

STAGED FLOATING-FIXED-BED GASIFICATION: HISTORY AND FUTURE

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Abstract

Thermochemical conversion of solid biomass in gasification processes provides a highly efficient opportunity for biomass derived renewable energy. The PowerBox gasification setup using the floating-fixed-bed reactor technology has proven the potential to bypass issues of comparable gasification technologies at medium power range. Three years of improvements and long term testing based on a 500kW thermal power demonstration plant verified the advantages of the innovative reactor design and gasification concept and lead to a commercially available gasification concept, which closes the gap between small and large scale gasification plants. Beside continuous improvement of the gasification technology the current development aims for upscale possibilities and increased fuel flexibility.

Key words: *gasification, biomass, floating-fixed-bed, decentralized energy*

1. INTRODUCTION

Multi-staged fixed-bed gasification systems represent one of the most promising and effective methods for transforming solid biomass into heat and power (CHP) at medium scale. The limitation in size and some other bottlenecks of conventional fixed-bed systems (Kreutner et al. 2007) have been successfully dealt with by the floating-fixed-bed gasification technology as described by Huber et al. (2008).

Based on the findings with the first pilot plant, an Austrian consortium under the leadership of the MCI and supported by the Standortagentur Tyrol, initiated in 2009 the 3-year project PowerBox. Aim of the project was to verify the first findings with an upgraded setup of the demonstration plant under long-term conditions. During the three-year PowerBox project, the great potential of this highly innovative gasification concept has been demonstrated, but also restrictions concerning applicable biomass have been found.

In the follow-up project PowerBox², which was started in 2013, the adaption of the gasification setup and gasification reactor from wood gasification to the utilization of communal and agricultural biogenic residues will be dealt with. Investigations on the gasification behavior of straw raw material regarding ash melting temperature and carbon conversion show a significant influence onto the gasification reactions. These effects caused by higher ash content and different composition, compared to wood, show a not negligible influence onto the operational parameters of the gasification setup.

2. APPROACH

2.1 The PowerBox Gasification Setup

The PowerBox is a pilot gasification plant with 500kW thermal power based on the new floating-fixed-bed technology. In total, during the 3 years of the project, the gasification plant has passed more than 5.000 hours in more than 300 test runs that led to a constant process and concept optimization. The standard setup of the multi-staged floating bed reduction gasification system can be found in Figure 1.

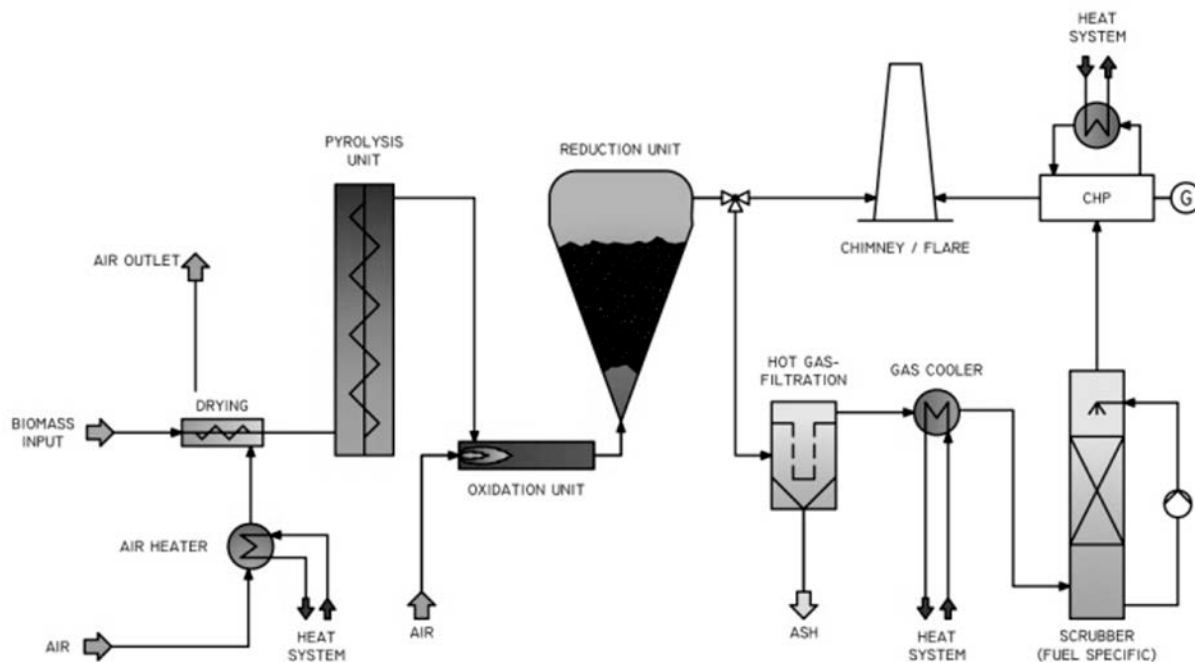


Figure 1: Scheme of the floating-fixed-bed gasification concept

The main advantage of the system is the technical separation of the plant into the three different reaction zones pyrolysis, oxidation and reduction. Therefore, the zones can be operated at the ideal temperature range (Table 1); the temperatures in the pyrolysis unit and in the oxidation zone are directly influenced by the introduced air ratio. Only the temperatures in the char bed of the fixed-floating-bed reactor are relating to the previous process steps.

Table 1: Temperature zones in floating-fixed-bed reactor setup

Process step	Temperature range
Pyrolysis	450 – 500°C (outlet)
Oxidation zone	950 – 1000°C
Floating-fixed-bed (in)	800 – 900°C
Floating-fixed-bed (out)	< 700°C

2.2 The Floating-Fixed-Bed Reactor

The core of the staged floating bed technology is the floating-fixed-bed reduction reactor. Due to its unique design, it allows the gasification process to happen, contrary to a fluidized bed, within a strict tubular reactor, preventing axial exchange of reaction material. The pyrolysed particles enter the reduction reactor at the bottom and get integrated in the stable floating bulk. Due to the continuous feeding of the pyrolysis unit, new char particles enter the fixed-floating-bed and build up a new layer below the former bulk. This leads to an upward movement of the bulk to a new position, where a balance between the up- and downward forces exists (Figure 2).

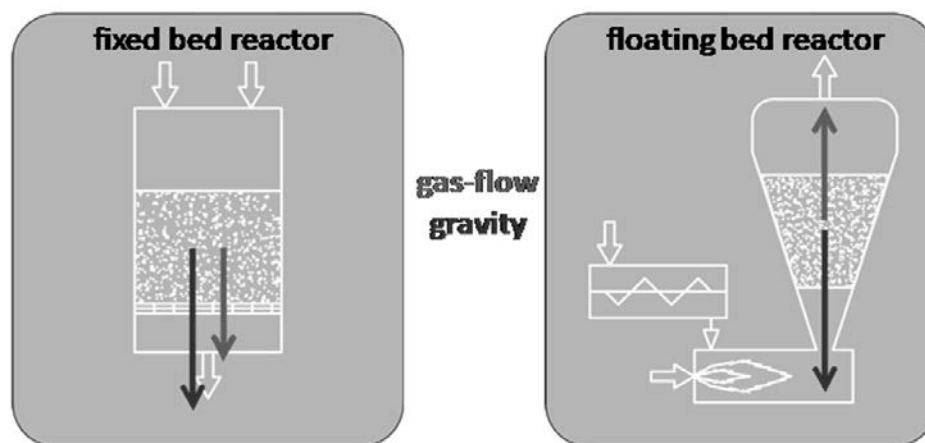


Figure 2: Forces in a fixed bed / a floating-fixed-bed reactor

During the gasification process, the particles pass through the floating bed. As a consequence of reduction reactions, the particle size declines until the char pieces reach the upper side of the bulk. Depending on the individual sinking speed, the residual ash fraction is transported by the fluid volume flow rate into a hot gas filter. After passing a cooling unit, the producer gas runs through a fuel specific water scrubber and enters an internal combustion engine. Beside the good tar cracking behaviour of the floating-fixed-bed-system due to a relative long residence time of the gas in the reactor and also the low pressure drop, the avoidance of channeling or compaction of the char bed are the main advantages of the system which lead to a nearly tar-free product gas (Huber et al. 2013).

3. KEY FIGURES

The continuous operation tests have been done with standard spruce wood-chips classified G30-W10-S150 according to ÖNORM M 7133; still containing bark. The plant has been operated within an air ratio of 0.3 to 0.38. All mass and energy input and output flows were registered online. Beside the continuous analysis of the gas main components, almost all interesting gasification parameters like tar-loads, ammonia, etc. have been sampled and analysed according to common standards and knowledge (British Standards Institution 2006).

During all continuous operation test runs a detailed mass- and energy balance has been calculated and analysed. Some typical parameters are given with the following Table 2 which have been logged during 100 hour test runs.

Table 2: Key figures - 500kW pilot plant

Parameter	Value	Unit
Biomass Input	100	kg/h dm
Air ratio pyrolysis	0.09 – 0.11	
Air ratio gasifier	0.21 – 0.27	
Air ratio total	0.3 – 0.38	
Filter dust	4 - 5	kg/h
Gas	250 - 280	m ³ u.s.c./h
Heating value	4.9 – 5.2	MJ/m ³ u.s.c.
Cold gas efficiency	74 - 80	%

3.1 Overall performance with wood chips

One of the most important criteria of a modern gasification system is a steady gas composition and quality. The result of the continuous monitoring of the gas composition over a representative 100-hour test run is shown in Table 3.

Table 3: Exemplary producer gas composition - 100h test run

Producer gas component	Average values (n=5)			
H ₂	18.1	±	0.28	[%]
CO	20.2	±	0.20	[%]
CO ₂	15.4	±	0.16	[%]
CH ₄	2.0	±	0.20	[%]
Sum BTEX	10.8	±	4.3	[mg/m ³ u.s.c.]
Sum PAH	0.035	±	0,004	[mg/m ³ u.s.c.]
Grav. Tars	15.3	±	2.9	[mg/m ³ u.s.c.]

Beside the composition of the main gas components, the load with tar and other impurities must be below certain values for utilization within gas engines (Hellat, Wimmer, & Strasser 2003). The test run demonstrates a steady >99% degradation of tars within the floating bed reduction reactor to an uncritical sum value <50 mg/m³ u.s.c. even before gas cleaning throughout the whole test run. Several research groups are focusing on tar reduction methods to reach similar low tar contents in the producer gas for other gasification concepts. Especially the gasification temperature and residence time as well as the catalytic tar reduction potential of gasifier char show a high influence onto the tar conversion (Fuentes-Cano et al. 2013). Based on these findings, investigations will be carried out to describe the tar reduction mechanisms in dependence of the gasification temperature in the floating-fixed-bed gasifier which lead to the low tar contents in the producer gas.

3.2 Development of plant availability

Availability and reliability are important key figures for the commercialization of the gasification concept. The development of the availability of the pilot plant is shown in Figure 3.

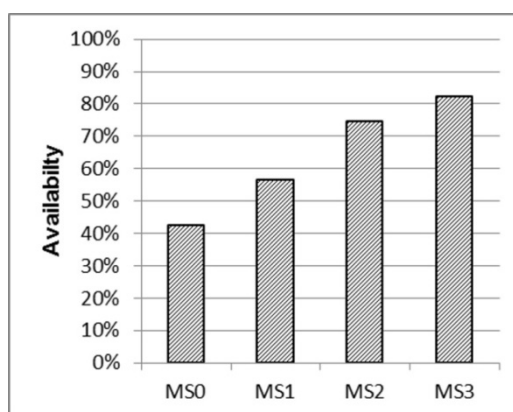


Figure 3: Development of pilot plant availability

During 3 years of continuous improvement of the gasification concept based on findings of several test runs some milestones (MS) of major improvements in the availability can be identified. The starting value of 42.6% calculated availability of the pilot plant increased significantly through the implementation of a reliable advanced biomass feeding system (MS1) to a value of 56.6% availability. A further major increase in the availability to 74.5% was achieved by the optimization of the bio-char discharge system (MS2). The current level of 82.4% (MS3) was reached by the implementation of an inorganic discharge system, which allows the separation of impurities derived from biomass and also agglomerations during continuous plant operation. Ongoing development promises a further increase in the availability of the gasification concept.

3.3 Upscale possibilities

Investigations on upscale possibilities of the gasification setup with 1.2MW thermal power have been carried out on a gasification plant based on the floating-fixed-bed technology. The gasification plant, shown in Figure 5, is operated since 2012 in Southern Tyrol / Italy.



Figure 4: 500kW pilot plant



Figure 5: 1.2MW upscaled gasification plant

Several test runs showed promising results and approved the flexibility in scale of the floating-fixed-bed concept. Since 2014 the 1.2MW gasification plant is in a state of continuous operation. The upscale limit for a single reactor is actually predicted with 2MW thermal power.

4. FUEL FLEXIBILITY

Current work packages focus on the utilization of alternative fuels, conditioned as pellets (like straw pellets). As the floating bed behaves much more tolerant against low melting points of materials (due to missing hot spots similar to fluidized bed reactors) these test runs will provide many new experiences and conclusions. A laboratory testing procedure for alternative fuels has been developed to analyze the chemical and physical characteristics (e.g. thermal shrinking of pellets, mechanical stability of pellets, elementary analyses, melting behaviour etc.) (Hofmann et al. 2011). Until now, several different fuels (mainly agricultural and silvicultural residues) have been pre-tested. Test runs with different kind of wood pellets have already started in the beginning of 2011 in order to describe the operation conditions with this fuel shape and showed that especially the diverse bulk behaviour in relation to wood chips leads to restrictions within the floating-fixed-bed concept. Further amendments were necessary to allow the operation on pellets from e.g. forestry residues, which led to an adapted reactor design for the utilization of pelletized biomass. First test runs with wood pellets show promising results and indicate a successful adaption of the floating-fixed-bed concept which provides the basis for the utilization of pelletized alternative biomass like straw, biogas residues or forestry residues.

4.1 Influence of ash constituents

One of the actual research focuses is the description of the gasification behaviour different biomass types for the utilization in the PowerBox gasification setup. The gasification of agricultural residues, for example crop straw, has to deal with lower ash melting temperatures mainly caused by higher amounts of alkali salts (Rathbauer, Thrän & Kaltschmitt 2001). Other problems are the release of these alkali metals and chlorine emissions with high gasification temperatures (Bläsing, Zini & Müller 2012). Hofmann et al. (2012) discussed an approach with controlled carbon degradation to avoid sintering effects in hot temperature zones through a dilution of the ash by the remaining carbon. The results indicate higher carbon conversion ratios for the Boudouard reaction and the heterogenous water gas reaction.

For a further investigation of the enhanced carbon degradation in the gasification of straw compared to wood several bench-scale gasification experiments have been carried out using a tubular reactor with CO₂ as gasification agent to simulate the Boudouard reaction. The following table shows the biomass characteristics which were used for the gasification experiments.

Table 4: Biomass composition and key figures

	Spruce	Wheat straw	Spelt straw
Carbon [% _{dm}]	50.4	47.5	45.7
Ash [% _{dm}]	0.3	4.0	5.9
Potassium [ppm]	347	10,500	5,820
Silicon [ppm]	64	6,180	17,100
Ash melting [°C]	1,350	~850	~1,000

The results of the gasification of the three biomass resources in tubular reactor experiments in reducing CO₂-atmosphere is exemplary shown in Figure 6.

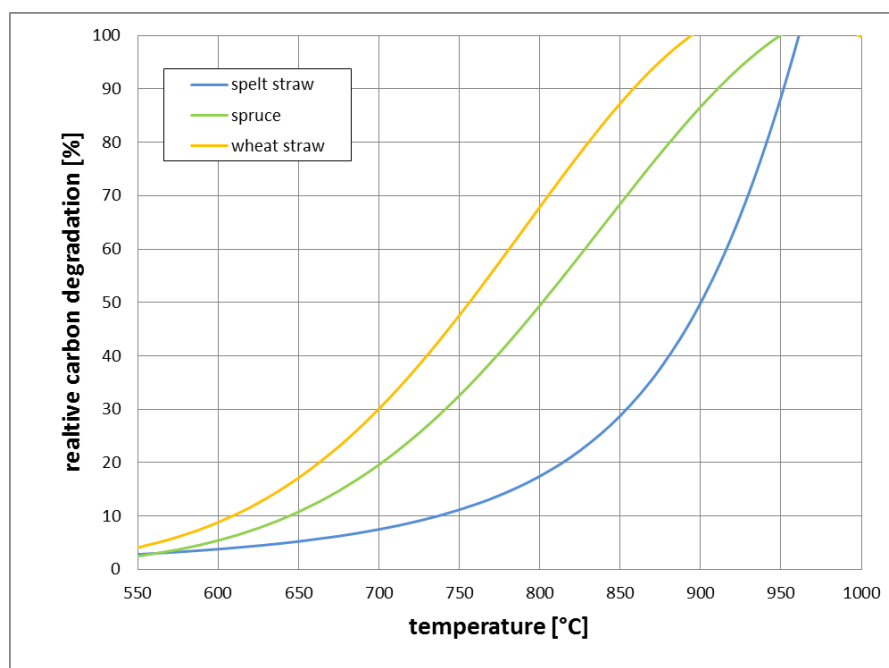


Figure 6: Carbon degradation as function of gasification temperature: RSM – tubular reactor

The results indicate a possible gasification temperature reduction for an equal target carbon conversion. A possible explanation for the enhanced carbon degradation could be found in a catalytic influence of ash constituents like potassium, which is well known for its catalytic effect in coal gasification (Koenig, Squires & Lauerendeau 1986; Mims et al. 1984). With an excess of silicon concentration over potassium, see also Table 4: Biomass composition and key figures, the effect was reversed regarding the gasification kinetics following Boudouard reaction.

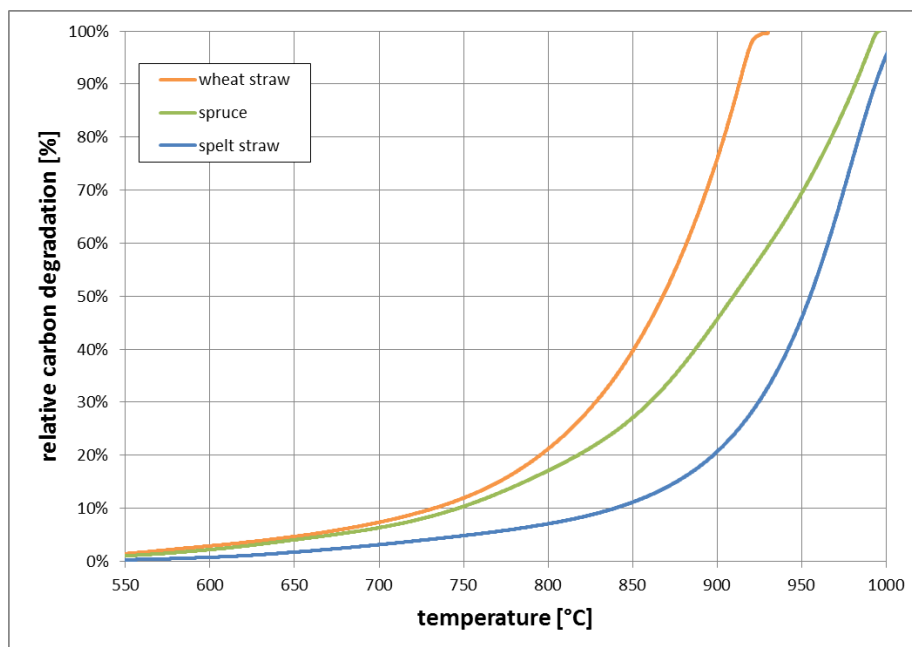


Figure 7: Carbon degradation as function of temperature – TGA

The same effects could be measured in the thermogravimetric analysis (TGA) of the biomass resources, shown in Figure 7. The difference in the curve progression regarding the temperature can be explained through the nature of the analysis. While the TGA was measured with a constant heating rate the tubular reactor experiments were carried out at isothermal conditions with several temperature levels.

To verify the influence of potassium and silicon first thermogravimetric analyses have been carried out with potassium and silicon as additives to spruce raw material.

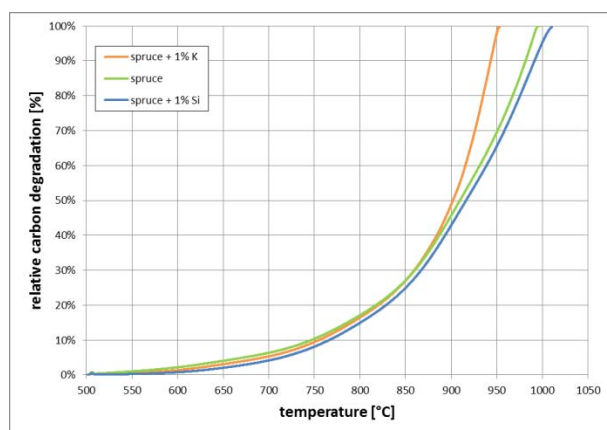


Figure 8: Carbon degradation TGA – spruce with additives

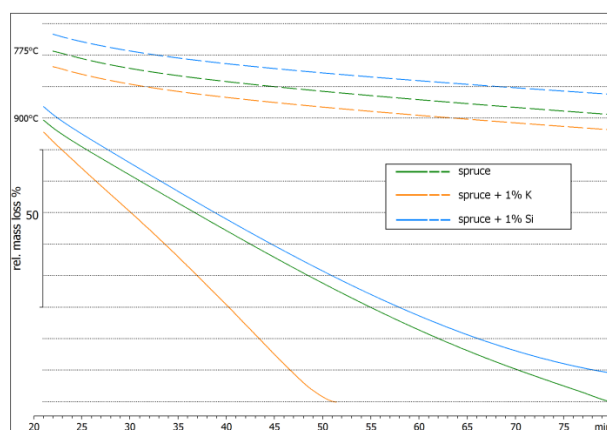


Figure 9: Carbon degradation TGA isothermal – spruce with additives

First analysis with spruce and additives show the catalytic effect of potassium on the gasification reactions, especially under isothermal conditions. Silicon as single additive shows a minor influence onto the carbon degradation. Further analysis on the influence of potassium and silicon on the gasification reaction and also blends of both with changing excess will be carried out.

5. SUMMARY AND CONCLUSION

The floating-fixed-bed technology closes the gap between small-scale fixed-bed (up to 300 kW thermal power) and fluidized bed (starting from 10 MW thermal power) gasification plants. The system provides a low tar product gas for the utilization in decentralized CHP-plants which already demonstrated its long-term reliability with the use of wood chips. First test runs of the adapted reactor design for the utilization of pelletized fuels show promising results and prove the flexibility of the technology in terms of fuel flexibility.

In addition to the adaption of the gasification setup some important biomass characteristics could be identified during biomass testing and characterisation. Especially the description of the potassium / silicon ratio onto the gasification reactions showed to be from important parameter for the utilization of alternative biomass. The adaption of the gasification temperature has the potential to avoid sintering and agglomeration effects with similar carbon conversion levels.

6. OUTLOOK

Based on the project findings, in a follow-up project PowerBox² started in 2013, the setup of the gasification plant will be optimized for the gasification of industrial pellets in order to utilize alternative biomass, especially forestry residues (needles, bark etc.) or agricultural residues. The further development for pellets applications allows the utilization of a broad range of fuels.

Beside the adaption of the gasification setup further investigations will be carried out to clarify the influence of ash constituents onto the gasification reactions as well as the transferability of these findings onto the operational parameters of the gasification plants.

7. ACKNOWLEDGEMENT

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