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Heat transfer enhancement and fuel consumption reduction in heaters of CGS gas stations

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ABSTRACT

In this study, the effect of turbulators (coiled wire tube insert) as a passive method for heat transfer enhancement on heater performance of Mokhtar city gate station of Yasuj city has been evaluated. To analyze the performance and the effect of geometrical parameters of turbulators and physical parameters of the flow, steady state and incompressible flow were simulated through ANSYS CFX 14.5. Shear stress transport (SST) turbulence model for modeling turbulated flow regime besides the wall has been used. Using simulation results, important performance parameters such as friction factor, Nusselt number, and thermal performance factor were calculated and deeply studied. In this study the effect of coiled wire tube insert as a turbulator on the performance of heater in two states of circular and elliptical tubes with similar cross sections has been surveyed. The result show that the spring tube insert with diameter ratio of 10 for the elliptical tube heater, and diameter ratio of 0.95, have the best performance.

1. Introduction

City gate stations (CGSs) placed at the entrances of cities, are the urban gateways of high-pressure gas from the refinery to reduce the current consumption. One of the most important parts of the station, which is preheating system for this purpose at the station are usually linear heaters. The basic problems of these heaters are high fuel consumption and low efficiency. On the other hand, Fuel consumption growth, increasing energy prices and lack of standards for energy consumption and environmental standards in various industrial sectors, threatens the present and future of the world. Thus, there must be significant modifications in the design of energy-consuming devices. Accordingly, improved thermal heaters performance and reduce their impact on the environment is a necessity. Pozivil [1] presented a comprehensive investigation on use of expansion turbines in natural gas pressure reduction stations. The model used in this study consisted of steady state calculations based on the isentropic efficiency of a turbo expander, a set flow rate, and set inlet and outlet gas conditions. The simulation was carried out for a variety of set inlet and outlet conditions and isentropic efficiencies. Outputs of the model included electric power and preheating requirements. Using these values, thermal efficiency values were found for each case. Rami et al. [2] described a study to determine optimal operating conditions for fuel conservation. They found that the dynamic behavior of pressure regulators could be modeled to accurately predict flow and pressure variations by comparing simulation data with actual measurements.

Farzaneh-Gord et al. [3] presented a study on feasibility of accompanying uncontrolled linear heater with solar system in natural gas pressure drop stations. The proposed solar system has been applied to a case study to investigate the thermal/economical behavior of the system. The results showed that as the number of collector increases, the fuel cost decreases but the capital cost

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Nomenclature

c_p	specific heat capacity, J/kg K
D_{eq}	hydraulic diameter of tube, m
f	friction factor
h	average heat transfer coefficient, W/m^2 K
k	thermal conductivity of fluid, W/m K
L	length of tube, m
Nu	Nusselt number (hD/k)
P	pressure, pa
ΔP	pressure drop, Pa
Pr	Prandtl number
Re	Reynolds number (ρuD/??)
u	mean flow velocity, m/s
T	temperature, K

Greek symbols

ρ	density of gas, kg/m^3
η	thermal performance factor
??	dynamic viscosity, Pa.s

Subscripts

a	augmented
0	smooth tube
eq	equal
eff	effective
r	augmented
t	turbulence

Superscript

-	average

increases as well. Aramesh et al. [4] introduced an approach to predict the transmission of natural gas (NG) in city gate stations (CGSs) by neural and fuzzy neural networks. The proposed approach constructs a model that is based on a primary station data and utilizes it to predict the NG transmission of a secondary station. The artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS) are optimized for minimum error. Results showed that ANFIS is more accurate than ANN and its mean absolute percentage error (MAPE) in primary station is 5.57%. This method is useful for prediction of transmitted NG in stations with insufficient data but similar consumption. Besides, it saves the cost of the construction of new prediction model for each station. Andrei et al. [5] presented a study on recovery of wasted mechanical energy from the reduction of natural gas pressure. They proposed the use of turbo-expanders in the pressure reducing stations, where the natural gas pressure from the transportation grid is high and needs to drop to lower levels to enter the distribution grids; in this way, parts of the energy consumed in the compression stations are recovered. Ashouri et al. [6] published a study for a computational procedure for the calculation of Joulee-Thomson coefficient of natural gas using fundamental thermodynamic equations and AGA-8 equation of state. Besides, the minimum possible temperature of the natural gas entering to the pressure regulator of city gate stations (CGS) is calculated. Results of their study help to determine the minimum temperature values of entering gas with different pressures to the regulator in order to avoid hydrate formation of the outlet gas, and can be exploited to design the appropriate temperature control systems for water bath heaters and in turn save consumed energy for gas heating. The results showed that heating up the gas to calculated minimum temperatures can save energy consumption of heaters by 43%. Also, it is indicated that in the CGS by applying a control system based on the result of this study, the payback period would be less than a year.

Methods of increasing the heat transfer and efficiency enhancement in the heat exchangers used in various industries have been considered for years. Heat transfer increasing strategies essentially reduce the thermal resistance of the heat exchangers and heat transfer coefficient is improved. Consequently, the heat exchanger size can be reduced and the economical results show up. In general, heat transfer augmentation methods in the heat exchangers are classified into three broad categories of active, passive or compound methods [7]. The main characteristic of passive methods, unlike the active methods, is that these methods do not require an external power supply to increase heat transfer. In these methods, by employing several techniques to generate the swirl in the bulk of the fluids and disturb the actual boundary layer so as to increase effective surface area and residence time increases heat transfer coefficient. Superficial reforms or geometric flow channels combine and incorporate materials or specific springs or add liquids and gases are used in these methods. Effectiveness and usefulness of each of these methods relies heavily on heat transfer, whether single-phase flow, free convection heat transfer or forced, forced convection boiling or condensation, type of heat exchanger and heat exchanger depends on the application process. A passive technique for enhancing the convective heat transfer by introducing swirl into the bulk flow and disrupting the boundary layer at the tube surface could be achieved using the tube inserts. Thus, by inducing turbulence and superimposed vortex motion (swirl flow) this induces a thinner boundary layer and consequently results in a better heat transfer coefficient and increases heat transfer [8]. For decades, the tube insert devices employed for augmentation of laminar or turbulent flow heat transfer have been reported and discussed. Promvonge and Eiamsa-ard [9,10] investigated the effect of conical-nozzle or V-nozzle together with the snail entry on heat transfer and friction characteristics in a uniform heat-flux tube; and reported that the heat transfer rate increases considerably for using both enhancement devices, but also substantial rise in pressure loss. Date and Gaitonde [11] developed the correlations for predicting the heat transfer coefficient and friction loss characteristics of laminar flow in a tube fitted with regularly spaced twisted-tape elements. Coiled wires are of practical interest, and therefore, their data are required to extend the use of this technique. Several investigations were carried out to determine the effect of the coiled wire on heat transfer and friction factor for a long time [12–16]. A comparison of the thermal and hydraulic performances between twisted tape inserts and coiled wire inserts was introduced by Wang and Sunden [17] for both laminar and turbulent flow regions. They found that the coiled wire performs effectively in enhancing heat transfer in a turbulent