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Artificial neural network prediction of exhaust emissions and flame temperature in LPG (liquefied petroleum gas) fueled low swirl burner

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ABSTRACT

This study deals with ANN (artificial neural network) modeling of a swirl burner. The model was used to predict the flame temperature and pollutant emissions (CO (carbon monoxide) and NO_x (nitrogen oxide)) from combustion of LPG (liquefied petroleum gas) in the swirl burner. The data for the training and testing of the proposed ANN was obtained by combusting LPG at various equivalent ratios (LPG/air ratios) and swirler's vane angles in a low swirl burner. Vane angles of 35–60° in steps of 5° and equivalent ratios of 0.94, 0.90, 0.85, 0.80, 0.75, 0.71, 0.66 and 0.61 were considered. An ANN model based on standard back-propagation algorithms for the swirl burner was developed using some of the experimental data for training and validation. The performance of the ANN was tested by comparing the predicted outputs with the experimental values that were not used in training the network. *R* values of 0.94 were obtained for CO and NO_x and 0.99 for flame temperature. These results show that very strong correlation exists between the ANN predicted values and the experimental results. Therefore, this study demonstrates that the performance and emissions of swirl burner can be accurately predicted using ANN approach.

1. Introduction

Preference for LPG (liquefied petroleum gas) in domestic and industrial heating appliances is predicated on its comparatively clean combustion product as it does not produce visible emissions [1]. However, it produces gaseous pollutants such as NO_x (nitrogen oxides) and CO (carbon monoxide) when its combustion devices are not efficient. The negative impact of these pollutants on the environment is of global concern [2], hence, various combustion and post combustion techniques [3] are being employed by combustion engineers to reduce these harmful emissions to acceptable levels [4].

Efficient combustion of LPG requires the use of appropriate equipment to produce turbulent mixing of atomized fuel and oxidant for achieving high efficiency in combustors [5]. This proper mixing of the constituents provided by high aerodynamic flow gives good combustion and produces lower pollutant emission. It also generates high temperature for total release of the fuels net calorific value [6]. Inefficient combustion leading to high emission of pollutants in the flue gas results where this turbulence and proper mixing could not be achieved due to design shortcomings. Hence, the injection of fuel and oxidant through swirler is used to impart turbulence on the charge with a view to achieving high combustion efficiency [7,8].

Knowing the performance of a burner for different range of operating conditions is usually desired by manufacturers and combustion engineers. This requirement is either met by conducting a comprehensive experimental study or by modeling the burner operation [9]. Testing the burner under all possible operating conditions and fuel cases is practically impossible as it is both time consuming and expensive. Also, developing an accurate model for the operation and combustion dynamics in a burner system is difficult due to the complex processes involved [10]. As an alternative, the performance and exhaust emissions of a swirl burner can be modeled using ANN (artificial neural network). This modeling technique can be applied to estimate desired output parameters when enough experimental data is provided.

ANN can be used to model physical phenomena with simple mathematical representations. Prediction of ANN is achieved from training on experimental data which can be validated by independent data sets [11]. Selection of an appropriate neural network topology is therefore very important in terms of model accuracy and model simplicity.

Various researchers have shown ANN as a powerful modeling tool for predicting complex relationships. The ANNs approach has

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been applied to predict the performance of various thermal and energy systems. Investigation of the performance of solar air collectors [12] and prediction of the bottom ash formed in a coal-fired power plant [13] were done using artificial neural network. ANN modeling was also applied in assessing [14] and in estimating the performance [15] of ground coupled heat pump systems used for cooling and heating purposes. Ref. [16] employed artificial neural networks for analyzing energy and predicting greenhouse basil production. ANN has also been found efficient in estimating the maximum power [17] and the annual energy produced [18] by a photovoltaic generator.

The performance and exhaust emissions in spark ignition engine using ethanol-gasoline blends were done by Ghobadian [19] using ANN prediction. It was concluded that ANN provided the best accuracy in modeling the performance and emission indices. Ref. [20] utilized ANNs to predict specific fuel consumption and exhaust temperature for a diesel engine. Likewise Ref. [21], used ANN to predict the performance and exhaust emissions of a gasoline engine. Ref. [22] also analyzed the effect of octane number on exhaust emissions from engine using artificial neural network. They all concluded engine performance, exhaust emissions and exhaust gas temperature can be predicted by ANN model quite well.

In this study, the use of ANN has been proposed to determine CO emission, NO_x emission and flame temperature obtained from the combustion of LPG at different fuel equivalence ratio and swirlers vane angles using results from experimental analysis.

2. Experimentation

2.1. Description of the experimental setup

The sectional view of the swirl burner experimental rig is shown in Fig. 1. The set-up consists of a swirl burner, air compressor, gas cylinder, fuel and air flow lines, rotameters, combustion exhaust chamber, temperature measuring devices, gas analyzer and digital camera. Omega rotameters calibrated in liter per minutes were used to independently measure the air and LPG flow rates into the swirl burner's pre-mix duct. The swirl burner was specifically designed to properly mix the gaseous fuel with the compressed air coming from a compressor (2.5 hp, 1500 W, 8 atm, 2800 rpm, POMA Air Compressor, ISO 9001:2000). The temperature distributions at the outlet of the swirl burner were measured using type K, mineral insulated grounded junction, 1.6 mm diameter thermocouple. The thermocouple which is capable of reading temperature of up to 1200 °C was connected to a digital read-out device. Gas sampling probe was inserted into the exhaust chamber and the composition of the exhaust gas was determined by using a gas analyzer (Eclipse EGA4 Combustion analyzer). The analyzer is capable of measuring oxides of nitrogen (NO_x) and carbon monoxides (CO).

2.2. Testing procedure

Tests on the swirl burner were carried out using six swirlers with different vane angles. Experiments were carried out using LPG which has composition of 75% butane and 25% propane as a fuel and air as a charge. Air and fuel were supplied into the pre-mixed duct of the swirl burner through the flow lines. Quantities of fuel and compressed air required to achieve desired equivalence ratios for combustion were measured using rotameters. Variations of the equivalence ratio were obtained by changing fuel flow rate while maintaining constant air flow rate. Each swirler was placed inside the swirl burner to impact a swirling flow onto the various air/fuel mixture for efficient combustion. Data on pollutant emissions and flame temperature were collected for vane angles from 35 to 60° in steps of 5° and equivalence ratios from 0.65 to 1.0 in steps of 0.5.

3. Experimental results

3.1. NO_x and CO emissions

Fig. 2 represents a variation of NO_x emissions from the combustion of LPG in the swirl burner with equivalence ratio at different vane angles. NO_x emissions lower than 5 ppm were obtained for the range of operating equivalence ratios ($0.61 \le ø \le 0.95$). The minimum NO_x emission of 0.33 ppm was obtained at swirler's vane angle of 55°. It represents a total NO_x reduction of 93.4% at equivalence ratio of 0.90.

Fig. 3 presents the profile of carbon monoxide emissions with equivalence ratio for all vane angles. CO emissions of less than 300 ppm were obtained for the range of operating equivalent ratios considered. Performance testing of vane swirlers revealed that CO emission level was drastically reduced to 45 ppm at equivalence ratio of 0.66 for swirler with vane angle of 55°. This value represents a reduction of 85% in total CO emission. However, at equivalence ratio of 0.90, CO emission was higher for swirler with vane angles of 35°, 45° and 50°, indicating inefficient combustion. This resulted from poor mixing of combustion reactants in comparison with vane angle of 55° and 60° at the same equivalence ratio. Reduction of 55.3% and 82.1% in carbon monoxide (CO) emissions

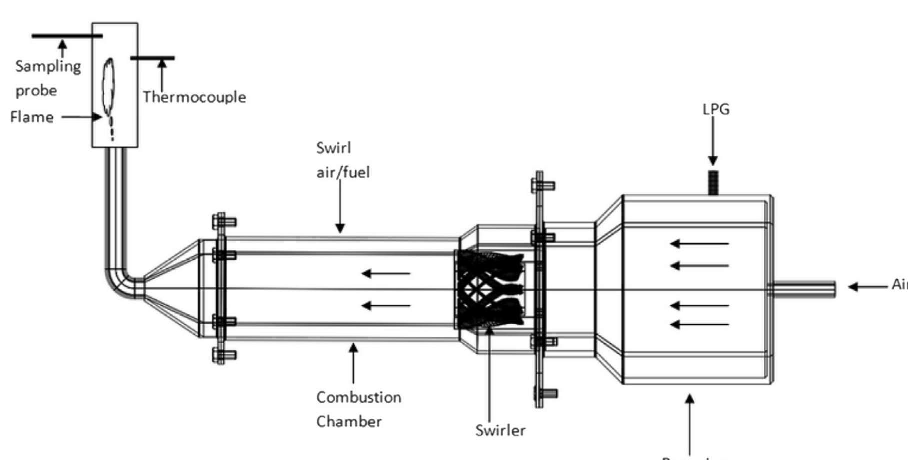

Fig. 1. Sectional view of the swirl burner experimental rig.