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The Effect of Reducing Supply Temperature in Fourth Generation District Heat Networks on Design of In-house Heat Substations

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Abstract

Lowering the district heating supply temperature is crucial for improving the efficiency of the heat network. A recently developed concept of the fourth generation low temperature district heating with supply temperature just above the required secondary conditions allows for heat loss reduction, increases the plant room efficiency and enables more efficient integration of alternative energy sources for energy production. This paper aims to determine the requirements and constraints for increasing the efficiency of in-house heat substations to enable the implementation of next generation heat networks. Heat transfer calculation software tools are used to analyze the impact of the domestic hot water peak capacity, cold and hot water temperatures, district heating flow and return temperatures and pressure drop limitations on the design of in-house heat substations. Challenges associated with low primary temperature have been identified in this paper from the perspective of in-house heat substation performance, comprising the increase of primary flow rate due to lowered primary temperature difference, and the resulting the pressure drop across the components. It is concluded in this paper that by utilizing the plate heat exchanger technology available, it is achievable to design and implement heat substations that are capable of producing instantaneous domestic hot water at safe temperatures with minimized approach flow temperature to 3-5°C.

Keywords - district heating, low temperature, heat substation, heat exchanger

1. Introduction

The heat network supply temperature is the parameter that significantly affects and limits the efficiency of the district heating system, therefore a concept of fourth generation heat network has been developed, where primary supply temperature is lowered to below 55 °C. This increases the efficiency of heat networks by reducing the distribution heat loss and allows the implementation of renewable and low carbon emission energy source. The supply temperature reduction is limited to a temperature that will ensure that the end-user's space heating and domestic hot water comfort temperatures are achieved. A number of fourth generation heat network pilot projects have proven that the district heating supply temperature can be reduced to 55 °C and lower all year around without sacrificing the end-user's comfort. [1] Current heat networks in Europe operate with supply temperatures of up to 110 °C in winter and 65 °C in summer depending on the local conditions. [2]

To allow for the reduction in supply temperature in fourth generation heat networks requires, a lower flow and return temperature approach across the in-house heat substations is necessary for instantaneous domestic hot water production. The minimum supply domestic hot water temperature is set in national standards, due to the Legionella bacteria outbreak risk. This paper focuses on challenges placed on in-house heat substation design, due to lowered temperature approach and increased primary flow rate for instantaneous domestic hot water production.

The minimum hot water temperature is defined in Danish Standard 439 as 50 °C allowing the temperature to drop to 45 °C during peak periods. [3] German Technical regulations DVGW 551 makes no requirement if the overall hot water volume is below 3 liters. [4] British Standard BS 5885 requires 50 °C delivered to the hot water outlets or thermostatic mixing valves. [5] Previous studies of hot water production in low temperature heat networks are based on 'the rule of 3 liters' [6], however in this paper, the minimum hot water temperature is assumed to be 50 °C to reflect current requirements in heat substation design.

In-house heat substations are designed to provide hot water and heating typically for a single family home. In this study three scenarios have been considered for the peak domestic hot water draw off at 10, 12 and 14 liters per minute at 50 °C and the cold water temperature is assumed to be 10 °C.

In this study, selection of plate heat exchangers based on the flow temperature approach of 1, 2, 3, 4 and 5 °C in combination with return approach temperature from 5 to 15 °C in 1 °C steps, is carried out.

To demonstrate the impact on sizing of the plate heat exchangers used in heat substations on comparison to a typical existing systems, the reference conditions have been selected and are as follows: primary supply temperature 70 °C, return temperature 25 °C. [7]

Table 1. Nomenclature

Δp	total primary side pressure drop of the heat substation, kPa
LMTD	logarithmic mean temperature difference in heat substation, °C
ΔT_A	flow temperature approach of the heat substation, °K
ΔT_B	return temperature approach of the heat substation, °K

2. Methods

The heat-transfer calculation software tool provided by the plate heat exchanger manufacturer is used to select the plate heat exchanger at the defined conditions. [8] Other manufacturer plate heat exchanger tools are used to verify that the results are valid and similar. [9] The plate heat exchanger is selected based on the conditions described below.

A. *Turbulent fluid flow*

The plate heat exchanger is selected to ensure the turbulent flow of fluid within both primary and secondary sides of the plate heat exchanger to ensure the heat transfer and self-cleaning effect for the plate heat exchanger. Turbulent flow in brazed heat exchangers is ensured when the Reynolds number for the fluid is greater than 150. [10]

B. *Total pressure drop*

The total pressure drop across the primary side of the heat substation is calculated with the selected plate heat exchanger at the peak conditions, this includes the following components:

- Pipework differential pressure Δp_p - typical stainless steel DN20 pipework pressure drop calculations are used for this study. It is ensured that the velocity does not exceed 1.5 m/s;
- Heat meter differential pressure Δp_{hm} - the typical heat meter used for a single family home heating and domestic hot water operates with k_{vs} value of 3. [11]
- Control valve differential pressure Δp_{cv} - different types of control valves currently are used for in-house heat substation demand modulation. In this study, a fixed value of minimum differential pressure of 25 kilopascals is used for all the scenarios.
- Plate heat exchanger differential pressure Δp_{phe} - the plate heat exchanger is selected with the maximum differential pressure of less than 20 kilopascals.

The total pressure drop of the heat substation components is calculated as follows:

$$\Delta p = \Delta p_p + \Delta p_{hm} + \Delta p_{cv} + \Delta p_{phe} . \tag{1}$$

According to industry guidelines the pressure drop of the heat substation and fitting should be within 30 to 50 kPa, therefore, if the total pressure drop exceeds this value, a plate heat exchanger with a lower operating pressure drop is selected:

$$\Delta p < 50 . \tag{2}$$

C. *Volumetric size and weight*

It is assumed that the weight of the plate heat exchanger is proportional to its cost, and the size of it will directly affect the size of the heat substation and therefore the cost of it. From available plate heat exchangers that meet the conditions set out in paragraphs above, the one with the lowest weight and the smallest dimensions is selected.

The implication of the reduction of the flow and return approach temperatures on the in-house heat substation size and cost is expressed by the volumetric size increase ratio and weight increase ratio, expressed as ratio of the size or weight of the selected plate heat exchanger in comparison to a typical system operating at 70/25 °C conditions. The results of the size and weight increase ratios are demonstrated depending on the logarithmic mean temperature difference LMTD that is dependent on the flow and return temperature approach ΔT_A and ΔT_B:

$$LMTD = (\Delta T_A - \Delta T_B) / (\ln\Delta T_A - \ln\Delta T_B) \quad (3)$$

The table below shows the LMTD conditions the calculations have been carried out for, based on the cold inlet temperature 10 °C and domestic hot water temperature 50 °C. The calculations are carried out for three loads 10, 12 and 15 liters per minute, therefore in total 225 conditions have been reviewed.

Table 2. LMTD depending on the flow and return temperature approach, DHW at 50°C and cold inlet 10°C

LMTD, °K		Flow temperature approach, °K				
		1	2	3	4	5
Return temperature approach, °K	5	2.49	3.27	3.92	4.48	5.00
	6	2.79	3.64	4.33	4.93	5.48
	7	3.08	3.99	4.72	5.36	5.94
	8	3.37	4.33	5.10	5.77	6.38
	9	3.64	4.65	5.46	6.17	6.81
	10	3.91	4.97	5.81	6.55	7.21
	11	4.17	5.28	6.16	6.92	7.61
	12	4.43	5.58	6.49	7.28	8.00
	13	4.68	5.88	6.82	7.64	8.37
	14	4.93	6.17	7.14	7.98	8.74
	15	5.17	6.45	7.46	8.32	9.10

3. Results

As mentioned above the reference conditions have been selected based on the primary flow and return temperatures 70 °C and 25 °C accordingly. LMTD for this case scenario is 17.83 °K. The following are the reference conditions of the selected plate heat exchanger used for further calculations.

Table 3. Reference conditions used for calculations

DHW flow rate	Volumetric size, mm^3	Weight, kg
10 l/min	932,400	1.64
12 l/min	1,030,302	1.75
14 l/min	1,226,106	1.99

The chart below shows the calculated volumetric size increase ratio from the reference conditions depending on LMTD for the three domestic hot water loads.

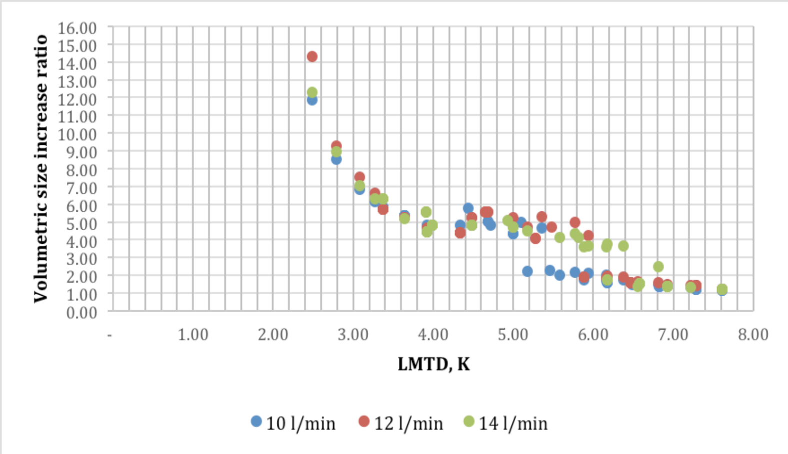

Fig. 1 Volumetric size increase ratio dependency on LMTD, DHW draw off at 50 °C

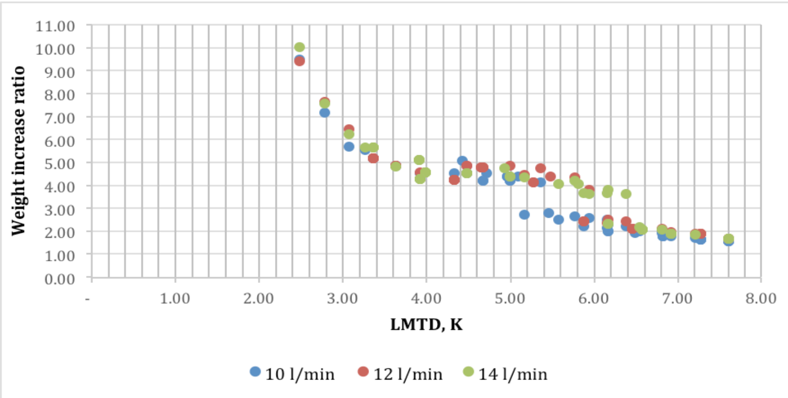

Fig. 2 Weight increase ratio dependency on LMTD, DHW draw off at 50 °C

The figures 1 and 2 above show that the volumetric size and weight increases exponentially as the LMTD is decreased. The break in the tendency of the result trendline is explained by the availability of the plate heat exchanger model only up to a certain size, as well as the requirement to maintain the total pressure drop on the primary side of the heat substation below 50 kPa.

Results show that for 55/21 °C flow and return conditions (LMTD = 7.61 °C) the volumetric size increases 1.18-1.24 times and the weight increases 1.59 to 1.7 times depending on the domestic hot water load.

4. Conclusions

The results demonstrate that with the current plate heat exchanger technology available it is possible to provide instantaneous domestic hot water production for single-family homes in fourth generation district heating networks, however higher investment cost of the heat substations should be considered due to increase of the size and weight of the plate heat exchanger required.

The volumetric size and weight increase ratios are higher for smaller temperature approach, and are lower at 3-5 °C flow approach temperature and 9-15°C return approach temperature.

Results provide figures for further project specific studies, allowing to define the feasible flow and return temperature approach, to ensure that the increase of the investment cost of the project is justified by the lowered system running cost, due to reduced heat loss and implementation of low carbon energy source.

Further studies should be carried out to investigate the performance of selected heat exchangers under a partial and small domestic hot water draw off.

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