Sizing and Simulation for Optimization of a Water Pumping Installation Using Fuzzy Logic

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Abstract – In this article we present the way how to create a program in the Scilab-Xcos environment with which it can be dimensioned, mathematically modeled and simulated a water pumping installation.

The mathematical equations implemented in the program with which the dimensioning and simulation are done are presented.

Fuzzy logic was used to generate the pump characteristics.

Keywords – fuzzy logic, modeling, simulation, water pumping, Scilab-Xcos

Nomenclature

Description	Unit of measurement	Description	Unit of measurement
Re Reynolds number	[-]	H_R network load	[m]
v speed of water circulation	[m/s]	H_s static load	[m]
ν kinematic viscosity	[m ² /s]	H_g geodesic height	[m]
t water temperature	[°C]	Q water flow	[m ³ /s]
D diameter of the pipe	[m]	n_l pump speed	[rot./min.]
λ Darcy coefficient	[-]	Q_{PF} the water flow at the point of energetic operation	[m ³ /s]
k the equivalent roughness of the pipe	[m]	H_{PF} the height at the point of energetic operation	[m]
M the hydraulic resistance module	[s ² /m ⁵]	P_{util} the pump power output	[W]
ξ coefficient of local loss of hydraulic load	[-]	P the power consumed by the pump	[W]
L the length of the pipe	[m]	P_{ag} the electrical power consumed by the aggregate	[W]
g gravitational acceleration	[m/s ²]	η the efficiency of the pump at the point of energetic operation	[%]
h_r total hydraulic load loss	[m]	η_{mot} engine efficiency	[%]
h_d the loss distributed by the hydraulic load	[m]	e_{sp} specific energy	[Wh/m ³]
h_l local loss of hydraulic load	[m]	ρ water density	[kg/m ³]

1. INTRODUCTION

The dimensioning and simulation for optimization of the water pumping installations is a topical thing in the context in which the emphasis is increasingly on reducing the energy consumption, given that the energy resources (produced from hydrocarbons) of the land are limited.

In this article, a mathematical model was developed in Scilab-Xcos, which is used to size and simulate in order to optimize a water pumping installation between two free-level tanks using fuzzy logic to determine the pump characteristics.

Nowadays, fuzzy logic arouses a great interest from researchers, engineers and industry everywhere, but especially from all those who feel the need to formalize empirical methods, to generalize natural thinking modes, to automatize - in computer science sense - taking decisions in their field of activity, to build artificial systems to perform tasks that are usually performed by people [1].

The fuzzy set theory was developed in the United States of America in the early 1960s by mathematician Lotfi Zadeh, a professor at Berkeley University in California.

Fuzzy logic is a multipurpose logic, unlike Boole's logic which is bivalent (binary). The difference between classical logic, where it is rationed only in "all or nothing" mode and "fuzzy" logic, is that the latter takes into account a myriad of intermediate situations of the type: everything, much, medium, little, a little, nothing.

People's judgments are rarely binary, because the notions of "true" or "false" strictly appear only sometimes. Much more often the notions "maybe" and "more than true or false haste" are used.

Applications based on fuzzy logic were not possible until relatively recently, when the computing technique became performance and the fact that fuzzy logic requires more calculations than binary logic, it is no longer an obstacle in approaching applications [2].

Systems with fuzzy logic represent a branch of artificial intelligence and can also be used in applications for approximating functions.

In this article, fuzzy logic was used to approximate the pump characteristics.

2. MATHEMATICAL MODEL

Knowing the flow rate Q required for pumping and for the economic speeds v , is determined from the norm I9-2013 [10] or I22-1999 [11] diameter D of the pipes of the water pumping installation.

With their help and using the relations below [3 ÷ 9], no. Reynolds Re , Darcy's coefficient λ (using Swamee's relation (1993) [6]) and hydraulic resistance module M are determined.

The diagram of a water pumping installation is shown in the figure below, fig. 1.

Also, depending on the temperature of the water conveyed by the pumping system, the kinematic viscosity of the water ν [7] is determined using Poiseuille's equation (2).

$$Re = \frac{v \cdot D}{\nu} \quad (1)$$

$$\nu = \frac{1.78 \cdot 10^{-6}}{1 + 0.0337 \cdot t + 0.00022 \cdot t^2} \quad (2)$$

$$\lambda = \left\{ \left(\frac{64}{\text{Re}} \right)^8 + 9.5 \cdot \left[\ln \left(\frac{k}{3.7 \cdot D} + \frac{5.74}{\text{Re}^{0.9}} \right) - \left(\frac{2500}{\text{Re}} \right)^6 \right]^{-16} \right\}^{0.125} \quad (3)$$

$$M = \left(\lambda \cdot \frac{L}{D} + \sum \zeta \right) \cdot \frac{8}{\pi^2 \cdot g \cdot D^4} \quad (4)$$

$$h_r = h_l + h_d = M \cdot Q^2 \quad (5)$$

Fig. 1. Diagram of a water pumping installation

Then the characteristic of the network is determined using the next relations [3÷5]:

$$H_R = H_S + M \cdot Q^2 \quad (6)$$

$$H_s = H_g + \frac{p_e - p_i}{\rho \cdot g} \quad (7)$$

$H_s = H_g$ (when the two suction and discharge tanks are open, at atmospheric pressure).

The characteristic of the network $H_R(Q)$ was generated by the program realized in Scilab-Xcos (fig. 11) and is represented in fig. 6.

Knowing the pumping flow Q and the pumping height H the pump is chosen. The pumping height H is determined by calculating the local and linear load losses (for long pipe sections the local load losses are neglected).

A few points are mentioned on the Q - H catalog feature (eg CERN pump 200-150-315, $\Phi = 330$ mm, $n = 1450$ rpm) [4], of the chosen pump (fig. 2), with the help of fuzzy logic (system Mamdani) and using Scilab the sciFLT toolbox, the Q - H feature of the pump is realized (fig. 6), which simulates the operation of the water pumping system.

Fig. 2. The catalog characteristics of the pump for which the simulation is performed [4]

Fig. 3. The points read on the Q-H characteristic curve of the pump supplied by the manufacturer

Fig. 4. Fuzzy sets for input variable Q

Fig. 5. Fuzzy sets for the output variable H

Also, using the similarity relations [3÷5], the characteristic curves of the pump for its different speeds are determined.

$$\frac{Q_1}{Q_n} = \frac{n_1}{n_n} \quad (8)$$

$$\frac{H_1}{H_n} = \left(\frac{n_1}{n_n} \right)^2 \quad (9)$$

This can be seen in the figure below (fig. 6).

Fig. 6. The characteristic curves of the pump H (Q) for various speeds (1450, 1400, 1350 rotations / minute) realized with fuzzy logic and the characteristic curve of the $H_R(Q)$ network, generated by the program realized in Scilab-Xco

For the H_{PF} and Q_{PF} values of the operating point of the installation and using the relations (10÷13), the following parameters are calculated [3÷5]:

- The pump power output

$$P_{utila} = \rho \cdot g \cdot Q_{PF} \cdot H_{PF} \quad (10)$$

- Power consumed by the pump

$$P = \frac{\rho \cdot g \cdot Q_{PF} \cdot H_{PF}}{\eta} \quad (11)$$

- The electrical power consumed by the aggregate

$$P_{ag} = \frac{\rho \cdot g \cdot Q_{PF} \cdot H_{PF}}{\eta \cdot \eta_{mot}} \quad (12)$$

- Specific energy of the aggregate

$$e_{sp} = \frac{P_{ag}}{Q_{PF}} \quad (13)$$

We used the Thiesen-Scheel-Diesselhorst relation (14) to determine the water density according to the temperature [12].

$$\rho = 1000 \cdot \left[1 - \frac{t + 288.94}{508929.2 \cdot (t + 68.12963)} \cdot (t - 3.9863)^2 \right] \quad (14)$$

The Q - η characteristic of the pump was generated using the fuzzy logic (Mamdani system), reading a few points on the pump's performance characteristic of fig. 2, provided by the manufacturer [4].

Fig. 7. The points read on the characteristic Q - η curve of the pump used to generate the characteristic with fuzzy logic

Fig. 8. Fuzzy sets for input variable Q

Fig. 9. Fuzzy sets for the output variable R

For the operating flow of the Q_F water pumping installation, the pump efficiency, used in the energetic calculations of the installation was read on the Q - η characteristic.

Fig. 10. The characteristic yield curve of the η (Q) pump achieved with fuzzy logic in Scilab-Xcos

All these mathematical relations were implemented in the program realized in the Scilab-Xcos environment (fig. 11), which allows the simulation of a pumping installation.

Fig. 11. The scheme developed in Scilab-Xcos, which allows the simulation of equipment sizing and water pumping

Scilab-Xcos environment has a free license. The program being realized in this environment, allows the immediate implementation, without costs in the hydraulic systems. By making simulations with its help, the hydraulic systems can be made more efficient.

This program is also useful to specialists working in the design of hydraulic systems and those who carry out mathematical modeling and simulation programs.

The program allows a wide spectrum of simulations of a water pumping installation, including the limit situations in which for various water temperatures the pumping installation operates cavitationaly, thus avoiding this mode of operation from the design stage.

Also, this program can be very easily implemented in the Matlab-Simulink environment.

3. SIMULATION RESULTS

For the following input data: $Q=0.12 \text{ m}^3/\text{s}$; $D=0.40 \text{ m}$; $t=8 \text{ }^\circ\text{C}$; $L=2500 \text{ m}$; $\Sigma\xi=0$; $\eta_{\text{mot}}=0.89$; $k=0.00025 \text{ m}$; $g=10 \text{ m/s}^2$ and for the pump characteristics of fig. 2, implemented

in the program of fig. 11, the values for the following parameters resulted from the simulation: $v=0.00000139 \text{ m}^2/\text{s}$; $Re=275466.1$; $\lambda=0.0191$; $M=385.33 \text{ s}^2/\text{m}^5$; $\rho=999.877 \text{ kg/m}^3$; $P_v=34797.37 \text{ W}$; $P=41673.497 \text{ W}$; $P_{ag}=46824.154 \text{ W}$; $e=99.414 \text{ Wh/m}^3$ and the graphs in fig. 6 and 10.

3. CONCLUSIONS

In this article we presented the way how to create a program that allows the sizing, mathematical modeling and simulation of a water pumping installation.

This program was developed in Scilab-Xcos environment, uses fuzzy logic for generating the pump characteristics and has a wide spectrum of use, being able to make simulations for generating the pump characteristics and for its different speeds.

Simulations can also be made for variations in the temperature of the water conveyed by the pumping system. It can also be used to simulate pumping of other fluids.

The program has immediate applicability and is recommended to designers, specialists in the field and all those interested.

4. REFERENCES

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