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Modelling a biomass gasification system by means of “EES”

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Abstract

A stationary computer model of a CHP plant for thermal gasification of biomass has been build in ”Engineering Equation Solver” (EES). The model is not based on a specific plant, but can simulate many down draft gasifiers, by adjusting the input parameters accordingly. To obtain this flexibility it has been necessary to include all the possible components in a biomass gasification system in the model. This also includes the possibility of having different internal heat exchanger systems.

The model has been used for optimising and comparing different down draft gasification systems, some of which have not yet been tried out in actual plants. The model is also a very useful tool in learning about the gasification system due to its user-friendly interface.

One of the disadvantages of using EES for building this model is that the thermodynamic functions in EES do not share a common reference state. This can be a cause of errors if the model builder is not careful.

Introduction

A system model of a biomass fired CHP plant has been developed. The CHP plant in the computer model is based on thermal gasification of biomass. The model is restricted to gasification systems based on down draft gasifiers, for example two-stage gasifiers and open core gasifiers.

Modelling tool

The model is built in the equation solver program ”Engineering Equation Solver” (EES), which is developed primarily for modelling refrigeration systems. EES has been found very suitable also for modelling thermal power systems, since it contains all necessary thermodynamic functions. These are for example enthalpy, molar mass and density.

Thermal conversion of biomass

Thermal conversion of biomass in a gasification system can be split into three main sequential processes. The three processes are drying, pyrolysis and gasification. Pyrolysis is thermal conversion in an oxygen free atmosphere at a temperature of 200-600 °C. The products from the pyrolysis are char, tar, steam and pyrolysis gas. The main components in the pyrolysis gas are carbon dioxide, carbon monoxide, methane and hydrogen.

In the gasification process a gasification agent, for example air or steam, is added to the pyrolysis char. Hereby the char is converted into producer gas and ashes. The producer gas mainly consists of carbon dioxide, carbon monoxide, methane, hydrogen and nitrogen. With exception of nitrogen the components are the same as in the pyrolysis gas, but the concentrations differ a lot. To obtain a reasonable conversion rate for the gasification process the temperature should be 800 °C or higher.

In a gasification system drying, pyrolysis and gasification can either take place in the same unit or in separate sequential units. If the processes take place in separate units, it is possible to separate the products between units. For example the steam produced in the drying unit could be extracted before the pyrolysis unit, and the heat from condensation of the steam could be used for district heating.

In the two-stage gasification technique, which is developed at the Technical University of Denmark, the pyrolysis and the gasification take place in different units. In this process most of the pyrolysis tar will undergo a partial oxidation and thermal cracking when entering the top of the gasification chamber where the air supply is. Hereby most of the tar will be converted into gas. Pyrolysis tar is also converted into gas, while passing the char bed in the gasification chamber.

It is essential to minimise the tar and sot content in the producer gas, if the gas is to be used in an IC gas engine. However, even with the partial oxidation and thermal cracking of the tar as well as the tar cracking in the bed, it is necessary to have a gas cleaning system before the IC engine.

Gasification system

The gasification system comprises all of the major components from the drying unit to the engine and power generator. These components are the drying unit, pyrolysis unit, air preheater, steam evaporator and superheater, gasifier, cyclone, heat exchangers, gas cleaning unit, fan, IC engine and power generator (see figure 1).

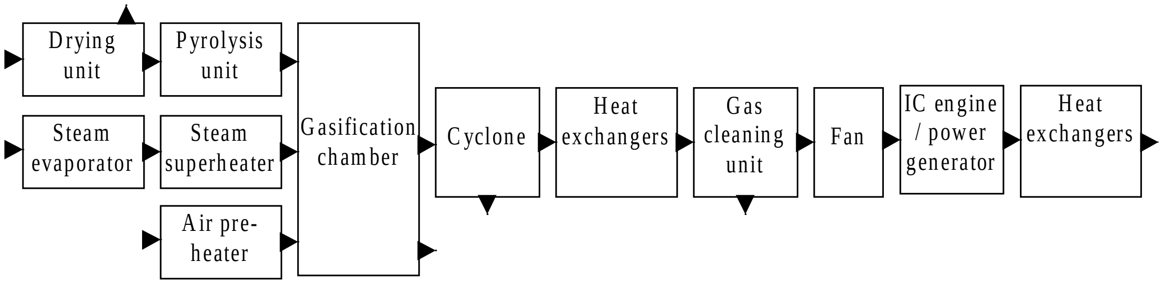


Figure 1 Components in the energy system. The arrows indicate mass flows. Qualitative indications of the mass flows can be seen on figure 2.

The energy outputs from the system are power produced by the engine and heat. High temperature heat is produced from cooling the producer gas from the gasification chamber and the exhaust gas from the engine. This heat is used internally. Low temperature heat for district heating is produced by cooling of the engine and the power generator, condensation of steam from the drying of the biomass and end cooling of the producer gas and the exhaust gas.

A major part of the high temperature heat can be used for internal heat exchanging. This can raise the temperature of the gasification agent(s) and of the biomass in the drying/pyrolysis unit. The temperature of the flows going into the gasification unit (gasification agent and biomass/pyrolysis products) affects the quality of the producer gas and hereby the power conversion efficiency for the whole system. The higher the temperature of the ingoing flows, the lower the need for airflow to the gasifier. With a lower airflow, the producer gas obtains a higher calorific value, and hereby the power conversion efficiency is increased. Therefore the design of the internal heat exchanging system is very important for the efficiency of the plant.

Model

The gasification model is made up of a series of modules each containing one process. The modules are shown in figure 1. Not all components need to be active in a certain computation. If for example a one-stage gasification system is modelled, the pyrolysis unit in the model is not active. In such a system the pyrolysis will take place in the gasification chamber in a zone above the gasification process.

The fundamental equations in the model are conservation of mass and energy. In modelling the pyrolysis unit the energy demand for this unit is calculated as the difference in the energy contents of the incoming and out going flows. The composition of the pyrolysis products in the out going flows is determined by means of experimental data.

Determination of the gas composition from the gasification chamber is based on equations for element balances and the water gas shift equation. The water gas shift equation is a temperature dependent equation for chemical equilibrium between hydrogen, carbon dioxide, carbon monoxide and water (gas phase).

Three different models for IC engines have been made on basis on empirical data. The three engines, which have been modelled, are of different sizes.

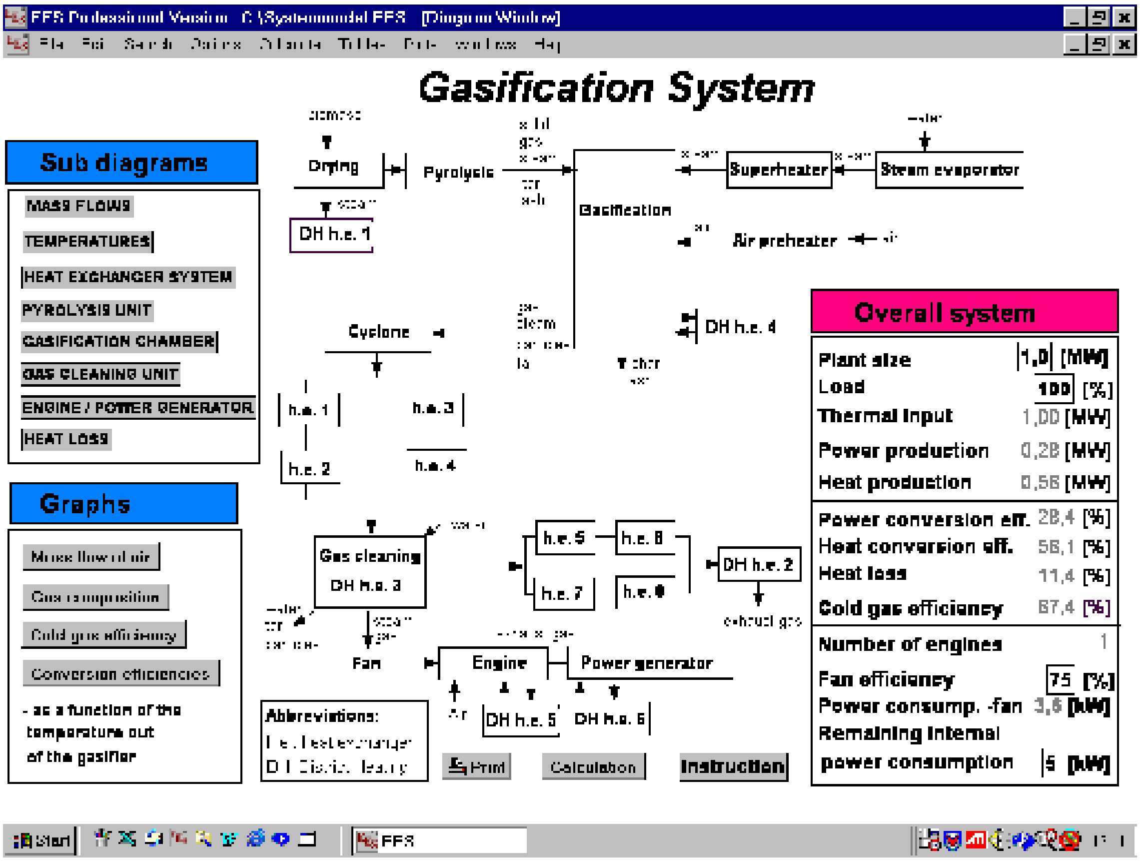
An internal heat exchanging system is implemented in the model. This makes it possible to preheat the streams going into the gasification chamber by means of excess heat in the system. The excess heat at high temperature comes from cooling of the producer gas from the gasification chamber and from cooling of the exhaust gas from the IC engine. In the model, the user can design the heat exchanging system. On the basis of the chosen heat exchanger system the model will calculate the resulting temperatures of the streams going into the gasifier and also the temperature levels of the hot streams after the heat exchanging.

The model also calculates the heat loss from each component in the system and from some of the pipes. The user can decide the thickness and the conductivity of the insulation material for each component.

User interface

In EES it is possible for the model builder to make a user interface, which can make the model user-friendly. In this gasification model, the user interface consists of windows, which contains drawings and tables with input and output values, diagrams and hot areas with links to other windows. This way of presenting the input and output variables makes it easy for the user to get an overview of the operating conditions in a certain computation.

Figure 2 shows the main diagram window in the model. Here a simplified diagram of the gasification system is shown and some key variables for the overall system are shown in a table. Furthermore some hot areas/buttons give access to a number of graphs and sub windows.



Plant size 1,0 [MW]
Load 100 [%]
Thermal input 1,00 [MW]
Power production 0,28 [MW]
Heat production 0,56 [MW]
Power conversion eff. 28,4 [%]
Heat conversion eff. 56,1 [%]
Heat loss 11,4 [%]
Cold gas efficiency 67,4 [%]
Number of engines 1
Fan efficiency 75 [%]
Power consump. -fan 3,6 [kW]
Remaining internal power consumption 5 [kW]

Figure 2 Main diagram window in the model.

Some of the sub windows deal with only one component in the system and contains different kinds of data for this component. Other sub windows contain one kind of data for the whole system, in example temperatures, mass flows or heat losses from all of the components.

The heat exchanging system is set by the user in one of the sub windows. The biomass and gasification agents can each be preheated in either one of eight heat exchangers before entering the gasification chamber. As there are only two hot streams at high temperature in the system: the producer gas and the exhaust gas, the heat exchangers will in many cases have to be on the same gas string, either in parallel or in series. The user can decide the design of the heat exchanger system. The possibilities for inserting heat exchangers are indicated on figure 2, as boxes marked with h.e.1 – h.e.8.

Using the model

This gasification model is a general model, in that it is not a model of a specific gasification system. In this way it is a good tool for comparing different kinds of gasification systems based on the same assumptions.

The model has been used to optimise different kinds of CHP plants based on different types of down draft biomass gasifiers. The plants have been optimised with regards to mass flows and to the internal heat exchanging system. After the optimisation, the plants have been compared in terms of energy conversion efficiencies calculated by the model. A two-stage gasifier and an open core gasifier with a thermal input of 2 MW have amongst other been optimised and compared. It was found that the power conversion efficiency for the two-stage gasifier was 4 percentage points higher than for the open core gasifier.

The model has also been used for examining gasification processes, which have not yet been built. Hereby different operating conditions can be studied before the plant is build. This has resulted in knowledge about which parameters are of importance to certain variables.

The model can be used to analyse, which parameters that have the most influence on certain output variables for example the composition of the producer gas or the heat and the power conversion efficiencies for the total system. Amongst others it has been found that the higher the temperature of the mass flows going into the gasification chamber, the higher the calorific value of the producer gas, and the higher the power conversion efficiency. This possibility for illustrating relations between various parameters in a gasification system by use of the model makes the model very suitable for teaching purpose. In addition the user interface of the model is composed in a way that the user easily can get an overview of how different parameters affects the variables.

So far one course has already been held on how to use the model. The participants, who were people producing gasification plants, did amongst others learn how to use the model for simulating different plant designs.

Evaluating EES as a modelling tool for power producing energy systems

By using EES as a modelling tool some experiences have been obtained. Both qualities and weaknesses in EES have been discovered, however a general assessment of EES as a modelling tool for CHP plants based on biomass gasification is positive. EES is easy to use as a tool for system simulations since the equations can be written in random order.

When modelling thermal plants, involving thermo-chemical reactions, it is a great advantage that EES contains thermodynamic built-in functions such as enthalpy, density and molar mass. EES is developed mainly for modelling refrigeration systems, where chemical reactions rarely occur. Therefore it is usually not a problem that the reference state, upon which the value of enthalpy is based, is not the same for all substances. When modelling thermal power plants, where chemical reactions occur, it is a problem that the substances do not share a common reference state. Therefore it has been necessary to add correction factors to some of the enthalpy functions in order to obtain a common reference point for all the used substances.

When modelling large systems with many loops and feedbacks, the numerical solver can in some cases have difficulties finding a solution. Particularly in a distributable version of the model, which is a special version of the model where the user can not change the start guess values, this can cause problems. If the values of certain parameters are changed a lot and the start values are not changed accordingly, the numerical solver can have problems finding a solution.

The possibility of creating a user interface is a great advantage, both for the user, but also for the model builder. By means of the user interface the model builder can test results from sub models while creating the total model. When making parametric studies in tables and graphs, one can very quickly observe if the model somehow behaves wrong. For the user, the interface makes the outputs from a computation much more clear.

Conclusion

By building this model experiences have been obtained with regards to using EES as a tool for modelling biomass gasification systems.

It is concluded that EES can be used for modelling gasification systems. But using the thermodynamic functions in EES can cause problems if the model builder is not careful since the reference state, upon which the value of enthalpy is based, is not the same for all substances in EES.

Building a model in EES can be done relative easily, because the equations can be written in random order. Although major equation systems with many loops can cause problems in EES, it must however also be considered as an advantage that EES is able to handle quite large equation systems.