EXPERIMENTAL AND NUMERICAL PERFORMANCE ASSESSMENT OF STANDING COLUMN WELL OPERATING STRATEGIES

Gabrielle Beaudry[1], Philippe Pasquier[1], Denis Marcotte[1], Alain Nguyen[2]

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

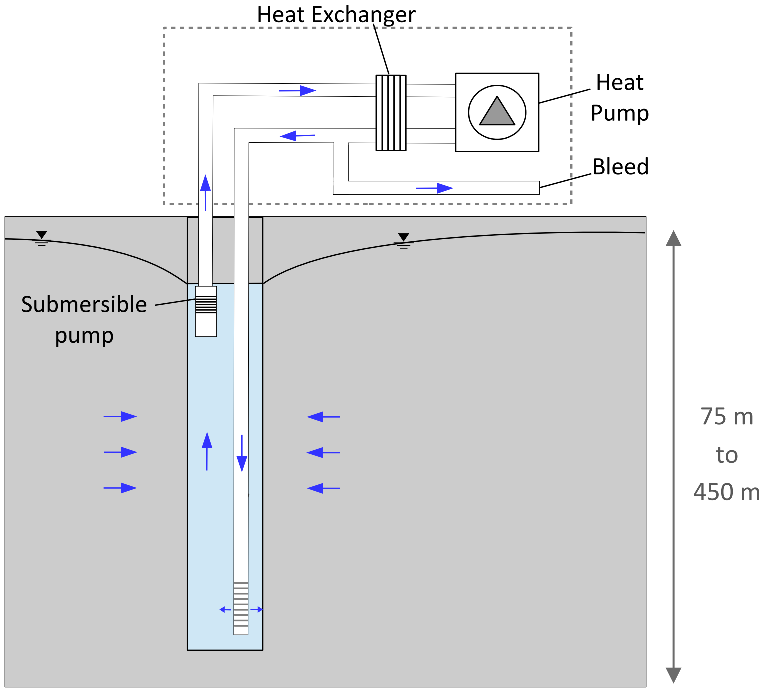
[2] CanmetENERGY, Natural Resources Canada, Canada

EGU General assembly

May 5, 2020

STANDING COLUMN WELLS

Standing column wells (SCWs) are hybrids between closed- and open-loop systems.



- Groundwater is pumped and recirculated inside a deep and open well.
- Discharging groundwater outside of the SCW (bleed) boosts the thermal efficiency.

SCWs allow **reducing total borehole depth and initial costs by about 2 to 5 times** compared with conventional closed-loop systems (O'Neill *et al.* 2006).

Their compact configuration (depth + efficiency) also makes them **better adapted to dense urban areas** (Pasquier *et al.* 2016).

PROBLEMATIC AND OBJECTIVE

Problematic :

Very few research projects are documenting the operation of SCWs, leading to poor knowledge of the various conditions and operating strategies affecting their performance.

Objectives :

Provide insights on the various conditions and operating strategies affecting the performance of SCWs in order to promote adoption of this energy-efficient technology and encourage good practice.

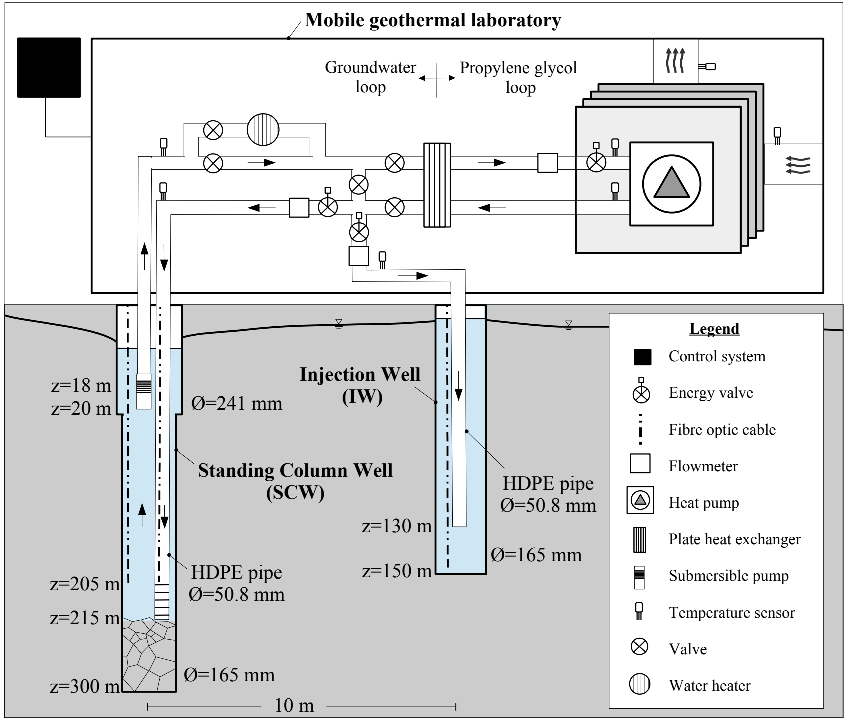
Methodology :

1. Experimental data acquisition and analysis through the characterization and operation of an experimental SCW system.

2. Numerical analysis of a high-accuracy simulation model developed and validated using the experimental data.

EXPERIMENTAL – GEOTHERMAL LABORATORY

A mobile geothermal laboratory coupled to a SCW is installed near Montreal, Canada.



Adapted from Beaudry *et al.* 2019

- A SCW (215 m) with a near-surface pumping chamber for easier installation and maintenance ;
- An injection well (150 m) for reinjection of the bleed water ;
- 4 heat pumps with a total 56-kW capacity ;
- A plate heat exchanger to avoid groundwater circulation in the heat pumps ;
- A water heater for thermal response tests ;
- A control and monitoring system including 550 m of fibre optic cables ;
- A water treatment unit with a sediment filter, a cationic ion exchanger and a disinfection system (Cerclet *et al*. 2020).

POLYTECHNIQUE MONTRÉAL
TECHNOLOGICAL UNIVERSITY

EXPERIMENTAL – HYDROGEOTHERMAL SETTING

A series of field test was conducted on the experimental site (Beaudry *et al.* 2018, 2019).

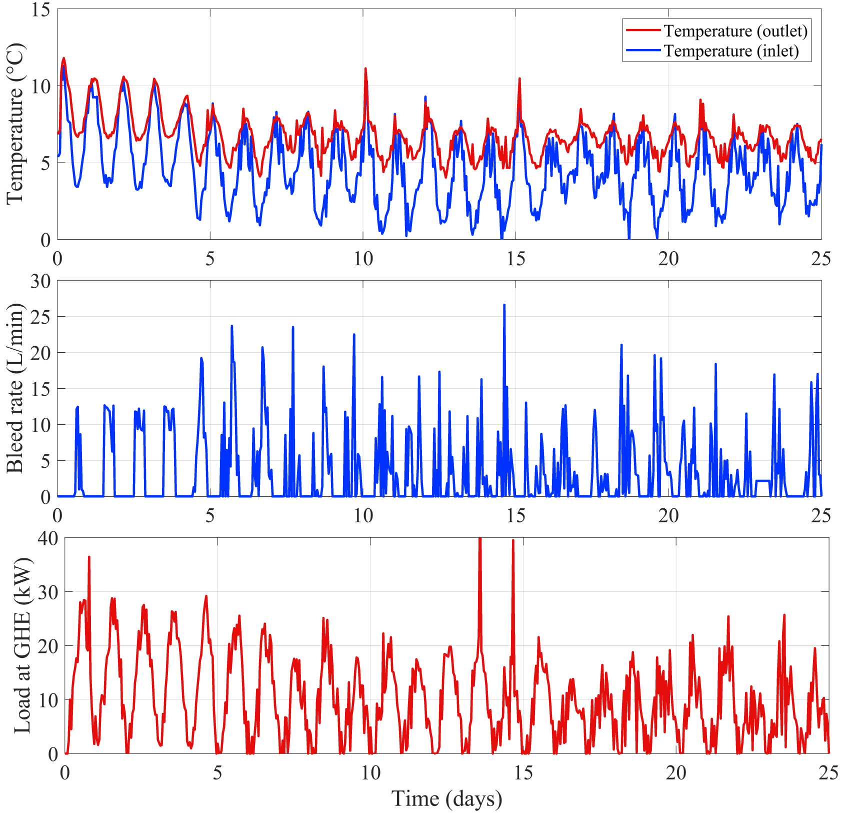
Tests	Investigated parameters	Results
Analysis of drill cuttings	Nature of soil Nature of bedrock	Clayey silt (z<3 m) Shaly limestone (z>3 m)
Temperature profiles	Average ground temperature on 215 m Geothermal gradient	10.2 °C 2.3 °C/100 m
Pumping test	Water table depth Specific storage Hydraulic conductivity	2 m (variable) 7.5e-7 m^{-1} 5.7e-7 m s^{-1}
Injection test	Maximum sustained bleed rate without overflowing	8 L/min
Thermal response test	Thermal conductivity	2.74 W $m^{-1}K^{-1}$

The mobile geothermal laboratory was used to perform 25 days of **dynamic winter operation**. It involved :

- a three-level bleed control to minimize the volume of discharged water. Respectively, 10%, 20% and 30% of the total flow were deviated to the injection well when the water temperature at the outlet of the well reached 7°C, 6°C and 5°C.
- an on-off sequence to protect heat pumps against freezing. Heat pumps were deactivated for 5 minutes when the water temperature at the outlet of the well reached 4 °C.

Over the test duration, the groundwater temperature was maintained within the operational range while the system sustained an **average heat exchange rate of 10 kW** and an **average bleed rate of 3 L/min.**

During peak periods, the system was able to extract 120 W/m from the ground and deliver a **peak load of 180 W/m** to the ambient air (COP = 3).



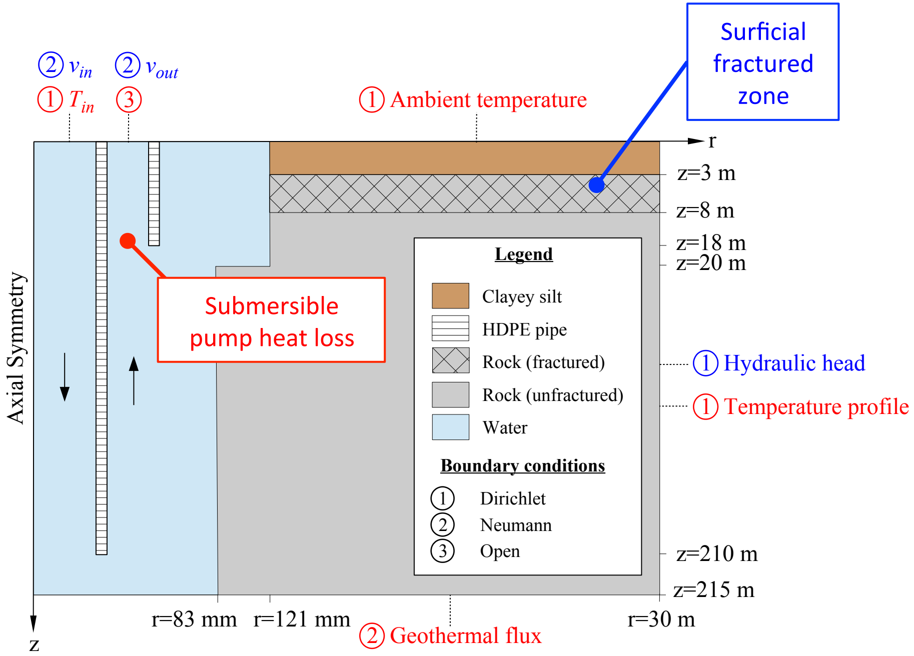
POLYTECHNIQUE MONTRÉAL TECHNOLOGICAL UNIVERSITY

A finite-element model was developed in COMSOL Multiphysics (Beaudry *et al.* 2019). It couples a groundwater flow model (continuity equation and Darcy's law) to a heat transfer model (heat equation).

The materials properties were selected to represent the conditions on the experimental site.

A **heat source was set at the location of the submersible pump** to account for the thermal loss of the pump motor.

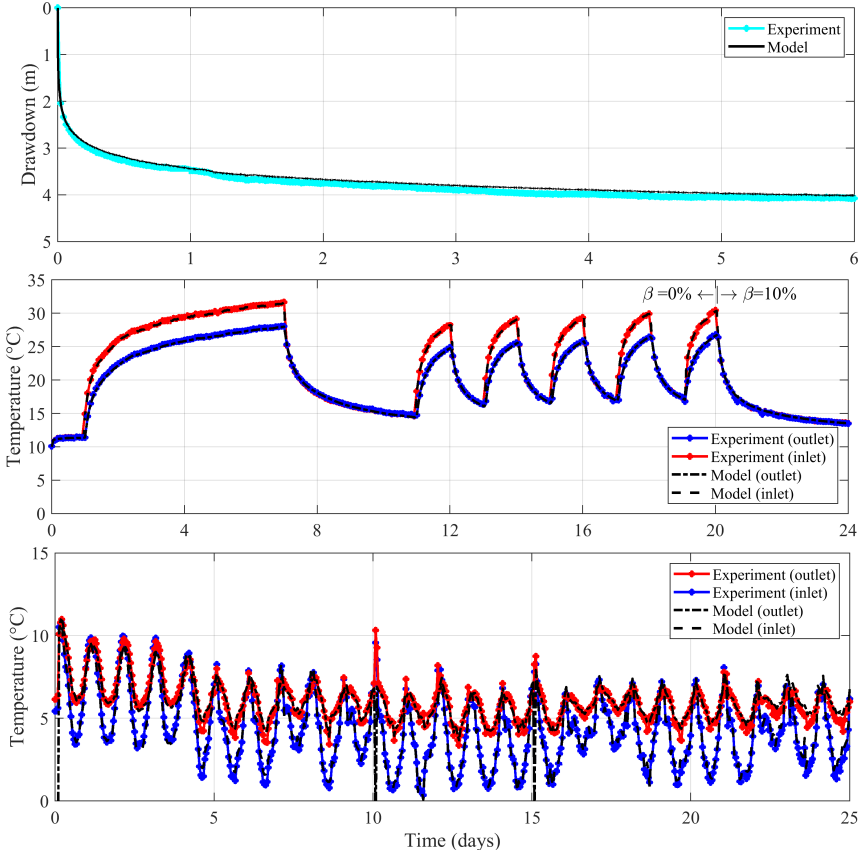
Based on geological evidence and field observations the rock formation was divided in a **more permeable fractured horizon near the surface** (between 3 m and 8 m) and a less permeable horizon for the lower part of the SCW.



POLYTECHNIQUE MONTRÉAL
TECHNOLOGICAL UNIVERSITY

SIMULATION – NUMERICAL MODEL VALIDATION

Source : Beaudry *et al.* 2019



The numerical model was validated using the experimental data collected with the mobile geothermal laboratory .

The measured initial temperature profile, pumping rate, bleed rate, heating power and submersible pump heat loss were used to emulate the field tests :

- Pumping test (MAE = 7.3 cm)
- Thermal response test (MAE = 0.15 °C)
- Dynamic winter experiment (MAE = 0.32 °C).

MAE : Mean absolute error

The numerical model reproduces the drawdown at the well and the operating groundwater temperatures in both stable and dynamic conditions with good accuracy.

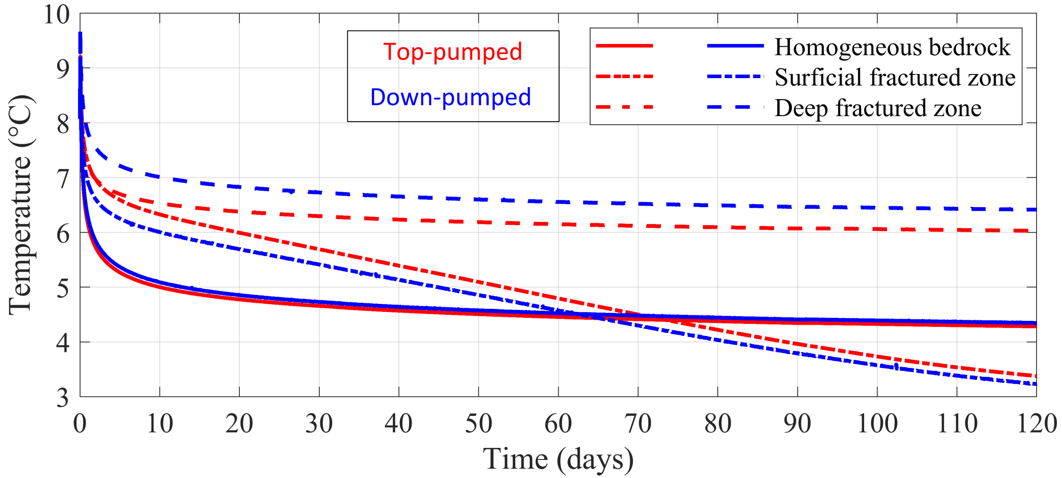
POLYTECHNIQUE MONTRÉAL
TECHNOLOGICAL UNIVERSITY

SIMULATION – EFFECT OF ROCK FRACTURING AND PUMP INLET DEPTH

The numerical model was then exploited to investigate the impact of the **depth of a fractured zone** and the **submersible pump inlet depth** on a SCW. To this end, we simulated 4 months of **winter operation** (20 kW constant heat extraction) under a **high hydraulic solicitation** (30 L/min bleed rate).

- Deep fracturing is beneficial to winter operation as it favors recharge of the well with warmer water due to the geothermal gradient.
- Near-surface fracturing is less favorable as the temperature of groundwater recharging the well is strongly influenced by the ambient air.
- The submersible pump inlet depth has minimal impact that is associated with the presence of fractured zones.

Source : Beaudry *et al.* 2019



Simulated temperature at the outlet of the well.

POLYTECHNIQUE MONTRÉAL TECHNOLOGICAL UNIVERSITY

MAIN RESULTS AND CONCLUSION

Our work suggests that :

- A **three-level bleed control** and **on-off sequence** allow maintaining the groundwater temperature above the freezing point, while minimizing the volume of discharged water and allowing to reach a **120 W/m heat extraction rate**.

- A site investigation involving a **pumping test**, a **thermal response test** and **downhole temperature measurements** should allow for **accurate modelling** of a SCW.

- Deep and surficial **fractured zones can have a strong impact on heat pump operation** when bleed is active and should be included for better modelling accuracy.

- The **submersible pump inlet depth has minimal impact on the well heat exchange efficiency** and can be placed near the surface to facilitate installation and maintenance operations.

POLYTECHNIQUE MONTRÉAL
TECHNOLOGICAL UNIVERSITY

REFERENCES

- Beaudry, G., Pasquier, P., Marcotte, D., 2019. The impact of rock fracturing and pump intake location on the thermal recovery of a standing column well: model development, experimental validation, and numerical analysis. Science and Technology for the Built Environment, 25(8), 1052-1068.

- Beaudry, G., Pasquier, P., Marcotte, D., 2018. Hydrogeothermal characterization and modelling of a standing column well experimental installation, in: Proceedings of the IGSHPA Research Track 2018. Stockholm, Sweden.

- Cerclet, L., Courcelles, B., Pasquier, P., 2020. The impact of standing column well operation on carbonate scaling. EGU General Assembly 2020.

- Comsol Multiphysics, 2013. Version 5.2, COMSOL.

- O'Neill, Z.D., Spitler, J.D., Rees, S.J., 2006. Performance analysis of standing column well ground heat exchanger systems. ASHRAE transactions 633–643.

- Pasquier, P., Nguyen, A., Eppner, F., Marcotte, D., Baudron, P., 2016. Standing column wells, in: Advances in Ground-Source Heat Pump Systems. Elsevier, 269–294.

POLYTECHNIQUE
MONTRÉAL

TECHNOLOGICAL
UNIVERSITY