Small Scale Gasifiers – Market and Technology Evaluation for Promising Developments

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Abstract:

The flexible and sustainable use of biomass leads to the development of different technologies. Large-scale gasification applications are equipped with a complex gas cleaning facility, to prevent the following components from e.g. fouling due to tars. Examples for such plants are in Güssing/AT, Harboøre/DK. For small scale gasifiers (here defined as $< 2\ MW_{th}$) a complex tar cleaning device is too expensive. Therefore the gasifier should be operated in the way to produce a product gas with low tar content. This paper reviews the current available technologies for small scale gasifiers with regard to the gas quality (e.g. heating value, tar content). The result of this assessment leads to a statement which concepts might be promising for future applications or wide spread usage.

The variety of gasification technologies cause various gas composition and tar concentrations. The gasifier process can be divided into autothermal and allothermal operation and the technology into fixed bed gasifiers with co-current or counter-current operation mode, partly floated or partly fluidized operation mode, fully fluidized bed gasifiers and entrained flow gasifiers. The direction of the movement of the product gas flow in a fixed bed leads to the definition of a downdraft or updraft gasifier. Product gas cleaning is normally done with two-step-venturi-scrubbers (cooling and separation) combined with cyclones, RME scrubbers and/or electrostatic participators. Gasifiers with low tar production are using only pre- coated ($CaOH_2$) bag filters or hot gas filters out of sintered metals depending on the further usage of the gas. For gas engines values of $< 100\ mg/m^3n$ tar are necessary.

In the past only fixed bed gasifiers were used for small scale operations. Meanwhile as well fluidized bed gasifiers (e.g. HPR, THPR) and even entrained flow gasifiers based on carbonized biomass are in operation or under development for small scale applications. Depending on the technology, the operation mode and the temperature of gasification the tar content various enormous in the range of 50 mg up to $> 10.000\ mg/m^3n$. Co-current gasifiers, for example show advantageous in low tar concentrations (tar 50-500 mg) but they show higher amounts of particles in the wood gas compered to counter-current gasifiers (tar up to 7.000 mg). Due to the low gasification temperature (800-900 °C) and low oxygen content for fluidized bed gasifiers tar values up to $10.000\ mg/m^3n$ are known. At higher temperatures above 1.000 °C the tar content can be reduced even below $100\ mg/m^3n$ without gas cleaning. This effect can be realized in autothermal partly floated/fluidized gasifiers and entrained flow gasifiers.

Actually the combination of a fixed bed with a partly floated bed as co-current updraft gasifier shows low tar concentrations. Gasifiers of those types are the gasifier of the Burkhardt GmbH/GER, Spanner/GER, Stadtwerke Rosenheim/GER and Syncraft/AT. At the Burkhardt gasifier pellets and char move slowly upward and the wood gas leaves the reactor at height temperatures of > 800°C. The gas is cooled down, filtered with a bag filter, and used in a piston engine. Fully fluidized bed gasifiers can be used in combination with gas turbines. An example for it is the autothermal TurboHPR/GER. The hot product gas can be burned directly in the burner of the gas turbine and therefore tars will be cracked. Due to that tar concentrations are less critical in combination with gas turbines. These are two examples of gasifiers with different tar content, which can be used for CHP concepts.

As mention above low tar content is essential for a small scale application in combination with piston engines. The development of fixed bed gasifiers moves to combinations with floated and fluidized bed gasifiers-concepts to avoid complex gas cleaning. Fluidized gasifiers give the advantage to combine them with gas turbines and entrained flow gasifiers are a new option in combination with new biomass products.

1. Introduction:

Usage of biomass for heat and power generation seems a promising way to diversify the primary energy demand and contribute to climate requirements. But biomass in the energy sector competes with food and fodder production as well as forest products on the one hand and with other energy sources on the other. Therefore a flexible and sustainable use is important. This leads to development of different technologies, of which one is gasification.

Large scale facilities (here defined as > 2MW) such as the plants in Güssing/AT or Harboøre/DK have a complex gas cleaning facility to prevent the downstream equipment from slagging and fouling caused by tar and particles. In small scale a complex tar cleaning equipment is too expensive in comparison to the investment costs of the gasifier. For this reason the process of small scale gasifiers has to be optimized to low tar content in the gas.

This paper reviews market available technologies with regard to gas quality. Especially the heating value and tar content are considered and promising future technologies are assessed

Starting with an overview of basic gasification and gas cleaning technologies is given. Second, technologies are described in detail and compared to each other. At last the results of this comparison are explained.

2. General gasification technologies:

The various gasification technologies differ in gas quality, tar and dust concentrations. They can be divided in autothermal gasification and allothermal reforming. The first receives required energy from partial oxidation of the fuel during the gasification process. Air or oxygen is used as gasification agent. Allothermal reforming receives energy from an external source and the gasification agent is often steam.

Usually biomass gasifiers are either characterized as fixed bed gasifier or fluidized bed gasifier depending on the bulk density of the fuel filling and the motion between solid and gas. The residence time of the biomass in fixed bed gasifiers varies from 2 to 10 hours. [2,3]

In general biomass is added at the top of the reactor and moves to the bottom of the system while it is decomposed (drying, pyrolysis, oxidation, reduction). The ash is conducted at the bottom. Depending on the relative movement of gas and solid fixed bed gasifiers can be discriminated between co-current (gas and solid move the same direction), counter-current (gas and solid move in opposite direction) and cross-flow (gas and solid move right-angled to each other) gasifiers. In contrary to the usual notation in this paper a downdraft gasifier is not equal to a co-current gasifier. The term describes a gasifier where the gas moves downward. The term updraft gasifier describes only a gasifier where the gas moves upward. [2,3]

Fluidized bed gasifiers feed the gasification agent (e. g. air, oxygen, steam) from the bottom of the reactor, which is filled with fuel and inert material. The gasification mode can be autothermal or allothermal. The temperature distribution is homogeneous within the reactor and all gasification reactions take place in the fluidized bed. The residence time of the fuel is shorter than in fixed bed gasifiers. A fluidized bed reactor can be operated under atmospheric or pressurized conditions.

Two types of fluidized bed reactors are the main representatives: Bubbling fluidized bed gasifiers (BFB) run at air speeds that a bubbling surface is formed at a defined height. In circulating fluidized bed gasifiers (CFB) air speed is much higher than in BFB gasifiers. A significant amount of material (inert compounds and fuel) is carried out of the reactor and no defined bubbling surface is formed anymore. The solid particles are separated from the gas stream and re-circulated to the reactor. [3]

Entrained flow reactors have the highest gas velocities and the highest requirements on fuel properties. The fuel (biomass, coal etc.) has to be quite dry and fine milled. The fuel particles are pneumatically transported with the gas stream. The temperatures also are the highest (above 1000°C) of all gasification concepts. At such temperatures there is the danger of ash melting and slagging, but the concentration of condensable organic compounds is quite low. [6]

Table 1 shows a general comparison of different gasification technologies with regard to PM and tar content, heating value and gasification efficiency. Especially the differences in the tar content are significant and influence the required cleaning equipment for further use, e. g. internal combustion (IC) engines. These kinds of engines need particle concentrations below 50 mg/m^{3}n and tar concentrations below 100 mg/m^{3}n. Gas turbines have even tighter requirements. Therefore all general gasification types need gas cleaning facilities, for particles, tar and possibly for alkali, chlorine and sulphur compounds. [4,5]

	Particles	Tar	Heating Value	Gasification Efficiency
	g/m^{3}n	g/m^{3}n	MJ/m^{3}n	%
Co current	0.2 – 8 (1)	0.1 – 6 (0.5)	4.0 – 5.6	65 - 75
Counter current	0.1 – 3 (1)	10 – 150 (50)	3.7 – 5.1	w. t. >90 wo. t. 50 – 70
CFB	8 – 100 (20)	1 – 30 (8)	3.6 – 5.9	70 – 85
2 CFB	?	9 – 15	14.2 – 18.1	65 - 75

Tab. 1: Particle and tar content, heating value and gasification efficiency for different reactor types. Co- and counter-current plus CFB with autothermal air gasification. 2 CFB allothermal steam reforming in two CFB reactors. (w. t. with tar content, wo. t. without tar content) [1]

3. Gas cleaning [3-5]

The required gas cleaning facility for the product gas depends on the gasification technology and the content of the impurities. Aim of the conditioning is the reduction of impurities to a level which prevents the following systems from slagging, fouling and corrosion and fulfills environmental regulations.

The particle removal can be done by cyclones, sand bed filters, fabric filters, electrostatic precipitators (ESP), granular filter beds or ceramic candle filters. Sand bed filters have quite high pressure losses. The sand bad have to be replaced after certain time and must often be treated as hazardous waste due to the condensed tar components. Cyclones and rotational particle separators (RPS) are simple and low cost, with good particle reduction rates. They also can be operated at high temperatures to avoid tar sticking on the walls.

Electrostatic precipitators are very effective to separate particles even if they have diameters below 0.05 µm. Due to the content of condensable organic compounds it is preferable to use wet ESP. Fabric or bag filters as well as ceramic or metal candle filters are efficient cleaning systems for particles. They are cleaned regularly after a certain time interval by a jet impulse. The fabric filters are limited in allowed temperature range and therefore there is the risk of plugging by condensable organic compounds. For this reason the candle filters are more applicable for wood gas cleaning, because they can handle temperature above 400°C. Candle filters have higher pressure losses in comparison to ESP systems and are more suitable for pressurized gasifiers.

The second impurities, which have to be separated or converted into harmless substances, are tars or condensable organic compounds. Especially heavy tar components have boiling point temperatures around 300°C and are adhesive when condensing. Sand bed filters are possible, as mentioned above, but have problems with pressure drop and condensed tar. Another bed filters are granular filter beds. The bed material consists of charcoal or activated carbon and can handle temperatures around 300°C. The tar components adsorb on the granular material. The filled charcoal or activated carbon can be used as fuel in the gasifier or another combustion facility. Granular filter beds can be used in combination with de-dusting equipment like candle or bag filters.

In order to separate impurities wet scrubbing techniques are employed. Such systems are two step-venturi-scrubbers, spray towers, two stages rotational atomizer, wash tower or swirl scrubbers. Advantages of wet scrubbers are that they separate not only tar but also dust and other impurities like chlorine or sulpur. The biggest disadvantage is the production of waste water, which requires extra treatment, and increases costs.

Due to the fact that condensable organic compounds are energy carriers, it is reasonable to use this energy. Therefore tar has to be transformed in species, which can be used by engines or gas turbines. But the amount of energy, which is stored in the tar, depends on the gasification technology. For this reason it is not appropriate, if the energy demand for converting tars is higher than the gain of energy through decomposed condensable organic compounds. In order to decompose the condensable organic compounds into non-condensable organic compounds catalytic or thermal cracking is required. Wood gas is heated up to temperatures over 1000°C so that heavy hydrocarbons dissociate into smaller pieces [9]. The temperature increase is caused by partial oxidation of produced gas. The cold gas efficiency decreases severe, if the tar content is quite low. The efficiency can be improved by recycling the produced heat to the gas before the cracker. This process is suitable for counter current gasifiers with high tar contents.

Catalytic tar reforming is less energy intensive than thermal cracking but still a highly endothermic process. The required temperature range is from 750°C to 900°C and a sufficient amount of steam has to be present. Heat recovery can also increase the plant efficiency within this process. Nickel-based catalysts or calcined dolomit seems promising.

The more severe impurity in product gas are the condensable organic compounds, caused by the fact it is more complicated to separate them from gas stream than dust. Therefore the gasification process can enhance the economic and technical performance if tar and dust content can be controlled.

4. Technology Evaluation

A concept for a low tar gasifier is a co current updraft gasifier with high gas outlet temperatures. The small block combined heat and power plant (CHP) system of the company Burkhardt employs this principle. Wood pellets are feed together with air as gasification agent from the bottom. Inside the reactor is a floating bed consisting of pellets and char coal. The product gas leaves the gasifier together with small char coal particles and ash at about 750°C. The high temperatures and the char coal cause a very tar low (especially an uncritical amount of condensable organic compounds) gas. This gas is cooled and particles are filtered with a bag filter. The gas is also dried before it enters the pilot injection engine. The measured total efficiency is 69%, which consists of 39% heat and 30% power. The cold gas efficiency is 83%. This block CHP is commercially available and is in the power range of 180 kW$_{el}$ and about 250 kW$_{th}$ [8]. The biggest advantage is that there is no need for tar cleaning. The methane concentration is used as indicator for tar. If it exceeds a certain level the gas is burned in a flare. Disadvantageous is the use of costly wood pellets and that ignition oil for the engine is needed.

The Stadtwerke (public services) Rosenheim use a similar concept and also measure low tar contents. This gasifier is not yet at commercial services. Two companies from Austria, which use the principle of floating beds, are Syncraft and Cleanstgas. They use a heated pyrolysis screw conveyer and an attached floated bed reactor for tar dissociation. Another company is SpannerRe^2. All this concepts need only de-dusting, which limits the investment costs. The biomass used for these gasifiers are wood chips. An overview of companies using a kind of floating beds can be seen in table 2. Such systems can reach tar concentrations below 100 mg/m^{3}n, which are suitable for gas engines.

Manufactuer	Principle	kW$_{el}$	kW$_{fuel}$	Market status
Burkhardt GmbH	Aut, CoC,	180	550	Commercial series
Stadtwerke Rosenheim	Aut, CoC,	50 / 150	250 / 750	Pilot plant
Spanner Re^2 GmbH	Aut, CoC,	30 / 45	130 / 200	commercial
Syncraft	Aut, CoC	250	990	Demo plant
CleanstGas	Aut / all, CoC, air / steam	125 / 250	n/a	Demo plant

Tab. 2: Companies, which employing a kind of floating bed as gasification technologie. Aut : autothermal; all : allothermal; CoC : co current [8,9 - 12]

A different approach is used by Agnion GmbH. A bubbling fluidized bed reactor reforms the fuel allothermal with steam. The heat is brought to the system by heatpipes and a second fluidized bed, where the charcoal is burned. Caused by allothermal gasification the heating value of the product gas is higher than of autothermal gasification. Another advantage of this gasification method is the lack of nitrogen, which allows SNG production. Thus the application spectrum is broadened. But the gas still contains a significant amount of tar, which has to be separated in a rapeseed-methyl-esterscrubber (RME-scrubber). The cold gas efficiency is 70% and the heating value of the product gas is about 11 MJ/m³n. Nominal power output is 400 kW_{el} and 630 kW_{th}. First commercial plants are in service.

Manufactuer	Principle	kW_{el}	kW_{fuel}	Market status
Agnion GmbH	all, BFB, steam	380	1300	First Commercial service
HS Energie-anlagen	all, BFB, steam	250	830	Demo plants
REW GmbH	all, pc, fuel steam	75	n/a	Test rig
Natur Bio Energie GmbH	all, steam	330	n/a	Test rig

Tab. 3: Companies, which employ allothermal steam reforming. all : allothermal; BFB : bubbling fluidized bed, pc : pyrolysis conveyer uses fuel water for steam gasification [7, 10]

Another company employing BFB gasifiers is hs Energieanlagen. It also uses allothermal steam reforming. The heat for the gasification is produced in a gas turbine combustion chamber. The power range starts at a fuel input of 825 kW, which results in a output of 250 kW_{el} power and 375 kW_{th} heat. Table 3 show companies, which produce nitrogen free wood gas with high energy content by allothermal reforming.

Because of the complex technology of fluidized bed reformers, financial and technological risks for manufacturers and customers are higher. Fixed bed gasifiers or gasifiers, which employ a floating bed or staged gasification, have a simpler system configuration.

Manufactuer	Principle	kW_{el}	kW_{fuel}	Market status
ENTEC GmbH	Aut, CoC, air	30 - 90	110 - 310	commercial
Hans Gräbner Behälter und Aparate Bau	Aut, CoC, air	30	110	commercial
Holzenergie Wegscheid	Aut, CoC, air	120	540	commercial
Kuntschar Energie-erzeugung	Aut, CoC, air	150	600	commercial
Lenz BHKW	Aut, CoC, air	150	330	commercial
Mothermik	Aut, CoC, air	250	945	commercial
Pritschner Holzgas	Aut, CoC, air	25	100	commercial
Terra-Tec GmbH	Aut, CoC, air	50 - 250	150 - 750	commercial
Urbas Maschinen-fabrik	Aut, CoC, air	70 - 200	250 - 720	commercial
Xylogas GmbH	Aut; CoC, ait	220 - 900	880 - 3330	commercial
A.H.T. Pyrogas GmbH	Aut, df, air	65 - 1000	200 - 3030	commercial

Tab. 4: Companies, using fixed bed gasifiers with gas cleaning. Aut : autothermal; CoC : co current; df : double fire a two zone gasification fixed bed gasifier. [9, 10, 13]

Despite new technologies, fixed bed gasification methods with a gas cleaning facility are still employed by numerous companies. The power range varies from about 30 kW to 1000 kW. These companies can be seen at table 4.

5. Conclusion

The chapter above describes companies, which employ different gasification methods for small-scale applications. These methods are fluidized bed gasifiers, floating bed gasifiers and fixed bed gasifiers. The requirements for promising techniques in small-scale are a small number of components and a short erection time to reduce high specific investment costs. A flexible and reliable operation is also crucial. This favors technologies, which do not require a tar separation, e. g. floating bed gasifiers, and crack tar components during the process. Compact or modular systems are easy to erect and save building costs. Examples for these systems are partly ordinary fixed bed gasifiers and floating bed gasifiers.

More flexible systems are the fluidized bed gasifiers, which can use the gas in engines or upgrade it to SNG and feed it to the gas grid. But their big disadvantage is the complex facility design and the high investment cost plus the need of tar cleaning. Therefore the compact low tar systems seem to be more promising in small-scale.

6. References

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