

DEVELOPING WORK ON GROUND HEAT EXCHANGERS

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1. BACKGROUND

Ground couple heat pump performance is to a great extent depending on the GHEX (Ground Heat Exchangers), the ground loop. The conventional GHEX for vertical bore holes looks as a U when it is installed in the ground and therefore called a U-loop. In order to improve thermal performance expressed in terms of W per installed boreholes meter sometime double U-loops are installed in the borehole. However, a conventional U-loop doesn't utilize the investment that the borehole constitutes in the very best way. It has to operate at high mass flow, i.e. turbulent flow, in order to offer high heat transfer performance from the fluid in the pipe to the ground. High flows means high pump losses and hence electric consumption. If the GHEX could operate with lower flows, preferably in the laminar flow regime the pump losses could be reduced considerably. Further more, in the conventional U-loop there is a heat transfer between the flow upward and the flow downwards which reduce heat transfer from the fluid in the U-loop to the ground.

There are new ideas coming up regarding more efficient GHEX. The most promising type of GHEX seems to be a type that is often called coaxial pipe. This paper describes a recent developing work on such type of coaxial GEHX, which is also characterized by having one of the legs thermal insulated.

2. NEW GROUND HEAT EXCHANGERS, TIL-PIPE (THERMAL INSULATED LEG)

As mentioned above in the background conventional U-loops suffer from some thermal deficiencies. For instance, heat is transferred between the upward and the downward flow. When heat is desired from the ground, cold fluid is going down in one leg. The fluid gets warmer the deeper down in the ground it flows. However, when going upwards the warm fluid transfer heats the downward flow, and hence cold down the upward flow as illustrate in Figure 1. There is a degradation of energy quality, Exergy, during the heat exchanging process in the GHEX. The same degradation takes places during summer when the warm fluid is supposed to get colder.

If one leg is thermally insulated at a conventional U-loop the heat transfer between the two legs can be reduced considerably but there will then be only one leg that has thermal contact with the ground and therefore decrease the desired heat transfer between the fluid in the pipe and ground. Further more, if a conventional U- GHEX ground loop with a diameter of 40 mm is operated at low flow velocity in order to obtain a large temperature difference between the inlet and outlet leg it will perform bad from heat transfer point of view. The reason to that is that the large hydraulic diameter calls for turbulent flow in order to get a good heat transfer coefficient in the pipe. Normally a conventional U-loop is operating with a flow velocity that gives about 3-degree temperature difference between the inlet and outlet leg. The thermal resistance between the fluid and the ground and between the two legs determines the transfer performance.

The thermal resistance between the fluids in the pipes collectively, and in the borehole wall can be defined according to following equation:

$$R_b^* = R_b + \frac{1}{3} \frac{1}{R_a} \cdot \left(\frac{\Delta T}{q} \right)^2$$

where;

R_b [K/(mW)] = Thermal resistance between the bulk of fluid and the bore hole if no heat transfer between the upward and downward flow takes places.

ΔT = Temperature difference between the inlet and outlet leg.

q [W/m] = Average power per meter transferred between the fluid and the borehole wall.

R_a [K/(mW)] = Thermal resistance between the upward and downward flows

For a certain power q it can be seen that ΔT which correspond to the flow velocity influence R_b^* very strongly. Further more thermal resistance R_a between the two legs influences the heat resistance R_b^* . With a good thermal insulation and high flow velocity, that is high, low temperature difference ΔT between the inlet and outlet legs the thermal resistance R_b^* will be low and thus high performance W/m is possible. However, if the GHEX could operate with low flow velocity and still has a low heat transfer between the two legs (high R_a) there is a great potential to improve a ground couple heat pump installation performances. In Figure 2 temperature profiles for one conventional U-loop and one TIL-pipe (Thermal Insulated Leg) are illustrated. The U-loop is operated with a flow velocity that gives $\Delta T = 3$ -degree. If there is no heat transfer between the two legs at all the temperature profile will look like the straight blue line for the fluid flowing downwards and the straight yellow line flow upwards. For the U-loop the dotted black line illustrate the mean temperature from the two legs together. The ground temperature is $+ 8$ °C and the driving temperature difference between the mean temperature from the GHEX and the ground is illustrated with arrows. The mean driving temperature will then be 3.5 °C. In reality the driving temperature difference less due to the heat transfer between the legs. The dotted line illustrates the real temperature profile schematically.

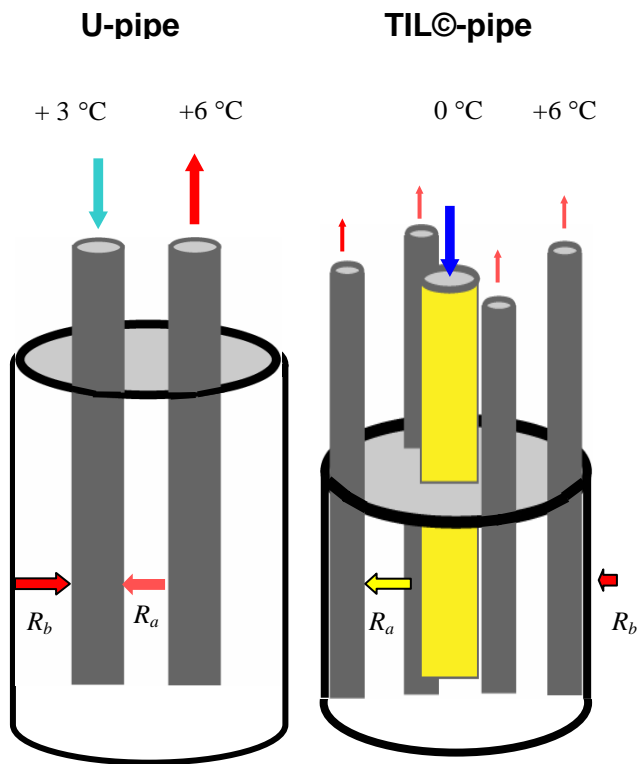


Figure 1 Conventional U-pipe and a TIL-pipe

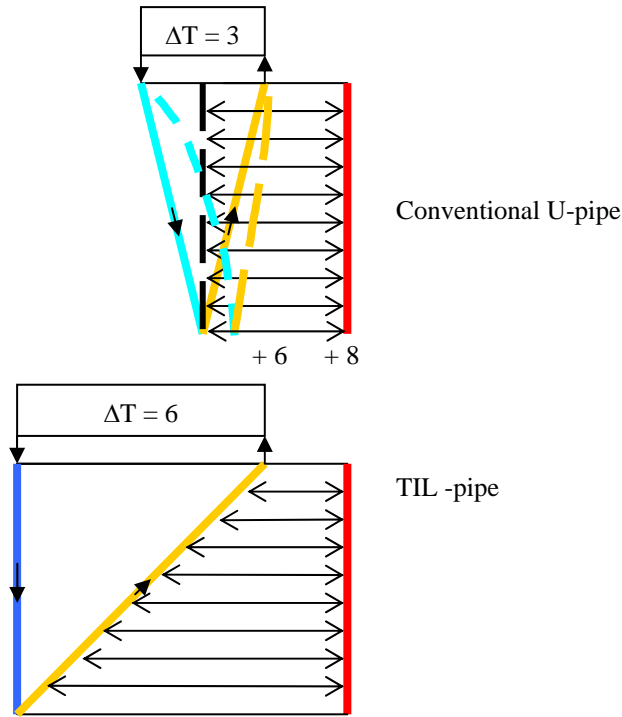


Figure 2. Temperature profile for a U-pipe and a TIL-pipe

In the lower part of Figure 2 the temperature for a TIL-pipe is illustrated that operates with half the flow velocity and hence twice as large ΔT . It is also assumed that the heat transfer between the legs are zero, that is, infinite high R_a .

With the TIL-GHEX the driving temperature difference illustrated by arrows is 30 percentage higher than for the conventional U-pipe. That means that it is possible to obtain 30 % higher performance (W/m) if it is possible to design a TIL-GHEX that has at least the same thermal resistance R_b^* as the conventional U-pipe.

Figure 3 shows one example of a TIL-design with 4 pipes constituting the outer leg that are in thermal contact with the borehole wall and a central thermal insulated leg.

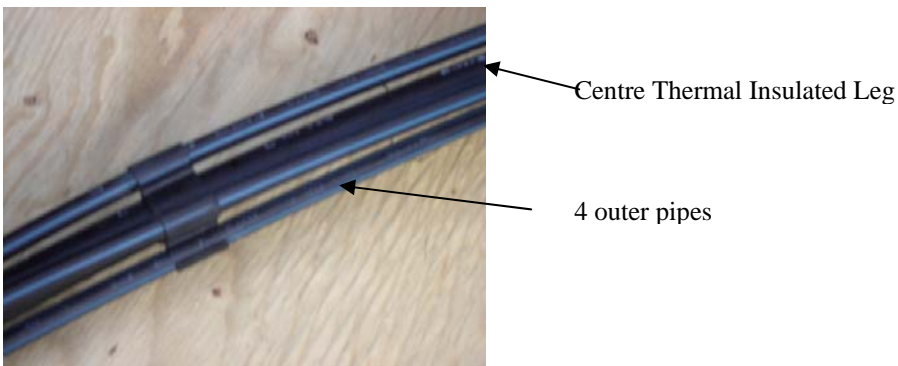


Figure 3. TIL- GHEX with 4 outer pipes.

As a reference a conventional U-pipe operating at normal condition, that is, volume flow of 0.48 l/s which corresponds to $\Delta T = 3$ -degree is used. Such an installation has a borehole resistance R_b^* of 0.14 if borehole-filling conductivity is 0.75. Pressure drop in a 200 m deep borehole is 58 kPa, which gives approximately 270 W circulation pump power if assuming a pump efficiency of 10 %.

In table 1 are the borehole resistance R_b and pressure drop for different TIL-designs listed. The TIL-designs are operating at half of the normal flow for a U-pipe, which means approximately 0.24 l/s. If we assume a high R_a ($R_b = R_b^*$), that is, a good thermal insulation between the upward and downward leg the temperature profile will look as in Figure 2.

A TIL-design involving 3 pipes with a diameter of 25 mm will involve a R_b of 0.14, that is, in the same order of magnitude as a conventional U-pipe operating with $\Delta T = 3$ degree temperature.

Table 1. Total volume flow= 0.24 l/s, $\Delta T = 6$, Borehole diameter =140 mm

TIL-Pipe Design	R_b	Pressure drop [kPa]	Circulation pump power [W]
3 * 25 mm * 2 mm	0.14	25	105
4 * 16 mm * 2 mm	0.12	160	400
6 * 16 mm * 2 mm	0.075	140	330
6 * 16 mm * 1 mm	0.065	70	180
9 * 16 mm * 1mm	0.045	45	90

It is always important to get close with the pipes toward the borehole wall to get the very best heat transfer. In table 1 the clearance between the pipes and the borehole wall is 1 mm and for a TIL-design with 4 * 16 mm pipes the thermal resistance is 0.12. With a clearance of 4 mm heat resistance will increase to 0.13. With a larger borehole diameter there is a possibility to increase heat transfer ratio due to the larger peripheral length if many and small pipes are in good contact with the borehole wall. However, it is not possible to take advantages of this opportunity with a conventional U-GHEX.

All TIL-designs in table 1 have a less thermal resistance between the fluid in the ground loop and the borehole wall, R_b . If operated according to Figure 2 there is a substantial performance improvement for the ground loop. With 9 pipes with each having a diameter of 16 mm and pipe wall thickness of 1 mm and a good thermal insulation the borehole resistance will be $R_b = 0.045$ ($R_b = R_b^*$) compared to the U-loop with $R_b^* = 0.14$. Ground thermal resistance is approximately in the order of 0.14 that is, in the same order of magnitude as the borehole resistance $R_b^* = 0.14$ for the conventional U-pipe, and thus a total thermal resistance of 0.28. With the TIL-GHEX the total thermal resistance is 0.19 which means a thermal resistance reduction of 30 %. Together with the higher driving temperature differences of 30 % a total increase of performance of almost 70 % is obtained with the TIL-GHEX. However, it is also important that the HVAC equipment can utilize the higher temperature differences ($\Delta T = 6$) from the ground in an energy efficient way. According to a study [ref 1] there is a potential to improve COP for a heat pump using R407-C as working fluid operating with high “glides” as $\Delta T = 6$. When operating with such high glides it seems possible to improve COP with 3.5 % compared to normal heat source temperature glides as $\Delta T = 3$.

When installing several GHEX in a certain configuration that is determined by the thermal property of an energy storage can be created with different temperature levels. In Figure 5 are temperature profiles illustrated that can be developed in the ground [Platell O,1988]. The temperature profiles that are illustrated occur two times per year, when the maximum charge and discharge takes place.

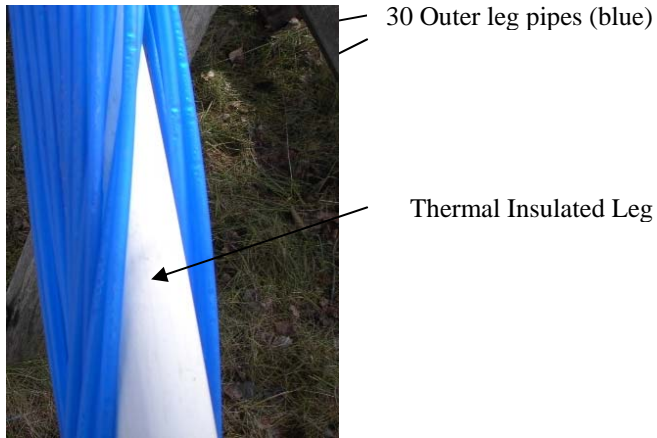


Figure 4 .TIL- Multi-pipe

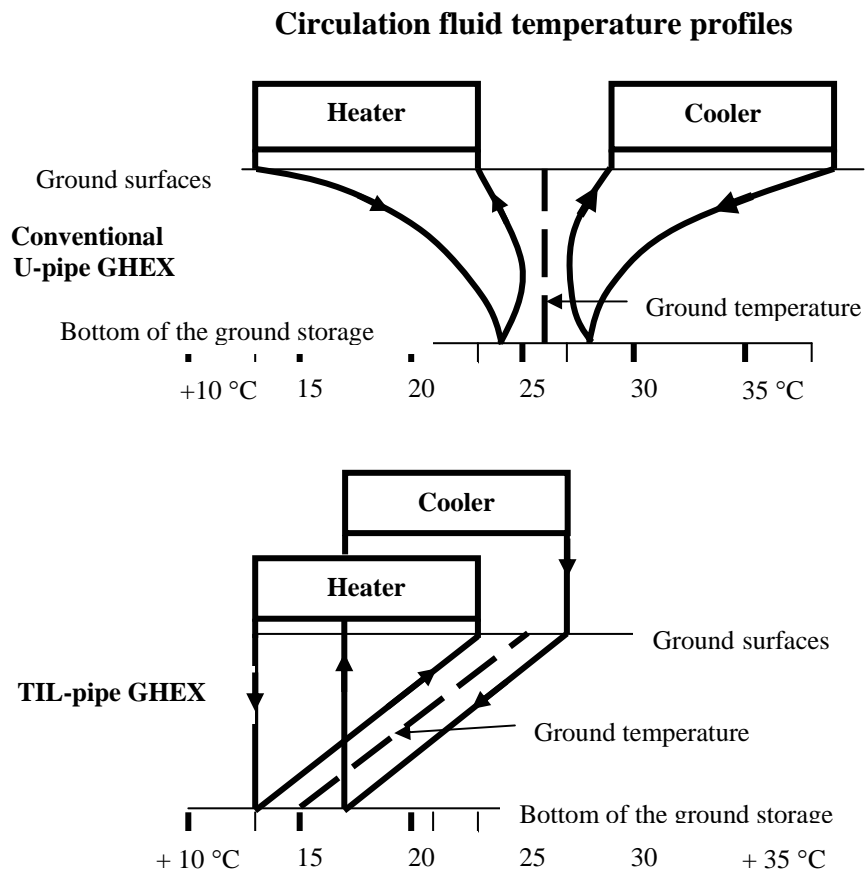


Figure 5 Temperature profile in the ground storage for U-pipe and TIL-pipe

The supply temperature during heating period is the same for the U-type installation and the TIL-type installation. Temperature difference between inlet and outlet (heat source glide) is also the same. However, in the TIL-type installation there is a temperature gradient that means that the bottom temperature of the ground storage is lower than the upper part of the ground storage. This means that heat losses from the TIL-type installation is lower than in the U-type installation if the ground is supposed to supply the same temperature during heating season. During summer season it can be seen that the TIL-installation offer lower temperature than the U-installation.

3. CONCLUSIONS

The optimal TIL-pipe will have many small pipes close toward the borehole wall. In figure 3 is a TIL- GHEX illustrated with 30 pipes with a diameter of 6 mm and wall thickness of 1 mm. If such a “carpets” of many small pipes is installed closed toward the borehole wall the borehole resistance R_b will almost be eliminated [Kjellson E, Hellström G. 1999], and improving thermal performance per meter two fold compared to conventional U-pipe loops. Considering the higher driving temperature differences further performance improvements is obtained. COP of the heat pump is also improved and circulation pump power is about 10 times less than for a conventional U-GHEX loop. However, concern regarding higher cost is justified for the TIL-GHEX. But in mass production the amount of material tends to determine the product cost and when amount of plastic material does not necessary have to be higher for a TIL-GHEX there is a considerably potential of more cost effective Geexchange technology. Energy storage implemented with many TIL- GHEX seams to have a great potential but requires a new control approach to exploits the inherent advantages that the TIL-GHEX seams to offer.

ACKNOWLEDGMENTS

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