

OPERATIONAL RESULTS FROM GASIFICATION OF WASTE MATERIAL AND BIOMASS IN FIXED BED AND CIRCULATING FLUIDISED BED GASIFIERS.

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1 Abstract

The paper will discuss the application of different gasification principles relating to the utilisation of various types of feedstock based on operational experience from existing plants.

The economical and technical viability of a gasification plant strongly depends on its capability to cope with a variety of feedstocks either by direct feeding or indirect feeding, i. e. employing a feedstock pre-treatment.

Furthermore the gas composition originating from different feedstocks should not vary too much relating to the heating value in case the producer gas is used as a fuel gas for energy production or relating to the hydrogen/carbon-monoxide ratio in case it is used as a synthesis gas.

Thus, already in a very early stage of the project a decision on the gasification principle has to be made. The decision will have impact on other plant components such as feedstock pre-treatment and handling, gas conditioning (conversion, cleaning) or waste water treatment when applicable.

Two commercial installations – based on fixed bed and circulating fluidised bed gasifiers – with markedly different demands on the product gas quality and the feedstock will be described. Experience gained so far from extending the fuel range and the impact on the gasifier performance will be discussed.

2 Principles of Gasification in the Circulating Fluidized Bed (CFB)

The circulating fluidized bed has characteristics combining the advantages of both the stationary fluidized bed and the transport reactor. The process is characterized by a high difference in velocities between the solids (the fuel and bed material) and the product gas, the so-called 'slip velocity'. This difference in velocities ensures the intimate mixing of gas and solids thus prompting a high level of mass and heat transfer. Small particles are converted instantaneously or carried over and are recycled. Larger

particles are consumed more slowly, recycling within the main reactor bed, until they become small enough for external recycling.

The CFB system comprises a reactor, an integral recycle cyclone and a seal pot with connecting lines. As a result of the high gas velocities (5-8 m/s) almost a large part of the solid particles are entrained and discharged from the reactor. The solids separated in the cyclone are returned to the reactor via the seal pot. The gasifying agent, air, is fed as primary air through the nozzle grate and as secondary air at a level above the fuel supply point. For biomass, the only fuel preparation required before it is fed into the gasifier is size reduction to below 25-50 mm and removal of major iron and other metal components.

The gasification reactions begin immediately the fuel is fed into the reactor. A uniform bed temperature profile is established because of the high re-circulation rate of the bed material and the high heat exchange efficiency in the CFB system. This ensures rapid heating of the incoming fuel. Significant expansion of the fluidized bed is a further important effect of the high recirculation rate. There is no freeboard which means that the bed material is almost uniformly distributed inside the reactor, having the advantages of a high carbon conversion rate of the fuel (C content of the coarse bottom ash < 2 %) and a low hydrocarbon content in the gas. This is of particular importance if the gas is to be dedusted and cleaned downstream.

The gasification process takes place at pressures slightly above ambient (approx. 1.3 bar) and at temperatures between 800 and 950 °C depending on the reactivity of the fuel. The product gas leaves the cyclone at reactor temperature and with a dust content of about 20-50 g/mn³. The dust content depends on the fuel type and its ash structure.

Fuels for CFB Gasification

The CFB pilot plant with a capacity of 1.7 MW_{th}, originally built for developing the combustion process in the Lurgi laboratories (Frankfurt/Main), was adapted by changing the fuel feeding system, providing additional measuring points etc. to convert the plant to operate the gasification process.

Since 1983 the pilot plant has been operated in the gasification mode for a total of more than 6,000 hours mainly in test campaigns of several days.

Fuels tested include bark, green woods, grass, SRF (short rotating forestry), demolition wood, construction wood, paper, rubber waste, refuse-derived fuel, plastic waste, miscellaneous wastes, petrol coke, hard coal, lignite, lignite ash with a high C content, sewage sludge. The tests demonstrated the fuels to be suitable for CFB gasification.

2.1 Direct Integration - Concept of a new Kiln Line at Rüdersdorfer Zement GmbH

Following the takeover of Rüdersdorfer Zement GmbH by Readymix AG, a comprehensive restructuring program was launched. This program comprised all production stages of cement manufacture from limestone extraction through to cement shipment. The focus of these actions was on the construction of a new kiln plant with a throughput capacity of 5,000 t clinker per day as a substitute for 7 old kilns.

Important prerequisites for the concept of the kiln line were high flexibility in utilizing secondary raw materials and fuels for cement production, without any tradeoffs concerning environmental protection or quality of the product while at the same time leveraging to a maximum extent the possibilities of production-integrated environmental control.

These prerequisites were taking account of the situation that the raw-material and fuel-intensive cement process provides excellent conditions for the utilization of secondary resources which involve a high cost curbing potential. As another important raw material component, lignite ash – with a relatively high content of unburned carbon – was available. These fuel residues are to become part of the raw meal. If they were contacted with the kiln offgases in the cyclone pre-heater of the kiln at about 360 °C, they will be partly burnt leading to an undesirable offgas temperature increase. This will jeopardize compliance with the officially prescribed emission limits for carbon compounds. But also feeding this high ash fuel directly to the kiln as a viable alternative implies serious process drawbacks because the high content of minerals would substantially influence the quality of the product. However, feeding it further downstream to the process, improvement achieved at great expense in the upstream stages through mixing bed, gravi-metric dosing and quality control in the raw mill as well as homogenizing silos, would be impaired again. It was therefore essential to provide for a burnout of the ash to add it after the raw mill and exploit its energy content at maximum economy.

This scope of requirements led to the first-time integration of a circulating fluidized bed with a cement kiln plant. In accordance with its function, the fluidized bed reactor is arranged between the raw mill and the kiln.

The new technology makes it possible to convert diverse residues, both those containing carbon with a high portion of minerals and the respectively low calorific value and those of high calorific value, into a fuel gas under sub-stoichiometric conditions in the fluidized bed. In the circulating fluidized bed, the residues are separated into combustible and mineral components. The accruing weak gas is fed without further intermediate treatment to the calciners of the cement kiln, the entire burnt out ash is passed through an ash cooler into the raw mill where it is accurately metered into the raw mill as a feed component. This means that no residue remains.

In the circulating fluidized bed, waste is thus becoming a resource for the cement process by complete conversion to energy and feed material.

2.2 Plant Description

The cement kiln plant operates on a dry process, being equipped with a two-line pre-heater in five cyclone stages and with two calciners. In order to achieve the high degree of de-carbonization required for the raw meal even before the short rotary kiln, about 62 % of the total fuel demand of the kiln plant is supplied through the calciners.

The CFB essentially comprises the following plant units:

- storage and feed supply facilities
- gasification reactor with cyclone and recirculation of the fluidized bed material

- discharge of the burnt out ash (hot ash), cooling and transportation of the ash to the raw mill
- fuel gas duct to the calciner
- provision of utilities: air, natural gas, inert gas, preheating burner, flare, instrumentation

Provision of Feed Materials

A maximum of four different materials may be supplied to the CFB simultaneously through four different hopper and feeding systems:

1. Materials that can be handled by blowing, directly into the gasification reactor by means of pneumatic conveying
2. Lumpy fuels directly to the gasification reactor by means of mechanical conveying
3. Mineral residues with upstream drying by means of mechanical conveyance to the seal pot
4. Residues which are difficult to handle or lumpy fuels by means of mechanical transportation into the seal pot

In the first case, the feed material is metered in through an impact plate system and in the other three cases, with speed controlled discharge devices.

The hoppers are placed on load cells for better monitoring and calibration of the material flow. In order to achieve reliable sealing of the hoppers towards the environment, a small amount of seal air is supplied to the mechanical feed devices.

Gasification Reactor

Preheated air from the ash cooling system is supplied to the reactor as gasification air. It is composed of primary air which is routed via the nozzle grate and additional fluidizing air as secondary air. The air is delivered by Root's blowers.

The solids/gas mixture is separated in the recycle cyclone. Via a seal pot, the solids are returned to the gasifier and recirculated until they are burnt out.

Hot Ash Discharge and Cooling

The ash is burnt out to a residual carbon content of not more than 2 %. Via a rotary valve it is discharged from the reactor bottom and passed on to the pre-chamber of the ash cooler. The ash cooler is fluidized with air which is subsequently utilized as secondary air in the reactor. The heat exchange with primary air which has to be kept dust-free is effected through tube bundle heat exchangers.

Any coarse particles entrained into the ash cooler with the ash which may hamper the fluidization of the ash can be discharged through a cooling screw.

Fuel Gas Duct to the Calciner

The fuel gas, dedusted in the recycle cyclone, is fed to the two calciners without further gas treatment. By means of gas tight gate valves in the fuel gas ducts, a safe separation between CFB and cement kiln can be effected in the event of an upset case.

The pulverized coal burners of the cement kiln have been designed such that it is possible in such a case to operate the kiln without CFB.

2.3 Operational Results

As secondary fuels for weak gas production, primarily shredded used wood and light recycling fractions which cannot be exploited further as materials are applied. Sizes of up to 50 mm are accepted. In spite of the mostly low calorific values (ncv = 12,000-15,000 kJ/kg) and the high water content (up to 35 %) of these substances, the combustion conditions warrant a sufficiently high gas quality and, in conjunction with the cement kiln, a very good burnout. The low emission levels for organic compounds attest to this situation and are attained despite the fact that the combustion temperatures are always below 1,000 °C in this case. The missing temperature is apparently more than compensated by the combustion conditions and the retention time (CFB approx. 4 seconds, calciner approx. 6 seconds).

A further positive effect is observed with respect to NO_x emissions which are reduced in the cement kiln offgas by about 300 mg/Nm³ if part of the hard coal for firing the calciner is replaced with gas from the CFB. It is to be assumed that here the fuel distribution is better and the changed kinetics of reaction make it possible for the gaseous components CO and hydrocarbon radicals to reduce the NO_x from high temperature combustion in the main firing system of the cement kiln.

Another important prerequisite for disturbance-free operation has proved to be the removal of undesired components like metals or stones during the preparation process. In the initial phase, such undesired materials were repeatedly leading to cloggings on the material route, damage to rotary valves and screw conveyors or deposits on the nozzle grate of the reactor and ash cooler which caused interruptions in operations.

An absolutely new task for the CFB was to produce besides the gas, major amounts of burnt out ash. With respect to the allowable feed particle size, more exacting demands have to be made on the feed materials with elevated mineral content than on the secondary fuels ($d_{\max} = 5 \text{ mm}$, $d_{50} = 0.5 \text{ mm}$). The initially mentioned ash component is therefore comminuted in an impact breaker and screened. In the case of other materials which have so far been supplied as partial substitutes for the ash, a reduction in size was not necessary because of their properties.

After commissioning, the hot ash discharge from the reactor and fluidization in the ash cooler proved to be unfavourable. The proper function of the discharge device could only be restored after replacing the tubular screw with a rotary valve. The necessary permanently uniform fluidization in the ash cooler was achieved by differentiated allocation of controllable blowers to individual chambers of the cooler. By reducing the amount of undesired components and extending the possibilities of emptying the cooler as needed it was possible to improve further the operational reliability.

The burnout quality of the ash does not present any problems. It is constantly monitored by means of a manual sampling device at the gasifier outlet and complies with the quality requirement $C < 2 \%$ and can therefore be described as inert.

Re-circulation of the ash to the raw mill leads to the desired quality assurance in the cement process. The standard deviation in the individual process stages can be used

as an important reference for this. It can be seen that the relatively low standard deviation of 2.2 in raw meal after homogenizing is rising in the next step, in the hot meal, to 3.5. The inevitable reason for this increase is supposed to be the ash content of the coal and will be the more pronounced in practice the higher the ash content is.

3 Application of Fixed Bed Gasification

The Schwarze Pumpe site (the literal translation means 'Black Pump') is located about 100 km (60 miles) east of Dresden, Germany.

Large lignite mines are to be found in the area around Schwarze Pumpe. Since lignite represented the only major energy source of the former German Democratic Republic (GDR), a number of large chemical, coking and power plants were erected in this region. The town gas plant at Schwarze Pumpe started production in 1964 with 24 fixed bed gasifiers. Schwarze Pumpe finally supplied about 75 % of the total town gas consumption of the GDR. After reunification, town gas production from lignite was replaced by natural gas.

Various ideas were pursued to use the existing facilities for the conversion of all sorts of wastes, contaminated solids and liquids and other difficult materials into useful products in an environmentally friendly manner.

In 1996, Schwarze Pumpe – now 'SVZ Sekundärrohstoff Verwertungszentrum Schwarze Pumpe' (Centre for the Re-use of Secondary Raw Materials) – was acquired by BWB-Berliner Wasserbetriebe (Berlin Water Authority).

Based on new environmental laws and regulations for the re-use of waste materials it was decided to proceed with the gasification route since most of the units that make up the gasification process chain have been available on site. Compared to conventional combustion methods gasification offers the advantage to produce synthesis gas for methanol production or fuel gas for power production e. g. from solid or liquid wastes.

3.1 Description of the Gasification Plant

Waste gasification is the core unit of the SVZ plant. Three types of gasifier are being commercially used in the present configuration.

Solid wastes such as plastics, sewage sludge, rubber, fluff, contaminated wood, residues of plant, household wastes etc. are processed in seven fixed bed gasifiers of the former town gas plant. These gasifiers have an inner diameter of 3.6 m and operate at a pressure of 24 bar. Gasification agent is a mixture of steam and oxygen. Gasifier capacity range from 8-14 t/h depending on feedstock composition. Since fixed bed gasifiers require fuel in lump form (20-80 mm) prior agglomeration of the feed by briquetting, pelletizing or some other method is required for the counter-current operation of descending fuel and rising gasification agent/produced gases.

Liquid wastes – such as tar/oil from the fixed bed gasifiers, used oils, solvents, oil/water emulsions – are gasified in a refractory lined, entrained flow gasifier. This type of entrained flow gasifier has been in operation since 1969 for the gasification of tar and oil from lignite coking.

A former GSP (Gaskombinat Schwarze Pumpe) entrained flow reactor for dry lignite gasification has been modified to process liquid feedstocks – e. g. oils and slurries. The reactor is equipped with a cooling system for operation at temperatures between 1,600-1,800 °C. The ash leaves the reactor in liquid form.

The gases from the entrained flow reactors are partly shifted prior to purification in a Rectisol gas purification unit.

3.2 Extensions of the SVZ Plant

Since the German reunification, the Schwarze Pumpe complex has undergone a number of major changes. Some plants have already been pulled down, e. g. the coke ovens; other are replaced by modern ones, such as the 1,000 MW lignite fired power plant and new plants will be or have already been added to serve SVZ's new purpose as centre for the use of secondary wastes.

Those plants include:

- Waste receiving and pelletizing
- BGL (British Gas Lurgi) gasification of various wastes; gas liquor separation
- 120,000 t/a methanol synthesis
- 75 MW_e gas/steam-turbine combined cycle power plant

The methanol synthesis and the combined-cycle power plant was started up in 1997. In principle, both plants represent well known, proven technologies for conventional fuels and feedstocks, respectively, like natural gas or (fuel) oil. The use of fuel-/synthesis gas from wastes and residues for methanol production and IGCC power generation is, however, new and unique. Those applications require special experience and know-how, as developed at SVZ, because of components in the waste feed – which are then found in the gas – that are not normally contained in natural gas or oil, or at least in much smaller concentrations.

Waste Receiving and Pelletizing

As mentioned earlier, fixed bed gasifiers require feedstock in lump form. Coal and coke are normally available in coarse form, 20-60 mm. Waste materials such as sewage sludge, plastics, household wastes of fine consistency or in rags, however will require agglomeration prior to being fed to the gasifier.

These materials are first crushed in a shredder to pieces below 60 mm. Iron and metals are removed magnetically or electrically, respectively. If required, organic and inorganic residues are removed either for disposal or separate pelletizing, which produces pellets of better quality. The wastes are then dried from about 30 % to below 10 % moisture, mixed with a binder, if necessary to improve pellet quality, and fed to pelletizing presses. In the presses the wastes are pressed by rollers through a die ring having a large number of 10-20 mm holes. In this way, pellets of 20-70 mm length are produced. Through internal friction pellets achieve a temperature of around 100 °C. They are subsequently cooled in a down-stream air cooler to around 30 °C.

The plant has a capacity of 120,000 t/a of household waste. Continuous operation has been established in early 2001 and since 2002 a daily throughput of more than 500 t has been achieved.

BGL Gasification

The pellets and other wastes are gasified at a pressure of 25 bar in a BGL fixed bed gasifier, using steam and oxygen as gasification agents. The BGL gasifier was developed by British Gas, London and Lurgi for the gasification of coals and cokes. It is the only gasifier in which gasification of large particles and vitrification of inorganic matter can be carried out under pressure in the same reactor.

Steam and oxygen are introduced at the bottom through so-called tuyeres (water-cooled tubes). Slag is withdrawn automatically – after quenching in the water filled quench vessel – from the slag lock hopper as a frit of about 3 mm. Crude gas leaves the top of the gasifier with a temperature of between 400-500 °C. It is then scrubbed with recycled gas liquor. CO-shifting of the gas flowing to the methanol synthesis is required to obtain the necessary H₂/CO ratio. Gas liquor from gas cooling contains tars and oils from the carbonization zone in the gasifiers. After separation by gravity tars and oils are recycled to the gasifier or sent to an entrained flow gasifier.

In the first step of extension one BGL gasifier has been installed. The gasifier capacity will vary with feedstock (i. e. waste) properties and composition. Construction on site started in the first half of 1998. The unit has passed successfully its guarantee run and has started a demonstration and optimization phase.

3.3 Operational Results

In the period between 1992 and 2001, close to two million tons of waste materials have been gasified, with waste plastics and sewage sludge being the main solid feedstocks. The addition of coal (lignite, briquettes) was required to comply with the permit issued by the environmental agency, Freiberg/Saxony. Basic engineering and permitting for the new BGL gasifier started in 1996. Already in August 1998, SVZ received a new permit from the permitting agency to increase the waste/coal ratio from 50/50 to 85/15 to further improve the economics of waste recycling.

Various ‘menus’ – waste mixtures – were established by SVZ which would represent the feedstock to be gasified at Schwarze Pumpe in the future. Large scale tests were carried out in 1996 in the existing fixed bed gasifiers to demonstrate the waste mixtures’ suitability for fixed bed gasification in general. These tests have confirmed that this type of solid waste could be converted under elevated pressure – 25 bar – into a crude fuel/synthesis gas.

In 2000 the BGL gasifier has been commissioned and the trial run period started. Significant changes to the WDC demonstration plant (British Gas Development Centre, Westfield, UK) are the scale-up of the inner reactor diameter from 2.4 m to 3.6 m and the gasification of waste material instead of coal. As a target a fuel mix ratio of 80 % waste and 20 % coal has been set. The main objectives of the trial run period are to become acquainted with the gasifier operational behaviour and to test out the capacity limits above design values. Prior to the utilisation of mixed fuel a test run using coal only has been carried out to establish operational parameters in comparison with the known

data of the demonstration plant. As expected the larger diameter clearly showed an improved bed behaviour in the reactor shaft, thus resulting in smoother operation.

In the following trial run gasification of mixed fuel was demonstrated. Starting on coal the content of waste material in the fuel mix has been increased stepwise up to the design ratio of 75 % waste and 25 % coal. Within this trial run the performance test has been carried out.

For the first time a fuel mixture containing up to 75 % waste material has been successfully converted into synthesis gas in a slagging fixed bed gasifier.

The ash content of waste and coal has been completely discharged as a glassy frit throughout the trial run. Analytical tests proved the non-leachability of the slag. Disposal requirements according to TA Siedlungsabfall, class 1 are met.

During the performance test the following production and consumption figures have been achieved:

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| - Mixed fuel (a. r.) | 27 t/h |
| - Specific oxygen consumption | < 0,2 m ³ n/m ³ n |
| - Gasification agent ratio steam/oxygen | < 1,0 kg/ m ³ n |
| - Raw gas (dry) | 31,500 m ³ n/h |

The gasified fuel mix consisted of 25 % hard coal, 45 % RDF pellets, 10 % plastic waste 10 % wood and 10 % tar sludge pellets.

The trial runs performed so far show potential to increase the gasifier load. In the forthcoming trial runs the fuel throughput will therefore be increased stepwise to check-out the maximum possible capacity.

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