Alf Malmgren, BioC Ltd, UK, discusses the milling of biomass in coal mills.

TALKING ABOUT THE REVOLUTION

Solid biomass fuels come in many shapes and types. They are all of organic origin and the vast majority are plant derived. This means that they display at least some of the fibrous structure of plants. Coal is also plant material, although highly metamorphosed after tens of millions of years in geological deposits exposed to varying levels of pressure and heat, which has removed almost all signs of this fibrous origin on a macroscopic level. So when coal is processed in a mill, it behaves much like a mineral, hard and brittle and with no apparent fibrous structure. Coal mills are, thus, designed to process hard and brittle materials.

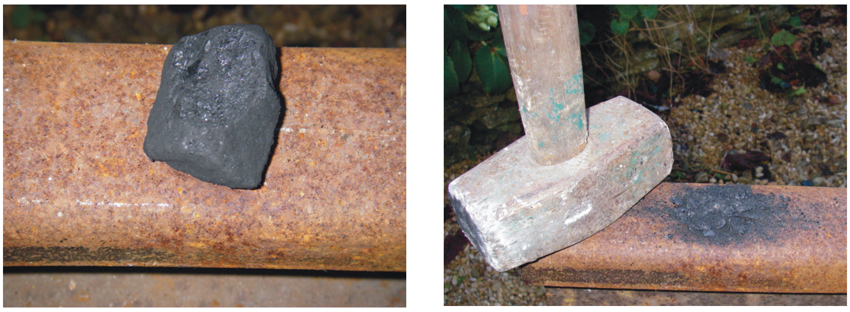

Figure 1. The effect of hitting a lump of coal with a sledge hammer.

Figure 2. A briquette of biomass before and after being hit by the same sledge hammer.

If the biomass fuels can be ground in existing coal mills, the required investment for co-firing is very low. However, it is also possible to use many coal mills to process neat biomass – and wood pellets are particularly popular for this. The lower heat content in wood pellets compared to coal generally results in a lower thermal throughput when a coal mill is converted to process them.

Milling

A mill is a tool used to reduce the size of a bulk material. This can be done using many different principles, such as slow mechanical crushing or high-speed impact. This article will focus primarily on the vertical spindle mill, which is one of the most common coal mill types, but will also mention hammer mills, which are the most common replacement mill type in conversion of coal-fired plants to biomass.

Hammer mills operate on the principle that fuel particles are hit by fast moving parts rapidly passing close to a screen with small holes for the milled material to pass through. Hammer mills are the most popular type of mill for wood pellets, both in conversions and new plants.

Vertical spindle mills have a bowl or table, which the fuel rests on, forming a grinding bed. The fuel in this bed is crushed between the bowl or table and large steel balls or rollers. This type of mill is very popular in power plants that burn bituminous and sub-bituminous coals and is probably also the most popular type for conversion to biomass.

If the existing mills cannot be converted, then a decision has to be made regarding which type of replacement mill to install during a conversion. If the existing coal mills are of vertical spindle type, then vertical spindle mills designed for biomass have the advantage over hammer mills, in that they are likely to be able to use more of the existing infrastructure, such as conveyors, fuel bunkers, feeders, etc.

There are many different types of vertical spindle mills. They are quite different in terms of their ability to successfully process biomass fuels. The disintegration of a wood pellet demands more than only compressive forces when the pellet in the grinding bed is squeezed between the mill table and rollers. A larger relative movement between the roller and the table is beneficial as this introduces more shear forces, which help break up the constituent particles in the pellet. Mills with a flat mill table and wide rollers will therefore be more likely to be successful with wood pellets.

The mill will produce a product with a wide range of particle sizes, from very fine to hardly broken up at all. This material is blown to a classifier that separates the particles that are fine enough from the oversized particles that are returned to the mill for further processing.

Vertical spindle mills have traditionally been made with integrated static classifiers that in principle are dust cyclones. They are nowadays often replaced by modern dynamic classifiers, which have static rows of vanes, combined with a rotating set of vanes. This results in a much sharper cut-off point for particle size, which gives significantly better NO_X performance burning coal in low NO_X burners. They are also more efficient in rejecting large biomass particles. This results in a higher degree of over milling and a higher power consumption with biomass.

Properties of biomass and coal

Many different biomass fuels have been used to replace coal in power plants. The most popular for complete conversions to biomass is wood pellets, which are traded internationally in increasing quantities.[1] They are easy to handle and have a relatively high heat content.

One important advantage with wood pellets is that there are internationally accepted quality standards, so the buyer knows they will purchase a consistent product. The hygroscopic nature of these pellets means that they have to be stored under cover, protected from any dampness. They also release noxious gases, which can be a safety issue when stored in a closed space and has led to fatalities in some cases. Gas detection is therefore crucial. The pellets are also dusty and release a very fine dust that stays airborne for a long time when handled, resulting in health risks for exposed personnel, as well as creating an explosion risk.

Grinding brittle and hard coal is very different to the visco-elastic and plastic biomass, which has the capacity to absorb and dissipate a substantial amount of energy before failure. The crushing action of a vertical spindle mill only tends to make the biomass a bit flatter, or break up a pellet into its constituent particles (Figures 1 and 2). Size reduction past the constituent particle size is limited and these particles need recycling through the grinding zone in the mill more than coal. The grinding of biomass therefore consumes more energy than coal. However, on the positive side, typical biomass particles burn faster than coal, so the particles can be larger, which reduces the need for size reduction in the mill.

The fibrous nature of biomass fuels will result in long fibres rather than particles and they can be very far from spherical. A particle from wood pellets processed in a hammer mill is shown in Figure 3, while Figure 4 shows a particle from a vertical spindle mill. Figure 5 finally shows coal particles milled in a vertical spindle mill. These are much closer to a spherical shape.

Typical specific power consumption milling coal in a vertical spindle mill is in the order of 8 – 16 kWh/t, depending on coal quality, and double that in a tube/ball mill.

The specific power consumption for milling of traditional white wood pellets in a hammer mill is shown in Figure 6 and compared to that for processing Zilkha Black Pellets. This is one example of the second-generation pellets, which are starting to reach the market. They are thermally treated to improve grindability by breaking down some of the fibrous structure. This makes them less hygroscopic and less prone to release noxious gases, thus addressing the problem of moisture absorption and degassing.

The particle size distribution of traditional white wood pellets and Zilkha Black Pellets after milling in a hammer mill with 6.4 mm mill screens can be seen in Figure 7. The Black dashed line in Figure 6 is an attempt to extrapolate what the specific power consumption for white wood pellets might be with 6.4 mm mill screens, using the line of best fit for the black pellets and transposing it to the level of white pellets. Unfortunately, no experimental data is available for white pellets and 6.4 mm screens. This indicates that these particular type of thermally-treated wood pellets both mill to a finer dust than traditional white wood pellets and with a significantly lower specific power consumption in identical mill configurations, and that the power consumption is similar to that for coal in a vertical spindle mill.

Combustion

A typical coal has a volatile content below 30%, while in biomass, the volatile content is typically above 70% of its mass. Devolatilisation is a faster process than combustion of the solid char. The non-spherical shape of the biomass (Figures 3 and 4) allows oxygen to reach the surface and combustion products to leave more quickly. It also provides a larger surface area receiving heat radiation. All of this results in a significantly faster combustion of the wood particles. They can therefore be larger than coal particles and still burn completely.

A typical power boiler designed for coal will have a particle residence time in the combustion zone of 1.5 – 2 sec. A typical coal particle will need to be ground to a size around 70 μm to be able to burn in this time. A wood particle burning under the same conditions can be 1 – 2 mm and still burn out due to the higher volatile content and non-spherical shape.

The mill does not have to produce the same fineness with all fuels. A biomass optimised mill must produce particles around 1 mm, while a coal optimised mill should produce particles around 70 μm. This is difficult to achieve at the same time in a co-firing situation, where coal and biomass are milled together. This will likely result in a significant over milling of the biomass fraction, which will have a negative affect on the mill capacity.

Figure 3. Particle from wood pellets milled in a hammer mill.

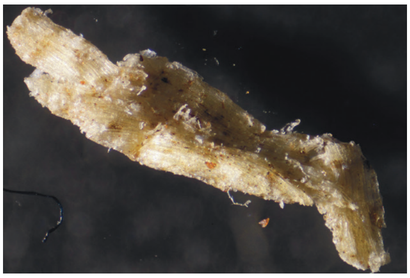

Figure 4. Particle from wood pellets milled in a vertical spindle mill.

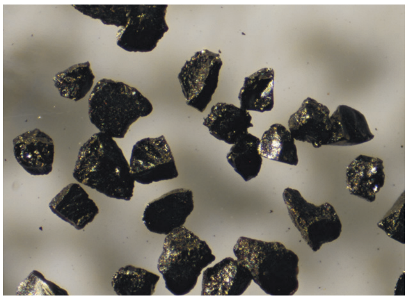

Figure 5. Coal particles from vertical spindle mill.

Required modifications for biomass

The different density and surface-area-to-volume ratios, as well as a different target particle size of biomass particles, mean that optimal air velocities in the mill are different to those for coal. A common practice is to introduce

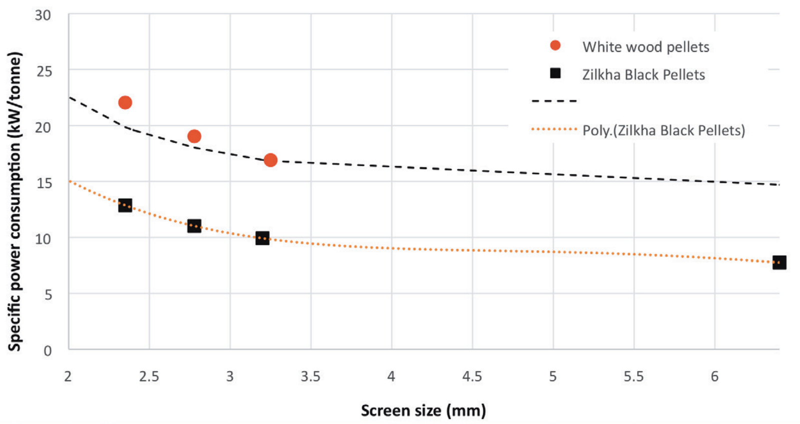

Figure 6. Specific power consumption in a hammer mill plotted vs mill screen size.

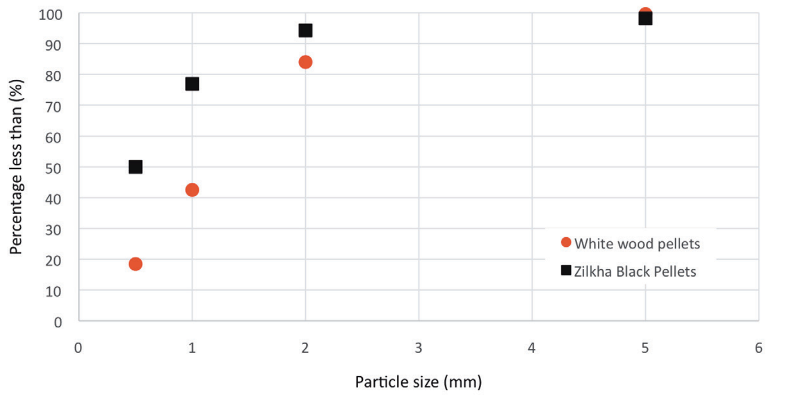

Figure 7. Size distribution of the mill product from a hammer mill with 6.4 mm screens.

baffles inside the mill body to control the flow of air and partially-milled fuel particles. The operating parameters and configuration of the classifier will also need modifying to allow larger biomass particles to pass through.

An extremely important aspect to consider during a conversion is health and safety. Biomass fuels have generally lower ignition temperatures for both dust clouds and layers. They also require lower ignition energy. This means that a spark that would be harmless in a coal mill might ignite the dust in the same mill processing biomass. The maximum temperature in the mill needs to be kept well below the minimum ignition temperature of the fuel. This might require modifications to the mill instrumentation, as it is common to only control the mill exit temperature. Explosion suppression systems have been installed in many converted mills.

Converted mills

There are many examples of successfully converted vertical spindle mills. Sweden, in particular, boasts a number of success stories. These include:

- Hässelby Energi: a company that converted three Babcock ball mill units, each of around 100 MW, from coal to 100% wood pellets in 1993. These units are still running today.
- Västhamnsverket, in Helsingborg, the company converted three Lopulco (Loesche design) mills to wood pellets 1997.
- In Uppsala, a 130 MW_e/240 MW_{th} combined heat and power boiler also converted two Loesche mills to grinding peat briquettes and sawdust in 1987. These are also still operating today.

The Amer 9 power plant in the Netherlands is another example of a successful conversion of a vertical spindle mill to wood pellets.

Tilbury power plant in the UK converted to 100% wood pellets in 2011. Their MPS mills and dynamic classifiers were successfully modified and the former 1062 MW_e coal plant was able to produce 742 MW_e after conversion to 100% wood pellets.

One of the most well-known plants burning wood pellets, Avedøre power plant in Denmark, converted one unit with MPS mills to wood pellets by introducing internal baffles in the mill to control the flow of fuel and air. They also built a new unit with new Loesche mills designed for wood pellets: this mill has a specific power consumption of around 9 kWh/t at a throughput of 48 tph.

Conclusions

Vertical spindle mills, designed for coal, can be converted to grind wood pellets. In most cases, this will result in a reduced milling capacity and also increased power consumption, but this will vary with different mill designs, which perform differently with wood pellets and will require different modifications. Thermally treated wood pellets grind more finely with a lower specific power consumption.

The different ignition and explosion properties of biomass materials compared to coal makes reduced mill temperature a requirement and a thorough safety review must always be carried out in connection to conversions to biomass. WC

Acknowledgements

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Note

1. Around 22 million t of wood pellets were produced globally in 2013, according to The Food and Agriculture Organization of the United Nations (FAO). Enough to generate around 12 000 MW of heat for a year. For comparison, 8.8 billion t of coal was produced in the same year according to the World Coal Association.