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Heat transfer enhancement using alumina and fly ash nanofluids in parallel and cross-flow concentric tube heat exchangers

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ABSTRACT

This study experimentally demonstrated the effect of using nanofluids produced from alumina or fly ash, which is comprised of various types of metal oxides in varying concentrations, on the performance of a parallel flow concentric tube heat exchanger (PFCTHE) and a cross-flow concentric tube heat exchanger (CFCTHE). Alumina and fly ash nanofluid/water and water/water, hot/cold working fluids were used for monitoring the differences in the performance of the heat exchangers. Triton X-100 dispersant was used to produce 2% (wt) alumina and fly ash nanofluid *via* direct-synthesis. A double pipe type heat exchanger with hot water flowing through the central tube while cooling water flows through the annular space was used for the analyses. Concurrent or counter-current flow was utilized along with all ancillary equipment and instrumentation for the determination of surface and overall heat transfer coefficients during turbulent flow. Efficiencies of the PFCTHE and CFCTHE improved by 31.2% and 6.9%, respectively, when the fly ash nanofluid was used as the working fluid. The improvements in the efficiency of the heat exchangers were determined as 5.1% and 2.8%, respectively, when alumina nanofluid was used as the working fluid.

1. Introduction

Heat exchangers are widely used in many engineering applications. Heat exchangers have become an attractive choice for heat transfer applications due to their high rate of heat transfer, low cost, low cost of maintenance as well as being less bulky. Despite all of these advantages, there is still room for improvement in energy efficiency through improvements in thermal performance. The heat conductivity of the transfer fluid is an important parameter to be taken into consideration in the improvement of the performance of heat exchangers along with other design aspects. New nanotechnologies and advanced fluids have a potential to improve the flow and thermal characteristics of heat exchangers. Recent advances in nanotechnology have allowed development of a new category of fluids termed nanofluids. Such fluids are liquid suspensions containing particles that are significantly smaller than 100 nm and have a bulk solids thermal conductivity higher than that of the base liquids. Nanofluids have been successfully utilized as working fluids in heat transfer units such as heat exchangers and heat pipes owing to the presence of nano-sized solid particles which impart higher thermal conductivity than that of the carrier fluid alone [1–10]. A number of studies have reported improvements in heat transfer by a heat exchanger *via* the use of nanofluids obtained by suspending X_2O_3 type oxides such as Al_2O_3, TiO_2 and SiO_2 in water [6,7]. Different experimental and theoretical studies have been performed to analyze and verify the advantages of nanofluids in various heat exchange systems including shell and tube heat exchangers [8], double tube heat exchangers [9,10] and plate heat exchangers [10]. Additionally, there have been a few engineering applications employing nanofluids such as flat panel solar thermal collectors and automobile radiators [11–13]. For automobile radiators, up to 45% and 116% improvements in heat conductivity by employing Al_2O_3 and Fe_2O_3 nanoparticle containing nanofluids have been reported, respectively [11,12]. For flat panel solar thermal collectors, up to a 6.7% improvement and an increase in the convective heat transfer coefficient of up to 25% by employing various nanofluids has been reported [13].

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Nomenclature

A	area of heat transfer, m^2
C_p	specific heat capacity, $kJ\ kg^{-1}\ K^{-1}$
d	pipe diameter, m
h	surface heat transfer coefficient, $Wm^{-2}\ K^{-1}$
k	thermal conductivity, $(Wm^{-1}\ K^{-1})$
lpm	liter per minute
$\dot{m}$	mass flow rate, $kg\ s^{-1}$
Q	heat transfer ratio, W
T	fluid temperature, °C
ΔT	temperature difference, °C
ΔT_{ln}	mean logarithmic temperature difference, °C
U	total heat transfer coefficient, $Wm^{-2}\ K^{-1}$

Subscripts

al	alumina nanofluid
cold	cold
fly	fly ash nanofluid
hot	hot
i	inner
o	outer
r	rate
T	total

This study experimentally investigates the effect of suspending fly ash obtained from the flue gas released from the cyclones of the Yatağan thermal power plant (Turkey) on improving the thermal performance of heat exchangers for the first time. Flue gas contains various metal oxides such as SiO_2, TiO_2, Al_2O_3, Fe_2O_3, CaO and MgO in varying amounts. The presence of more than one type of metal oxide contributes to its amorphous structure and the existence of flocculation in an ultrasonic bath in the presence of surface active reagents renders fly ash more advantageous than the use of pure metal oxides for the improvement of the thermal conductivity of heat exchangers. Possessing an amorphous structure, the presence of more than one type of metal oxide and occurrence of flocculation in an ultrasonic bath in the presence of surface active reagents renders fly ash more advantageous than other metal oxides.

2. Materials and methods

2.1. Experimental setup

Hot fluid passes through the innermost concentric tube and cold fluid is transported in the annulus of the system as shown in the experimental setup diagram in Fig. 1. The unidirectional circulation of the hot fluid in the inner tube was facilitated through a brass and stainless steel centrifugal pump connected to the line. Two electrical heaters placed in a stainless steel container were used to maintain the temperature of the fluid. Circuit breakers were placed as a safety measure against an uncontrolled temperature rise in the tank, an external pressure regulating valve was placed against the uncontrolled rise in pressure and a bullseye was placed to monitor the water level. The hot and cold fluid circuits were both equipped with a flow meter (Fig. 1). A total of 10 thermocouples were placed at various locations in the system so as to enable monitoring of the temperature at various points. The technical specifications and capacities of the equipment, devices and controllers used in the experimental setup are provided in Table 1.

The design of the experimental setup allowed for both concurrent and counter-current flow heat exchange. Valves indicated as V1, V2, V3 and V4 were kept open and V5, V6 and V7 kept closed during concurrent flow heat exchanger operation of the system (Fig. 1). Valves indicated as V1, V4, V5, V6 and V7 were kept open and V2 and V3 were kept closed during counter-current flow heat exchange operation of the system (Fig. 1).

2.1.1. Hot working fluid circuit

Hot working fluid heated through an electrical resistance type water heater was fed by a pump into the central tube of the heat exchanger. The working fluid cools as it flows through the heat exchanger and upon leaving, passes through a flow meter and then back to the heating tank, where it is reheated. Two drains on the lower right-hand side of the panel allow complete draining of the hot working fluid circuit if required.

2.1.2. Cold water circuit

Cold water passes through a flow control valve and a flow meter to a junction on the face of the panel. A similar junction spot is connected to the central spot for draining the water. Flexible hoses with quick release joints connect to the annulus at either end of the heat exchanger. This structure allows the cooling water to flow in a parallel or counter-current direction. The experimental setup is arranged such that the feed and drain connections can be fixed to achieve the required direction for the flow of the cooling fluid relative to the hot stream.