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Research Paper

An experimental study on the effects of the use of multi-walled carbon nanotubes in ethylene glycol/water-based fluid with indirect heaters in gas pressure reducing stations

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HIGHLIGHTS

- Design and construction of the experimental indirect gas heater.
- Use of MWCNTs in an experimental device.
- Obtaining experimental data for different volume fractions and temperatures of nanofluid.
- Increasing Nusselt number of gas at volume fraction of 0.05 and temperature of 70 °C.
- Increasing outlet temperature difference of gas (48%) at volume fraction of 0.05.

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ABSTRACT

Heaters that work with indirect fire and water heating have a variety of applications, especially in the gas industry and in gas processing. In the present study, an experimental device is first constructed to enhance heat transfer in indirect heaters in gas pressure reducing stations in Iran, and then its efficiency is examined by adding multi-walled carbon nanotubes (MWCNTs) to ethylene glycol/water-based fluids. The efficiency of the experimental device was tested with MWCNTs at volume fractions of 0.025, 0.05, 0.1, 0.2 and 0.3 and diameters of 20–30 nm to enhance heat transfer. The results showed that the viscosity of the nanofluid was enhanced by increasing the volume fraction of their nanoparticles while an increase in the temperature reduces the viscosity and density of the nanofluid. Besides, the specific heat coefficient of the nanofluid is increased with temperature, but did not show significant changes with the increase in volume fraction. Increasing the volume fraction, however, increased the thermal conductivity coefficient and viscosity ratios, and increasing the Nusselt number also increased the convective heat transfer coefficient. Furthermore, results show a 34.5 °C increase in the outlet gas temperature difference and a 48% growth in efficiency at volume fraction of 0.05 and temperature of 70 °C. These findings are relatively consistent with the theoretical assumptions.

1. Introduction

Gas needs to be under high pressure for transportation through pipelines without causing pipeline blockage. Since the end users of gas need to receive their supply at a lower pressure, gas stations are installed at the entrance of consumption areas such as cities. The main function of heaters is to heat the compressed gas before it enters the pressure-reducing station, which helps prevent the formation of hydrates in the gas pipelines that can cause the clogging and corrosion of pipes and inhibit the hydration caused by a temperature drop (the Joule-Thomson effect). The energy crisis of the past few years and environmental problems caused by fossil fuels have further highlighted the need to optimize these widely-used devices. Angelo et al. [1] suggested the design of heaters for natural gas stations with the help of a two-phase closed-loop thermosyphon, which can lead to the production of smaller heaters with higher efficiencies and lower thermal capacities. They also require the burner to be switched on and off more frequently such equipment requires the precise and processed control of information and combustion control systems. Choosing the two-phase closed-loop thermo-syphon technology to replace the existing heaters will solve the problem of having to refill water. It will increase the heat transfer coefficient of the working fluid and its only problems will be corrosion in the system and the possibility of gas leaks.

Farzaneh-Gord et al. [2] were the first to study flat solar collectors

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Nomenclature

A	cross-sectional area, m^2
C_p	specific heat, J/(kg K)
D	pipe diameter, m
H	heat transfer coefficient, W/(m^2 K)
K	thermal conductivity, W/(mK)
L_p	nanotube length, m
L	length of test tube, m
Nu	Nusselt number
P	pressure, Pa
Re	Reynolds number
T	temperature, K
u	velocity vector, m/s
V	volume, m^3
Pr	Prandtl number
T_m	mean temperature, K
$\dot{m}$	mass rate, kg/s

Subscript

bf	base fluid
P	nanoparticle
I	inlet
o	outlet
Exp	experimental
C	cold fluid
h	hot fluid
nf	nanofluid
m	average
EG	ethylene glycol
W	water
MWCNTs	multi-walled carbon nanotubes

Greek symbols

ΔP	pressure drop, Pa
ρ	density, kg/m^3
μ	dynamic viscosity, kg/(ms)
φ	volume fraction

to supply part of the heat required in CGSs. In another study, Farzaneh-Gord et al. [3] made considerable effort to use solar systems in Sari in northern Iran and proposed a solar system to store part of the required heat using solar collectors and hot water storage tanks during the day, which would to be used throughout the night. The system consisted of an array of 450 solar collectors and a storage tank with a capacity of 45 m^3. This reduced fuel consumption by 11.3%. In their second study, they changed the system by adding a storage tank; in this configuration, the storage tank collected solar heat during the day and returned it to the heaters at night when more heat was required. The new system saved 14% fuel consumption (instead of the 11% in the first system). In a third study, Farzaneh-Gord et al. [4] replaced the conventional linear heater in CGSs with an automatic controlled heater and compared the thermal behavior of this system to other proposed systems and found the latter to be superior.

MWCTNs provide an effective way to lower energy consumption. Choi [5] used nano-sized particles in suspensions for the first time at the Argonne National Laboratory and observed that the conductive heat transfer coefficient increases with the volume fraction of the suspended particles in nanofluids. Many researchers showed that adding nanoparticles to the base fluid dramatically increases thermal conductivity [6–20]. Murshed et al. [21,22] also showed that CNT-nanofluids in a pool boiling environment can extend the saturated boiling regime and burnout of the heated surface.

In another study, Noghrehabadi et al. [23] showed that though the amount of heat transferred by nanoparticle migration was very small, the nanoparticles' slip in the base fluid induced nanofluid heterogeneity. The induced heterogeneity caused local changes in the properties of the nanofluid and thus affected convective heat transfer in the nanofluid. Hussein et al. [24] performed a numerical solution of heat transfer and friction in elliptical pipes with titanium nano-oxide of 0.25% and 0.1%. and a particle diameter of 27–50 nm. They reported a 9% increase in heat transfer and a 6% increase in the friction coefficient compared to circular pipes. Mehmood et al. [25] also showed that surface tension and heat transfer have a greater Nusselt number in stagnant ethylene glycol fluids using iron oxide nanoparticles compared to water-based fluids. Owing to the unique thermal properties of carbon nanotubes, they have been attached to metal-oxide nanoparticles by some researchers. In this regard, Baghbanzadeh et al. [26] investigated the effect of MWCNT-silica hybrid nanostructures on the thermal conductivity of distilled water. Munkhbayar et al. [27] reported a significant enhancement in the thermal conductivity of Ag-MWCNT/water hybrid nanofluid, and Chen et al. [28]. Moreover, Soltanimehr and Afrand [29] reported a thermal conductivity enhancement of COOH-functionalized MWCNTs/ethylene glycol–water nanofluid. Research on a new class of nanofluids, termed "ionanofluids," has also been reported. A review reveals that ionanofluids exhibit superior thermal properties compared to their base ionic liquids and these properties further increased by increasing the concentration of carbon nanotubes as well as the fluid temperature to some extent. Carbon nanotubes, based on both nanofluids and ionanofluids, show great potential as advanced heat transfer fluids in many important applications [30,31]. The influence of stress rate is during pre-shear, and the effect of resting time is before viscosity measurement. It has been revealed that CNT water-based nanofluid behaves like a viscoelastic media at low shear rate and it is shear-thinning at higher shear rates [32–35]. The problem of carbon nanotube-suspended magneto hydrodynamic stagnation point flow over a stretching sheet for variable thermal conductivity with thermal radiation was investigated by Akbar and Khan [36]. Their results showed that the velocity profile and boundary layer thickness increase with increases in nanoparticle volume fraction for SWCNT with Grashof number and nanoparticle volume fraction for MWCNT with Grashof number. Akbar and Khan [37] studied the magneto hydrodynamics squeezed flow of nanofluid over a sensor shell under the influence of temperature-dependent viscosity. The results obtained show that when we increase the Hartmann number, the viscosity parameter and the random constant decreases the temperature profile and the thermal boundary layer thickness, too, decreases. Increasing the permeable velocity parameter increases the temperature profile and the thermal boundary layer thickness also increases. Akbar and Khan [38] investigated the two-dimensional stagnation-point flow of carbon nanotubes toward a stretching sheet with water as the base fluid. This was done under the influence of temperature dependent viscosity and influence of the flow parameters on the dimensionless velocity, temperature, skin friction, and Nusselt numbers were explored and displayed in the form of graphs and interpreted physically. Akbar et al. [39] studied how single-wall carbon nanotube's nanofluids were transported with a temperature-dependent variable viscosity in a peristaltically-driven manner. It was observed that with an increase in the Grashof number, velocity of the governing fluids started to decrease significantly, and the pressure gradient was higher for pure water as compared to single-walled carbon nanotubes owing to their low