ABSTRACT

Biomass energy is the long-lasting available resource to be used for the alternative form of energy. At present, around 90 % of the energy consumption for the modernization of the countries is fulfilled by fossil fuels, and that is why we reached the edge of its availability. Excessive reliance on non-renewable sources of energy is affecting the climate change negatively. Therefore, we are facing a shortage of energy and to save the environment and clean energy resources for the coming generation, biomass energy can play a significant role.

In the present energy crisis scenario, focus of the scientists has been to produce the sustainable, renewable and continuous form of energy. In this quest, the response of energy production technique using gasification has produced positive results. The research discussed herein relates to the producer gas produced from the downdraft gasifier system and more specially to the contaminants present in the producer gas, which is cleaned by the filtration system. The gasification is the process in which solid fuel such as agricultural wastes, sawdust, wood wastes and the like, is converted into the gaseous fuel. Producer gas leaving from the downdraft gasifier system has lots of impurities and hence, it cannot be used directly. Therefore, it needs to be cleaned to be used as a fuel for heat and power application. Good quality of the producer gas increases the efficiency of the engine to be used as a fuel for driving.

Although there are lots of research work still going on producer gas filtration system, and researchers are mostly interested in finding a suitable catalyst which is a necessary part of the filtration system but very few are working on the design parameters of the filtration system that are as important as finding catalyst.

The objective of the present work is to perform experiments on gasification system, propose a new design of a filtration unit: an integral part of the downdraft gasifier system to improve the quality of producer gas. Also, to develop a experimentally validated *3D* numerical model for multi-stage filtration system to investigate the effect of various geometric parameters on system performance.

Different techniques are used for eliminating the impurities like tar, dust and ash particles etc. from the producer gas. Tar is one of the unwanted contaminants in the producer gas which needs to be cleaned. There are two principle methods exist for tar

removal. In the first method which is known as primary filtration method or in-situ filtration in which catalyst is mixed with the biomass feedstock inside the gasifier system for tar removal.

An experiment has been conducted followed by primary filtration method in which *10 wt. % CaO* is used as a catalyst with the biomass feedstock and checked the producer gas quality. It was found from the experiments that *0.0742 gm/min* or 48.18% at 850^{o}C tar got reduced while using *CaO* with wood feedstock. Similarly, *0.009 gm/min* or 7.2% at 790^{o}C tar got reduced when *CaO* mixed with a coconut shell.

The reduction of the tar from the producer gas increases the quality of the producer gas, which reflected in the diesel fuel consumption when used together. To check the producer gas quality, another experiment has been conducted for measuring the diesel fuel consumption at different load conditions when only diesel and diesel together with producer gas (producer gas is obtained by biomass feedstock wood and coconut shell to be used alone and together with catalyst *10 wt. % CaO*) is used for running dual-fuelled diesel engine.

It was found from the experiments that for *20 ml* of diesel fuel consumption, the dual-fuelled diesel engine takes *41* seconds for *1 kW* load when run by only diesel fuel. As a comparison for the same amount of fuel consumption and load condition, dual-fuelled diesel engine takes *71* seconds when it is run by diesel together with producer gas (producer gas obtained from wood biomass feedstock). On the other side, the dual-fuelled diesel engine takes *75* seconds for consuming *20 ml* of diesel fuel at *1 kW* load condition when driven by diesel with producer gas and producer gas is obtained by biomass feedstock wood is mixed with *10 wt. % CaO*. Similarly, for biomass feedstock, coconut shell and coconut shell mixed with *10 wt. % CaO*, the diesel fuel consumption time is *77* seconds and *79* seconds respectively for *20 ml* of diesel fuel consumption and *1 kW* load condition when producer gas is obtained from these feedstocks and used together with diesel fuel.

The fuel consumption time increases for the same amount of fuel consumed, clearly shows the enhancement of producer gas quality due to tar elimination from the producer gas by mixing the catalyst *CaO* with the biomass feedstock.

Impurities like dust and ash particles also contribute as a major impurity in the producer gas and responsible for the deterioration of the producer gas quality. Different techniques are available in the markets for cleaning the dust and ash particles in the producer gas. Cyclone separators are largely used due to economical aspect, filtration

efficiency as well as easy to operate. Presence of dust and ash particles creates sever problems in the engines as a result engine efficiency decreases or in other words, the fuel consumption increases. Therefore, experiments have been conducted to evaluate the performance of the cyclone separator and compared with the empirical approach of Leith and Licht model for its validation. Wood and coconut shell with and without *10 wt. % CaO* is used as a biomass feedstock for the study to obtain the producer gas through downdraft gasifier system.

It was found from the experiments that using feedstock with *10 %* calcium oxide (*CaO*) by weight, the efficiency of cyclone got reduced from *71.87%* to *70.75%* for wood feedstock, whereas in case of coconut shell, the cyclone efficiency got reduced from *78%* to *73.44%*. Decrease in the cyclone efficiency is due to the reduction of the inlet loading of the heavy particles in the producer gas.

Although the producer gas quality is not always the same, it fluctuates according to the impurities present in it. Therefore, the quality of the producer gas affects diesel fuel consumption when it is used together with diesel fuel. To compensate the diesel fuel consumption, blending of the biodiesel with the conventional diesel is the best option. The blending of biodiesel with conventional/or traditional diesel always maintained the fixed fuel consumption rate, whether the quality of the producer gas is deteriorated or not with the diesel fuel. Therefore, the quality of the biodiesel fuel has to be checked before it is used together with the mixture of conventional diesel and producer gas for heat and power production application.

Experiments have been performed with soybean methyl ester (biodiesel) in-home prepared by transesterification process and stored in a polyethylene tank for *14* days for calculating the effect of calorific values and viscosity of the fuel. In addition, the biodiesel fuel is blended with different proportion; *B10, B20* and *B30 v/v* to know the effect on emissions.

It was found from the experiments that the storage time affects the kinematic viscosity of the fuel. This is due to the formation of different oxidized products, including hydroperoxides and aldehydes, ketones etc. As the fuel viscosity increases, it is difficult to make a fine spray particle by the fuel injector in the diesel engine and therefore, all the fuel is not burned inside the combustion chamber at once. On the other view, more fuel accumulates in the combustion chamber, and when all fuel burned together, it creates huge pressure which caused damage to the engine.

It was observed from our various experimental studies that the technique used in the first phase of filtration of producer gas did well, but even then, the quality of the producer gas fluctuated and for that reason, the requirement of a secondary filtration system is mandatory for the efficient cleaning of producer gas.

In the secondary filtration system, most of the previous investigations on flow control devices have been reported on a single-stage perforated plate with variable porosity and circular holes. This is the reason that functional relationships for pressure loss coefficient or Euler number *(Eu)* variation reported earlier are a strong function of porosity. In this thesis, multi-stage filter design with constant porosity has been investigated using an experimentally validated numerical model. Several researchers have worked on the design of the producer gas cleaning system by using different filter materials such as electrostatic precipitators, wet scrubber, ceramics, fabric, and sand bed separately. However, these methods are inefficient in the final stages of the gas purification. Hence, multi-stage filters designs are conceived and investigated. Effect on pressure loss coefficient variation has been investigated for different hole geometry having the same porosity with multiple filters. In a first, four new correlations have been developed for *Eu* variation as a function of the number of filters and different hole shapes. The *Eu* variation has the form: $Eu = a(N)^b(t/d_h)^c$ where *N* is the number of filters, *a, b* and *c* are constants whose value depend on the type of hole geometry. The prediction from correlation agrees within *4%* accuracy with the numerical data.

An inhouse experimental setup was developed to study the effect of various multi-stage filter designs. Computational model of the multi-stage filter system was developed keeping the porosity of the system constant. It can be observed that pressure drop shows is strongly dependent on number of holes than with the thickness ratio. New correlations were developed for various perforation shapes. The predicted data from the correlation agrees well with the numerical data.