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Gasification of Woodchips from the San Rossore natural Reserve Maintenance for CHP Application: a Case Study Analysis

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This work aims at analyzing a complete biomass gasification chain for CHP purposes. The biomass production step is related to an existing scenario, the woodchips produced from the maintenance of the S.Rossore natural reserve. Two different gas cleaning systems are taken into account, a wet gas clean-up and a hot gas clean-up (based on a dolomite bed with air injection for tar cracking). Performance indicators are calculated according to an inventory of the energy and mass fluxes. The results show that the most significant energy loss of the wet gas clean-up is due to syngas cooling, while for the hot tar clean-up part of the syngas sensible heat is recovered, however this is a benefit only if a suitable heat demand is available in the plant. Since part of the syngas chemical energy is lost in the dolomite bed in the hot clean-up, the overall energy efficiency of this chain is lower compared to the wet gas clean-up. The main advantage of the hot clean-up is the reduction of the wastewater.

1. Introduction

Biomass gasification is an option to exploit residual biomass and promote the decentralized production of combined heat and power (CHP). However, despite the simplicity of the gasification reaction, the installation and management of a gasification process require an accurate planning, involving economic, environmental, safety and process management issues. These issues are routinely addressed in an industrial context, but they may become critical when small plants in non industrial contexts are considered. Therefore case studies and technical assessment are required in order to provide information to support the development of this technology. This work is a case study analysis referred to the use of residual biomass deriving from the maintenance of the S.Rossore natural reserve as a fuel supply for a gasification installation. It aims at analyzing a complete biomass gasification chain for CHP purposes. Fuel, electricity, materials and utilities consumption and wastewater production are determined for each step of the chain. Finally global indicators are developed to evaluate the technical and environmental performances of the chain.

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2. Scenario Description

The S.Rossore natural reserve is located on the west border of the city of Pisa. It covers 4800 hectares; about 3000 hectares are destined to forest. The annual maintenance of the forest produces nearly 10.000 ton of wood delivered to several customers. This study considers the use of nearly 2000 ton of wood per year (the production derived from 600 hectares) as a fuel source for a 1 MWth gasification installation. The harvested trees are forwarded outside of the forest and chipped. The woodchips are then delivered to the plant. The gasification plant is designed to operate 7500 hours per year, however the tree cutting is performed from October to March (almost 22 weeks) to allow animals reproduction and fire prevention during spring and summer; thus there is need for woodchips storage. The raw syngas exiting the gasifier must be cleaned to allow its combustion in an IC-engine. Two clean up systems (see Figure 1) are taken into account. A wet clean-up, based on the work of Sharan et al. (1997) and a hot clean-up derived from an internal design. This system includes a dolomite bed with air injection for tar cracking (based on the design of Van de Beld et al. , 1996). Finally the syngas is burned in a CHP engine providing heat and electricity, the hot flue gases are used for woodchips drying.

2.1 Biomass supply

The wood harvesting is based on three phases: tree cutting by means of feller-bunchers, removal of branches and leaves operated with electric saws and finally wood forwarding to the chipping site. The wood is chipped shortly after the cutting. According to the data provided from the maintenance company, the average moisture content of the wood from October to March is 45%. It is possible to assume a global consumption of 5 liters of diesel per ton of woodchips with a moisture content of 45%, a similar value related to the supply chain “road-side chipping” is reported from Wihersaari (2005a). It is assumed that the mean distance from the plant to the chipping site is 15 km, with a 25 ton load truck, the total distance covered during the year is 3512 km. The diesel consumption is taken as 0.249 Liters per Ton of wood. The total energy demand of harvesting, chipping and transportation is equal to 2.76% of the energy of the woodchips; this value is comparable to the range reported by Wihersaari (2005a).

2.2 Biomass conditioning and storage

The wood chips delivered to the plant are a suitable fuel for the gasifier, however they have to be conditioned in terms of size and moisture content (<20%) to meet the gasifier specifications. The screening process allows reducing the size distribution of the woodchips to the desired range. This operation causes an energy loss since the material out of specifications is rejected. The woodchips need to be stored for a certain time since the woodchips are harvested in 22 weeks while the gasifier operates throughout the year (7500 h). During the year the woodchips are accumulated in a pile. It is assumed that during storage the woodchips pile is covered with a plastic cloth. The storage period modifies the woodchips properties due to fermentation reactions producing two effects:

1) the temperature of woodchips pile increases thus reducing the woodchips moisture content, the moisture of the pile is assumed to decrease linearly over the storage period from 45% to 27%, leading to a mean value of woodchips moisture content from the storage equal to 35%.
2) there is a loss of organic matter which reduces the energetic content of the wood chips, considered as 1% per storage month (Wihersaari, 2005b).

Prior to gasification the moisture content the wood has to be reduced from 35% to 15% in a dryer. To this purpose a band dryer is selected. The drying medium is air mixed with the hot flue gases from the engine to obtain a gas temperature of 75°C.

2.3 Biomass gasification

The downdraft gasifier performance is evaluated according to the performance of the Lettner et al. (2007). The gasifier thermal input is 954 kWth .The tar and particulate matter loads, which are basic input data for the clean-up system, are selected according to Hasler and Nussbaumer (1999).

2.4 Syngas Clean-Up and Wastewater management

The aim of the two clean-up systems is to make the gas produced from the gasifier suitable for combustion in an IC-engine. The flow-sheet (see Figure 1) and performance of the wet gas clean-up line are based on the publications of Sharan et al. (1997) and Hasler and Nussbaumer (1999). The clean-up line includes a cyclone for particulate matter removal, two wash towers devoted to cool the gas as well as remove tar and particulate matter and two sand filters (coarse and fine). The gas is cooled nearly to environment temperature so the sensible heat associate to the gas is lost. The system is simple and requires few inputs (water for quenching, periodic sand refreshment, electric power). This system can ensure the required removal of particulate matter but cannot safely meet the tar concentration recommended from the engine manufacturer (Sharan et al. (1997)) causing short engine lifetime, frequent maintenance and high engine emissions. The wastewater is highly polluted with suspended solid and tar. The suspended solids can be removed in a wastewater plant with conventional operations (settling, flotation, and filtration). Part of the tar behaves as oil so can be removed by flotation, the addition of active carbon is meant to reduce the presence of organic compounds which are not readily biodegradable (Sharan et al., 1997). Figure 1 reports the flow-sheet of the hot gas clean-up, the data related to this clean-up are based on our design . The gas from the gasifier enters a cyclone for particulate matter removal, and subsequently a “reverse flow” dolomite bed. This technology was developed by Van de Beld et al. (1996) and it is based on a periodical inversion of the gas flux in the bed to allow the recovery of the heat of reaction. The dolomite bed is fed with air which burns a certain amount of gas to increase the temperature to 1000°C and promote tar cracking reactions, thus reducing the gas LHV. The amount of gas to be burned is calculated assuming that the gas must be heated up from 850°C to 1000°C, with a gas outlet temperature of 760°C. The tar removal efficiency is taken from Van de Beld et al. (1996).

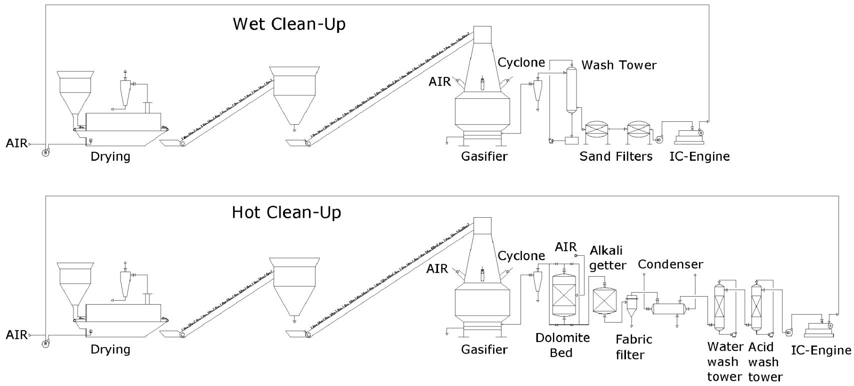

Figure 1 – Flow-sheets of the two gasification plants.

The hot clean-up is composed as follows: alkali getter (Turn et al., 2001), ceramic filter, thermal recovery in a heat exchanger-condenser, batch water wash tower, batch wash tower with sulphuric acid solution. The hot clean-up line is likely to upgrade the gas to the engine specifications. The hot clean-up line needs water for alkali getter regeneration and the wash towers and allows recovering some of sensible heat of the gas from the gasifier. This heat source can be used to heat up air to dry an additional quantity of woodchips, thus saving methane or other fuel. Water from alkali getter regeneration, heat exchanger condensate and wash towers is delivered directly to a biological treatment. No pre-treatment is required since the tar is removed in the catalytic bed.

2.5 Syngas Utilization

The gas from the clean-up section is destined to combustion in a CHP engine for the production of electric power and heat as water at 90°C. The heat associated with the hot flue gases is used to dry the woodchips entering the plant by mixing them with air to reach 75°C and the desired water vapour concentration. The engine performance was evaluated by comparing scientific articles and data-sheet about the use of gas from gasification in IC-Engine (Baratieri et al. 2009, Sridhar et al. , 2001).

3. Performance Indicators and Discussion

The two gasification chains are based on different gas clean-up systems, which influence the energetic output of the gasification plant and the global performance of the gasification chain. The hot gas clean-up is more complex than the wet gas clean-up and it is likely to be more expensive from an economic point of view (especially in relation to the plant size). Vice-versa the hot clean-up maintenance operations seem to be safer than the wet clean-up where personal protection devices are needed. Figure 2 shows the Sankey diagrams of the two chains. Table 1 reports some performance indicators adopted in the analysis. Prior to gasification two energy losses occur due to

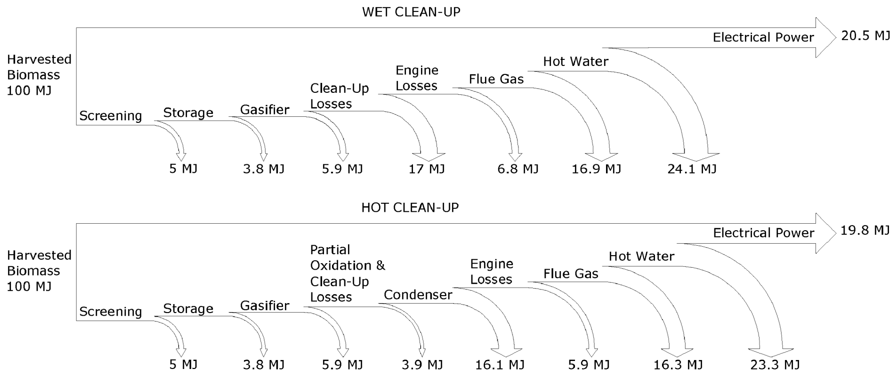

Figure 2: Sankey diagrams of the two gasification chains.

the rejection of out of size chips, and the organic matter losses due to fermentation during the storage period. These losses are 5% and 3.8% of the original energy associated to the harvested biomass. Gasification itself causes an additional energy loss (5.9%) due to thermal dispersion and unconverted organic material. In the case of wet clean-up the cooling of syngas is the main energy loss (17%). In the case of hot clean-up the energy loss (3.9%) is due to partial oxidation of the syngas in the dolomite bed to reach the temperature required for tar cracking, however the syngas must be cooled to nearly 40°C in order to be used in a IC-Engine, so the sensible heat of the gas is transferred to an air stream. This heat stream (16.1% of the initial energy) doubles the available heat for drying per MJel produced, compared to the wet clean-up (see Table 1). However when a CHP system is installed there is plenty of heat in the plant and finding a suitable destination for this stream may not be feasible. So the availability of a heat demand is a key issue in determining the performance of this clean-up system. It is worthy to note that the performance of the two systems depends also on the tar output from the gasifier. The wet clean-up causes the loss of all the chemical energy associated to tar, so the higher the tar content the higher the energy loss due to syngas cleaning. The hot clean-up converts tar into combustible species so this system allows saving the chemical energy retained in the tar. In this work typical medium-high tar content in the raw syngas was considered (2500 mg/Nm3). In this condition the hot gas clean-up leads to lower efficiency in terms of electrical energy production (19.8% VS 20.5%, or in other terms 9304 VS 9634 MJel per ha of forest). As consequence the electrical and fuel demands of the chain have a higher impact related to main output, as reported in Table 1. The main fuel demand is due to biomass production and transportation to the plant (nearly 2.8% of the initial energy content of the biomass). A second demand is the wastes transportation (in particular wastewaters) which becomes significant when the destination approaches 50 km. The main electrical demands in the gasification plant are due to gas blowers and solid handling equipments. Wastewater is most significant residue from this plant; the hot clean-up allows reducing the amount of wastewater from the plant (8e-5 VS 9e-5 Ton wastewater per MJel produced). However since the more than half of the water generated from the clean-up line derives from condensation of water vapor contained in the syngas, the hot syngas clean-up plant must deal with a considerable amount of wastewater. The real benefit of the hot clean-up is that the expected pollution level is lower than that of wet clean-up, so there is no need for a pre-treatment of the raw wastewater (for instance active carbon and flotation) needed to allow the biological treatment. In addition a higher engine life-time can be expected.

Table 1: Performance Indicators

Index	Electrical power yield	Heat yield	Wastewater production	Electrical demand	Fuel demand	Thermal recovery
Unit	%[Jel/Jw]	%[Jth/Jw]	[g/Jel]	%[Jel/Jel]	%[Jth/Jel]	%[Jth/Jel]
Hot	19.8%	23.3%	8e-5	19.1%	9.8%	42%
Wet	20.5%	24.1%	9e-5	17.1%	9.5%	21%

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