Heat loss of geothermal water though a pipeline

Heat and mass transfer

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Abstract

The main purpose by this paper is to calculate and to explain the heat loss of geothermal water through a pipeline. Geothermal water is located in high temperature areas in Iceland. These areas are only in some parts of the country, that's why transmission pipeline are required to transport the water. Several factors can affect the heat loss including pipe materials, insulation, pipe size, pipe length, temperature inside and outside the pipe and velocity of the water.

Nomenclature

Air

$T_{\infty,2}$	Temperature of the air outside the pipe $[^\circ C]$
$R_{conv,out}$	Resistance of the air outside the pipe $[^\circ C/W]$
h_2	Heat transfer coefficient for the air $[W/m^2 \cdot^\circ C]$

Water

$T_{\infty,1}$	Temperature of the water inside the pipe $[^\circ C]$
V	Velocity $[m/s]$
$\dot{Q}$	Heat Flow $[W]$
ΔT	Temperature differance $[^\circ C]$
$R_{conv,in}$	Resistance of the water inside the pipe$[^\circ C/W]$
h_1	Heat transfer coefficient for the water $[W/m^2 \cdot^\circ C]$
$\dot{m}$	Mass flow rate $[kg/s]$
k_1	Thermal conductivity $[W/m \cdot^\circ C]$
ρ	Density $[kg/m^3]$
ν	Kinematic viscosity $[m^2/s]$
μ	Dynamic viscosity $[kg/s \cdot m]$

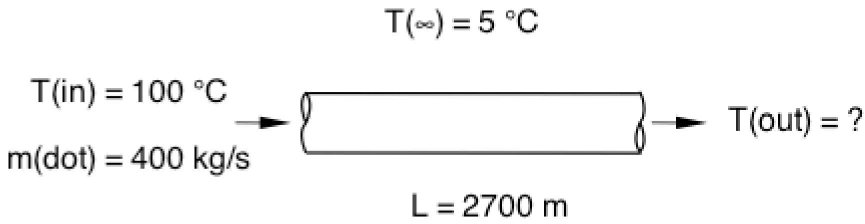
Pipe

L	Length $[m]$
D	Diameter $[m]$
A	Area $[m^2]$
R	Resistance $[^\circ C/W]$
k	Thermal Conductivity $[W/m \cdot^\circ C]$
r	Radius $[m]$

Introduction

The source of geothermal fluid for a direct use application is often located some distance away from the user. This requires a transmission pipeline to transport the geothermal fluid. The pipeline can either be below or above the ground. In this paper the explanation and calculation of the heat loss of a geothermal water flowing through a insulated pipeline, around 27 km, from the Nesjavellir power plant to Reykjavík.

Problem statement



The aim in this report is to calculate the final temperature or the heat loss of geothermal water flowing through a pipeline. The water is pumped up from the ground and the temperature is 100 °C. It flows through an insulated pipeline around 27 km, which is located above ground. The pipe is made from steel, insulated with rock wool and covered with aluminum sheets. The biggest challenge in the calculations is to find and assume the heat transfer coefficient parameters and the heat conduction parameters. The choice of these parameters will affect the outcome, specially the thermal conduction for the wool k_2.

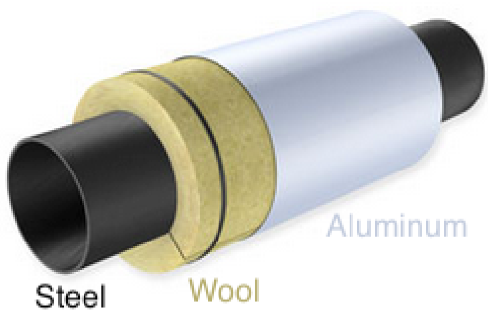


Figure 1: Cross section of the pipeline

Literature survey

The Nesjavellir geothermal field is among the largest high temperature areas in Iceland. High geothermal activity is closely connected to three active volcanic systems in the region. The hot geothermal fluids will be used to heat up fresh water to a temperature of about 100 °C using heat exchangers. The hot fresh water is then be piped to the capital, and distributed. After use, most of the spent water is discharged into the sea at a disposal temperature of some 40 °C. [1] [3]

The main buildings of the power station are at an elevation of 177 m above mean sea level. From there the hot water is pumped through a pipeline, 80 cm for most of the 27,2 km distance to the capital. The pumps have only to be used to conquer the uphill gradient through the mountains to the 406 m level and after that it free flows downhill to Reykjavík. The pipeline is design to carrie a maximum of 1870 l of 100 °C hot water per second. It is thoroughly insulated and the heat loss never exceeds 2 °C, the greater the quantity of water running through, the less the heat loss.

The steel pipeline to the surge tank has a diameter of 900 mm and a wall thickness of 12 mm. It is designed to carrie water up to 96 °C hot with a maximum transport capacity of 1870 liters per second. The steel pipeline from the surge tanks has a diameter of 800 mm and a wall thickness of 8 to 10 mm, depending on the maximum inside pressure. The steel pipe is laid mostly above ground and rests on concrete pillars. It is insulated with rock wool and covered with plastic and aluminum sheets. Snow never melts on the pipeline in winter, which goes to show how well it is insulated. [3]

Figure 2: Nesjavellir power plant

Project description

The heat conduction is steady and temperature is independet of time. Surface temperature is constant and uniform. The inner surface of the pipe are smooth. Heat transfer to the surroundings is negligible.

The mass flow in to the pipe is known and also the diameter of the pipe, then the velocity of the water inside the pipe can be calculated.

$$v = \frac{\dot{m}}{\rho \cdot \pi \cdot \frac{D^2}{4}} = \frac{400kg/s}{960 \cdot \pi \cdot \frac{(0.576m)^2}{4}} = 1.599m/s$$

Kinematic viscosity is calculated by using tabel A4. in the heat transfer book.

$$\nu = \frac{\mu}{\rho} = \frac{282 \cdot 10^{-6} kg/s \cdot m}{960 kg/m^3} = 2.9375 \cdot 10^{-7} m^2/s$$

Reynolds number calculated to see if the flow is laminar or turbulent.

$$Re = \frac{v \cdot D}{\nu} = \frac{1.599m/s \cdot 0.576m}{2.9375 \cdot 10^{-7} m^2/s} = 3135440.171$$

The Reynolds number is really high and that's why there is a turbulent flow.
Assuming fully developed flow in the entire pipe give the Nusselt number formula below.
Where Pr is the Prandtl number found in table A4. in the heat transfer book.

$$Nu = \frac{h \cdot D}{\nu} = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4} = 0.023 \cdot 3135440.171^{0.8} \cdot 1.75^{0.4} = 4528.7867$$

The heat transfer coefficient for the water inside the pipe is calculated with the formula below.

$$h_1 = \frac{k_1}{D} \cdot Nu = \frac{0.679 W/m \cdot^\circ C}{0.576m} \cdot 4528.7867 = 5338.6219 W/m^2 \cdot^\circ C$$

The total length of the pipe is L = 27000 m, the area of the steel pipe A_1 with the inner radius $r_1 = 0.288$ m and the area of the whole pipe A_4 with the radius $r_4 = 0.4$ m.
The area for the whole pipe includes the wool insulation and the aluminum sheet covers.

$$A_1 = 2 \cdot \pi \cdot r_1 \cdot L = 2 \cdot \pi \cdot 0.288m \cdot 27000m = 48858.0489m^2$$

$$A_4 = 2 \cdot \pi \cdot r_4 \cdot L = 2 \cdot \pi \cdot 0.4m \cdot 27000m = 67858.4013m^2$$

In order to calculate the heat flow the total resistance needs to be calculated. Parameters needed for the calculations are:

$k_1 = 26W/m \cdot^\circ C$	is the thermal conduction for steel pipe
$k_2 = 0.5W/m \cdot^\circ C$	is the thermal conduction for rock wool insulation
$k_3 = 40W/m \cdot^\circ C$	is the thermal conduction for the aluminum cover sheets
$h_2 = 25W/m^2 \cdot^\circ C$	is the heat transfer coefficient for the air
$r_2 = 0.298m$	is the outer radius of the pipe
$r_3 = 0.398m$	is the outer radius of the pipe plus the insulation

The indicidual thermal resistances become $[^\circ C/W]$:

$$R_{conv,in} = \frac{1}{h_1 \cdot A_1} = \frac{1}{5338.6219W/m^2 \cdot^\circ C \cdot 48858.0489m^2} = 3.8339 \cdot 10^{-9}$$

$$R_{pipe} = \frac{\ln \frac{r_2}{r_1}}{2 \cdot \pi \cdot k_1 \cdot L} = \frac{\ln \frac{0.298m}{0.288m}}{2 \cdot \pi \cdot 26W/m \cdot^\circ C \cdot 27000m} = 7.7385 \cdot 10^{-9}$$

$$R_{wool} = \frac{\ln \frac{r_3}{r_2}}{2 \cdot \pi \cdot k_2 \cdot L} = \frac{\ln \frac{0.398m}{0.298m}}{2 \cdot \pi \cdot 0.5W/m \cdot^\circ C \cdot 27000m} = 3.4113 \cdot 10^{-6}$$

$$R_{aluminum} = \frac{\ln \frac{r_4}{r_3}}{2 \cdot \pi \cdot k_3 \cdot L} = \frac{\ln \frac{0.4m}{0.398m}}{2 \cdot \pi \cdot 40W/m \cdot^\circ C \cdot 27000m} = 7.3868 \cdot 10^{-10}$$

$$R_{conv,out} = \frac{1}{h_2 \cdot A_4} = \frac{1}{25W/m^2 \cdot^\circ C \cdot 67858.4013m^2} = 5.8946 \cdot 10^{-7}$$

All the resistance are in series, the total resistance becomes $[^\circ C/W]$:

$$R_{total} = 4.0131 \cdot 10^{-6}$$

The heat flow is

$$\dot{Q} = \frac{T_{\infty,in} - T_{\infty,out}}{R_{total}} = \frac{100^\circ C - 5^\circ C}{4.0131 \cdot 10^{-6}} = 23672501.17W$$

Then the temperature differance becomes:

$$\Delta T = \dot{Q} \cdot R_{pipe} = 23672501.17W \cdot 7.7385 \cdot 10^{-9} = 0.1832°C$$

The final temperature is then:

$$T_{final} = T_{\infty,1} - \Delta T = 100°C - 0.1832°C = 99.8168°C$$

Conclusions

For these calculations regarding the parameters that where used, the heat loss is very little, only around 0.2 °C. This loss is reasonable considering that in real life the loss of this specific pipe is less than 1 °C. The main factors that have effects on the outcome, giving little heat loss, is the insulation of the pipe, the thermal conduction for the wool k_2, and the high mass flow rate.

References

[1] G.S. Bodvarsson, S. Bjornason, A. Gunnarsson, E. Gunnlaugsson, O. Sigurdsson, V. Stefansson, B. Steingrimsson, *A SUMMARY OF MODELING STUDIES OF THE NESJAVELLIR GEOTHERMAL FIELD*, April 2013. url: https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/1988/Bodvarsson.pdf

[2] *NESJAVELLIR GEOTHERMAL POWER PLANT*, April 2013. url: http://www.nat.is

[3] *NESJAVELLIR hot water main*, April 2013. url: http://www.verkis.com/projects/geothermal/hot−water−mains/nr/1415

[4] B. Sundén *Introduction to Heat Transfer*, Lund University, Sweden, 2012.

[5] J.P Holman *Heat Transfer*, Southern Methodist University, US, 2010.