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Evaluation and Examples of Biomass Utilization Concepts

Paper 62

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ABSTRACT

Saving of fossil fuels and reduction of carbon dioxide emissions are important aims in energy technology and policy. One way is the use of biomass. Biomass can be used for generating different kinds of net energy like thermal energy, electrical energy, liquid fuels and gaseous fuels.The effective use of biomass depends on the chosen method. Because it is definite that in the world they can not be enough biomass produced for all uses, it is very important to choose the most effective application.

It can consistently be shown by balancing that the effect of fossil energy saving and carbon dioxide reduction from different biomass applications can be very different. With respect to the energy exchange ratios it is possible to find more effective applications and to increase the benefits for the biomass usage.

One substantial result is that decentralised biomass utilization, e.g. for heat and power generation by combustion or gasification, is a suitable path.

A serious problem from biomass gasification is the high amount of polycyclic aromatic hydrocarbons in gas. The gas cleaning stage plays an important role in the entire process. Our development is based on the catalytic and non-catalytic partial oxidation to treat tar contained in product gases. Theoretical and experimental results will be discussed in the following paper focused on the above mentioned aspects.

1 INTRODUCTION

In relation to the reduction of emissions from the fossil CO_2 and the protection of resources, the efficiency increase next to energy supply and saving of energy for application et.al the contribution of renewable energy carriers, are being discussed.

Biomass is quantitatively one of the important regenerative energy sources and that is indicated by comparative good storability and plannable availability. Currently the energy carrier biomass possesses a high and partly unused potential.

Biomass is available decentralized depending on the source region, for e.g. directly at the harvesting place or as agricultural waste. Moreover it contains relatively lower heating value and normally a small energy density. Hence the transportation in relation to the energy units is energetically and also economically extensive. For the energetic use of biomass, especially the smaller decentralized plants provide the direct energy conversion into usable energy and where necessary also for fuel pre-treatment.

However, the potential from Biomass is limited. It is therefore important to find the best useful paths and apply them.

The Biomass is converted through chemical, biochemical or physical processes into thermal energy, electrical energy or chemical energy into liquid and gaseous secondary bio-energy carriers. Thereby the possibilities for biomass applications are strongly different, and that is determined through the efficiency of the biomass use and the comparable use to fossil energy carriers.

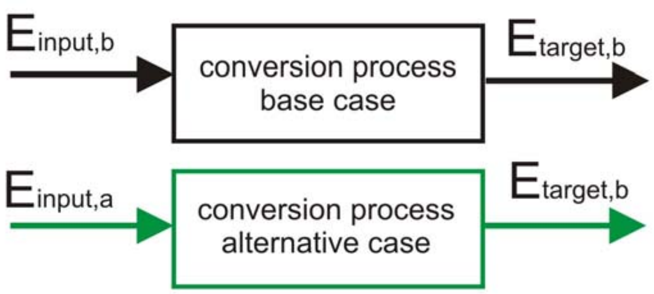
Since the existing potential of biomass and refuse derived fuels is not enough in order to supply all fields, it is therefore an important task for energy process engineering and energy economics, that specific processes chosen and applied. The chosen processes should be able to facilitate high specific reduction of resources from fossil energy carriers and on carbon dioxide emissions. An assessment of the process into biomass usage and lastly an evaluation of which application of the biomass is preferred can be done through the aid of exchange ratios. In evaluation of the processes in view of the saving of the resources and from CO_2 emissions, the energy exchange ratios and the emission exchange ratios are used.

The second part of the paper focuses on a concrete application of energetic use of biomass and that is thermo-chemical gasification. The focal point is the tar reduction in the gasification gas through catalytic and non-catalytic partial oxidation. Thereby, firstly a short review of the theoretical principles and then the experimental investigations on two gasifiers and the related results will be discussed.

2 FORMATION OF THE EXCHANGE RATIOS

The energy exchange ratios can be derived from different boundary conditions. Fig. 1 shows the possibilities of the formation of energy exchange ratios in the supply of energy.

Fig. 1: Energy exchange ratios



Compared here are: the Base case (Index b for Base case), e.g. input (Index E for Input energy) from fossil primary energy to the conversion into target energy (Index Z for Target energy) with the Alternative case (a for Alternative case), whereby e.g. Bio-energy as input energy for the conversion into target energy. The target energy can in both cases can be thermal (Index th), electrical (Index el) and chemical (Index ch, fuel, burnable gas). From the energy exchange ratios, relations of the input energy and the target energy can be expressed as follows:

Equation 1. Energy exchange ratios for the input energy:

$$f_E = \frac{E_{E,a}}{E_{E,b}}$$

Equation 2. Energy exchange ratios for the target energy:

$$f_Z = \frac{E_{Z,a}}{E_{Z,b}}.$$

In the same way the emission exchange ratios are formed. The emission exchange ratios are as shown according to Fig 1:

Equation 3. Emissions exchange ratios based on the input energy

$$f_{E,CO_2} = \frac{m_{E,a,CO_2}}{m_{E,b,CO_2}}$$

Equation 4. Emissions exchange ratios based on the target energy:

$$f_{Z,CO_2} = \frac{m_{Z,a,CO_2}}{m_{Z,b,CO_2}}.$$

3 DESCRIPTION AND EVALUATION OF TECHNICAL PROCESSES (EXAMPLE)

The conversion of biomass is mainly through the desired target energy determined. A detailed description of the process and strategies are found in [1]. For the supply of the target energy there exists respectively a series of processes that are available. Important target energy for the use of Biomass and Refuse Derived Fuels (RDF) are:

- thermal energy as heating or process heat,
- electrical energy,
- chemical energy as
  - liquid fuels, especially for the application as fuels in the transport sector.
  - chemical energy gaseous fuel, with different applications, as e.g. supply of natural gas in the grid or chemical industry

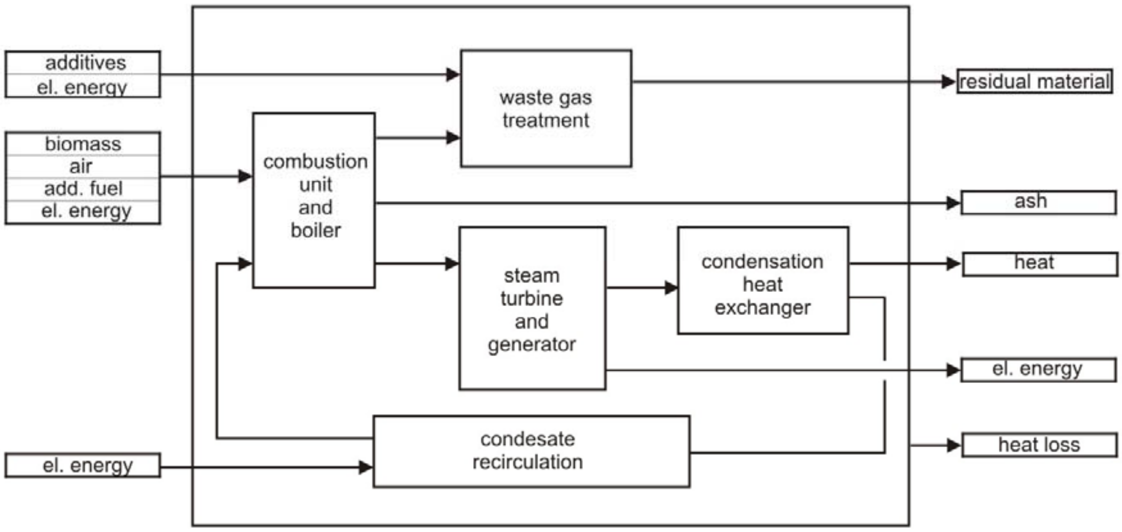
3.1 Generation of electrical energy

Currently there is series of technical possibilities for the generation of electrical energy. While for the use of solid fuels in big plants, steam energy processes with steam turbines absolutely dominate, there is competition from different processes for smaller plants which essentially use biomass. This case is above all justified, since the steam processes with steam turbines for smaller power plants have a poor efficiency.

Basically there are two process concepts for the conversion of biomass initially into mechanical and then in the electrical energy:

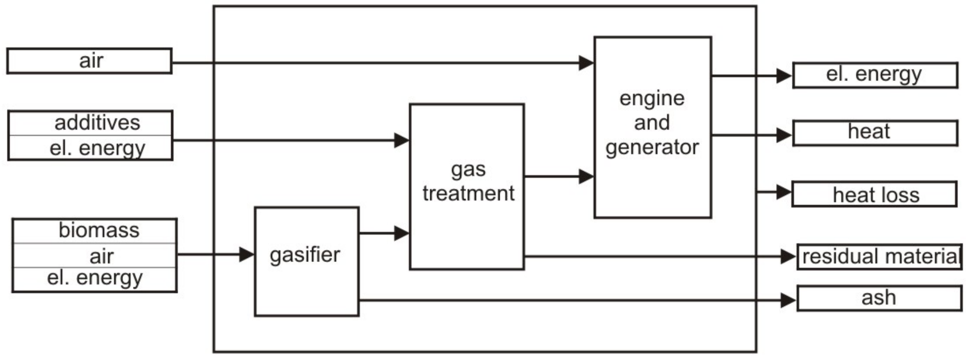
- conversion into thermal energy through combustion and cycle processes (e.g. steam energy process, ORC-process), Fig. 2:

Fig. 2: Steam energy process



- conversion into chemical energy through pyrolysis and/oder gasification and cycle process (e.g. Gas-Engine, Gas-Turbine), Fig. 3:

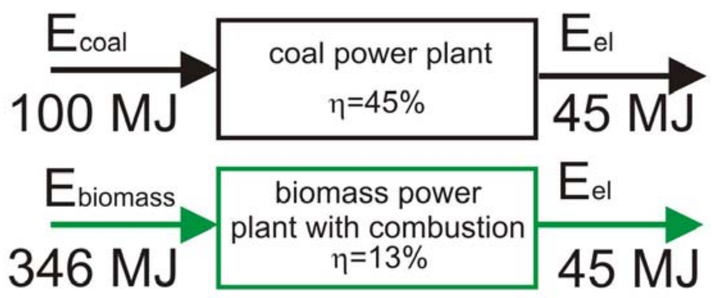
Fig. 3: Gasification process with gas engine



3.2 Process evaluation

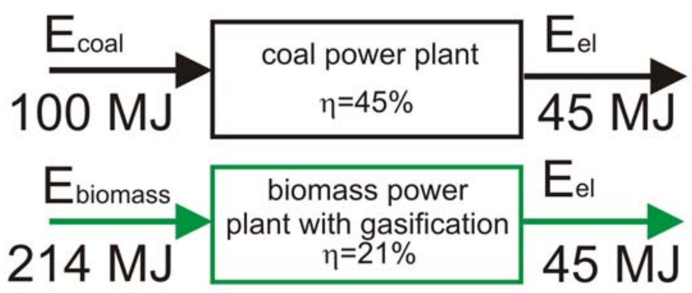
In the first case a biomass power plant with the conversion through combustion having an electrical efficiency of 0,13 [2] is compared with a coal power plant with an electrical efficiency of 0,45 [3]. It results for energy exchange ratios, input energy, $f_{E,el}$ = 3,46 (Fig. 4).

Fig. 4: Evaluation of electrical energy generation, first case.



In the second case a biomass power plant with the conversion through gasification having an electrical efficiency of 0,21 is compared with the same Coal Power Plant. In this case $f_{E,el}$ = 2,14 (Fig. 5).

Fig. 5: Evaluation of electrical energy generation, second case.



4 APPLICATION OF BIOMASS GASIFICATION

The gasification of biomass into smaller decentralised plants up to 500 kW rated thermal input is since many decades with variable intensity a subject of research and development. The current development state is however regardless of the progress still insufficient, so that a reliable and economic operation can be guaranteed. For example, a gas-engine use of the produced fuel gas, high requirements are necessary due to its quality. They are currently not or only attainable with a very high apparatus and technical operation efforts. For the preparation of the gas therefore a process must be developed and applied, which is technically simple and cheaper to implement and operate.

As for the quality of the gasification gases (engine – applicable), the following requirements are placed:

- possible high heating value
- low concentration of the dust and other trace elements (e.g. alkali-, halogen compounds)
- low content of high boiling hydrocarbons (tar)

4.1 Process of Gas Treatment through catalytic and non-catalytic partial oxidation

The catalytic and non-catalytic partial oxidation can be classified into thermo-chemical processes

Partial oxidation means that the oxygen supply in the form of the air-oxygen takes place in sub-stoichiometric conditions, such that the CH-and respectively the CHO compounds react to CO and H_2 and not completely oxidized to CO_2 und H_2O. Furthermore the combustible components CO, CH_4 und H_2 only react partly, such that low or respectively no losses in the heating value and energy content of the fuel gas occur.

Through the partial oxidation of tar into other gaseous combustible components, also in lower molecular hydrocarbons, the tar in the raw gas associated energy content is converted and hence the process is useful.

4.1.1 Catalytic partial oxidation

The reaction in the gas phase is supported through a solid catalyst, i.e. a heterogeneous catalysis exists. Through the use of the catalyst, the required temperature for pure partial oxidation is reduced from approx. 1000°C for the same conversion. The desired reaction starts by the reduction of the activation energy right at lower temperatures (approx. 650°C), such that the eventual occurrence of unwanted decomposition of the reaction partner components is eliminated. The temperature increase from the amount of the gas entry on the reaction system occurs from the exothermic reaction.

For the tar reduction normally metal or metal compounds are used. They are attached to an inactive support material with a greater outer and inner surface area.

In the following described investigations Nickel and Palladium were tested as the catalytic active components under different operational conditions (temperature, residence time).

4.1.2 Non-catalytic partial oxidation

For the partial oxidation of tar, the temperatures in the range from 900 to 1000°C are required. The exit temperature of the gases from the gasifier is about 500°C, such that heating is necessary in order to reach the required temperature. This process demands additional energy input, which has to be supplied either by partial combustion of the fuel gas or from external energy sources (natural gas, electrical). The heat introduction can occur basically directly or indirectly, in any case the possibility of heat recovery should be considered. In the above case for the heat recovery, then especially regenerative processes come into question. The principle is based on heat transfer in two alternating periods. In period 1, heat transfer from a hot gas into a storage material occurs. In the following period 2, the heat storage material transferred its absorbed heat to the „cold" raw gas.

A possibility to compensate for losses during heat transfer lies in the internal process heat introduction (directly) through the oxidation of the combustible gas components in the gas flow with the fed oxygen.

In the following section the design fundamentals for the regenerative heat transfer will be addressed.

4.2 Test Facility

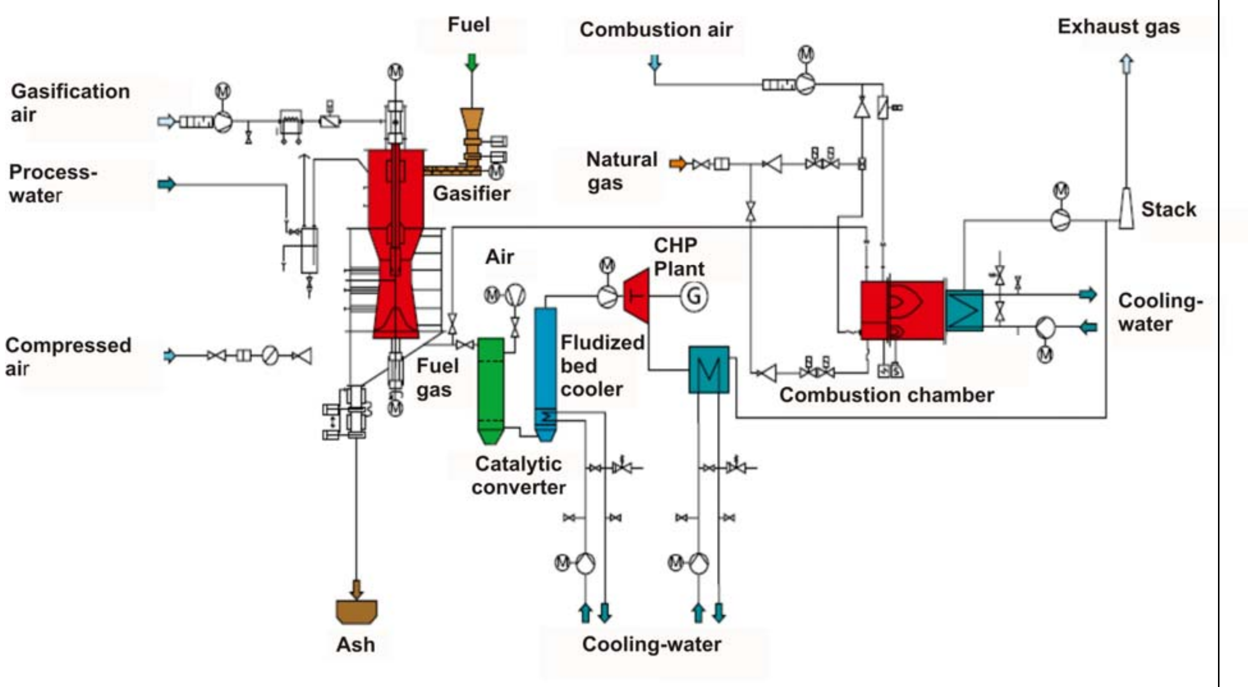
At the Technical University Dresden – Institute for Power Engineering, Chair for Combustion, Heat and Mass Transfer exists two test facilities for gasification:

- Co-current - fixed bed gasifier
- Combined – counter- and co-current gasifier (Combi-gasifier)

The rated thermal input of the Co-current fixed bed gasifier is 75kW, and that equates to a fuel use of wood chips of approx 20 kg/h and the gas generation of approx. 35 Nm^3/h. For the Combi gasifier, it is about a Counter-current and co-current gasifier with a rated thermal input of approx. 100 kW. The gasifier is currently under construction.

The complete plant engineering is shown in the process flow chart in Fig. 6.

Fig. 6: Process flow chart of the complete process, consisting of Gasification, Gas preparation, CHP plant and the Combustion chamber



4.2.1 Catalytic Partial Oxidation

The practical testing of the catalytic partial oxidation of the tar contained fuel gas from the co-current fixed bed gasifier occurs in 2 steps:

Firstly a reactor with a fuel gas flow rate of 10 Nm^3/h is operated in a bypass mode. The design and construction of the reactors and the required periphery are based on the theoretical pre-calculations in view of the mass and energy balances, equilibrium and reaction kinetic considerations. In this plant different series tests were carried out under the variation of the operational parameters of temperature, oxygen and residence time.

In the second development stage, a reactor for the treatment of the total gas flow from the gasifier will be tested.

Knowledge based from the small technical investigations, will aid the plant second development phase in the evaluation and optimization of efficiency of the gas treatment and the quality of the pure gas in view of the engine applicability. For the start-up process and the control of the temperature behavior the reactor is equipped with an electrical trace heating. The desired reactions i.e. the separation of the highly boiling hydrocarbons in the raw gas, are attained by the supply of the air. Until now in the experiments, nickel and palladium have been applied as the catalytic active components. The inlet parameters (temperature trace heating, air supply, flow rate of fuel gas) for both catalysts were identically varied as much as possible. The parameter „flow rate of fuel gas“ is dependent on the total plant operation and hence only slightly influenceable. At different experimental test points, gas samples were taken. By the evaluation of the results, a statement can be made about the quality of the gas dependency to the operational parameters.

The analysis in this section part of the development is confined to the determination of the concentration of the gaseous substances CO, CO_2, H_2, CH_4 and O_2 and on tar and the dust respectively in the raw and pure gas. A detailed description of the measuring method can be found in [4] and [6].

Until the optimal fuel gas quality is reached for the application of the combined heat and power unit (CHP), the gas will be burnt in the combustion chamber.

4.2.2 Non-catalytic partial oxidation

The process of non-catalytic partial oxidation for tar removal from biomass generated gasification gases is currently in planning.

For the testing of non-catalytic partial oxidation is a fixed bed reactor for the use designated, which converts tar through partial oxidation and the regenerative heat transfer of hot gas into cold raw gas.

In stationary operation, the raw gas-air mixture in the regenerator after entry initial warms up and simultaneously the bed material cools down. When the temperature from 900 to 1000°C is attained, the exothermic reaction of the tar conversion starts. At the end of the reactor, the released heat from the reaction is transferred by the gas to the cold material of the packed bed. Through the continual heat losses from the lower layers of packed bed and the continuous heating of the upper section, a reversal of the fluid flow direction necessary after a certain operational period. Through this process, the operation is possible without external energy addition over the total stationary operation period. The change in the gas quality from the raw to the clean gas side is determined and evaluated identically to the measurements for catalytic partial oxidation.

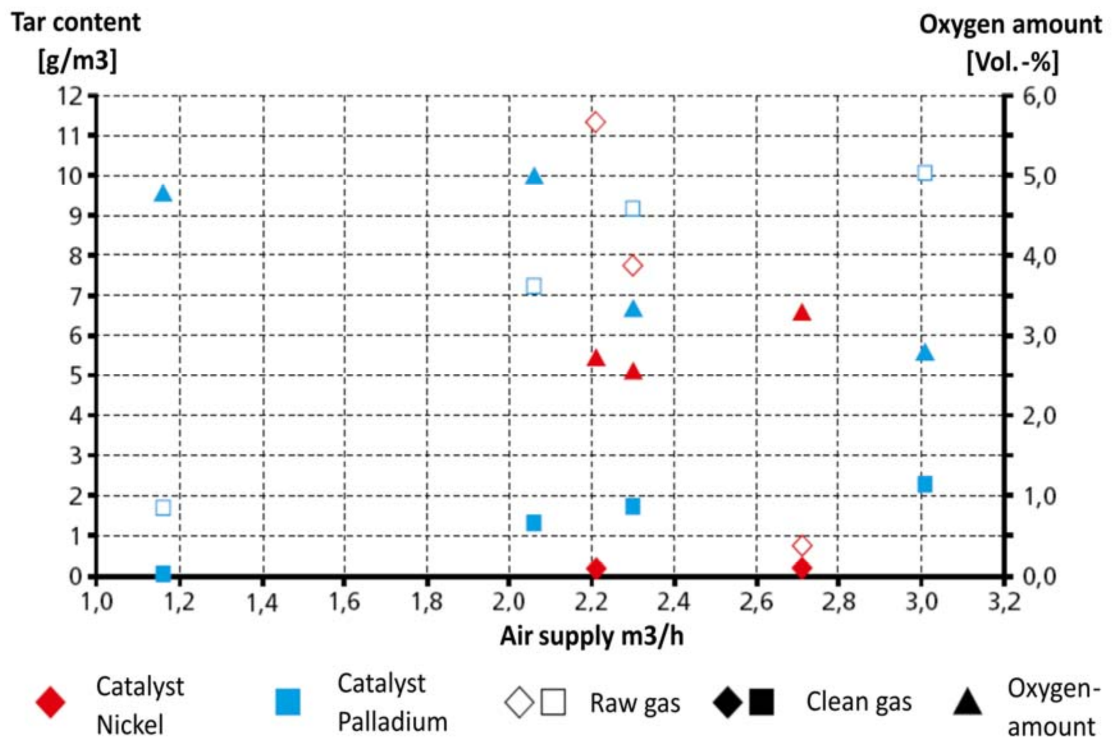
4.3 Experimental Results

The results of the experimental investigations from the first construction phase into catalytic partial oxidation are shown detailed in [5] und [6]. Summarized it can be pointed out that, through a catalytic partial oxidation it is possible, to reduce the tar content in the gas at optimal operating conditions, to an extent that the gas can be applied combustion engine. The degradation of tar is definitely intensified by an increase in the supplied air. Furthermore as expected it is shown that the temperature conditions in the reactor have a great influence into the conversion rate of the tar. For the evaluation of gas quality in view of „Tar content“ as a measure of the suitability as fuel gas for the combustion engine**,** it is essential that the tar should be analyzed from the amount and the quantity. In order to examine this point to reach a clear statement, gas chromatography investigations were carried out. The compounds which were identified in the raw gas were of a smaller concentration in the clean gas i.e. were below the detection levels. Furthermore, it can be ascertained that the quality in view of the heating value determinant components, is at a level which adheres to the specified values from the engine manufacturer.

For the evaluation of the experiments in the second construction phase (total gas flow, demonstration plant), the focus point is about the parameters of tar loading and the concentration of the gaseous non-condensable gas components.

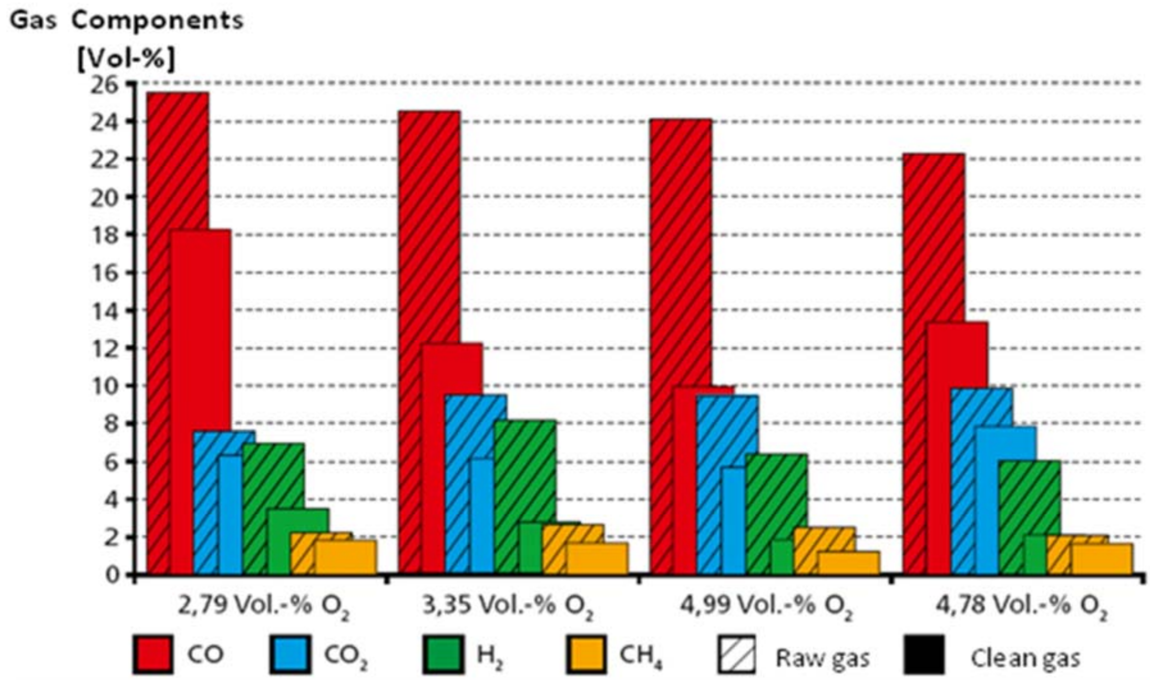
The results of the investigations in view of tar concentration in raw and clean gas are shown Fig. 7. In order to quantify the tar content three repeat determinations were carried out at the raw and clean gas sides.

Fig. 7: Tar content in raw and clean gas in dependency to the supplied oxygen amount for a set point temperature of 500°C for the trace heating



A tar degradation rate between 75 and 100 % is attained. The concentration in the clean gas lies between 0 and 1,7 $g_{tar} /m^3_{fuel\ gas}$. The first results don’t indicate a clear statement as to which catalyst has better characteristics in view of the tar reduction. As for catalytic partial oxidation there is definitely a change in the concentration of the non-condensable gas components [6]. In Fig. 8, the gas components are shown with their volumetric fractions in the fuel gas in the raw and clean gas sides in dependency to the supplied oxygen content.

Fig. 8: Gas composition of the raw and clean gas under the variation of the oxygen supply and catalyst Palladium



As expected, the fraction of the combustible components CO, CH_4 and H_2 decrease in the reactor through catalytic partial oxidation at every experimental test point. It can be noticed that the concentration of CO_2, not as expected due to oxidation of CO to increase, but instead it decreases at every experimental point.

The comparison of the results with small technical investigations in overall indicate that, currently for the experiments in the demonstration plant there still exists an optimization necessity in view of the desired tar degradation and the change in the heating value of defined gas concentrations.

5 CONCLUSION

The examples show that for the energetic biomass use there are different strategies. Importantly it appears that for the assessment of the efficiency of the individual processes in the energy conversion process, inclusive of the fuel treatment, the process chains must through respective balances be investigated and with the aid of energy and emissions exchange ratios then evaluated. Firstly from this basis it can be determined, which effect can be achieved in a greater frame within the complete economic system.

The demands must be such that the biomass is so effective to be possibly applied, such that the fossil fuel CO_2- emissions can be reduced as much as possible. It means that the criteria which results from balancing, for biomass it must be at a development state as for the fossil fuels.

As a summary it can be concluded that with a goal-oriented substitution of fossil fuel carriers through biomass and refused derived fuels, the effect can be clearly increased.

The carried out investigations on existing experimental plants for the gasification from biogenic fuels, with the objective of the production of electrical energy and heat energy, have indicated that there is exists an extensive optimization potential in the plant engineering, operational methods for the individual gas treatment functional units and their combinations.

An important focus point is the control of the ratios between the fuel gas amount and the supplied oxygen amount in the process of partial oxidation.

In order to experimentally test the process of non-catalytic partial oxidation and hence the verification of theoretical pre-calculations, currently an experimental plant is at the planning stage.

A comprehensive energy balancing is necessary for an extended balance cycle of the overall process. In the results, both processes were clearly defined in respect to the energy efficiency. Therefore a comparison of both processes amongst each other is acceptable. The balancing is based on concrete application examples.

In the evaluation of the economics, the results of the investigations of the energy balance indicate an important factor. The main focus points in the considerations are the investment and operational costs. For the application cases, the complete economic analysis must be carried out, such that a basis for the decision-making for the operators of biomass gasification can be made.

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