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Effect of radiator position and mass flux on the dryer room heat transfer rate

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ABSTRACT

A room radiator as usually used in cold countries, is actually able to be used as a heat source to dry goods, especially in the rainy season where the sun seldom shines due to much rain and cloud. Experiments to investigate effects of radiator position and mass flux on heat transfer rate were performed. This study is to determine the best position of the radiator and the optimum mass flux. The radiator used was a finned radiator made of copper pipes and aluminum fins with an overall dimension of 220 mm × 50 mm × 310 mm. The prototype room was constructed using plywood and wood frame with an overall size of 1000 mm × 1000 mm × 1000 mm. The working fluid was heated water flowing inside the radiator and air circulating naturally inside the prototype room. The nominal mass fluxes employed were 800, 900 and 1000 kg/m^2 s. The water was kept at 80 °C at the radiator entrance, while the initial air temperature inside the prototype room was 30 °C. Three positions of the radiator were examined. The results show that the effect of the mass flux on the forced and free convection heat transfer rate is insignificant but the radiator position strongly affects the heat transfer rate for both forced and free convection.

Introduction

In cold countries a room radiator is used for heating a room to make occupants feel comfortable and warm. It is widely used in Europe, America, Russia, China, Japan etc. The heat source of the room radiator is usually water heated up in a gas or an electrical boiler/heater placed on the wall in a kitchen. Therefore, operating this heating system needs energy for heating the water and power for turning the pump. The energy required for this system is quite large especially when the size of the radiator is huge.

The radiator, as used in the cold countries, is usually big and heavy, and has a big gap in it. The big gap needs a lot of hot water while increasing the amount of hot water raises the energy demand. The energy demand is proportional to the mass flux and the pump power. Moreover, almost all of ordinary radiators are made of cast iron or stainless steel. The two materials have very low thermal conductivity, therefore, the efficiency of the radiators is low because the radiator cannot release much heat to the air. In this study, the investigated radiator was made of copper pipe with aluminum fins. Copper has a very high thermal conductivity, it is around 400 W/m K, Incropera et al. [1].

In hot/tropical countries, a radiator is not needed, but an air conditioning (AC) unit is. However, the radiator can be used for drying some products or goods such as agriculture products, foods or clothes. Nevertheless, this drying method has not been implemented nor even known by people yet, whereas this method is indeed suitable in the rainy season. In the rainy season, a conventional drying method “putting goods directly under the sun” is difficult because the sun seldom shines due to much rain and cloud, while this novel method does not depend on the weather because the goods being dried are placed in a room. Other advantages of this method compared to the conventional drying method are (i) the goods are cleaner than that being put under the sun directly, (ii) the quality of the goods is better because the drying temperature can be controlled, (iii) the energy used can be obtained from renewable energies, Coronado et al. [2]. Moreover, the radiator can be operated using water heated up by utilizing the heat waste such as heat waste from tahu production processes, from tobacco drying process, from clay brick production process, and from industrial processes. There are thousands of live coals in the stove used to produce tahu. When several pipes with water flowing in them are placed under the live coals, hot water can be produced. Similarly, in the drying tobacco process that uses a vertical oven, there is plenty of heat. When several copper pipes with water flowing in them are installed on the inner surface of the vertical oven wall, the hot water can be gained. Some other heat sources that

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can be employed for this purpose are biomass energy, biogas energy, geothermal energy etc, see Coronado et al. [2].

Previous studies that focused on radiator topics are performed by Bangert [3], Myhren and Halberg [4], and Ploskic and Holmberg [5]. Bangert [3] enhanced the heat transferring from the radiator to the room by coating the wall behind the radiator. Myhren and Halberg [4] focused on the performances of the radiator due to ventilations. Then their results were used for validating the CFD research. Ploskic and Holmberg [5] investigate the thermal performance of the hydronic radiant baseboards currently used for space heating in built environments and they used their data to construct a new correlation. Recently, Embaye et al. [6] investigated the performance of a central radiator using pulsation mass flow rates, but their researches were mostly simulation. They elucidated that using their method could save energy by 22% and even it could reach 27% when the pulsation was controlled using a PID. However, they did not consider the power of the pump when the pump was running “on and off”. Previous works using flow rate pulsations had also been conducted by Lemlich [7], Shuai et al. [8] and Zohir [9], but they investigated heat transfer rates in heat exchangers not in room radiators. Due to the “on-off”, the energy used by the pump may fluctuate and this should be considered because this can increase the pump power. Different purposes to investigate the radiator also have been raised, e.g. Liu et al. [10], Lehmanna et al. [11], Adolph et al.[12], but they focused on the reducing of the energy use. Actually, the energy for heating the room does not only depend on the heat transferring from the radiator to the room but also the amount of the water flow rates. The mass flow rate increases the energy consumption for both pumping and heating also increase, see Dittus-Boelter in Holman [13]. On the contrary, as reported by Calisir et al. [14] and Mirmanto et al. [15], the effect of mass flow rate on the heat transfer rate is insignificant. This becomes an interesting phenomenon that needs to be clarified.

Radiator position may affect greatly the air circulation and the successful heating. For the heating room in homes, the radiator is placed under the window/glass wall. This will allow the cool air from the window opening to heat before it passes into the room. The cold air would be heading down and the warm air from the radiator would be heading upward to meet it. This was certainly a good idea when all windows were single glazed. Now that most homes have double glazing, the heat loss through windows is much less and the drafts coming in have all but disappeared http://www.diyfixit.co.uk [16]. Another reason why radiators might be placed under a window is that they are much less likely to interfere with furniture placement. Most people do not put their couch under the window due to the drafts and so the radiator would always be in a clear position. Unfortunately, there is very limited information regarding the radiator position for a heating room. Even so, in this study three radiator positions were examined.

In addition, the heat transfer coefficient increases as the size of the conduit decreases. This was studied by Venkatesan et al. [17], Mirmanto et al. [18], and Wang and Sefiane [19]. Meanwhile the conventional room radiator, as mentioned in the previous paragraph, is constructed with a big gap. Hence, the heat transfer coefficient for the conventional radiator is lower than that of the thin gap radiator. For this reason, in this study, the radiator employed is thin/slim and thus it is expected to increase the heat transfer rate. Other advantages of this radiator compared to the conventional one are (i) the radiator needs less working fluid, (ii) it is light, and (iii) it needs lower heating energy and pump power. Due to the advantages above, the authors are encouraged to perform this experimental study with several objectives as follows:

1. To know the effects of the radiator position and the mass flux on forced and free convection heat transfer rate.
2. To obtain the best position of the radiator.
3. To know the optimal mass flux.
4. To examine the free convection heat transfer coefficient which is usually assumed of being approximately 7–10 W/m^2 K as used by Qu and Mudawar [20] and Embaye et al. [6] in their papers.

Experimental setup

Experimental facility

This study uses experimental method with a schematic diagram presented in Fig. 1. The test rig consists of several components such as a main reservoir, centrifugal pump, a calibrated flow meter, three electrical heaters controlled using PIDs, a gas heater, radiators and a prototype room. The water was used as the working fluid and was circulated throughout the loop/test rig using a centrifugal pump, while the air as the second working fluid was initially at 30 °C and prevailed in the prototype room. Due to the increased temperature, the air circulated naturally.

The test rig was an open loop, because at the end of the process, the water was drained to the ambient. Before entering the radiator, the water was heated up in four heaters so that the desired temperature of the water at the entrance of the radiator could be achieved. Nominal mass fluxes, G, ranging from 800 to 1000 kg/m^2 s were tested in this current work and were measured using a calibrated flow meter FLR1012ST-D with an uncertainty of ±0.5 g/s. The water at the radiator entrance was kept at 80 °C during the test.

The test section (radiator) was made from copper pipes and aluminum fins with an overall dimension of 220 mm × 310 mm × 50 mm and a total outer heat transfer area of 0.56 m^2. The test section was placed inside the prototype room constructed from 5 mm thick plywood and wood with an overall dimension of 1000 mm × 1000 mm × 1000 mm. The construction of the radiator and the position of the radiator are presented in Fig. 2. The positions of the radiator examined are Case A (standing in the middle), Case B (standing near the prototype room wall) and Case C (lay down on the floor), see Fig. 3.

The pressures were measured using 26PCCD Honeywell pressure transducers with an uncertainty of ±0.3 kPa obtained from the calibration. To measure the temperatures inside the prototype room and temperatures of the radiator wall, calibrated T type thermocouples with an uncertainty of ±0.5 °C were implemented. All data were recorded during 3000 s using a data acquisition (DAQ9714) interfaced with a LabView program.

However, it should be noted that in this study, the water is not heated using the heat waste or renewable energy but it is heated using gas and electrical energies for simplifying the research. Moreover, there is no load in the dryer room, so the heat coming from the radiator is just used for increasing the air temperature inside the prototype room.

Data reduction

To analyze the experimental data, some equations or correlations are used and there are two subjects that are investigated experimentally, i.e. (1) heat transferring from the hot water to the radiator wall and fins and (2) heat transferring from the radiator wall and fins to the air inside the prototype room. The heat transferring from the hot water to the radiator wall and fins can be predicted using Eq. (1), which can be obtained in Holman [13], Incropera et al. [1] and is given by:

$$q_f = \dot{m}c_p(T_i - T_o) \tag{1}$$

where q_f is the forced convection heat transfer rate, $\dot{m}$ represents the mass flow rate, T_i is the inlet temperature and T_o is the outlet