Doosan Lentjes

40 Years of Power Plants Based on Circulating Fluidized Bed Combustion (CFBC) – a successful technology through the ages

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THE EARLY BEGINNINGS – GASIFICATION, CRACKING AND ROASTING

New technology does not fall from the sky and is also usually not an instantaneous creation; based on an initial idea, it is a medium to long term development. It is the same with the circulating fluidized bed technology, successfully applied for 40 years to clean coal combustion for the purpose of steam and power generation.
In 1921, Fritz Winkler, an engineer of German BASF developed in the course of the invention of the Haber-Bosch-Process for ammonia production the Winkler Generator for the gasification of fine lignite in a fluidized bed. His experiment initiated a new gas/solids reaction principle, called fluidization, and he has been credited with this invention. A first large scale plant went into operation in 1926 and others followed.
During the further development of the bubbling or stationary fluid bed technology in the US it was found that by operating at higher gas and solids velocities in pneumatic transport regime certain shortcomings in comparison to “slow” beds could be overcome, in particular scale-up of capacities.
In 1938, Lewis and Gilliland filed a first patent based on high-velocity-fluidization for with a concept similar to a CFB. Realization of this patent in industrial practice never has been reported, however.
In the fifties, BASF applied classical fluid bed combustion technology to a process for roasting pyrites with horizontal tube bundles for raising steam while generating electric energy or process heat. It was then, that the company Lurgi became aware of the technology and used it under license intensively in the inorganic chemical and non-ferrous metallurgical industry.

FLUID BED COMBUSTION OF COAL

The idea of burning coal in a bubbling fluidized bed certainly crossed the minds of many innovators and scientists. There is unanimous agreement that it was first pursued and promoted vigorously by Douglas Elliott of Central Electricity Generation Board Laboratory at Marchwood / Southampton, who first proposed the use of FBC in the UK in 1960. He recognized the merit of burning high carbon-in-ash residue in fluidized beds to recover thermal energy and to generate steam by immersing boiler tubes in the bed. His original idea was soon extended to coal-fired power generation in its entirety.

CALCINATION OF ALUMINUM HYDROXIDE

High velocity fluidization technology did not have a direct entry into the application for steam generation by coal combustion.
Among others also Lurgi found higher velocity fluidization to be an excellent technique for carrying out reactions with finely grained solids. Based on laboratory-scale work around 1958 with a first direct diesel oil injection fired CFB at 1100°C and based on the external doctorate thesis about fluid dynamic similarity of fluidization in the boundary regime to pneumatic transport by Lothar Reh, Lurgi developed during the 60ties in cooperation with Vereinigte Aluminium Werke AG a novel aluminium calcining process. It was tested in a 24 tpd pilot plant at Lünen and was followed by a first commercial plant of 500 tons per day in 1970 there, too. For the endothermic process of Aluminum calcining, gas or oil has been burnt for the first time in an air staged low NOx emission mode in the CFB calciner. The generated heat was recovered from the product in a multi-stage cooler, whereas waste gases exchanged heat with feed materials. Use of the CFB process allowed uniform control of the calcining temperature within its required limits. As a result of this attractive feature, a large number of CFB calciners were soon put into commercial operation.

ELRED PROCESS FOR IRON ORE PRE-REDUCTION

The Elred process is characterized by a fluidised bed pre-reduction stage at 950 – 1000 °C fed with fine ore and coal to produce a partially metallized DRI which is then smelted in a DC arc furnace to give a liquid iron product. The off gas from the pre-reduction stage together with that from the electric furnace forms the fuel for electrical power generation.
The process concept originated from Per Collin at Stora Kopparberg Bergslag AB, a former major steel producer in Sweden and jointly developed it with ASEA AB, the major manufacturer of electrical machines and systems in Sweden.
In 1975 the developers entered into a cooperation agreement with Lurgi to provide the knowhow for circulating fluidised bed reactors which had been developed for calcination of alumina, and between 1976 and 1979 a CFB reduction pilot plant was built and tested at ASEA's Central R&D Department at Vaesteraas as part of the overall process development. However to date no sale of a commercial Elred process unit has been made.

HOW AND WHEN IT ALL BEGAN – THE REAL BIRTH OF CFB BOILER

In the course of the development work for the ELRED process for the reduction of fine iron ore with fine coal in a CFB in spring of 1974 the four engineers Per Collin (Stora Kopparsberg), Sune Flink (ASEA Vaesteraas), Lothar Reh and Martin Hirsch (Lurgi) discussed the possibilities of the combustion of fine coke residue after magnetic separation from fine ore.
The story goes that the four of them met in a restaurant in Frankfurt, popular with Lurgi research associates, and that in the course of the discussion Mr. Collin drew the attention towards the CFB´process. He initiated the idea to place parallel water tubes in the upper part of the combustor for cooling, which in fact also Dr. Reh had already considered in earlier roasting plant development work.
We do not know under which condition the four men developed their ideas in the restaurant and which inspiring alcoholic beverage promoted their invention (in Frankfurt it should have most likely been a jar or more of apple cider instead of Polish Piwo or Wódka), however it surely was a more serious situation then in the animation in this slide.

FLUID BED SYSTEMS

The inventors of the CFB principle placed the fluidization velocity in a regime between the classical fluid bed (stationary or bubbling bed) and the transport reactor, where the so-called slip velocity – the difference between the mean gas velocity and the mean solids velocity - is at its largest. There high internal solids recirculation occurs, allowing the optimum mixing of gas and solids and achieving the best performance in terms of heat and mass transfer as well as high temperature uniformity.
After all it was the Lurgi engineers who created the term Circulating Fluidized Bed CFB.

THE INVENTORS PROPOSAL

The ideas initiated during the historical dinner had been further discussed by the four engineers and developed into the Inventors Proposal, for which the two Lurgi engineers developed the technical concept and performed the process calculations.
The proposal was finally issued on February 4, 1975. It is remarkable that this early idea already incorporated such advanced features like an external FBHE with several chambers and both, a water cooled combustor and cyclone as well as wing walls. It already includes ideas for desulphurization with limestone as well as oxygen enriched combustion.
In order to verify the new technology and to be in a position to test various fuels and combustion conditions as a basis for the design of the commercial plants Lurgi built and operated various laboratory and pilot size facilities, the largest with a thermal capacity of 1,5 MWth. The plant has been intensively used for testing and combustion verification until the end of the 90th.

THE ORIGINAL PATENTS

There are two basic patents, which have been granted to protect the CFB boiler inventions: The first patent applied for on September 5, 1975 „Process for Burning Carbonaceous Materials“ was granted to the four inventors Collin, Flink, Reh and Hirsch and is based on the original invention initiated in the Frankfurt restaurant. It already mentioned SO2 removal over 90%, possible NOx emissions below 100 ppm and use of oxygen enrichment in combustion air. With a second patent “Method of and Apparatus for Carrying out an Exothermic Process” applied for on May 31, 1976 by Lothar Reh, Martin Hirsch and Ludolf Plass the invention was completed. It marks the anniversary day in 2016: **CFB-Boiler Patent - 40 years of CFBC Power Plants**. Key of this patent is the external FBHE and its solid recirculation into the combustor.

RANSTAD SHALE COMBUSTION DEVELOPMENT

Before the first coal burning plant was built, Lurgi and Swedish engineers developed a boiler concept for complete low temperature, oxygen enriched combustion of Swedish oil-shale at 650°C. The sketch shows a popular artist`s concept which in fact is already close to an advanced CFB boiler, even though it contains features on which we look today with a certain curiosity. A plant according to this concept was however never built.

VAW LÜNEN 1981 – THE FIRST COAL FIRED CFB POWER PLANT

For the engineers at Lurgi it was only a short step from the calcining technology to the first purely coal-fired boiler at the VAW Lünen works in 1981. At a capacity of 84 MWth it generated steam, power and process heat from high ash coal wash residues for their novel alumina operation. The very low SO2 - and NOx- of the first patent were confirmed. Undoubtedly the plant still looked more like a metallurgical application with a round, refractory lined combustor and refractory lined cyclone, an external FBHE re-heating molten salt as a heat carrier for the bauxite tube digestion process and a waste heat boiler generating steam.
After closure of the aluminum operations the plant was converted to burn coal and waste fuels and is as part of the Remondis Lippe Werk recycling activities in operation until today.

AHLSTRÖM CFB DEVELOPMENTS

In 1976 Folke Engström of the Finnish company Ahlström Oy started works to develop a CFB boiler, unaware of the existing patents and without applying for own patents. He became inspired by a lecture of Prof. Arthur Squires at Stockholm and by experience as supplier of classical roaster boiler equipment for Lurgi in Finland. In 1979 they were the first company to start up a plant with 15 MWth to burn bark, wood waste and coal (Suomen Kuitulevy, Pihlava, Finland). Several plants followed including the depicted reference Kauttua, Finland in 1981.

Lurgi defended its patent rights and the situation resulted in license agreements with Ahlström and other boiler makers entering the new CFB boiler market.

Ahlström established itself as Pyropower in the US and continued to market CFB until it merged into Foster Wheeler in 1995.

THE LICENSEE FAMILY

In the years 1984 – 2000 an extensive licensing program was undertaken. This had various reasons: Lurgi had no own power boiler technology and had to rely on a worldwide network of boiler manufacturers, the extensive market volume could not be handled alone and a number of suppliers was obliged to agree to license payments in their dis-regard of the original patents.

As a side effect of the policy and the related know-how transfer the technology was spread to a number of companies, many of them emerging as future competitors.

THE CFB BOILER WORLD LANDSCAPE

From the early developments the CFB Technology spread out to a wide network of suppliers. The original technology is mainly represented today by Doosan Lentjes (Lurgi) and GE Alstom (CE, Stein and EVT) and is including the external FBHE.

A second group developed around the Ahlström technology (originally avoiding the external heat exchanger) and is living on as AMEC Foster Wheeler.

The Studsvik System owned by Babcock & Wilcox has a distinct difference to the other technologies by using U-beam separators in lieu of the traditional centrifugal or cyclone separators.

Valmet has inherited the design from Götaverken and Tampella (via Kvaerner and Metso) and Andritz from AE&E. Both are similar to the Ahlström system.

A number of CFB manufacturers emerged in the traditional coal countries China and India; the remarkable development in China I will outline later on.

MILESTONES OF CFB DEVELOPMENT

We have now already heard about the development from the earliest fluid bed technology ideas up to the first commercial combustion plants in the early 80’s. Thereafter the development took off rapidly. Already the second unit had a capacity of close to 100 MWe and in every decade a new milestone could be reached: 100 MWe in the 80’s, 250 MWe in the 90’s, close to 300 MWe until 2010 and today boilers of 600 MWe plus are on the engineering table.

DOOSAN LENTJES CFBC PRODUCT PORTFOLIO

The rapid development of the technology also caused standardization and capacity increase, in particular for the utility applications, going hand in hand with a more “power plant” typical design. One cyclone being sufficient up to 100 MWe was soon succeeded with a two cyclone design up to 200 MWe (Berlin, Carling, Tisova), a four cyclone design up to 350 MWe (Twin Oaks, Gardanne, Starobeshevo) and for larger units a 6 cyclone design will be mandatory.

Let us review a few major milestones of the Doosan Lentjes CFBC Power Plant references:

STADTWERKE DUISBURG HKW 1 – 1985

Being the second commercial CFB power plant, the unit 1 of HKW Duisburg is a real champion: First CFB worldwide to apply Benson (once-through) boiler principles, even though it was still with sub-critical conditions! First CFB boiler delivering in cogeneration mode heat to a large city district heating network with high fuel utilization efficiency of close to 70% reducing CO2 emissions considerably! First 100 MWe CFB worldwide! This capacity was considered the utmost possible at the time. Commissioned in September 1985 and with over 230.000 operation hours Duisburg is the longest continuously running CFB boiler in the world!

BERLIN, MOABIT (VATTENFALL) – 1990

The Berlin plant with 100 MWe was another huge step forward. It was the first CFB close to 200 bars on Benson (once-through) principle! And the first CFB worldwide with steam cooled cyclones and FBHE’s. This outstanding plant was honored with the International Power Plant Award by Power Magazine in 1990 for outstanding environmental achievements.

TWIN OAKS (TEXMEX), TX, USA – 1990

A milestone in American CFB history TexMex (now known as Twin Oaks) was the world’s first 175 MWe CFB and the plant world’s first pant leg solution with integrated water-cooled FBHE’s.

GARDANNE, FRANCE – 1995

Gardanne in the French Provence was for many years the world’s first 250 MWe CFB plant and the largest CFB worldwide. Originally designed for local lignite and later converted to bituminous coal combustion the unit is presently converted to biomass combustion with 170 MWe capacity. The plant proves the true flexibility of this technology, in particular with FBHE application.

NEYVELI, INDIA – 2009

Presently, the largest Doosan Lentjes CFBC references with 2 Units of 280 MWe each and fired with lignite are the two plants in India, Neyveli and BECL.

CONCEPTS FOR CFBC POWER PLANT TECHNOLOGY

Certainly the CFB technology has changed face over the years. Starting as a chemical and metallurgical application the overall design had to be adapted to power plant use. The first units still used circular / refractory lined combustors and cyclones, the second generation already had water cooled combustors, FBHE'S and sometimes even cyclones, however in a conventional arrangement as depicted in the left image. Finally modern designs use extreme integrated arrangements, are entirely water / steam cooled and of course require minimum space.

ALTERNATIVE CFBC POWER PLANT TECHNOLOGIES

Various companies came up with different solutions to implement the CFB-principle. GE Alstom represents the closest to the original (or conventional) CFB arrangement with clear distinction of combustor, cyclones (usually refractory lined), FBHE's, back pass and air pre-heater.

The innovative design of AMEC Foster Wheeler is a compact water /steam cooled solution.

In the Circofluid® CFB solution (developed by Babcock and owned by Doosan Lentjes) the circulation loop does not maintain full temperature over the height of the combustor, but uses heat transfer surfaces to reduce the temperature in the top of the combustor and consequently uses a cold cyclone design in the recycle loop. This technology is nowadays mainly used in China for small scale boilers and in India.

The Babcock and Wilcox design uses so-called U-beam separators in lieu of centrifugal cyclones in the circulation loop and finalizes the solids separation in a cold recycle by a multiclone separator arranged in the back pass.

THE CHINESE CFBC STORY

A comprehensive look at the world wide history of CFB power plants cannot neglect the developments in China. Already from the early 80's Chinese institutes started to develop an own CFB design, based on international technology and initially free of regarding patent rights. The concepts were based on standard sizes, were limited to below 150 MWe and did not have EHE's. 11 major boiler manufacturers built well over 3000 plants based on the local technology, mostly smaller capacities (35 t/h, 75 t/h etc.).

As Chinese technology could not be expanded to larger sizes without external help, various Chinese boiler companies concluded license agreements with GE Alstom and AMEC FW for capacities from 150 – 300 MWe, including concepts with EHE's. Over 20 300 MWe units are already in operation.

Based on the 300 MWe concepts provided by the licensors, Chinese Dongfang in co-operation with
Tsinghua University developed and implemented a 600 MWe CFB unit with supercritical steam parameters at Baima/China in follow-up of a national development program.

Various Chinese CFB boiler suppliers are in the meantime also internationally active (Turkey, South Africa, Vietnam, Indonesia etc.).

WHERE IS THE LIMIT?

This raises the question: Where is the limit in size? In the early times of CFB power plants 100 MWe was considered to be a limit in size but design improvements rapidly allowed to go to larger capacities:
20 MWe Ione in California with 1 cyclone burning lignite
100 MWe Tisova in Czech Republic with 2 cyclones burning lignite
200 MWe Starobeshevo in Ukraine with 4 cyclones burning anthracite
300 MWe Neyveli in India burning lignite
600 MWe supercritical applications with 6 cyclones have already been realized and
800 MWe concepts are on the drafting board.

TRACK RECORD OF CFBC BOILERS

An estimated total number of app. 800 CFB power plant units with a total capacity of app. 50.000 MWe are installed worldwide. In addition app. 4000 CFB boilers exist in China with app. 70.000 MWe capacity, designed and manufactured by Chinese boiler companies (2000 therefrom with capacities below 25 MWe). CFB power plants are under operation with unit sizes from app. 15–600 MWe. The average capacity is app. 75 MWe with a trend to larger capacities. Largest sizes in construction and operation are supercritical boilers with 550 MWe (Samcheok, Korea) and 600 MWe (Baima, China), design concepts are available up to 800 MWe.

40 YEARS PATENT EVENT – CFB POWER PLANTS

On June 14 2016 Doosan Lentjes could proudly celebrate the 40 Years Patent Event in their Ratingen, Germany offices together with the three inventors of the CFB combustion technology, major contributors and scientists, plant owners / operators and staff.
Dr. Plass outlined the CFB technology as a promising solution that meets the requirements of future power generation: **“Plant operators face demanding future challenges in terms of their used fuel types as well as framework conditions, which means power production plants need to be flexible when it comes to efficient combustion of changing fuels – even those with the most difficult properties. CFB plants can reliably deliver on these requirements, making them the solution of choice for both efficient and environment-friendly future energy generation.”**

SELECTED FURTHER CFBC POWER PLANT MILESTONES

To name all the references collected over the years would go beyond the target of this event. So
here just a few more outstanding examples:
Bayer Leverkusen (Currenta), Germany
EEW Premnitz, Germany
Emile Huchet, Carling, France
Wachtberg, Germany
Stadtwerke Kassel, Germany
Stadtwerke Duisburg, Germany
Stadtwerke Flensburg, Germany
Scott Paper, Chester, PA, USA
Chatham, Canada
AES Shady Point, Panama, OK, USA
Subic Redondo, Philippines

Our trip into 40 years of history of the circulating fluidized bed combustion technology and its successful application to power generation is finished, but by far not the ambitious look into the future. Our engineers are constantly improving the design. All the major application companies worldwide are looking for new challenges, new applications and new visions for this technology. We know the next stations, but we know by far not yet the final destination.

WIR WIRBELN WEITER – THE CIRCULATION GOES ON!