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Method of Evaluation of Efficiency Improvement Potential for District Heating Systems with Focus on Variable Speed Centrifugal Pumps

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Abstract: The goal of this research is the derivation of method for evaluation of efficiency improvement potential for district heating systems with focus on variable speed centrifugal pump. The effectiveness of the usage of the proportional pressure control is compared with the constant pressure control. This is why, energy calculation analyses have been realized for variable speed centrifugal pumps, and the theoretical tool of estimation of the effectiveness improvement potential has been derived using the correlation research method. The conclusions are: the 11.2 GWh in total or 58.3% of the annually consumed electrical energy by variable speed centrifugal pumps can be saved up in low scale district heating systems in Latvia, if proportional pressure control is used with the deviation of 80%.

Keywords: Centrifugal Pump, Control Mode, Efficiency, District Heating

1. Introduction

About10% of the total electrical energy produced in the world has been consumed by pumps and pumping systems and almost half of that can be saved up [1].

It is very important to determine the space for improvement for district heating systems with a focus on variable speed centrifugal pumps.

Approximately 6.94 TWh of heat energy is annually produced at all district heating systems in Latvia [2]. About 1.9 TWh of heat energy is annually produced at towns and cities with the population of up to 10000 inhabitants. It has been assumed that about 19.2 GWh of annually consumed electrical energy comes to network pumping systems for transmission and distribution of heat energy in small district heating systems [2].

Main circulators in district heating systems are traditionally controlled via constant differential pressure or proportional pressure control mode. The district heating systems are closed hydraulic systems and the proportional pressure control mode can mainly be handled nearly hydraulic system curve. The closer proportional pressure control curve is to the system curve, the higher level of efficiency can be obtained. In order to make an evaluation of effect-tiveness improvement potential for district heating systems the proportional pressure control has been compared with the constant differential pressure control [3-5].

The usage of the proportional pressure control mode for variable speed centrifugal pumps at district heating systems in small cities (up to 10000 inh.) in Latvia is shown in Fig. 1.

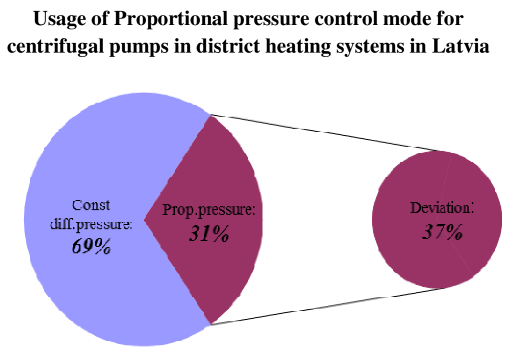

Fig. 1. Usage of proportional pressure control mode vs. constant differential pressure control mode for centrifugal pumps in district heating systems in Latvia.

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It is important to evaluate the energy improvement potential of 69% of main circulators in small district heating systems. And it is possible to estimate the saving potential if the deviation from head value of duty point at zero flow will vary from 37% up to 80%. It has been assumed that 20% of head value is related to control valves in the systems. With focus on the evaluation of pumps' operation, it's possible to increase the efficiency of district heating networks, thus contributing to energy saving.

2. Development of the evaluation method of efficiency improvement potential

During the development of the method for evaluation of efficiency improvement potential for district heating systems the proportional pressure control mode has been compared to the usage of constant differential pressure control mode.

In order to analyze the consumption of electrical energy, if proportional pressure control mode with the deviations from head value of duty point at zero flow rate is used as it is seen from Fig. 2, the load profile of pumping system for certain part of district heating system should be taken into account.

It has been assumed that annual operation of pumping system in district heating systems is 6840 hours and the load profile is divided into four parts with the flow values: 100%, 75%, 50% and 25% of flow rate in duty point as it's shown in Table 1 [6,7]. Each flow rate corresponds to certain duration of operational time as a part of the total duration of operation per year [8,9].

Each flow component corresponds to certain duration of operational time(Fig. 3):

- 100% -> 6%;
- 75% -> 15%;
- 50% -> 35%;
- 25% -> 44%.

The energy consumption has been analyzed if proportional pressure control mode comes as an alternative to constant differential pressure control mode for the same system.

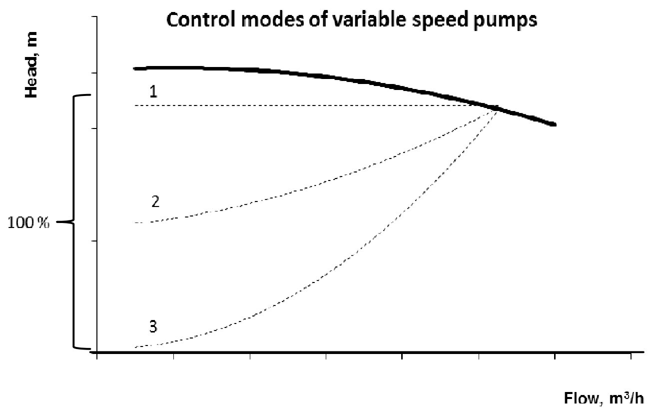

Fig. 2. Control modes for circulators in district heating systems. 1- constant differential control; 2 and 3 - proportional pressure control with square influence.

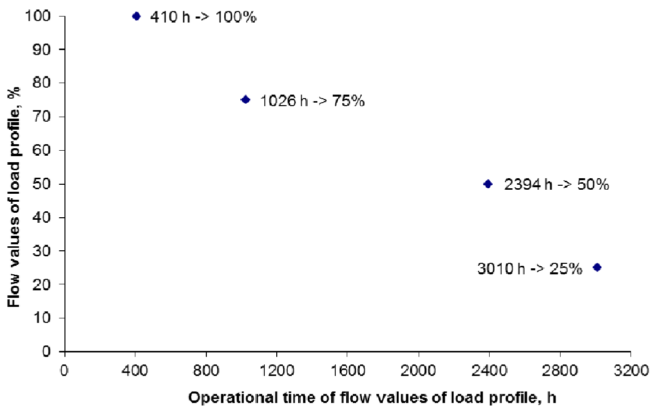

Fig. 3. Load profile of main circulators in district heating system according Blue Angel Profile.

Eqs. (1-6) show the relationships among rotational speed, flow rate, head, power and efficiency values when variable speed drive is used for centrifugal pumps [10-13].

$$\frac{Q_n}{Q_x} = \frac{n_n}{n_x} \qquad (1)$$

$$\frac{H_n}{H_x} = \left(\frac{n_n}{n_x}\right)^2 \qquad (2)$$

$$\frac{P_n}{P_x} = \left(\frac{n_n}{n_x}\right)^3 \qquad (3)$$

$$\frac{\eta_n}{\eta_x} = 1 \qquad (4)$$

$$\eta_{TOT} = \eta_P * \eta_M * \eta_{FC} \qquad (5)$$

$$\eta = \frac{P_H}{P_1} = \frac{\rho * g * Q * H}{P_1} \qquad (6)$$

The Table 1 shows the change of head values at the flow divisions at the deviations within the range of 0-100% from head value of duty point at zero flow [14].

During the analysis of the proportional pressure control mode with the deviations of 20%, 40%, 60%, 80% and 100% from head value of duty point at zero flow there has been carried out the calculation of annual energy consumption for centrifugal pumps (Fig. 4.).

It is found, that the regression Eq. (7) of the linear trend type ($y = a_0 + a_1 * x + \varepsilon$) can evaluate the effectiveness improvement potential for district heating systems with variable speed centrifugal pump, if proportional pressure control is used.

$$y = (0.7 \pm 0.01) * x + 0.02 \pm 0.01 \qquad (7)$$

The Eq. (7) can be used as a tool for evaluation of the potential reduction of energy consumption, if proportional pressure control is used with the deviations within the range of 0-100%.

The potential reduction of the energy consumption is estimated in comparison with the usage of constant differential pressure control mode, if the value of duty point remains invariable.

There are various limitations which have been taken into consideration during the energy consumption. The limitations are as follows:

- Calculated proportional pressure control mode with square influence has been chosen.
- Each duty point is met with appropriate pump.
- The deviation from pump efficiency optimum is up to 3% for each duty point.
- The deviation from head value of duty point at zero flow varies from 0 to 100%.

During the study the energy analyses of 8 variable speed centrifugal pumps have been realized.

Table 1. Deviations from head value of duty point if proportional pressure control mode is used with square influence

Deviationsfrom headvalue of dutypoint at zero flow (%)	Flow division (%)			
	100	75	50	25
0	100	100	100	100
20	100	91	85	81
40	100	82	70	63
60	100	74	55	44
80	100	65	40	25
100	100	56	25	6

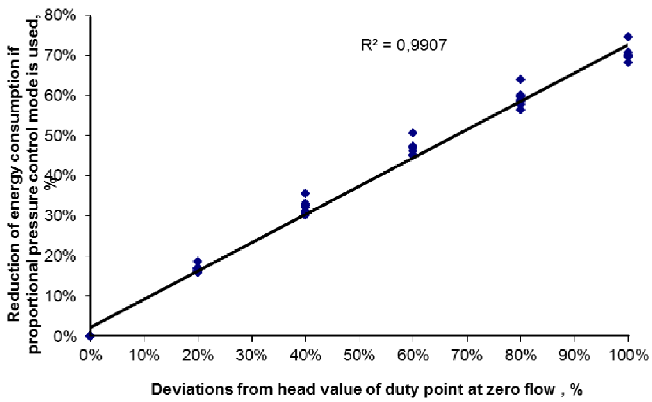

Fig. 4. Reduction of energy consumption, if calculated proportional pressure control is used with the deviations within the range of 0-100% from head value of duty point at zero flow in comparison with constant differential pressure control mode.

3. Verification of the evaluation method of efficiency improvement potential

The measurements were done in the district heating system with parameters:

- Heat power demand is 12.75 MW.
- Design differential temperature is 15 °C.
- Design outside temperature is -20 °C.
- Design inside temperature is 20 °C.
- Design differential pressure from boiler house is 18 m.
- Quantity of buildings in the system is 196 units.
- Length piping network is 18 km.
- Operation time of the existing boiler house in Estonia is 5640 h/year.

Main circulator centrifugal pumps are described with the following parameters:

- 2 main pumps (1 – duty, 1 – stand by).
- Each pump is equipped with an external frequency drive.
- Each pump is with nominal flow/head: 750 m^3/h; 28 m.
- Each pump has a motor of P_2=90 kW.
- Each pump has a maximum efficiency (BEP) of 77 %.
- Proportional pressure control mode (constant differential pressure from the boiler house is 18 m).

During the investigation flow, head, temperature and energy consumption have been measured: electrical. Each of these parameters used to be measured every 10 minutes during 3 days with the deviation of proportional pressure control mode (as for monitoring). In overall the measurements have been realized during 2 years at the boiler house.

Electrical energy consumption (kWh) is shown in Fig. 5, if the deviation is 35.7% and 64.3%.

Proportional pressure pump control mode was realized at the certain deviations of the head value from the duty point at zero flow (from 18 m or 35.7% to 10 m or 64.3%).

During the analysis of variable speed pump the flow variation was from 190 m^3/h up to 750 m^3/h. Within the flow variation the differential pressure are being changed from 1.1 bar up to 2.8 bar (Fig. 6).

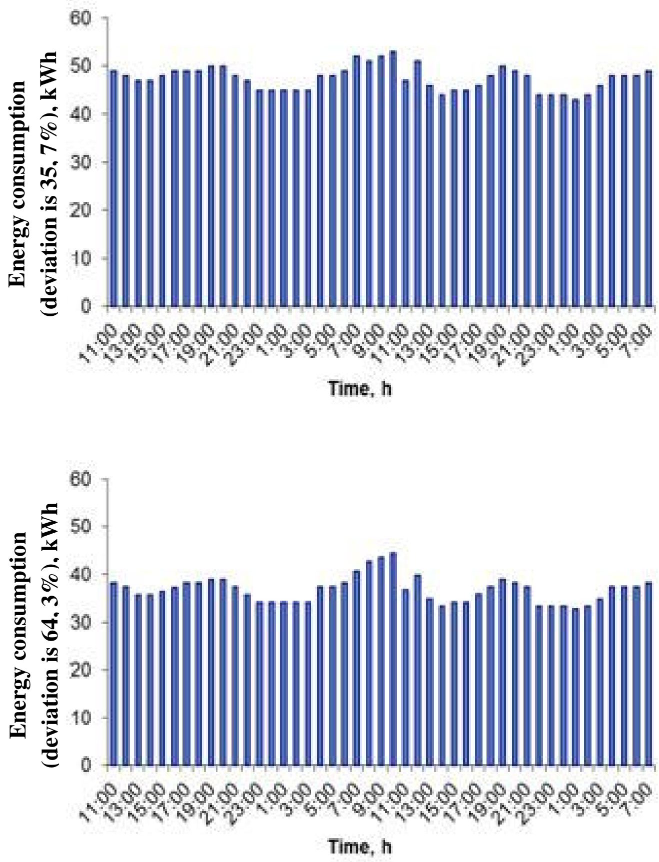

Fig. 5. Pump energy consumption if proportional pressure control mode has been realized with

the deviations of 35.7% and 64.3%.

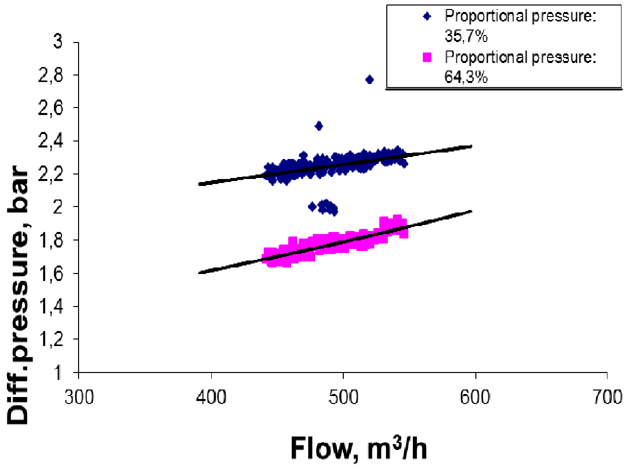

Fig. 6. The pump flow and head during the proportional pressure control mode with the deviations of head value from duty point at zero flow.

It has been found that the efficiency has been improved by 30.2%, (if proportional pressure is used with the deviation of 35.7% – 189000 kWh/year; if proportional pressure is used with the deviation of 64.3% – 132000 kWh/year).

By applying the evaluation tool (evaluation method of savings' potential if proportional pressure control mode is applied for main circulators in comparison with constant differential pressure control mode) and making additional calculations, the pump efficiency profential will be improved by 27.4%:

$$y = 0.7 * x + 0.02 = 0.7 * 0.357 + 0.02 \approx 27\%$$

$$y = 0.7 * x + 0.02 = 0.7 * 0.643 + 0.02 \approx 47\%$$

Accuracy within 9.3% is performed if the theoretical evaluation tool has been compared with on the field measured data at district heating system.

4. Conclusions

19.2 GWh of annually consumed electrical energy comes to variable speed centrifugal pumps, 69% of main circulators are operating via constant differential pressure control mode, and the average deviation from head value of duty point at zero flow is 37% (can achieve 80%), then the saving potential has been calculated for small district heating systems in Latvia. In this research it has been found that 3.5 GWh of annually consumed electrical energy can be saved up, if the control mode of variable speed main circulators will be changed from constant differential pressure to proportional pressure control mode with the deviation of 80% from head value of duty point at zero flow.

7.7 GWh of annually consumed electrical energy can be saved, if the proportional pressure control mode with the deviation of 37% will be changed to the deviation of 80%.

Totally 11.2 GWh or 58.3% of the annually consumed electrical energy by variable speed centrifugal pumps can be saved up in small district heating systems in Latvia.

Nomenclature

- g — Acceleration of gravity (9.81 m/s^2)
- H — Pump head (m)
- P_1 — Pump motor input power (kW)
- P_H — Power delivered to pumped liquid (kW)
- Q — Flow rate (m^3/s)
- R^2 — Coefficient of determination
- x — Deviation from head value of specific duty point at zero flow (%)
- y — Reduction of energy consumption if the calculated proportional pressure control with deviations from head value of duty point at zero flow is applied, in com-

parison with constant differential pressure control mode (%)

η_P	Efficiency of pump (%)
η_M	Efficiency of motor (%)
η_{FC}	Efficiency of frequency converter (%)
η	Efficiency of complete pump unit: pump and motor (%)
η_{TOT}	Total efficiency of complete pump unit with frequency converter (%)
ρ	The density of the pumped liquid (kg/m^3)

Glossary

- Efficiency: the ratio between useful power and input power;
- Circulators: centrifugal pumps which provide ensure liquid circulation process in HVAC systems;
- Duty point: the intersection of the pump H-Q and the system H-Q curves.
- Small district heating systems: the population of towns is up to 10000 inhabitants.

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