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Contents

Introduction

It is possible to distinguish between two types of pipes used in SDH systems according to their purpose. The first is utilized in the solar system itself as connection between the heat source (collectors) and other components. These are sometimes referred to as "solar pipes". The second group of piping is used in the distribution grid of the district heating system.

Solar pipes

General requirements for solar pipes

Solar system piping must meet requirements on functionality, operation life and resistance to effects of the collector fluid and external environment. Pressure and temperature conditions are equally important in the solar system. The size of the pump(s) has to match the dimension of the pipes in order to achieve the desired flow. Typically a flow corresponding to a ΔT over the collector of 25-45 K is chosen. The cost of the pipes increases with the pipe's diameter, but if the pipe diameter is increased, the pressure loss and corresponding required pump power is decreased. As for ordinary DH systems, the pipe dimensions and annually pump costs has to be optimized with respect to lowest lifetime costs. The pressure loss in the system depends as well on the setup of the collector area. If the collectors in the collector field are coupled in series, it results in a larger pressure drop over the rows than if they were coupled in parallel. However the extra distribution pipes required due to the parallel setup lead to an increase in the pressure drop - and investment costs. Control valves in each collector row can be used to ensure that the temperature increase is equal in all of the collector rows regardless of location in the field (i.e. distance from pump) and the number of collectors in the row.

For large scale applications steel pipes are used. There is also the possibility to use copper pipes (as well), but the advantage of the easy installation is at the expense of a significantly higher price. It is also possible to utilize compact systems using pre-insulated pipes including wiring between regulator and temperature sensor that is placed in the collector.

Thermal expansion

Thermal expansion and soil-pipe interaction must be taken into account. Since the pipes in the solar collector loop is exposed to much more fluctuating temperatures than ordinary DH pipes, it is important to take precautions in terms of both the pipe materials, pipe configuration and surrounding soil (if buried). Regarding the pipe design please check EN 13941.

To handle the thermal expansion of the pipes, a lyre is often used. Figure 7.3.1 shows an example of such an installation. More information on the effect of temperature variations can be found in fact sheet 8.1 *"Temperature variations"*.

Fig. 7.3.1. Built in lyre to withstand stress in the pipe system. [1]

District heating pipes

General requirements for DH pipes

For the assembly of small district heating networks (DH-network) with small expansion mainly radial distribution systems are put into practice which will be defined in the following section.

In radial distribution systems one or more routes run directly from the heat supplier to the domestic stations. Flow and return pipes are dimensioned symmetrically. The diameter has its major amplitude at the heat supplier and decreases it in accordance to the heat demand. The pressure stabilisation is configured in a way that ensures the agreed pressure difference for the last domestic station at the end of the network. In comparison with other structures this one has the minimal length of the network.

The route planning of the DH network is based on heat density, building positions and routes of the public roads. Since valve chambers are to be avoided, due to high investment and operating costs, buried valves should be used instead.

Usual directly buried pre-insulated bonded pipe systems are used for the main and distribution route. Since, in case of reparation or new connection, the surface recreation costs are much lower, favourably the pipeline route is to be made in the area of sidewalks or green fields.

Costs can be saved by installing pipes together with other service pipes in a stepped trench before the roads are built so that the excavation expenses can be shared with other utilities.

For economic reasons, the pipes should be installed as close to the surface as possible with the minimum cover necessary.

For economic reasons a multiple-service house entry for water, district heating and electricity should be preferred. Open line pipes frequently show the lowest investment and operating costs. Therefore areas, where houses are built with cellars, should be examined for cost advantages for installation by using open line pipes instead of buried pipelines.

Principally the installation of buried pipes is horizontal and parallel in routes. However an installation on top of each other is feasible if required. In case of reparation the lower positioned pipeline is not as easy to get to, so it has to be considered that a special foundation material is needed.

Network parameters

With the help of the key plan (land-use plan) and a topographical map for the geographic structure the general requirements for the DH network can be revealed.

Flow pipe temperature:

The temperature of the flow pipe is the most important parameter towards the design of the network. It influences the selection of heat generation as well as the selection of material of service pipes. Therefore it is necessary to consider its impact on economy. Likewise special customer requirements are able to affect the temperature of the flow pipe.

Experiences show that a flow pipe temperature of 90 °C is practical for networks with small expansion and > 110 °C for networks with large expansion.

The minimum flow pipe temperature normally has to exceed 70 °C to consider appearing temperature losses within the network and safety measures to avoid Legionella (DVGW W 551) for domestic hot water processes.

Return pipe temperature:

The set temperature of the return flow is supposed to be defined to a maximum of 40-45 °C (and 50-55 °C for domestic hot water preparation). To ensure an economic supply the return temperature should not extend this limitation. The lower the return temperature, the higher the efficiency of the DH System.

Network operation mode:

To define the network operation mode it is important to know about the annual load duration curve of heat demand for customer installations. In summertime the heat demand is only one fifth of the demand in wintertime (there is more or less only a heat demand for the domestic hot water system).

For the operation mode of the flow pipe temperature the heating curve according to outside temperature and heat demand is defined. To adjust the operating mode curve the lowest outside temperature appropriate DIN EN 4701 is chosen. Normally the highest temperature is set at +15 °C.

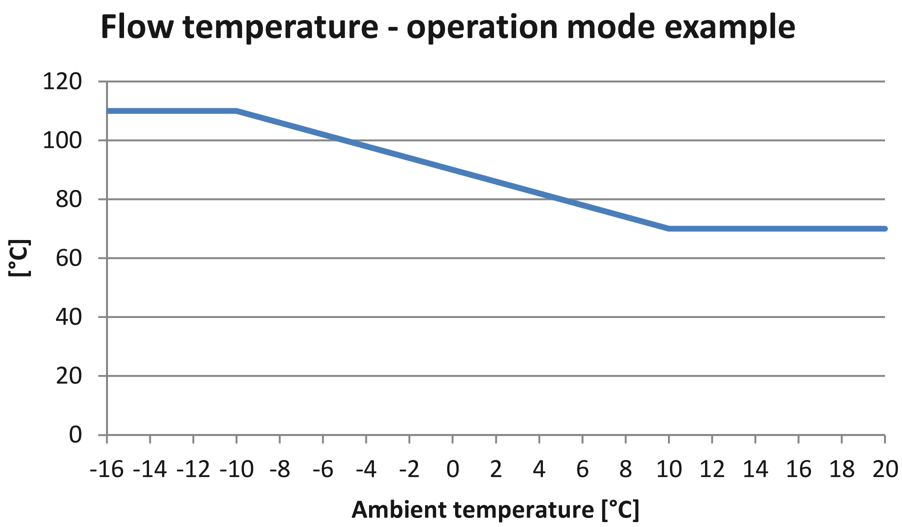

Fig. 7.3.2. Example for the operation mode of the flow temperature at the range of 100 °C variable / constant to 70°.

Figure 7.3.2 shows an example for an operation mode between -10 °C and +10 °C which is variable for the flow pipe temperature. Beyond these parameters the flow pipe temperature remains constant.

Short term fluctuations of heat demand are controlled by mass flow adjustment, because the variation of temperature is very slow and would affect the last customer not until hours later.

Installation systems

The selection of the installation system depends on operating flow and return temperatures, operating pressure and local requirements at the domestic station. Also it has to be decided if a surveillance and fault location system is required.

Pipeline construction companies and companies which carry out sleeve mounting must fulfil different special requirements for DH networks. Table 7.3.1 opposes applicable installation systems, followed by criteria that have to be considered for the draft planning.

Table 7.3.1. Special features of common installation systems.

System parameters	Rigidly pipe system	flexible pipe systems	
	Pre-insulated pipes KMR	Metallic service pipes MMR	Polymer service pipes PMR
EN-rules	EN 253 (singel pipe) EN 15698-1 (twin pipe)	EN 15632-1 EN 15632-4	EN 15632-1 EN 15632-2 EN 15632-3
AGFW-rules	FW 401	FW 420-2 and -3	FW 420-1
Material grade and preperation	Steel pipe	Steel or copper pipe Corrugated stainless steel or copper pipe	PE-X and PB
Insulation	PUR-foam	PUR- or PIR-foam	PUR-foam Polyolefin-foam
Outer casing	PE-HD	PE-LD /PE-LLD Steel case or steel tissue	PE-LD (PE-LLD)
Pipe joints for service	Welding joints	Metallic screwing joint Braze joint (for Cu) Welding joint. (for St)	Pressing joint (for PE-X und PB) Welding joint (for PB)
Pipe system	Single- or twin pipe system	Single pipe system	Single- or twin pipe system
Operating temperature	120 °C	120 °C	80 °C
Peak temperature (occasional)	Max. 140 °C	Max. 140 °C	Max. 95 °C
Pressure	Up to PN 25	Up to PN 25	Operation pressure up to 10 bar
Available nominal diameters	≥ DN 15 to DN 1200	DN 15 to DN 200	Up to ~ D_A 110 mm

<u>KMR:</u>

The pre-insulated bonded pipe system (KMR) is the currently most applied installation system. It can be used for DH networks without any constrictions. It is a non self compensative system. Therefore pipe statics (like in FW 401) are essential and compensation arrangements should be made:

- thermal and mechanical pre-stressing
- expansion bends (U-, L- and Z- bends)
- Single-use compensators

Bonded pipes can be manufactured with wire conductors for surveillance and fault location. The functional requirements of these systems are listed in EN 14419. Design and installation requirements for pre-insulated bonded pipe system are to be found in the AGFW rule FW 401.

Flexible metallic service pipes:

The application area of metallic service pipes predominantly covers nominal diameters up to DN 50. Therefore they are used for sub-distribution and house entry. The self compensation of metallic medium pipes is effected by special manufacturing processes of medium pipes such as soft annealing or corrugation of the copper pipe, installation in form of sinus waves or application of certain materials like stainless steel.

Due to flexibility and self compensation this technology enables a fluctuating and simple pipeline routing. Furthermore it is possible to adapt to local circumstances, obstacles can be easily avoided. Also, because fewer joints are needed, installation requires much less time and effort. Generally it is possible to respond to structural barricades without evaluating a new statistic and/or insert additional adaptors as it would have to be done for the KMR system.

Flexible service pipe systems with corrugated medium pipe have a higher pressure loss per meter than other systems. It could be compensated by using the next larger nominal diameter. For monitoring and fault location the same systems as the ones of KMR are used.

Flexible Polymer Service Pipes:

Flexible polymer service pipes are suitable for DH networks with small structural expansion such as for housing areas with small domestic houses. Similar to metallic service pipes no static is required.

Flexible polymer service pipes remain economical solely within small nominal diameters. No monitoring systems with conductors for surveillance and fault location are required. Furthermore polymer service pipes are only ‘low diffusion’ and not ‘no diffusion’ towards oxygen and water vapour, even if there are built after DIN 4725. Therefore only such pipe systems with a diffusion blocking tissue have to be used for saving the insulation against water steam output and the system against active oxygen input.

Possibilities of combination of installation systems:

Each individual case is to be verified for coast advantages due to a combination of the pipe systems instead of using only one technology. By combining the systems it has to be considered that network parameters for the whole network are defined by the system with the lowest requirements. Accordingly the flow temperature for a combination of KMR with polymer service pipe is limited at 80 °C and the pressure at 5 bar. Since combinations of different systems arouse measurement errors, there has to be agreed on a uniform monitoring system.

For pipes > DN 50 it is suggested to use KMR. For the distribution of the small to medium dimensions all other systems are possible. The problem of contact corrosion between different materials is overcome by the use of specific transition pieces.

Sizing

For an estimated sizing table 7.3.2 may be consulted. For known temperature deviation and heat demand the essential nominal diameter can be assessed. The loss of pressure has been nominated with 2 mbar/m of pipe (4mbar/m route). The diameters are based of steel pipes of DIN 2458.

Table 7.3.2. Transportable heat demand at a pressure loss of 4 mbar per route meter (VL+RL) incl. 20 % for installations.

Nominal diameter	Outside diameter [mm]	Inside diameter [mm]	Flow rate [m/s]	Δp [mbar/m]	Δt [K]		
					70	60	40
					Q_{max}		
					[kW]	[kW]	[kW]
DN 15	21.3	17.3	0.48	2.1	33	28	19
DN 20	26.9	22.9	0.58	2.1	70	60	40
DN 25	33.7	29.7	0.68	2.04	139	119	79
DN 32	42.4	37.8	0.80	2.06	264	226	150
DN 40	48.3	43.7	0.88	2.06	380	330	220
DN 50	60.3	55.7	1.02	2.03	730	620	410
DN 65	76.1	70.9	1.20	2.07	1 390	1 190	790
DN 80	88.9	83.1	1.32	2.05	2 100	1 800	1 200
DN 100	114.3	107.9	1.55	2.04	4 160	3 570	2 380
DN 125	139.7	132.5	1.77	2.06	7 170	6 150	4 100
DN 150	168.3	160.3	2.00	2.08	11 860	10 170	6 780
DN 200	219.1	210.1	2.35	2.06	23 950	20 530	13 680

With table 7.3.2 it is also possible to check the nominal flow temperature against 85 °C or 110 °C.

It has to be considered that accordant with the decrease of heat demand the diameter of route decreases as well, otherwise very low flow speeds would be resulted due to the small heat demand in summertime. To size the house service pipe not only the heat demand for heating is important, but also the one for hot water. Therefore both factors have to be regarded separately. At first the house service pipe nominal diameter is sized according to the heat demand of the winter time and its ΔT. After that the pressure loss at this nominal diameter for the heat demand of summertime and its resulting ΔT has to be calculated. If it is too high, the diameter has to be decreased.

Pipe heat loss calculations

Heat losses of pipes are based on the formula:

$$Q_{loss} = U \cdot l \cdot (T_{c,out} - T_a) \qquad \text{(eq. 7.3.1)}$$

where

Q_{loss}:	Total heat loss of pipes from collectors to heat exchanger	[W]
l:	Length of the pipe	[m]
$T_{c,out}$:	Temperature of the solar collector fluid when it exits the collectors	[°C]
T_a:	Temperature of the environment	[°C]
U	Pipe heat loss coefficient calculated by formula 7.3.2 below [2]	[W/(m·K)]

$$U = \frac{\pi}{\frac{1}{2 \cdot \lambda_{iz}} \cdot \ln\left(\frac{d_e + 2 \cdot s_{iz}}{d_e}\right) + \frac{1}{\alpha_e} \cdot \frac{1}{(d_e + 2 \cdot s_{iz})}} \qquad \text{(eq. 7.3.2)}$$

where

λ_{iz}:	Thermal conductivity of the insulation	[W/(m·K)]
d_e:	Diameter of pipe (external)	[m]
s_{iz}:	Thickness of thermal insulation	[m]
α_e:	Heat transfer coefficient on the external surface of thermal insulation	[W/(m^2·K)]

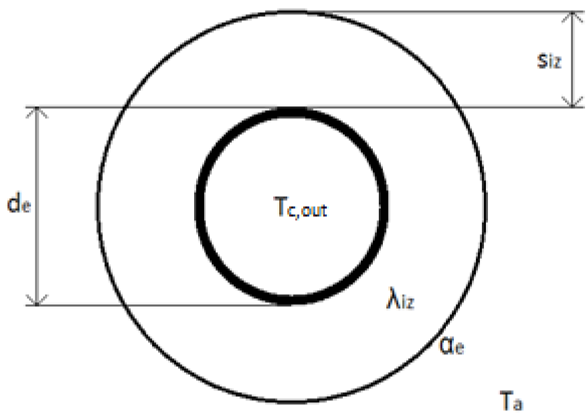

Fig. 7.3.2. Values used in the formula 7.3.2 above.

Determined values of heat loss coefficient related to the length unit for piping placed in the ground is shown in table 7.3.3.

Table 7.3.3. Examples of nominal diameter (DN) and corresponding heat loss coefficient for solid piping (A) and flexible and double piping (B) [3].

DN [mm]		**20**	**25**	**32**	**40**	**50**	**65**	**80**	**100**	**125**	**150**	**175**	**200**
U [W/(m·K)]	**A**	0.14	0.17	0.18	0.21	0.23	0.25	0.27	0.28	0.32	0.36	0.38	0.39
	B	0.16	0.19	0.20	0.24	0.26	0.30	0.31	0.32	0.36	0.40	0.44	0.46

European standard EN 12976-2 recommends thickness of thermal insulation 20 mm for pipes with external diameter lower than 22 mm and 30 mm for pipes with external diameter between 28 and 42 mm. For the pipes with higher diameters there should be used thermal insulation with thickness equal to the pipe diameter. It is assumed that the thermal conductivity of used insulation is lower than 0.04 W/(m·K). Often polyurethane (PUR) with a thermal conductivity of 0.027 W/(m·K) is used as insulation in the pipes.

Pumps and pressure rating

The transport of collector fluid between collector array and heat exchanger (and back again) is provided by pump(s). The pump in the primary loop has to be powerful enough to overcome the pressure losses and still maintain the desired flow[*]. This means that the dimensioning of the pumps and the pipes has to be done simultaneously in a way that minimizes the total sum of:

- Buying and installing pipes
- Buying and installing pumps
- Electricity costs for the pumps during operation throughout the lifetime

In other words the optimal balance between the following scenarios must be found:

a) Small pipe diameter => large pressure loss => low costs for pipes but high electricity costs for pumps
b) Large pipe diameter => low pressure loss => high costs for pipes but low electricity costs for pumps.

The pump on the secondary side of the heat exchanger has to be able to maintain a capacity rate similar to the one in the primary loop[†]. Since the capacity rate only depends on the flow rate and the fluid properties, the pump on the secondary side of the heat exchanger is not affected by the choice of pipe diameter – only by the choice of operating flow rate.

Pressure rating

The minimum pressure rating in the network usually depends on network size and geodetic differences (a growing difference in altitude implies a higher nominal pressure rating). The maximum operating pressure will be influenced by the highest located user and the user at the end of the network. This is transferable to the static pressure, which has to be maintained during standstill periods of the system (no pump operation).

The higher the operating pressure, the more effort is needed for pressure stabilisation, safety requirements and circulation pumps. Therefore the operating pressure should be remained as low as possible (see EN 13480-3 and AGFW rules FW 442).

Another important parameter is the nominal pressure rating, due to its influence on the minimum pressure rating for pipes, fittings, valves, domestic stations and customer installations.

The nominal pressure rating level is defined through the static pressure and the delivery head H of the pump with consideration of the geodetic altitude of the network. Small DH networks often need PN 6 and large DH networks PN 16. The maximal operating pressure within the network has to be lower than the nominal pressure rating level.

The static pressure has to be higher than the saturated steam pressure at the highest geodetic point of the network at the maximum flow pipe temperature, so that it is impossible to have evaporating fumes within the

[*] *For more information on flow rate control see fact sheet 6.3 “Control strategies”.*
[†] *Capacity flow rate is explained in fact sheet 7.4 “Heat exchanger”.*

network. Also, in direct DH networks, where customer installations are directly served with DH network water, the maximum height for customer installations has to be defined.

Example for the calculation of the static pressure (p_{RU}) at a flow temperature at 110 °C:

Height of the supplier (H_H):	100 m asl‡
Highest point of the network (H_A)	137 m asl
Saturated steam pressure at 110 °C ($p'(t_v)$)	1.43 bar
Safety factor for saturation (p_S)	0.5 bar (e.g.)
Density for water at 110 °C (ρ)	950 kg/m^3
Gravitational acceleration (g)	9.81 m/s^2

$$p_{RU} = p'(t_v) + p_s + \frac{\rho \cdot g(H_A - H_H)}{100\,000}$$

(eq. 7.3.3)

$$= 1.43 + 0.5 + \frac{950 \cdot 9.81 \cdot (137 - 100)}{100\,000} = 5.37 \text{ bar}$$

The max. operating pressure (p_{Bmax}) is defined by the factors static pressure, the pressure losses of the plant (Δp_H), of the network (Δp_N), the pressure difference at the last customer station ($\Delta p_Ü$) and a safety factor for pressure fluctuations (p_{SD}).

$p_{B,max} = p_{RU} + \Delta p_H + \Delta p_Ü + \Delta p_N + p_{SD}$ (for return flow pressure stabilization).

Pump characteristics

It is possible to use hydrodynamic or hydrostatic pumps. More often are used hydrodynamic pumps especially those that are resistant to influence of collector fluid and higher temperatures. For solar systems with special requirements on adjusting of flow according to operating conditions (e.g. constant temperature at the collector output) pumps with variable speed are used.

‡ *asl = above sea level.*

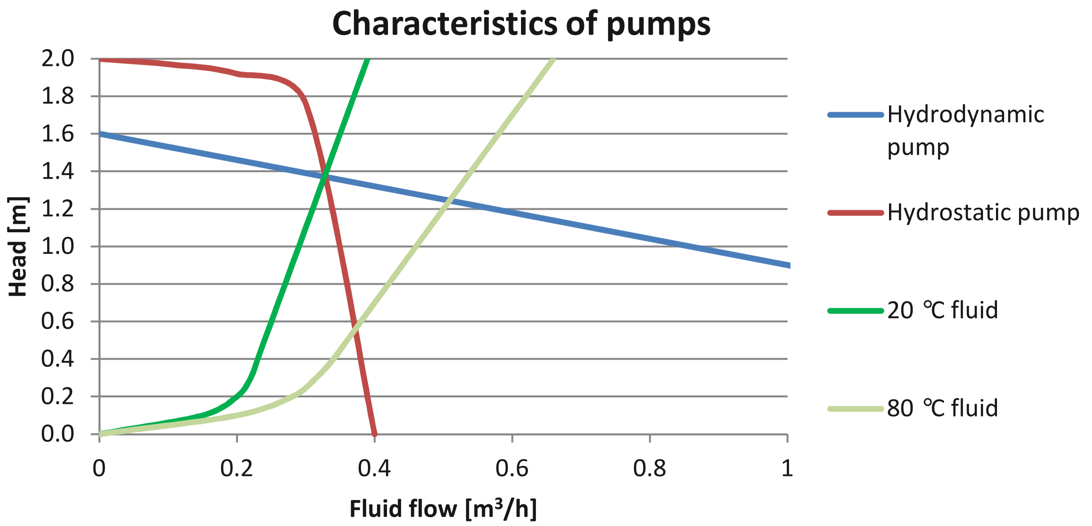

Fig. 7.3.3. Characteristics of pumps along with the characteristics of the pipe network [2].

Comparison of pump's characteristics along with the characteristics of the pipe network (propylene glycol + water at 20 °C and 80 °C) shows that change of the fluid temperature causes significantly lower variation of fluid flow in case of using hydrostatic pumps.

The optimal operating point of the selected pump should be in the range of its maximum efficiency. Dimensioning and operating parameters adjustment of the pump has a significant impact on energy consumption and thus operating costs of the system.

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The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

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