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ESTIMATING THE WAVE MOVING SPEED ON HYDRAULIC HIT IN BIPHASE MEDIA

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***Key words*: hydraulic hit, wave speed, biphasic media.**

Summary. Wave process that is happening in fluid by rapid change of its speed is called the hydraulic hit. That process in pipelines is done by local pressure increases and decreases that can dramatically surpass the domain that appears instable regime. Examination of the wave process that follows the process of heat steam appears to be a problem in the speed of wave motions propagation on hydraulic hit in biphasic electricity. In operation we analyze the electricity flow of fluid with steam and gas bubbles, not the steam with fluid drops.

1. INTRODUCTION

In contemporaneous heat systems with water as the carrier of the heat, the possibility of hydraulic hit appearance in the last few years has dramatically grown in relation with the increase of unit heat power in heat source, bringing in to word long heating conduit with big diameter and powerful pump substation with big quantity of regulatory appliances, gate valves, valves, as well as bringing in to the system obtaining heat in peak water heat boilers. In this system by cancellation of any element, for example the sudden stop of circulation pumps in heating station, or pumps in pump substation, or if a biphasic media appears (water, steam) that is very possible, can lead to rapid speed change in water system, followed by hydraulic hit.

When examination the wave processes, that are followed by the steam of heat (carrier), question of speed spreading waves of hydraulic hit in biphasic media occurs and we are interested in fluid flow with gas and steam bubbles, not the steam with fluid drops. The operation is based on determining the speed of sound near the lower curve border. Based on analysis, we can say that presence of gas suspension and steam has for tendency rapid decrease of sound speed. The starting equation is Laplace's equation:

$$a = \sqrt{\left(\frac{\partial P}{\partial \rho}\right)_S} \tag{1}$$

Fluid stream depends on capacity, where the most important are density(ρ), compressibility$(1/E)$, steam pressure (P_S) and kinematics viscosity (v).Compressibility $(1/E)$ is inherent to fluid to lower its volume with the pressure increase. It is equals to the relative volume decrease by the unit of pressure increase. The median compressibility is equals to the reciprocal term of flexibility module(E), and it is the function of temperature and pressure, meaning, in this case we will use Newton's podern:

$$c^2 = \frac{E_P}{\rho_P} = E_P\left[v' + x\left(v'' - v'\right)\right] \tag{2}$$

In other words:

$$E_P = \frac{c^2}{v'+x(v''-v')} \tag{3}$$

Formulation (3), the dependence of flexibility module is given of dumpily steam in function with temperature and steam content (x). The values for E_P are systemized in table T.1. Where c is the speed of sound spreading in examined media $(c = 1428\, m/s)$.

2. THE ANALYSIS OF WAVE CHANGES IN HYDRAULIC HIT ALONG THE PIPELINE

Share of the pipeline is shown in figure 1, where we have foam. In some moment in time wave front of hydraulic hit will be found in intersection I-I. Through time interval $\Delta\tau$ the wave front is moving on distance $a \cdot \Delta\tau = \Delta l$ and it is on location II-II
In the given perimeter (volume) the pressure will increase for Δp ,the asipe area of the intersection will increase to $F + dF$, density of flow in this perimeter will get to

$$\rho' = (x - dx)\cdot(\rho_P + d\rho_P) + (1 - x - dx)\cdot(\rho_T + d\rho_T) \tag{4}$$

Volume (undisturbed) flow between intersection I-II is equals to:

$$dM_1 = \rho \cdot F \cdot a \cdot \Delta\tau = [x \cdot \rho_P + (1-x)\cdot \rho_T]\cdot F \cdot a \cdot \Delta\tau \tag{5}$$

x	$t(^0C)$	
	50	100
10^{-1}	1.693.674	12.120.685
10^{-2}	16.811.080	114.818.919
10^{-3}	156.499.156	751.911.504
10^{-4}	925.639.582	1.689.184.891
10^{-5}	1.820.212.443	1.929.729.730
10^{-6}	2.014.944.221	1.957.606.617

Table T.1. *Dependence* $E_P = f(t,x), Pa$

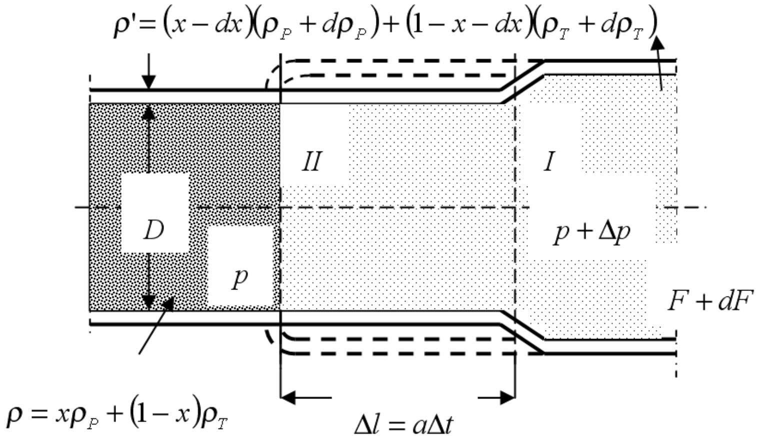

Figure 1. *Wave changes in hydraulic hit along the pipeline*

Volume of flow after the disturbing is equals to:

$$dM_2 = \rho'(F + dF)\cdot a \cdot \Delta\tau = \\ = [(x - dx)(\rho_P + d\rho_P) + (1 - x + dx)(\rho_T + d\rho_T)]\cdot(F + dF)\cdot a \cdot \Delta\tau \tag{6}$$

The increase of volume during the hit, after rational (stimulation) transformation and disregarding small values of higher rows is equals to:

$$\Delta dM = dM_2 - dM_1 = \\ = \left[x \cdot \left(d\rho_P F + \rho_P dF\right) + (1-x)\cdot\left(F d\rho_T + \rho_T dF\right) + dx \cdot (\rho_T - \rho_P) F\right] \cdot a \cdot \Delta\tau \quad (7)$$

On the other side, this increase can be determined approximately, through expression:

$$\Delta dM = \Delta w \cdot F \cdot \Delta t \cdot \rho' \quad (8)$$

By solving the equations (5) and (6) together with the equation of N.E.Zukoovski:

$$\Delta P = \rho' \cdot a \cdot \Delta W$$

We will get the following quadratic equation:

$$F \cdot dW \cdot \Delta\tau \cdot \rho = \\ = \left[x\left(d\rho_P F + \rho_P dF\right) + (1-x)\left(F d\rho_T + \rho_T dF\right) + dx\left(\rho_T - \rho_P\right) \cdot F\right] \cdot a \cdot \Delta\tau \quad (9)$$

Or in this formulation:

$$a^2 \cdot \left[x \cdot \left(d\rho_P \cdot F + \rho_P \cdot dF\right) + (1-x)\cdot\left(F \cdot d\rho_T + \rho_T \cdot dF\right) + dx \cdot \left(\rho_T - \rho_P\right) \cdot F\right] = \\ = \Delta P \cdot F \quad (10)$$

Or, after solving equation (10), we have the sound spreading speed in biphasic media is equals to:

$$a = \sqrt{\frac{\Delta P}{x\rho_P\left(\frac{d\rho_P}{\rho_P} + \frac{dF}{F}\right) + (1-x)\left(\frac{d\rho_V}{\rho_V} + \frac{dF}{F}\right) + dx\rho_T\left(1 - \frac{\rho_P}{\rho_V}\right)}} \quad (11)$$

Using the flexibility law theory, we ratify the following ratio:

$$\frac{dF}{F} = \frac{d\left(D^2\pi/4\right)}{D^2\pi/4} = \frac{2dD}{D} = \frac{2 \cdot d\sigma}{E_S} = \frac{D \cdot \Delta P}{S \cdot E_S} = \frac{D \cdot E_P}{S \cdot E_S \cdot \rho_P}$$

$$\Delta P = \frac{E_T}{\rho_T}; \quad \frac{\rho_T \cdot D \cdot E_P}{\rho_P \cdot S \cdot E_S} = \frac{\frac{E_T}{\Delta P}}{\frac{E_P}{\Delta P}} = \frac{E_T \cdot D \cdot E_P}{E_P \cdot S \cdot E_S} = \frac{E_T \cdot D}{E_S \cdot S};$$

$$d\rho_P = d\rho_T = 1 \quad (12)$$

$$\rho_T = \frac{E_T}{\Delta P}; \rho_P = \frac{E_P}{\Delta P}; \Delta P = \frac{E_T}{\rho_V}$$

After the relational adjustments and solving the equation (11), we get that:

$$a = \sqrt{\frac{E_T/\rho_V}{(1-x)\left(1 + \frac{E_T D}{E_S S}\right) + \frac{x\rho_P E_T}{\rho_T E_S}\left(1 + \frac{E_P D}{E_S S}\right) + \frac{dx E_T}{\Delta P}\left(1 - \frac{\rho_P}{\rho_T}\right)}} \quad (13)$$

If the process of water steam is adiabatic, meaning:

$$P \cdot V^k = (P + \Delta P) \cdot (V + \Delta V)^k \quad (14)$$

$$P\left(\frac{x\cdot\rho\cdot F\cdot a\cdot\Delta t}{\rho_P}\right)^k=(P+\Delta P)\left[(x-dx)\frac{\rho'\cdot(F+dF)\cdot a\cdot\Delta t}{\rho_p}\right]^k \quad (15)$$

From where we can get that:

$$dx=x\left[1-\left(\frac{P}{P+\Delta P}\frac{\rho}{\rho'}\frac{F}{F+dF}\right)^{1/k}\right] \quad (16)$$

If we that $\rho\cdot F/[\rho'\cdot(F+dF)]=1$, and knowing that the flexibility module of gas and steam for adiabatic processes has formulation $E_P=kp_0$, we will get the final equation for determining the
Sound speed in biphasic media (biphasic flow) near the lower curve border:

$$a=\sqrt{\frac{\frac{E_T}{\rho_T}}{(1-x)\cdot\left(1+\frac{E_T\cdot D}{E_S\cdot S}\right)+x\cdot\frac{\rho_P\cdot E_T}{\rho_T\cdot k\cdot P_0}\cdot\left(1+\frac{k\cdot P_0\cdot D}{E_S\cdot S}\right)+}}\rightarrow$$

$$\rightarrow\sqrt{\frac{\frac{1}{1}}{+\frac{x\cdot\left[1-\left(\frac{P}{P+\Delta P}\right)^{\frac{1}{k}}\right]}{\Delta P}\cdot\left(1-\frac{\rho_P}{\rho_T}\right)}} \quad (17)$$

If in equation (17) we put that $x=0$, meaning if we take pure fluid in analysis , the equation (17) is turning in to known dependence of N.E.Zukovski ,or:

$$a=\sqrt{\frac{\frac{E_V}{\rho}}{1+\frac{E_V}{E_{ZC}}\frac{D}{S}}} \quad (18)$$

If we take that volume cordent of steam x in wave spreading process of hydraulic hit stays unchanged, meaning $dx=0$, that we will get the equation of V.O.Tokmadzajan for biphasic mixture water –solid fractions refer to water steam:

$$a=\sqrt{\frac{\frac{E_T}{\rho_T}}{(1\quad x)\quad 1+\frac{E_T\quad D}{E_S\quad S}+\frac{x\quad \rho_P\quad E_T}{\rho_T\quad k\quad P_0}\quad 1+\frac{k\quad P_0\quad D}{E_S\quad S}}} \quad (19)$$

It can be proved that equation (19) is showing the dependence of Korteveg [6], in developed form

$$a = \sqrt{\frac{a_1^2 a_2^3}{a_1^2 + a_2^2}} = \sqrt{\frac{a_1^2}{1 + \frac{a_1^2}{a_2^2}}} \tag{20}$$

Where: a_1-speed of sound spreading in free fluid and a_2- speed of sound spreading in uncompressible fluid, streaming in flexible pipe.
The speed of sound in biphasic flexible fluid without taking the pipe wall flexibility can be determined by dependences, given by M.E.Dejcem and E.V. Stekoljscikov (2, 3)

$$a_1 = \sqrt{\frac{E}{x \cdot \rho \cdot \left(1 + \frac{1-x}{x} \cdot \frac{C_T}{C_P}\right)}} \tag{21}$$

The given formulation can be written in different ways:

$$a_1 = \sqrt{\frac{E}{x \cdot \rho \cdot \frac{dW_P}{dW} + (1-x) \cdot \rho \cdot \frac{dW_V}{dW}}} \tag{22}$$

Taking in consideration that:

$$\frac{dW_P}{dW_V} = \frac{dV_P}{dV_V} = \frac{d\rho_V}{d\rho_P}; \frac{dW_V}{dW} = \frac{d\rho}{d\rho_V}; \tag{23}$$

We get that:

$$a_1 = \sqrt{\frac{\frac{E_V}{\rho_V}}{x \cdot \frac{d\rho_V}{d\rho_P} + (1-x)}} \tag{24}$$

The speed of impact waves spreading in uncompressible fluid that streams in flexible pipeline, is determined by Rezaljs formula (6)

$$a_2 = \sqrt{\frac{E_{ST} \cdot S}{D \cdot \rho}} \tag{25}$$

By switching equations (24) and (25) in equation (20) we will get equation (19) .That way, equation (17) we will get equation (19) .That way equation (17) is showing the basic equation (formulation), that makes possible the determination of wave spreading speed in hydraulic hit in biphasic media and which is taking in consideration the flexibility of the pipe wall, steam, fluid and the change of volume between phases. The gotten equation (17) shows, that the speed of wave spreading in hydraulic hit is the function of variables, or:

$$a = f\left(E_V, E_{ZC}, \frac{D}{S}, x, \Delta p, p_o, \rho_P, \rho_V\right) \tag{26}$$

For analysis of impact of some parameters on values of speed of hydraulic hit in biphasic media, let's examine the stream blend of water and steam in pipeline $D = 500(mm)$ and $S = 10(mm)$ the temperature of heat carrier is $t = 50(^0C)$, $\rho_P = 0{,}08(kg/m^3)$, $\rho_V = 1000(kg/m^3)$, $E_T = 206 \cdot 10^7(Pa)$, $E_{ZC} = 206 \cdot 10^9(Pa)$, $x = 10^{-n}$, where $n = 1,2,3,4,5,6$. In picture 2 the dependence of speed in hydraulic in hydraulic hit is shown on the degree of steam and pressure content, where is blend of water and steam,. In picture 3 the dependence of speed in hydraulic hit is shown from the value of pressure change ΔP . In picture 4 is shown the impact of geometric values of pipeline D/S for different values of the beginning content the impact relation D/S is pretty marked. With the diameter increase of pipeline the speed of wave spreading of hydraulic hit decreases.

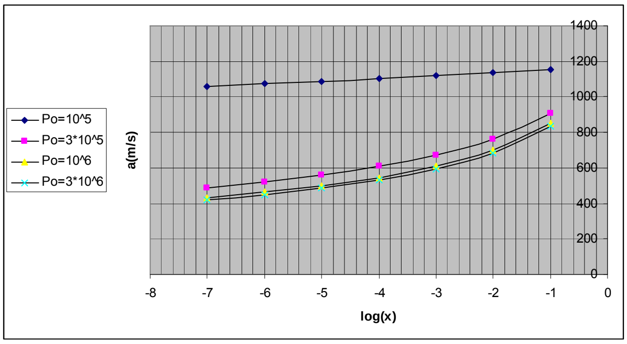

Figure 2. *Graphic dependence* $a = f(x, p_o)$ *where* $\Delta p = 10^5(Pa)$ *1-where* $p_0 = 10^5(Pa)$; *2- where* $p_0 = 3 \times 10^5(Pa)$; *3- where* $p_0 = 10^6(Pa)$; *4- where* $p_0 = 4 \times 10^6(Pa)$;

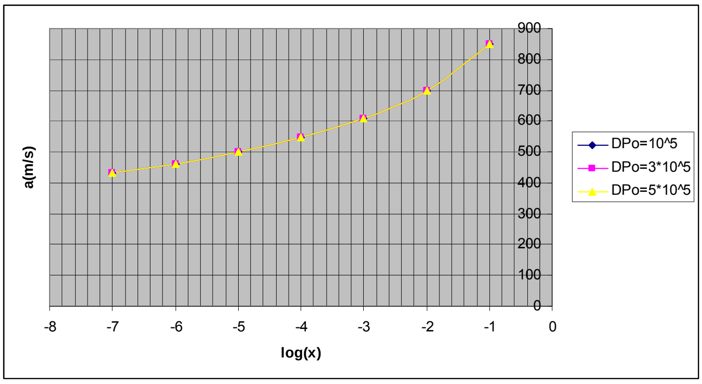

Figure 3.*Graphic dependence* $a = f(x, \Delta p)$ *where* $p_0 = 10^6(Pa)$; *1- where* $\Delta p = 10^5(Pa)$*; 2- where* $\Delta p = 3 \times 10^5(Pa)$*;3- where* $\Delta p = 5 \times 10^5(Pa)$

3. CONCLUSION

Under the calculation results we can say the following

1. Unknown increase of steam content x from 10^{-5} to 10^{-2} we have rapid decrease of speed from 1190(m/s) to 75(m/s).With the pressure increase P_o the speed dropping comes with bigger values of speed;

2. With the value increase for Δp $10^{-5}(Pa)$to $5\cdot10^{-5}(Pa)$ we have a tendency of speed increase when $x=10^{-3}$ from 840(m/s) to 890(m/s);
3. With lower steam content values the impact D/S is pretty marked. With the pipeline diameter increase the speed of wave spreading of hydraulic hit decreases.

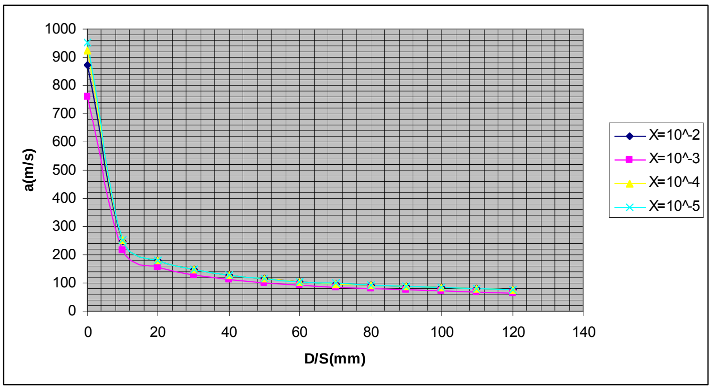

Figure 4. *Graphic dependence* $a=f(D/S)$ *where* $p_0=10^6(Pa)$; $\Delta p=3\times10^5(Pa)$
1- where $x=10^{-4}$ *2- where* $x=10^{-3}$ *; 3- where* $x=10^{-2}$

NOTATION

a -wave spreading speed by hydraulic hit, m/s
c -sound spreading speed in examined media, m/s
D -pipeline diameter, m
E_P, E_T, E_S -flexibility module, steam phase, fluid and pipeline material, Pa
F -aslope area of intersection of pipeline, m^2
k -Puassona coefficient
$M, \Delta M$ -Volume of relation flow and volume increase, kg
P_0 -pressure of biphasic area, Pa
S -pipeline wall thickness, m
x -steam content, %
σ -intension of pipe material, N/m^2
ρ, ρ' -mixture (blend) density, until and after pressure increase, kg/m^3
ρ_T, ρ_P -fluid density or steam-gas phase, kg/m^3
Δ -increase (change) of rational value,

REFERENCES

[1] Sokolov. J.J : Toplifikacija i toplotne mreze, IRO , GK , Beograd, 1985,
[2] Zinger N.M:Hidravličeskie i teplovije rezimi teplofikacionnih sistem, Moskva,1986
[3] Požar H.: Osnove energetike (drugi svezak), Skolska knjiga, Zagreb 1978
[4] Dejč M, Filippov G.A: Gazodinamika dvuhfaznjih potokov, Energija, 1968.