the extreme changes in pressure it causes. Based on it, in most of the cases, the dramatic increase in pressure can cause a rupture of the pipes. Accompanying the high-pressure wave, there is a negative wave, which is often overlooked, but the same can cause very low pressures leading to the possibility of contaminants interfering with the fluid if there are cracks or even damage to the pipes.

The noise caused by the water hammer can also be a concern. To model the phenomenon of water hammer in pipes it is required to solve a set of equations of moment and continuity that are given in this scientific paper. The equations of moment and continuity form a series of nonlinear, hyperbolic differential equations, which cannot be solved manually. The mathematical model has many more parameters needed to solve the water hammer problem. The complexity of the problem requires the use of modeling software. Like any fluid dynamics problem here, the solution will be given numerically through numerical models [3]. During transient processes, the pumps may operate in an unusual and abnormal manner. Furthermore through this paper we have aimed to treat numerically the behavior of pumps of these systems during the phenomenon of hydraulic shock.

2. Experimental study

The Regional Water Company "PRISHTINA" assumes a population growth for the service area from 554.000 inhabitants up to 938.000 in 2040. The total water demand increases from currently 49 Mio m^3 to 66 Mio m^3 in 2040, Figure 1.

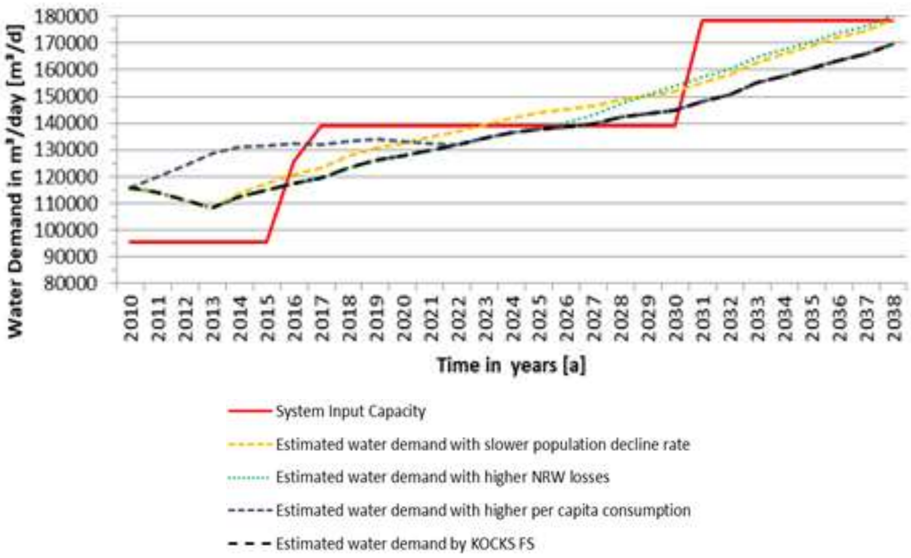

Figure 1: Comparison of Water Demands

In order to fulfil this water demand, it was necessary to build New Water Treatment Plant "SHKABAJ" which will enable water supply beyond 2030 for capital of Kosovo, Prishtina.

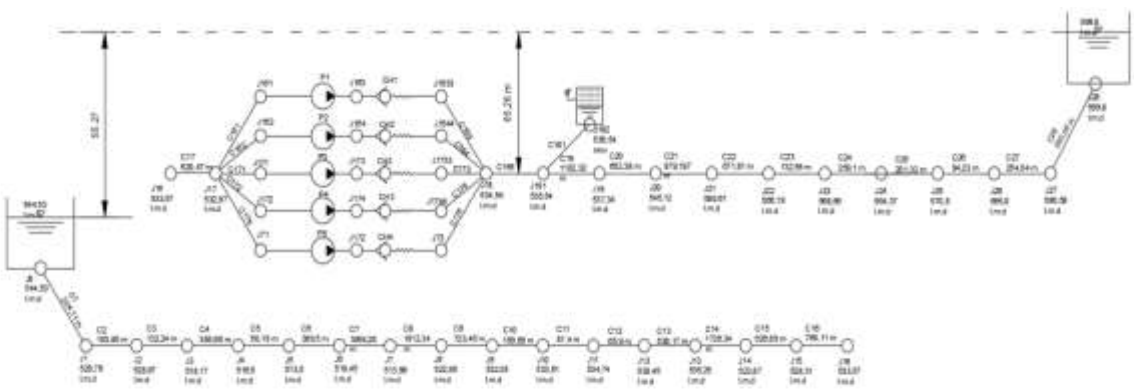

Figure 2. Diagram system for water supply

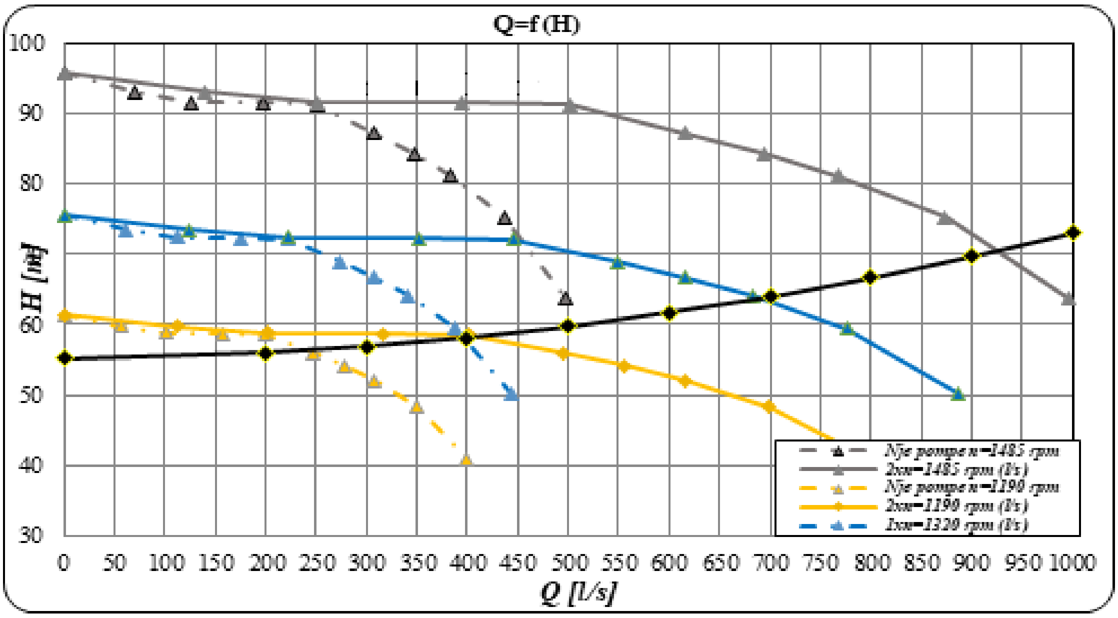

Figure 3. Characteristics of pumps when working alone and in parallel in relation to the number of rotations, rpm

2.1 Operation system with two pumps and an expansion vessel

This section has been focused on the operation system with two pumps and an expansion vessel. Based on it, pump works with n = 1190 rpm and the tube system has expansion vessel. Furthermore, we have a water intake first in the village of Mihaliq then with the 1200mm pipe. The water comes to the pumping station in Milloshevë, then from here the pumps transport the water in a pipe DN1200 mm, about Q = 500 l / s to the aerator in the water treatment plant SHKABAJ for human consumption. In scenario 3, the pumps work in stationary mode for 5s then the system intervention occurs where the pumps stop and we see the following results. We will monitor and follow this whole process with the Software for water hammer and oscillations inside the pipe -WHAMO, for the main pipe DN 1200 with a length of approximately 14 km. The input parameters and other data for the first simulation are summarized below in Tables 1-3 [4].

Table 1: Input parameters of the first simulation

Geodetic height $H\ (m)$	Pump supply $Q\ (l/s)$	Velocity $v(m/s)$	Losses in friction (m)	No. Of the pumps (rpm)	Diameters of pipes (mm)	Stopping of pumps $t\ (s)$	Pumps
84.00	500	1.219	0.028	1190	1200	5	WILO

Table 2. Data for nodes in the main pipe
SIMULATION OUTPUT
TIME HISTORIES FOR RUN OF 10/23/19 AT 22:17:51
TITLED: **STACIONI I POMPAVE – PRISHTINE**

TIME (SEC.)	**NODE HEAD** ***(bar)***	**NODE NO 1 DISCHARGE** ***(l/s)***	**NODE NO 1 ENERGY ELEV.** ***(m)***	**NODE NO 5 PRES. HEAD** ***(bar)***	**NODE NO 5 DISCHARGE** ***(l/s)***	**NODE NO 5 ENERGY ELEV. (m)**	**NODE NO 17 PRES. HEAD (bar)**	**NODE NO 17 DISCHARGE** ***(l/s)***	**NODE NO 17 ENERGY ELEV.** ***(m)***	**NODE NO 181 PRES. HEAD (bar)**	**NODE NO 181 DISCHARGE** ***(l/s)***	**NODE NO 181 ENERGY ELEV.** ***(m)***	**NODE NO 28 PIEZ. ELEV.** ***(bar)***	**NODE NO 28 DISCHARGE** ***(l/s)***	**NODE NO 28 ENERGY ELEV.** ***(m)***
0	1.54	444.57	544.49	3.02	444.57	544.31	0.98	444.57	502.86	6.47	444.57	600.52	1.30	444.57	599.79
5	1.54	444.57	544.49	3.02	444.57	544.31	0.98	444.57	543.03	6.47	444.57	600.52	1.30	444.57	599.79
10	1.54	444.57	544.53	3.07	441.74	544.77	5.87	0.00	592.87	6.41	0.00	599.94	1.30	436.08	599.79
15	1.65	-382.28	545.65	3.66	-365.29	550.87	5.93	0.00	593.45	6.35	0.00	599.27	1.30	430.42	599.79
20	1.55	-433.25	544.56	3.06	-433.25	544.74	-0.34	-2.83	529.53	6.29	0.00	598.63	1.30	413.43	599.79
25	1.28	-322.81	541.78	1.53	-269.01	529.10	-3.49	0.00	497.34	6.22	0.00	597.99	1.30	382.28	599.79
30	1.51	413.43	544.19	2.84	404.93	542.45	-3.48	0.00	497.49	6.17	0.00	597.41	1.30	351.13	599.79
35	1.54	421.92	544.49	3.03	421.92	544.43	4.58	0.00	579.64	6.12	0.00	596.89	1.30	317.15	599.79
40	1.95	5.66	548.73	5.14	5.66	565.95	5.66	0.00	590.64	6.07	0.00	596.43	1.30	269.01	599.79
45	1.55	-410.59	544.62	3.10	-407.76	545.07	4.64	0.00	580.28	6.03	0.00	596.04	1.30	223.70	599.79
50	1.52	-399.27	544.25	2.87	-390.77	542.73	-2.95	0.00	502.86	6.00	0.00	595.73	1.30	175.56	599.79
55	1.30	232.20	542.06	1.73	203.88	531.11	-3.28	0.00	499.48	5.98	0.00	595.52	1.30	118.93	599.79
60	1.54	402.10	544.49	3.02	399.27	544.31	0.18	0.00	534.83	5.96	0.00	595.37	1.30	65.13	599.79
65	1.68	317.15	545.96	3.83	294.50	552.60	5.36	0.00	587.56	5.96	0.00	595.30	1.30	11.33	599.79
70	1.64	-334.14	545.56	3.63	-317.15	550.47	5.33	0.00	587.32	5.96	0.00	595.27	1.30	-16.99	599.79
75	1.54	-390.77	544.53	3.04	-390.77	544.46	-0.42	0.00	528.71	5.95	0.00	595.24	1.30	22.65	599.79
80	1.29	-135.92	541.93	1.68	-124.59	530.63	-3.05	0.00	501.82	5.95	0.00	595.27	1.30	-25.49	599.79
85	1.51	365.29	544.16	2.83	359.62	542.33	-2.32	0.00	509.32	5.96	0.00	595.27	1.30	22.65	599.79
90	1.57	370.95	544.77	3.19	365.29	546.02	4.16	0.00	575.37	5.95	0.00	595.24	1.30	-19.82	599.79
95	1.80	-70.79	547.12	4.39	-62.30	558.24	5.23	0.00	586.34	5.95	0.00	595.27	1.30	14.16	599.79
100	1.55	-370.95	544.65	3.11	-368.12	545.26	3.03	0.00	563.88	5.95	0.00	595.27	1.30	-11.33	599.79
105	1.46	-311.49	543.64	2.55	-300.16	539.53	-2.51	0.00	507.37	5.95	0.00	595.24	1.30	5.66	599.79
110	1.37	220.87	542.82	2.13	206.71	535.26	-2.77	0.00	504.69	5.95	0.00	595.27	1.30	0.00	599.79
115	1.54	365.29	544.53	3.04	362.46	544.49	1.21	0.00	545.32	5.95	0.00	595.27	1.30	-5.66	599.79
120	1.71	198.22	546.23	3.95	184.06	553.79	4.96	0.00	583.51	5.95	0.00	595.24	1.30	11.33	599.79
125	1.63	-300.16	545.38	3.52	-291.66	549.34	4.53	0.00	579.12	5.95	0.00	595.27	1.30	-14.16	599.79
2995	1.54	2.83	544.49	3.03	2.83	544.37	1.06	0.00	543.76	5.95	0.00	595.27	1.30	0.00	599.79

Table 3: Maximum, minimum static pressure and maximum, minimum pump flows.

NR.	Chainage (m)	MAXIMUM ENERGY ELEV. (m)	TIME (s)	MINIMUM ENERGY ELEV. (m)	TIME (s)	MAXIMUM DISCHARGE (l/s)	TIME (s)	MINIMUM DISCHARGE (l/s)	TIME (s)
0	0	544.53	0	544.53	0	444.57	0	-433.25	17
1	203.5	551.93	12.4	539.37	26.2	444.57	0	-433.25	21.4
2	367.35	557.63	12.4	535.32	26.2	444.57	0	-433.25	21.4
3	499.17	561.87	12.4	532.15	26.2	444.57	0	-433.25	21.2
4	1054.83	575.37	12.4	520.26	26.2	444.57	0	-433.25	21
5	1114.93	576.41	12.4	519.17	26.2	444.57	0	-433.25	20.8
6	1504.4	581.77	12.6	512.95	26.2	444.57	0	-433.25	18.4
7	1582.57	582.66	12.6	511.88	26.2	444.57	0	-433.25	18.4
8	2651.79	590.18	13	502.46	26.4	444.57	0	-433.25	19.4
9	3664.09	592.93	13.4	498.65	26.6	444.57	0	-433.25	20
10	4387.55	593.23	13.2	497.59	26.8	444.57	0	-430.42	20
11	4577.23	593.23	13.2	497.43	26.8	444.57	0	-427.58	20
12	4634.47	593.23	13.6	497.40	26.8	444.57	0	-427.58	20
13	4700.19	593.23	13.6	497.37	26.8	444.57	0	-424.75	20
14	5238.22	593.29	14	497.19	26.8	444.57	0	-413.43	19.8
15	6964.55	593.42	15.2	497.04	28	444.57	0	-297.33	19.4
16	7591.42	593.48	15.8	497.01	28.4	444.57	0	-189.72	19.4
17	8359.53	593.54	16.2	496.95	28.8	444.57	0	-2.83	19.4
18	8980	600.52	0.6	595.21	67.4	223.70	0	0.00	9.4
181	9531.16	600.52	0.6	595.21	67.4	444.57	0	0.00	9.4
182	9531.16	600.52	0.6	595.24	67.4	8.50	0	-441.74	9.4
19	10082.32	600.40	12	594.45	67.8	444.57	0	0.00	66
191	10408.48	602.89	71.6	596.28	66	444.57	0	0.00	66
20	10734.65	602.62	71.4	596.89	66.2	444.57	0	-5.66	69.6
21	11613.12	601.80	71.8	597.74	66.6	444.57	0	-14.16	69.2
22	12284.78	601.10	72	598.47	66.8	444.57	0	-22.65	69
23	12417.31	600.97	72	598.63	66.8	444.57	0	-22.65	69
24	12676.37	600.67	72.2	598.90	59.6	444.57	0	-25.49	68.6
25	12877.59	600.46	72.2	599.11	59.6	444.57	0	-25.49	68.6
26	12971.74	600.36	72.2	599.21	8.6	444.57	0	-28.32	68.6
27	13225.01	600.12	9.8	599.48	8.8	444.57	0	-28.32	68.8
28	13465.05	599.79	0	599.79	0	444.57	0	-28.32	68.8

The Figure 4 and 5 depicts comparison of water pressure at the joints in the main pipe and several nodes, with expansion vessel for number of rotations n = 1190 rpm

Water pressure at the nodes p (bar)

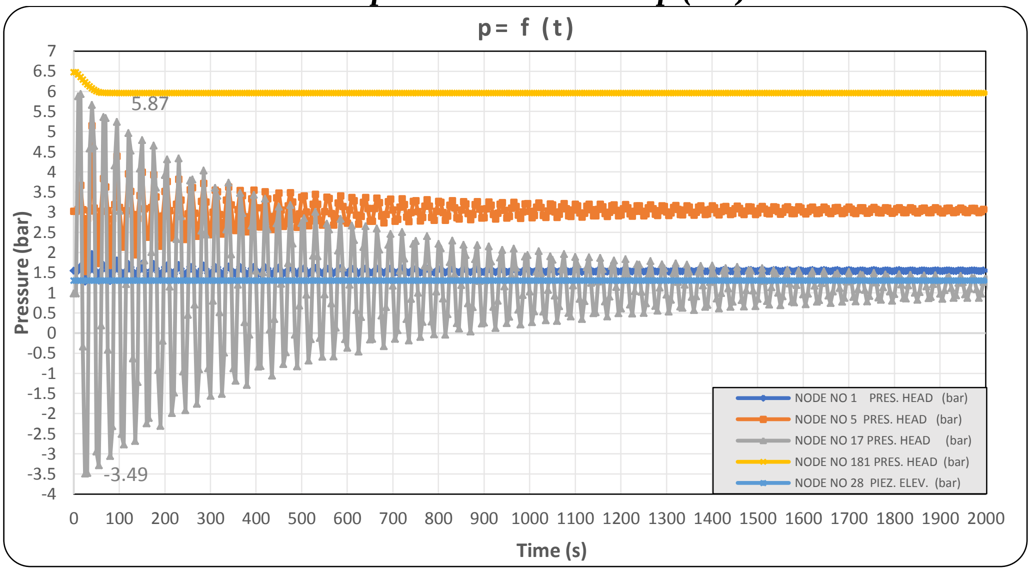

Figure 4. Comparison of water pressure at the joints in the main pipe, with expansion vessel with number of rotations n = 1190 rpm.

Figure 4 depict the inlet pressure of the pump station which is 0.98 bar and the outlet of the pump station at 6.47 bar, while the pump flow is 444.57 l / s. The pump operates with a number of rotations of 1190 rpm where the electric motor power of the pump were 181.88 kW. Pressure in node no. 17 is pressure that has large differences in pressure and counter pressure and this can be dangerous for the system. The pressure in this node after 10 s is 5.87 bar and drops after only 15s to -3.49 bar. Then the pressure drops approximately 0.21 bar every 15 seconds, thus continuing to decrease and increase the pressure even after 2000 s (33 min).

Water flows at the nodes Q (l/s).

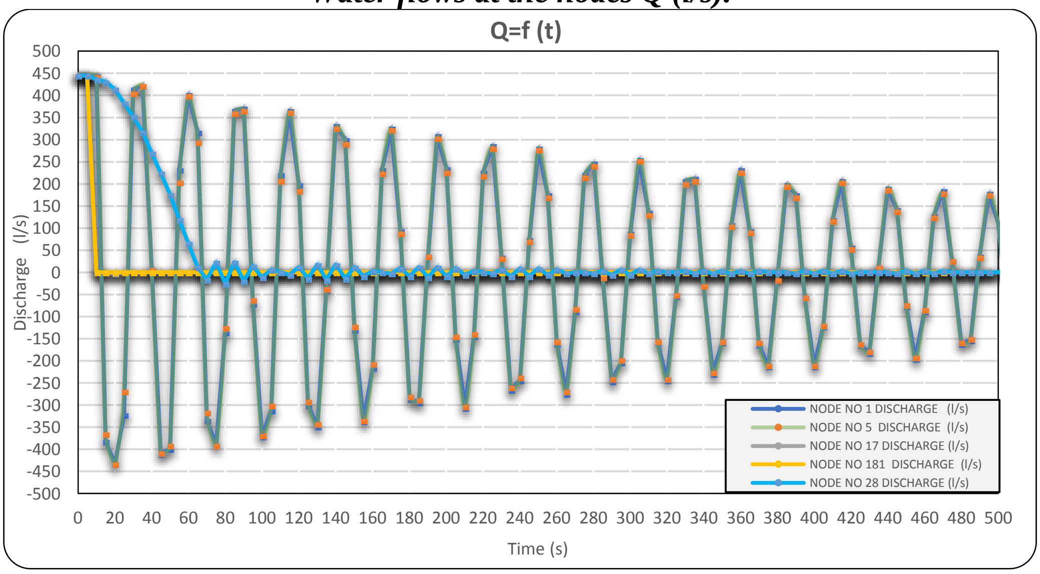

Figure 5. Comparison of flows at several nodes in the main pipe, by number of pump rotations n = 1190 rpm with expansion vessel.

In the Figure 5, flow drops uncontrollably at node 5 and that from 444.57 l/s in second 5 to -433.25 l/s in second 20 and this large change in flow creates tensions inside the pipe and is dangerous for the system at that node. Then it continues to increase the flow in the 35th second to 421.92 l/s, again we have a decrease in the 45th second to 407.76 l/s and this oscillation continues every 15 s we have a decrease of about 15 l/s as in the growing part as well as in that which descends. It is important to mention that in node no. 17 after 5 s after stopping the pumps the flow drops to 0 l/s, while at node 181 the flow drops in a controlled manner from 444.57 l/s to 0 l/s in the 10th second and poses no danger.

Static pressure values H(m).

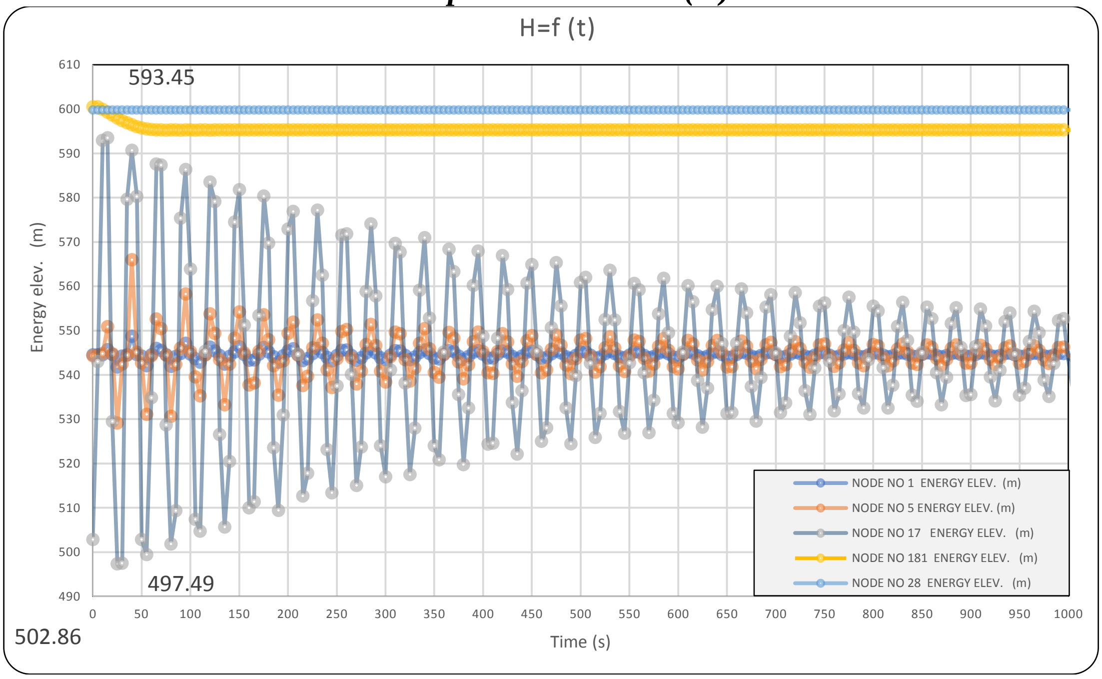

Figure 6. Comparison of levels at several nodes in the tube with expansion vessel, with number of pump rotations n = 1190 rpm.

Static pressure at node 17 (fig. 6) presents a dangerous situation for the system because at the start of the pump operation we have a level of 502.86 m and after 15 s the pressure increases to 593.45 m, then in the second 25 it drops to 497. 49 m. This difference (9.6 bar) is a significant pressure difference inside the pipe and which could damage the pipe at this joint, at the inlet of the pump station. After this state the static pressure drops both in the direction of water flow and in the opposite direction approximately every 25-30 seconds the pressure drops by 3m approximately (0.3 bar).
Practically this is the most dangerous honor situation in the entire length of the pipe from the beginning to the water treatment plant for human consumption. And this situation is caused due to the intervention in the water transportation system and due to the large volume of water that hits this node after the interruption of work. WHAMO software does not deal with the change of phases, i.e. the transition from the aggregate state of liquid to the aggregate state of steam, so the simulation with WHAMO software will produce negative pressures that exceed the vapor pressure and the software gives only a warning about the possibility of cavitation with this also the possibility of destroying the pipe.

Comparison of maximum potential energy and minimum potential energy

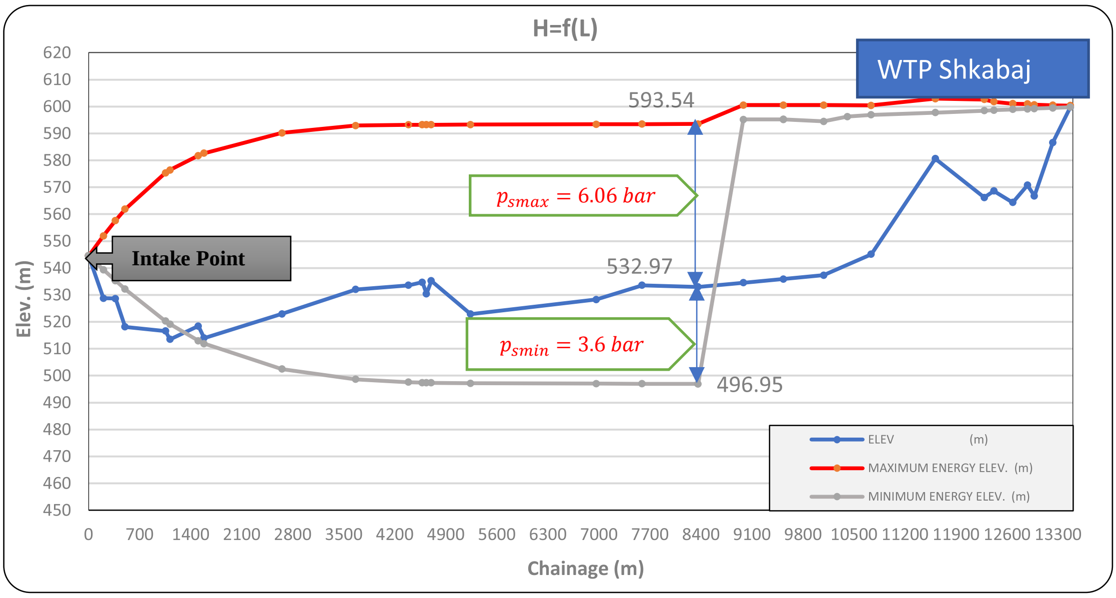

Figure 7. Comparison of static pressure at joints in main pipe with expansion vessel, with number of pump rotations n = 1190 rpm

Stationary mode Figure 4 when operating two pumps with expansion vessels and number of rotations n = 1190 rpm with total flow in the pipeline Qtot = 444.57 l/s. So, with the blue line represents the potential energy of the position (i.e. the height of the pipeline lmd) at the nodes along the length of the pipeline that we have selected for study (supply pipe nodes 1, 5, 17 and the push pipe node 181, 28). In figure 7 the red line of the pipeline represents the full potential energy at the nodes along the length of a pipeline with a stationary mode of operation of the two pumps. From these curves, the static pressure change at each point of the pipeline can be read.
At node 17 (at the inlet of the pump station), the static pressure is the change of full energy (red line) and position energy (blue line), i.e.

$H_{stmax} = 593.54\,m - 532.97\,m = 60.57\,m,\ \ or$

$p_{stmax} = 1000 * 9.81 * Hst = 1000 * 9.81 * 60.57 = 594191.7\,Pa = 5.94\,bar$

(this is the maximum static pressure at node 17)

$H_{stmin} = 532.97\,m - 496.95\,m = 39.02\,m,\ \ or$

$p_{stmin} = 1000 * 9.81 * Hst = 1000 * 9.81 * 36.97 = 382786.7\,Pa = 3.82\,bar$

(this is the minimum static pressure at node 17)

$$p_{st} = p_{stmax} + p_{stmin} = 5.94 + 3.82 = 9.76\ \text{bar}$$

We have a difference between the static pressure calculated by the software Figure 3 and the static pressure calculated in Figure 4 for 0.1 bar which comes as a result that we have not taken into account the numbers after the decimal point and this affects the appearance of this error [5]. From the diagram of the energy curve (static pressure) can be seen the pressure drop, which is due to hydraulic losses in the supply pipe of the pump station (nodes 1 to 17), while the pressure increases due to the pump (node 18 and 28).

2.1.1 The results of this Scenario

In this scenario, the inlet pressure of the pumps is 0.98 bar and the outlet pressure of the pumps is 6.47 bar, while the pump flow is 444.57 l / s. The pump operates with a number of rotations of 1190 rpm. The electric motor power of the pump is 181.88 kW.

The intervention occurs in the 5th second and the most critical point that appears in the system is in node 17 because there we have a change of pressure from 0.98 bar at the inlet of the pump station at the beginning of the pump operation, flow 444.57 l / s and then from the wave in the opposite direction the pressure increases to 5.93 bar which occurs in the 15th second, with a flow in that node of 223.70 l / s. Then from the water oscillations the pressure drops to -3.49 bar in the 30th second with a flow of 0 l / s, this pressure changes so large causes pressures inside the pipe. Then the pressure continues to decrease every 30 s from 0.23 bar in the direction of water flow or in the opposite direction but the system does not calm down completely until the 2985 s second (about 50 min.) At node 17. At node no. 181 we have a pressure change after the pump stops working from 6.47 bar gradually the pressure drops to 5.95 bar in the 75 second but here we have pump and tube protection because the pressure in the pipes from the expansion vessel drops slowly without large amplitudes. In the same way as the pressure drops in node no. 181 also drops the flow in a controlled manner and the flow drops from 444.57 l/s to 0 l/s in the 10th second and poses no risk to the system.

Based on this result that software gives us for hydraulic calculations, we recommend that this pipe sector (node 17) to be secured with an automatic valve to regulate the water pressure in this part of the pipe. This safety valve would be activated or opened if the pressure in that node increases above 10 bar (although the pipe is PN12 it means that we have a pressure reserve) and this amount of water we recommend to connect to the sewer system so as not to create problems with the surroundings. The calculation of the operating parameters of the safety valve and the type, should be the subject of a special scientific paper in the future by researchers whether external or even by KUP and will be used by all of those who deal with the design of new networks or with the reconstruction of those in use [6, 7].

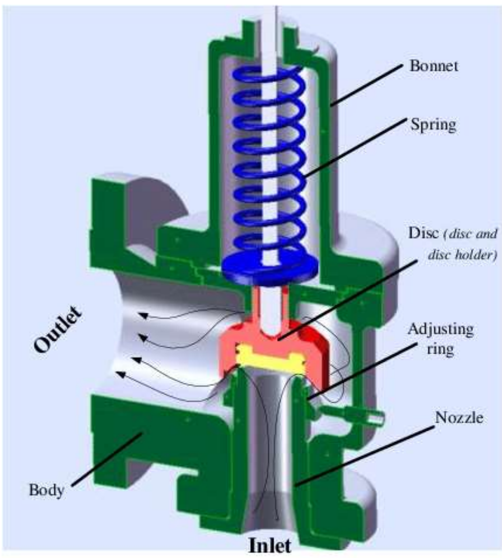

Figure 8. Example of a mechanical safety valve [8]

3. CONCLUSION

The scenario system has been focused in the expansion container where we have the amount of water in this scenario at 500 l / s. In this scenario the most critical point in the whole pipe and pump station was in node 17 which has been presented the dangerous situations for the system due to the pressure change in the second of 15 at 593.45 m, then in the second of 25 falls to 497. 49 m. This 96 m difference (9.6 bar) were considerable pressure difference inside the pipe which could also damage the pipe at this node, at the entrance of the pumping station. Practically this is also a dangerous condition even though it only lasts 10 seconds. This situation is caused due to the intervention, stopping of the pumps and due to the oscillations of the large volume of water that hits this node after the interruption of the 466 s. The software in this case warns us that here we may have damage to the pipe due to increased pressure. This is due to oscillations in the volume of water and the configuration of the pipe installation. While in nodes no. 1, 5 and in node no. 181, 28 we have no events that happens during this scenario that will endanger the water transport system in general. Based on our research results we can implement this hydraulic modeling of operating modes in the Mihallaq main pipe-water treatment plant.

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