Forest residues valorisation for energy purposes through a small-scale CHP system

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Keywords: forest residues, gasification, CHP, small-scale.
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The use of wood chips and wood pellets are common choices for feedstock in biomass gasification. The gas obtained, commonly known as producer gas, can be used to operate internal combustion (IC) engines that generate power. IC engines are widely used in de-centralized energy production (Kaupp, 2013). However, the use of fossil fuels, such as gasoline or diesel, makes operation of such engines harmful for the environment. One solution for this problem could be to use carbon-neutral fuels, such as producer gas obtained from biomass gasification. Besides its environment-friendly nature, its suitability in high compression ratios of IC engine cylinders make it a viable alternative (Sahoo *et al*, 2009). With relatively simple modifications, diesel engines can be adapted to operate on gaseous fuels thus making them of dual-fuel type. However, due to low-energy densities of producer gas a full-substitution of diesel is not feasible and therefore dual-fuel operation becomes necessary.

This study evaluates the performance of a dual-fuel CHP (combined heat and power) system operated on diesel and producer gas. The primary interest is that of the feedstock used for gasification. Forest residues (FR) and wood chips (WC) are collected from the local region (South Tyrol, Italy) and used as feedstock in a pilot-scale gasifier. Forest residues (Figure 1) are those branches, twigs, pinecones, and leaves that are deposited on the forest floor due to forest management activities and meteorological events such as storms, rain, etc. The use of these feedstocks is challenging due to its physical and chemical characteristics, which differ from that of standard woodchips (Borooah *et al*, 2021). However, the main advantage lies in the fact that they come at little to no costs. Hence, the aim of this study is to explore the possibility of exploiting forest residues as a low-cost, renewable feedstock to generate heat and power via gasification coupled with a CHP system.

Figure 1. Forest Residues.

The feedstocks (WC and FR) are first prepared by chipping and sieving the collected material into batches of different particle sizes. These fractions are tested for their physical and chemical characteristics and suitable mixtures are prepared to be fed into the gasifier (Borooah *et al*, 2021). Four different mixture ratios are studied in this work, with the FR fraction varying from 0% to 75%, and the remaining portion being WC. The prepared feedstock mixture is fed from the open top of the pilot-scale, fixed-bed, downdraft gasifier, which is operated at the optimum operating parameters controlled by the flow of secondary air into the combustion chamber, i.e., by controlling the equivalence ratio (Antolini *et al*, 2020).

The gasifier setup **(**Figure 2) is equipped with a gas cleaning system, comprising of one cyclone, three scrubbers, and a fabric filter, through which the producer gas passes before it is fed to the IC engine. A micro-GC is used to measure the producer gas composition. K-type thermocouples and U-tube manometers are installed at various points in the gas flow line to measure the temperatures and pressures respectively at those locations.

The producer gas is provided to the engine through a modified mixing chamber which is attached to the air intake manifold. This chamber also draws air from the ambient which, due to turbulence, is premixed with the producer gas before entering the combustion chamber. Diesel, on the other hand, is directly injected into the cylinder. The engine is coupled with an alternator which provides the electrical power up to a maximum load of 3 kW. Incandescent light bulbs of various ratings were used to provide the desired load. A cooling water circuit is used to recover the waste heat from the engine. Appropriate instrumentation, such as mass flow controllers, flow regulating valves, thermocouples, and load cells are provided to measure the various parameters and control the mass of water, gas, and fuel supplied to the engine. A particulate matter (PM) analyzer and a flue gas analyzer are used to measure the PM and the composition of the exhaust gases, respectively. The various mass flows, temperatures, and power data are recorded on the computer using a LabVIEW interface.

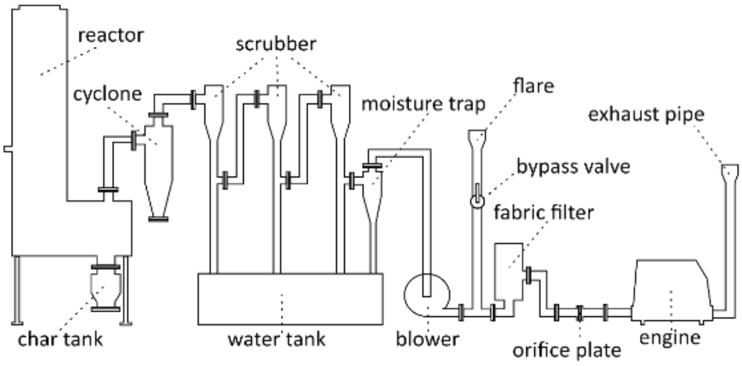

Figure 2. Scheme of the open-top pilot gasifier connected with a CHP system.

Forest residues are usually unexploited biomass since they are commonly left on the forest floor after maintenance activities. These materials can be effectively used as additional energy resource and exploiting them also can avoid safety problems in the forest, such as the spreading of tree diseases, pests, and forest fires. The valorization of these residues in gasification and CHP technologies for energy generation can thus be used to provide an economic advantage of operating the plant, as well as a strategy to increase the local clean energy production. Moreover, these residues can also be considered as an additional source of feedstock or a buffer material to be used in the gasifier in the seasons in which the maintenance activities are not performed (i.e., during summer and winter). Thus, the feedstock studied in this work can provide the possibility to feed the gasifier constantly throughout the year regardless of the seasonal changes. In fact, running a gasification plant throughout the whole year will definitely increase the economic feasibility.

The producer gas obtained by the gasifier was fed to the engine operated at two different loads: 2 kW and 3 kW. At each load three different diesel substitution rates, in liters per minute (LPM), were tested: 54, 70, and 82, corresponding to differential pressure in the orifice meter of 3 mbar, 5 mbar, and 7 mbar respectively. The heat recovered generally increases with the increase in the load. Not much difference was observed between the different feedstock mixtures and wood chips alone. The values of heat recovered was roughly in the range of 31-43 J/kg of cooling water. A decrease in the NO_x concentrations in the exhaust was also observed when diesel substitution rates (DSR) was increased, while an in increase was recorded for CO and CO_2. For WC-FR mixtures, the total counts of particulate matter in the engine exhaust also decreased with an increase in the DSR.

The preliminary results are encouraging in the fact that the producer gas obtained from gasification of biomass was successfully used to operate the dual-fuel engine with DSR up to 50%. However, due to design limitations higher DSR could not be tested. A study, by Caligiuri *et al* (2021), using standard wood chips on the same set up reported knocking of the engine above 50% DSR.

Acknowledgments

This work has been supported by the project "BIO-CHEAPER: BIOmasses Circular Holistic Economy APproach to EneRgy equipments" funded by the Ministero Italiano dell'Università e della Ricerca (MIUR) in the framework of Progetti di Ricerca di Rilevante Interesse Nazionale (PRIN) Bando 2017, nr. 20175TXJER.

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