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Refrigeration Potential Investigation of Liquefied Petroleum Gas under Atmospheric Conditions †

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Abstract: One of the potential refrigerants for refrigeration systems is liquefied petroleum gas (LPG) that can absorb latent heat from the surrounding and provide cooling, if introduced in liquid state. The present study determines the cooling effect produced in flowing water in coils after exchanging heat with liquid LPG, coming from an inverted cylinder. In an insulated box with a copper coil, the water flow rates were varied while maintaining the amount of surrounding liquid LPG. The results reveal that the cooling effect is proportional to the rate at which water flows, but the time for liquid LPG to evaporate decreases. For smallest water flow rates, the temperature differential across the water inlet and outlet was found to be the largest.

Keywords: liquid LPG; latent; heat of vaporization; copper coil; atmospheric conditions

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1. Introduction

Liquefied petroleum gas (LPG) is one of the most widely used fuels in the world, with applications ranging from heating and cooking, to automotive fuels. In addition to its stated purpose, LPG is increasingly being considered as a refrigerant, e.g., for cooling. According to recent studies, LPG has the potential to produce air-conditioning and refrigeration effects [1,2]. Because LPG has a very low saturation temperature, it absorbs latent heat from its surroundings, lowering the surrounding temperature. Both Compressed Natural Gas and LPG produce a prospective cooling effect when evaporated within the vaporizer units. When stored in a cylinder, LPG has a lower pressure than CNG, namely 0.8–1.0 MPa for LPG and 20–27 MPa for CNG. The former is easier to handle because it is under less pressure and in a liquid state [3]. LPG is a possible replacement refrigerant with a low global warming potential due to restrictions on the refrigerants that are destroying the ozone layer. Despite being highly combustible, it is widely used. The risk of flammability has been found to be reduced by the addition of modest amounts of components such as carbon dioxide [4]. LPG often contains a combination of propane, butane, or isobutene. Setiyo et al. explored, by simulation, that the composition of LPG affects the cooling impact created [5].

The current study investigates the cooling effect of LPG by exchanging heat between water flowing into a copper tube surrounded by LPG. Water flows at different flow rates in a circular copper tube that is directly in contact with LPG at atmospheric pressure and is enclosed in an insulated box. The LPG used in the experiment was composed of 65% propane and 35% butane [2]. The goal of the tests was to see if LPG has the ability to produce refrigeration in flowing water under normal atmospheric conditions. The LPG is stored as a liquid in a cylinder under high pressure. It evaporates and absorbs heat from the environment as it expands. LPG is chosen in liquid form from the cylinder and poured into an insulated box where heat is exchanged between running water in copper tubes surrounded by liquid LPG about to evaporate. This evaporation cools the surrounding and

decreases the temperature. The cooling characteristics of LPG under atmospheric pressure for various water flow rates were investigated using an experimental setup designed in house.

2. Materials and Methods

Methodology and Setup Design

The experimental setup schematic is shown in Figure 1, a copper coil surrounded by liquid LPG was stored in an insulated box to examine the possibility of LPG to create cooling in flowing water. Water inlet and outlet temperatures were recorded with a waterproof LM35 sensor, and water flow rate was measured with a flow sensor connected to a computer through an Arduino Uno.

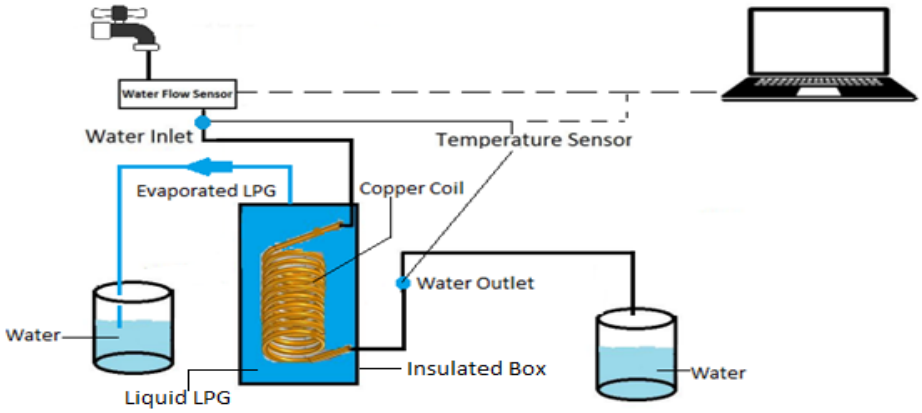


Figure 1. Schematic of Experimental Setup.

The flow of water in the copper coil absorbs the latent heat to evaporate the surrounded liquid LPG. As a result, the temperature of the water begins to drop. Equation 1 was used to calculate the rate of heat transfer.

$$\dot{Q} = \dot{m}C\Delta T \quad (1)$$

where $\dot{Q}$ is the rate heat transfer, $\dot{m}$ is the mass flow rate of water, C is the specific heat constant, and ΔT is the change in temperature of the water.

3. Design of Experiments

A regulating tap was used to control the water flow rate. The trials were carried out at four different water flow rates: 0.03 kg/s, 0.07 kg/s, 0.12 kg/s, and 0.15 kg/s. The volume of LPG in the insulated container remained constant, at 125 mL. At atmospheric circumstances, the copper coil was submerged in a container filled with LPG. Water was passed through the coil tube, which had an internal diameter of 6 mm. Temperature sensors were installed at both the intake and the outflow of the copper coil, while a water flow sensor was installed only at the inlet. For each flow rate, a predetermined volume of LPG was used. LPG evaporated as heat exchange occurred between running water and the surrounding liquid LPG. By providing passage over an insulated box, evaporated LPG vapors were dropped in the water. As the amount of Liquid LPG in the water diminished, the temperature differential between the input and output reduced, and eventually the difference disappeared as the liquid LPG evaporated.

4. Results and Discussion

Figure 2a shows that, for a low water flow rate of 0.03 kg/s, the temperature drops by 10 °C, and it takes approximately 180 s for 125 mL Liquid LPG to evaporate and the flow water to return to its initial temperature. It can also be concluded from Figure 2a–d that, as the flow rate increases, the time to evaporate the same amount of liquid LPG decreases, and the maximum decrease in water temperature was observed at low water flow rate.

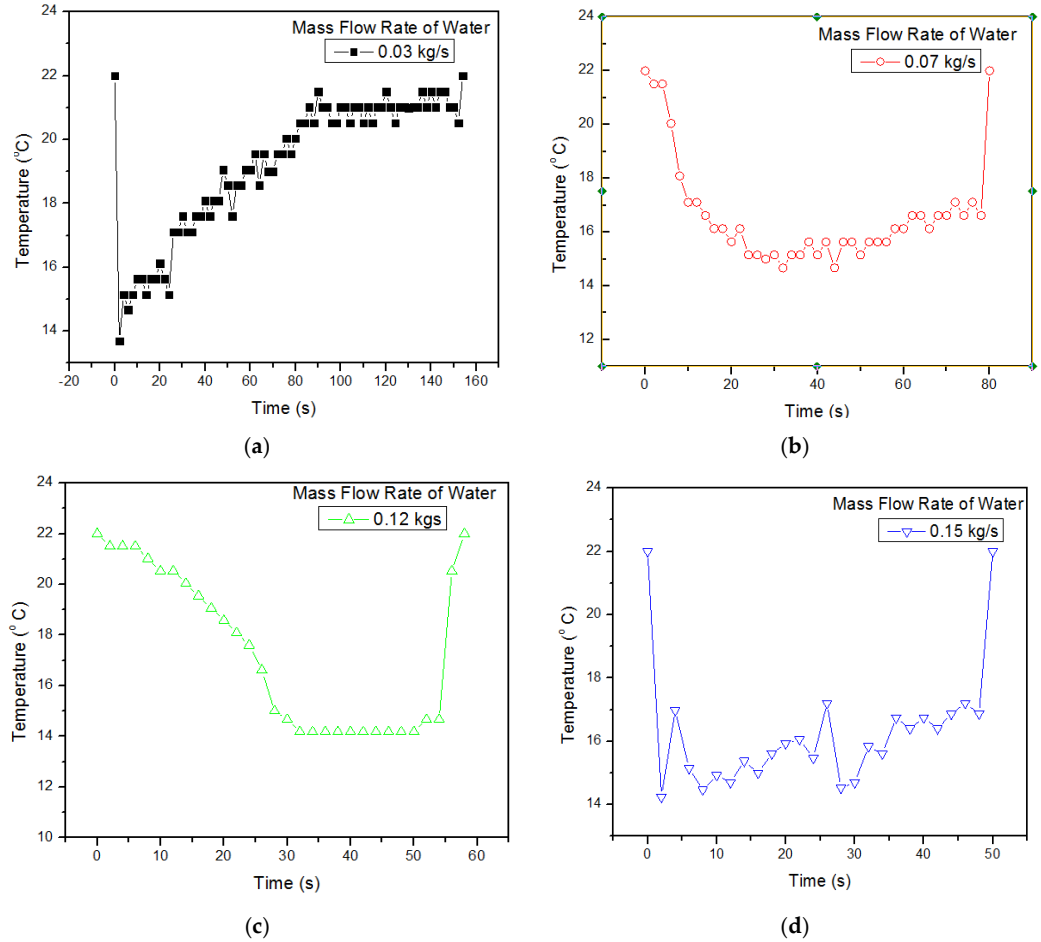


Figure 2. Water outlet temperature as a function of time for different water flow rates.

Figure 2a–d indicate that, at low flow rates, the temperature of flowing water drops abruptly and gradually rises as the amount of liquid LPG evaporates, whereas, at higher flow rates, the temperature gradually decreases and remains nearly constant for a few seconds.

Figure 3 shows that, as the mass flow rate increases, the heat transfer rate with liquid LPG also increases. As a result of the increased heat transfer rate, the liquid-surrounded LPG evaporates faster. For example, at a flow rate of 0.15 kg/s, 125 mL liquid LPG evaporates in approximately 50 s, while at a flow rate of 0.03 kg/s, liquid LPG evaporates in approximately 160 s.

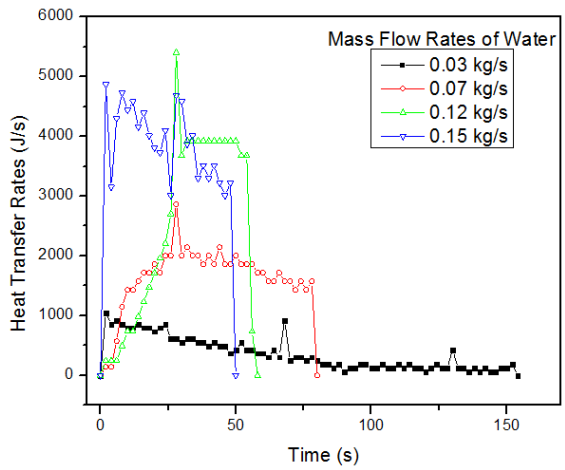


Figure 3. Heat transfer rate of water with surrounded liquid LPG at diferent water flow rates.

Flow rates influence the temperature difference between the inlet and outlet water. Surrounding liquid LPG must absorb latent heat from flowing water to evaporate. Because liquid LPG absorbs latent heat from flowing water at relatively low flow rates, it cools faster than water at relatively high flow rates. Using Equation (1), however, the heat transfer rate is greater for relatively high water flow rates. As a result, for relatively high flow rates, the surrounded liquid LPG evaporates in less time.

5. Conclusions

The results of the study demonstrate that liquid LPG can be used to instantly lower water temperature because liquid LPG has the potential to produce refrigerating effects under ambient conditions before evaporating. When water was flowing through the coil at a low rate, the temperature dropped significantly more than when it was flowing at a high rate, but high flow rates had a higher rate of heat transfer, which caused surrounding liquid LPG to evaporate more quickly than it did at low flow rates.

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