



Development status of WTA fluidized-bed drying for lignite at RWE Power AG

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1. Industrial significance of lignite drying

The high moisture content of lignite of approx. 50 – 60% wt is an undesirable inert component that reduces the lignite's calorific value and has a negative effect on the profitability of using lignite. When employed in conventional power plants, a considerable portion of the lignite's energy content is needed to evaporate this high proportion of water prior to combustion, regardless of whether the plants are equipped with pulverized fuel-fired steam generators or steam generators with circulating fluidized-bed combustion (CFBC). In both variants, the lignite is dried at a high temperature level of 900 – 1,000°C and approx. 800°C respectively, and the evaporated coal-inherent water leaves the power plant together with the flue gas without being used as a source of energy.

If drying is decoupled from the rest of the process, the drying procedure may be carried out at a low temperature level, which is exergetically more efficient, and drying can be optimized as a separate process step. This conceptual design has the potential to significantly increase the efficiency of the entire power plant process irrespective of whether pulverized fuel-fired steam generators or steam generators with CFBC are involved. If electricity is generated in a combined-cycle plant with integrated coal gasification or in an oxyfuel process, the lignite used must always be pre-dried. In these cases as well, an energy efficient drying process can contribute to further increasing efficiency /1/.

In the case of so-called low-rank coals, which have both a high moisture content and a high ash content, the calorific value can be increased by pre-drying to the point that they can be used for combustion in conventional steam generators without requiring back-up firing by other energy sources.

As a modern method for upgrading and drying lignite, WTA¹ technology can be used for all above-mentioned processes and adapted to the various requirements.

The efficiency increase achieved with the WTA process integrated into a power plant process depends to a considerable extent on the underlying conditions of the individual case (e.g. coal specification; power plant arrangement; drier heating steam pressure) and on the vapour utilization variant, so that universally valid values cannot be given. For a steam power plant process, 4 to 5% points efficiency increase (based on the net calorific value (NCV)) may be expected by reducing the moisture content from approx. 51 to 12% wt is depending on the WTA variant employed. For higher raw coal moisture contents, the values increase accordingly.

The flue gas emissions associated with electricity generation are directly proportional to the fuel-specific emissions and the output of the power plant and inversely proportional to the

¹ Wirbelschicht-Trocknung mit interner Abwärmenutzung = Fluidized-bed drying with internal waste heat utilization

efficiency of the power plant /2/. The efficiency increase achieved with the aid of WTA technology thus makes a direct contribution to reducing emissions and to further enhancing the environmental compatibility of electricity generation.

2. Process principles of WTA drying technology

Applied process principles

The WTA drier operates in a stationary fluidized bed with low expansion at slight overpressure. Energy is input almost exclusively via heat exchangers installed in the fluidized bed and only to a small extent via the fluidizing media. Owing to this principle – also referred to as contact drying – the necessary fluidizing flow of the drier can be established independently of energy needs merely on the basis of fluid-mechanical aspects. Due to the good heat transfer between the fluidized bed and the installed heat exchangers even slight temperature differences suffice, allowing compact driers to be built with high evaporative capacity. Since milled raw lignite is virtually impossible to fluidize as a bulk material due to its cohesive properties, the fluidized bed is designed as a mixed bed. In the mixed bed, the fluid-mechanical behaviour of the fluidized bed is mainly determined by the dry lignite, which is easy to fluidize and, by back-mixing, serves as a carrier medium for the cohesive raw lignite. Unlike in the widespread, groove-shaped fluidized-bed driers, in mixed-bed driers the main transport direction of the coal particles is vertical and the fluidized bed is relatively high.

The lignite is dried in virtually 100% pure steam that is slightly superheated. At constant pressure, a balance is obtained between the temperature of the steam and the residual moisture of the dry lignite in the hygroscopic range of the lignite, which is described by the desorption isobar. Fig. 1 shows this dependence for Rhenish and Australian lignite at a system pressure of approx. 1.1 bar. At a temperature of approx. 110 °C (Rhenish lignite) and 107 °C (Australian lignite), an equilibrium moisture content of approx. 12 % wt is obtained. Thus the moisture content can be adjusted and constantly kept at the desired value by controlling the fluidized-bed temperature.

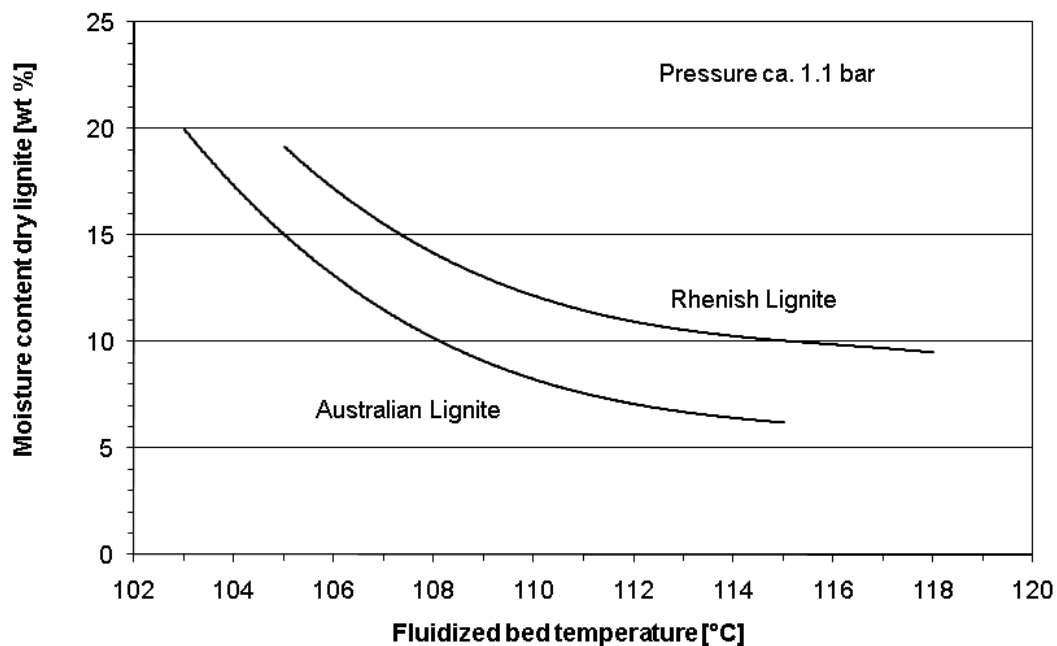


Fig. 1: Desorption isobars of Rhenish and Australian lignite

Steam drying has a number of fundamental advantages for the drying of hydrous bulk materials:

- Drying is carried out in an inert atmosphere, ensuring a high degree of inherent safety especially in the case of potentially explosive bulk materials (e.g. dry lignite).
- Virtually 100% of the drying vapour consists of steam, so that it condenses isothermally. It is thus an attractive source of waste heat that can be used energetically in a sensible manner.
- The condensation of the vapour avoids large-volume steam emissions, dust emissions and possible odour emissions caused by outgassed accompanying substances.
- At the same time the condensate formed is a utilizable source of water that can contribute to meeting the water requirements of an industrial plant.

Although a patent application for the principle of drying moist bulk materials in superheated steam was filed in Switzerland as early as 1898 /3/, this drying technology variant has been relegated to a niche existence until today. In 1979, Potter et al. took up the principle of steam drying and proved in laboratory tests that lignite can be dried in a stationary fluidized bed using slightly superheated steam /4/.

Fluidized-bed variation parameters

The design of a fluidized-bed contact drier can be varied by the particle size of the feed coal, the system pressure of the drier and the heating steam pressure of the heat exchanger installed in the drier. The influence of these parameters was investigated in-depth at RWE Power both theoretically and experimentally within the scope of the development activities. The most important results can be summarized as follows:

Influence of particle size

The heat transfer and fluid mechanics of fluidized-bed processes can be significantly influenced by varying the particle size. The heat transfer coefficient k between the fluidized bed and the heat exchangers immersed in it consists of a gas-convective portion α_G , a particle-convective portion α_P and a radiative portion α_{Str} . Finer particles allow the particle-convective portion α_P to be significantly increased so that the heat transfer coefficient, which is decisive for the design of the heat exchanger, increases accordingly. In addition, finer particles lead to lower fluidizing points and consequently to lower fluidizing velocities. All theoretical advantages of grinding the feed coal to a smaller particle size were confirmed in the operation of the commercial-scale WTA-1 and WTA-2 test plants that RWE Power built at its lignite beneficiation plant at Frechen, Germany. As Table 1 shows, the k -value (average) of the heat exchanger installed in the fine grain drier of the WTA-2 plant was 70 - 80% greater than that of the coarse grain drier of the WTA-1 plant, while the required fluidizing velocity above the fluidizing bottom was reduced by approx. 65% /5/.

	WTA 1 – coarse grain	WTA 2 – fine grain
Particle size of feed coal	approx. 0 - 6 mm	approx. 0 - 2 mm
Fluidizing velocity (average)	0.4 m /s	0.14 m/s
k-value (averages)		
- Upgraded coal	approx. 260 W/m ² K	approx. 440 W/m ² K
- Steam coal	approx. 230 W/m ² K	approx. 420 W/m ² K
k-value (maximum values)	approx. 340 W/m ² K	approx. 510 W/m ² K

Table 1: Characteristic operating data of the WTA coarse and fine grain plants

Influence of system pressure

Increasing the system pressure shifts the desorption isobar for a defined equilibrium moisture content to higher steam temperatures. At RWE Power this dependence was experimentally investigated for Rhenish lignite in a laboratory fluidized-bed plant that can be operated under system pressures of 1 - 6 bar. Fig. 2 shows how the required steam and fluidized-bed temperature rises from approx. 110°C to approx. 165°C as the system pressure is increased from 1.1 to 6.0 bar for an equilibrium moisture content of 12% wt. Assuming a specified average temperature difference of 30 K between the heat exchanger and the fluidized bed, the required heating steam pressure for the heat exchanger installed in the drier increases as well; as is shown in Fig. 2, it rises significantly from 3.7 to 13.7 bar.

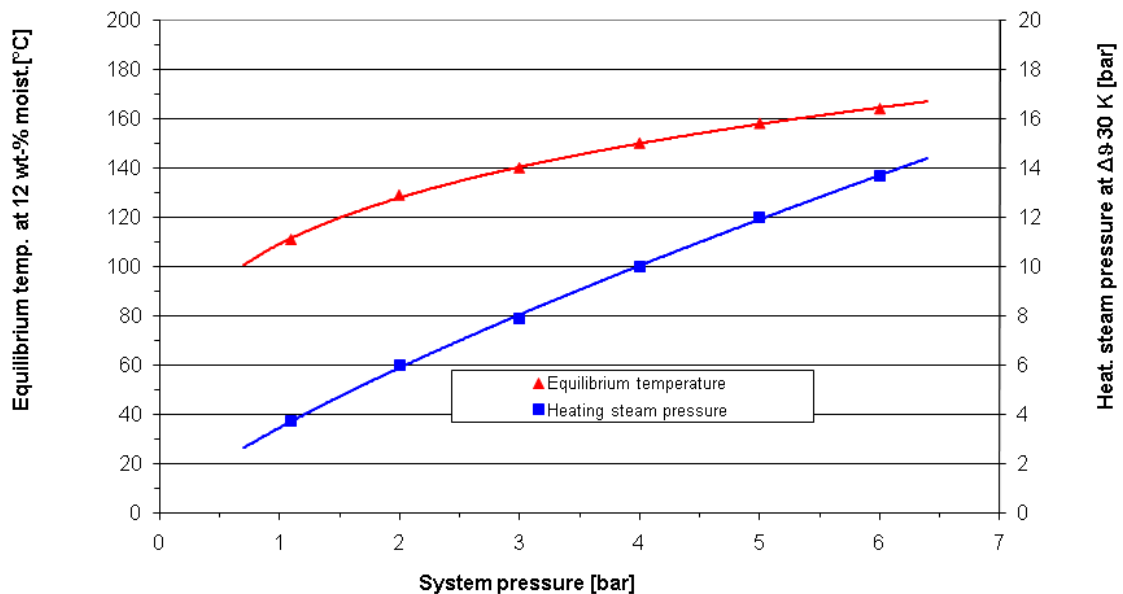


Fig. 2: Equilibrium temperature of Rhenish lignite for 12% residual moisture and required heating steam pressure at $\Delta\theta = 30$ K depending on system pressure

With increasing system pressure, the heat transfer at the heat exchangers of the fluidized-bed drier is influenced by the material parameters of the gas, which mainly affects the gas-convective portion α_G , causing it to increase by $\alpha_G \sim p^{0.5}$. The effect of an system pressure increase on the particle-convective portion α_P is much smaller, and the radiative portion α_{Srf} is independent of pressure [6]. The contribution of α_G , becomes less important for finer particles sizes, so that the influence of the system pressure on the overall heat transfer coefficient k diminishes for finer-grained fluidized beds, in which the particle-convective portion α_P will dominate. On the basis of measurements taken at RWE Power, Fig. 3 illustrates the effect increasing pressure on the heat transfer co-efficient of Rhenish lignite with a particle size of 0 -

6 mm /7/ compared with other bulk materials /8/. A similar increase of the heat transfer coefficient of lignite is also reported by /9/. At a constant evaporation rate, the increase in system pressure is associated with a reduction in superficial velocity in the drier. But since the fluidizing point varies only slightly with pressure, the sharp decrease in superficial velocity leads to a considerably reduced volumetric bubble flow rate. Both fluid-mechanical effects reduce the mixing intensity of cohesive raw lignite and easily fluidized dried lignite. This is particularly disadvantageous to the operation of fluidized beds with a high specific surface load.

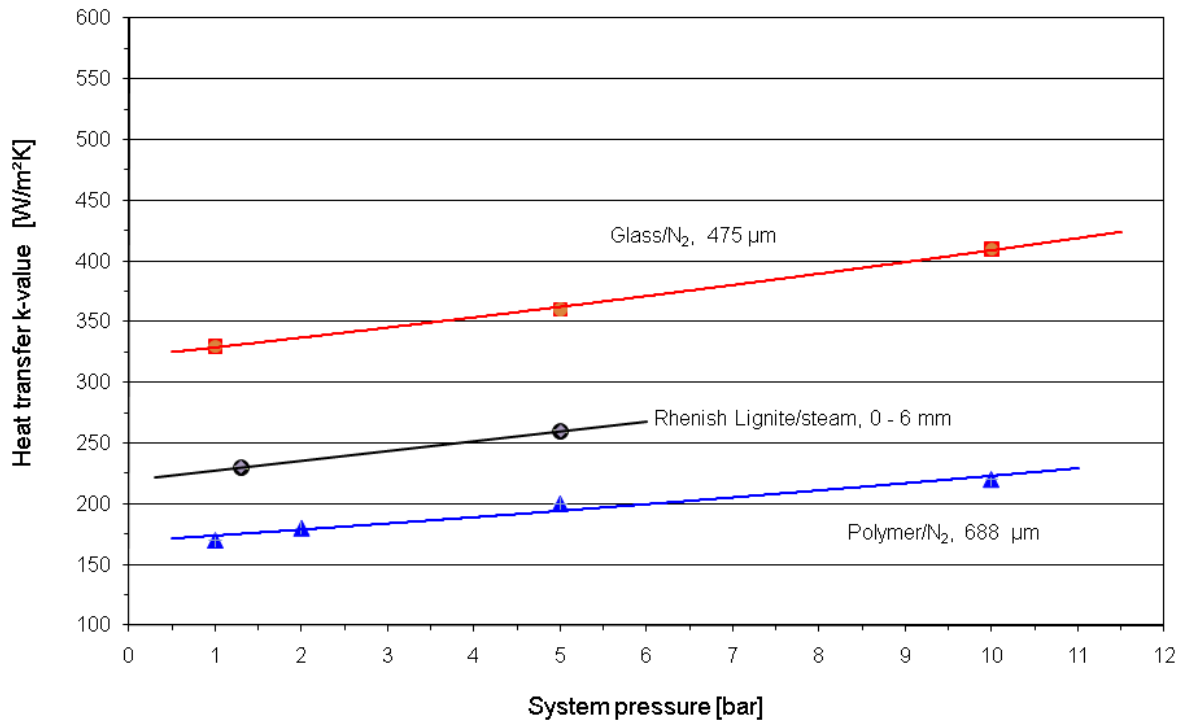


Fig. 3: Heat transfer coefficients as a function of system pressure

Influence of heating steam pressure

Increasing the heating steam pressure leads to an increased temperature difference across the heat exchanger. Thus on the one hand, the required heat exchanger area, i.e. the size of the drier, and the investment cost are reduced. On the other hand, the specific exergy requirements of the drier increase, which diminishes electricity production and the efficiency of the power plant, irrespective of whether the drier is heated by bleed steam from the power plant turbine or re-compressed vapour. At constant heat-transfer and evaporation rates, the upper limit of the heating steam pressure is set by fluid-mechanical aspects. The bottom limit of the heating steam pressure is determined by the maximum size of the drier, which can be manufactured and transported economically as a complete unit or in modules. Within these limits, the drier can be optimized in technical and economic terms.

Effects of the parameters of pressure and particle size on machinery and equipment

As indicated in Table 1, smaller drier feed coal particles lead to significantly higher k-values, while the required fluidizing velocity at the fluidizing bottom decreases considerably. Thus at a constant drying rate, the size of the drier, vapour dust collector, fluidizing fan and connecting pipes can be reduced and a less heavy steel structure will be required so that the entire plant is more compact. In addition, electric power requirements decline.

Since the design of the drier is based solely on heat transfer considerations, the drier is scaled down only to the degree that an improved heat transfer coefficient causes the heat exchanger area of the drier to decrease. Since an increased system pressure leads only to a slight improvement in the k-value, approx. 20% for coarse lignite the corresponding reduction of drier size has to be juxtaposed against the considerable extra outlays for the pressure design of process equipment and machinery, which also affect other plant equipment. The large pressure difference at the coal feed and discharge systems also leads to increased wear and leakages that have to be safely drained, necessitating further process-related outlays.

To establish the effects of particle size and system pressure on the investment cost, the costs were compared on a standardized basis for the following plants:

- Frechen WTA 2 plant (fine grain: 0 - 2 mm)
- Niederaußem WTA 2 plant (fine grain: 0 - 2 mm)
- Vattenfall DDWT² plant (system pressure: 6 bar; coarse grain: 0 - 6 mm)

Neither the DDWT nor the Frechen WTA 2 plant (as-built) recovers the heat of evaporation, whereas the Niederaußem WTA 2 plant includes a vapour condenser with a double-stage heat input system. For pressurized drying (DDWT) the cost comparison was based on the data given in /10/ and for the two WTA variants on actual cost (total plant cost incl. engineering and assembly). All costs were escalated to 2010 levels based on German Federal Statistical Office indices. To eliminate size-dependent cost effects, the plants under review were standardized to the same unit size by regression analysis. The result of the comparison (Fig. 4) shows that the cost of the DDWT plant is significantly higher than that of the WTA variants, as expected. The outlays required are 3.2 times higher than those for the Frechen WTA-2 plant and 1.9 times higher than those for the Niederaußem WTA-2 plant, which includes a vapour condenser.

Since the significantly higher investment cost caused by the increase in system pressure is not offset by any decisive advantages in other areas, RWE Power decided in favour of reducing the particle size of the feed coal when further developing WTA coarse grain drying.

² Druckaufgeladene Dampf-Wirbelschicht Trocknung = Pressurized steam fluidized-bed drying

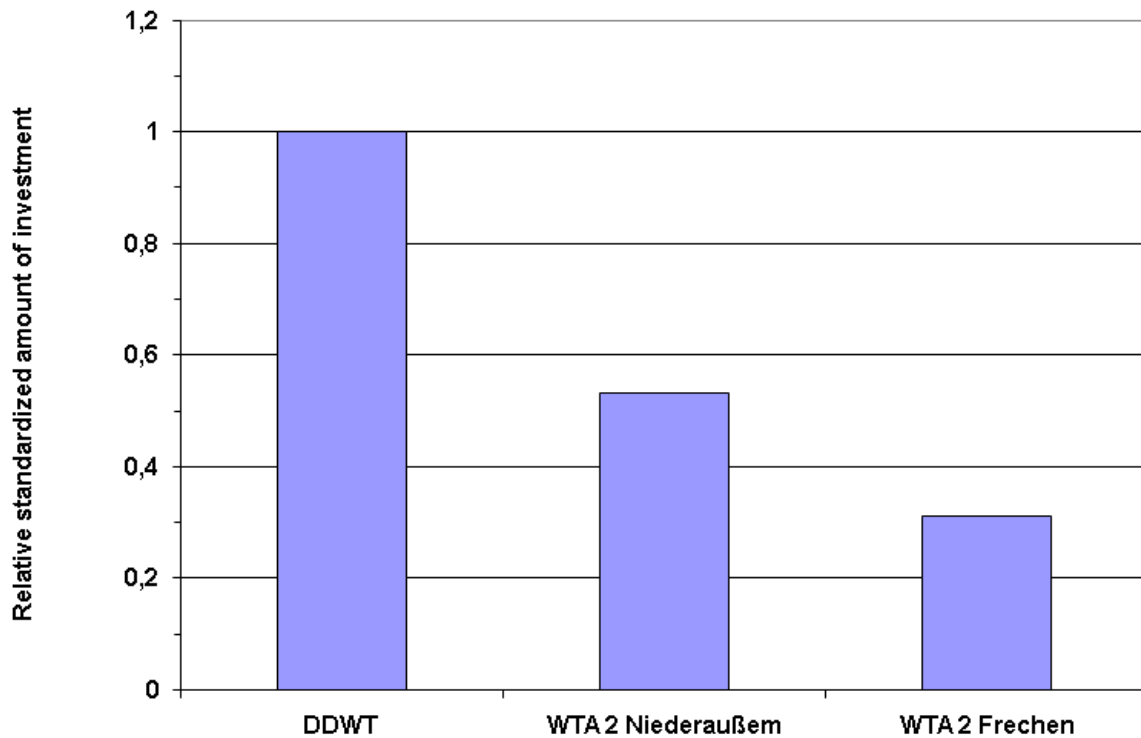


Fig. 4: Investment cost comparison between DDWT and WTA fine grain technology on a standardized basis

3. Process configurations of WTA drying technology

Variants of energetic vapour utilization

Utilizing the vapour removed from the lignite as an energy source allows the net thermal energy requirements of the drier to be significantly reduced. The following process variants can basically be used for vapour utilization:

- Mechanical compression of the vapour in an open heat pump process
- Direct condensation of the vapour in a process heat sink
- Expansion of the vapour in a condensing turbine

RWE Power developed both vapour compression and vapour condensation to commercial-scale maturity in order to meet the objective of integrating the WTA process into the overall process in an optimal manner depending on different underlying conditions and requirements.

Mechanical vapour compression is integrated into the drying process as an open heat pump process in such a way that the vapour can directly be used to heat the heat exchanger in the drier. If the sensible heat of the vapour condensate ex heat exchanger is used in the WTA process to preheat the raw lignite, the WTA process is virtually self-sufficient in steam, i.e. the

heat exchanger of the drier is not supplied with any external steam from the power plant process— if reducing the moisture content from > 55% to 12% wt.

Vapour condensation was developed for two different purposes: firstly for preheating boiler feedwater and secondly for producing secondary steam. The idea of expanding the vapour in a condensing turbine was abandoned following in-depth theoretical investigations, because this variant requires considerable outlays for machinery and equipment and does not have any efficiency advantages over vapour compression.

Vapour compression – either with or without coal preheating – is particularly advantageous, if lignites with high moisture contents have to be dried and if the overall process provides no or only small heat sinks. For lignites with low moisture contents and a sufficient number of heat sinks, the WTA variant including vapour condensation is an attractively priced option.

Variants of feed coal particle size

The WTA process was developed for two different feed coal particles sizes: the coarse grain WTA plant is operated with a feed coal particle size of 0 - 6 mm and the fine grain WTA plant with a particle size of 0 - 2 mm. The coarse grain variant is used, if the dried lignite needs to have a particular minimum particle size for reasons related to the subsequent process, e.g. for gasification in the HTW (High-Temperature Winkler) process or for the coking of lignite. For all other processes, the fine grain variant is generally technically and economically more attractive, due to better thermal and fluid-mechanical conditions. The fine grain WTA process has advantages especially when used as a pre-drying stage in conventional power plants, since the dried lignite does not require any or only little secondary milling.

RWE Power developed a pulverization method for raw lignite that is particularly suited for lignite and the downstream fluidized-bed drying process. It consists of two series-connected milling stages that reduce the lignite's particle size from approx. 0 - 80 mm to 0 - 2 mm. Owing to their compact design, the mills can be directly integrated into the drying process as an upstream process stage.

4. Function of the WTA drier

The raw lignite is introduced by a star feeder into the drier, which is under slight overpressure. A system developed specially for WTA technology and installed in the upper part of the drier distributes the added lignite evenly across the fluidized-bed surface. The middle part of the drier houses the actual fluidized bed with the built-in tubular heat exchangers. Either low-pressure steam or (depending on the process variant) recompressed vapour is used for heating; the pressure is approx. 3 - 4 bar in either case. A special system geared to the conditions of the lignite drying process is used for fluidizing the fluidized bed, which has a total height of about 3.5 m. A fixed-bed, from which the dry lignite is removed via suitable systems, forms below the

fluidizing level. The water evaporated from the lignite is withdrawn from the freeboard via the drier top. Fig. 5 shows a schematic view of the structure of the drier structure, which features high specific capacity and a particularly compact design. The drier of the Niederaußem WTA 2 plant (for data see Table 2) has a total height of less than 10 m.

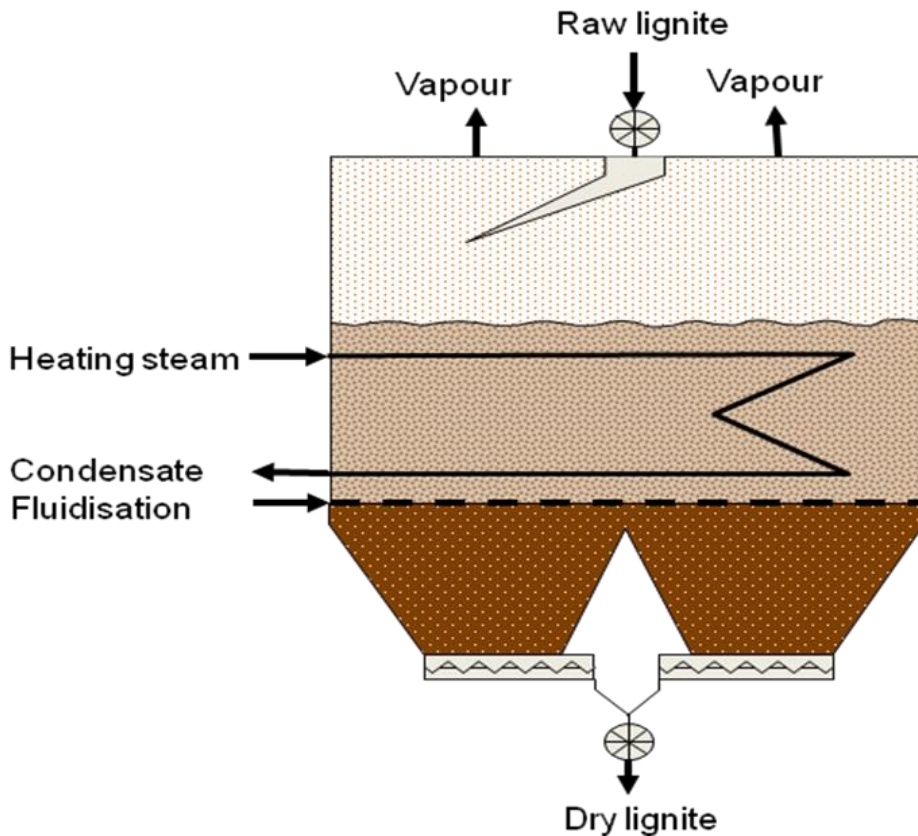


Fig. 5: Drier structure

5. Overall process

Fig. 6 shows the overall process of the fine grain WTA variant with upstream milling and integrated mechanical vapour compression to utilize the vapour energy within the drying process. Following dust removal in the electrostatic precipitator, the evaporated coal-inherent water (vapour) is recompressed in a compressor to approx. 3 - 4 bar so that the vapour can be used for heating the heat exchanger installed in the drier. The sensible heat of the vapour condensate produced is used to preheat the raw lignite to approx. 65 - 70°C, making an important contribution to the energy requirements of the drier. Some of the cleaned vapour is recirculated and used to fluidize the fluidized bed. The dry lignite is cooled and – if necessary – reduced to a particle size of 0 - 1 mm by a mill integrated in the process, so that it can be used directly for firing in the power plant.

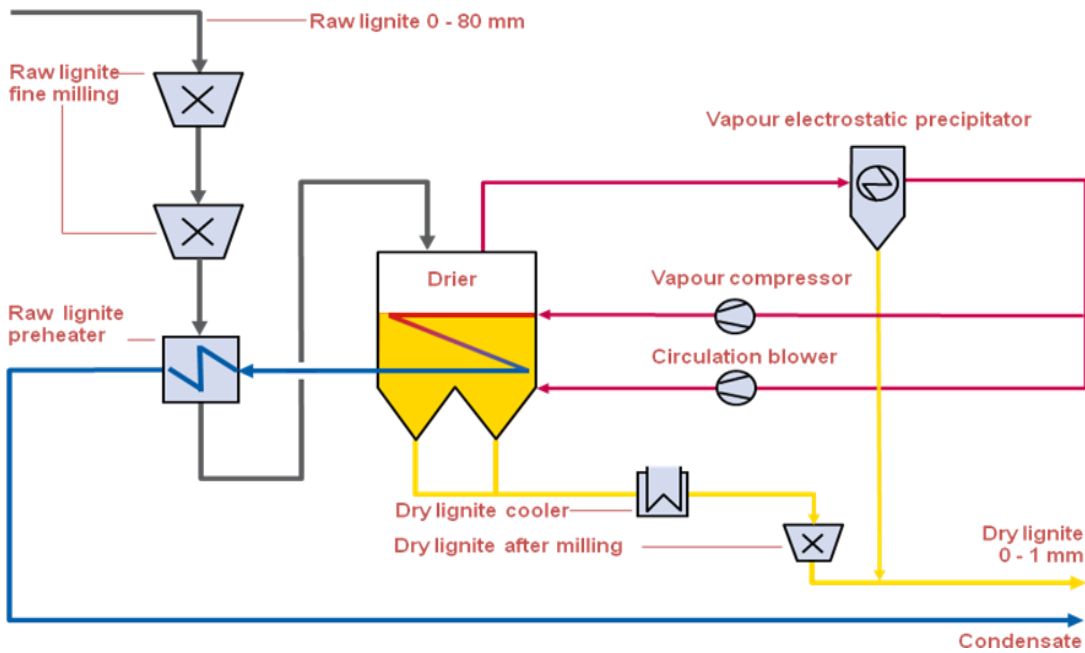


Fig. 6: WTA variant with integrated vapour compression and coal preheating

Fig. 7 shows the overall process of the fine grain WTA variant with upstream milling and downstream vapour condensation for preheating boiler feedwater of the associated power plant.

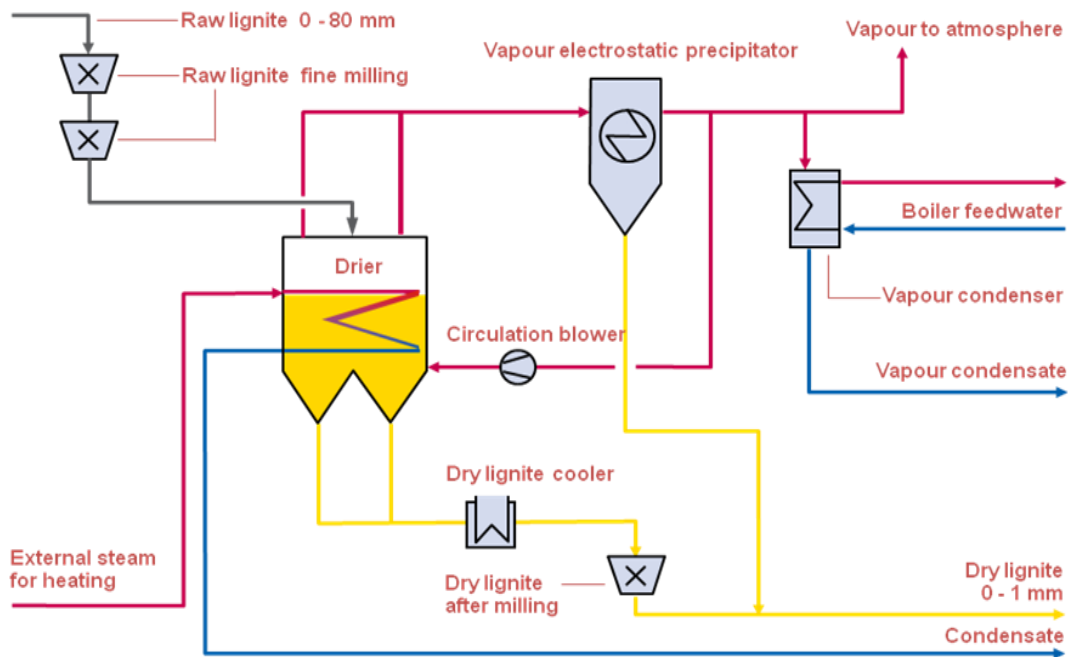


Fig. 7: WTA variant including vapour condensation

Fig. 8 shows a low-cost variant without vapour utilization, which may be used, for instance, to improve the calorific value of low-rank coals /11/.

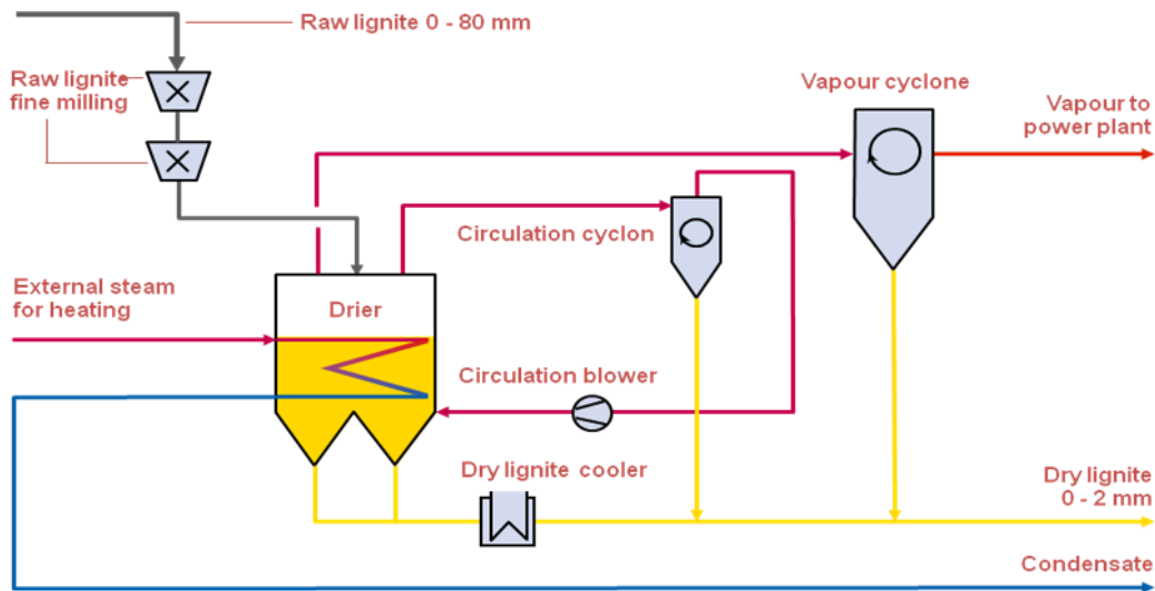


Fig. 8: WTA as low-cost variant

6. Plants built as part of WTA development and their results

The development of WTA technology was initially based on a particle size of 0 - 6 mm, as is common in coal upgrading and necessary for HTW gasification. The coarse-grain WTA plants (WTA 1 technology) at Frechen and Niederaußem were constructed for this feed coal particle size in a two-stage development process. The other work performed to increase technical and economic efficiency led to the development of the fine grain WTA plants (WTA 2 technology), which at the first stage of development were again erected at Frechen and at the second stage, having been scaled up by a factor of 8, at Niederaußem. The plants implement different vapour utilization concepts. In accordance with the objective of integrating the WTA process into the overall process in an optimal manner depending on different underlying conditions and requirements, the plants were based on different vapour utilization concepts.

Frechen WTA 1 plant

The WTA 1 plant at Frechen is a coarse-grain drier with integrated vapour compression and coal preheating /12/. The particle size of the feed coal is in the range of 0 - 6 mm, that of the dry lignite in the range of 0 - 5 mm. The process corresponds to the one shown in Fig. 6. The heat

exchanger of the drier is equipped with a cleaning in place (CIP) system that permits any fouling occurring in continuous operation to be removed quickly and effectively. The WTA 1 plant was in operation for a total of 20,000 hours and exhibited a high degree of availability. The vapour compression system for heating the drier, employed worldwide for the first time for lignite, has proved extraordinarily successful. In general, low-ash upgrading lignites were used, but in some special tests, different boiler lignites of the Rhenish mining area were employed. The performance data is given in Table 2. Fig. 9 shows a photo of the plant together with the WTA 2 plant, built at a later time.



Fig. 9: Photo of the WTA 1 plant (left part) and WTA 2 plant (right part) at Frechen

Niederaußem WTA 1 plant

The WTA-1 plant at the Niederaußem power plant was also designed as a coarse-grain drier with an integrated vapour compressor, but does not include a coal preheater. The particle size of the feed coal and dry lignite is the same as for the Frechen WTA-1 plant. To ensure that the energy balance is maintained (necessary in the absence of a coal preheater) some of the heat exchangers installed in the drier are heated with LP steam from the power plant network. The plant was operated in conjunction with unit H of the Niederaußem power plant only for a short time owing to the insolvency of the plant builder. The performance data are given in Table 2.

Frechen WTA 2 plant

In the Frechen WTA-2 plant, the principle of fine-grain drying was tested successfully for the first time on an industrial scale. The feed coal has a particle size of 0 – 2 mm, the dry lignite of 0 - 1 mm. The plant shown in Fig. 9 was erected right next to the WTA-1 plant, so that the infrastructure (consumables, supply and disposal systems) could be shared. The process largely corresponds to the one shown in Fig. 8. To allow the WTA-2 plant to be supplied with different types of lignite as flexibly as possible, two supply systems were installed: the first system supplies the plant with 0 - 6 mm sized low-ash coal from the Frechen upgrading plant; the second system feeds customer-supplied lignite (e.g. for customer tests) with a particle size of 0 - 100 mm. Owing to the excellent operating results, the original design capacity could be increased by about 64% in three optimization steps. In the course of these optimization measures, a vapour condenser was retrofitted to test the heating of boiler feedwater. So far, the plant has been in operation without disturbances for a total of 8,000 hours and is used today for customer tests within the scope of the international WTA technology marketing efforts.

Niederaußem WTA-2 plant

The Niederaußem WTA-2 plant is a fine grain drier with an integrated vapour condenser for double-stage preheating of boiler feedwater. With a raw lignite input of 210 t/h, it is the largest lignite drying plant worldwide. The feed coal has a particle size of 0 - 2 mm, the dry lignite of 0 - 1 mm. The plant shown in Fig. 10 was erected right next to the 1000-MW BoA unit of the Niederaußem power plant. The interaction of the power plant and drying plant in operation was tested here on a commercial scale for the first time. The process is shown in Fig. 7. The Niederaußem WTA-2 plant is the last development stage before commercial introduction and the plant size is equivalent to that of future commercial plants. Its design is based on the specific performance data of the Frechen WTA 2 plant, scaled up by a factor of 8 and the first raw lignite was dried in December 2008. An unexpected number of plant-related problems in the conventional (not WTA-specific) section led to a considerable delay in commissioning. Meanwhile these problems have been solved, so that the plant functions smoothly during extended phases of operation and consistently produces dry lignite to specification. Further optimization measures are necessary for the plant to reach full design capacity. The performance data of the Niederaußem WTA 2 plant are given in Table 2.



Fig. 10: Photo of the Niederaußem WTA 2 plant

Performance data	WTA1 Frechen	WTA1 Niederaußem	WTA2 Frechen	WTA2 Niederaußem
Raw coal throughput	53 t/h	170 t/h	29 t/h	210 t/h
Evaporated water	25 t/h	80 t/h	13 t/h	100 t/h
Dry lignite produced	28 t/h	90 t/h	16 t/h	110 t/h

Table 2 Performance data of RWE Power's WTA plants

7. Summary

WTA technology is an important element in RWE Power's efforts to further increase efficiency in electricity generation. In order to cater for different requirements and underlying conditions, several process variants were developed that allow pre-drying to be optimally integrated into the power process. As a preprocessing stage of lignite-based gasification, WTA technology will also contribute to an overall energy optimization of the coal conversion process. The construction and operation of the WTA plants in their various development stages have demonstrated industrial-scale maturity of the technology.

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