CONSTRUCTAL LAW CONFERENCE – CLC2024
Design in Nature and Evolution
Romanian Academy, Bucharest, 10–11 October 2024

Proceedings of CLC2024
pp. 21–24

ANALYSIS OF HEAT TRANSFER TO A SHEET-TYPE HEAT EXCHANGER PLACED IN RUNNING WATER-THERMAL ENERGY EXTRACTION FROM IRRIGATION WATER

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A sheet-type heat exchanger has been extensively used as a device for extracting heat from the ground soil. This heat exchanger consists of polyethylene capillary tubes bundled together in a sheet, positioned between two header pipes that serve as the inlet and outlet for circulating brine. The bundled thin tubes, with an outer diameter of 6 mm and an inner diameter of 5mm, are highly flexible, allowing for easy winding and bending. This flexibility provides significant freedom in configuring the device within the soil. This paper examines the possibility of using the same heat exchanger to collect heat from water flowing in irrigation channels and rivers.

We discuss an analytical method capable of predicting the performance of the heat exchanger when it is positioned parallel to the water flow. In this analysis, we employ the concept of overall heat transfer coefficient to evaluate a single polyethylene tube. Specifically, we determine the dimensionless inner convective heat transfer coefficient, known as the inner Nusselt number, for laminar flow conditions. Meanwhile, the outer convection heat transfer coefficient is derived from forced convection correlation obtained from an isothermal flat plate. Additionally, numerical simulations are conducted to account for the influence of header pipes on the flow field and to relax the assumption of a constant outer wall temperature. We find that the analytical and numerical results generally agree.

Furthermore, we compare the analytically predicted results with available experimental data, revealing agreement between the predicted and experimentally obtained heat transfer rates.

Keywords: Heat transfer; Convection; Heat exchanger; Irrigation water; Energy tapping; Agricultural use.

1. INTRODUCTION

In many agricultural areas, additional thermal energy is often required to cultivate a variety of fruits, vegetables, and flowers in greenhouses during the winter. Typically, this heat is provided by oil heaters and air-to-air heat pumps. However, in scenarios where irrigation water is available near the greenhouses, it becomes feasible to either extract heat from or dissipate heat into the water. Due to water's significantly higher thermal conductivity compared to air, utilizing water for heat exchange can reduce the energy consumption of heat pumps compared to air-to-air systems.

In this study, we focus on a specific type of heat exchanger and demonstrate how we can predict its performance when placed in an irrigation water channel. The heat exchanger consists of approximately 120 polyethylene capillary tubes, each with outer and inner diameters of 6mm and 5mm respectively, and a length of about 6 m. These tubes are tightly bundled together to form a single sheet, with a spacing of approximately 0.5 mm between them. Heat transfer occurs between the circulating brine within the capillary tubes and the surrounding irrigation water.

DOI: https://doi.org/10.59277/CLC/2024.04

Initially, we conduct an approximate analysis based on overall heat transfer coefficients. Subsequently, we compare these approximate heat transfer results with more accurate numerical simulations. Finally, we compare the experimentally measured heat transfer rates with those obtained from the approximate method.

2. APPROXIMATE AND NUMERICAL METHODS TO PREDICT HEAT TRANSFER RATES

A simplified approach was suggested using the overall heat transfer coefficient and assuming a constant convection heat transfer coefficient over the outer surface of the tube. The method utilizes convective heat transfer principles from a flat plate with a constant temperature to derive a straightforward expression for the brine temperature [1–6]. Additionally, a numerical method is employed, considering the influence of header pipes on flow fields and relaxing the assumption of a constant heat transfer coefficient over the outer pipe wall, as assumed in the simplified analysis [7–10]. Figure 1 illustrates a numerical result showing the development of brine temperature in a sheet-type heat exchanger. The simulation assumes the brine enters at an initial temperature of 0°C with a flow rate of 15 L/min, while the water in the channel is at 10°C and flows at a velocity of 10 m/min. The brine is introduced at the downstream inlet position to ensure the heat exchange process aligns with a counter-flow arrangement. As shown in the figure, the brine temperature increases rapidly near the inlet region and slows as it approaches the exit region, validating the constant heat transfer coefficient assumption used in the simplified analysis. Overall, the two approaches yield consistent results, as demonstrated in Table 1.

Table 1

Analytically predicted outlet brine temperatures compared to numerically obtained values

Water Flow Velocity U_∞[m / min]	4		10	
Water Temperature T_∞[°C]	8.2		7.4	
Refrigerant flow rate Q[L / min]	15	30	15	30
Inlet Temperature [°C]	–0.4	1.6	-0.8	1.5
Outlet Temperature [°C] (Analytical)	7.48	5.10	6.80	5.10
Outlet Temperature [°C] (Numerical)	7.57	6.42	6.80	5.82

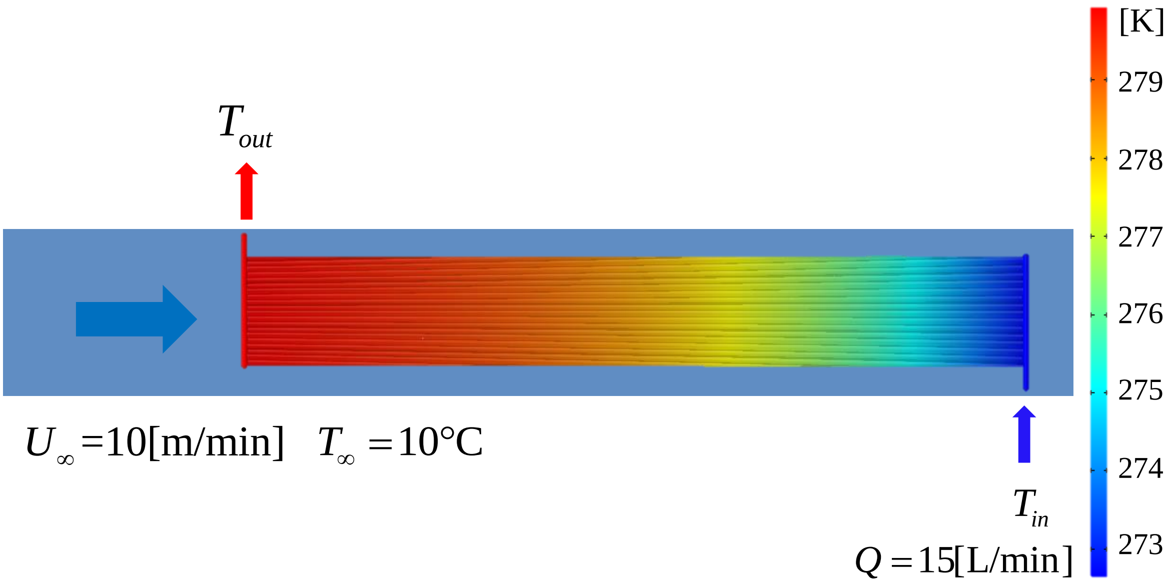

Fig. 1 – The brine temperature development in the sheet type heat exchanger when it is installed vertically in the water channel.

3. APPROXIMATE ANALYTICAL RESULTS COMPARED WITH EXPERIMENTAL ONES

Goto *et al.* [11] reported experimental results obtained from a real-size water channel as seen in Fig. 2. A comparison was made between the analytical predictions and the experimental findings. As indicated in Table 2, while the analytical predictions are generally underestimated, both methods agree within a margin of 15%.

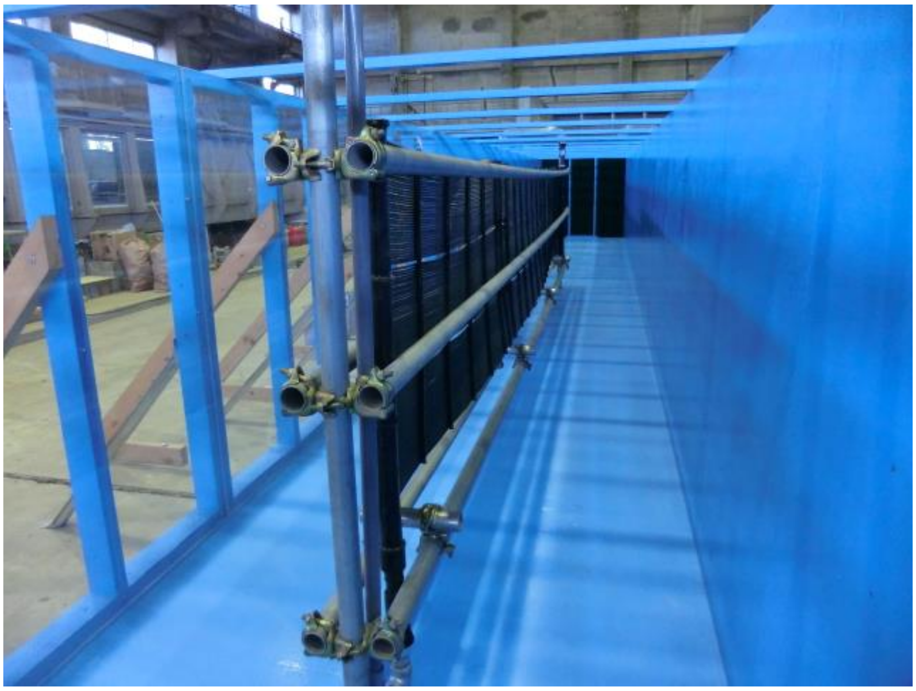

Fig. 2 – A sheet type heat exchanger installed vertically in the real scale water channel whose cross section is 1.6 m × 1.6 m.

Table 2

Analytically predicted outlet brine temperatures compared to experimentally measured values

	Heating		Cooling	
Water Flow Velocity $U_\infty[\mathrm{m/min}]$	10		10	
Water Temperature $T_\infty[°\mathrm{C}]$	6.75		12.3	
Refrigerant flow rate $Q[\mathrm{L/min}]$	15	30	15	30
Inlet Temperature $[°\mathrm{C}]$	-1.5	0.8	24.4	20.1
Outlet Temperature [℃] (Analytical)	5.0	4.04	14.8	15.9
Outlet Temperature $[°\mathrm{C}]$ (Experimental)	5.3	4.5	13.7	15

4. DISCUSSION AND CONCLUSIONS

A straightforward approximate method was introduced to predict the heat exchange performance of a sheet-type heat exchanger when placed parallel to water flows. This method was validated against numerical simulations and real-size experimental results, demonstrating its effectiveness in predicting the heat exchange performance of such heat exchangers.

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