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TRNSYS Type 451

Vertical Borehole Heat Exchanger EWS Model

Version 3.1

Model description and implementing into TRNSYS

Developed in the project

Low Temperature Low Cost Heat Pump Heating System

carried out by the Information Center for Electricity Applications

under contract of the Swiss Federal Office of Energy

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October 23, 1997

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Type451: Vertical Borehole Heat Exchanger, EWS Model

Note: The enhancements to this Type in Version 3.1 are not backwards compatible with previous versions. Please note the changes to inputs, outputs and parameters (see end of this document).

General description

With this TRNSYS type, vertical borehole heat exchangers with double-U-pipes can be simulated. They are normally used as heat sources for ground coupled heat pumps. But it is also possible to use them directly (without a heat pump) in air-conditioning systems for cooling purposes.

To simulate heating systems with heat pumps, it is very important, that short time steps can be simulated and the transient behavior is calculated properly, since most of these heat pumps are controlled by turning the pump on and off. Measurements have shown that the start up losses (cycling losses) of heat pumps normally cannot be neglected. Therefore it is also important that the model of the heat source is able to predict the transient behavior correctly. Furthermore, a PC should take not more than a few minutes of computational time for the simulation of a whole year.

The problem can be solved by a simulation of the transient heat flux in the earth within a radius of about 2 m around the borehole with the Crank-Nicholson algorithm. In the vertical direction, the earth is divided into several, horizontal layers. Each layer can have thermal properties of its own. The brine is simulated dynamically to take into account the transient behavior when starting up. For the outer boundary condition, the analytical formula of Werner [5] for constant heat extraction could be adapted for the present problem. This formula belongs to a group of analytical solutions first described by Kelvin in his line source theory. By superposing constant heat extractions, starting at different time steps, it is possible to calculate the temperature profile at the outer boundaries of the simulation area and even to predict properly the refilling of the temperature sink in the summer.

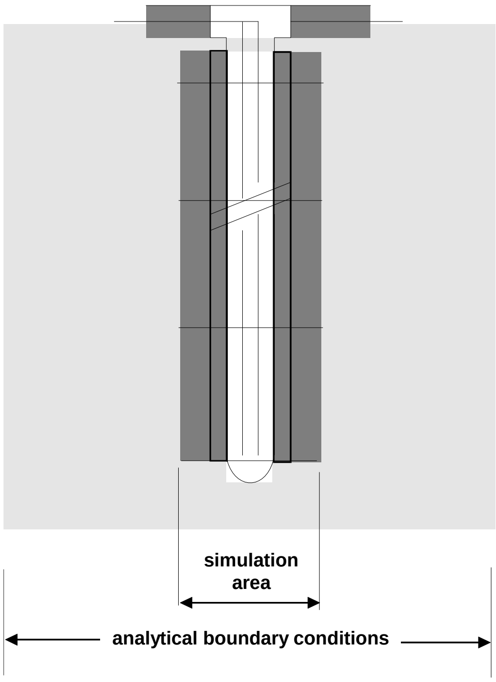

Fig. 1: Simulation of the earth next to the borehole with Crank-Nicholson schema and analytical outer boundary conditions with an adaptation of the formula of Werner [5]

A more comprehensive description of the used models and a comparison of calculations with measurements can be found in [2]. In these comparisons the transient behavior was investigated as well as the long term behavior over a period of 4½ years. They showed very good correspondence between calculation and measurement. To get such a good result, though, it is crucial to know the thermal properties of the ground and the temperature profile at the beginning of the simulation period. The best model cannot help, if they are not known. Usually a good guess for the thermal properties can be found in [4].

Symbols

Variables

α_o	Heat transfer coefficient from the brine to the pipes at non operating mode
α_1	Heat transfer coefficient from the brine to the pipes, when the pump is running
Δ	Difference
λ	Thermal conductivity
ν	Kinematic viscosity
ρ	Density
ξ	Friction factor
C	Heat capacity
c	specific heat capacity
D_b	Borehole diameter
D_i	Inner diameter of the pipes
dl	Length of a borehole element
dt	Internal time step to calculate the earth
dt2	Internal time step to calculate the brine
f	grid factor in radial direction
L	Thermal conductance
L_0	Thermal conductance of the flowing brine in vertical direction
L_1	Thermal conductance between the brine and the filling material
m	mass of the brine in the element dl in 2 pipes
$\dot{q}$	Specific heat extraction
r	Radial distance from the borehole axis
r_o	Inner radius of the pipes
r_1	Radius of the borehole
r_m	Radius of the outer boundary of the simulation area
rz	Radial center of gravity
R	Thermal resistance
R_a	Internal thermal resistance
R_b	Borehole thermal resistance
t	time
T	Temperature
T_b	Borehole temperature
TEarth	Temperature of the earth
TDown	Temperature of the downward flowing brine
TUp	Temperature of the upward flowing brine
TSource	Source temperature (brine coming out of the vertical borehole heat exchanger)
TSink	Brine temperature at the inlet of the vertical borehole heat exchanger
v	Brine velocity in the pipes

Indices

DimAxi	Number of grid points in axial direction
DimRad	Number of grid points in radial direction
i	Axial coordinate
j	Radial coordinate
k	time coordinate
lam	Laminar
p	constant pressure
turb	Turbulent
Erde	Earth
Fill	Filling material
Sole	Brine
t	Time
Woche	week of focus for the outer boundary conditions

Dimensionless Numbers

Nu	Nusselt Number
Pr	Prandtl Number
Re	Reynolds Number

Mathematical description

The Crank - Nicholson schema

In radial direction the one-dimensional heat equation or Fourier equation has to be solved:

$$\frac{\partial T}{\partial t} = \frac{\lambda}{\rho c_p}\frac{\partial^2 T}{\partial x \partial x} \quad \text{with } T = T(t,x)$$

Eq. 1

As an implicit equation of differences it is written as:

$$T_{k+1,j} - \frac{dt}{2}\frac{L_j}{C_j}\left(T_{k+1,j-1} - T_{k+1,j}\right) - \frac{dt}{2}\frac{L_{j+1}}{C_j}\left(T_{k+1,j+1} - T_{k+1,j}\right) =$$
$$T_{k,j} + \frac{dt}{2}\frac{L_j}{C_j}\left(T_{k,j-1} - T_{k,j}\right) + \frac{dt}{2}\frac{L_{j+1}}{C_j}\left(T_{k,j+1} - T_{k,j}\right)$$

Eq. 2

Index k belongs to the time coordinate and index j to the radial coordinate. C is the capacity which is described below. L is the conductance, the reciprocal of a resistance:

$$L = \frac{1}{R} = \frac{\dot{Q}}{\Delta T}$$

Eq. 3

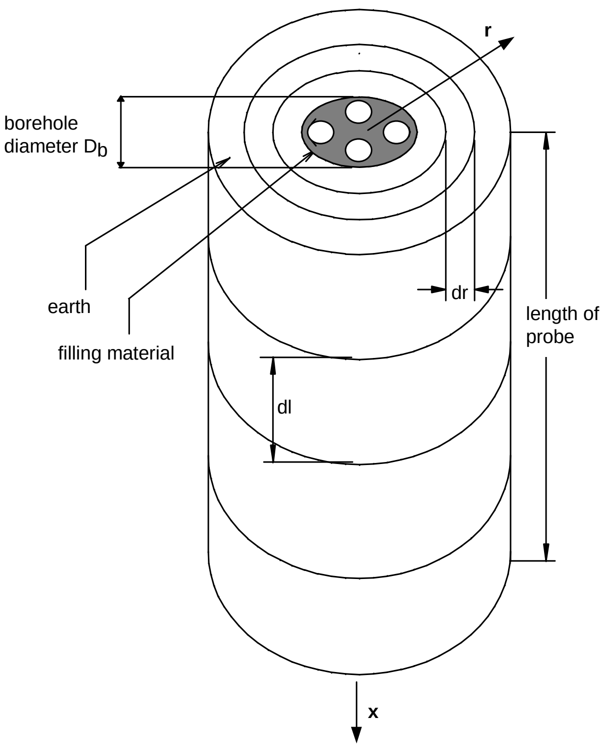

Fig. 2: Cylindrical coordinate system to solve the one-dimensional heat equation for each axial layer, with thermal properties of its own in each layer.

Arithmetical grid

In axial (vertical) direction, the borehole heat exchanger and the adjacent earth are divided into equidistant layers of length

$$dl = \frac{borehole\ length}{DimAxi}$$

Eq. 4

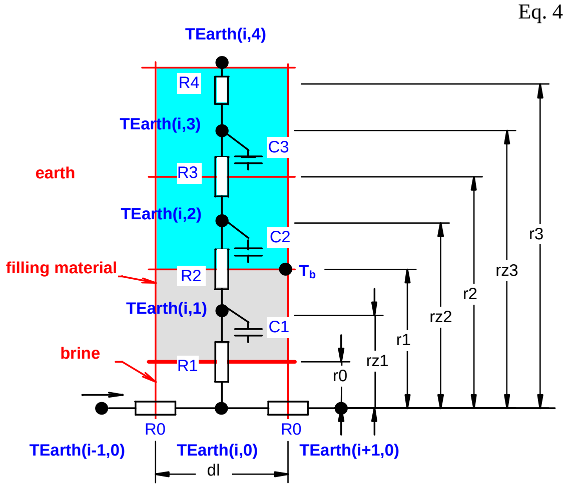

Fig. 3: Overview of the naming in a vertical layer

The grid in radial direction is variable. It is defined by the grid factor

$$grid\ \ factor\ \ f \ = \frac{r_{j+1} - r_j}{r_j - r_{j-1}}$$

Eq. 5

A grid factor 2 doubles the difference of the radiuses of two neighboring calculation volumes.

The simulation area is defined by pre-setting a maximum radius. The grid is given then by the following expression:

$r_0 = D_i/2$ = inner radius of the pipes
$r_1 = D_b/2$ = radius of the borehole
r_m = maximum radius of the simulation area

$$j \geq 2: \ r_j = r_{j-1} + (r_m - r_1)\frac{1-f}{1-f^{m-1}} f^{j-2}$$

Eq. 6

Definition of capacities and resistances

Heat capacities

Heat capacities are defined for the filling material and for all layers of the surrounding ground. The heat capacity of the pipe wall is ignored:

$$C_1 = c_{p,\,\mathrm{Fill}}\,\rho_{\mathrm{Fill}}\,\pi(r_1^2 - 4\ \ r_0^2)dl$$
$$C_2 = c_{p,\,\mathrm{Erde}}\,\rho_{\mathrm{Erde}}\,\pi(r_2^2 - r_1^2)dl$$
$$C_3 = c_{p,\mathrm{Erde}}\,\rho_{\mathrm{Erde}}\,\pi(r_3^2 - r_2^2)dl$$

Eq. 7

Thermal resistances

The heat resistances of the filling and the ground are:

$$R_1 = \frac{1}{4}\left(\frac{1}{2\,\pi\,\alpha\,r_0\,dl} + \frac{1}{2\,\pi\,\lambda_{\mathrm{Fill}}\,dl}\ln\frac{r_1 - rz_1}{r_0}\right)$$

Eq. 8

$$R_2 = \frac{1}{2\,\pi\,dl}\left(\frac{1}{\lambda_{\mathrm{Fill}}}\ln\frac{r_1}{rz_1} + \frac{1}{\lambda_{\mathrm{Erde}}}\ln\frac{rz_2}{r_1}\right)$$

Eq. 9

$$R_3 = \frac{1}{2\,\pi\,dl}\,\frac{1}{\lambda_{\mathrm{Erde}}}\ln\frac{rz_3}{rz_2}$$

Eq. 10

$$R_4 = \frac{1}{2\ \pi\,\lambda_{Erde}\ dl}\ln\frac{r_3}{rz_3}$$

Eq. 11

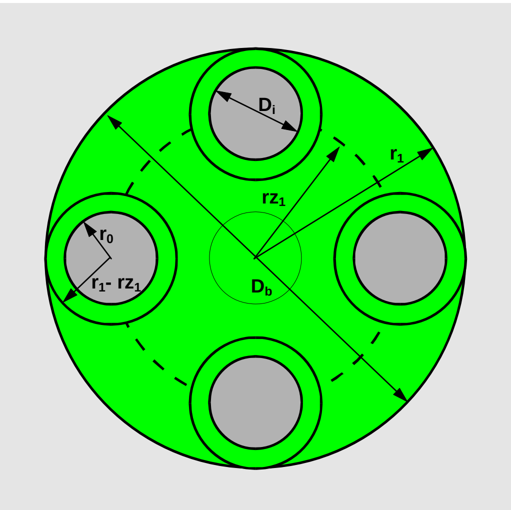

Fig. 4: Double-U-pipe borehole system

R_3 and R_4 can be obtained analytically. With R_1 and R_2 this is not possible, since we do not know the precise location of the pipes in the borehole. So far, we assumed that they are rather peripherally located. But the user of the present TRNSYS-Type is free to use any other value for R1, since R1 can optionally be set as an input parameter. As a third possibility, we can use the internal thermal resistance

$$R_a = \ 4\ \ dl\ \ R_1$$

Eq. 12

and the borehole thermal resistance

$$R_b = \frac{dl\ \ (T_{Sole}\ \ -\ \ T_b)}{\dot{Q}}$$

Eq. 13

as they were defined by Hellström [1].

If only R_b is given instead of R_1, then R_1 can be calculated with the following equation:

$$R_1 = \frac{R_b}{dl}\ -\ \frac{1}{2\ \ \pi\ \ \lambda_{Fill}\ \ dl}\ \ln\frac{r_1}{rz_1}$$

Eq. 14

If R_a and R_b are given as parameters, then R_1 can be calculated with

$$R_1 = \frac{R_a}{4\ \ dl}$$

Eq. 15

and R_2 with

$$R_2 = \frac{(R_b - \frac{R_a}{4})}{dl} + \frac{1}{2\,\pi\,dl}\,\frac{1}{\lambda_{\mathrm{Erde}}}\ln\frac{rz_2}{r_1}$$

Eq. 16

With the input parameter calcBTR the preferred option can be chosen by the user :

calcBTR	R_1	R_2
1	Eq. 8	Eq. 9
2	R_1 given as input	Eq. 9
3	Eq. 14	Eq. 9
4	Eq. 15	Eq. 16

Solving the equations

Eq. 2 can be rewritten as a matrix equation:

$$[A]\cdot\{T\}_i^{k+1} = [F]\cdot\{T\}_i^{k}$$

Eq. 17

To find the new temperature field, the Matrix A has to be inverted

$$\{T\}_i^{k+1} = [B]\cdot\{T\}_i^{k}$$

Eq. 18

where B is defined by:

$$[B] = [A]^{-1}\cdot[F]$$

Eq. 19

Non steady-state calculation of the brine

The brine temperature is used as the inner boundary condition for the simulation of the earth with the Crank-Nicholson schema. If we set the flag *Stationaer = 0* then the brine temperature is calculated with an explicit, non steady-state time-step method.

The velocity of the brine in the pipes can be calculated with the mass flow rate:

$$v = \frac{\dot{m}}{2\,\pi\;r_0^2\;\rho_{Sole}}$$

Eq. 20

As in the radial direction, we can define a thermal conductance in axial direction:

$$L_0 = c_{p,Sole}\,\dot{m} = 2\pi\;r_0^2\,v\,\rho_{Sole}\,c_{p,Sole}$$

Eq. 21

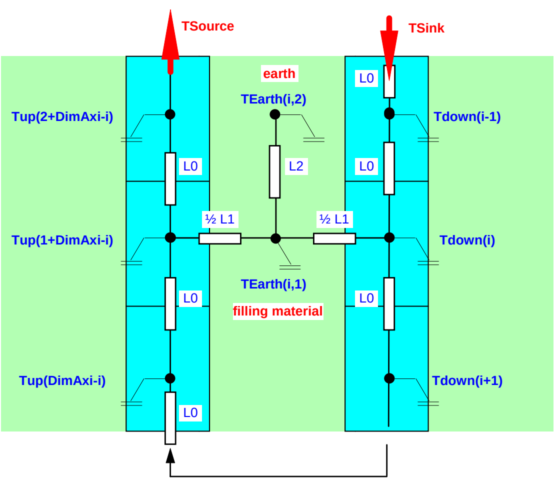

Fig. 5: Non steady-state simulation of the brine with an explicit time-step method

Now we calculate the energy balance for the upward and the downward flowing brine in a vertical layer. To simplify the calculations, we combine the two pipes in which the brine flows in the same direction and treat them as a single element for computational purposes. The mass of this element is then

$$m = 2\;\pi\;r_0^2\;dl\;\rho_{Sole}$$

Eq. 22

The energy balance for such an element gives:

$$Tdown_{k+1,i} = Tdown_{k,i} + \left(Tdown_{k+1,i-1} - Tdown_{k,i}\right)\frac{L_0\;dt2}{m\;cp} + \left(TEarth_{k,i,1} - Tdown_{k,i}\right)\frac{L_1\;dt2}{2\;m\;cp}$$

Eq. 23

and in the upward direction

$$Tup_{k+1,i} = Tup_{k,i} + \left(Tup_{k+1,i-1} - Tup_{k,i}\right)\frac{L_0\;dt2}{m\;cp} + \left(TEarth_{k,1+DimAxi-i,1} - Tup_{k,i}\right)\frac{L_1\;dt2}{2\;m\;cp}$$

Eq. 24

with the boundary condition

$$Tdown_{k+1,0} = TSink$$

Eq. 25

$$Tup_{k+1,0} = Tdown_{k+1,DimAxi}$$

Eq. 26

$$TSource = Tup_{k+1,DimAxi}$$

These equations have to be solved in direction of the flowing brine.

Steady-state calculation of the brine

As an option, a steady-state calculation can be carried out for the brine. To do so, we set the input parameter *Stationaer = 1*. Then the energy balance gives us

$$Tdown_i = \frac{\left(L_0\;Tdown_{i-1} + \frac{L_1}{2}\;TEarth_{i,1}\right)}{\left(L_0 + \frac{L_1}{2}\right)}$$

Eq. 27

and

$$Tup_i = \frac{\left(L_0\;Tup_{i-1} + \frac{L_1}{2}\;TEarth_{1+DimAxi-i,1}\right)}{\left(L_0 + \frac{L_1}{2}\right)}$$

Eq. 28

Outer boundary condition

For the outer boundary condition, the analytical formula of Werner [5] for constant heat extraction can be adapted for the present problem. This formula belongs to a group of analytical solutions first described by Kelvin in his line source theory. By superposing constant heat extractions, starting at different time steps, it is possible to calculate the temperature profile at the outer boundaries of the simulation area and even to predict the refilling of the temperature sink in the summer properly.

The temperature drop in the earth in function of the distance from the borehole and time can be written as:

$$\Delta T(r,t) = \frac{\dot{q}}{4\,\pi\,\lambda} W(u)$$

Eq. 29

with

$$W(u) = \left[-0.5772 - \ln(u) + u - \frac{u^2}{2\,2!} + \frac{u^3}{3\,3!} - \frac{u^4}{4\,4!} + \ldots \right]$$

Eq. 30

and

$$u(r,t) = \frac{c_{p,Erde}\ \rho_{Erde}}{4\ t\ \lambda_{Erde}} r^2$$

Eq. 31

In these formulas, the specific heat extraction

$$\dot{q} = \frac{\dot{Q}}{\text{borehole length}}$$

Eq. 32

has to be constant. Since in real boreholes the heat extraction is not constant, we must superpose different constant heat extractions q, starting at different time steps to get a variable heat extraction:

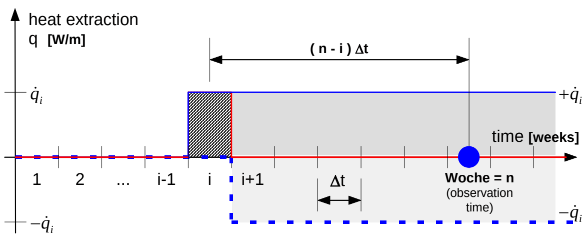

Fig. 6: To get a discrete heat extraction q_i we superpose q and -q, starting at different time steps.

To get the temperature drop at the time (n·Δt) we have to add all the effects of this constant heat extractions in the following way:

$$\Delta T(r, t = n\ \Delta t) = \sum_{i=1}^{n} \frac{W(u(r, t = i\ \Delta t))}{4\ \pi\ \lambda} \left[\dot{q}_{n-i+1} - \dot{q}_{n-i}\right]$$

Eq. 33

with

$$\dot{q}_0 = 0$$

Eq. 34

Thus the temperature at the outer boundary of the simulation area can be written as:

$$TEarth(DimRad + 1) = T_0(i) - \Delta T(r = r_{DimRad})$$

Eq. 35

Of course this has to be calculated for each vertical layer with its own specific heat extraction rate.

These outer boundary conditions are calculated weekly and then held constant during the whole week.

Pressure drop

The friction factor ξ can be calculated for laminar flow (Re < 2’300) with

$$\xi = \frac{64}{\text{Re}}$$

Eq. 36

and according to the recommendations of Merker [3] for turbulent flow (Re > 2’300) with

$$\xi = \frac{1}{\left(1.82\ \log(\text{Re}) - 1.64\right)^2}$$

Eq. 37

The pressure drop is then calculated with

$$\Delta p = \frac{[boreholelength]\,\xi\,\rho_{Sole}\,\text{v}^2}{2Di}$$

Eq. 38

Heat transfer coefficient

The heat transfer coefficient can be calculated from the Nusselt Number:

$$\alpha_1 = \frac{Nu(\mathrm{Re},\mathrm{Pr})\ \lambda_{Sole}}{D_i}$$

Eq. 39

When we have laminar flow (Re < 2'300), the Nusselt Number is taken constant:

$$Nu_{lam} = 4.36$$

Eq. 40

With turbulent flow (Re > 10'000), the Petukhov Formula [3] is used:

$$Nu_{turb} = \frac{\frac{\xi}{8}}{K_1 + K_2 \sqrt{\frac{\xi}{8}} \left(\mathrm{Pr}^{2/3} - 1\right)} \ \mathrm{Re}\ \mathrm{Pr}$$

Eq. 41

with

$$K_1 = 1 + 27.2 \left(\frac{\xi}{8}\right)$$

Eq. 42

$$K_2 = 11.7 + 1.8\ \mathrm{Pr}^{-1/3}$$

Eq. 43

In the transition laminar - turbulent (2'300 < Re < 10'000) we use

$$Nu = Nu_{lam} \exp\left[\ln\left(\frac{Nu_0}{Nu_{lam}}\right) \frac{\ln\left(\frac{\mathrm{Re}}{2'300}\right)}{\ln\left(\frac{10'000}{2'300}\right)} \right]$$

Eq. 44

with

$$Nu_0\ (Re = 10'000) = \frac{\frac{\xi_0}{8}}{1.107 + K_2 \sqrt{\frac{\xi_0}{8}} \left(\mathrm{Pr}^{2/3} - 1\right)} \ \mathrm{Re}\ \mathrm{Pr}$$

Eq. 45

$$\xi_0 = 0.031437$$

Eq. 46

When the pump is not running, we use the following heat transfer coefficient:

$$\alpha_0 = \frac{\lambda_{Sole}}{\frac{D_i}{2}\left(1 - \sqrt{0.5}\right)}$$

Eq. 47

The heat transfer coefficient is only used, when R_1 is calculated internally.

Flow chart

The present model is calculating internally with smaller timesteps. These are optimized in the code, so the user does not have to be concerned with them.

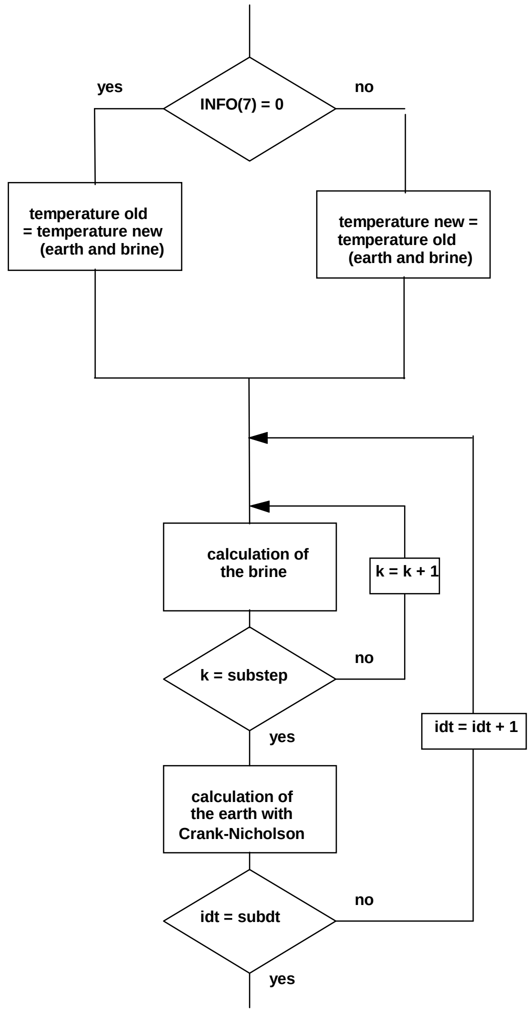

Fig. 7: Flow chart of the code.

Component configuration for Version 3.1

Parameters

	Name	Dimension	Unit	Type	Range	Default
1	**Steady-state calculation**	Dimensionless	-	integer	[0;1]	0
	This parameter is a flag to indicate whether the transient effects in the fluid will be calculated or not. 0 = transient effects in the fluid simulated, 1 = steady-state fluid conditions.					
2	**Mode for Borehole resistances**	Dimensionless	-	integer	[1;1]	1
	This flag (calcBTR) specifies the way of calculating the borehole thermal resistances: 1: calculate R1 and R2 internally. The equivalent resistances Ra and Rb (as defined by Hellström) are also calculated and their value is reported for information in the log file. 2: R1 is an input parameter (parameter 22+3*nL), R2 is calculated internally 3: Rb is given (parameter 22+3*nL). R1=f(Rb), R2 is calculated internally 4: Ra and Rb are given (parameter 22+3*nL and 23+3*nL, resp.). R1=f(Ra), R2=f(Ra,Rb)					
3	**Design mass flowrate**	Flow Rate	kg/hr	real	[0;+Inf]	2000
	Design mass flowrate for the borehole (total flowrate for both U-pipes). This flowrate is used to calculate the convection heat transfer coefficient alpha in design conditions (which is used throughout the simulation)					
4	**Radius of the simulation area**	Length	m	real	[0;+Inf]	100
	This parameter fixes the maximum extent of the simulation in the radial direction. The boundary conditions (undisturbed ground) are applied outside that area.					
5	**Radius for average temperature**	Length	m	real	[0;+Inf]	5
	This radius is used to define the volume in which the average ground temperature, output 4, is calculated. It only affects that output and does not have an impact on the simulation accuracy. This parameter should be larger than the borehole radius and smaller than the simulation radius.					
6	**Grid factor**	Dimensionless	-	real	[1.00001;+Inf]	2
	Grid factor for ground discretization in the radial direction: a grid factor of 2 doubles the difference of the radiuses of two neighboring calculation volumes. Note that 1 is not acceptable. Use (1+e) where e is a small value (e.g. 0.001).					
7	**Borehole depth**	Length	m	real	[0;+Inf]	100
	Depth of the borehole (this is referred to as the axial dimension)					
8	**Pipe inside diameter**	Length	m	real	[0;+Inf]	0.0345
	Inside diameter of one U-pipe.					
9	**Borehole diameter**	Length	m	real	[0;+Inf]	0.1524
	Diameter of the borehole (space which is filled with the grout and the 2 U-pipes)					
10	**Geothermal gradient**	Temp Gradient	K/m	real	[-Inf;+Inf]	0.018
	Axial temperature gradient in the ground at the start of the simulation. This is often referred to as the geothermal gradient. Positive values are used for increasing temperatures downwards.					
11	**Average ambient temperature**	Temperature	C	real	[-100;100]	10
	Yearly average ambient (air) temperature at the location. The initial (undisturbed) ground surface temperature is the sum of this parameter and the average surface-air temperature difference.					
12	**Average surface-air delta T**	Temp. Difference	deltaC	real	[-100;100]	2

	Yearly average temperature difference between the ground surface and the air temperature. The initial (undisturbed) ground surface temperature is the sum of this parameter and the average ambient temperature.					
13	**Fill specific heat**	Specific Heat	kJ/kg.K	real	[0;+Inf]	3.3
	Specific heat of the fill (grout) material.					
14	**Fill density**	Density	kg/m^3	real	[0;+Inf]	1170
	Density of the fill (grout) material.					
15	**Fill thermal conductivity**	Thermal Conductivity	kJ/hr.m.K	real	[0;+Inf]	2.628
	Thermal conductivity of the fill (grout) material.					
16	**Fluid specific heat**	Specific Heat	kJ/kg.K	real	[0;+Inf]	3.904
	Specific heat of the borehole fluid					
17	**Fluid density**	Density	kg/m^3	real	[0;+Inf]	1032
	Density of the fluid.					
18	**Fluid thermal conductivity**	Thermal Conductivity	kJ/hr.m.K	real	[0;+Inf]	1.543
	Thermal conductivity of the fluid					
19	**Fluid kinematic viscosity**	Kinematic Viscosity	m^2/s	real	[0;+Inf]	$6.78\ 10^{-6}$
	Kinematic viscosity of the fluid.					
20	**Nb. of radial layers, nR**	Dimensionless	-	integer	[1;20]	15
	Number of simulation layers in the radial direction.					
21	**Nb. of axial layers, nL**	Dimensionless	-	integer	[1;10]	10
	Number of simulation layers in the axial direction.					
21+3*i-2	**Ground specific heat, axial layer i (i=1:nL)**	Specific Heat	kJ/kg.K	real	[0;+Inf]	1
	Specific heat of the ground for the given axial layer.					
21+3*i-1	**Ground density, axial layer i (i=1:nL)**	Density	kg/m^3	real	[0;+Inf]	2300
	Density of the ground for the given axial layer.					
21+3*i	**Ground conductivity, axial layer i (i=1:nL)**	Thermal Conductivity	kJ/hr.m.K	real	[0;+Inf]	7.2
	Thermal conductivity of the ground for the given axial layer.					
22+3*nL	**R1 or Rb or Ra**	Thermal Resistance per unit length	m.K.h/kJ	real	[0;+Inf]	See text
	The role of this parameter depends on the calcBTR flag (Parameter 2). calcBTR = 1: This parameter does not exist calcBTR = 2: R1 (default value: 0.0015) calcBTR = 3: Rb (default value: 0.0343) calcBTR = 4: Ra (default value: 0.059)					
23+3*nL	**Rb**	Thermal Resistance per unit length	m.K.h/kJ	real	[0;+Inf]	0.0343
	This parameter only exists if calcBTR (Parameter 2) = 4.					

Inputs

	Name	Dimension	Unit	Type	Range	Default
1	**Inlet Temperature**	Temperature	C	real	[-Inf;+Inf]	0
	Borehole fluid inlet temperature.					
2	**Inlet mass flowrate**	Flow Rate	kg/hr	real	[0;+Inf]	0
	Borehole fluid mass flow rate. This is the total flowrate for both U-pipes.					

Outputs

	Name	Dimension	Unit	Type	Range	Default
1	**Outlet temperature**	Temperature	C	real	[-Inf;+Inf]	0
	Borehole fluid outlet temperature.					
2	**Outlet mass flowrate**	Flow Rate	kg/hr	real	[0;+Inf]	0
	Borehole fluid mass flowrate. This is the total flowrate for both U-pipes.					
3	**Borehole heat transfer rate**	Power	kJ/hr	real	[-Inf;+Inf]	0
	Heat transfer rate from the ground to the fluid (positive values if outlet temperature higher than inlet temperature).					
4	**Average ground temperature**	Temperature	C	real	[-Inf;+Inf]	0
	Average temperature of the cylindrical ground volume defined by the borehole depth and the radius given as parameter 5. Note that this volume includes the borehole itself (fill, or grout, volume) but not the fluid.					
5	**Pressure drop**	Pressure	Pa	real	[-Inf;+Inf]	0
	Pressure drop across the borehole heat exchanger. Note that the pressure drop is only calculated once at the beginning of the simulation, using nominal fluid properties. Pressure drop is either 0 (no flow) or the nominal value.					
5+i	**Fluid temperature down, node i (i=1:nL)**	Temperature	C	real	[-Inf;+Inf]	0
	Temperature of the fluid going down (entering the borehole) for the given node. The number of nodes is set by the number of ground nodes in the axial direction. Note that the fluid flows downwards, from node 1 to nL, in this part of the pipes.					
5+nL+i	**Fluid temperature up, node i (i=1:nL)**	Temperature	C	real	[-Inf;+Inf]	0
	Temperature of the fluid going up (coming back from the borehole) for the given node (the number of nodes is set by the number of ground nodes in the axial direction). Note that the fluid flows upwards, from node nL to 1, in this part of the pipes.					
nR*nL last outputs	**Ground temperature for node (i,j) (i=1:nR, j=1:nL)**	Dimensionless	-	real	[-Inf;+Inf]	0
5+2*nL+1 .. 5+nL*(nR+2)	Ground temperature for given node (layer). The first index designate the radial layer (from 1 to nR), the second index designates the axial layer (from 1 to nL). Note that radial layer 1 is the grout (filling) within the borehole itself while other nodes are in the ground surrounding the borehole. The outputs order is : Tgnd (radial 1, axial 1) – i.e. grout temperature in axial layer 1 (top) Tgnd (radial 1, axial 2) – i.e. grout temperature in axial layer 2 … Tgnd (radial 1, axial nL) – i.e. grout temperature in axial layer nL (bottom) Tgnd (radial 2, axial 1) – i.e. temperature of first radial node (next to grout) in first axial layer (top) … Tgnd (radial 2, axial nL) – i.e. temperature of first radial node (next to grout) in last axial layer (bottom) … Tgnd (radial nR, axial nL) – i.e. temperature of last radial node (outside) in last axial layer (bottom)					

Summary of changes in Version 3.1 (from version 2.4)

- Fixed outputs for initial time step (time0)
- Changed order of first two inputs and outputs (temperature and flowrate) to make them consistent with usual input/output order in TRNSYS components **(not backwards compatible)**
- Changed order of parameters for ground layers properties to make them consistent with TRNSYS usual order (all properties for 1st layer then all properties for 2nd layer, etc.) **(not backwards compatible)**
- Changed units of Resistances given as parameters (when calcBTR = 2, 3 and 4) to make them consistent with other parameters (i.e. use TRNSYS units) **(not backwards compatible)**
- Added average ground temperature for comparison with DST model. The volume for which temperature is averaged is set by the borehole depth and by a new parameter **(not backwards compatible)**
- Removed parameters and outputs for "monitoring temperatures" since all nodes are now available **(not backwards compatible)**
- Added pressure drop to output list
- Added fluid temperature (up and down) and all fill+ground nodes to output list
- Increased maximum nb. of years to 30, maximum nb. of nodes to 20 (radial) and 10 (axial)
- Added message (notice) with Ra and Rb values, pressure drop in design conditions, as well as Type version number.
- Added check that only one unit of Type 451 is used.

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