Groundwater Flow and Heat Transfer Within a Standing Column Well

A. Nguyen[1], P. Pasquier[1], D. Marcotte[1]

[1]Department of Civil, Geological and Mining Engineering, École Polytechnique de Montréal, Montréal, QC, Canada

Abstract

Ground coupled heat pump systems such as Standing Column wells (SCW) use groundwater as heat source/sink to heat and cool buildings. In a SCW, groundwater is pumped at the base of a deep well, transferred to one or several heat pumps, and then re-injected at the top of the same well (Figure 1). During peak periods, a portion of the pumped water is not re-injected into the well, thereby creating a drawdown that stimulates the groundwater flow to the SCW. This operation, known as bleed, helps maintaining the pumped water temperature within the heat pump' operational range. In cold climates, the bleed is sometimes unable to maintain the pumped water within the heat pump' operational temperatures. In such situation, an off-loading sequence is initiated and the building's heat pumps are shut down sequentially until the pumped water comes back to a suitable temperature. To maintain a sufficient comfort level within the building, auxiliary systems are used, which is undesired since their energy efficiency is significantly lower. A simplified but fully coupled multiphysics model (Figure 2) involving heat transfer and flow within a SCW and its surrounding ground was implemented in COMSOL Multiphysics 4.2a with MATLAB® to simulate a 24-hour heating operation. The heat pumps were modeled using interpolation functions (based on commercially available data) taking into account the effect of the pumped water temperature on the capacity and coefficient of performance (COP) of the heat pumps. In the model presented here, a three level bleed control is applied when the temperature of the pumped water drops to 7, 6, and 5°C. If the pumped water temperature drops below 4°C, an off-loading sequence implemented via a MATLAB® function allows the heat pumps to automatically shut down one by one at intervals of 10 minutes. If the pumped water goes above 4°C, the model allows the reopening of the heat pumps. A simple example is used to demonstrate the various functionalities of the model (constant heating load of 200kW provided by four heat pumps and a backup heating system). Figure 3 shows the hydraulic head at the outflow (pumping) and inflow (injection) boundaries and the corresponding temperature over time. The three hydraulic head drops at 7, 6, and 5°C indicate that the implementation of the bleed operation was successfully achieved by the model. It also indicates that the off-loading sequence accurately started at 4°C and then that a heat pump stopped every 10 minutes after that instant. Figure 4 shows the thermal loads provided by the heat pumps and the auxiliary heating system as well as the COP of the heat pumps, allowing an evaluation of energy consumption of each subsystem. A coupled SCW model that integrates a three level bleed control and an off-loading sequence was developed. Since these features affect the operation of a standing column well in addition to the energy savings generated by the heat pumps, such a model should be considered during the design of a SCW system.

Figures used in the abstract

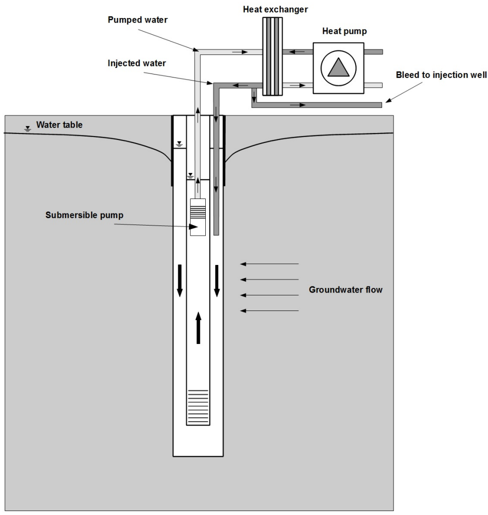

Figure 1: Illustration of a standing column well system.

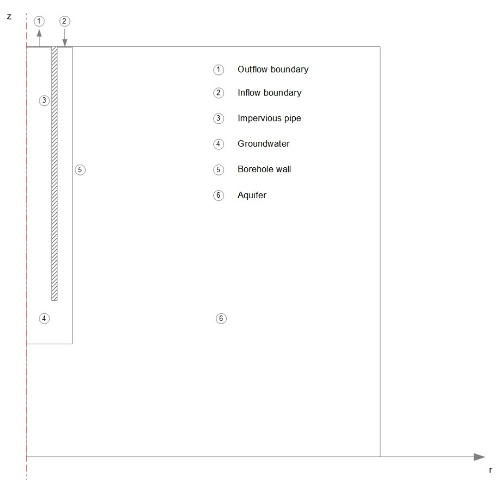

Figure 2: Simplified representation of a standing column well.

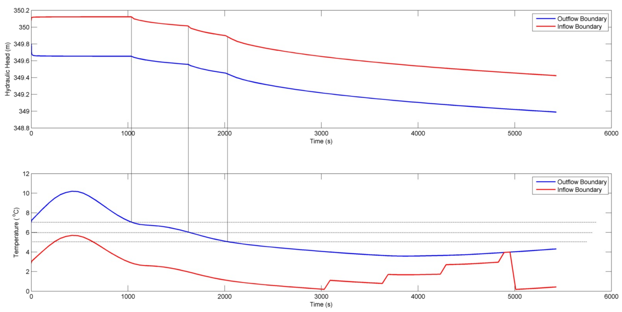

Figure 3: Illustration of a three level bleed control.

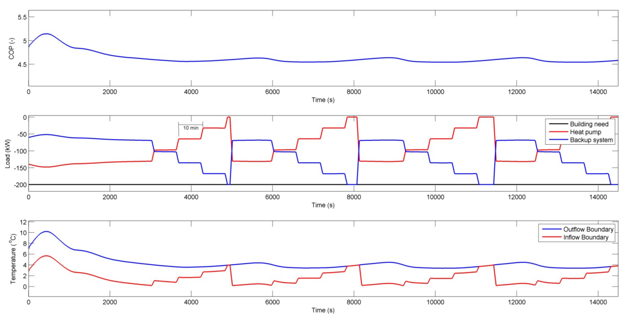

Figure 4: Illustration of an off-loading sequence.