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HTW based Gasification of Indonesian Low Rank Coal as an Alternative for an Efficient and Sustainable Production of Chemicals

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The demand on chemicals such as ammonia, urea, methanol etc. is continuously increasing worldwide; however, the pressure on the production costs leads to both: (i) looking for more efficient units and technologies, and (ii) looking for alternative resources. Recently natural gas (NG), being the main source for production of chemicals, became extremely expensive or sometimes even not available in some regions in Asia-Pacific. As a result, the chemicals produced on NG basis became non-affordable. Therefore, the use of new and cheaper sources such as low grade local coals could be an alternative not only to save, but also to provide a long-term, sustainable perspective for the whole sector. This issue became extremely topical in countries having huge reserves of low rank coals, such as Indonesia and India.

Gasification is a process of thermal conversion of solid carbonaceous materials into a gaseous fuel called syngas. Coal gasification is an efficient technology for a range of sustainable systems for producing low emissions electricity and other high value products such as chemicals, synthetic fuels etc.

The paper presents the High Temperature Winkler (HTW) gasification process which is specially designed for utilization of low rank feedstock such as coals with high ash content, *lignite, biomass etc. The process is characterized by (i) a bubbling fluidized bed, where coal devolatilisation and partial oxidation of coal char and volatiles take place and by (ii) a free board, where the gasification reactions occur. This process has been used for decades for industrial production of chemicals.*

The recent development of the high pressure HTW process will be reviewed. Further, gasification of low rank coals such as Indonesian coals with respect to gasification temperatures, conversion rates and syngas quality will be discussed. The main HTW design steps required for an industrial scale design are presented. Special attention will be given to accumulated experience in gasifying low rank coals and subsequent industrial production of chemicals.

INTRODUCTION

During the last three decades, the primary energy consumption has increased worldwide by about 70% (Figure 1) reaching 11 gigatonnes oil equivalent (Gtoe) at the end of 2009. There was a fast increase in oil and natural gas consumption having shares of 35% and 25% respectively of the total consumption.

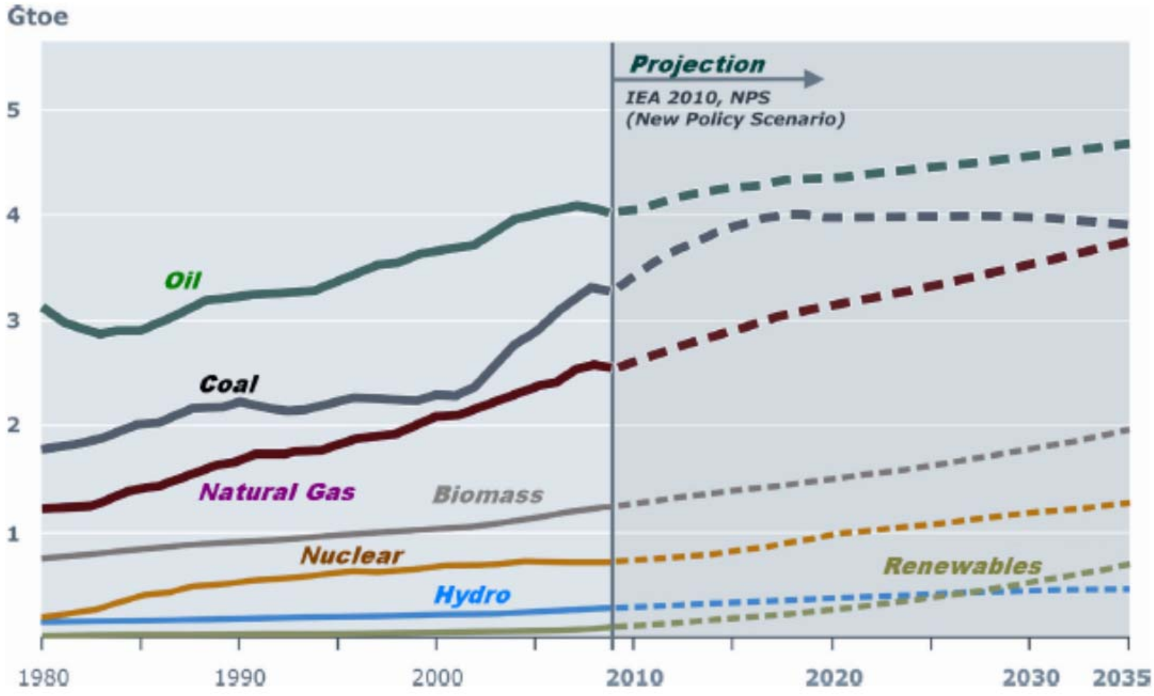

Fig. 1: Development of primary energy consumption worldwide (cumulative) and projections of IEA until 2035, [1]

Coal possesses the largest potential of all non-renewable fuels and provides 56% of the reserves and 89% of the resources worldwide [2]. Thus coal, being the most abundant, available and affordable fuel, has the potential to become the most reliable and easily accessible energy source and thus to provide a crucial contribution to the world energy security.

Indonesia plays an important role in world coal markets. According to the global energy statistics data [1,2], the proved coal reserves in Indonesia for hard coal and lignite are 13,500 Mt and 9,000 Mt respectively, as shown in Table 1.

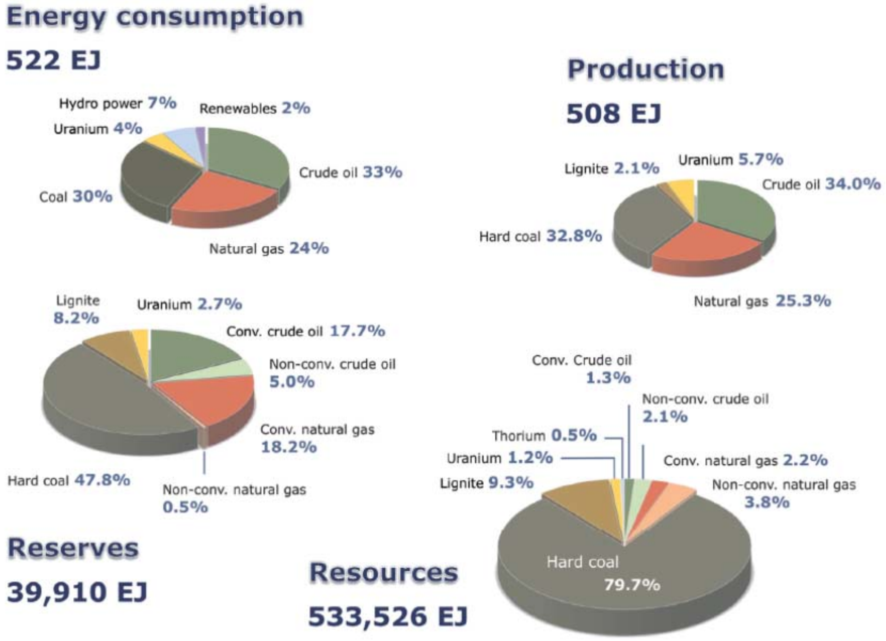

Fig. 2: Global share of all energy resources in terms of consumption as well as the production, reserves and resources of non-renewable energy resources as at the end of 2012, [1]

Closer look at this data shows that Indonesia contains abundant reserves in medium (5,100-6,100 cal/g) and low-quality (<5.100 cal/g) coal. These types of coal are competitively priced on the international market. The low price of Indonesian coal together with country's strategic geographical position towards the giant emerging markets of China and India made Indonesia the world's largest exporter of coal by weight taking a share of 30 % in the global coal market (383 Mt export for 2012). However, only hard coal is exported, while the lignite (due to their high moisture content) can be used only locally. From other side, Indonesia being currently the world's third-largest exporter of liquefied natural gas will start importing the fuel by 2018 to meet increasing domestic demand, according to the nation's energy regulator [4]. Indonesia is increasing the reliance on gas as crude oil output declines. As a result, the current price levels of LNG are about $16-$17 per million Btu, for domestic market around $10 per million Btu.

Table 1
Global figures for Indonesian coal, in Mt, 2012 [1]

	Reserves	Resources	Remaining Potential	Production	Export	Consumption
Low Rank	9,002	29,023	38,025	60,0	-	58,0
Medium Rank	13,511	91,285	104,796	383	322	65

Summarising, the increased demand for energy and chemicals inside the country lead to increased demand for NG and as a result to its high prices thus making LNG far too expensive for sustainable use in the country's energy and chemical industries.

Coal gasification, being one of the Clean Coal Technologies, provides an environmentally-friendly and efficient solutions not only for power production, but also for production of variety of chemicals, such as methanol, ammonia, hydrogen, as well as synthetic fuels such as synthetic natural gas (SNG), gasoline and Fischer-Tropsch liquids.

Gasification of low rank coals is even more attractive due to low prices of the coal and its local availability on the one hand and the high prices or the non availability of other resources such as natural gas and oil on the other hand. However, gasification of low rank coal, such as Indonesian coal, is not a trivial task. Among the existing state-of–the-art gasification technologies, namely entrained flow, fluidized bed and moving (fixed) bed, only the HTW (fluidized bed) and Lurgi (fixed bed) technologies have been applied commercially for lignite, thus being the only technologies that have a long term experience and the expertise in gasification of lignite. The reference plants are listed in Table 2.

Table 2
Commercial gasification plants operating with lignite as primary feed [5]

Plant Owner	Plant Name	Country	Year	Technology	Total Units	Syngas Capacity Nm^3 / day	Product
Dakota Gasification Co.	Great Plains Synfuels	United States	1984	Sasol Lurgi Dry Ash	14	13.900.000	SNG
Fabrika Azotnih Jendinjenja	Gorazde Amm. Plant	Former Yugoslavia	1952	LP Winkler	1	120.000	Ammonia
Sokolovska Uhelna, A.S.	Vresova IGCC Plant	Czech Rep.	1996	Sasol Lurgi Dry Ash	26	4.700.000	Electricity
RWE AG	Berrenrath HTW Plant	Germany	1986	HTW	1	840.000	Methanol

The High Temperature Winkler (HTW) gasification process was specially developed for utilization of low rank feedstock such as lignite. The technology development steps, the process description as well as the design steps will be discussed in details in the following chapters.

DESCRIPTION OF THE HIGH TEMPEATURE WINKLER (HTW™) GASIFICATION PROCESS

Historical

The HTW™ fluidized-bed gasification process is based on the Winkler generator which was developed in the 1920s in Germany by I.G. In 1920-30 I.G. were much concerned with the possibility of using low rank local coals, such as brown coal, instead of expensive coke, for synthesis gas production and subsequent production of ammonia and methanol. Dr. Winkler in 1921 conceived the idea of using a “boiling” bed, i.e. using particles of fuel small enough to be almost gas-borne and hence comparatively mobile. Under such conditions the fuel bed behaves very much like a liquid; the gas passing through the fuel gives an appearance as if the bed were boiling, the bed finds its own level, as does a liquid, and circulation of particles within the bed is such as to give substantially equal temperatures throughout the bed. This is what we actually call nowadays a fluid bed.

The first Winkler generator was put into operation at Leuna, Germany in 1926, making power gas and having a capacity of 40,000 Nm^3/h. In 1930 began the production of nitrogen-free water gas, which was obtained by continuous blast of pure oxygen with steam (Fig.3). Commercial-scale Winkler gasifiers were operated at atmospheric pressure in over 40 applications around the world. Just since 2000 there are more than 40 new atmospheric units build in China only. Thus the Winkler gasification process became widely used technology characterized with the following advantages:

- Low oxygen consumption due to moderate temperatures;
- Optional use of air or pure oxygen as an oxidant;
- Simple coal preparation;
- Good partial load behavior over a wide range of performance;
- Simple start-up and shut-down conditions;
- High operational reliability;
- No by-products in the raw gas, such as tars, phenols and liquid hydrocarbons, etc.

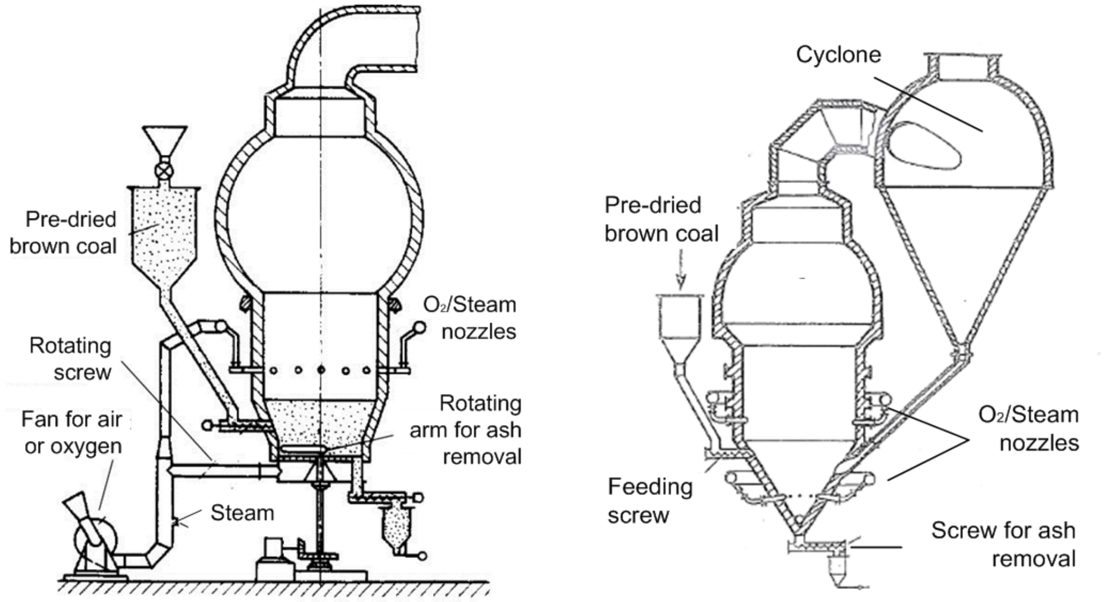

Fig. 3: Earlier Winkler generators
(i) with traveling grade, 1930s (left) and (ii) grateless modification, 1940s (right) [6]

In the 1970s, ThyssenKrupp Industrial Solutions together with Rheinische Braunkohlenwerke AG (now RWE AG) commenced with the development of a pressurised version of the Winkler gasifier – the High-Temperature Winkler (HTW^{TM}) gasification process. The development process went through several steps characterized by building and operating several pilot, demonstration and commercial plants operating at increased pressure as shown in Figure 4. This development led to adding several major characteristics to the said advantages of the atmospheric Winkler gasifier, such as:

- By increasing the pressure to 10 bar and higher the reaction rate and thus the specific performance per gasifier cross-section unit was increased, while the compressive energy required for the subsequent chemical synthesis was reduced;
- By increasing the temperature the methane content in the raw gas was reduced and the carbon conversion rate and thus the gas yields increased;
- By recirculating the dust fines entrained from the fluidized bed it was possible to essentially increase the C-conversion rate;
- Proven and robust systems such as dry dust filtration and waste heat recovery;
- Great variety of feedstocks (coal, peat, biomass, MSW etc.) and high flexibility regarding grain size of the feedstocks;
- High cold gas efficiency.
- Stable gasifier performance with great inherent safety due to large carbon inventory.

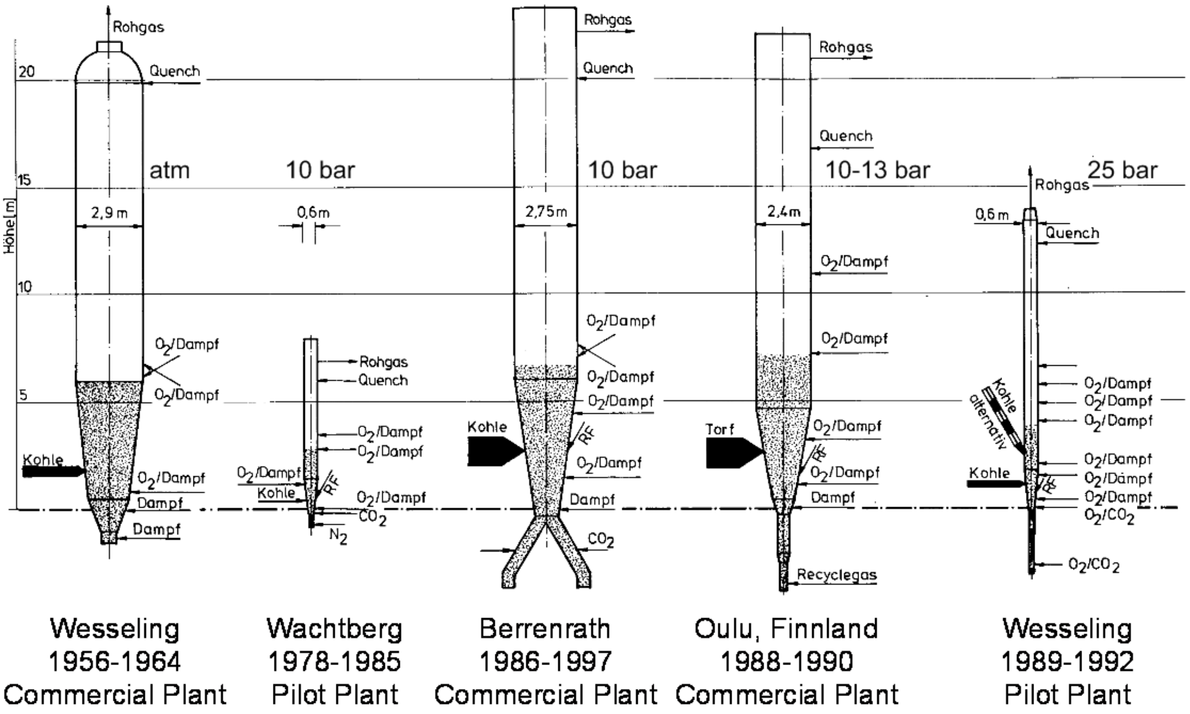

Fig. 4: Development steps in HTW Gasification

Thus HTW gasification plants, like the Oulu plant (Finland) gasifiying peat for ammonia [9], the Niihama plant (Japan) gasifying MSW for power [8] and the Berrenrath plant (Germany) gasifying German brown coal for methanol production [7] have been operated on commercial basis thus attaining industrial maturity. The latest was in operation for more than 12 years and is an excellent reference for the HTW^{TM} gasification technology (shown in Figure 5).

Fig. 5: HTW Demonstration Plant Berrenrath, Germany
Production Rates: 300 t /d Methanol, Total Operating Hours: 67,000h [7]

Some typical operating figures, obtained for industrial scale HTW™ gasification of different low rank feedstock are listed in Table 3.

Table 3
HTW™ gasification process data for industrial scale plant

Parameter	German lignite	Finnish Peat	High Ash Hard Coal*	Dimensions
Feed	23.2	21	76.2	t/h (d.a.f.)
C	68	58	70.8	Wt.-% d.a.f.
H	4.9	6.0	6.0	Wt.-% d.a.f.
O	25.7	33	20.7	Wt.-% d.a.f.
N	0.7	1.9	1.7	Wt.-% d.a.f.
S	0.6	0.3	0.8	Wt.-% d.a.f.
ID.T. reduced	>1,150		1,270	°C
Ash content	4.0	7.0	48	Wt.-% dry
Thermal Input	140	140	600	MW
Operating Pressure	10	10	30	bar
Fluid bed temperature	810	720	870	°C
Free board temperature	900	1,030	1,100	°C
Syngas Quality				
CO	45	35	48	Vol.-% (N_2 and H_2O free)
H_2	34	33	28	Vol.-% (N_2 and H_2O free)
CO_2	17	27	21	Vol.-% (N_2 and H_2O free)
CH_4	4	5	3	Vol.-% (N_2 and H_2O free)
Carbon conversion efficiency	95.5	90	93	Carbon in dry gas / carbon in feed, %
Synthesis gas ($CO+H_2$) yields	1,500	1,000	1,440	Nm^3 / t of feed, d.a.f.
Specific Oxygen Consumption	0.39	0.36	0.55	O_2 Nm^3 /kg of feed, d.a.f.
Cold gas efficiency	85	75	75	% (100 x Heating value of product gas, MW_{HHV} / Heating value in feedstock, MW_{HHV})

*estimated

THE HTW™ PROCESS

The HTW™ process involves (Figure 6) a gasification unit consisting of a feeding system, the gasifier itself, a bottom product removal system located below the gasifier, a gas exit in the head of the gasifier with a cyclone. In the following steps the raw syngas is cooled down and de-dusted and then further treated in accordance to the needs of the downstream processes. Screw conveyors or gravity pipes (according to the feedstock) are used for supplying the feedstock to the HTW™ gasifier. Due to the gasifier pressure, both the feeding system and the bottom product removal system have to be performed by lock-hoppering systems.

The gasification is controlled using the gasification agents, steam and oxygen (or air) that are injected in the gasifier via separate nozzles. The nozzles are organized in several levels which are located in both the fluidized bed (FB) zone and the freeboard zone called also post-gasification zone. A high material and energy transfer rate is achieved in the FB and this ensures uniform temperature distribution throughout the FB. In order to avoid the formation of particle agglomerations the temperature is maintained below the ash softening point.

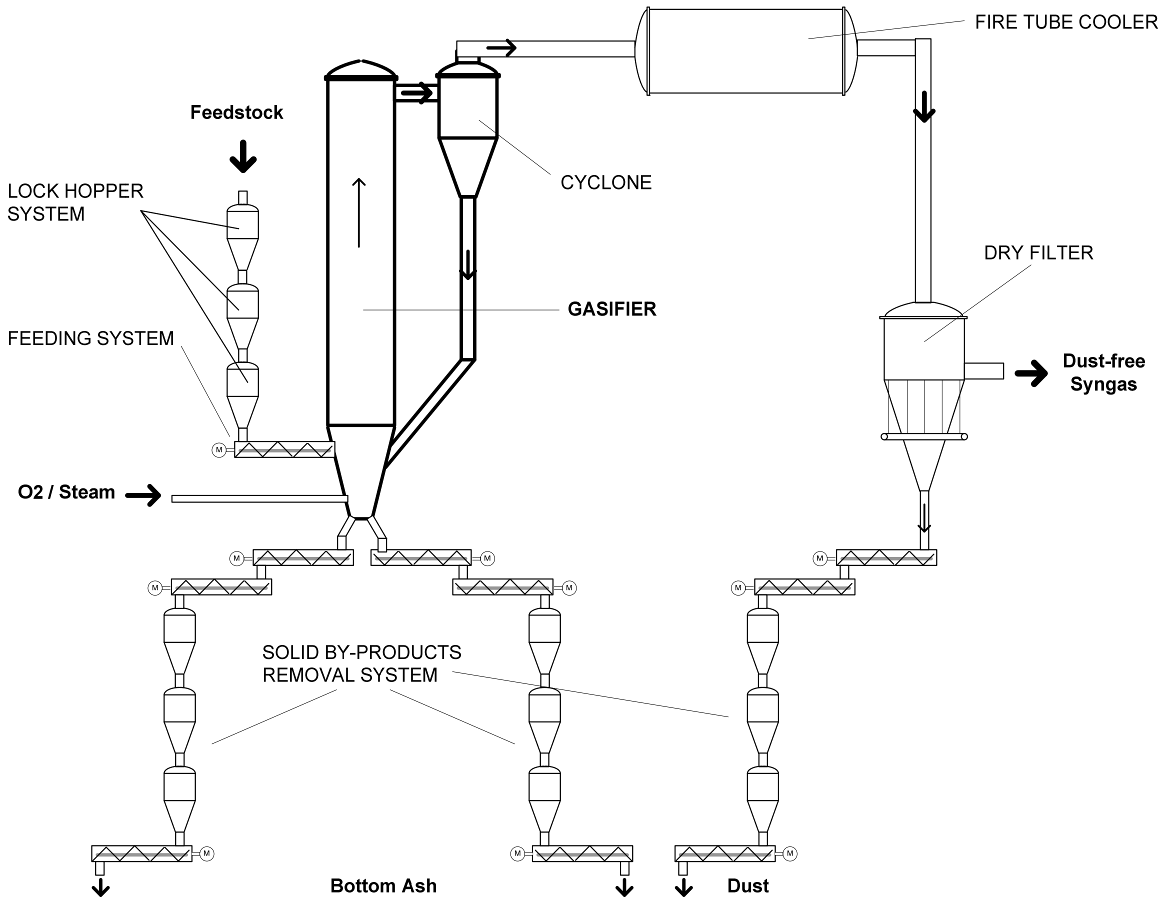

Fig. 6: The HTW^{TM} Process

Additionally the gasification agents are injected in the post-gasification zone in order to improve the syngas quality and the conversion rate due to the temperature increase.

Thus summarizing, the industrial scale pressurized HTW^{TM} process is characterized with two distinguished temperature zones, namely FB with operating window between 800 – 1000 °C and a post-gasification zone with temperature levels between 900 and 1200 °C.

The cyclone separates approx. 95% of the entrained solids from the syngas and returns them to the FB of the gasifier thus increasing the overall carbon conversion rate. Downstream of the gasifier, the raw syngas is cooled in the raw gas cooler and the heat is used to produce saturated steam that can be exported to external steam consumers. Afterwards the remaining fine ash particles are removed from the syngas in the hot gas ceramic filter. The fly ash is further cooled and then discharged from the pressurized system using a lock hopper system. Subsequently the syngas is sent to the scrubbing system, where it is quenched with water so that the chlorides are removed from the gas by dissolving them in the water. The syngas is saturated thus making further chemical treatment like CO-shift easier.

During the long-term operation of the HTW Berrenrath plant many improvements in plant equipment such as oxygen nozzles, raw gas cooler, screw feeders, hot gas filtration, process control system etc. have been implemented. These measures increased significantly the plant availability. Today the annual availably for a state-of-the-art HTW gasification plant can be estimated to be 91 % (8,000 h per annum).

GASIFICATION OF INDONESIAN LOW RANK COALS IN THE HTW^{TM} -PROCESS

The properties of Indonesian low rank coals are very similar to that of German lignite mined from the Rheine basin and used in the HTW plant in Berrenrath. This can be seen from Table 4, where a comparison of the ultimate and proximate analysis between German lignite and some typical Indonesian coals is made.

Table 4
Ultimate and proximate analysis of lignite coals from Germany and Indonesia

Coal Properties	German lignite	Indonesian 1	Indonesian 2	Indonesian 3	Indonesian 4
Proximate Analysis					
Moisture	51	36.94	61.6	41.9	56.5
Volatiles, dry	50.5	50	53.7	48.3	48.6
Fixed Carbon, dry	44	45.7	41.4	43.7	39
Ash, dry	4	4.3	4.8	6.8	11.8
Ultimate Analysis					
C, wt %-dry	64.9	69.27	63.59	64.27	61.16
H, wt %-dry	4.5	4.92	5.01	4.78	4.85
O, wt %-dry	24.8	20.36	24.11	21.77	21.27
N, wt %-dry	0.74	1.01	0.82	0.7	0.6
Cl, wt %-dry	0.03	-			
S, wt %-dry	0.46	0.17	0.16	0.21	0.34
HHV, kJ/kg, dry	25,000	27,200	24,600	26,200	21,800
ID.T. reduced, °C	1,150	1,290	1,090	1,100	1,130

Therefore it can be expected that the utilisation of Indonesian lignite in HTW process will be similar to that of German coal as shown in Table 3.

Despite the great similarity, the following pre-design steps are required:

- Definition of the key feedstock parameters at laboratory, such as: ultimate and proximate analysis; coal ash analysis; ash softening temperature at reduced atmosphere; coal char reactivity; physical properties (such as density, bulk and true density); bulk fluidisation behaviour; calorific values etc.
- Definition of the key operation parameters. Here real gasification tests are performed at the state-of-the-art HTW™ pilot plant (0.5 MW thermal Input), shown in Figure 8. These tests are required in order to obtain real data about the gasification temperature in both fluidised bed and in the post-gasification zones, the composition of syngas, bottom ash and dust (incl. trace elements, tars etc.), C-gasification degree, agglomeration limits, fluidisation behaviour etc.

After obtaining the key feedstock and operational parameters, the HTW-specialised in-house software can be used for obtaining information about:

- Syngas composition, production rates and HHVs;
- bottom ash & dust composition, production rates and HHVs;
- cold gas efficiency, C-gasification degree;
- utilities (air or oxygen, steam, carbon dioxide, water, etc.)

for a given industrial scale HTW-gasifier's geometry, operation pressure and temperature.

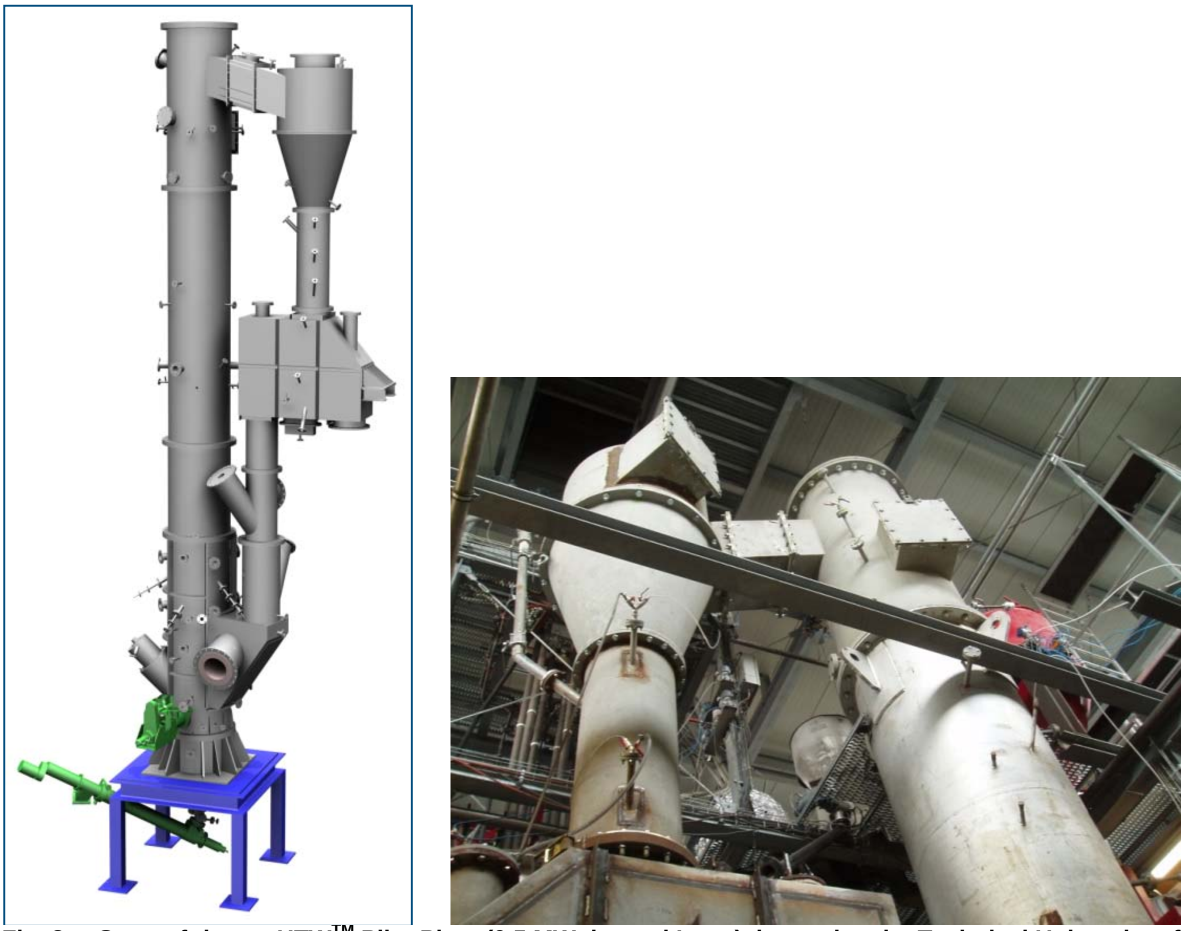

Fig. 8: State-of-the-art HTW^{TM} Pilot Plant (0.5 MW thermal Input), located at the Technical University of Darmstadt, Germany. 3D Scheme of the gasifier (left) and real view (right)

Preliminary estimations show that from each 1 ton (dry-ash-free basis) of typical Indonesian lignite gasified in HTW process can be produced the following products as shown in Figure 9:

The values shown in Figure 9 are estimated on the basis of syngas (CO+H2) produced from the HTW gasifier plus the syngas produced from an Auto-Thermal Reformer (ATR) or similar device where the methane produced in the HTW process and appearing in the raw syngas can be converted together with the off-gas coming from the synthesis of the final product and other units (e.g. Methanol, FT, PSA etc). The combination of HTW gasifier with a methane reformer leads to an increase of the overall syngas yields with up to 20%.

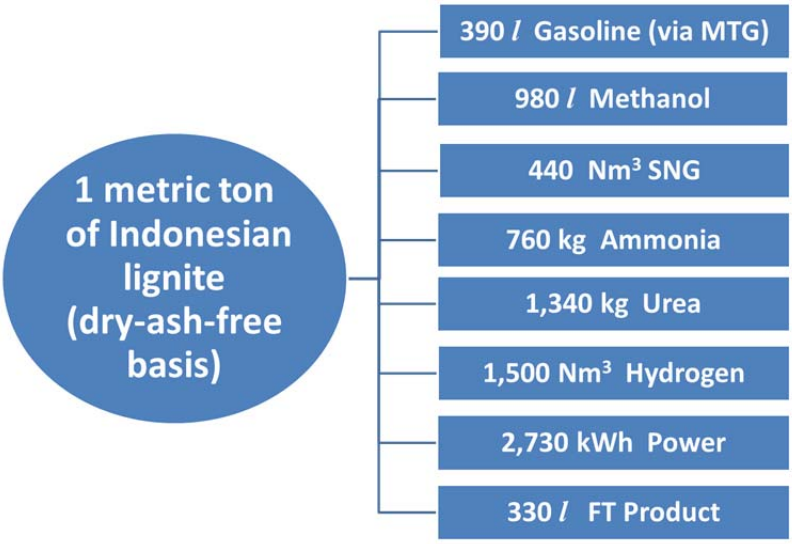

Fig. 9: HTW gasification of Indonesian coal: main products production figures

CONCLUSIONS

The High Temperature Winkler (HTW^{TM}) gasification process is characterised with reacting bubbling fluidised bed operated at elevated pressure and temperatures thus achieving high efficiency and high flexibility in terms of feedstock quality, reaction conditions, throughput and syngas quality. The use of nozzles for supplying of the gasification agents (oxygen, steam and CO_2) provides the opportunity to achieve a uniform fluidisation conditions and to have high flexibility in temperature and stoichiometric conditions among the gasifier height.

HTW^{TM} is a mature gasification technology for utilisation of low rank solid feedstocks such as Indonesian lignite. More than 30 years of intensive R&D led to building and operation of several industrial scale gasifiers producing syngas on commercial basis for many years.

Recent developments made by ThyssenKrupp Industrial Solutions AG are focused on widening of the feedstock portfolio (high ash content coals, biomass, municipal solid waste etc.) and improving of the design by intensive research and development program based on both experiments at the HTW pilot plant and numerical simulations.

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