Development of a lignite-fired power plant concept with integrated pressurised fluidised-bed drying and fuel cells

F.U. Leidich and R. Breitenfelder
ALSTOM Power Generation AG,
Boveristrasse 22, 68309 Mannheim, Germany
E-mail: frank-udo.leidich@power.alstom.com

H. Mandel
Vattenfall Europe Generation AG & Co KG,
Vom-Stein-Strasse 39, 03050 Cottbus, Germany
E-mail: hans.mandel@vattenfall.de

J. Krautz
Brandenburgische Technische Universität Cottbus,
Karl-Jannack-Straße 3, 03044 Cottbus, Germany
E-mail: Krautz@TU-Cottbus.de

M. Gniazdowski
Babcock-Borsik Service GmbH,
Duisburger Straße 375, 46049 Oberhausen, Germany
E-mail: michael-gniazdowski@babcock-service.de

Abstract: In the coming decades lignite will become one of the most important fuels for power production in Germany. In the last five years, Vattenfall Europe and RWE have put power plants of the 800–1000 MW class with efficiency of up to more than 43% into service. Four to five per cent efficiency can further be gained by using pre-dried lignite as fuel (BOA plus concept of RWE). Additional steps are possible if the lignite-drying process and combustion are operated under pressure. This paper describes the first steps based on the A.M. technology whereby the waste heat of fuel cells is used for operation of the lignite dryer to achieve highest efficiency levels.

Keywords: lignite-fired power plant; pressurised fluidised-bed dryer; fuel cells.

1 Introduction

Coal will undoubtedly remain the most important primary energy source in the world. The mineable deposits of brown coal, that is lignite, will guarantee a reliable power generation for another 80 years. The competitiveness of future lignite-fired power plants in today’s deregulated power market requires that innovative technologies are implemented in order to make the prime power production costs comparable to those in plants using other sources of energy.

The new 800/900 MW power plants of Vattenfall Europe AG (formerly VEAG), located at Schwarze Pumpe, Lippendorf and Boxberg, are representative of a very high technological quality standard in lignite-fuelled steam power plants. A 950-MW lignite unit combined with an optimised plant concept (referred to as ‘BoA’) by RWE Energie AG in Niederaußem provides an even higher quality standard and delivers a net efficiency of more than 43%. This is achieved by the currently best technology that is available for conventional steam power plants based on lignite firing (RWE Energie, 2001).

Against the background of deregulation and rising national environmental-control requirements, utility companies and manufacturers nowadays put forth great efforts in order to improve lignite-based power generation regarding both plant engineering and process engineering.

In a next step, RWE Energie AG plans to operate a boiler fired with dry lignite. It will be a modified lignite unit (referred to as ‘BoA-plus’) with an upstream coal drying plant that is operated with low-temperature heat. This way, it will be possible to enhance the efficiency by another 4 or 5%.

In addition to the conventional steam power cycle, pressurised combustion offers great technical and economical potential due to its compact design and the utilisation of the gas and steam turbine cycle. This concept may exceed the possibilities of ‘BoA’ and ‘BoA-plus’ and support a long-range advancement of the lignite-fuelling technology. An important variant of this technology is referred to as ‘Circulating pressurised fluidised-bed combustion of the second generation’, a project, which is presently in progress at the Technical University of Cottbus. Among the other partners,
RWE Energie AG and Vattenfall Europe AG are participating in this project within the framework of a university promotion programme (Krautz and Schierack, 2001).

Pressurisation offers advantages not only in terms of the combustion process, but it also largely improves the lignite drying process (Schiering and Gniazdowski, 2002).

Another enhancement of efficiency and plant performance can be expected from integrating a fuel-cell plant into the overall plant, in addition to an upstream lignite drying system. In that case, the waste heat from the fuel cells can be used both for condensate or feed-water heating in the conventional steam process and for lignite drying (ALSTOM Switzerland Ltd., 2002). The portion of the fuel-cell output in the total output of the power plant is mainly determined by a potential heat input into the steam process and the lignite drying procedure.

In cooperation with the partners involved in this project – Vattenfall Europe, BBP, Laubag, Mibrag and the Technical University of Cottbus (BTU) – ALSTOM Power plans to examine a concept for a lignite-fired facility where both the lignite drying plant and the fuel-cell plant are integral components of the power plant.

ALSTOM Power and Vattenfall Europe will place the focal point of their research on the development of a concept and the integration of the fuel-cell plant into the overall plant.

BBP will primarily focus on the advancement of the steam fluidised-bed drier.

The Technical University (BTU) of Cottbus will be in charge of performing the experiment and Laubag / Mibrag will deliver, that is develop, the necessary lignite handling technology.

2 State of the art, R&D

2.1 Steam fluidised-bed drying process

The drying of lignite containing mine moisture in a steam fluidised-bed process has been developed under atmospheric conditions, both theoretically and experimentally, over a period of about 20 years and is now applied commercially (Leithner, 2002).

With test, pilot and reference plants in
- Zeithain: 1 tonnes/hour of dry lignite throughput
- Borna: 10 tonnes/hour of dry lignite throughput
- Wachtberg: 27 tonnes/hour of dry lignite throughput
- Loy Yang: 20 tonnes/hour of dry lignite throughput

This technology has reached the state of technological maturity. It was found that an efficiency increase of 4 to 5% is possible by using the coal/steam enthalpy.

Based on these findings, a pilot drying plant for a dry lignite throughput of 90 tonnes/hour was designed and built by BBP (formerly L & C Steinmüller) in RWE’s power plant in Niederaußem. Commissioning took place in 2001.

Considering the investment costs involved for an atmospheric drying plant, the improvement of the cost-benefit ratio – in relation to the prime power production costs – is not yet sufficient.

A possible solution is offered by employing a pressurised vaporisation fluidised-bed drying process, as it provides not only an increase in efficiency of 4 to 5%, but also keeps
the costs of the pressurised drying process below the potential investment cost savings as compared to a conventional ‘lean’ raw lignite unit.

For this purpose, BBP (formerly Balcke-Dürr Energietechnik GmbH) worked out a drier concept at the order of Vattenfall Europe AG that is suitable for a ‘lean’ 500-MW dry lignite unit.

Based on a comparison of these two variants, that is an upstream atmospheric and a pressurised drying plant, a clear cost advantage of about 20% may be expected from a pressurised drying plant. The savings potential presented by the dry lignite unit with an upstream pressurised drying process is thus between 7 to 10% as opposed to a ‘lean’ raw lignite unit.

2.2 Fuel cells

Fuel cells of the PAFC type (phosphoric acid fuel cells) are known to be capable of responding to very rapid load cycles, with the partial-load efficiency rate being even higher than the efficiency level during full-load operation (Wismann, 1996). As a result, the configuration suggested here will additionally provide a better maneuverability and an improved load cycle response of the overall plant, especially with respect to the power generated by the PAFC plant.

Another advantage worth mentioning is a dual ecological benefit provided by a PAFC plant. With respect to pollutants, such as CO, SO₂, NOx and dust, power generation by PAFC fuel cells is emission-free. Compared to coal-fired power plants, PAFC fuel cells emit only very low noise and less than 40% of specific CO₂ emissions. The environmental balance of the overall power plant is thus enhanced.

3 Objectives of the research project

The joint research venture is aimed at elaborating design and planning guidelines for lignite-fired power plants with pressurised fluidised-bed drying and integrated fuel-cell plants and at designing such a power plant.

One of the core activities in this joint project will be the development of an overall thermal concept that includes optimising the main steam and re-heater parameters, determining the number and arrangement of the feed-heater stages, and integrating the lignite drying plant as well as the waste heat of the PAFC module.

Special attention will be given to the interplay between the major components of the steam process, considering the operating conditions of the lignite drying plant, and to the specific effects on fuel cell operation – which are crucial factors for the start-up and control response of this highly complex plant.

Another important part of the research programme will be concerned with the testing and operation of a pilot drying plant that is built at the Technical University (BTU) of Cottbus, promoted by the State of Brandenburg.

The test drier will be operated with a real-life vaporisation fluidised bed with lignite particles of varying grain size ranges in order to experimentally identify the parameters relevant to heat transfer and to compare them with the values calculated theoretically. Furthermore, this test plant will be used to perform k value measurements in an atmospheric environment in order to verify the integral k values obtained from the Wachtberg test plant and to deliver workable standards of reference. The test drier was
dimensioned so that the fluidised-bed cross-section would correspond to the circular section of the actual fluidised bed that would be used for the actual large-scale driers.

The general test programme includes the following studies:

• measurement of $k$ values for different grain diameters
• determination of $k$ values depending on pressure and grain size
• measurement of the discharge of dust depending on fluidisation
• optimisation of the fluidisation point for different grain size ranges (0 to 6 mm, 0 to 4 mm, 0 << 4 mm)
• testing of charging and discharging systems under pressurised conditions
• testing of integrated fabric filters for steam scrubbing
• determination of the stability limits of the fluidised bed
• optimisation of start-up and shut-down procedures, warming-up and heating operation as well as simulation of disturbances serving as a basis for availability analyses
• determination of the water content of the dry coal depending on the raw smalls, the temperature in the driers, dwell time, and grain size

In addition to the fluidised-bed studies, the test plant is expected to be used for further developing, optimising and testing of the plant components and of the thermal arrangement for pressurised systems.

Last but not least, the project will include cost analyses and site-specific decision criteria regarding the use of hydrogen or natural gas.

4 State of the R&D activities

4.1 Test drier

The setup of the pilot drying plant is finished, except for a few minor activities. Most of the component testing has taken place. The photograph below (Figure 1) shows the pilot drying plant in the hall of the Power Plant Engineering Institute at the Technical University (BTU) of Cottbus.

The cylindrical fluidised-bed drier is visible left of the centre. It is dimensioned for operating pressures of up to 6 bars. Its total height is approximately 6,000 mm and its bed diameter is approximately 450 mm.

The facilities for coal handling are located on the right, in the front area. Raw lignite is delivered in 2m³ silo tanks or big bags and is transported to the feed hopper above the fluidised-bed drier through a chain conveyor pipe.

The dry lignite is collected in 2m³ silo tanks again.

The coal feed-in rate is between 250 and 500kg/hr, the moisture content is between 50 and 60%.

The collecting tanks in the front – for steam condensate – are needed for accurate balancing.
The boiler in the background, on the right, is used for generating the necessary fluidisation and drying steam.

The schematic below (Figure 2) depicts the operating principle of the large-scale drying plant.

For an arrangement without vapour recondensation, the heating steam needed for drying the raw lignite is routed separately from the steam used for fluidisation. This way it will be possible, in the large-scale plant, to refeed the steam condensate without including a costly scrubbing procedure or installing heat exchangers in the water/steam process. Moreover, the residual thermal energy contained in the condensate, approximately 120 to 150 °C, can be used for feedwater preheating.

A certain portion of the drying steam is used for heating the shell. The remaining, larger portion of the heating steam is condensed in immersion heater sections inside the fluidised bed and thus effects the actual drying.

Figure 1 Pilot drying plant at the technical university (BTU) in Cottbus
Coal is added to the driers from the top through a rotary-vane feeder. The rotary-vane feeder is heated in order to prevent wet raw lignite from agglutinating or caking. In addition, the rotary-vane feeder has the task to seal off the driers against the atmosphere. A shut-off flap and an inertisation facility complete the safety concept of this system.

The dried lignite is discharged accordingly from the lower end of the drier. The vapour needed for fluidisation is finally fed into the lower part of the drier through nozzle assemblies. The filter inside the drier scrubs the steam from entrained dust particles. The steam is fed back into the drier via a steam blower for maintaining the fluidised bed. Excess steam is condensed. In the large-scale plant, the released heat is planned to be utilised as well.

### 4.2 Thermal calculations

The operation of a PAFC fuel cell plant requires that hydrogen is provided. Since, at the planned location of the actual plant, hydrogen is not available in sufficient quantities, it needs to be generated from natural gas via a reforming process.

The research activities of ALSTOM, therefore, focused first on optimising the thermal arrangement of the fuel cell plant while integrating the reforming reactor.

Figure 3 shows the thermal arrangement of the fuel cell stack and the reforming reactor for combustible gas treatment.

The given arrangement delivers heat at a temperature level of 176 °C – from the cooling of the fuel cells – and saturated steam at 23 bars and 220 °C.
This steam is suited for the lignite drying process in the steam fluidised-bed drier. In addition, reformer condensate of a temperature of 128 °C is produced.

The saturated steam is preferably used for the lignite drying process. The process condensate in the driers, the reformer condensate and the condensate from the fuel cell cooling process can be used for the low-pressure preheating of the boiler feedwater. One of the possible arrangements is shown in Figure 4.

As compared to the use of extraction steam for the lignite drying process, this concept provides the following benefits:
• The lignite drying process is decoupled from the operation of the water/steam cycle, that is this provides greater variances and a better controllability of the individual processes.

• Savings in the use of extraction steam for lignite drying will increase the power output and thus improve the overall efficiency of the plant.

• Savings in the use of extraction steam for low-pressure preheating will increase the power output even further and improve the overall efficiency of the plant even more.

5 Prospects

Upon successful completion of the research project, it is planned to integrate the knowledge gained into project phase II where it is planned to build a demo plant of a total capacity of approximately 50 MW.

The heat flow diagram (Figure 5) below will serve as an engineering basis for process-specific and thermal optimisation of this highly complex plant.

The most important process characteristics of the arrangement presented here are:

• Life steam of 290 bars / 600 °C.

• Single-stage reheating with steam parameters at 57 bar / 620 °C.

• Pressurised dry lignite firing.

• Pressurised steam fluidised-bed drying with vapour compression, thus reducing the steam consumption for the coal drying process.

• Utilisation of the waste heat from the fuel cells for lignite drying.

• Use of the condensate heat from lignite drying, the reforming process and the fuel cells for low-pressure condensate preheating.

• Integration of a flue-gas heat channeling system for low-pressure condensate preheating.

Based on the specifics of the heat flow diagram, it is assumed that a net efficiency of the overall power plant of 50 + x % can be achieved.

However, it should be noted that the cost-efficiency of this plant concept would not only depend on the technical feasibility of an optimised efficiency level and the corresponding advantages, such as:

• reduced consumption of primary energy and thus lower operating costs

• reduced carbon dioxide emissions (=> CO₂ tax)

but also on the investment costs involved regarding the entire plant.

This aspect still requires further optimisation.

The key parameters are the prime power production costs of ≤ 30 euros/MWh and the specific investment costs of ≤ 1000 euros/kW.
Figure 5  Heat flow diagram of the overall 500 MW plant
6 Summary

Pressurised steam fluidised-bed drying is derived from the atmospheric drying process and is an advancement of that technology. It is primarily aimed at increasing the cost-benefit ratio of lignite-based power generation. Generating the process steam needed for the lignite drying process in a fuel cell plant suggests that a net efficiency ratio of 50 + x% will be possible. However, it is not the maximum increase in efficiency alone that will determine the ultimate cost-effectiveness of the real plant, but it will also depend on an effective limitation of the investment costs. These considerations will form part of the future activities in this joint research venture.

Acknowledgements

I would like to thank the Federal Ministry for Economics and Labour (formerly the Federal Ministry for Economics and Technology), represented by the project sponsor in Jülich promoting this research project. Without this promotion, it would not have been possible to bring about the joint research venture.

Furthermore, I would also like to thank the State of Brandenburg for granting state promotion funds that allowed the participating partners to build a pilot drying plant at the Technical University of Brandenburg in Cottbus. This paper was also presented at the PowerGen Europe Conference in Düsseldorf.

References


RWE Energie (2001) Niederaußem Power Plant, BoA – Unit K – Brief Description; and BoA Niederaußem – Extension of the Niederaußem Power Plant by a 1000-MW Unit.
