Heat Transfer Model of Underground Heat Exchanger in the Aquifer

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Abstract.Combined with the theory of the vadose of porous medium,considered the change of the flow field around the U-type pipe laying,we establish the model of the flow and heat transfer in the aquifer to research the heat exchange problem between the U-type pipe laying and the medium around in the aquifer,analyse the heat transfer which influenced by the groundwater velocity,thermal parameters in the aquifer and so on.The result shows that compare with the claypan,the pipe laying will have better performance of heat exchange in the aquifer. Under the same work situation,the average temperature of the drilling wall in the aquifer is lower than that in the claypan,the process of pipe laying and heat exchange will come to the "steady state "more faster;the heat exchange of the pipe laying in aquifer will be easier when the coefficient of thermal conductivity be higher,and the change of temperature will be little in the aquifer if the heat capacity is greater;at the upstream and vertical direction,the faster of the groundwater flow velocity,the shorter to achieve to the steady state,the minor of the hot process radius,however,at the down stream,it will be line increasing between the hot process radius and runtime,and the faster of the groundwater flow velocity,the bigger of the hot process radius.

Introduction

This article will combine with the theory of the vadose of porous medium,considere the change of the flow field around the U-type pipe laying,research the heat exchange problem between the U-type pipe laying and the medium around in the aquifer in the two dimension lay,analyse the heat transfer which influenced by the groundwater velocity,thermal parameters in the aquifer and so on.

The Establish of the Model of the Flow and Heat Transfer in the Aquifer

The Flow Control Equation in the Aquifer. For the aquifer under pressure,the excursion on the depth direction of groundwater should be ignored,and fluxion only carry on the horizontal,the two dimension control equation when the groundwater flow stably in case of the aquifer isotropy,incompressible is shown as follows:

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}=0 \qquad (1)$$

In this equation,h stand for water head,m.

Establish of Heat Transfer Control Equation in the Aquifer. We make a hypothesis of the pipe laying heat transfer course in the aquifer combine with the real heat transfer course:

(1)The liquid speed is uniform in the U-type pipe laying(ignore the influence of gravity that to flow velocity.

(2)The liquid in the U-type pipe laying have heat transfer only on the radial,ignore the heat transfer on the depth direction.

(3)The parameter such as initial temperature and thermal conductivity,porosity,specific heat and density of the soil is uniform in the aquifer and is unacted on the temperature.

(4)It is impinge between U-type pipe laying and borehole backfill as well as the borehole backfill and soil,there's no thermal contact resistance exist between them.

Based on the hypothesis talked above,we can make the heat-transfer process of the pipe laying as a planar unstable state heat-transfer process which occur in the aquifer.As the hole of the backfill materials is little,the mass density and thermal conductivity is higher than the general soil,we suppose that the heat transfer exist only by conduction of heat in the backfill materials.However,in the aquifer around the bore,the heat transfer is not only consist the heat conduction but also the role of convection which brought by the course of the groundwater.Hence,different position have different energy equation representation in the hole computational domain.

In the bole,as the heat quantity only transfer by the conduction of heat,the energy equation is shown as follows:

$$\rho c\frac{\partial t}{\partial \tau}=\frac{\partial}{\partial x}(k\frac{\partial t}{\partial x})+\frac{\partial}{\partial y}(k\frac{\partial t}{\partial y}) \quad (2)$$

In this equation,t is the temperature of the backfill materials and the pipe wall of the pipe laying,ºC,ρ,c,k is actual the consistency,specific heat and thermal conductivity of the backfill materials and the pipe wall of the pipe laying.kg/m3,kJ/(kg·ºC),W/(m·ºC), ι is the time,s.

In the aquifer,the energy equation in the aquifer when the groundwater course is shown as follows:

$$\rho c\frac{\partial t}{\partial \tau}+\rho_w c_w v_x\frac{\partial t}{\partial x}+\rho_w c_w v_y\frac{\partial t}{\partial y}=\frac{\partial}{\partial x}(k\frac{\partial t}{\partial x})+\frac{\partial}{\partial y}(k\frac{\partial t}{\partial y}) \quad (3)$$

In this equation,ρw, cw is actual the consistency and specific heat of the groundwater,kg/m3,kJ/(kg·ºC); ρ, c is the consistency and specific heat of the solid particle and total liquid volume in the aquifer;vx,vy is actual the flow velocity of the groundwater that flow along the x and y direction,m/s,these two parameter is the result of the flow calculation.

Boundary Condition

Heat Transfer Boundary Condition(1)The temperature is unacted on the left,right and lower boundary of the computational domain,so we can conclude the formula below

$$t\big|_{x=-L/2}=t\big|_{x=L/2}=t\big|_{y=-H}=t_0$$

In this equation,t0 is the initial temperature of the soil.

(1)At the wall of the pipe laying,use the invariablenes as boundary condition to simplified calculation,so we can conclude the formula below

$$q\big|_{r=Rin}=q_0$$

(2)The heat flow is 0 on the halfway line of the computational domain due to the symmetry,so we can conclude the formula below

$$q\big|_{y=0}=0$$

Flow Boundary Condition(1)As the symmetry of the computational domain,there's no groundwater at the halfway line,so we can conclude the formula below

$$v_y\big|_{y=0}=-\frac{K_s}{f}\frac{\partial h}{\partial x}\bigg|_{y=0}=0$$

(2)It will be regard as known conditions of the left and right boundary,so we can conclude the formula below.

$$h\big|_{x=-L/2}=H_0 \quad h\big|_{x=L/2}=0$$

(3)The lower boundary is the same with the condition 1,so we can conclude the formula below

$$v_y\big|_{y=-H}=-\frac{K_s}{f}\frac{\partial h}{\partial x}\bigg|_{y=-H}=0$$

(4)There's no groundwater at the boundary of the well drilling,so we can conclude the formula below

$$v_r\big|_{r=R} = -\frac{K_s}{f}\frac{\partial h}{\partial r} = 0$$

When have a meshing,we have to make the step double if it is less than 0.2m along the x and y exposure to reduce the spending and accelerate the iteration.We define the left part(x<0) as upstream and the right(x>0) as downstream and the vertical flow direction as vertical.In the meanwhile,we disposal the compute node so as to analyse the temperature of the different point,it is shown in Fig.1:

The Disperse and Solving of the Governing Equation

We use the method of controlling the dimension to have a disperse about flow equation and energy equation difference.This method tend to control the integral balance of the dimension and is easy to meet the conservation of momentum, conservation of mass and conservation of energy.The

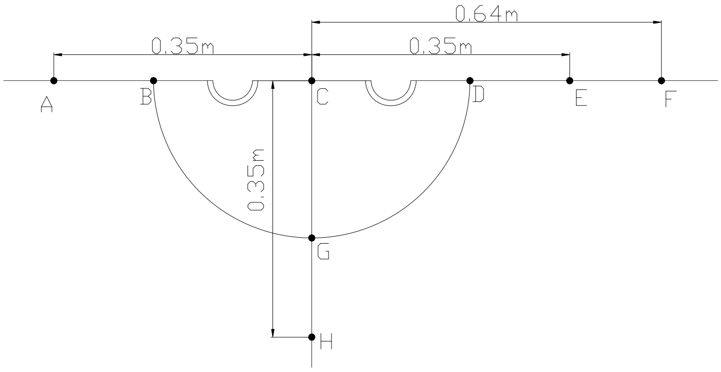

Fig.1 The Fig to Define the Compute Node Around the Pipe Laying

alternating direction implicit iterative method ADI(Alternating Direction Implicit)is used in this article to have a solving of the disperse equation.We use the TDMA arithmetic along the x direction to calculate the temperature of the different gridding node at the mid point,then use the TDMA arithmetic to calculate the temperature of the next time along the y direction so as to finish a boost of a time level.

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