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Determining the Critical Consumer in the Central Heating System

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Abstract:- *The content of this article is focused on hydrodynamic modeling and application of methods for the calculation of complex systems of pipes respectively networks for transport and distribution of incompressible fluids during stationary regime. When selecting the method of thermal energy supply for heating and preparation of heating water, thermal networks have to respond to customer requirements in quantity and in quality i.e. the heat carrier fluid must have the required quality and quantity when it reaches the consumer. On the other thermal networks service must be safe and simple. With the use of personal computer software's we can calculate at the same time the sizes of the fluid for all branches and for all nodes.*

Key Words: Optimal, critical, consumer, thermal network, flow, velocity, energy.

I. INTRODUCTION

Remote heating means thermal energy supply for heating, ventilation, heating water for sanitary and technological needs of all consumers of a city or of certain areas of a city from one or more thermal sources connected in the joint system.

Hydrodynamic analysis, of the fluid flow within the transportation system, represents the initial and fundamental work, the results of which determine the possible design solutions, if it is about a new system or the required activities in the existing system, in order to meet the set requirements and to ensure an optimal unit for remote heating. This is especially valid for large network systems (water supply, gas pipeline, oil-pipeline, overheated water pipeline, and etc.) from which a high degree of security is required for the supply to consumers, rational use, development in harmony with the needs of consumption, saving human environment and acceptable service price.

Today, we cannot imagine that any one system can meet the requirements mentioned without using computers at all stages of use (management, leadership, reconstruction, etc.) and development. With the help of mathematical models we simulate the efficiency of the system in different situations, analyze the obtained results and choose the most acceptable solutions.

Hydrodynamic models, developed with the assumption that the fluid is incompressible and that the flow of the fluid is one-dimensional and one-phase, are most frequently used for the analysis of stationary flow (stable) of the fluid in the aforementioned networking systems.

II. MAKING THE HYDRODYNAMIC MODEL

From the basic laws of physics we can derive, with the application of the fluid continuum hypothesis, the general mathematical model of fluid flow which applies to all fluids – the mathematical model based on the continuity equation and the amount movement equation. With the introduction of complementary relations, the number of unknowns is equaled with the number of equations and application of the model is limited on the Newtonian fluid (homogeneous, isotropic, one-phase one-component and chemically inert).

2.1 The Basic Differential One-Dimensional Flow Equations

The structure which has a highly expressed linear dimension present the pipeline network, as is the one of boiling water. At such structure the changes in the direction of flow are more dominant compared to other directions. As defined, one-dimensional flow is the flow of the fluid in the basic flowing pipe, while all physical measures are a function of the coordinate on the side of the flow.

The fluid flow in technical pipes, with great precision, can be considered as one-dimensional flow if the following conditions are met:

- the changes in physical sizes along the cross section of the flow direction is negligible against the changes of the flow direction,
- the relative change of the cross section of flow direction is small, reflection direction is small, the radius of the axle tube is bigger than the characteristic linear dimension of the cross section, and
- the profiles of all physical sizes in the cross section change very in the direction of the flow.

Thus, the mathematical model of the stationary flow can be formulated in this form:

1. For each node the flow amounts (flowing amounts) entering the node must necessarily be equal to the sum of flows leaving the node.

$$\Delta \dot{m} = 0 \qquad (2.1)$$

2. For each tube should be definitely completed the Darcy-Weisbach equation must be completed for each pipe, respectively the ratio between the amount of loss, mechanical energy and fluid flow should be determined.

The Darcy-Weisbach equation is:

$$h_f = \lambda \frac{l}{d}\frac{v^2}{2g} = \lambda \frac{l}{d^5}\frac{8V^2}{g\pi^2} \qquad (2.2)$$

The coefficient of the friction resistance can be expressed depending on the Reynolds number, $R_e[-]$, and the relative severity of the inner surface of the pipe, $k/D[-]$:

$$\lambda = f(R_e, k/D) \qquad (2.3)$$

In order to determine the value of λ, the following formulas will be used in this study:

- for the laminar flow regime

$$\lambda = 64/R_e, \qquad R_e \le 2320 \qquad (2.3.a)$$

- for the turbulent flow regime

$$\lambda = \frac{1,325}{ln\left[\left(\frac{k}{3,7D} + \frac{5,74}{\mathrm{Re}^{0,9}}\right)\right]^2} \quad , \quad 5\cdot 10^3 \le \mathrm{Re} \le 10^8 \quad , \quad 10^{-6} < \frac{k}{D} < 10^{-2} \qquad (2.3.b)$$

The Reynolds number is expressed by the equation

$$\mathrm{Re} = \frac{vD}{\nu} = \frac{4V}{D\pi\nu} \qquad (2.4)$$

2.2 Application Of One-Dimensional Flow In Distant Heating

The city of Pristina has built, during the 80 's, remote heating in which are connected for heating near 1,050,000 m^2. One of the city's neighborhoods is Dardania. In Fig.2.1 are given technical data for customers connected to this part of the district water heating network, and in Fig.2.2 is given the customer structure for the modeled Dardania neighborhood. The calculation of the amount of heat for heating has been done on the basis of the average value of the specific amount of heat required q= 50 W/m3. Distance heating system is designed for the distribution of overheated water 140/80 °C, the primary network.

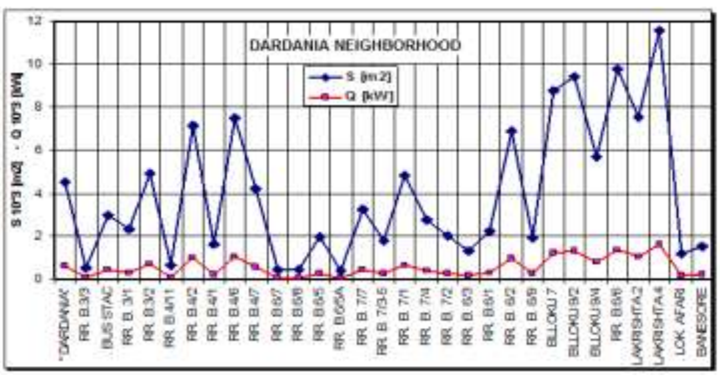


Fig.2.1 DARDANIA neighborhood – Heating surface and the amounts of heating needed

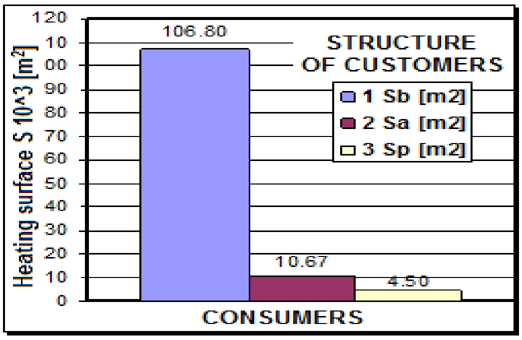


Fig.2.2 Structure of customers

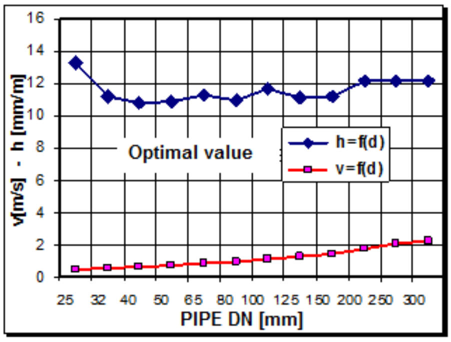


Fig.2.3 Optimal value for energy and velocity

The calculation is performed for the parameters of the overheated water:

- Average temperature $t_m = 110\,^oC$
- Fluid density $\rho = 948.95$ kg/m^3
- Kinematic viscosity of the fluid $\nu = 2.90$ e-7 m^2/s
- Specific heat of the fluid c_p=4.24 kJ/kgK
- Pristina's designed outdoor temperature $t_{jp} =$ -17 ^{o}C.

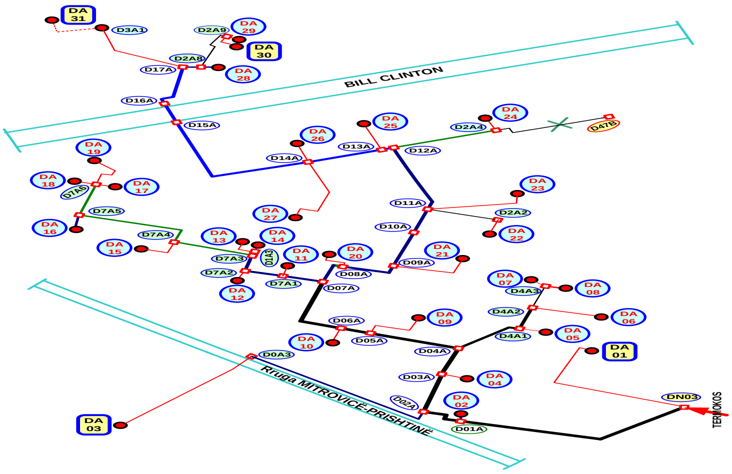


Fig.2.4 Thermal network for Dardania neighborhood

Distance heating system is designed according to the system with heat exchangers which are located in certain areas of the buildings. The secondary network operates with temperatures of 90/70°C, on the basis of which the calculations for the amounts needed for heating and ventilation are carried out.

The network is built of steel pipes, pre-insulated standard type. The hydrodynamic analysis for the modeling of the thermal network, shown in Fig.2.4, has been carried out with the use of the RORNET-RAMBOLL software.

Thermal network system will be placed in a stationary mode where we will have optimal consumption of superheated water. The simulation of the modeled network, Dardania neighborhood, will be carried out for these options:

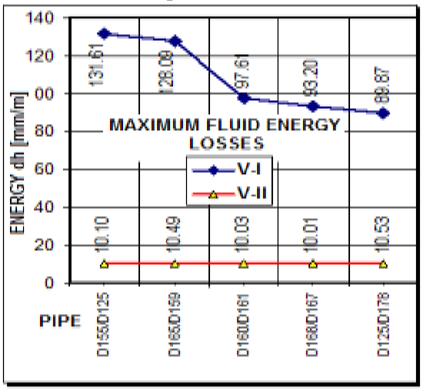
- **Option V-I:** Hydraulic calculation will be carried out for the existing network.
- **Option V-II:** Hydraulic calculation as per criterion of optimal loss of the mechanical energy.

The critical consumer will be defined for both options. The results obtained will be compared based on the recommendations for optimal limitation of mechanical energy loss and maximum speed limits allowed for the appropriate pipe diameter, Fig.2.3.

III. NETWORK MODELING RESULTS OVERVIEW

The DARDANIA neighborhood consists of 31 thermal substations, with S_b=106,798 m^2 residential area, S_a=10,667 m^2 commercial area and S_p=4,500 m^2 public area. In order to achieve thermal energy supply, a network with a length of 3,262.30 m has been built with installed diameters DN25 to DN300 for the distribution

of 17.08 MW, respectively 254.51 m^3/h heated water. Local losses in the network are replaced with increases of longitudinal losses of 10 %.
The results obtained are presented in the following figures.



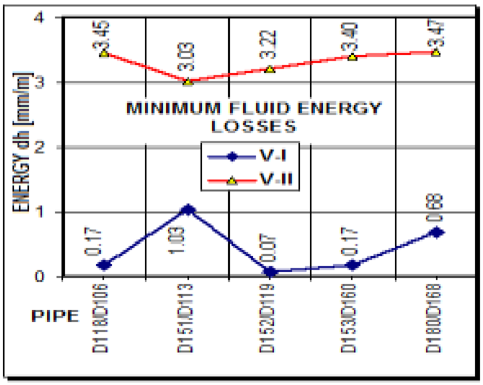


Fig.3.1 Maximum fluid energy losses in the network Fig.3.2 Minimum fluid energy losses in the network

While Table 3.1 presents the hydraulic network calculation for the modeled network as per the RORNET software, only for optimal option V-II. This table also presents the geometry of the network, (length and diameter) for each consumer as well as supply and return pipes, as well as the results of calculation of parameters of the state carrier of heat such as: the amount of fluid, speed, fluid energy, specific and total energy loss for each pipe.

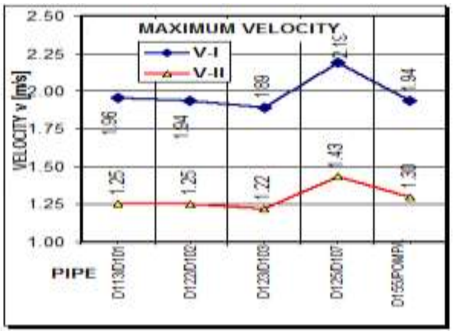


Fig.3.3 Maximum fluid velocity

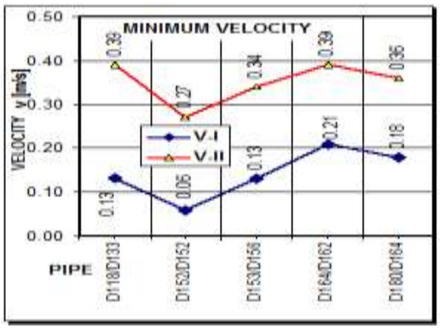


Fig.3.4 Minimum fluid velocity

PRISTINA: Hydraulic Calculation: Option V-II

Branch	Node	Node	L	D	V	v	c_v	Δh	h_1-h_2
No.	1	2	[m]	[mm]	[m^3/h]	[m/s]	[m]	[mm/m]	[m]
D151	D00A	DA01	160.00	82.50	9.39	0.49	0.01	3.88	0.62
D152	D01A	DA02	15.00	37.20	1.07	0.27	-	3.53	0.05
D153	D0A3	DA03	165.00	70.30	6.26	0.45	0.01	4.02	0.66
D154	D03A	DA04	10.00	54.50	4.88	0.58	0.02	9.15	0.09
D155	D4A1	DA05	27.00	82.50	10.20	0.53	0.01	4.55	0.12
D156	D4A2	DA06	50.00	37.20	1.34	0.34	0.01	5.40	0.27
D157	D4A3	DA07	15.00	82.50	14.94	0.78	0.03	9.56	0.14
D158	D4A3	DA08	12.00	54.50	3.35	0.40	0.01	4.45	0.05
D159	D05A	DA09	50.00	82.50	15.67	0.81	0.03	10.49	0.52
D160	D06A	DA10	20.00	82.50	8.77	0.46	0.01	3.40	0.07
D161	D7A1	DA11	10.00	28.50	0.91	0.40	0.01	10.03	0.10
D162	D7A2	DA12	15.00	28.50	0.89	0.39	0.01	9.72	0.15
D163	D1A3	DA13	15.00	54.50	4.07	0.48	0.01	6.45	0.10
D164	D1A3	DA14	5.00	28.50	0.83	0.36	0.01	8.52	0.04
D165	D7A4	DA15	36.00	70.30	6.81	0.49	0.01	4.74	0.17
D166	D7A5	DA16	20.00	54.50	3.79	0.45	0.01	5.62	0.11
D167	D7A6	DA17	20.00	70.30	10.02	0.72	0.03	10.01	0.20
D168	D7A6	DA18	10.00	70.30	5.80	0.42	0.01	3.47	0.03
D169	D7A6	DA19	72.00	54.50	4.17	0.50	0.01	6.78	0.49
D170	D08A	DA20	30.00	43.10	2.71	0.52	0.01	9.84	0.30
D171	D09A	DA21	70.00	54.50	4.65	0.55	0.02	8.36	0.58
D172	D2A2	DA22	16.80	82.50	14.36	0.75	0.03	8.84	0.15
D173	D11A	DA23	66.00	54.50	4.00	0.48	0.01	6.23	0.41

D174	D2A4	DA24	27.00	107.10	18.28	0.56	0.02	3.70	0.10
D175	D13A	DA25	19.00	107.10	19.68	0.61	0.02	4.27	0.08
D176	D14A	DA26	27.00	82.50	11.88	0.62	0.02	6.12	0.17
D177	D14A	DA27	108.00	107.10	20.37	0.63	0.02	4.56	0.49
D178	D2A8	DA28	10.00	82.50	15.70	0.82	0.03	10.53	0.11
D179	D2A9	DA29	20.00	107.10	24.10	0.74	0.03	6.33	0.13
D180	D2A9	DA30	5.00	43.10	2.46	0.47	0.01	8.14	0.04
D181	D3A1	DA31	5.00	54.50	3.25	0.39	0.01	4.19	0.02

Tab. 3.1 Results of hydraulic calculations for option V-II

PUMP					
Description	FLOW	HEAD	HYDRAULIC	EFFICIENCY	ELECTRIC
Unit	[m3/h]	[m]	[kW]	[%]	[kW]
Amount	254.63	22.54	14.84	70	21.20

Tab. 3.2 Head, hydraulic and electric power of the pump

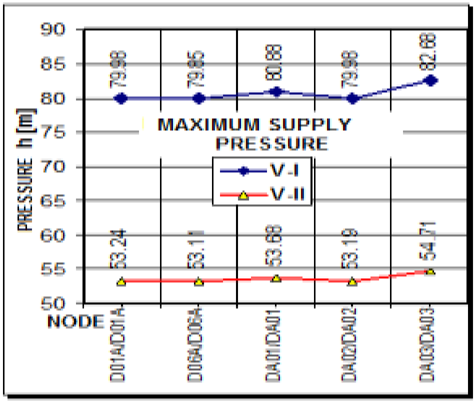


Fig.3.5 Maximum supply pressure values per node-customer

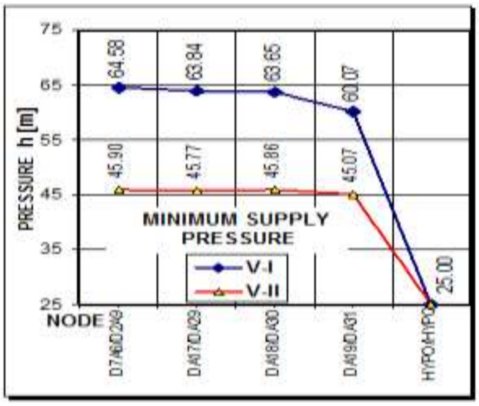


Fig.3.6 Minimum supply pressure per node-customer supply

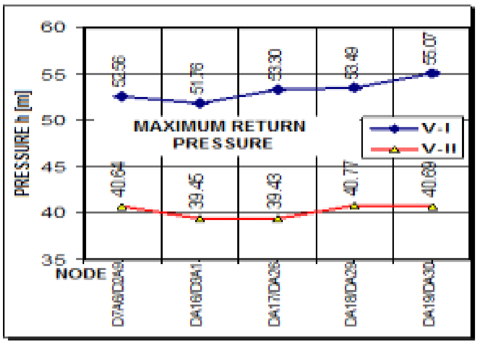


Fig.3.7 Maximum return pressure values per node-customer

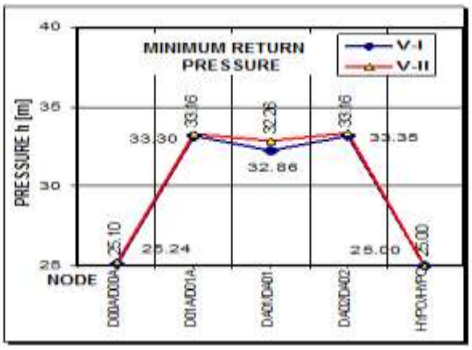


Fig.3.8 Minimum return pressure values per node-customer

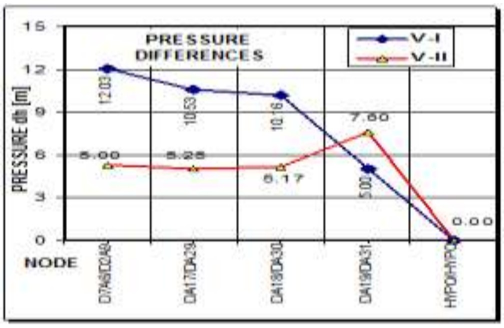


Fig.3.9 Pressure differences before and after optimization of the critical customer

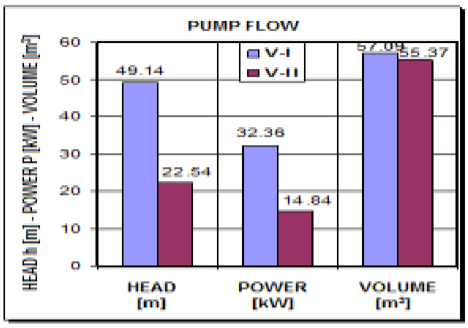


Fig.3.10 Optimization of head and power of the pump

IV. CONCLUSION

In this paper we have conducted the hydrodynamic analysis for the network modeled for the supply of boiling water for central heating of Dardania neighborhood which has connected three types of customers as presented in Fig.2.1 and Fig.2.2. Thermal energy supply is carried by the network with a length of 3,262.30 m which has a distribution capacity of 17.07 MW, respectively 254.51 m^3/h of overheated water, as calculated by Excel and RORNET programs.

Based on the results obtained from the modeling of option V-I, Fig.3.1 and Fig.3.2, it can be concluded that the network has not been calculated correctly. From these figures we can see that pipe D155 has a maximum power loss of 131.61 [mm/m] while pipe D152 has minimum power loss of 0.07 [mm/m]. Based on these values we can see that customers of these parts of the network, DA19, DA18 and DA17 are in the critical customer group. The results shown in Fig.3.5, Fig.3.6 and Fig.3.7 prove incorrect dimensions of this part of the network. With the replacement of pipes according to the criteria set for optimal power loss with margins 3 mm/m (~ 30 Pa/m) to 15 mm/m (~ 150 Pa/m) and the optimal flow speed of 0.40 to 2, 25 [m/s]; according to figures Fig.3.8 Fig.3.5 we have a decrease of pressure in the supply in the network from a value of 82.68 [m] for the consumer DA03 to 54.71 [m], respectively for the pressure in the return from a value of 55.07 [m] for the consumer DA19 to 40.69 [m] for the customer DA30.

Therefore, the critical consumer for option V-I is customer DA19 where the pressure difference if 5 m (minimum requirement for pressure losses in the system considering the regulating and exchanging valve), while for option V-II the critical customer is DA30.

Based on the results, Fig.3.10 and Fig.3.9, we see that head of the pump was reduced to 26.60 m and the hydraulic power for running the pump from 32.36 [kW] to 14.84 [kW]. All this is achieved by optimizing energy losses and achieving optimal speeds while replacing parts of pipes as shown in Fig.3.10, with the ratio of the water volume in the network V-I 57.09 m^3 in V - II 55.37 m^3.

From the presented results the optimization of the thermal network is achieved as per the theoretical approach that the critical customer in the network will be the one that is the furthest away from the source of thermal energy, in our case customer DA30.

Analyzing the results of hydraulic calculations can be concluded that the calculation of thermal network based on the criterion of minimum/maximum losses of mechanical energy due to fluid flow in the pipe is a basis for optimizing the hydraulic parameters of the network.

The gained results present:

1. Reason for the analysis of this type, as a basis for the development and implementation of programs, such as those for the command, supervision, operation and training of persons handling of networks during use.
2. Based on the analysis it is possible to extract some information:

- Which is the critical customer in the network;
- The impact of the types of boundary conditions in the calculation of new networks;
- Possibility of nominal load, boiling water requirements, optimal location of supply stations and the optimal size of the hydraulic parameters of the heat carrier.

Nomenclature

A = area of the pipe [m^2]
D = diameter of the pipe [m]
L = length of the pipe [m]
h = pressure on the nodes [m]
h_P = the effect of the pump [m]
P_H= hydraulic power of the pump [kW]
P_E= electric power of the pump [kW]
V= fluid flow [m^3/s]
z = node height, consumer [m]
hf= amount of mechanical energy losses due to friction resistance [m]
r – coefficient [-]
k = severity of the pipe [mm]
Re = Reynolds number [-]
η_P= pump efficiency [-]
λ = coefficient of friction resistance [-]
k/D - relative roughness [-]
t= fluid temperature [K]
c_p = specific heat of the fluid [kJ/kgK]
ρ - fluid density [kg/m^3]

ν = kinematic viscosity of the fluid $[m^2/s]$
v = velocity $[m/s]$

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