EXPERIMENTAL INVESTIGATION AND OPTIMISATION OF A PUMPING STATION OPERATING POINT USING THE VARIABLE SPEED APPROACH

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Abstract: Many existing pumping station, as well as the design for the new ones, increasingly use the idea of reducing the pumping units number, while operating at or around the best efficiency point by adjusting the rotational speed. This approach requires a frequency converter which continuously modifies the electrical engine speed within the required range. Modifying the flow rate by adjusting the outlet vane is by far less economical than changing the pump rotational speed.

A clear image of an optimum operation mode can be obtained by overlapping the pump operation characteristic at variable rotating speed on the pipe network operation characteristic.

A variable rotating speed pump installed in a hydraulic loop and a real time computerized data acquisition system was used in order to perform the experimental investigation.

Introduction

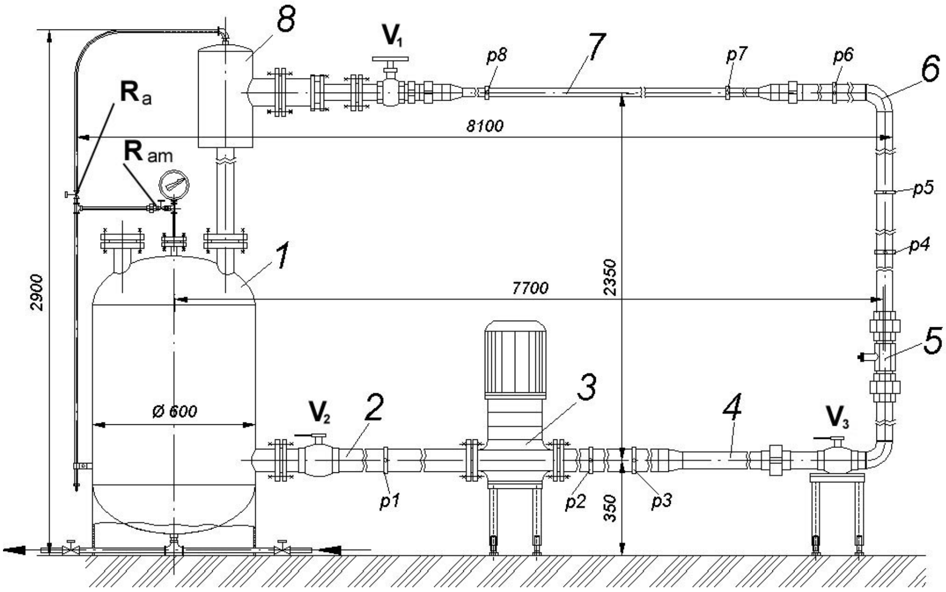
Economical and social development of the cities leads to capital changes in the daily and annual water consumption. The water supply is assured by one or more pumping stations. The adaptation of the operating parameters of the pumping stations to the dynamic of the consumption and the most efficient exploitation is a serious challenge for the decision factors from local administration.

In order to take the best decisions it must be followed the next steps:

- Measurement of the operating parameters of the pumping station in the operating conditions at the present moment
- Measurement of the energetic operating characteristic of the pumps
- Identification of the present exploitation domain
- Determination of the optimal operating point which satisfies completely consumers' requirements at a minimum cost

The Hydraulic Machinery Laboratory of "POLITEHNICA" University of Timisoara has a real time computerized data acquisition system which uses the program LabView 5.1 and the portable equipment P22 for the measurement of the energetic parameters of a centrifugal pump, based on the thermodynamic method. In order to set a general testing method, which can be applied to any pumping system, a case study was released on a closed hydraulic loop from a test facility at the Hydraulic Machinery Laboratory. This hydraulic loop is fully equipped with modern measuring instruments for the testing of the pump and for fluid mechanics experiments.

Figure 1. Multifunctional installation in closed loop (without the measuring instruments)



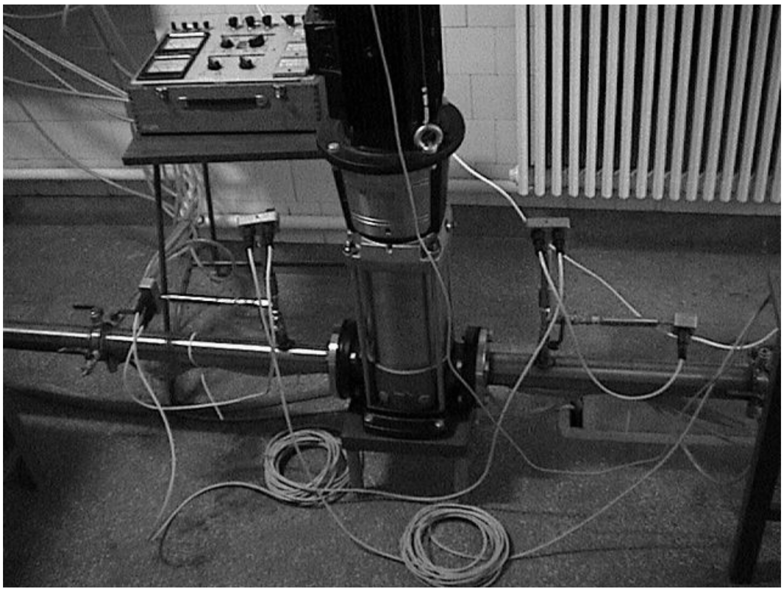
Description of the experimental installation and of the measuring instruments

The installation contains the following parts:

1- A suction buffer water tank with a capacity of 200 l which represents a reserve of liquid for taking up the heat resulted from the hydraulic losses so that the temperature of the working liquid to raise relatively slow

2, 4- Four pipes, with a nominal diameter D=65 mm, for the connection of the pump with the hydraulic loop. On these pipes at a distance of 10D from the pump suction and delivery nozzles are assembled pressure wall-taps for the measurement of the pressure with LabView applications so that to avoid the disturbance effect of the pump on the sections with the pressure wall-taps. The hydraulic losses on the two sections with length L_a, L_r are compensated through the pressure drop on section with the length L_c (figure 2)

Figure 2. Connecting diagram of the pressure probes for the pump testing



For the equipement that uses the thermodynamic method are necessary tapping points to measure the differential temperature and pressure across the pump, fitted with a ½ inch ball valve (or equivalent on either side of the pump), about 2 pipe diameters away from the pump flanges. The temperature probes are inserted into the flow, and the pressure sensors are mounted on a T-piece, fitted to the gate valve.
The temperature probe tips are made from copper, to improve heat transfer and the accuracy of temperature measurement. The temperature probe calibration is valid over the range 0-45°C. These probes are for use in thermowells only. The thermowell is angled downwards, so light machine oil is added to displace the air, and improve thermal conduction.
The pressure sensor is manufactured by Keller. The calibration is referenced to atmospheric pressure (gauge). The inlet (suction) pressure probe has a range of 0 - 2.5 bar. The outlet (discharge) pressure probe has a range of 0 - 15 bar. The calibration is most accurate over the range 0 - 40°C.
3- The centrifugal pump is a multistage in line pump, type CRNE 32-4 produced by Grundfos. The electrical equipment of the pump contains a frequency converter which permits the control of the rotational speed of the pump in 20 steps between 500 and 2900 rot/min. At the same time an adjusted speed is automatic maintained independent of the charge given by the adjustments from the hydraulic loop.
5- A flow meter with a special transducer based on Hall effect has been used. The signal given by the transducer is an impulse having a constant equal with 11,36 imp/l.
6, 7, 8- Sections for the experimental determination of the local and distributed hydraulic losses.
The measurements of the energetic characteristics of the pump can be made with the thermodynamic method and for verifying these results the parameters of the classical method are measured: pressures, flow rates, electrical consumed power and rotational speed. The used probes are connected to a real time computerized data acquisition system.
The program used for data acquisition is LabView 5.1. LabView contains application libraries for data acquisition, for data analysis and for data visualisation. LabView also includes tools for developing the applications so that data flux through the application can be visualised and the application can be ran step by step for a better debugging.

The energetic characteristics of the tested pump

In a first phase there were tested the energetic parameters Q, H, P_S measured and calculated with the classical method and then these parameters were compared with those obtained with the thermodynamic method. It results a good overlapping of the results. The differences were in the range of errors. Then these parameters were compared with the reference data given by the pump producer. The tests were made at 3 different rotational speeds so that the pump operation characteristic can be obtained. The rotational speeds were: n_1=2900 rot/min as a maximum reference speed (100%), n_2=2320 rot/min (80%) and n_3=1740 rot/min (60%).

$$\eta_{i,pump} = \frac{P_{deliver}}{P_{deliver} + P_{loss}} = \frac{\Delta h_{t,deliver}}{\Delta h_{t,deliver} + \Delta h_{t,loss}}$$

$$= \frac{\frac{1}{\rho}\cdot(p_O - p_I) + \frac{1}{2}\cdot(v_O^2 - v_I^2) + g\cdot(z_O - z_I)}{\frac{1}{\rho}\cdot(p_O - p_I) + \frac{1}{2}\cdot(v_O^2 - v_I^2) + g\cdot(z_O - z_I) + \Delta h_{t,loss}} \tag{1}$$

$$\eta_{Pump} = \frac{Q \cdot \left[(p_O - p_I) + \frac{\rho}{2} \cdot (v_O^2 - v_I^2) + \rho \cdot g \cdot (z_O - z_I) \right]}{P_S}$$
$$\Leftrightarrow Q = \eta_{Pump} \cdot \frac{P_S}{(p_O - p_I) + \frac{\rho}{2} \cdot (v_O^2 - v_I^2) + \rho \cdot g \cdot (z_O - z_I)} \quad (2)$$

O- outlet
I- inlet
In figure 4 and 5 is shown pumping head vs. flow rate and pump efficiency vs. flow rate. These results were obtained with the thermodynamic method and were compared with the reference data.

Figure 4. Pumping head vs. flow rate, measured and given by the pump producer

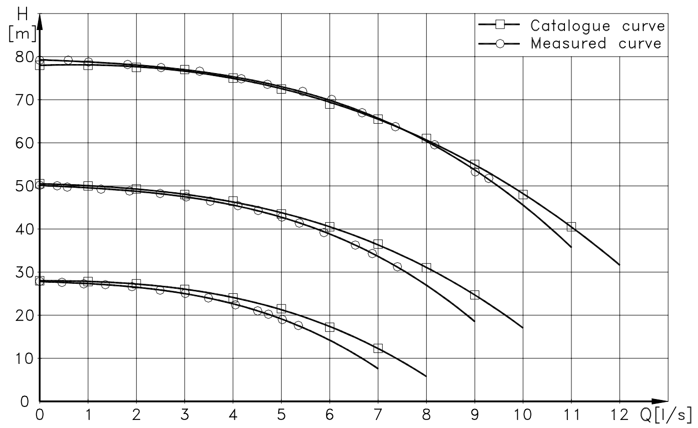
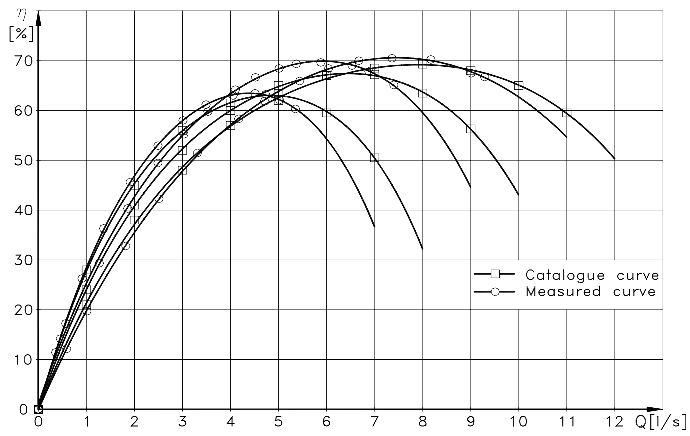


Figure 5. Pump efficiency vs. flow rate, measured and given by the pump producer



Our experimental results obtained with the thermodynamic method are in a good agreement with reference data. Bigger deviation it is observed at maximum flow rates where it seems that the tested pump is a bit different than the prototype for which the data are given by the pump producer.
The interpolation curves are polynomial regression of the 3rd order for pumping head and the 4th or 5th order for pump efficiency.
With these two curves we can build the pump operation characteristic which gives us information about the optimum operating points of the pump. The identification of the equal efficiency curves was made analytical, using a program developed by us and the graphic postprocessor program used was developed in AutoCAD under AutoLisp.
The results obtained for the pump operation characteristic are shown in figure 6 and 7 according to the reference data and those measured with the thermodynamic method.

Figure 6. The pump operation characteristic according to reference data

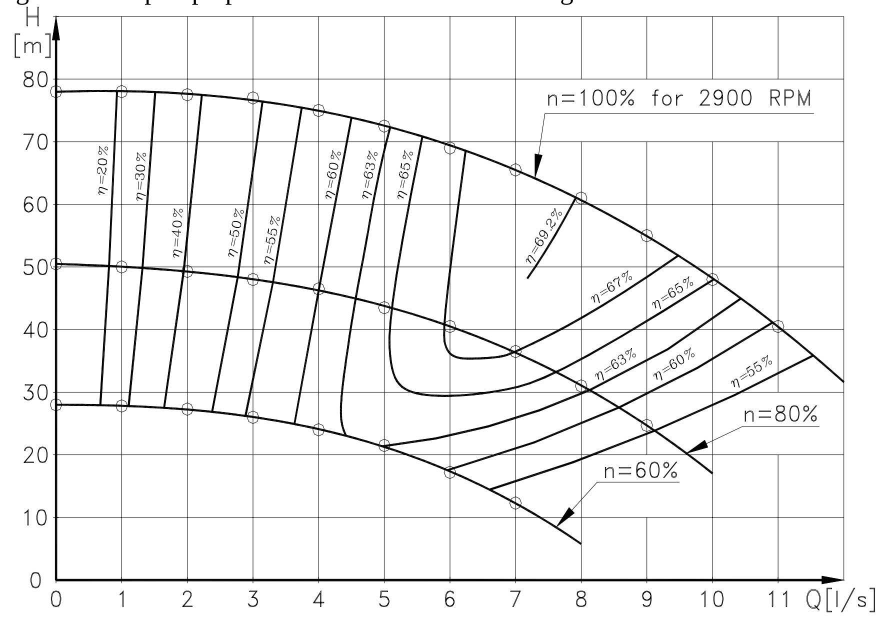
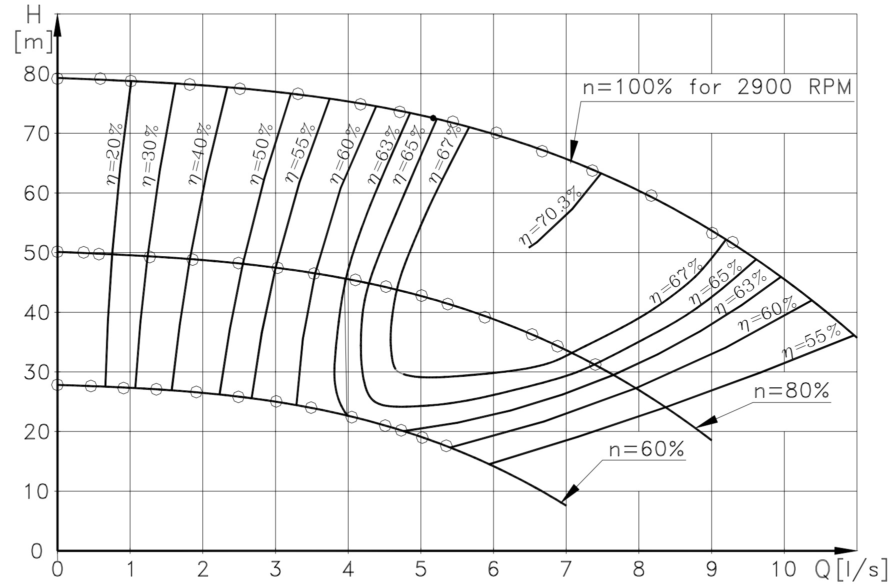


Figure 7. The pump operation characteristic according to measured data with the thermodynamic method



The pipe network operation characteristic, H_{ec}, represents the amount of the losses from the hydraulic loop exterior to the pump and it is calculated with the formula:

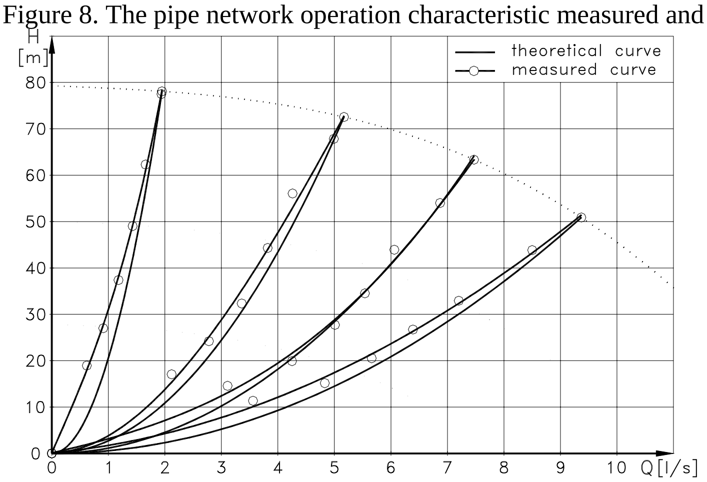
$$H_{ec}=H_g+C_d \cdot Q^2 \tag{3}$$

H_g- geodesic pumping head
C_d- losses constant
The losses constant is calculated for an operating point measured from the pump characteristic knowing that $H_{ec}=H$ and from equation (3) results:

$$C_d = \frac{H - H_g}{Q^2} \tag{4}$$

For the installation from the laboratory, being a closed loop, $H_g=0$. The other points of the pipe network operation characteristic are calculated giving values to flow rate from zero to the measured flow rate.
Having an installation with variable rotational speed, the pipe network operation characteristic was obtained adjusting the flow rate through the modification of the rotational speed. The results are presented in figure 8.

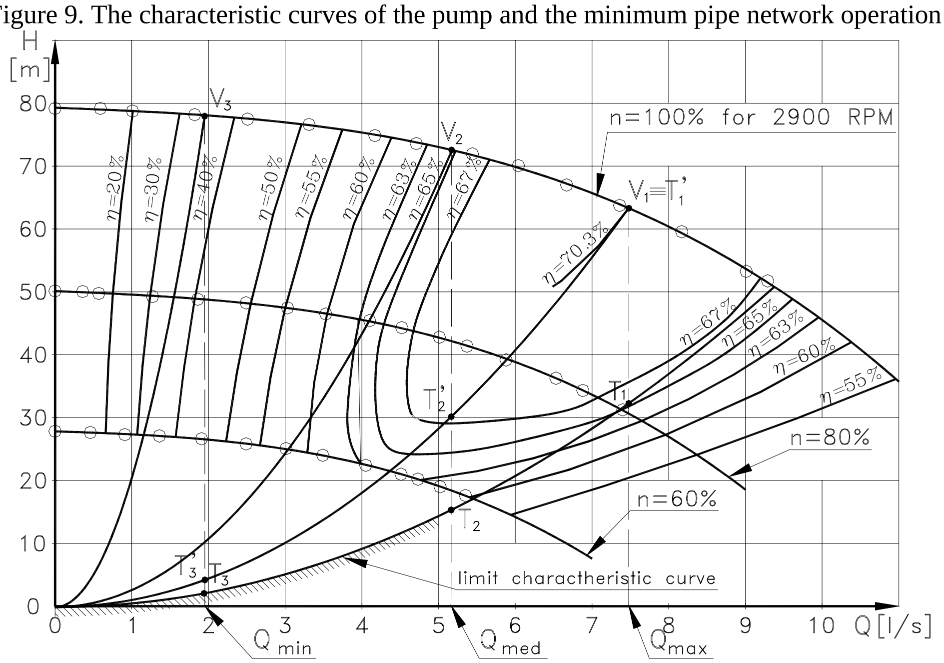
Figure 8. The pipe network operation characteristic measured and calculated



A case study on energy saving from the adjusting flow rate through rotational speed instead of adjusting flow rate through the outlet vane

The pumping station behaviour results by overlapping the pump operation characteristic at variable rotating speed on the pipe network operation characteristic. A minimum flow rate Q_{min}, a medium flow rate Q_{med} and a maximum flow rate Q_{max} can be estimated by tacking into account the requirements of the consumers from a network supplied by the pumping station. The share of these flow rates in the exploitation is expressed in percents through a coefficient, C_p, which results from a statistical study.

Figure 9. The characteristic curves of the pump and the minimum pipe network operation characteristic



If we want to adjust the flow rate only through the variation of the rotational speed it means that the outlet vane it is in the completely opened position (minimum resistance) like in figure 9.

Adjusting the flow rate through the outlet vane the operating points for the 3 flow rates are V_i (figure 9). The same flow rates, if we obtain them through the adjustment of the rotational speed will be T_i. The shaft-power is calculated with the formula (5):

$$P_S = \frac{P_u}{\eta_{pump}} = \frac{\rho g Q H}{\eta_{pump}} \quad (5)$$

At the given operating flow rates, the difference of electrical consumed power ΔP_{abs} results from the difference of the electrical consumed power calculated in the operating points adjusted through the outlet vane (V_i) and in the operating points adjusted through the rotational speed (T_i), figure 9. Taking into account the efficiency of the electrical motor, η_{EM}=85%, from the equation (6) results:

$$\Delta P_{abs} = \frac{\rho g Q}{\eta_{EM}} \left(\frac{H_{V_i}}{\eta_{V_i}} - \frac{H_{T_i}}{\eta_{T_i}} \right) \quad (6)$$

The difference of consumed energy in the exploitation of the pumping station through the two methods of adjusting the flow rate is calculated with the formula:

$$\Delta E = \Delta P_{abs} \cdot N_{dy} \cdot N_{hd} \cdot C_P \quad (7)$$

N_{dy}- number of the days from a year (365)
N_{hd}- number of hours from a day (24)
The results obtained for the 3 operating flow rates are presented in the table 1

Table 1.

C_p [%]	Q [l/s]	H_V [m]	H_T [m]	η_V [%]	η_T [%]	P_{abs_V} [kW]	P_{abs_T} [kW]	ΔP_{abs} [kW]	ΔE [kWh]
20	1,95	78,00	2,00	34	35	5,16	0,13	5,03	8.820,23
70	5,17	72,50	15,30	65	58	6,66	1,57	5,08	31.158,32
10	7,47	63,25	32,25	70,3	65,5	7,76	4,24	3,51	3.076,39
ΔE_{tot}									43.054,94

Also it was analyzed the situation which characteristic of the installation is fixed to operate at Q_{max} and the flow rate adjustment through rotational speed will be made on this characteristic (points T_i', figure 9).

Table 2.

C_p [%]	Q [l/s]	H_V [m]	H_T [m]	η_V [%]	η_T [%]	P_{abs_V} [kW]	P_{abs_T} [kW]	ΔP_{abs} [kW]	ΔE [kWh]
20	1,95	78,00	4,15	34	37	5,16	0,25	4,91	8.603,29
70	5,17	72,50	30,15	65	67,5	6,66	2,67	3,99	24.467,28
10	7,47	63,25	63,25	70,3	70,3	7,76	7,76	0,00	0,00
ΔE_{tot}									33.070,58

Most of the pumping stations work in opened hydraulic loop. That is why in this study we simulated a situation when the pumping station would be in an opened hydraulic loop and would have a geodesic pumping head of 20m, (see figure 10).

For this situation it remarks that the exploitation of the pumping system in the same conditions with flow rate adjustment through rotational speed leads to a significant energy saving as shown in table 3 and 4.

Figure 10.

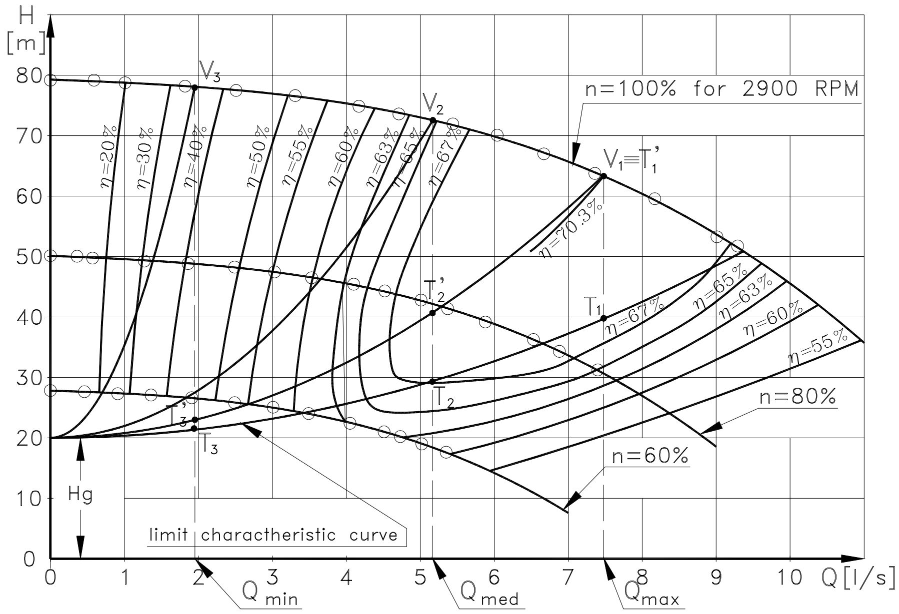


Table 3.

C_p [%]	Q [l/s]	H_V [m]	H_T [m]	η_V [%]	η_T [%]	P_{abs_V} [kW]	P_{abs_T} [kW]	ΔP_{abs} [kW]	ΔE [kWh]
20	1,95	78,00	21,35	34	44	5,16	1,09	4,07	7.132,32
70	5,17	72,50	29,35	65	67	6,66	2,61	4,04	24.782,20
10	7,47	63,25	39,75	70,3	67,8	7,76	5,05	2,70	2.367,11
ΔE_{tot}									34.281,63

Table 4.

C_p [%]	Q [l/s]	H_V [m]	H_T [m]	η_V [%]	η_T [%]	P_{abs_V} [kW]	P_{abs_T} [kW]	ΔP_{abs} [kW]	ΔE [kWh]
20	1,95	78,00	23,00	34	45	5,16	1,15	4,01	7.030,27
70	5,17	72,50	40,65	65	68	6,66	3,57	3,09	18.937,78
10	7,47	63,25	63,25	70,3	70,3	7,76	7,76	0,00	0,00
ΔE_{tot}									25.968,05

Conclusions

- From this study results that flow rate adjustment through the variation of the rotational speed leads to a significant energy saving. The difference calculated take in consideration that the difference of efficiency and the difference of power is proportional with the cube of the rotational speed ratio.
- The thermodynamic method it proves to be very efficient and precise in monitoring a pumping station.
- Using the P22 equipment for the determination of the efficiency of a centrifugal pump we obtained reliable results which prove that the equipment can be use for future industrial applications.

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