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Article

Distribution of district heating: 2nd Generation

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Distribution of district heating:
2^{nd} Generation

District heating (DH) is here to stay. Looking back on the history of DH it goes quite some years back. During the years it has developed to fulfill the demands as they came up, typically driven by the demand for reduced investment and heat costs, but also lower equipment space demands, concerns of energy efficiency and lower fire risks. The development has been categorized in 4 generations which each indicate major changes in the technology. Currently most DH schemes being operated are categorized as being at the stage of 3^{rd} generation DH technology starting its transition to the 4^{th} generation to address the challenge of the future non-fossil and renewable based energy system. To meet the demands of the future energy system, existing DH schemes will develop into the next generation, the 4^{th} and the most advanced generation. The intention of this series of articles is to describe the typical principles of each generation and discuss the motivation behind each generation and the main development drivers.

The main characteristic of the second generation DH system is that the heat is transported by pressurized super-heated water at temperatures above 100°C. This is a significant difference compared to the 1^{st} generation DH systems, where steam is used to transport the heat. By moving from steam a number of benefits were achieved, for example:

- Higher efficiency of condensing heat plants.
- Return water was easily collected and the low grade energy in the return water was further used.
- Better energy quality and energy usage match.
- Simple to build and operate the system, even under varying load.
- Simple way of metering heat consumption.
- Thermal storage in larger scale became possible, decoupling demand and supply.
- Moving from steam to pressurized water allowed significantly larger distribution networks, which reduced requirements to plant location.
- Reduced risk and consequences in case of leakages
- More reliable and secure supply, e.g. in case of flooding due to heavy rainfall

The 2^{nd} generation DH was dominating in DH systems from the 1930s to the 1980s. The distribution network typically consisted of two steel pipes, a flow pipe and a return pipe. To some extent also open systems were applied mainly in former Soviet Union countries, in which consumers tapped domestic hot water directly from the district heating pipes. A special case is seen in Iceland where only the supply pipe was installed due to abundance of free geothermal energy and sufficient water quality. After extracting the heat from the supply, the water is flushed to the sewers. Another difference to the 1^{st} generation steam based system was the centrally placed circulation pumps providing sufficient head to drive the water through the distribution network and allow heat extraction at the consumer site. Large pumps were available for the 2^{nd} generation systems, leading to the situation that steam pressure based water circulation was not a precondition for DH systems anymore.

The main driver for the development of the 2^{nd} generation DH system was increased operational safety, increased efficiency of both the heat distribution and operation of heat plants and the possibility to use a wider variety of heat sources compared to the 1^{st} generation. The 2^{nd} generation also paved the way for fuel savings by applying CHP in larger scale than before, driving down the cost of electricity generation and increasing both the living comfort and the air quality level for the population in urban areas. The super-heated hot water district heating allowed using the surplus heat from large power plants much more efficient, where some of them could even be modified to CHP extraction in a simple way. Although the decreased electricity generation could be as high as 0,2 MW per megawatt heat extracted, it reduced the fuel consumption for heating by 50% compared to the 1st generation DH. Moreover it opened for use of surplus heat from waste incineration plants. Altogether, including peak load boilers and heat losses, the consumption of fossil fuels could be reduced by 50-70% for heating compared with the 1st generation DH. Finally the heat storages tanks at the CHP plants allowed to optimize the heat production and extract the heat in off-peak periods without reducing the power capacity in power peak hours.

The flow and return steel pipes were placed underground into concrete ducts, similarly as for the 1^{st} generation

DH systems. In the early days the ducts for the 2nd generation systems were built on site sized large enough for persons to walk along the pipes, later when more experience with the concept had been acquired ducts became narrower. To speed up the installation time and to reduce the costs, pre-fabricated duct elements were invented. However chambers for e.g. valves, expansion joints, anchor elements and draining equipment were still built on site, which was both time consuming and expensive. In the 2nd generation the ducts typically have a longitudinal slope, leading the intruding water into the duct towards a drain located at the lower locations of the duct system. The longitudinal slope of the pipe additionally gave the opportunity to vent the pipe at the higher locations and to drain the pipes in the lover locations, e.g. in connection with service works.

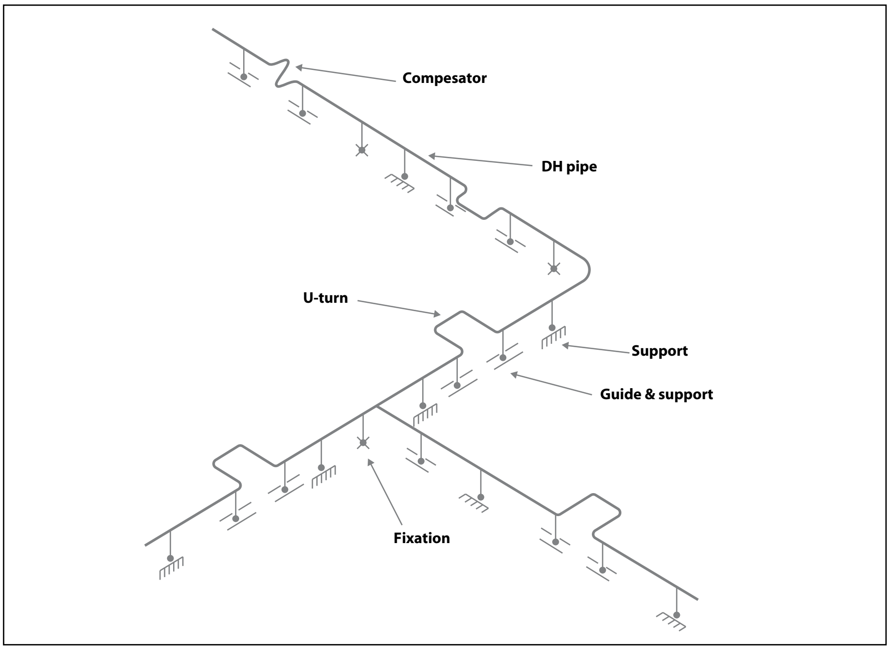

FIGURE 2: Principal pipe support principle, including supports, guides, U-turns, compensators and fixations.

The pipes were insulated on site using typical mineral wool and wrapped with a protective layer of fabric. As long as the insulation was dry and undamaged the thermal resistance was high, but when the mineral wool became wet, e.g. when the ducts were flooded, the thermal resistance dropped significantly. Although the design heat loss for the 2nd generation DH pipes was quite low it typically became high over time due to damage of the insulation and loss of insulation properties.

In the case the steel pipes, have been protected against corrosion from outside (concrete ducts for underground pipes or protection of above ground pipes) and the water quality was kept high, the systems have proven to last for many decades. Even today more than 40 year old pipes are in very good shape.

FIGURE 1: ***2nd generation DH pipes, U-turn with supply and return pipe placed in the lower pipelines, and a domestic hot water and domestic hot water circulation wrapped together in same insulation, placed in upper pipeline.***

Due to the high heat losses associated with the main pipes some countries utilized separate and smaller distribution pipes for DHW purposes and hence minimizing the heat loss during the non-heating period. Figure 1 shows four pipelines in a local 4-pipe system supplied from a group sub-station. The domestic hot water supply and circulation are wrapped in the same insulation on top. The two lower pipelines are for DH supply and return.

To maintain proper pipe position in the ducts, or proper pipe position above ground, a number of guide elements were installed along the pipe. These include anchor elements, simple support elements and guide elements. Besides this, compensators or U-turns were installed to absorb the large thermal elongations due to large temperature variations between highest winter operation temperature and no operation during summer (e.g. up to 170°C supply), limiting the stress in the pipe material.

Figure 2 shows a principal example of the pipe and the above mentioned elements.

The first pre-insulated pipes were developed in this period to be used in networks with temperatures typically below 130°C and often with special attention to the expansion, e.g. with expansion units and bends underground.

In general three operating principles were applied in the 2nd generation networks:

- Constant flow from one plant to the whole network.
- Fixed flow ratio to consumers.
- Variable flow, supply according to consumer's demands.

In the cases where the variable flow principle was applied the heat could be supplied from several base load and peak load plants, within the same network, in an optimized way. The tariff for the heat in the variable flow systems was based on both a fixed capacity part and a variable energy part.

The heat exchangers applied were typically of the tube and shell type, see Figure 3. They were used at the utility, in the DH network to separate primary and secondary networks and in the buildings as well. Domestic hot water was prepared by shell and tube heat exchangers for a larger group of consumers. In case of supplying on building level, the hot water storage tank principle was applied.

The radiator systems in the buildings were typically designed for supply temperature of 90°C, either via direct or indirect connection with the DH network. Due to the high supply temperatures the surface areas could

FIGURE 3: Shell and tube heat exchangers, controlled by manual valves.

FIGURE 4: One pipe radiator system, with no control devices.

be limited, leading to material and cost savings. But the drawback was a higher thermal distribution loss in the network. The buildings heating installations typically had one pipe radiator system (with or without a by-pass of the radiators) to save material and labor costs, see Figure 4.

Reduction of supply temperature on the building level was realized either by traditional mixing loops with pumps or by a jet pump concept. The building installations for the 2nd generation DH systems were typically made on site based on heavy and material intensive components.

Benefits

The main benefit of the 2nd generation DH system compared to the 1st generation DH system is the increased energy efficiency due to lower operating temperatures and reduced risk and consequences in case of leakages. Further the challenges related to the corrosive condensate experienced in the 1st generation were eliminated.

Reasons for the 2nd generation to develop into the 3rd generation

The increased focus on energy efficiency and energy costs in the 1970s resulted in the development of the 3rd generation of DH systems. The main technical improvements were related to:

Reducing the operation costs by:

- Reducing the temperature levels, leading to savings in distribution losses.
- Lower temperature opens the opportunity for other low cost and/ or renewable sources.
- Increasing the thermal resistance of the insulation, leading to savings in distribution losses.
- Pre-insulated pipes, leading to long lifetime of the pipes.
- Better efficiency of the CHP plant due to lower temperatures.
- Components and systems of higher quality and efficiency.

Reducing the investment costs by:

- Pre-insulated pipes buried direct into the ground without expansion joints.
- Pre-fabricated material lean substations.
- Improved DH pipe construction methods.
- More cost effective and larger unpressurized heat storage tanks.

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