Supplementary Document

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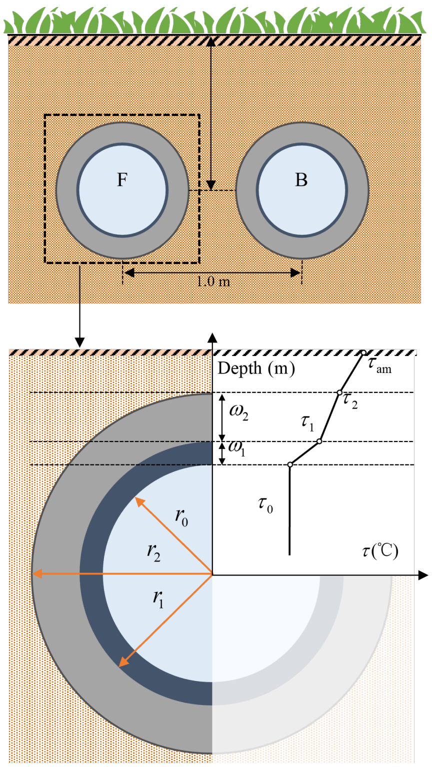

Fig. 1. Structure of underground cooling pipelines.

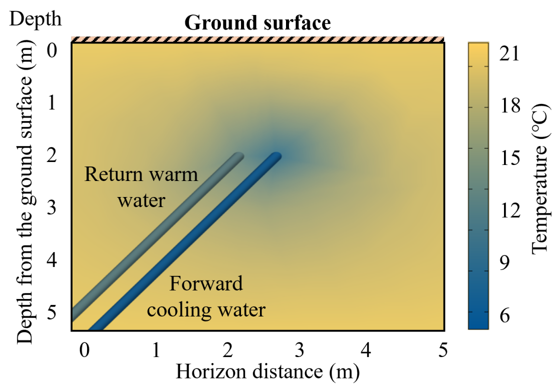

Fig. 2. Underground temperature field.

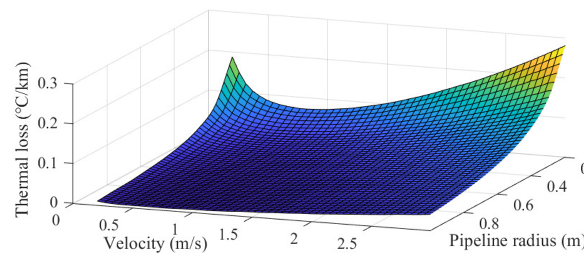

Fig. 3. Underground temperature field.

I. Pipeline Network Thermal Loss

The structure of the underground cooling pipeline is illustrated in Fig.1. The energy equation for the chilled water flowing in a cooling pipeline can be formulated [1] as:

$$\rho A C_p \frac{\partial \boldsymbol{\tau}}{\partial t} + \rho A C_p \boldsymbol{u} \cdot \nabla \boldsymbol{\tau} = \nabla \cdot A k \nabla \boldsymbol{\tau} + f^{\mathrm{D}} \frac{\rho A}{2 d_h} |\boldsymbol{u}|^3 + Q^{\mathrm{wall}} + Q^{\mathrm{p}}, \tag{1}$$

where ρ, A, and C_p are the density, pipe cross section area, and heat capacity of chilled water, respectively; $\boldsymbol{\tau}$ and $\boldsymbol{u}$ denote the water temperature and velocity field; k is the thermal conductivity; Q^{p} is the heat brought by pressure drop. Since it's attributed to pumps' power, $Q^{\mathrm{p}} = 0$; Q^{wall} represents radial heat transfer from the surroundings into the pipe, which is given by:

$$Q^{\mathrm{wall}} = \frac{(h \cdot A_Q)^{\mathrm{eff}}}{\Delta L} (\tau^{\mathrm{ext}} - \tau), \tag{2}$$

$$(h A_Q)^{\mathrm{eff}} = \frac{1}{\frac{1}{r_0 h^{\mathrm{int}} \Theta} + \frac{\ln(r_1/r_0)}{k_1 \Theta} + \frac{\ln(r_2/r_1)}{k_2 \Theta} + \frac{1}{r_2 h^{\mathrm{ext}} \Theta}}, \tag{3}$$

where A_Q denotes the area available for heat flux into the wall; ΔL is a short length section of pipe; τ^{ext} represents the external temperature; h^{int} and h^{ext} are internal film resistance and external film resistance, respectively; $\Theta = 2\pi \cdot \Delta L$.To get the more detailed derivation, please check the Reference Manual in [2].

Then with the recorded soil temperature, chilled water temperature and mass flow rate $\dot{m}$, the temperature field and thermal loss can be calculated by COMSOL 6.1 [2]. The underground temperature field is illustrated in Fig. 2. Furthermore, the simulation result, thermal loss of different pipelines with different mass flow rates is demonstrated in Fig. 3.

References

[1] M. V. Lurie, "Modeling of oil product and gas pipeline transportation," in *Modeling of oil product and gas pipeline transportation*, pp. 1–214, WILEY, 2009.

[2] "COMSOL: Multiphysics Software for Optimizing Designs." https://www.comsol.com/. [Accessed 20-02-2025].