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Drying of High-Moisture Coals For Power Production & Gasification

Given the global abundance of coal and its importance in the production of power, fuels and various chemical feedstocks, it is clear that coal will play an important role in the global economy for years to come. Due to the geological process by which coal is formed, the moisture content of the four commercially-important coal varieties (anthracite, bituminous, sub-bituminous and lignite) varies by type. Those coal types that are geologically-younger, specifically sub-bituminous and especially lignite, naturally have a higher moisture content. This increased moisture content has many implications for its utilization in the power-producing sector and gasification processes. As such, there are many reasons for considering drying of high-moisture coals.

It is well known that high-moisture content in coal reduces its fuel value. As such, the use of high-moisture ("low-rank") coals in coal-fired power plants means that more low-rank coal must be combusted to achieve the same heat output as would be achieved via the combustion of less quantities of low-moisture, "high-rank" coal (such as anthracite and bituminous). However, given the abundance of low-cost, low-rank coals, the use of high-moisture coal in power production facilities is common and, in many cases, growing. Although combusting "as-received" low-rank coals is common, given the growing domestic regulatory pressures being placed on coal-fired power plants, it can be seen that drying high-moisture coals can provide many benefits to the operation toward meeting the ever-increasing regulatory burdens, especially considering the fuel value increase in the coal with drying (which is typically reported as a 10% fuel value increase per every 20 wt% in moisture reduction). Additionally, with the advent of "fracking" and the abundance of cheap natural gas, drying low-rank coals prior to their combustion in the power plant may assist the operation become more economically-competitive with natural gas-fired power plants.

Figure 1 shows a simplified schematic of a typical coal-fired power plant, where coal and combustion air are fed to a boiler operation. The coal is combusted, producing turbine steam and an exhaust air ("stack gas") stream. After the steam is passed through the various steam turbines, it is typically condensed prior to its return to the boiler operation in a condenser unit via the use of a cooling water stream, with the cooling water requirement determined by the condenser's duty (i.e. greater condenser duty requires more cooling water, and vice-versa). As would be expected, when the cooling water is returned to the cooling tower, there are evaporative losses, thereby requiring a make-up water stream (which may be a "treated" water stream). The combustion process produces an exhaust / stack gas stream that must be cleaned of particulate and other pollutants prior to its release to the ambient, thereby requiring large, expensive unit operations for stack gas treatment. Additionally, the residual solids "ash" streams must be collected and disposed of in some manner, posing potential health and / or environmental concerns.

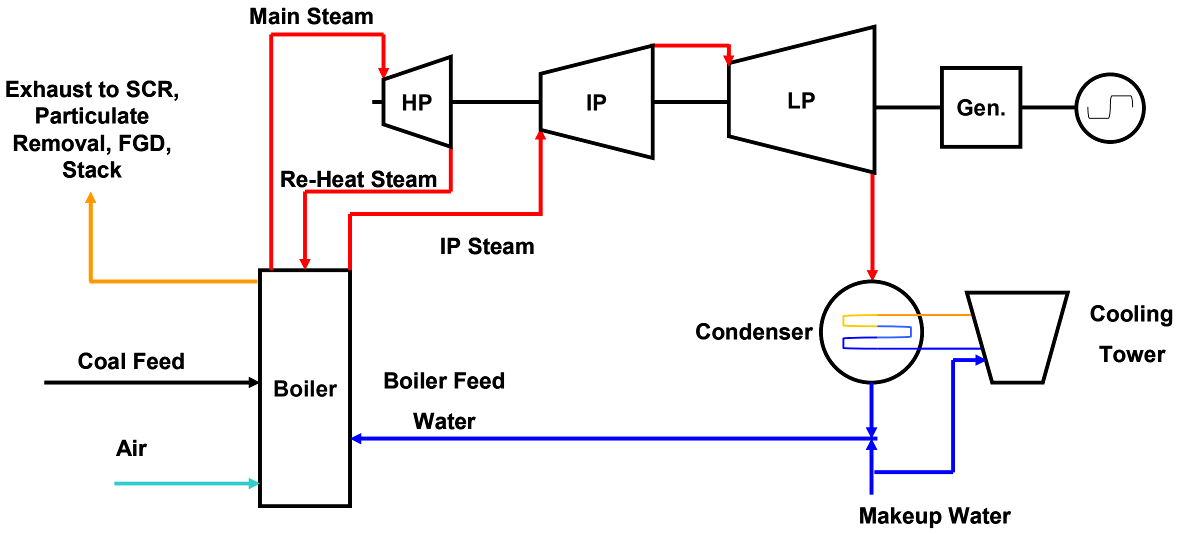

Figure 1: Simplified Coal-Fired Power Plant Schematic

As noted above, drying high-moisture coal has the effect of increasing the coal's fuel value by approx. 10% for every 20 wt% moisture reduction in the coal. Increasing the fuel value of the coal prior to feeding it to a coal-fired boiler operation would have many benefits to the operation, as illustrated by the following points:

- Increasing the coal's fuel value would allow the plant to use less fuel while achieving the same power production (reduced carbon footprint at same MW) or would allow for an increase in power production while using the same amount of fuel (greater MW at same carbon footprint).
- As would be expected, reduced fuel consumption rates would naturally lead to lower solids residual / "ash" production, thereby reducing ash disposal costs.
- Lowering the fuel feed rate also means lowering the introduction of sulfur and mercury into the process, thereby lowering the production rate of SO_2 and mercury emissions.
- Pre-drying the coal has been found to provide an increase in the boiler operation's efficiency, thereby reducing the amounts of CO_2 produced by, and exhausted from, the process. The increased boiler efficiency can also lead to reduced combustion air requirements, thereby lowering power consumption at the combustion air (FD) fan.
- If the coal is pre-dried prior to the boiler operation, there will be less water vapor in the stack gas from the boiler, since less water will be liberated from the now-drier coal feed stream (as well as by the benefit of feeding less coal). This would directly lower the exhaust gas volume to existing stack gas treatment operations, thereby further lowering SO_2 and Hg emissions as these treatment operations would operate more efficiently at the reduced volume to them. In like respect, particulate removal bag filter or electrostatic precipitator units would also operate more efficiently at the reduced volumes. The volume decrease would also lead to reduced exhaust (ID) fan power consumption.
- Pre-drying the coal will reduce the mass rate to boiler feed mechanical conveying equipment, thereby reducing their power consumption requirements. The same would be true for the coal pulverizing equipment prior to the boiler unit and may also allow for a reduction in the number of pulverizers to be used.
- Pre-drying the coal can also reduce the pulverizer primary air requirements, thereby directly (and substantially) reducing NOx emissions from the plant.

- In addition to the reduced pulverizer feed mass rate and primary air requirement reductions discussed above, it is possible that the drying process may reduce the overall particle size distribution ("PSD") of the coal. Figure 2 below helps illustrate this point and shows the PSD reduction for a lignite material upon drying at moderate temperatures, relative to an air dried portion of the same sample. Such a PSD reduction in the material would inherently improve pulverizer operations, since the pulverizer would not have to produce the same-sized pulverized material from a larger, non-dried material feed (i.e. the pulverizer unit would not have to "work as hard" to produce the same-sized pulverized material if it were fed a smaller-sized material from a coal drying operation).

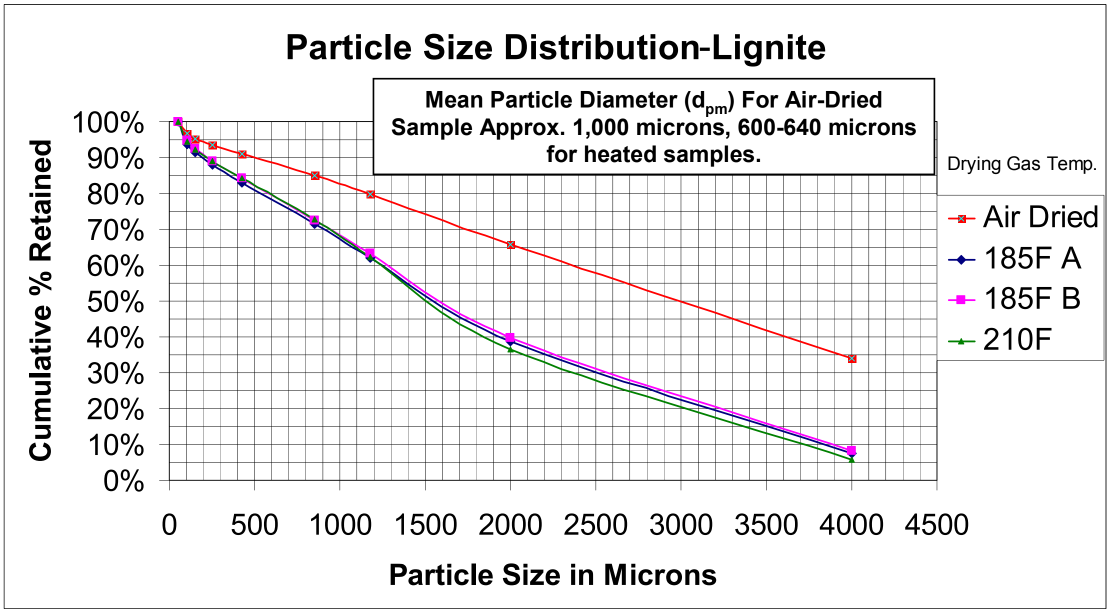

Figure 2: Lignite PSD Reduction With Drying

Clearly, as illustrated above, there are many benefits that can be gained via pre-drying the coal feed to the boiler. Given the many potential benefits of pre-drying high-moisture coal, it then becomes a matter of implementing the most cost-effective strategy that maximizes the use of excess or "waste" heat streams available in the plant to accomplish the drying process. As the two largest "waste" heat streams in a coal-fired power plant are the post-turbine steam to the condenser unit and the stack gas (representing approx. 45% and 20% of the fuel heat input, respectively), it makes sense to capitalize on the drying energy available in these two streams - either separately or concurrently.

With respect to stack gas energy utilization, the means by which this can be accomplished can vary. One method may be to pass the hot stack gas over a finned-tube heat exchanger, with a heat transfer liquid of some sort (usually water) circulating tube-side being heated by the hot stack gas. The hot liquid is then used by the drying system to dry the coal. As can be imagined, the large volumetric flow rate of stack gas can lead to large stack gas / heat transfer liquid heat exchanger unit operation sizes of considerable capital cost. There are several important parameters that must be considered for the use of stack gas as a coal drying energy source, as follows:

- Temperature - the stack gas must be of sufficiently-high temperature such that it can be utilized in a coal drying scheme.
- Mass Rate - the stack gas must be of sufficient abundance to effect a significant amount of heat transfer to the drying operation.
- Vapor Moisture Content - typically in the form of water vapor and “acid gas.” It is critical that the dew points for both of these condensable gases be determined, especially acid gases, to prevent condensing conditions on heat transfer surfaces which would ultimately led to corrosion on the heat transfer surfaces.
- Pressure - the stack gas must be of sufficient static pressure to compensate for the frictional losses it will sustain as it passes over the finned-tube heat exchanger, while maintaining sufficient static pressure to properly flow through the exhaust stack to the ambient.
- Particulate Matter (PM) Content - as the stack gas would be passing over finned-tube surfaces, it is critical that the stack gas be as particulate-free as practical to avoid fouling between the tube fins.

With respect to utilizing condenser steam heat for coal drying operations, following Figure 3 depicts one such utilization scheme. In this configuration, post-turbine steam is by-passed around the condenser unit and consumed directly by the drying process. The by-passed steam is consumed in two unit operations within the drying process - drying gas heating equipment (typically finned-tube heat exchangers, with the drying gas passing over the finned-tube surfaces) and heat transfer surfaces in intimate contact with the coal to be dried. The by-passed steam is condensed in the drying process and returned to the boiler feed water stream.

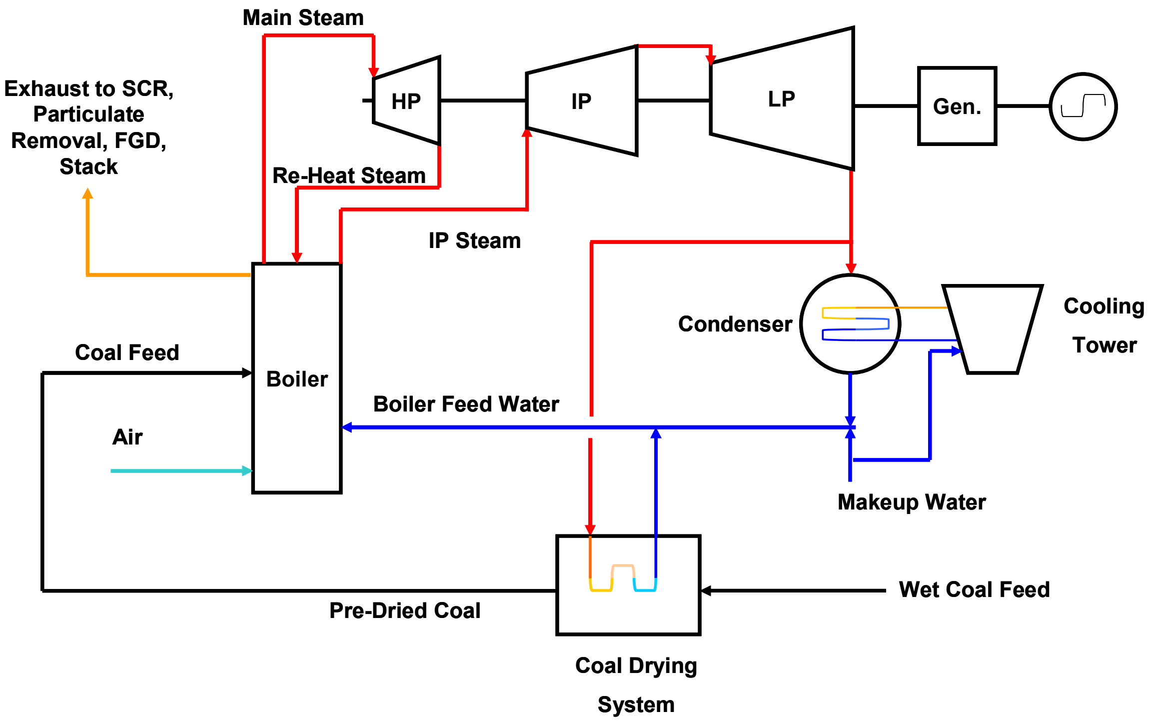

Figure 3: Pre-Condenser Steam Utilization in a Coal Drying Operation

There are several advantages of this energy utilization scheme to the plant:

- The condenser unit's duty is significantly reduced, thereby leading to proportional decreases in its cooling water requirements.
- A reduction in cooling water requirements at the condenser unit will reduce cooling water pumping power requirements.
- A reduction in cooling water re-circulation rates will lead to less cooling water evaporation at the cooling tower, thereby reducing makeup water requirements, improving the plants water balance and leading to proportionally-lower makeup water treatment requirements.
- The latent heat transfer of condensing the steam in the drying process minimizes the size of the drying system, relative to a drying system using condensate or a hot heat transfer

liquid. For example, assuming a latent heat of 950 BTU/lb for the steam, for every one pound of steam condensed, 950 BTU of drying energy is transferred to the drying process (neglecting thermal losses and / or inefficiencies). By comparison, assuming a specific heat capacity of 1.0 BTU/lb/deg F for hot water, 95 pounds of hot water would have to be reduced in temperature by 10 deg F to achieve the same energy transfer to the drying system and provide the same energy input as would be achieved by condensing only one pound of the previously-mentioned steam. Given that there are "good practices" to consider with respect to tube-side media velocities to be used, it can be seen that the 95:1 mass ratio of this example would likely require more tube-side cross-sectional area for the liquid phase heating media to remain within acceptable tube-side velocities. Additionally, if the steam temperature is greater than the hot thermal transfer liquid, there would be a greater temperature differential between the heating media and the coal to be dried, therefore providing a greater driving force for the drying operation and, consequently, reducing the dryer's physical size requirements.

- The steam heat that would have lost at the condenser would be utilized by the drying process, thereby increasing the overall thermal efficiency for the plant.

Commercial-scale coal gasification can trace it roots to the early 19th century where coal was heated to produce "coal gas" for street and residential lighting. Since then, coal gasification technology has continued to be developed for a variety of applications, such as for power production and "coal-to-liquids" (CTL). The process of coal gasification is well beyond the reach of this paper and much information is available in the general literature that can better describe the process than can be covered here. However, it is worthy to note that, with coal gasification technology, the process is such that a pathway to CO_2 capture (carbon capture and sequestration, "CSS") is more easily achieved. For power production facilities, this may be a means by which the plant can significantly reduce carbon emissions (by some accounts, to equivalent levels of natural gas-fired power plants) and better meet regulatory requirements in this regard.

With respect to high-moisture coal drying and how it relates to coal gasification, there are two main driving forces. The first is that, by pre-drying the coal, the gasification process gains efficiency in some way that improves the gasification plant's economics such that coal drying is desirable. In this case, it may be a matter of "want," not "need." The second reason is that, with some gasification technologies, the gasifier unit may be limited to a certain maximum-allowable coal feed moisture. For example, some gasifier technologies may not be able to accept a coal feed moisture of over 25 to 30 wt%. However, if the gasifier unit's feed is lignite, which is typically over 30 wt% moisture (and may be over 60 wt%, such as with Indonesian lignite or Australian "brown coal"), pre-drying the coal may be a necessity. Therefore, it is a matter of "need," not "want." Since the method of drying high-moisture coal for gasification operations is much the same as for drying high-moisture coal for power production facilities, namely by means of utilizing excess or "waste" heat from either of the processes, the reader is referred back to the above-discussed means by which plant heat can be incorporated into the drying process.

It is recognized that, on the large-scale operations represented by power plant and gasification operations, coal drying via the use of fluidized bed dryers is a more thermally-efficient method that can utilize a variety of heat sources, such as steam and condensate (either separately or in some combination). Therefore, the balance of this paper will focus on the various processes by which the high-moisture coal can be dried via a fluidized bed drying operation. To familiarize the reader with a fluidized bed dryer, following Figure 4 shows the major components of a fluidized bed unit operation.

Figure 4: Fluidized Bed Unit Major Components

The unit's geometry is typically rectangular in nature, but round units are not uncommon. For units operating on the scales typical of coal-fired power plants or large gasifier operations, rectangular configurations are predominant. As can be seen in Figure 4, the unit is comprised of three main sections - the lower "windbox" or "plenum," an "intermediate" section (comprised of the fluidized material product-contacting surfaces) and an upper "hood" or "freeboard" section. The plenum is separated from the intermediate section by the gas distributor, which evenly-distributes the fluidizing gas across the entire fluidized area. Essentially, the plenum receives the fluidizing gas from gas heating equipment by means of plenum nozzle connections and interconnecting ductwork between the two operations. The gas passes through the gas distributor and flows through the material, thereby fluidizing it and imparting a measure of convective heat transfer. Heat transfer surfaces may be immersed in the fluidized layer (known as "in-bed heat exchangers" / "HX's") and the extent of in-bed HX's used may be such that the majority of drying energy is delivered to the unit via conductive heat transfer means. The fluidizing gas passes through the material layer and is exhausted from the unit via the unit's freeboard area, which is an open space above the fluidized layer that allows for particles to disengage from the exhaust gas stream and fall back into the fluidized layer, reducing exhaust gas dust loading to the exhaust gas dust recovery equipment following the fluidized bed unit.

For smaller-scale operations, the fluidized bed configuration shown in Figure 4 may be appropriate. However, for larger-scale operations, it may be necessary to construct the unit such that it is in several sections that are easily-transported to the plant site. This design is called a "modular" unit design by which modules of different design are assembled together to form the dryer unit. Figures 5, 6 & 7 show three separate modules - "feed," "intermediate" and "discharge." In essence, a modularly-constructed fluidized bed unit would have one feed and one discharge module. A number of intermediate modules would then be added in order to obtain a dryer of sufficient size that meets its performance requirements, as is shown in Figure 8. As can bee seen from these figures, each module incorporates all of the major components of an individual dryer, in terms of material feed / discharge nozzles, fluidizing gas connections, exhaust gas connections, etc. For very large units, one or more in-bed HX's may be left out down the length of the unit in order to provide locations for closely-placed support steel members.

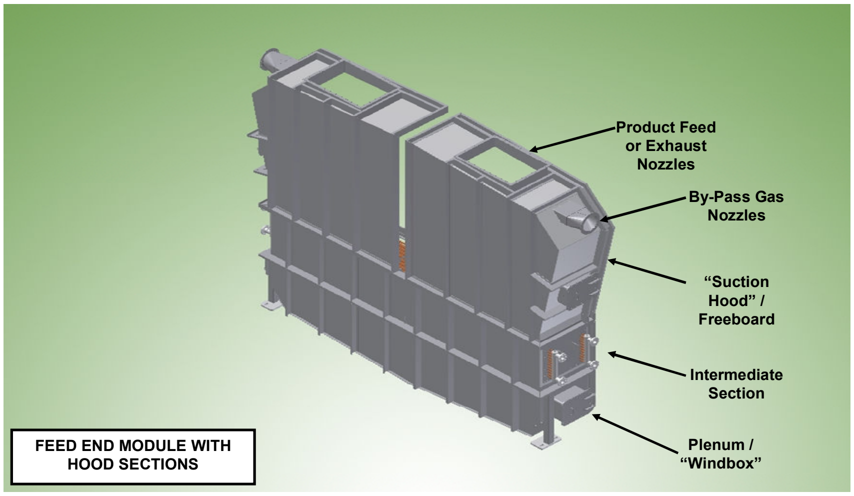

Figure 5: Feed Module

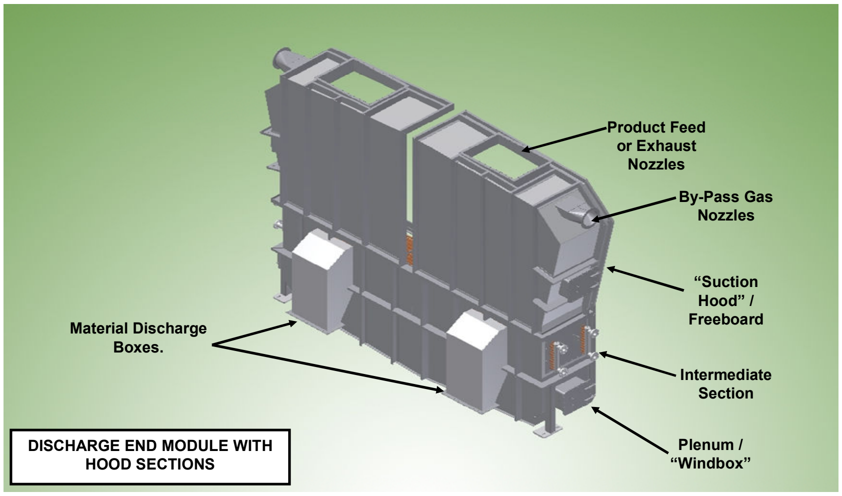

Figure 6: Discharge Module

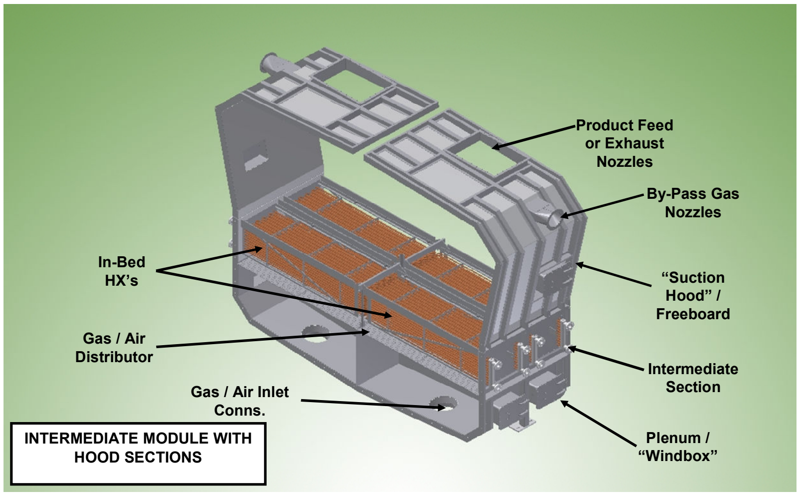

Figure 7: Intermediate Module

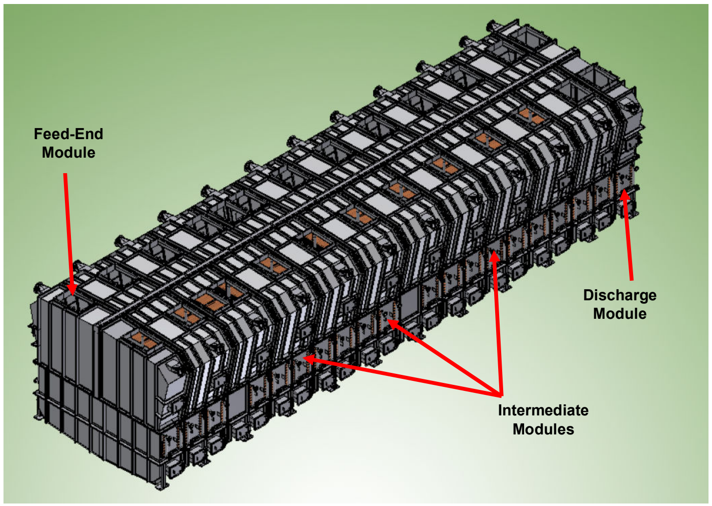

Figure 8: Assembled Modules

Depending on the characteristics of the coal to be dried and process requirements, a variety of drying configurations can be utilized. Figure 9 shows an “Open-Loop” configuration by which ambient air is heated to process conditions and then exhausted directly to the ambient after dust-recovery equipment. This drying configuration should be for less “reactive” coal materials (such as anthracite or bituminous) or in those instances where a more reactive coal (such as sub-bituminous or lignite) is being only slightly dried (i.e. a small reduction in material moisture content and / or a small increase in dried material temperature), although both of these points could be a matter of debate and / or operational philosophy.

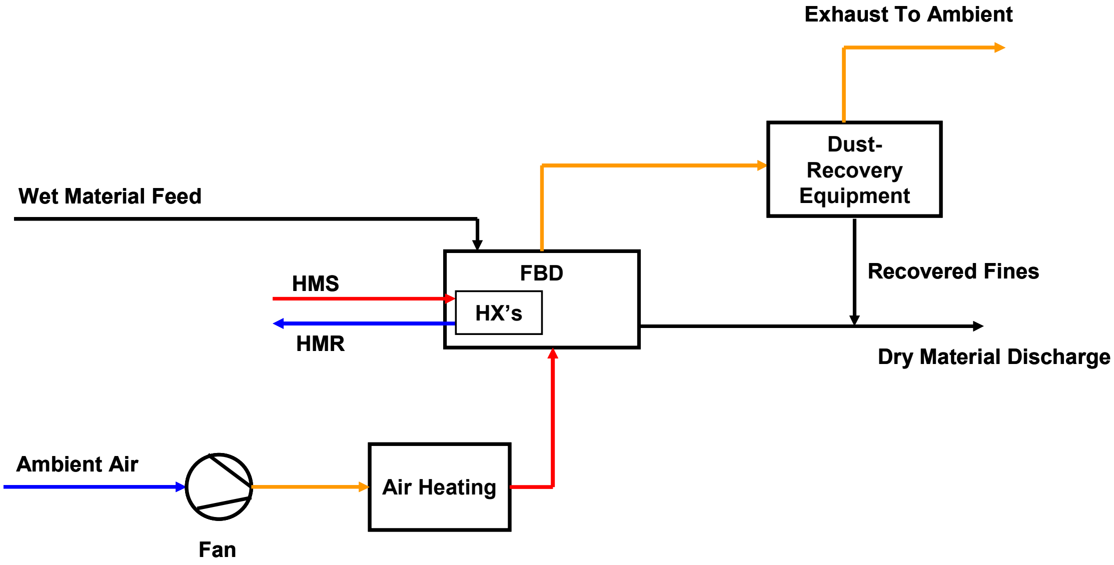

Figure 9: Open-Loop Drying Process

Figure 10 shows a "Partial Closed-Loop" drying configuration that is similar to the Open-Loop configuration, with the exception that a portion of the dryer's exhaust air is recycled. The applicability of this configuration would be similar to the Open-Loop configuration (less reactive material and / or only slightly drying the material). However, there are two advantages to this configuration over the Open-Loop configuration - (1) as part of the dryer's hot exhaust is recycled, the heating duty on the air heating equipment is reduced and (2) there is less air exhausted to the ambient.

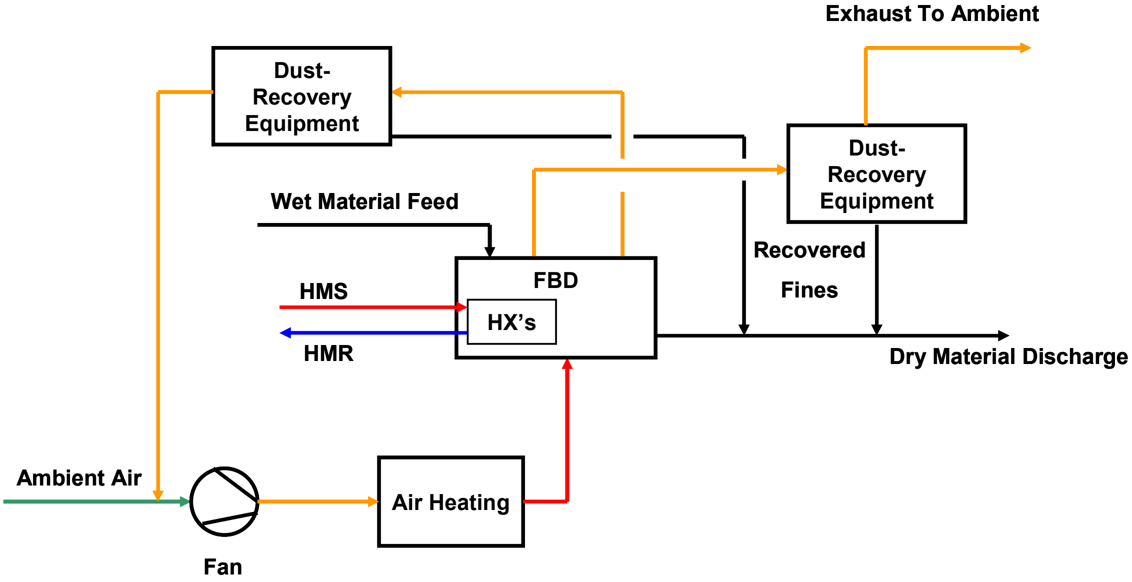

Figure 10: Partial Closed-Loop Drying Process

Figure 11 shows the configuration for a "Closed-Loop" drying system that is not inertized (i.e. ambient concentrations of oxygen exist in the Closed-Loop configuration). This configuration would have similar applicability to the previous two drying configurations (in terms of material reactivity characteristics and / or level of drying to be achieved). As all of the dryer's exhaust air is recycled, heat integration is enhanced over the Partial Closed-Loop configuration. Additionally, owing to the Closed-Loop design, exhaust / purge air to the ambient is minimized (and typically only that volume of air entering the Closed-Loop arrangement with the material fed to the unit). However, as the air stream is contained within a Closed-Loop configuration, it should be noted the mass of water evaporated in the dryer unit must be condensed-out of the recycled air stream in the shown scrubber-condenser unit, thereby requiring plant cooling water usage at the scrubber-condenser. It should also be noted that, owing to the relatively high dryer unit exhaust air humidity levels associated with Closed-Loop process, it may be necessary to "by-pass" a portion of heated fluidizing air around the dryer unit as a measure of exhaust air relative humidity control. Of final note to this configuration is that it may be desirable to use cyclones as the initial exhaust air dust-recovery mechanism (as indicated by the use of red text in the graphic). This is because cyclones do not need regular filter media replacement (as would a bag filter unit), thereby lowering the drying system's maintenance expenses. Additionally, as the cyclones are followed by a scrubber-condenser unit and a typical cyclone design offers a high degree of dust removal efficiency, stringent dust-removal equipment is not needed for the initial dust-removal stage in the Closed-Loop arrangement.

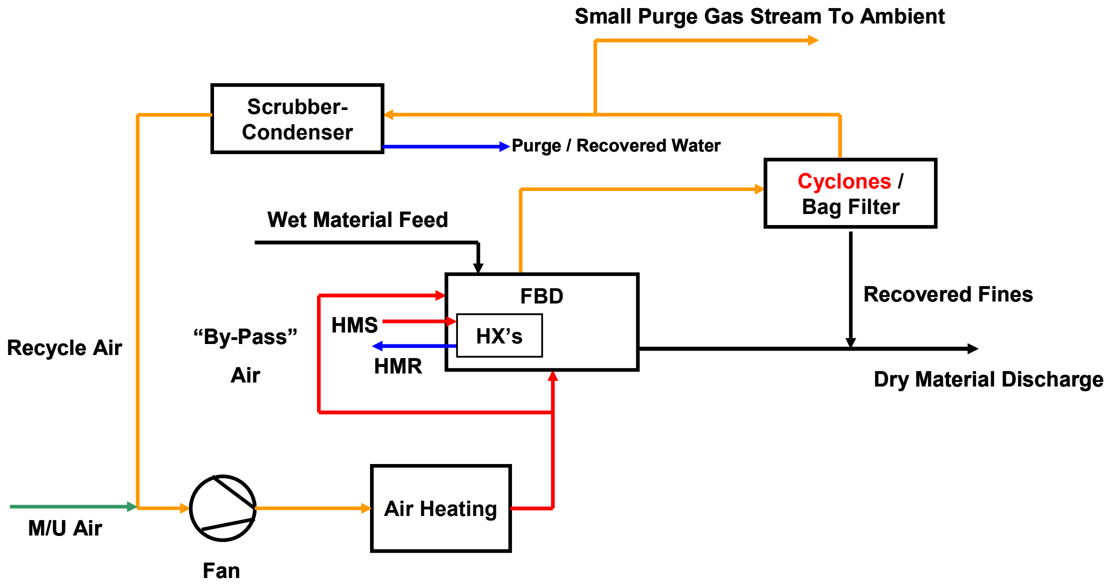

Figure 11: Non-Inertized Closed-Loop Drying Process

The final configuration is shown in Figure 12 as a Closed-Loop drying process that has been inertized (i.e. the oxygen level in the Closed-Loop gas arrangement is kept at less than 8 vol%). The applicability of this configuration is for reactive coals (particularly lignite) and those drying processes by which a large reduction in material moisture is desired. Owing to the fact that the fluidizing gas stream is inert, process safety is greatly-increased over non-inertized drying configurations. Closed-Loop gas inertizing is typically achieved via the injection of an inert gas into the Closed-Loop gas arrangement and, in similar fashion to the non-inertized Closed-Loop arrangement, the volume of inert gas injected into the system would be roughly equivalent to the volume of ambient air entering the Closed-Loop arrangement with the material feed to the dryer unit. The inertizing gas is typically dry nitrogen, but may be any other inert gas (such as CO_2). Inert gas selection may also be a matter of plant operating conditions. For example, a typical gasifier operation may have a large air separations unit (ASU) associated with it, by which appreciable amounts of N_2 and / or CO_2 may be available for use as the inertizing gas. In this case, the inert injection gas would be available for inertizing without the use of ancillary nitrogen-generating equipment (assuming inert gas is produced by the ASU in sufficient quantity for inertizing purposes). However, a coal-fired power plant would typically not have an ASU and would need to install a nitrogen-generating equipment set in the plant should an inertized Closed-Loop gas configuration be selected as the drying arrangement to be used.

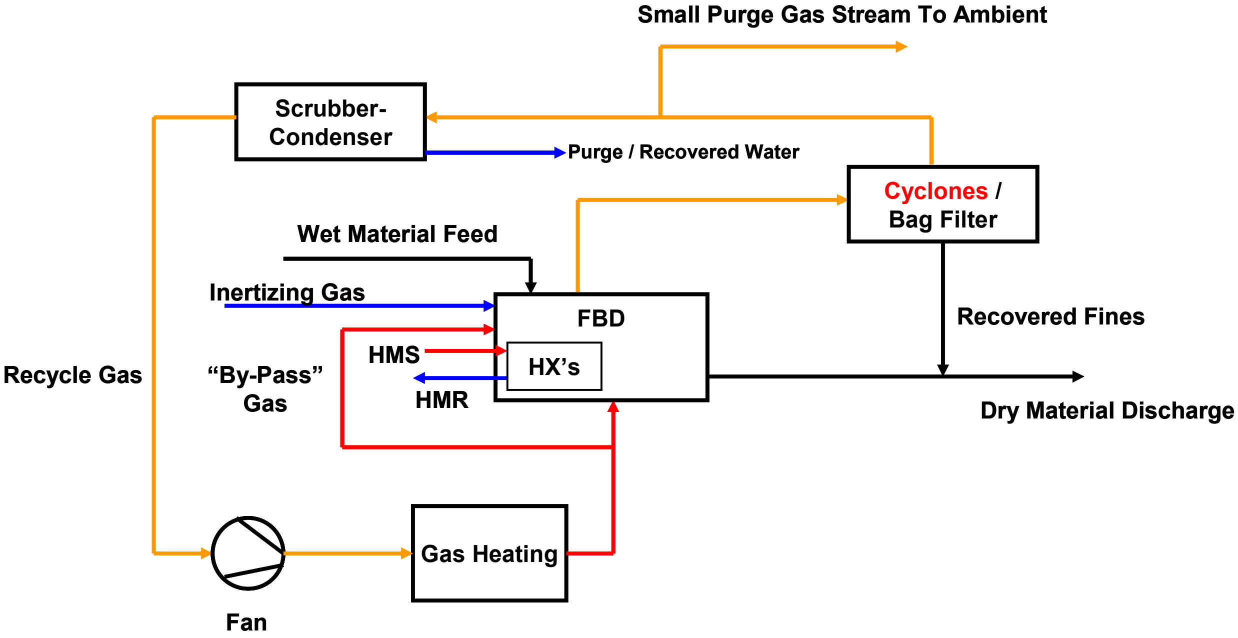

Figure 12: Inertized Closed-Loop Drying Process

In summary, it can be seen that there are many advantages that can be gained by drying high-moisture coals and, in some instances, it may be a requirement (such as with gasifier operations that cannot accept high-moisture coal feed). Owing to their thermal efficiency and flexibility to accept a variety of heat sources, fluidized bed drying operations have become the drying method of choice for large-scale coal drying operations. The fluidized bed unit can assume a variety of shapes (round or rectangular) and can be designed as a unit operation having only two or three sections in total or can be constructed in a modular fashion by which a number of modules are assembled together to provide a sufficiently-sized dryer unit that will meet a specific performance requirement. The fluidized bed drying system can be configured in several ways (or "Loop" configurations) that best suit the operation's needs and can be configured to maximize the system's thermal efficiency (by use of partial or total dryer exhaust air recycle), as well as enhance process safety (via the use of an inert drying / fluidizing gas stream). As coal's abundance and low cost make it an attractive material for use in power and gasification operations, it is clear that coal will play an integral part of the world's power production and chemical manufacturing processes for many years, if not generations. The challenge remains as to how best utilize this vital natural resource, for which high-moisture coal drying may play a key role.