The Reynolds number: laminar or turbulent flow

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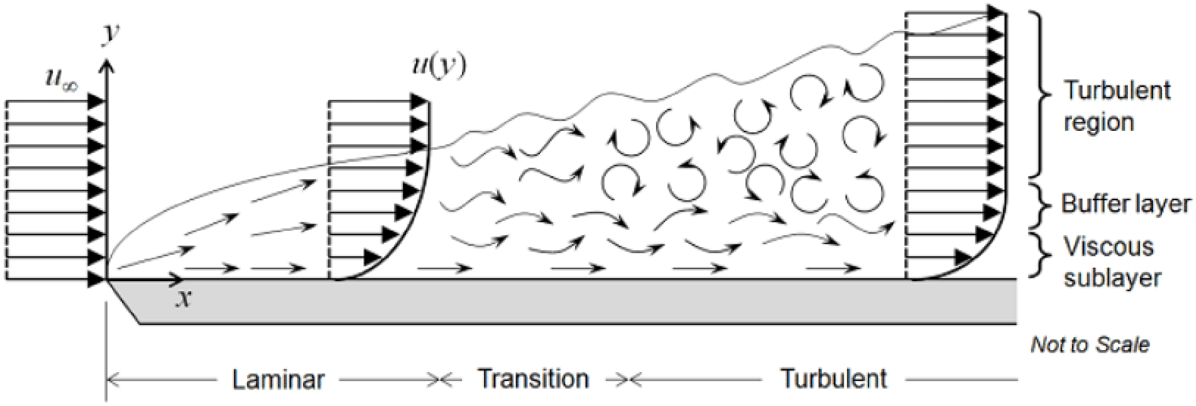
The borehole equivalent thermal resistance is a rather important parameter in the design of borefields, and it is significantly influenced by the Reynolds number. But what is this number exactly? And what has it to do with laminar or turbulent flows?

The Reynolds number (Re)

The Reynolds number is a non-dimensional number, i.e. a number without a unit, which tells you something about the fluid regime inside the borefield.



Source: https://www.comsol.de/blogs/which-turbulence-model-should-choose-cfd-application

For lower Reynolds numbers, the flow is **laminar** meaning that all the fluid particles move in parallel. This fluid regime has a low pressure drop and hence also low pumping costs, but due to the laminar nature of the flow, the heat transfer is rather bad, because the inner fluid layers are insulated from the pipe. Therefore, a laminar fluid regime gives a higher borehole thermal resistance.

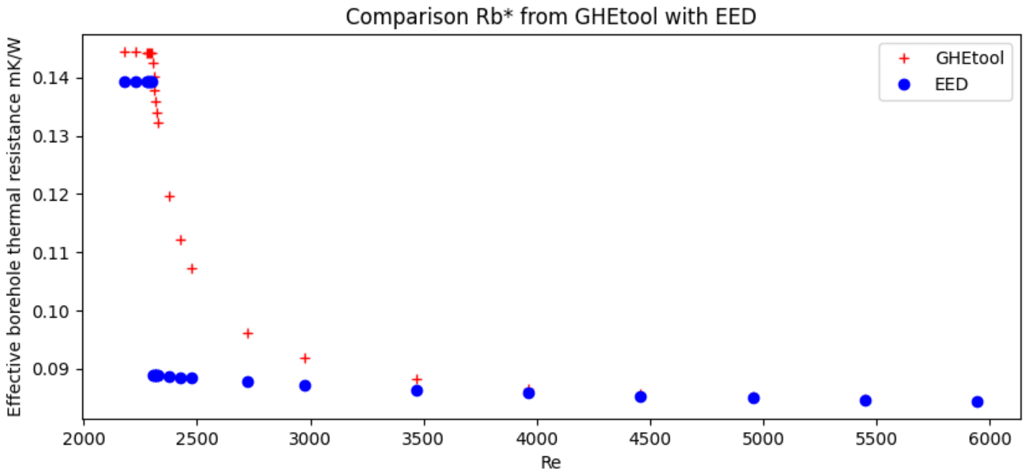
For high Reynolds numbers, the fluid is **turbulent** meaning that the fluid particles moves in a very chaotic way. This regime has a high pressure drop and corresponding higher pumping costs, due to the energy loss within the fluid itself. On the other hand, due to this mixing nature of the turbulent regime, the heat transfer is very good, since all the fluid particles can touch the pipe wall at one point or another. The borehole thermal resistance is hence lower.

Between the turbulent and the laminar flow, there exists a **transient** regime. There is not much known about this fluid regime from a theoretical point of view, but it can be understood from reasoning that it is unphysical that the laminar flow switched directly at a laminar to a turbulent flow. It is assumed that all flows with Re<2300 are laminar and that flows which have Re>4000 are turbulent. All flows in between those numbers or neither laminar nor turbulent. The borehole thermal resistance is hence interpolated for these cases. This approach follows (Gnielinski, 2013) [1].

> ***! Note***
> *The Reynolds number is defined as follows:* $Re=\rho D\dot{V}\ \mu$ *where:*
>
> ρ *is the density of the fluid [kg/m*^{3}*]*
>
> *D is the diameter of the tube [m]*
>
> $\dot{V}$ *is the speed of the fluid inside the pipe [m/s]*
>
> μ *the dynamic viscosity of the fluid [pa s]*

The fluid regime and the borehole thermal resistance

In the figure below you can clearly see the effect of the fluid regime on the borehole thermal resistance. Up until Re=2300, the borehole thermal resistance is more or less constant and so is the case after Re>4000. It is in the region between those two numbers where almost all the borefields in practise are designed, so it is important to understand how the borehole resistance already drops off quite a lot when just entering the transient fluid regime.



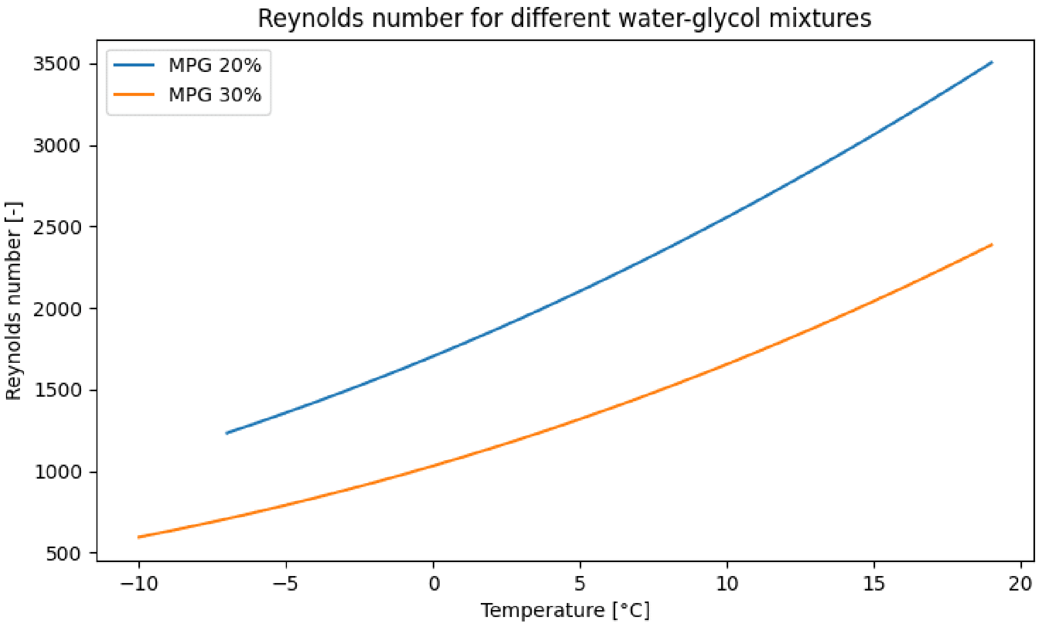
> ***!Caution***
> *Note that not all borefield sizing software take into account this transient regime. Earth Energy Designer for example goes from a laminar flow instantly to a turbulent flow, leading to big differences in the borehole thermal resistance when operating in the transient regime.*

Influence of viscosity and fluid temperature

The Reynolds number (and hence also the effective borehole thermal resistance) is strongly influenced by the viscosity of the fluid (denominator). By adding glycol for example to the heat transfer fluid, the fluid becomes way more viscous and hence the Reynolds number drops significantly. Another factor that has an effect on the viscosity is the temperature. Looking at the water-glycol mixture below, the fluid is more viscous when the temperature drops. This means that the borehole thermal resistance will increase during peak heating when the fluid temperature drops to smaller values. This is a negative spiral since when the heat demand is the most critical, the temperature will be the lowest. This leads to an increase in the viscosity, which leads to a decrease in the Reynolds number, causing an increase in the borehole thermal resistance. This causes again a lower peak temperature.

!Caution

This effect can be significant when you have designed your borefield at the border of the transient regime. Just a small drop in temperature can cause it to shift to the laminar regime and your fluid temperatures will drop significantly!



!Note

Currently, within GHEtool Cloud, the reference value for the viscosity calculation of the fluid is the minimum average fluid temperature which can be set on the 'General' tab. In the future, we want to update this model to work with a 'variable viscosity' that is calculated at every time step, giving you a more accurate result. The critical borefield size however will not change, since it is determined by the minimal temperature.

References

- Watch our video explanation over on our YouTube page by clicking here.
- [1] Gnielinski, V. (2013). On heat transfer in tubes. International Journal of Heat and Mass Transfer, 63, 134–140. https://doi.org/10.1016/j.ijheatmasstransfer.2013.04.015