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Determination of Optimal Distance Between Boreholes

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ABSTRACT

In Ground Source Heat Pump Systems (GSHPS), distance between boreholes is a very important parameter for reliability, long life time and performance of the whole system. In large scale applications of GSHPS, more than one borehole is needed and determination of the optimal distance between boreholes becomes an important issue. In this study, the effect of distance between boreholes on heat transfer rate per unit borehole length (unit HTR value) is computationally investigated. Four different configurations consisting of 2, 3, 5 and 9 boreholes are considered. 3 and 6 months averaged unit HTR value of the most critical borehole in each configuration is compared with that of single borehole to determine the performance loss. Variations of performance loss due to thermal interactions of boreholes with both time and distance are analyzed. Furthermore, the effects of thermal conductivity of ground on temperature distributions around borehole is also examined. Results can be used to determine the optimal borehole distance for various applications.

1. INTRODUCTION

In large GSHP applications, to transfer heat from/to ground, there is a requirement to drill more than one boreholes. Therefore success of GSHP applications strictly depend on good design in the ground side. The total length of borehole heat exchangers (BHEs) is usually optimized in terms of distance between BHEs by considering the method recommended by ASHRAE (2007), developed by Ingersoli and Zobel (1954) and by Kavanaugh (1985).

The final expressions for the parameters such as depth of boreholes, number of borehole and distance between boreholes depend on thermal conductivity (kgd) and thermal diffusivity of (αgd) soil. Knowing well this parameters is so important for sizing and installing of ground application and using the heat pump efficiently. In order to determine kgd, αgd, constant heating-temperature method is performed by Aydın M. et al. (2013) and their values are used in this study.

Some simulation models for the thermal interaction between BHEs are investigated by Eskilson (1987), Yu X. et al. (2010), Lazzari S. et al. (2010), Teza G. et al. (2012), Koohi-Fayegh S. and Rosen M. A. (2012).

In the present paper, thermal interaction between boreholes for different configurations is examined. Four different configurations consisting of 2, 3, 5 and 9 boreholes are considered. Averaged unit HTR value of the most critical borehole in each configuration is compared with that of single borehole to determine the performance loss for 3 and 6 months non-stop operation. Variations of performance loss of the critical boreholes due to thermal interactions of neighbor boreholes with both time and distance are analyzed. The calculations for both 3 and 6 months non-stop operation, which are the possible worst cases, are made. During these investigations, the temperature distributions around the critical boreholes (cBHEs) as well as the effect of thermal conductivity on ground temperature distributions also are examined.

2. MODEL DESCRIPTION

A single U-tube BHE is considered as shown in Figure 1. BHE consists of three domains, ground, grout and polyethylene inlet and outlet pipes. For determining the performance loss, some multi BHE configurations are considered as 2, 3, 5 and 9 BHEs as shown in Figure 2. Critical boreholes are one of two in 2 BHEs configuration and in the midst of 3, 5 and 9 BHEs configurations. Calculations are made for several distances between boreholes from 0.5 m to 15 m in order to study the thermal interaction between multiple boreholes. The analysis is performed by means of finite element simulations, implemented through the software package COMSOL Multi-physics.

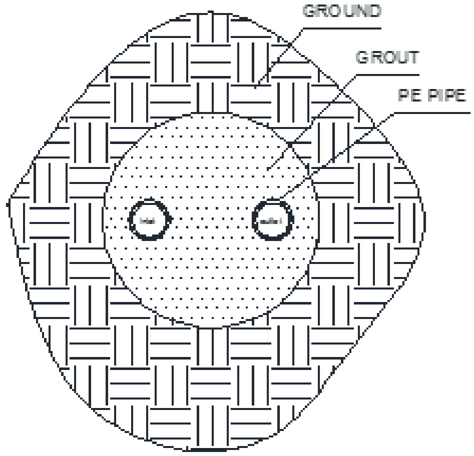


Figure 1: Sketch of a Single U-tube BHE

The following assumptions are made:

- Soil is isotropic and homogeneous.
- The effects of groundwater movement have been assumed as insignificant.
- The temperature distribution along the vertical direction has a negligible influence.
- There is no contact resistance between the boreholes and the ground.
- The fluid temperature in the BHEs is determined as average of inlet and outlet temperature.
- A uniform initial temperature of 17 ^{o}C is equal to the undisturbed ground temperature.

The properties and working conditions used in the models are summarized in Table 1. At the outer edge of the domain, a constant far field temperature condition, which is equal to the initial temperature, is applied. Domain radius is chosen as wide as not effected by temperature fluctuations.

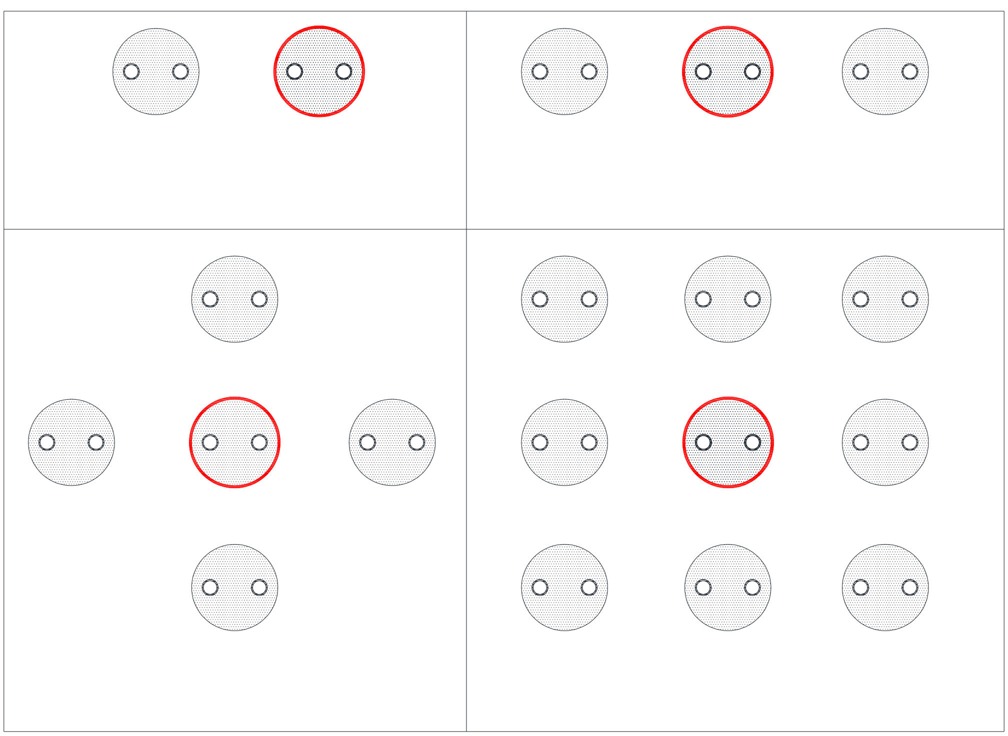


Figure 2: Sketch of BHEs configurations, BHEs with red boundary are cBHEs

Table 1: Geometrical parameters, properties of solid materials and working conditions

SYMBOL	VALUE	QUANTİTY
Geometrical Data of U-tube		
r_1	13.1	*Internal radius of PE tube [mm]*
r_2	16	*External radius of PE tube [mm]*
r_b	88	*External radius of grout [mm]*
R_d	50	*Radius of domain [m]*
Thermal properties of PE		
k_{pe}	0.38	*Thermal conductivity [W $m^{-1}K^{-1}$]*
c_{pe}	1900	*Specific heat capacity [J$kg^{-1}K^{-1}$]*
ρ_{pe}	958	*Density [kg m^{-3}]*
Thermal properties of grout		
k_{gt}	2.2	*Thermal conductivity [W $m^{-1}K^{-1}$]*
c_{gt}	750	*Specific heat capacity [J$kg^{-1}K^{-1}$]*
ρ_{gt}	1500	*Density [kg m^{-3}]*
Thermal properties of ground		
$k_{gd,eff.}$	3.4	*Thermal conductivity [W $m^{-1}K^{-1}$]*
c_{gd}	900	*Specific heat capacity [J$kg^{-1}K^{-1}$]*
ρ_{gd}	2000	*Density [kg m^{-3}]*
Working conditions		
T_{avg}	38	*Average water temperature [^oC]*
T_{gd}	17	*Undisturbed ground temperature [^oC]*

3. RESULTS AND CONCLUSION

In the current study, distance between the boreholes is set to 6 m unless stated otherwise. Figure 3 shows the soil temperature distribution at various times around three boreholes. It is obvious that for a specific distance from each borehole, the temperature of the region between the boreholes is higher than the temperature of the outer area. It is noticed that the effects of thermal interaction in terms of temperature rise are insignificant up to one week of heat input to the soil. However, temperature increases in the region between cBHE and other BHEs due to thermal interaction and temperature difference between inner and outer regions at the same distance from BHE exceeds 3 ^oC after 6 months.

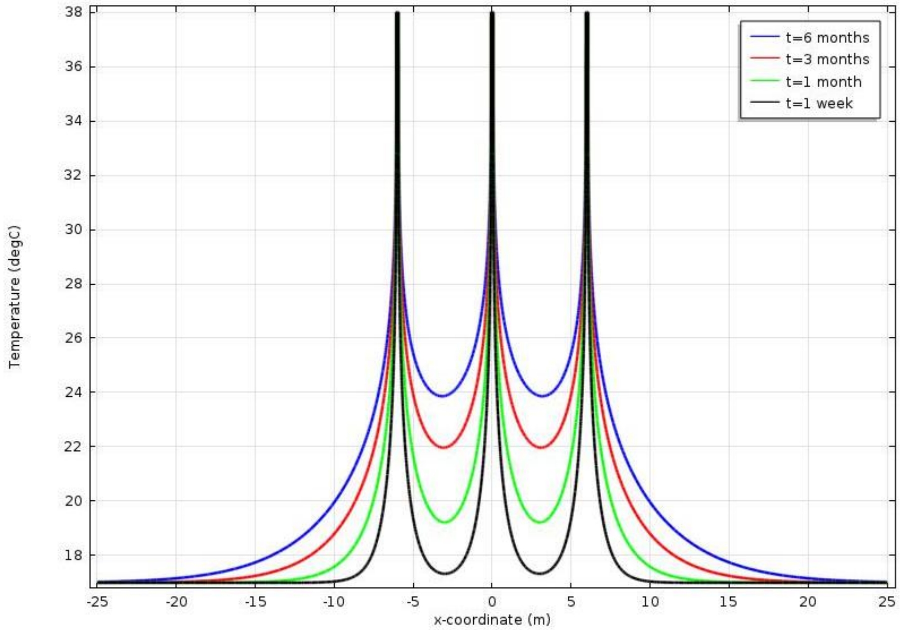
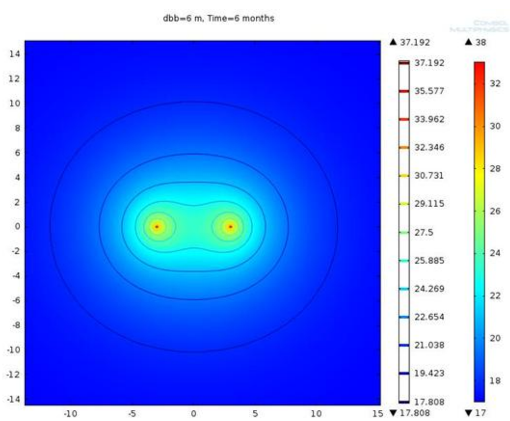
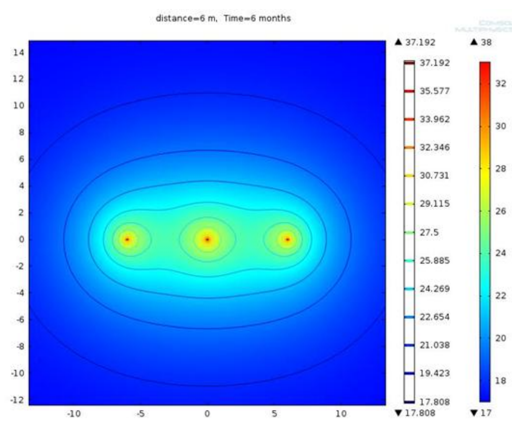


Figure 3: Comparison of temperature distribution at various times for 3 BHEs configuration.

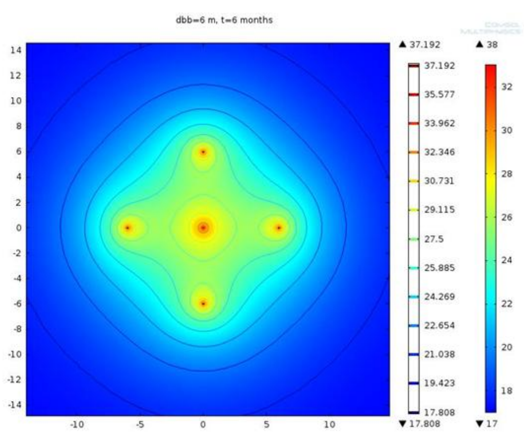
Figure 4 shows the temperature distributions around BHEs for all the configurations after 6 months under non-stop working conditions. It is clearly seen that the configurations which include more boreholes with the same distance have more thermal interaction.



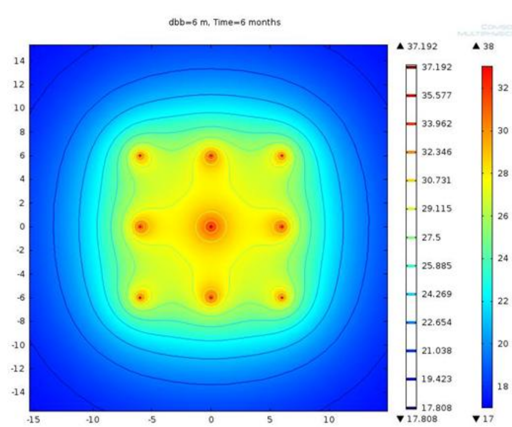
(a) 2 BHEs configurations



(b) 3 BHEs configurations



(c) 5 BHEs configurations



(d) 9 BHEs configurations

Figure 4: Temperature distributions around BHEs after 6 months.

Figure 5 shows the soil temperature distribution around 3 BHEs configuration after 6 months for different ground thermal conductivities from 2 W/m.K to 4 W/m.K. It is noticed that increment of thermal conductivity causes very small increment on the temperature distributions around BHEs.

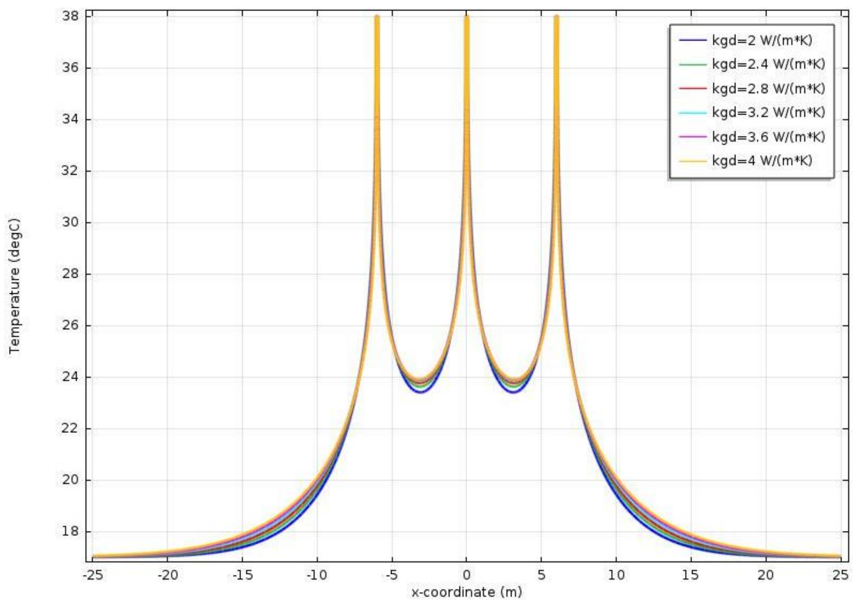


Figure 5: Effect of ground thermal conductivity on temperature distribution for 3 BHEs configuration after 6 months.

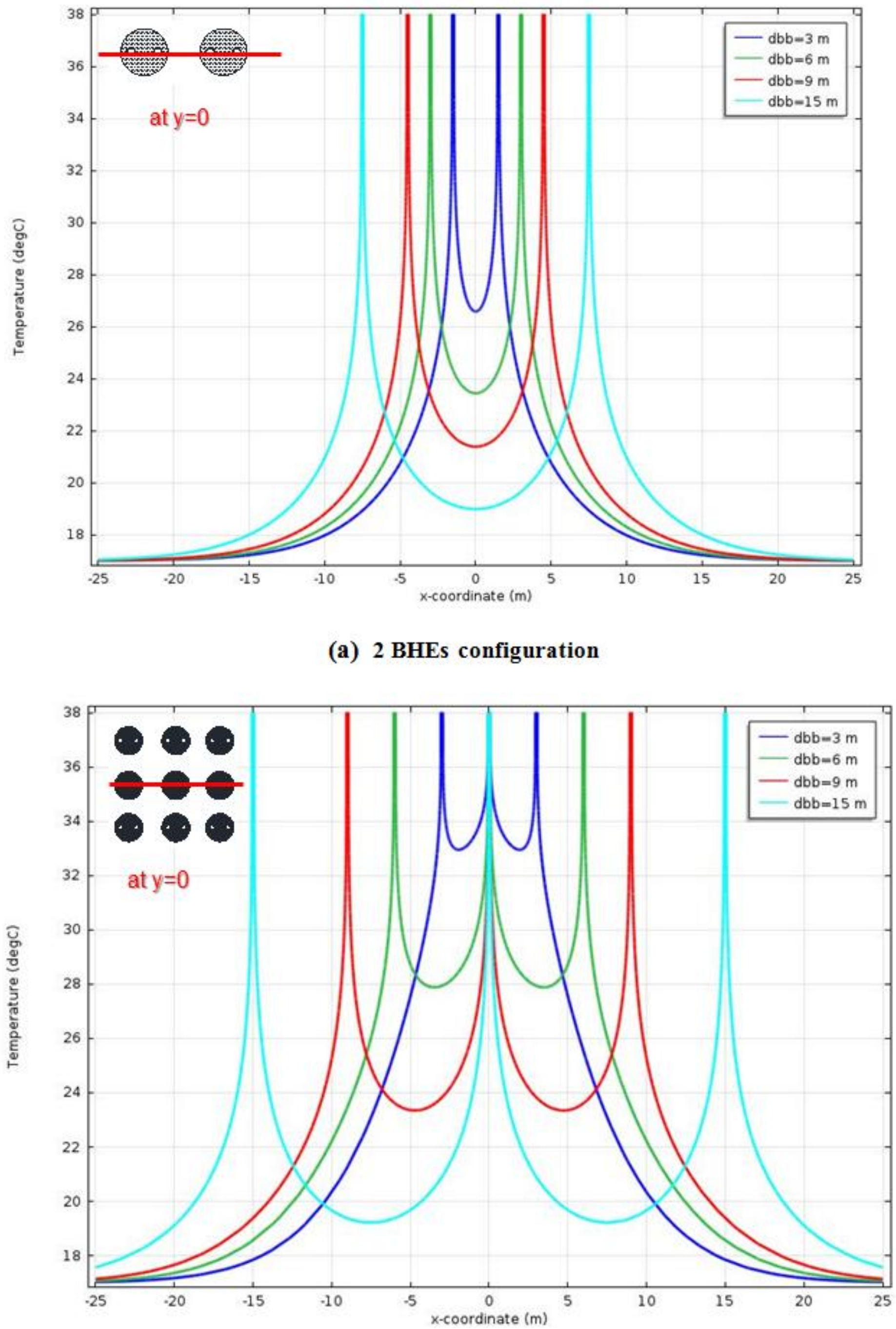
For 2 and 9 BHEs configurations, figure 6 shows temperature distributions after six months for several distances between boreholes. Increment of temperature around BHEs causes performance loss. It is seen that performance loss in 9 BHEs configuration can be much more in comparison with 2 BHEs configuration. By considering the temperature difference between fluid and ground, it is noticed that 9 m seems to be a reasonable distance to minimize thermal interactions.

Figure 7 shows the variation of performance loss of the cBHEs with distance for different configurations in case of 3 month non-stop operation period. When average fluid temperature is 38^{o}C, averaged unit HTR value of a sBHE is 72 W/m. When multiple boreholes are used, this amount can reduce depending on the distance between boreholes because of thermal interactions. Performance loss can be defined by considering the averaged unit HRT values of a sBHE and cBHE as Relative Performance Loss (RPL):

$$RPL = 1 - \frac{\dot{q}'_{cBHE}}{\dot{q}'_{sBHE}} \quad (1)$$

For instance, performance loss for cBHE in 2 BHEs configuration is around 6%, whereas it is 13%, 24% and 33% for 3, 5 and 9 BHEs configurations when the distance is 3 m. Similarly, when distance is 6 m, performance losses are 1%, 3%, 6% and 7% for 2, 3, 5 and 9 BHEs configurations. After 9 m distance, the performance loss in all configurations is nearly less than 1%. It means that thermal interactions are totally insignificant after 9 m.

Similar behavior is shown in Figure 8 for 6 months non-stop operation. After the application of the same conditions for 6 month-period, averaged unit HTR value of a sBHE is 68 W/m. In case of multiple BHEs configurations, performance loss can be as high as 25% for 9 BHEs configuration while it is 9% for 3 BHEs case if the distance is 5 m. On the other hand, performance loss in all configurations is less than 1% after 12 m distance. It means that thermal interactions become negligible after 12 m even for 6 months non-stop operation. The results given in figure 7 and figure 8 can be used to determine the total borehole length as well as the distance between them during a GSHP application design. It should be noted that the results are independent from the value of thermal conductivity of ground since the relative performance loss is examined.



(a) 2 BHEs configuration

(b) 9 BHEs configuration

Figure 6: Effect of ground thermal conductivity on temperature distribution for 3 BHEs configuration after 6 months.

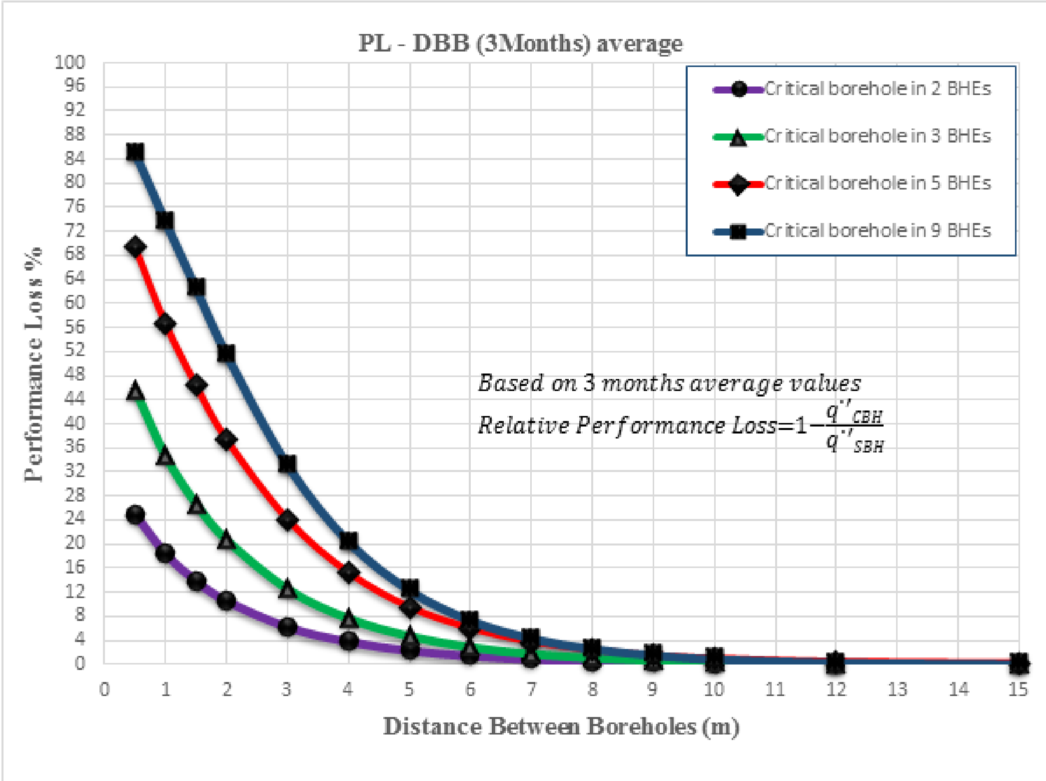


Figure 7: Variation of performance loss of the critical BHEs with the distance between boreholes in case of 3 months non-stop operation.

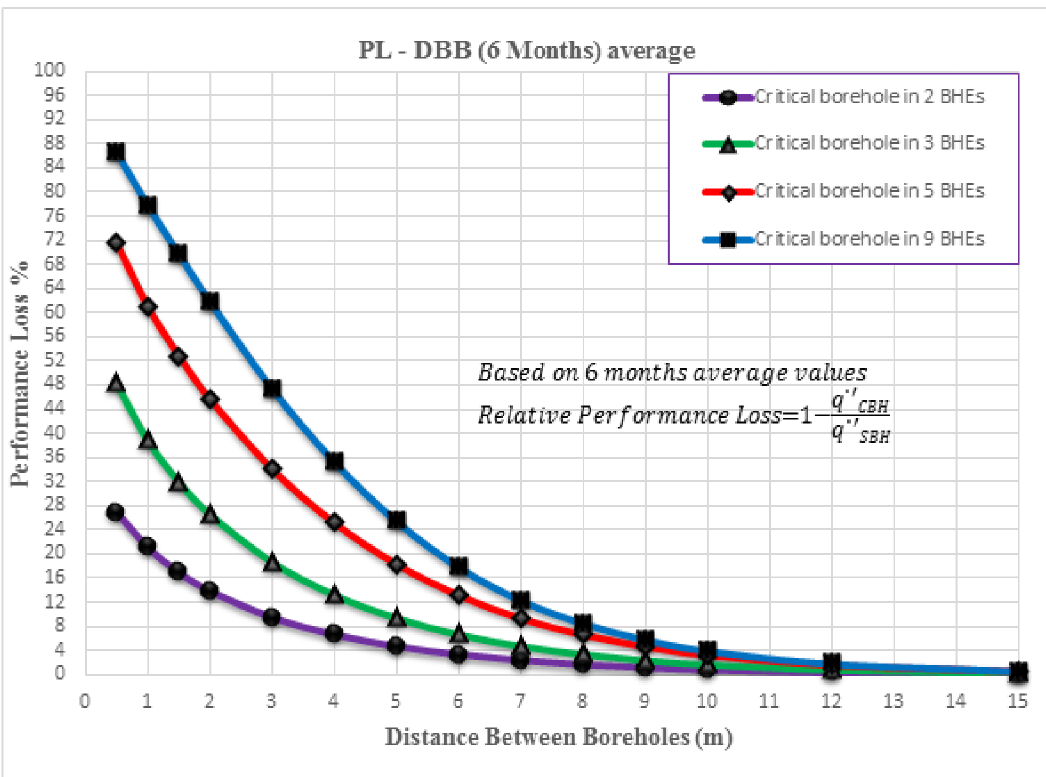


Figure 8: Variation of performance loss of the critical BHEs with the distance between boreholes in case of 6 months non-stop operation.

4. ACKNOWLEDGMENT

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