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The Effects of Non-Equidistant Arrangement of Buried Pipes on the Soil Temperature Field and Heat Flux

Li Bai [+] and Wenhao Che

School of Municipal & Environmental Engineering, Jilin Jianzhu University, Changchun, China 130118

Abstract. Based on 5m piping as an example, using the FLUENT software to simulate two ways of piping non-equidistant piping and equidistant piping, studying the impact of non-equidistant piping on soil temperature field and the wall heat flux under the condition of groundwater seepage. The simulation results show that the non - equidistant cloth tube system can significantly improve the wall heat flux in the presence of groundwater seepage, and the wider the pipe spacing, compared with its height, the greater the wall heat flux ; the average soil temperature change range is as same as wall heat flux. Therefore, this paper suggests that when the groundwater flow direction, flow rate and other parameters is known, when the conditions permit, non-equidistant of the pipe pattern is advocated in order to conserve resources, reduce energy consumption.

Keywords: Groundwater seepage, Equidistant, Non-equidistant, Equal area, Unequal area.

1. Introduction

Ground source heat pump is a process by entering a small amount of electricity, heat pump system can achieve high heat transfer from the shallow ground (soil, groundwater and surface water, etc.) [1], which has energy efficient, green features, and with small geographical constraints, which in today's increasingly tight energy situation, ground source heat pump technology has been vigorously promoted and developed by countries around the world.

Studies have shown that groundwater seepage has an important impact on the ground source heat pump heat exchanger, Cancan. Z.et al put forward that when groundwater seepage velocity 's order of magnitude is 10^{-6}m/s,it can greatly reduce soil heat accumulation due to the cooling and heating load imbalance [2], [3].Wang Jinxiang et al, who establish the full-size model of ground heat exchanger through FLUENT to simulating,analysis shows that the range of thermal effect becomes smaller when there is groundwater seepage, the changes of soil temperature around the pipe decreases [4]. Wei Yazhi et al proposes that pipe group should be buried according to the size of the groundwater seepage velocity and direction [5], Hao He et al proposes that different arrangement of ground heat pipe have a significant impact on import and export nozzle temperature, and larger ratio of length and width of the pipe group are more conducive to long-term operation of the heat pump system [6]. Based on these studies,using finite element analysis software FLUENT to simulate the non-equidistant arrangement of underground pipe , studying the effect of non-equidistant arrangement on soil temperature and heat flux when there is groundwater seepage.

2. The Mathematical Model of Saturated Porous Media

1) The Momentum equation of the porous media has an additional source term, source term was composed of two parts: viscous loss terms and internal loss items, the equation of homogeneous and isotropic porous medium is [4]:

[+] Corresponding author. Tel: +86 043184566045; fax: +86 043185935084.
E-mail address: baili0308@163.com.

$$S_i=\frac{\mu}{\alpha}\mathcal{V}_i+C_2\frac{1}{2}\rho|\mathcal{V}_j|\mathcal{V}_j \quad (1)$$

Among them, α is permeability; C2 is internal resistance factor.

2) the energy equation in porous media

$$\frac{\partial}{\partial t}[\phi\rho_f h_f+(1-\phi)\rho_s h_s]+\frac{\partial}{\partial x_i}(\rho_f u_i h_f)=\frac{\partial}{\partial x_i}(k_{eff}\frac{\partial T}{\partial x_i})-\phi\frac{\partial}{\partial x_i}\sum_{j'}h_j j_{j'}+\phi\frac{Dp}{Dt}+\phi\tau_{ik}\frac{\partial u_i}{\partial x_k}+\phi S_f^h+(1-\phi)S_s^h \quad (2)$$

$$k_{eff}=\phi k_f+(1-\phi)k_s \quad (3)$$

Among them, φ is the porous nature of the porous medium; h_f is the enthalpy of the fluid; h_s is the enthalpy of the solid; S_f^h is the source term of fluid enthalpy; S_s^h is the source term of solid enthalpy; k_{eff} is the effective conductivity of the porous region; k_f is the fluid thermal conductivity; k_s is the solid thermal conductivity [4].

3. Non-Equidistant Pump Arrangement

Fig. 1 and Fig. 2 shows the temperature distribution of equidistant arrangement of 5m pipe group with groundwater seepage (Fig. 1) and without groundwater seepage (Fig. 2) respectively.

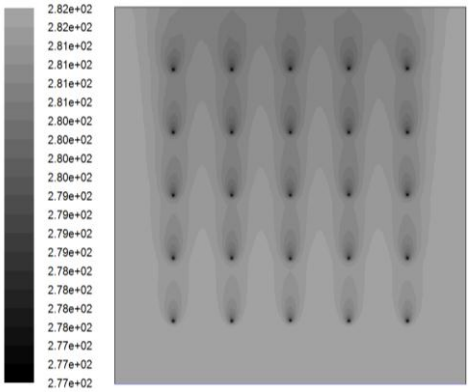

Fig. 1: equidistant arrangement with groundwater seepage

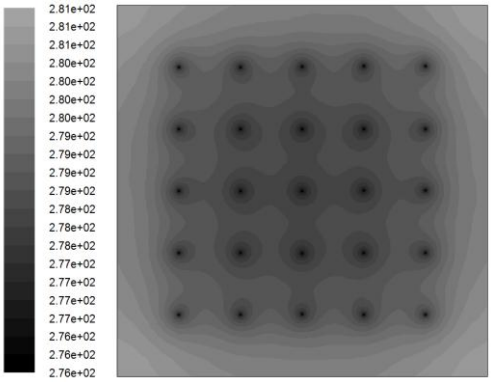

Fig. 2: equidistant arrangement without groundwater seepage

As can be seen from Fig. 1, compared with Fig. 2,due to the impact of groundwater seepage,the radius of heat exchanger cold effect become smaller and deformed,in other words, the effect scope of heat exchanger become smaller in the direction of perpendicular to the groundwater seepage, in the direction parallel with groundwater seepage the effect scope of heat exchanger become larger [7]-[9], thereby reducing the temperature transfer in the upstream direction of the groundwater seepage, increasing temperature transfer in the downstream direction of the groundwater seepage.Therefore, on the basis of previous research article on the use of non-equidistant arrangement of underground pipe, that is, in a direction perpendicular to the groundwater seepage pipe spacing decreases,at the same time increasing the pipe spacing seepage in the direction parallel to the groundwater seepage, the concrete piping is shown in Fig. 3 and Fig. 4.

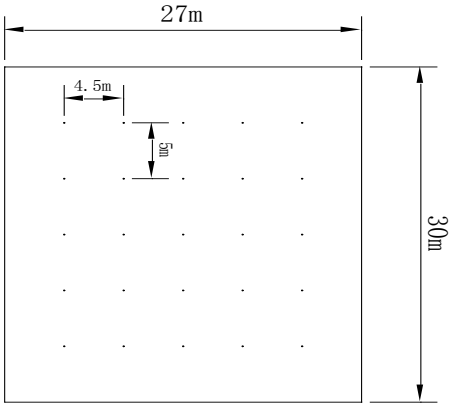

Fig. 3: 4.5×5m distant piping

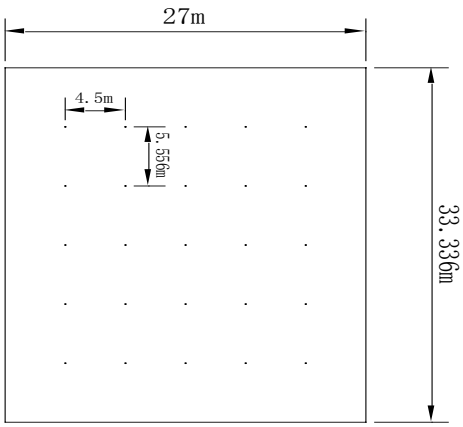

Fig. 4: 4.5×5.556m distant piping

There are two ways of concrete piping:One is non-equidistant but the area is not equal to the equidistant piping (Fig. 3), another is non-equidistant but the area is equal(Fig. 4). Take 5m piping for example, Fig. 3 is shorten the distance between the pipe parallel to the direction of groundwater seepage and unchanged the distance in a direction perpendicular to the groundwater seepage; Fig. 4 is shorten the distance between the pipe in a direction perpendicular to the groundwater seepage, but increasing the pipe spacing in a direction parallel to the groundwater seepage on the condition of the area is equal, reduce mutual interference between the pipes.

4. Simulation parameters

Area model region herein are 24m × 39m, 27m × 30m, 27m × 33.336m, 28.8m × 31.248m, 30m × 30m, or pipe spacing in the direction perpendicular to the groundwater seepage respectively 4m, 4.5m, 4.5 m, 4.8m, 5m, along the groundwater seepage direction of the pipe spacing is 6.25m, 5m, 5.556m, 5.208m, 5m, other conditions are being equal, which are shown in Table 1.

Table 1: Parameters

name	parameter setting	name	parameter setting
soil thermal conductivity	λ=2.2W/ (m·K)	soil temperature	282K
soil specific heat capacity	C=895kJ/ (kg·K)	initial temperature of water	275K
soil density	ρ=1975kg/m3	simulation time	6 months
seepage velocity	v=2.2E-6m/s	porosity	0.3

5. Analysis

Analog ground source heat pump system six months after continuous heating, heat flux and temperature changes of various pipe spacing is shown below. Due to a larger number of experimental simulation of drilling, therefore, comparing the results with the method of average analysis, the average value of heat flux and temperature are calculated by software, thus ensuring the accuracy of the simulation.

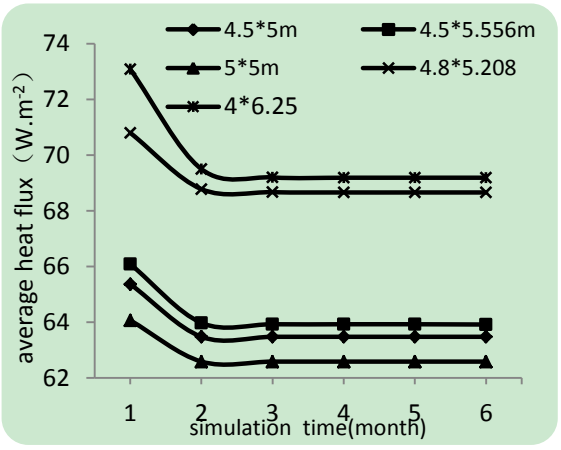

Fig. 5: different spacing heat flux change chart

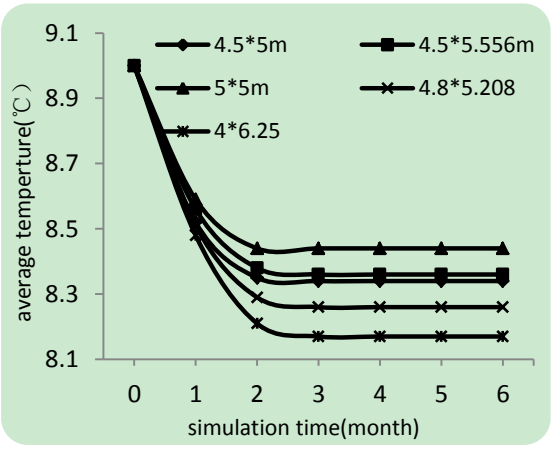

Fig. 6: different pitches temperature change chart

When the system is stable,the average soil temperature and heat flux changes as shown in Fig. 5 and Fig. 6,4 × 6.25,4.5 × 5m, 4.5 × 5.556m, 4.8 × 5.208,5 × 5m spacing soil temperature is 8.17 ℃, 8.34 ℃, 8.36 ℃, 8.26 ℃, 8.44 ℃ respectively, and wall heat flux is 69.19 W /m2,63.48 W / m2,63.92 W / m2, 68.66 W / m2,62.59 W / m2 respectively. As can be seen from the Fig. 5 and Fig. 6, although the average temperature of the soil of non-equidistant pipe spacing arrangement is slightly lower than the equidistant piping, but the average heat flux is bigger than equidistant piping , among them average heat flux of 4 × 6.25m is the largest,with respect to the equidistant arrangement the heat flux increased 10.5% , because it increases the pipe spacing which is parallel to the seepage direction , reducing the interaction between the tubes to enhance the disturbance, thus increasing the heat transfer. Therefore, in the arrangement of the tube when the group can be considered unequal pitch piping manner that is conducive to enhance heat transfer tube group.

6. Conclusion

In summary, take 5m spacing pipe arrangement for example, non-equidistant pipe arrangement can effectively enhance the borehole heat exchangers heat transfer effect, but have little effect on soil temperature. So in the engineering, the use of on-equidistant pipe arrangement can reduce the number of boreholes, and reduce costs. However, it should be noted that the non-equidistant pipe arrangement system is based on the direction and magnitude of the groundwater seepage is already known, for there is no groundwater or groundwater seepage velocity is small or there is no information about the groundwater in the engineering survey, the pipe arrangement shall take another way.

7. Acknowledgements

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