The importance of pressure drop in borefield design

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Pressure drop is an important but often overlooked parameter in the hydraulic design of borefields. In this article, we explore what pressure drop is, what factors contribute to it, and why it is crucial to consider this parameter when designing a borefield.

What is pressure drop?

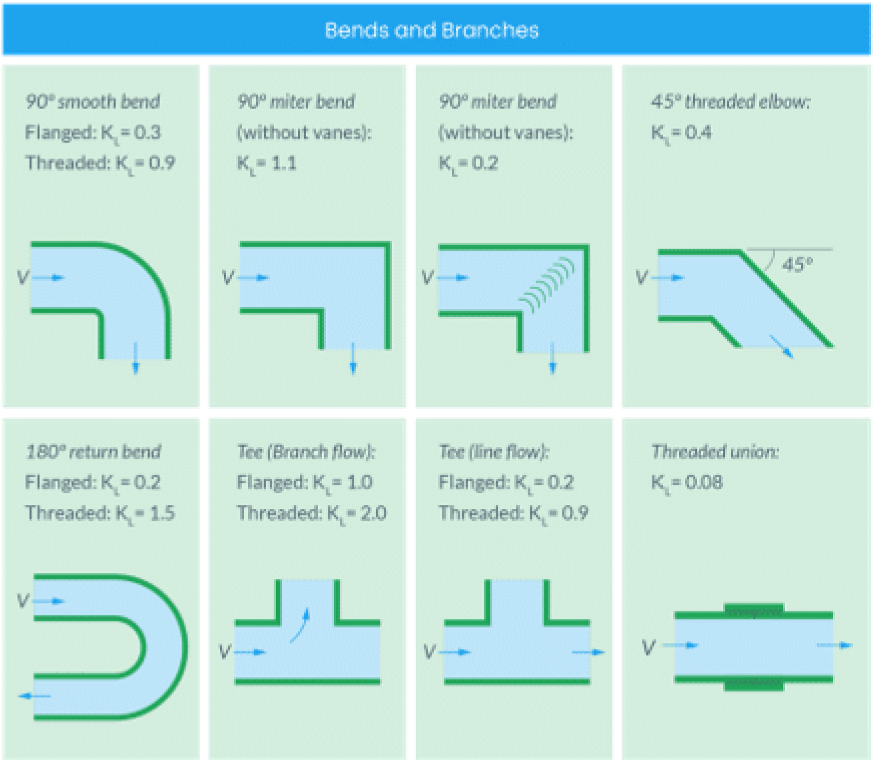
The pressure drop is a fluid dynamic concept defined as *the difference in pressure between point A and B due to friction*, and this friction element is crucial. This friction can occur between the fluid and the pipe walls, the valves, pumps, etc., but also within the fluid itself, between different fluid 'droplets'. The pressure drop can therefore be seen as the effort required to move the fluid through the system. Although the pressure drop can be a complicated parameter to calculate, the following parameters play a role:

- **Pipe length, diameter, and viscosity**. If you have a longer or narrower pipe, you will have a harder time pushing the fluid around. The same applies to viscosity: if you were to fill your borefield with honey, you can imagine the amount of effort required to move it through the system.
- **Routing**. A borefield where the horizontal connections between boreholes are straight and parallel will allow fluid to flow more easily than one where boreholes are connected with bends or right-angled connections.

Both aspects contribute to the calculation of the pressure drop and are respectively called **friction losses (major losses)** and **local losses (minor losses)**. Both are explained below, in reverse order, for ease of understanding.

Local losses

Local losses (also called minor losses) account for pressure drop contributions that can be pinpointed to specific components in the hydraulic design. These include bends, interconnections, valves, etc. The table below shows a few examples of different local losses, which are defined by a factor K.



Examples of different factors for the local losses. (Source: https://engineerexcel.com/loss-coefficient/)

As seen in the table, a smooth bend (especially when flanged) has a lower loss factor than a right-angled bend, which aligns with expectations. Similarly, 45° bends have lower correction factors than 90° bends.

To calculate the local losses, the following formula is used:

$$\Delta P = \left(\sum K\right) \cdot \frac{\rho \, v^2}{2}$$

where:

- K the local pressure drop factor (-)
- ρ the fluid density (kg/m^3)
- v the fluid velocity (m/s)

To determine the total contribution of all local pressure drops, all different K's are summed and multiplied by $\frac{\rho \, v^2}{2}$. The friction losses, however, are not as straightforward.

Friction losses

Friction losses (also called major losses) are pressure drops that cannot be pinpointed to specific components but instead occur throughout the entire system. These are calculated using the well-known **Darcy-Weisbach formula**:

$$\Delta P = f \cdot \frac{L}{D} \cdot \frac{\rho\, v^2}{2}$$

where:

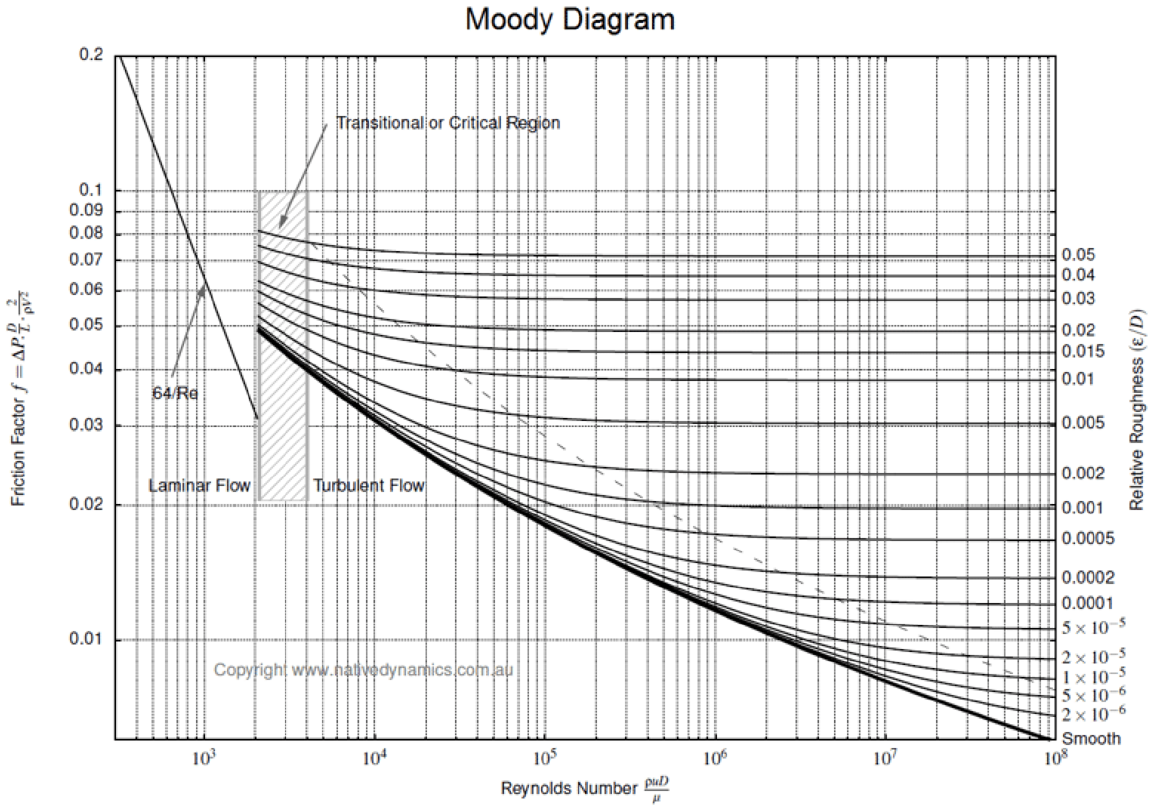
- f the Darcy-Weisbach friction factor (-)
- L the pipe length (m)
- D the pipe diameter (m)
- ρ the fluid density (kg/m^3)
- v the fluid velocity (m/s)

This aligns with intuition, as a longer pipe results in higher pressure drops. The only new factor here is the Darcy-Weisbach friction factor, which is explained below.

Moody diagram

The **Moody diagram** is a well-known graph in fluid dynamics used to determine the Darcy-Weisbach friction factor.

> ***!Caution***
> *Please note that this graph uses log-log axes, meaning that values do not increase linearly between neighbouring lines.*



Moody diagram

!Note
If you have not read our article on the Reynolds number, you can check it out here.

The Moody diagram is divided into two main regions based on the Reynolds number: laminar flow and turbulent flow. Three key observations can be made:

1. For the turbulent zone, there are multiple curves, each representing different *relative roughness* values. This is related to the smoothness of the pipe's inner wall. Pipes used in geothermal applications are typically made of smooth PE with minimal surface irregularities. However, steel or concrete pipes exhibit visible and tangible roughness, increasing their relative roughness.

   !Note
   Although traditional borefield pipes are smooth, some are specifically designed with a rougher surface. Always check the technical documentation for surface roughness values when calculating the friction factor.

2. For the laminar zone, there is only one curve for all surfaces, a direct consequence of Poiseuille's law in circular pipes. Although the derivation is beyond the scope of this article, interested readers can find more information here.

3. A sudden increase occurs between the laminar and turbulent friction factors. As discussed in our article on the Reynolds number, this is due to the transition from laminar

to turbulent flow. When considering pressure drop, it can be assumed that once the system moves beyond the laminar regime (Re > 2300), it quickly transitions to the turbulent friction factor.

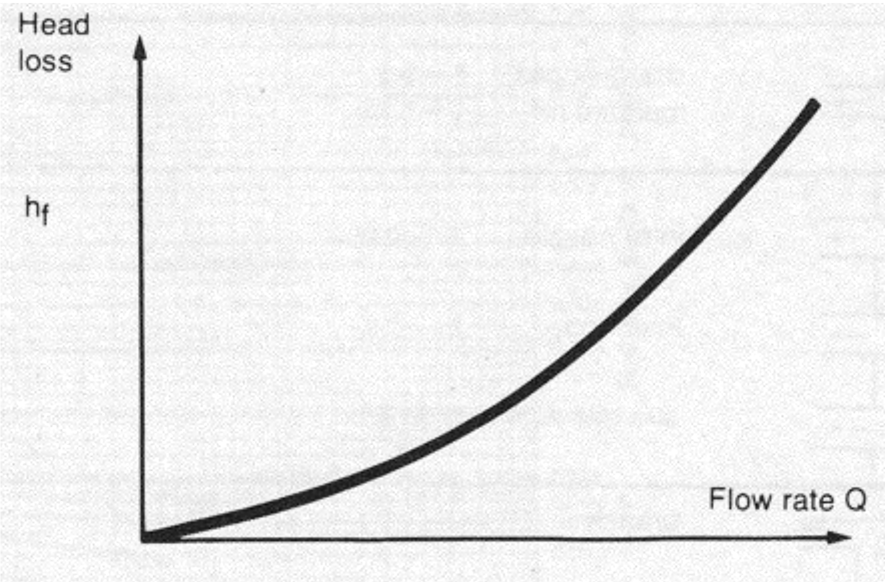
Total pressure drop

When both local and friction losses are taken into account, the total pressure drop is given by:

$$\Delta P = \left(f \cdot \frac{L}{D} + \sum K\right) \cdot \frac{\rho\, v^2}{2}$$

As shown in this equation, pressure drop increases quadratically with the flow rate. This means that even a small increase in flow rate significantly raises the total pressure drop. This is crucial when designing the hydraulics of a system and determining, for example, the diameter of the horizontal piping.

!Note
Strictly speaking, this relationship is not perfectly quadratic, as the friction factor also depends on the flow rate via the Reynolds number.



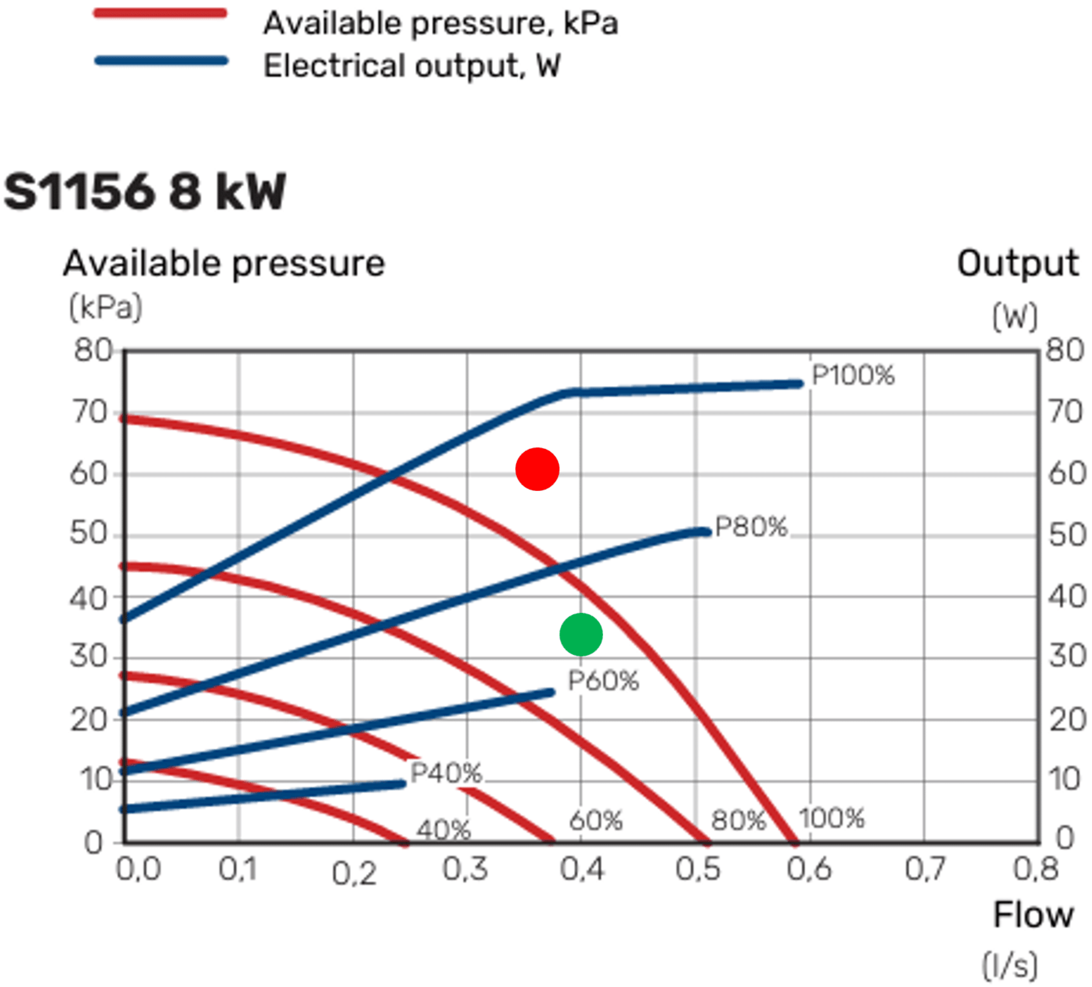
Typical pressure drop curve as a function of flow rate.
(Source: http://pumpfocus.com/pumpbook/total-head-loss-in-pipe-system/)

Importance of the pressure drop

Now that we have discussed what pressure drop is and how it is calculated, we will highlight two reasons why it is important to consider when designing a borefield: pump selection and pump energy consumption.

Pump selection

When designing your borefield, you always specify a certain flow rate. This flow rate determines the borehole's effective thermal resistance and, consequently, the overall performance of the system. However, each flow rate has an associated pressure drop, which the pump must be able to handle. Below is an example of a pumping characteristic, as typically found in technical documentation.



Pump characteristics from the S1156 8 kW. (Source: NIBE)

The red lines in the figure above represent what is known as the pump characteristic of our system at different load percentages of the circulation pump. The 100% line defines the boundary of all possible flow-pressure points that can be achieved when operating this heat pump at full capacity.

If, for example, a system is designed for a flow rate of 0.4 l/s with a calculated pressure drop of 33 kPa, this falls within the pump's operational range, meaning the system will work. However, if the design flow rate is 0.37 l/s but the pressure drop is 62 kPa, the pump will not be able to deliver this, and the borefield will not receive the required flow rate.

If the system cannot provide the necessary pressure drop for the required flow rate, an additional primary circulation pump must be installed.

Pump energy

Higher pressure drop leads to higher electricity consumption by the pump, reducing overall system performance. The power required by the pump to overcome the pressure drop is given by:

$$\boldsymbol{P = \Delta P \cdot \dot{Q}}$$

where:

- $\boldsymbol{P}$ is the pump power (W)
- $\boldsymbol{\Delta P}$ is the total pressure drop of the system (Pa)
- $\boldsymbol{\dot{Q}}$ is the flow rate of the system (m^3/s)

Since pressure drop increases quadratically with flow rate, pump energy consumption can be significantly affected.

!Note
Modern circulation pumps for borefields can be frequency-controlled, adjusting the flow rate dynamically and reducing pressure drop and energy consumption on average. This will be discussed in more detail in a future article on modulating heat pumps.

To illustrate this significance, we refer to the example below. Here we have taken the same borefield design with a certain flow rate and only changed the borehole internals.

Design	Flow/borehole [l/s]	Re [-]	Pressure drop [kPa]	Yearly electricity consumption [kWh/year]
Single U DN 32	0,30	2773	83,97	37,787
Single U DN 40	0,30	2211	17,57	7,907
Double U DN 32	0,30	1386	21,72	9,774

Example of the pump energy for different borehole internals.

As you can see, the single U DN32 has crossed the laminar boundary and is now in the transient-turbulent zone, resulting in a higher pressure drop and correspondingly higher electricity consumption for the circulation pump. Switching to a single DN40 significantly reduces the pressure drop, as well as the electricity consumption, since the system remains within the laminar regime.

If we opt for a double DN32 configuration, the Reynolds number is even lower than before, yet the pressure drop is slightly higher. This is due to the influence of pipe diameter on friction losses, where both fluid velocity and pipe diameter contribute to the overall pressure drop.

Conclusion

This article outlined the fundamental aspects of pressure drop calculations in borefield hydraulic design. We discussed local and friction losses and highlighted two key reasons why pressure drop is an important design parameter: pump selection and pump energy consumption.

In the next article, we will explore how GHEtool Cloud can assist in designing borefields while considering pressure drop calculations.

References

- Watch our video explanation over on our YouTube page by clicking here.

Check out GHEtool today at:
https://ghetool.eu