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**Low Tar and High Efficient Gasification Concept**

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***Abstract***

A new concept for low tar and high efficient gasification of moist and wet fuels such as wood and sludge has been developed. Designs of medium and large scale CHP-plants based on the new concept are suggested. COWI and the Technical University of Denmark have a patent pending for the new concept.

The new gasification concept combines and integrates the well known processes:  
1. Two-Stage gasification, 2. drying with superheated steam, 3. pyrolysis with superheated steam and 4. gasification with steam.

The fuel is dried by superheated steam. The steam produced in the dryer is superheated to 600-800°C and let to the pyrolysis zone. In the inert pyrolysis zone

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the hot steam will pyrolyse the fuel. The volatiles from the pyrolysis zone is led to a partial oxidation zone, where the oxidation agent is added. Hereby the volatiles are partially oxidised and the tar contents is dramatically reduced. The hot gases from the partial oxidation zone and the char from the pyrolysis zone are led to the gasification zone where the char is gasified.

### ***Introduction***

There is a large market for medium and large scale biomass gasification combined heat-and power plants (CHP). The existing atmospheric pressure gasification technologies for medium and large scale gasification are complicated in order to reduce the tar-content in the produced gas and have low electrical efficiencies.

The purpose of this work was to develop medium and large scale CHP biomass gasification concepts with high energy efficiency and low tar content in the produced gas.

### ***Background of the new gasification concept***

Experience with and insight in

- fundamental processes of pyrolysis and gasification
  - industrial drying technics
  - the demand of medium and large scale low tar and high efficient gasifiers
- was the inspiration to develop a new concept for medium and large scale low tar and high efficient gasification.

The new gasification concept combines the advantages of

1. Two-stage gasification
2. Drying with superheated steam
3. Pyrolysis with superheated steam
4. Gasification with steam.

### **1 Traditional two-stage gasification**

The two-stage gasification process developed on the Technical University of Denmark throughout the 1980ies and 1990ies, has a very high cold gas efficiency: 92-97% and the tar content in the produced gas is extremely low: below 25 mg/Nm<sup>3</sup> [1]. The tar content in the gas after the gascleaning (particle filtration) is about 5 tar/Nm<sup>3</sup> [1].

In the two-stage gasification process, the pyrolysis and the gasification process are separated into two different zones. In between the pyrolysis and the gasification zones, the volatiles from the pyrolysis are partially oxidised. Hereby, most of the tars are decomposed into gas [2].

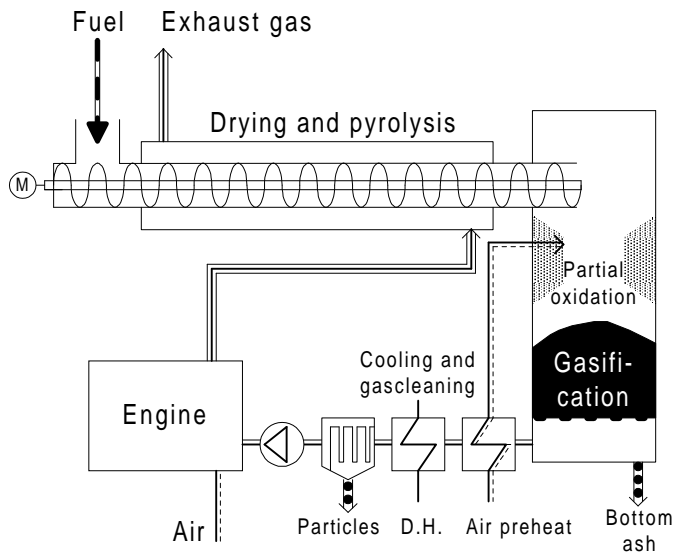


Figure 1: Traditional two-stage gasifier developed at DTU (the Technical University of Denmark).

In Figure 1 a traditional two-stage gasifier is shown. The pyrolysis reactor is indirect heated, and the gasification reactor is a fixed bed.

Table 1 The tar content in the raw gas after the gasifier before filtering.

Institution	Method	Date	Tar content mg/Nm <sup>3</sup>
Danish Technological Institute	Gravimetric	23 nov 1999	25
		24 nov 1999	25
	GCMS	23 nov 1999	5
		24 nov 1999	25
The Technical University of Denmark (DTU)	GCMS	9 sep 1998	16
		10 sep 1998	3
	GCMS	23 nov 1999	3
		24 nov 1999	6
Royal Institute of Technology, Sweden/DTU	Solid phase adsorption (SPA)	8 measurements 23-24 nov. 1999	5-18 Average 10
Risø National Laboratory, Denmark	GCMS	9 sep 1998	16
		10 sep 1998	2,5

It is seen in Table 3.1 that the tar content has been measured by several institutions. and that it is extremely low in the gas after the two-stage gasifier.

To enable high energy efficiency, the thermal energy in the gasification gas and the exhaust gas is being used for drying, air preheating and for pyrolysis.

For small gasification plants (up to about 4-6 MW thermal), the traditional two-stage gasification technology can be used. A 3 MW thermal indirect heated drying and pyrolysis unit at Haslev strawfired power plant has been demonstrated [3].

## 2. Drying with superheated steam

Drying with superheated steam involves on or more external heatsource(s) (fluegas, hot oil, steam..) that are heat exchanged with water vapour evaporated from the product. The superheated steam is led back to the dryer, and is then the drying medium in the dryer (see Figure 2)

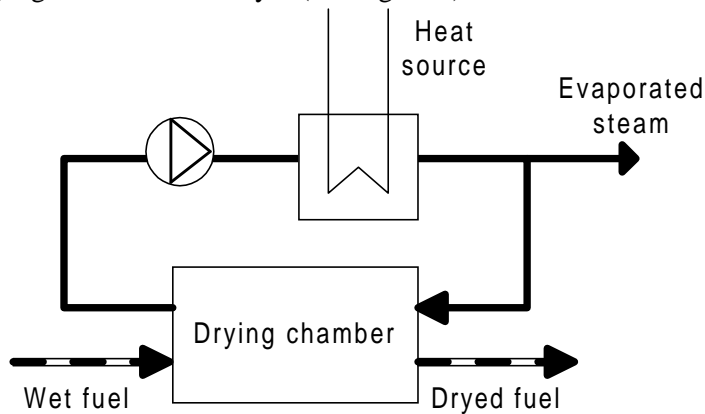


Figure 2 Principle of drying with superheated steam.

Drying with superheated steam is a well known technology, and it offers a number of advantages:

- *Environment friendly drying:* In many gasification processes, the fuel is dried directly by the flue gases, but hereby the exhaust gas becomes contaminated with organic compounds (acids and phenols) and particles. When the fluegas is heat exchanged with steam the fluegas is not contaminated, and can therefore without problems be used for district heat.
- *Fire hazards:* Since the oxygen content is extremely low in the dryer, when drying with superheated steam, the fire hazards are very low.
- *Better product after drying:* The product to be dried faces a low temperature gradient during the drying process, and therefore it does not break and crack as

- much as normally. The remaining moist in the fuel is also more evenly distributed when the product is dried in superheated steam.
- *Loss of product:* Due to oxidation, certain losses of the product is often seen, i.e. when biomass is dried with fluegasses.
  - *Drying rate:* In many cases, drying with superheated steam is faster than normal drying processes.
  - *Several heat sources:* Possible to use several heat sources in series.
  - *Drying of sludges:* Superheated steam dryers are developed to dry very wet fuel such as sludge.

Superheated steam dryers have been developed to dry from 0,5 to 50 tons vapour pr. hour. This corresponds to 2,5 –250 MW thermal input if the fuel is woodchips with a moisture content of 50%

### **3. Pyrolysis with superheated steam**

Pyrolysis with superheated steam is a well-known technology, used in kilns to make activated charcoal.

Since the produced steam from the dryer is used as the heat carrier for the pyrolysis process, the new two-stage gasification process is most applicable for fuels that are relatively wet. Moist content of about 40-60% is preferable. This makes woodchips ideal for this process, which however also will be able to use other biomass, sludge and selected solid waste's.

When dry fuels are used, other heat sources than the steam from the fuel must be added to the pyrolysis reactor:

- Additional water can be added to the dryer e.g. condensate from gas cooling or a condensing unit
- Other heat sources, e.g. returned charcoal, bed material or hot gases from the gasification chamber or radiation heat from the partial combustion zone, can be added to the pyrolysis process.

Since the heat carrier to the pyrolysing process is a fluid, the reactor can be formed as a moving bed or a fluidised bed reactor, where the steam is the fluidisation fluid as well as the heat carrier.

Experiments at DTU indicates pyrolysis reaction times of whole wood chips between 1-3 minutes [4].

### **4 Gasification with steam as gasification agent**

It is well known, that gasification with steam as gasification agent result in higher reaction rates than gasification with CO<sub>2</sub> [5]. If steam is the primary gasification

agent instead of CO<sub>2</sub> the temperature in the gasifier can therefore be lowered. There are several other advantages related to steam gasification.

- *Lower temperatures:* Experiments with a two-stage gasifier, with fuels with different moisture content, showed that the temperature in the partial oxidation zone decreases about 200°C when gasifying with steam compared to gasification of dry fuels. These observations are confirmed by mathematical modelling [6].
- *Lower soot production:* The amount of soot particles are reduced when gasifying with steam [1]. This is partly due to lower maximum temperatures and partly due to higher concentration of OH radicals which reduce the soot production.
- *Lower emissions:* The gas composition is different when steam is added as a gasification agent. The H<sub>2</sub> content is increased and the CO content is lowered. The results in a faster combustion and lower emissions of CO and NO<sub>x</sub>.

### ***Presentation of the upscaled two-stage gasification concept***

In order to be able to build medium and large scale biomass or waste gasification plants that are sturdy and have a high electricity and heat production, the two-stage gasification process should be modified. The challenge was to develop a gasification concept in which the drying and pyrolysis are directly heated instead of indirectly heated.

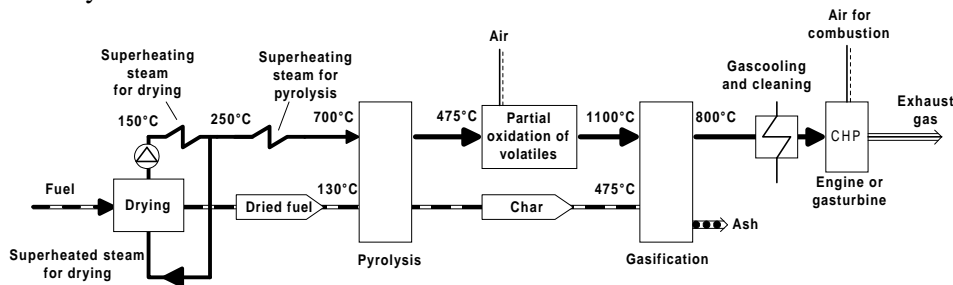


Figure 3 Basic concept with approximate temperatures.

The essential news in the upscaled two-stage gasification process shown in Figure 3, is that very hot steam, originating from the fuel, is used as the main heat carrier for the further process steps. In fluid bed applications the hot steam can also function as the fluidisation medium.

### ***Advantages of the upscaled two-stage gasification process***

The new gasification concept shown in Figure 3 can be designed in different ways.

Common advantages for the gasification plants will be that:

1. Low tar content in produced gas.
2. High energy efficiency (Cold gas efficiency about 90% even if the moisture content of the fuel is 60-70%)
3. The new two-stage gasification process is a combination of well-known technologies.
4. The gas cleaning will be relatively simple and sturdy.
5. Stable process: Pyrolysis reaction times of 1-3 minutes will result in a compact pyrolysis reactor and a stable gasification process even if the feeding rate varies.
6. Clean fluegas to be used for district heat in condensing mode without cleaning of condensate.
7. No fire hazards in dryer.
8. Low maximum temperatures in gasifier.
9. Low soot production.
10. Low emissions from combustor
11. Fuels with moist content of 40-60% preferable.
12. Pyrolysis of biomass with steam and gasification of biomass with steam makes excellent activated carbon.

#### *Moving bed design*

In a medium size (5-20 MW thermal) two-stage gasification plant, the pyrolysis and the gasification reactor can be of a moving bed type.

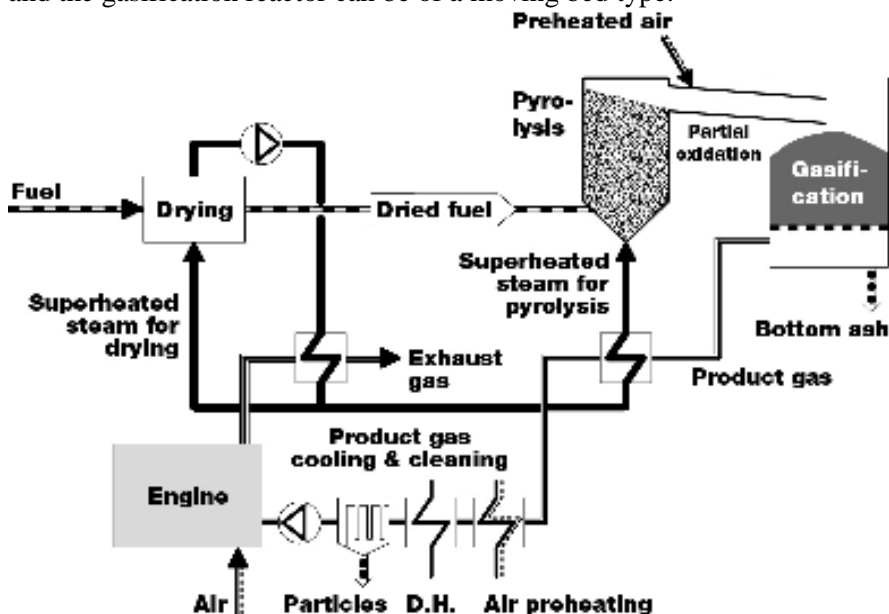


Figure 4 Schematic example of a two-stage gasification plant with pyrolysis and the gasification reactors of moving bed type.



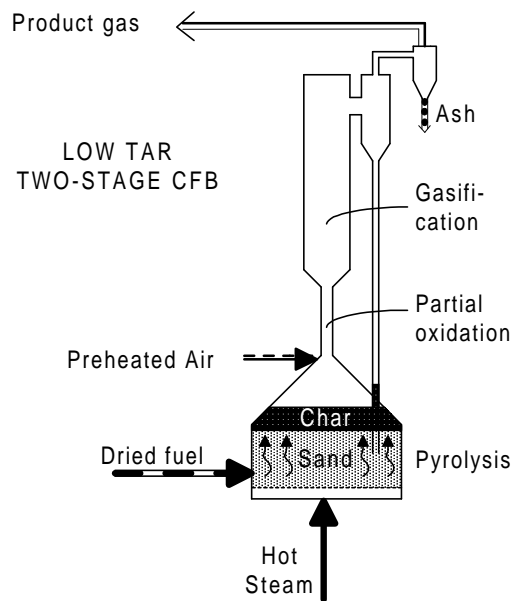
The design shown in Figure 4 is based on the well known fixed bed two-stage gasifier. The pyrolysis reactor is in this design direct heated by the hot steam instead of indirect heated by hot fluegasses. Hereby the retention time of the biomass in the reactor can be reduced from about ½-1 hour to about 1-3 minutes. The size of the pyrolysis reactor can therefore be reduced. Model calculations of a CHP plant with gas engines as suggested in Figure 4 shows an electrical efficiency between 30-35 % and a total efficiency above 90%.

**Fluid bed designs**

The pyrolysis and gasification reactors in the new two-stage gasification concept can be designed as fluid beds.

The pyrolysis and the gasification could take place in two fluid bed reactors as suggested in [7] with a high temperature partial oxidation zone in between as in Figure 3.

A more compact solution could be designed if the pyrolysis, the partial oxidation and the gasification process is integrated in one large fluidised bed reactor (see Figure 5).



*Figure 5 Possible fluid bed design of a medium and large scale low tar two stage gasifier.*

In the gasifier design shown in Figure 5, the pyrolysis zone is a bobbling bed in inert atmosphere, where steam is fluidisation media, and steam and recirculating char

and sand is heatcarrier. The air inlet is above the pyrolysis zone and the tars are partial oxidised. The gasification zone is a circulation fluid bed (CFB), with partial oxidised volatiles and steam as fluidisation media and heatcarrier.

The flows in the different zones and separation of sand and biomass are demonstrated and visualised in a small transparent fluid bed.

**Low tar fluid bed and IC engines.**

The gasifier shown in Figure 5 can produce gas to one or several gas engines. This type of combined heat and power plant could be built in the size range of 10-30 MW thermal input (see Figure 6)

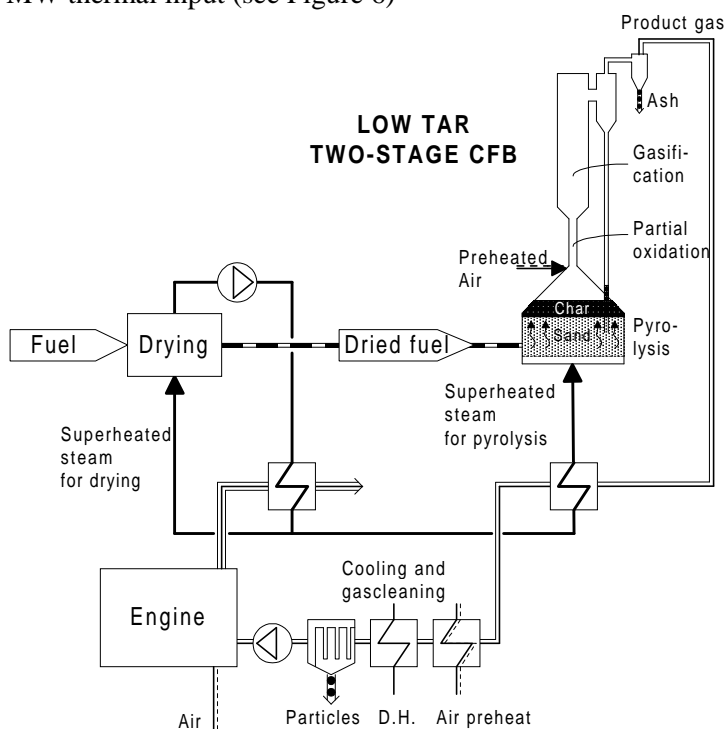


Figure 6 Schematic example of a medium size low tar two-stage gasification plant with gas engine(s)

Model calculations of a CHP plant with gas engines as suggested in Figure 6 shows an electrical efficiency of 30-35 % and a total efficiency above 90%, even at 60% moisture in the fuel.

### Low tar fluid bed and Combined Cycle

In a large scale (30> MW thermal) two-stage gasification plant, the gasification plant should be designed as a fluid bed e.g. as the design of the gasifier in Figure 5 and the energy system should be a Biomass Integrated Gasification and Combined Cycle (BIG/CC) system.

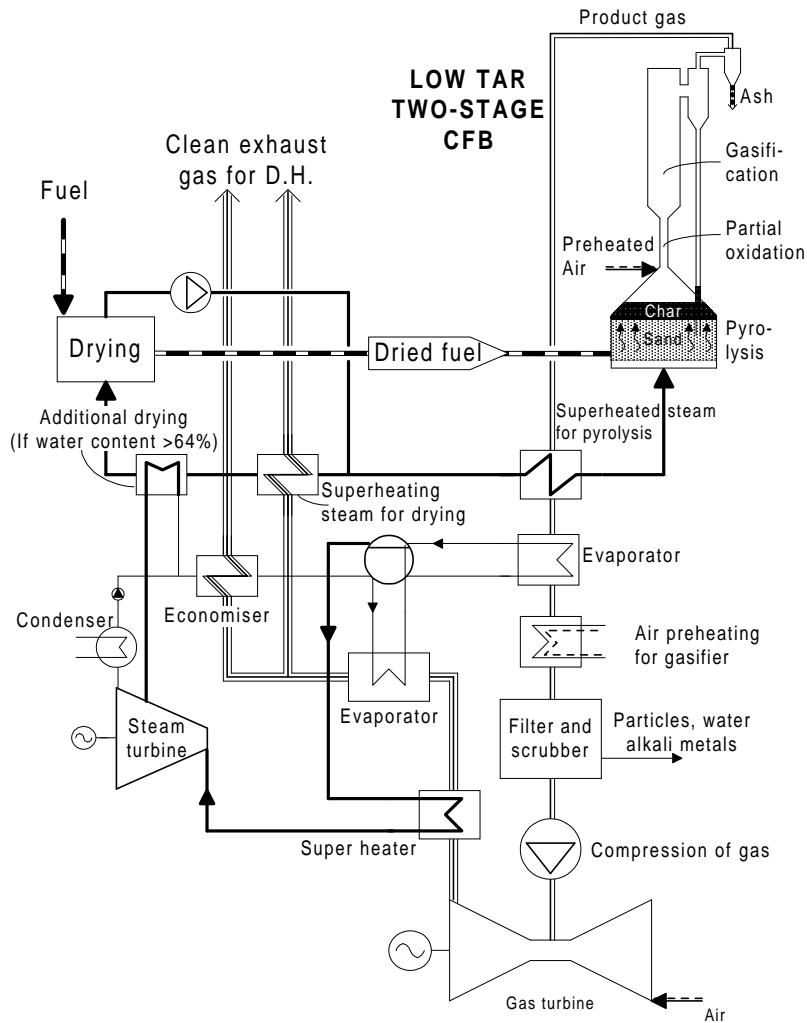


Figure 7 Schematic example of a large scale low tar two-stage gasification plant with Combined Cycle.

When the drying is done by superheated steam with external heat supply, different heat sources can be used. It can be fluegas but also medium pressure steam from the steam cycle can be used if the fuel is very wet. Hereby fuels with moist contents above 70% can be gasified with high energy efficiencies in an atmospheric low tar gasifier.

Model calculations of a BIG/CC plant as suggested in Figure 7 shows electrical efficiencies between 40-45 % and total efficiencies between 80-90%.

### Electrical efficiency at different water contents

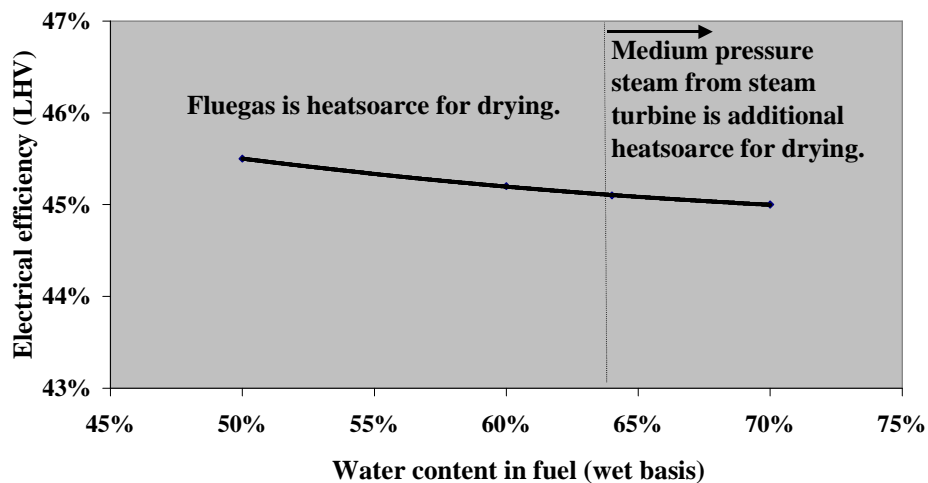


Figure 8 preliminary calculations of electrical efficiency versus water content in the fuel calculated on the plant shown in figure 7. In these calculations the inlet temperature and pressure of the gasturbine is 1150 °C and 20 bars.

In figure 8 it is seen, that the electrical efficiency remains high even if the water content is as high as 70%. It is therefore possible to built a high efficient plant using sludge as a fuel using this gasification concept.

### Conclusions

A new concept for low tar and high efficient gasification of moist and wet fuels combining the advantages of known processes has been developed. Designs of medium and large scale CHP-plants based on the new concept are suggested.

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