Optimization of hot service water temperature

Henrik Gadd
Dept. of Energy Sciences, Faculty of Engineering,
Lund University, Box 118, 22100 Lund, Sweden

ABSTRACT
District heating is used mainly for two purposes: building heating and hot service water heating. New houses have less use of building heating because of improved insulation and recovery of heat in modern building techniques. For district heating companies this result in increasing distribution costs.

One way of reducing the distribution cost would be to use other materials, e.g. plastic, in district heating networks. The temperature in the district heating network then has to decrease because of temperature limitations of the plastic materials. To avoid risk of Legionellosis the temperature of the hot service water may not be below 50°C in any point of the hot service water system.

This work shows that the temperature drop in hot service water pipelines do not exceed 2.5°C even for pipelines as long as 200 m.

INTRODUCTION
In the course MVK 160 Heat- and mass transport one of the tasks is to write a literature survey on a relevant topic. The main subject for the authors PhD-studies is “Future heat demand in district heating systems” In the future the heat demand will decrease and for that reason the distribution of district heating will become more expensive to distribute per MWh. For this reason it will be necessary to find technical solutions to decrease the distribution cost. One possibility is to use other materials in the district heating network pipelines. This on the other hand makes it necessary to decrease the temperature of the water inside the pipelines. There is also a conflict with lower temperatures caused by the temperature demand of hot service water.

NOMENCLATURE

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<thead>
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<th>Symbol</th>
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<tbody>
<tr>
<td>T</td>
<td>temperature [°C]</td>
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<tr>
<td>r</td>
<td>radius [m]</td>
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<tr>
<td>k</td>
<td>thermal conductivity [W/(mK)]</td>
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<td>h</td>
<td>heat transfer coefficient [W/(m²K)]</td>
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<td>Q</td>
<td>Energy [J]</td>
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Greek Symbols

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<tr>
<th>Symbol</th>
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<tr>
<td>ρ</td>
<td>density [kg/m³]</td>
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Subscripts

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<td>i</td>
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PROBLEM STATEMENT
In district heating systems it is of interest to have as low temperatures as possible. Low temperatures increase the efficiency because it can cool off the smoke gas more, it increases the electrical output in combined heat and power plants, the heat losses in the district heating network decrease and if you could lower the temperature enough it would be possible to use other material in the district heating network. Today steal or copper pipes are used, but with lower temperatures plastic pipes could be a possibility. The aim in this work is to determine the lowest temperature of the hot water just after the hot water heat exchanger depending of hot water flow rate, temperature at tap point, hot water pipe dimension and temperature outside of the hot service water pipe.

DISTRICT HEATING
District heating supply more than 60 % of the heat demand in buildings in Sweden. The main reason for introducing district heating was from the beginning safety and reducing air pollution in the cities. Safety because when e.g. coal, coke, oil or wood is used for heat generation an open fire in a boiler is present. Firing of fuels earlier polluted the air in the cities. Instead a heat plant was located outside the city and hot water distributed in pipes under the ground.

With a centralized heat generation it is also easier to clean the flue gases from particles and hazardousness subjects.

With the green house effect a need to phase out fossil fuels and use renewable fuels instead was needed. This has in Sweden been rather easy because of the district heating and large assets of biomass. By changing fuels in relative few heat plants instead of in every building the use of fossil fuels for building heating is nowadays rarely used.

The main sources for heat generation in district heating systems today is waste from households, different types of wood fuels, an also waste heat from industrial processes, mainly from chemical and pulp & paper industries.

District heating systems contain of three major parts:
-Heat plant
-District heating network
-District heating substation

The heat is generated in a heat plant. In several district heating systems waste heat from industrial processes is used as part of the heat generation.

The heat is distributed in insulated pipes under the ground. It is a closed network with one forward pipe and one return pipe. The temperature of the water in the forward pipe is 70-120 °C depending on the outdoor temperature. The return pipe temperature is 40-50°C.

In the buildings a district heating sub station is situated to transfer the heat from the district heating network to the building.[2]
There are normally two heat demands in the building: hot service water and building heat. For these purposes there are two heat exchangers because the two heat demands have different temperature demands and must be distributed in different piping systems in the building.

The hot service water shall have the same temperature all year around but the temperature demand for building heating changes with outdoor temperature.

**Fig 2. Schematic picture of a district heating system with two heat exchangers, one for building heating and one for hot service water. (Source: www.veab.se)**

### 4:TH GENERATION DISTRICT HEATING SYSTEM

Nowadays the third generation of district heating systems are in use.

The 1:st generation of district heating systems was steam systems. There are still some steam systems in use in the word i.e. in Paris and New York.

The 2:nd generation of district heating systems is high temperature water system with a forward pipe temperature of about 150 °C.

The 3:rd generation district heating system is the systems that are used today with a forward pipe temperature of 80-90 °C in most part of the year.

To be able to continue to be competitive in the future to deliver heat to houses with very low heat demands it is necessary to decrease the distribution cost of district heating. This can be solved with a low temperature district heating systems. The 4:th generation district heating system.

With a forward water temperature of 50-60°C it would be possible to use plastic pipes in the district heating network. This would decrease the cost of the district heating network and thereby the distribution cost.

But, there is one limitation that has to be taken under consideration: The temperature of hot service water.

### TEMPERATURES OF HOT SERVICE WATER

For hot water there are three temperature limits:
- Minimum temperature at tap point is 50°C. This is to avoid risk of legionellosis.
- Maximum temperature at tap points is 65°C. This is to avoid scalding.
- For some applications maximum temperature is 38°C.

This is at tap points were the risk of accidents. An example is showers that can’t be thermal controlled at the shower and is used by people that can not be expected to control the temperature themselves e.g. small children. [1]

### LEGIONELLOSIS

Legionellosis is caused by a bacterium that thrives in hot water. The bacteria causes a disease that is a type of pneumonia Legionellosis normally occurs after inhaling aerosol of water e.g. when taking a shower.

Optimum temperature for max growth of the bacteria is 35°C – 45°C. I.e. the same temperature that is preferable when taking a bath or a shower or when washing your hands.

At 50 °C the bacteria can survive but not multiply and at a temperature of 55 °C and above the bacteria will die.

The Legionella bacteria almost always occurs in service water so it doesn’t have to be polluted. [1]

### DEMARCATIONS

- The ambient of the hot water pipe is assumed to be air with a temperature of 20°C (T_a).
- To avoid sound in the water pipelines the velocity of the water inside the pipes should not exceed 1 m/s. All calculations is based on water velocity of 1 m/s.
- To simplify the calculations the temperature drop in the pipe is set to decrease linearly which is acceptable if the temperature drop is small.

### PROJECT DESCRIPTION

The objectives of the project is to show a way to decide the lowest possible temperature for hot service water. The reason is that if the 4:th generation district heating systems shall be possible to build, the forward temperature of the district heating water need to be as low as possible. But because hot service water need to be ≥ 50°C in the whole hot service water system because of Legionellosis risk, the hot water sets the limit of the lowest possible forward temperature of the district heating.

To do this a simple calculation model is made were the temperature loss in the hot service water pipelines is calculated.

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Fig 3 A simple model of a hot water system in a building were district heating is used for hot service water generation.

The temperature $T_h$ is the parameter that is supposed to optimize to supply water temperature at the tap point temperature $\geq 50^\circ C$.

The heat flux radial direction of a pipe is according to [3]

The heat energy loss from the heat exchanger to the taping point is:

$$Q = V \cdot \rho \cdot C_p (T_h - T_f) \quad (1)$$

$$K = V \cdot \rho \cdot C_p$$

$$\Rightarrow \quad \dot{Q} = K \cdot (T_h - T_f)$$

This heat transport through a pipeline according to [3] is:

$$\dot{Q} = \frac{1}{2\pi \cdot r_i \cdot L \cdot h_i} + \frac{1}{2\pi \cdot k \cdot L \cdot \ln \left( \frac{r_o}{r_i} \right)} + \frac{1}{2\pi \cdot r_o \cdot L \cdot h_o} \quad (2)$$

The heat resistance $R$ is defined as:

$$R = \frac{1}{2\pi \cdot r_i \cdot L \cdot h_i} + \frac{1}{2\pi \cdot k \cdot L \cdot \ln \left( \frac{r_o}{r_i} \right)} + \frac{1}{2\pi \cdot r_o \cdot L \cdot h_o} \quad (3)$$

(2) in (3) gives:

$$\frac{Q}{R} = \frac{(T_f - T_a)}{R} \quad (4)$$

Where $T_f$ is the temperature of the water inside the pipeline.

If the pipeline is not very long the temperature drop will be moderate. By this reason a simplification is made:

$$T_f = \frac{T_h + T_a}{2} \quad (5)$$

(4) in (3)

$$\dot{Q} = \frac{T_h + T_a - 2T_a}{2 \cdot R} \quad (6)$$

(1) and (6) gives

$$T_h = \frac{2 \cdot R \cdot K + 1}{2 \cdot R \cdot K - 1} T_f - \frac{2}{2 \cdot R \cdot K + 1} T_a \quad (7)$$

were

$$R = \frac{1}{2\pi \cdot r_i \cdot L \cdot h_i} + \frac{1}{2\pi \cdot k \cdot L \cdot \ln \left( \frac{r_o}{r_i} \right)} + \frac{1}{2\pi \cdot r_o \cdot L \cdot h_o}$$

$$K = V \cdot \rho \cdot C_p$$

In Fig 4 Hot service water temperature drop from the heat exchanger and taping point $(T_h, T_f)$ is plotted verses length of the hot service water pipeline. The hot service water pipeline is a copper pipeline with outside diameters from 15 mm to 35 mm. The pipeline wall thickness is 1 mm and the water velocity is 1 m/s and the pipeline material is copper.

![Fig 4 Temperature drop of hot service water from heat exchanger to tap point.](image)

Fil 4 shows that the cooling of is only 1 or 2 °C even for as long pipelines as 200 meters. i.e. From a Legionellosis point of view the temperature only needs to be 52 °C at the heat exchanger.
LONG PIPELINES

A problem with long hot service water pipelines is that the water in the pipeline cools off between the usages of hot water. This is undesirable because otherwise the pipeline while cool off slowly and the temperature of the water will for a longer period of time be in the optimal range of Legionellosis growth. This is the reason why the hot service water pipelines and heat exchanger are not insulated.

The problem with long uninsulated hot service water pipes is that when it has not been in use for some time e.g. during the night it takes a long period of time before the water is hot enough at the tap point. For single family houses this is normally not a problem since the pipelines do not get very long but in multi family houses with perhaps 4 floors or more there will be very long hot service water pipelines.

To solve this problem an extra pipeline parallel to the hot service water pipeline is installed. This pipe joins the tap point most far from the heat exchanger with the heat exchanger. There the water is reheated. See figure 5.

The water must have a temperature of 50°C when returning to the hot service water heat exchanger [1].

In this case it is preferable to insulate the hot service pipeline together with the pipeline for the circulating hot service water. In this case it is possible to keep the temperature at a level where it is possible to avoid risk of Legionellosis bacteria growth.

Fig 5 cold/hot service water system with circulating hot service water. (Source: www.zeonda.com)
CONCLUSIONS
Even for long (200 m) hot service water pipes the temperature loss is not more than 2-2.5 °C i.e. the temperature of the outgoing water at the hot service water heat exchanger need to be 52-53°C.
If circulating hot service water pipeline is installed and the pipelines are insulated is would be possible to decrease the temperature out from the hot service water heat exchanger but since the lowest allowable temperature is 50°C that possibility is limited.

Note! The heat “loss” from the hot service water pipelines are in most cases not losses for the building. Most part of the year in Sweden there is a heat demand for the building and the heat form the pipelines is just another way to supply the heat.

REFERENCES
[1] Boverket BBR