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Performance analysis of an internal combustion engine operated on producer gas, in comparison with the performance of the natural gas and diesel engines

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ABSTRACT

The growing economy and changing lifestyle have increased the demand for modern energy, like electricity. Globally 1.3 billion people are without access to electricity. In India, 289 million people do not have access to electricity. Decentralized distributed power generation using renewable energy is a competitive alternative for energy supply to all, with a sustainable growth. The performance of an internal combustion engine fueled with 100% producer gas was studied at variable load conditions. The engine was coupled with a 75 kW_e power generator. Producer gas generated from a downdraft gasifier system was supplied to the engine. The overall power generation efficiency of 21% was achieved above 85% load. The power generation efficiency of the producer gas engine was estimated at variable load conditions. The influencing factors of the power generation efficiency of a producer gas engine, such as volumetric efficiency, energy density of the fuel mixture, adiabatic flame temperature, compression ratio and expansion ratio were studied in detail. A relation between volumetric efficiency, expansion ratio, compression ratio and thermal efficiency was established and verified. The efficiency of the engine estimated using the new method has a correlation coefficient of 0.99 with the efficiency estimated using the energy input and output.

1. Introduction

Globally 1.3 billion people do not have access to electricity, 84% of these people live in rural areas. In India about 289 million of people who account for 25% of the population do not have access to electricity [1]. Biomass fuels are still contributing to 14% of the world energy demand and 38% of the developing countries [2]. In the past six decades India's energy need has increased by 16 times and the installed electricity generation capacity by 84 times [3]. With the economy projected to grow at 8%–9% per annum and the improving standards of millions of population, the energy demand is likely to grow significantly. Biomass is a potential renewable source for power generation [4]. Deployment of biomass gasification technology can meet the triple bottom line for growth of – local energy, local employment and local economy [5]. Biomass gasification is one of the potential options for DDG (decentralized and distributed generation) of electricity [6]. Electricity generation through biomass combustion and gasification was considered as a potential source to meet the rural energy needs [7]. India is having a biomass power potential of 16,000 MW from agro residues and 45,000 MW from plantations [8].

In India, a national program (Phase I) was launched during 1987–1993 for technology development and demonstration of biomass gasifier systems. This program focused on promotion of irrigation pumps in the range of 3–10 hp and decentralized power generation in the range of 3–100 kW_e [9,10]. Dual fuel engines were used during this program. A national program of Phase II was implemented during mid and end of 90's. During the second phase, the gasifier system was used in the range of 10–100 kW_e power generation system for rural electrifications. Based on the experience of this program, the need for compatibility of the engine in terms of ease of operation and economic viability was emphasized in Ref. [9]. DPS (distributed power system) is proposed as one of the options for economic, environmental and energy security [11]. During 2005, a VESP (village energy security program) was launched by the MNRE (Ministry of New and Renewable Energy), India. This program aimed at providing the total energy required by the remote villages. Only 45 biomass gasifier based power plants were installed out of 95 plants sanctioned for the program [12]. Only 34 plants out of the 45 plants installed were functional due to various reasons. The status of gasification technology for operating

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an internal combustion engine cannot be ignored. There is a need to understand the performance of the ICE (internal combustion engines), when running on producer gas and identifying ways to remove any barriers to their performance. Generally, internal combustion engines are fueled with producer gas either on dual fuel mode (along with diesel) or on 100% producer gas.

1.1. Internal combustion engines operated using producer gas on dual fuel mode

The history of gasification development starting from 1699 to 1970 as reported in Ref. [13]. It also reports that the first patent regarding gasification was obtained by Robert Gardner during 1788. The target and benchmarks for gasification were reported in 1906 [14]. Biomass gasification technology has been in existence for more than 80 years since world war two [15–17]. The first attempt to use producer gas to operate an internal combustion engine was carried out in 1881 [18,19]. The first well reported conversation about using a producer gas engine for operating tractors was during 1931–1934 [20]. Initially, diesel engines were operated along with producer gas in dual fuel mode. In dual fuel operation, 60–65% of diesel replacement was obtained while using an engine with a capacity of 5.25 kW [3,21].

A dual fuel engine was operated with a power generation efficiency of 19%, with a diesel replacement of 59% [22]. A maximum efficiency of shaft power was obtained at 21% in dual fuel operated engine [23]. The specific fuel consumption to generate one kWh of electricity was reported as 1.28 kg of fuel wood and 65 mL of diesel [24]. Presently most of the engines are working at a very low efficiency. Particularly the producer gas engines are working with an overall efficiency in the range of 20–22%. Efficiency closer to 20% is achieved only at the maximum operating capacity of the engine. At part load operating conditions, the efficiency of the engine is much lower. It is essential to operate the biomass gasifier based power generation system at higher efficiency to reduce fuel consumption and substitute the use of fossil fuel. Energy efficiency issues are discussed in the context of technology and trends in energy use [25]. While encouraging technology driven economic growth there should be a focus for reduction of GHG (green-house gas) emission [26]. Improvement in performance efficiency of engines by reducing fuel consumption helps to reduce GHG emissions substantially and achieve sustainable growth. The present study involves a detailed performance analysis of a biomass gasifier coupled with a producer gas engine for improving the overall efficiency of the system. Electrical output from the engine and energy flow through flue gas and radiator cooling fluid was monitored at variable load conditions.

Internal combustion engine operated using producer gas was studied during 1896 using different types of engines [14]. This report also highlights a serious limitation to the gasifiers for production of good quality gas in those days. This report mentions about 11 types of difficulties related to gas quality and technology status which act as a barrier for promotion of producer gas engines. Most of the difficulties mentioned in this report remain unsolved even with today's status of technology.

1.2. Internal combustion engines to run on 100% producer gas

Initially, diesel engines were run along with producer gas on dual fuel mode to avoid complications involved in modifying an engine to run on 100% producer gas. Due to increase in cost of diesel and its scarcity in rural areas it was preferred to run engines on 100% producer gas. The increasing cost of diesel price makes it too expensive to generate power on dual fuel mode [27]. A diesel engine needs more modifications to run with 100% producer gas. The engine modifications needed are introduction of a spark ignition system, a gas carburetor (fuel intake manifold) for supplying the required fuel mixture and a governor to control the throttle valve for controlling the fuel flow according to the operating load and hence, maintain engine speed. The engine manufacturers are not in favor of engines operating with 100% producer gas due to the impurities in the gas. Now engine manufacturers like Cummins are manufacturing heavy duty IC engines having 12 cylinders which can run on 100% producer gas [28].

1.3. Impurities in producer gas

The real difficulty is not generating combustible gas from a gasifier but obtaining a good quality gas which can be used to economically operate IC engines for a longer duration [20]. Tar formation remains a technical hurdle for the development of biomass gasification [29]. The key issue for successful application of producer gas engines is the removal of tar and further development of the system for obtaining cleaner gas [30]. The problems related to tar and particulate matters in the producer gas were discussed in context with power generation in Ref. [31]. Gas purification by removing contaminants like tar and particulate matters and problems associated with catalyst based gas purification were discussed by Ref. [32]. This paper also highlights the need for an advanced gasification system to produce cleaner gas.

Currently many institutions are involved in technology development to improve the gas quality and make the system user friendly [33,34]. The tar content in the producer gas was reduced to 19–34 mg Nm^{-3} by using a charcoal coupled two stage wood gasifier [35]. The producer gas generated from a downdraft gasifier has less tar content and is suitable for running IC engines [36]. To have an economical long term operation of an engine it is important to reduce harmful contaminants in the gas such as hard solid particles and corrosive compounds [37]. This paper also reports about the effect of particles present in producer gas on the performance of the engine. Particles larger than 1 ± 2 μm can bridge the protective oil film between the moving parts and cause abrasive wear. Smaller particles may contaminate and thicken the lube oil which can cause wear in the moving parts of the engines. Hence, the particulate matters in the producer gas and its size should be within the allowable range to ensure longer durability of the engine.

2. Methodology

Performance of a producer gas engine coupled with a power generator having a design capacity of 75 kW_e was studied and analyzed. The objective of this study was to analyze the performance of an internal combustion engine operated using 100% producer gas. The present study focuses on analyzing the property of producer gas and its influence on the performance of producer gas engines. The quality of producer gas depends upon the type of the gasification reactor used in the system. A downdraft type gasification reactor was designed to operate the producer gas engine. The experimental study and analysis were carried out by monitoring the performance of the gasifier system and the producer gas engine. An engine designed to run on natural gas was used to operate on 100% producer gas. The components of the gasifier system, analysis of the producer gas and performance of the producer gas engine are discussed in this paper. A diagram depicting the components of the biomass based power generation system with the producer gas engine is shown in Fig. 1. From Fig. 1 it may be noted that a biomass gasifier power plant consists of a biomass gasifier, gas cleaning train, manifold for supply of appropriate air–gas fuel mixture and a producer gas engine.