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District Heating Network Pipe Sizing

Oliver Martin-Du Pan

AALBORG UNIVERSITY
DENMARK

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Why Pipe Sizing

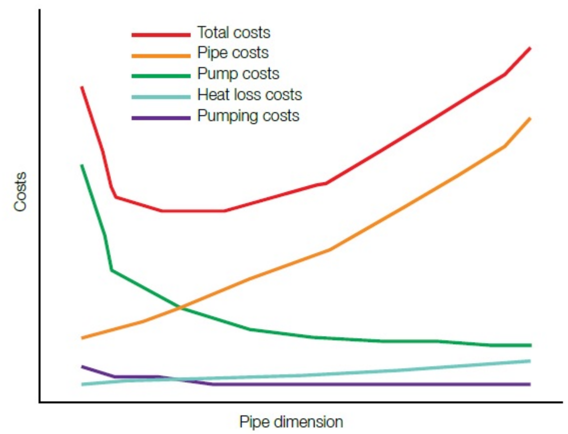
- In the UK, pipes are calculated based on a pressure drop target per meter of pipe. This has for effect of increasing the operational cost of a DH network because it does not take the heat losses into consideration and has for effect of:
  - Increasing the heat losses on small heating loads and smaller pipe diameters (Pipes are oversized).
  - Increasing the electricity consumption to pump the flow on higher loads and larger pipe diameters (Pipes are undersized).

Literature Review

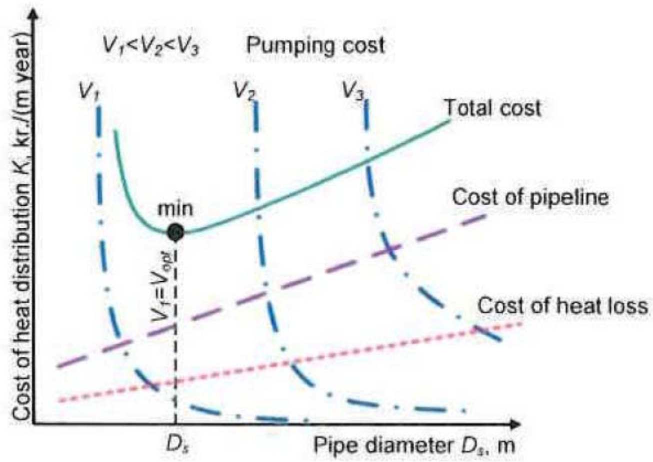
Reference 1: Risoe, 2004. Simple models of district heating systems for load and demand side management and oeprational optimisation. Technical University of Denmark: Department of mechanical engineering and Professor Benny Boehm and Dr Palsson.

Reference 2: Typical optimisation of pipe sizes on lifecycle cost basis produced by AECOM.

Reference 3: Doctoral school of energy and geo-technology, January 2007, Kuressaare, Estonia.



Reference 2



Reference 3

The Influencing Parameters on Pipe Sizing

a) The environment with effect on the resulting heat losses;

b) The DH network flow and return temperatures at peak load;

c) The electricity consumption to pump the flow and the ΔT;

d) The heat gain by friction of the flow and the pipe material/quality.

Assumed Environment and used Pipe

- In this analysis, stainless steel pipe was assumed with a roughness of 0.03;
- Insulation thickness of 40 mm with a thermal conductivity of k = 0.025 [W/(m*K)];
- Two different pipe environment:
  - Minimum heat losses environment when installed in a Block heated at 21^{o}C;
  - Maximum heat losses environment when buried in a moist soil maintaining the external insulated surface at 12^{o}C.

Methodology

- To minimise pipe sizes on smaller heating loads and the overall energy consumption, it was assumed that at peak load, the electricity is as valuable than heat (First law of thermodynamic) and the sizing is aimed to minimise the total energy consumption. When operating part-load, the electricity consumption always reduces whereas the heat losses may remain similar or increase in some cases.

- The energy flow in a pipe system includes:

  1) Electricity consumption

  2) Heat losses

  3) Heat gain by friction

Energy Consumptions with a varying Heating Load

- **Pipe sizing is calculated when operating at maximum load**

  Elec consumption + Heat losses is minimum throughout the range of all pipe diameters.

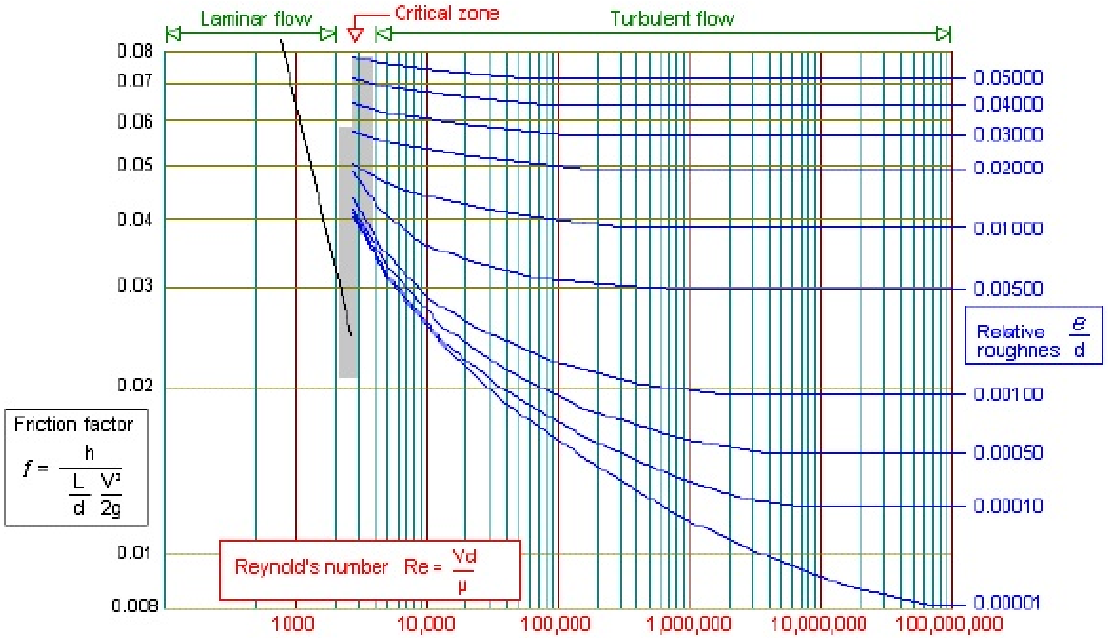
  - Electricity consumption increases when a pipe reduces in diameter
  - Heat losses increases when a pipe increases in diameter

- **Effect on the loads when operating at a reduced load**
  - Elec consumption reduces
  - Heat losses may remain constant or increase at a set flow temperature.

This methodology is in line with considering the electricity as a more valuable energy than heat because the electricity consumption usually reduces further than the heat losses when reducing the heating load.

The operational optimisation can then be undertaken to minimise the operational cost, the CO_2 emissions or to maximise the exergy efficiency.

Electricity Consumption



$$1/\sqrt{f} = 1.14 - 2\log_{10}\left(\frac{e}{D} + \frac{9.35}{\mathrm{Re}\sqrt{f}}\right) \quad \text{for Re} > 4000$$

$$\Delta P_{pump} = \frac{f \cdot \rho \cdot V^2 \cdot length}{2 \cdot Diameter}$$

$$P_{el} = \left(\frac{\Delta P_{pump}}{\eta_{pump}}\right) \cdot \dot{V}$$

η_{pump}= 65%

Pressure drop comparison with a Set Flow Temperature of 90°C or 70°C

For a similar maximum heating load and return temperature:

$$\frac{\left(\Delta P_{90/40}\right)_{Max\ load}}{m} > \frac{\left(\Delta P_{70/40}\right)_{Max\ load}}{m}$$

Pressure drop reduction comparison at part load:

$$\frac{\left(\Delta P_{90/40}\right)_{Max\ load} - \left(\Delta P_{90/40}\right)_{50\%\ load}}{\left(\Delta P_{90/40}\right)_{Max\ load}} > \frac{\left(\Delta P_{70/40}\right)_{Max\ load} - \left(\Delta P_{70/40}\right)_{50\%\ load}}{\left(\Delta P_{70/40}\right)_{Max\ load}}$$

In regards to electricity consumption for pumping, more electricity is saved when pumping a reduced load of a 90/40 DH network compared to a 70/40.

Heat Losses

Conduction

$$q_r = \frac{2\pi L k (T_{s,1} - T_{s,2})}{\ln(r_1/r_2)}$$

Convection

$Q = h*A*(T_{solid} - T_{env})$

Maximum heat losses
Moist soil at 12^{o}C

$$q_r = \frac{2\pi * 1 * 0.025 * (T_{s,1} - 12)}{\ln(r_1/r_2)}$$

Minimum heat losses
In a Block at 21^{o}C

$$Q_{Conduction} = Q_{Convection}$$

Natural Convection factor Calculation

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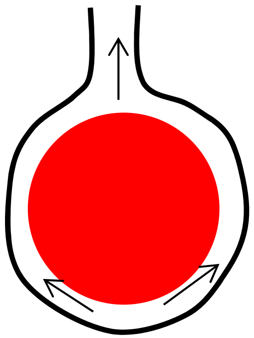
The Natural convection factor and heat loss was calculated using the:

a) Nusselt number
b) Rayleigh number

$$\bar{h} = \frac{k}{D} Nu_D$$

$$Ra_L = \frac{g\beta(T_i - T_o)L^3}{\nu\alpha}$$

$$\overline{Nu_D} = \left\{0.6 + \frac{0.387 Ra^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}\right\}^2$$



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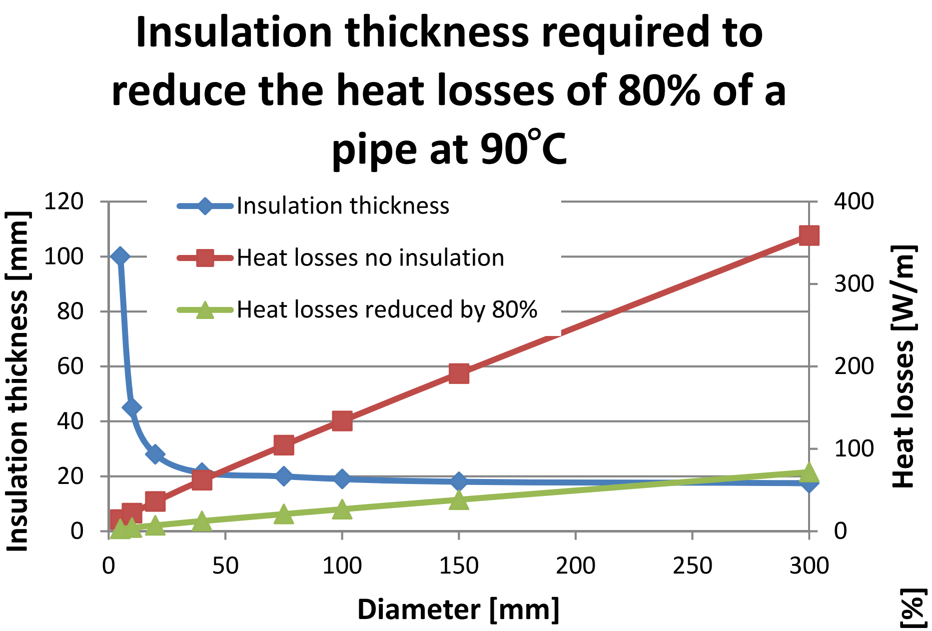
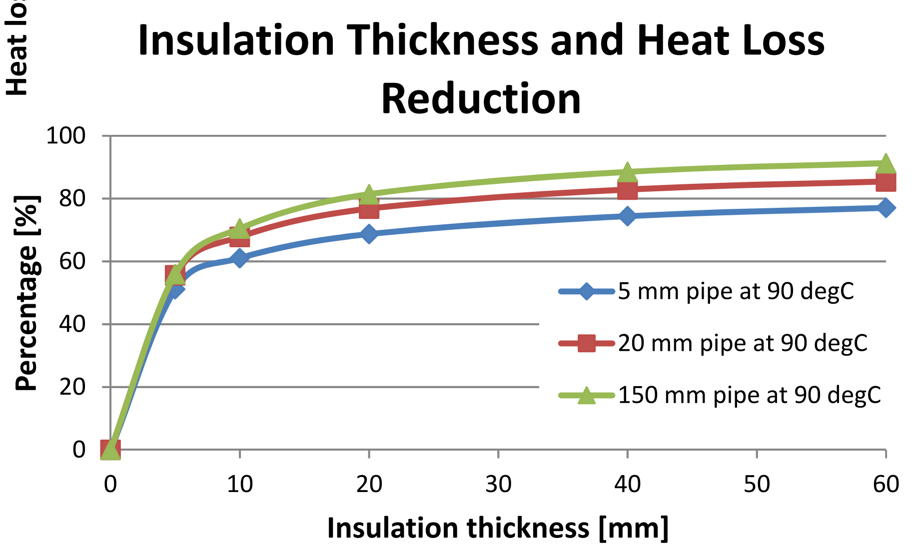
Insulation Thickness – Natural convection in a Block at 21degC





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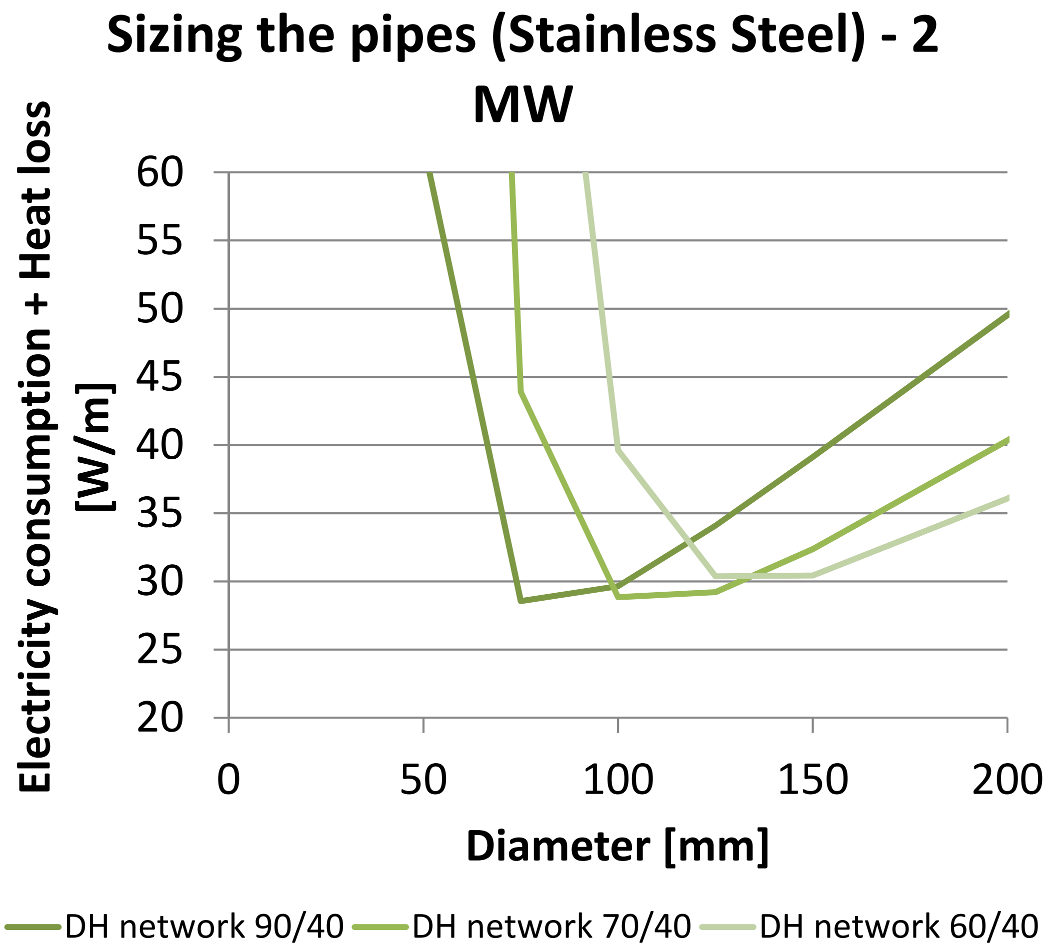
Heat Gain

The flow circulating in a pipe is submitted to friction and this friction is then converted to heat gained by the flow. To quantify this heat gained by the flow, it was assumed that 65 % of the required electricity is consumed by the pump to overcome the pressure drop (BSRIA reference). By conservation of energy, this loss of energy is then converted to heat.

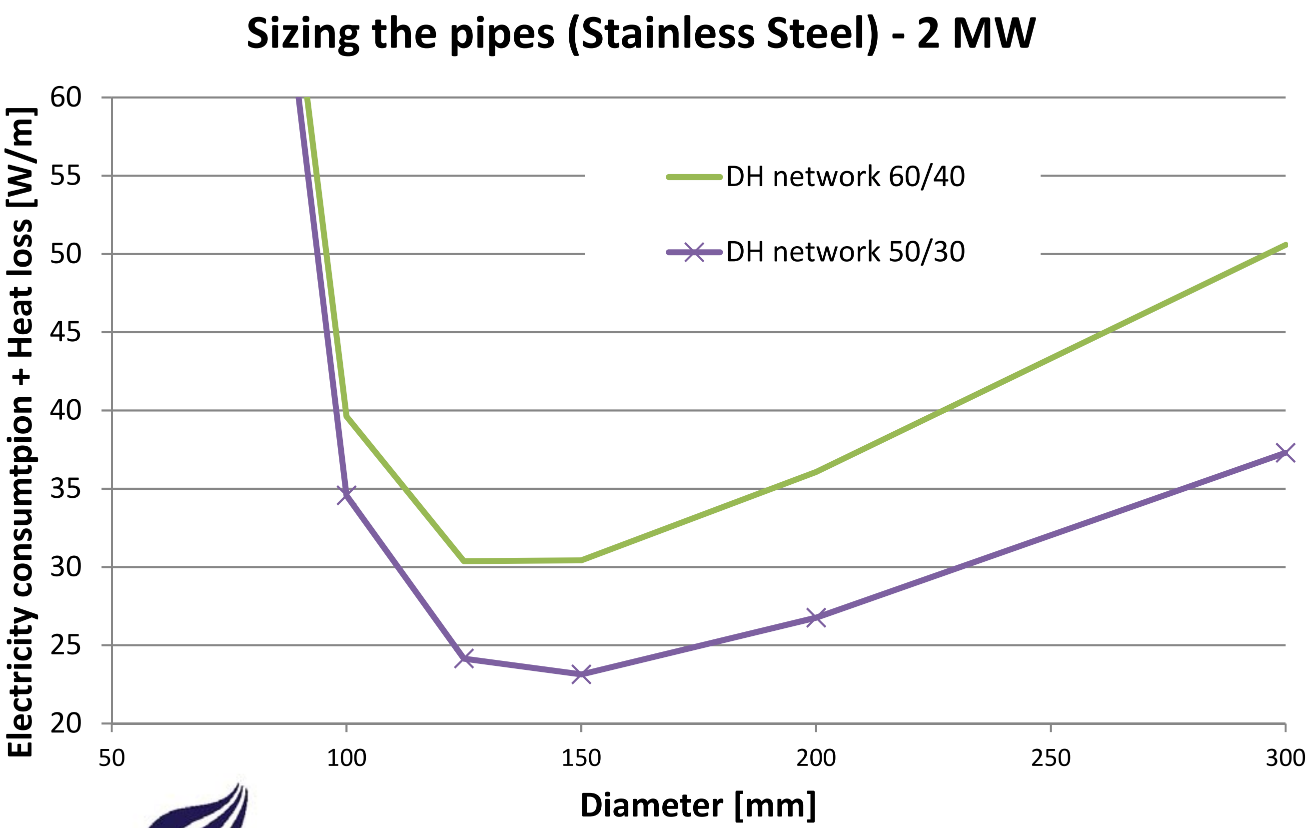
Result 1: Effect with reducing the Flow Temperature in similar Conditions



Operational cost is similar for a 90/40, 70/40 and a 60/40 DH network. However:

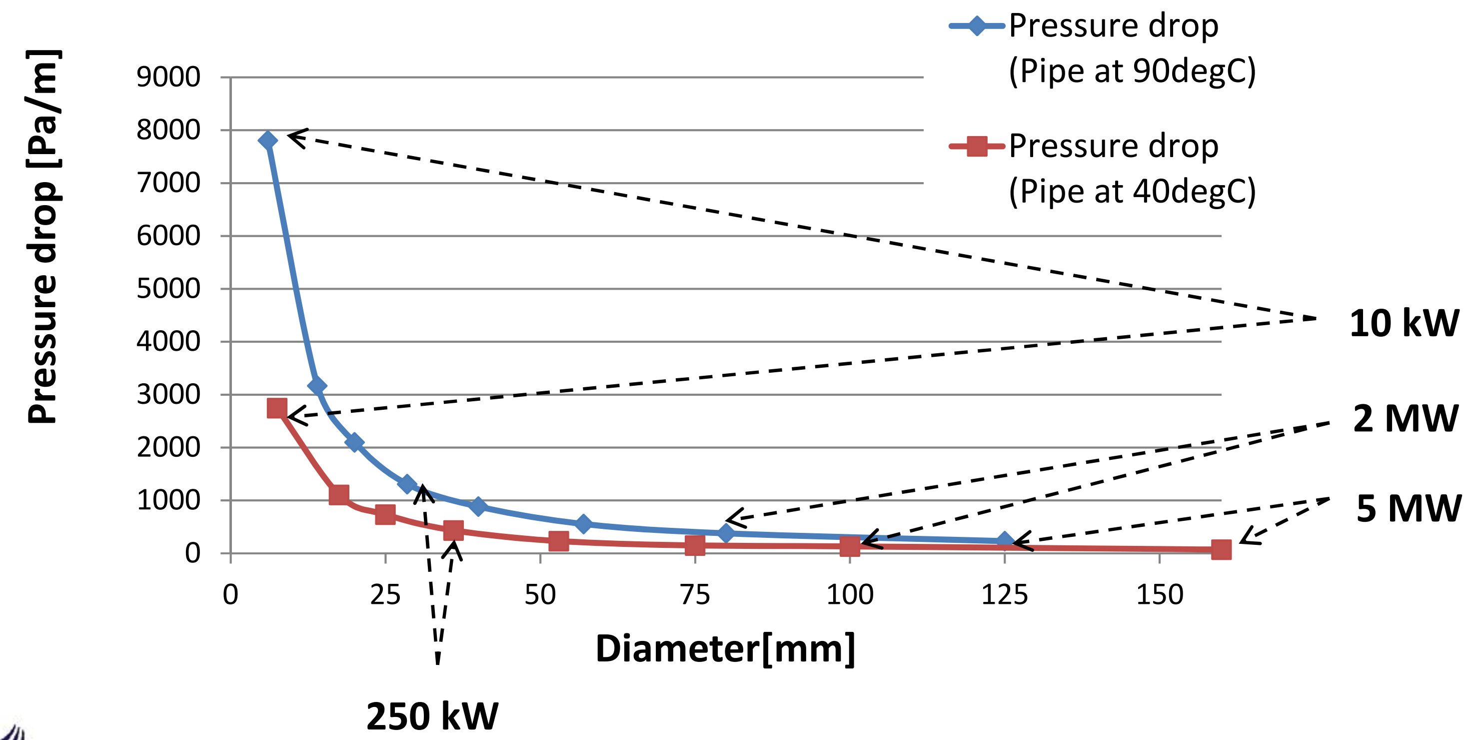
a) The heat losses and the operational cost is lower for the 90/40 than the 60/40 DH network when operating at part load

Result 2: 4th Generation and Minimising the Return Temperature



This is why we want to reduce the network temperature. However, it is the return that must be reduced in priority.

Result 3: Optimised Pressure Drop in a Steel Pipe and in a Block at 21°C



Result 4: Sizing Pipes – Maximum Velocity in a Heated Block at 21°C and 40 mm Insulation

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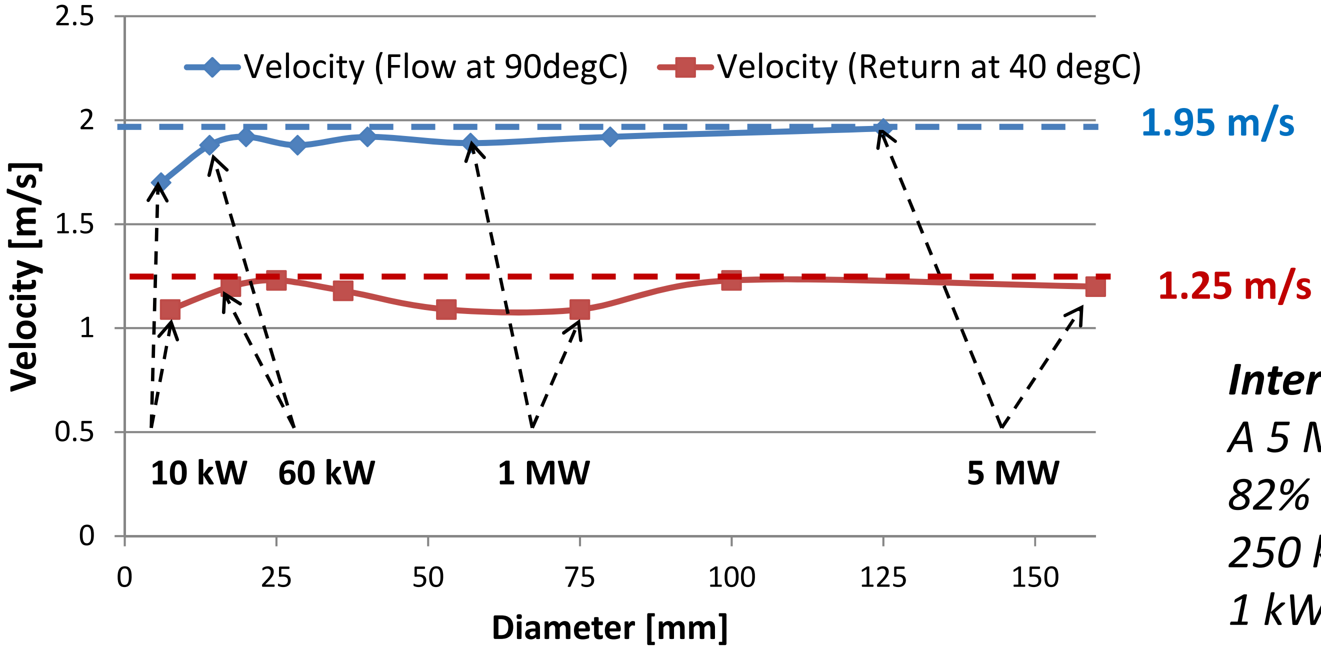

Interesting information
A 5 MW network requires 82% less electricity than a 250 kW network to pump 1 kWh of heat.

Pipe at 90°C (250 kW with a return at 40°C)
Diameter: 28.5 mm
Temperature: 90°C
Electricity : 2.4 W/m
Pipe heat loss: 7.3 W/m
Flow heat gain: 1.6 W/m

Consumption balance
-Heat: 70%
-Elec: 30%

Heat gain reduces the heat losses of 22%.

Pipe at 90°C (5 MW with a return at 40°C)
Diameter: 125 mm
Temperature: 90°C
Electricity : 8.5 W/m
Pipe heat loss: 19.0 W/m
Flow heat gain: 5.5 W/m

Consumption balance
-Heat: 61%
-Elec: 39%

Heat gain reduces the heat losses of 29%.

Result 5: Energy Consumption with a Varying Heating Load

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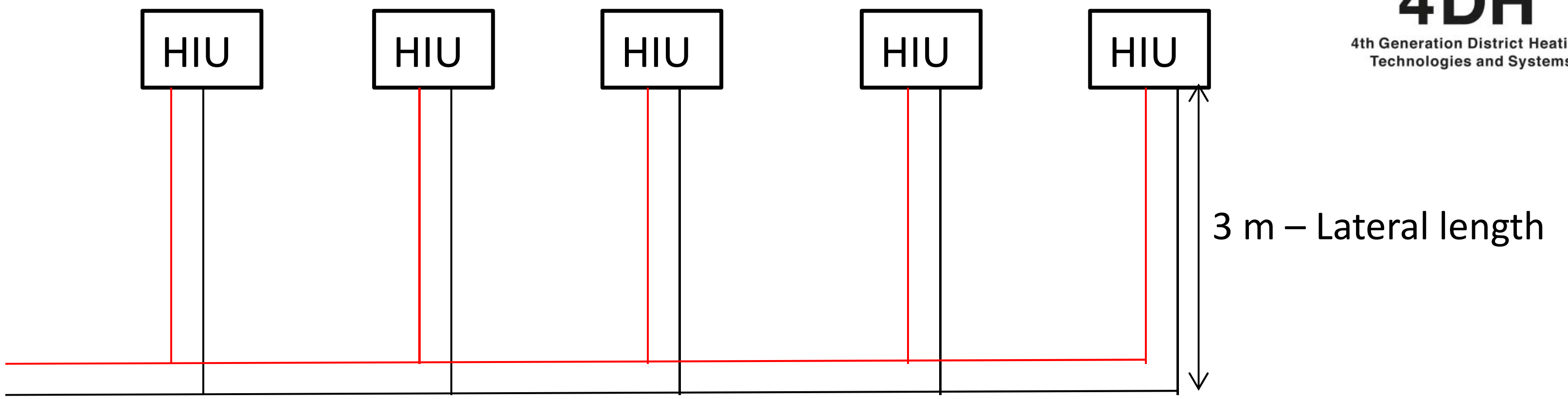
- Operational optimisation is possible on a 90/40 DH network and not on a 70/40 because 70^{o}C is assumed to be the minimum required temperature by the end-user. So a 70/40 DH cannot reduce the network heat losses by reducing the flow temperature to supply a lower heating load.

Incorporating this Pipe Sizing Methodology in a Design Software

Input:
1) Type of network: 90/40, 70/40, 90/30 or 60/30.
2) The maximum heating load.
3) If the pipe is fitted in the Block or in the soil.
4) To be discussed…

Temperature [ºC]	Velocity [m/s] Low heat losses	Velocity [m/s] High heat losses
40	1.25	1.3
60	**1.55**	**1.6**
90	1.95	2.1

Sizing Pipes when Pipes are in Parallel



Total length: 10 * 3 = 30 metres

So, we have 30 metres of pipes with heat losses; and 3 + 3 = 6 metres of pipes with pressure drop because the HIUs are connected in parallel.

In conclusion, we should also tolerate a higher pressure drop on pipes when installed in parallel.

Conclusion

- Return pipes should be of larger diameter than the supply pipe
- Restriction on the flow temperature should only happen if we have some waste heat for free at a lower temperature, otherwise
- We should have no restriction on the flow temperature but we should mandate a return temperature below 30^{o}C:
  - Heat pumps can operate with biofuel boilers to obtain higher temperatures in a sustainable way.
  - When the temperature reduces to 100^{o}C in a Rankine cycle the Carnot factor and maximum electricity generation is of less than 0.2 and 20%. This is to be compared to 100% of useable heat!
  - This also has for effect of reducing the heat losses and the electricity consumption for pumping.
- 4th generation district heating system should be with this return temperature definition instead of also setting a low flow temperature
- 5th generation could then be to operate anergy grids!

Questions

Contact: oliver_mdp@yahoo.com
Tel: 0044 79356 66388

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