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Steam gasification pilot plant: syngas suitability for SOFC fuel cell

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Abstract

The technologies for the use of biomass as an energy source are not always environmental friendly process: wood combustion, for example, can be a rather a dirty process that causes the release in air of several dangerous compounds. For those reasons it is important to develop approaches aimed at the use of biomass in a cleanest way, avoiding, whenever possible, direct combustion of solid biomass and, rather, pursuing fuel upgrade processes allowing a better combustion or direct conversion to electricity through fuel cells.

The products originating from the gasification process mainly comprise a mixture of the permanent gases CO, CO2, H2 and CH4, steam, char, tars and ash. The raw synthesis gas needs to be cleaned from tars before it may be upgraded to other commodities. In most cases if tars deposit on the catalyst surface it will block the active sites i.e., carbon acts as catalyst poison. Furthermore, tars in the raw gas can also cause corrosion and blockage of pipes in downstream process equipment. One of the main challenges in biomass gasification is the minimization of tar content in the product gas in combination with optimization of the gas composition. That is, to reduce the tar content as much as possible and to increase the permanent gases.
In this context, it is especially interesting the development of technologies for syngas production (i.e. synthesis gas) through biomass gasification and for syngas utilization in fuel cells system, in order to produce energy from renewable resources. In detail the SOFCs (Solid Oxide Fuel Cell) work at high temperatures, and can be fed with different type of fuels, such as methane, carbon monoxide and hydrogen. Thus, the syngas produced by means of biomass gasification, seems to be a suitable fuel for this kind of cells. This chance is particularly interesting, considering that small and medium size conversion plant technologies could be integrated in a distributed energy generation model that is expected to increase its diffusion.
The aim of the present project is to verify the possibility of coupling a biomass gasifier with a SOFC for energy production. The use of steam as gasifying agent increases the syngas heating value in comparison with the use of air, since its nitrogen content cause a dilution of the obtained gaseous fuel. Moreover, another beneficial effect in using water steam, is the increase of the H2 percentage up to 50 % in volume. A high hydrogen concentration is kindly recommended if the final aim is to feed a fuel cell. However, the disadvantages of the steam gasification are the lower steam reactivity, comparing with the oxygen one, and the decreasing of the temperature inside the

reactor due to the endothermicity of the main reactions. Thus, it is necessary to supply indirectly the heat of reaction. In fluidized bed gasifiers, the bed material acts as solid heat carriers and often provides the heat from char combustion; however fixed bed gasifier are more suitable for small scale application, especially when biomass is used as feedstock .

In the first part of this project a small scale (semi continuous, fixed-bed) gasifier has been designed and built. The syngas composition produced has been analyzed and the hydrogen concentration was approximately 60%. In a second stage the plant has been modified in a continuous fixed-bed gasifier, to perform long test duration. The gas composition slightly changes, even if anyway exploitable in fuel cell.

Between the gasifier and the fuel cell, a gas cleaning stage has been foreseen. A catalyst is needed for tar cracking. A series of air-gasification tests have been run in a fluidized bed gasifier to test two different catalysts: dolomite and iron. The results on tar concentrations have confirmed the higher efficiency of dolomite in tar cracking. Then, a catalytic filter filled with dolomite has been placed after the fixed bed gasifier for tar abatement. Finally, some tests coupling the gasifier with a solid oxide fuel cells stack have been run.

The temperature field measured during the experimental activity by some K-thermocouples has been elaborated to estimate an apparent thermal conductivity coefficient to be used in a 2D model for heat transfer simulation; moreover the data on the syngas composition have been used to test the reliability of a thermo chemical equilibrium model previously developed.

The agreement between the output of the equilibrium model and the experimental data is not satisfying. The main problems are the prediction of the residual solid carbon phase and the methane estimation. It is known that the methane prediction it is a difficult task, because it is mainly formed by tars cracking, and thus it is not an equilibrium compound. Several authors have already faced the problem of methane estimation modifying the model with different approaches.

In this work, the experimental data have been used to tune up the model, considering the residual solid carbon formed by means of the definition of a parameter called "carbon conversion efficiency". The accuracy between the thermodynamic equilibrium model and the experimental values significantly improves if the percentage of solid phase is considered. A second modification has been introduced to take into account the moles of carbon and hydrogen which contribute to the methane formation. A better agreement between the experimental results and the output of the modified model has been observed.

The experimental campaign shows that steam gasification represents an interesting pathway for the biomass utilization, because it leads to a high quality effluent gas, suitable for feeding solid oxide fuel cells. The proposed modified equilibrium model seems to be a useful engineering tool, as the syngas composition measured is not so far from the thermodynamic predictions.