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REPLACEMENT OF FOSSIL FUEL WITH BIOMASS IN PULP MILL LIME KILNS

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ABSTRACT

The lime kiln is responsible for most of the fossil fuel consumption in a kraft pulp mill. Fossil fuel prices, and the obligation to reduce CO2 emissions, are strong incentives to replace fossil fuel firing in the kiln with biomass waste products (e.g. bark and chip screening fines). The impact is significant. It is reported that, of all known solutions to reduce greenhouse gas emissions in European kraft pulp mills, a 10% reduction could be achieved by switching from fossil fuels to bioenergy in lime kilns. This substitution can be achieved with biomass gasification. A typical delivery would include a belt dryer and a gasification plant in combination with a multi-fuel burner in the lime kiln. The belt dryer utilizes low temperature waste heat available in the mill. The gasifier is a Circulating Fluidized Bed (CFB) air-blown gasifier operating at atmospheric pressure. ANDRITZ has two gasifier installations in full production in Finland (Metsä Fibre, Joutseno) and in China (Chenming, Zhanjiang). Both mills operate their lime kilns at full capacity with 100% biomass derived gas. At Joutseno, natural gas was replaced by the gasification of Nordic bark. At Zhanjiang, heavy fuel oil was replaced by the gasification of eucalyptus chip screening fines. Non Process Elements (NPE) found in the biomass fuels are efficiently removed. Gasification plants with capacities between 25-110 MW should offer an attractive payback. This roughly corresponds to a lime kiln capacity of 300–1,200 t/d. Key elements which will affect the feasibility of the investment are: lime kiln capacity, fossil fuel costs, biomass costs, need for co-firing, replacement with make-up lime, capital costs and, potentially, CO2 price.

Keywords: Biomass, Gasification, Lime Kiln

INTRODUCTION

The largest fossil fuel consumption in a kraft pulp mill comes from the lime kiln for the lime reburning process. With high oil or natural gas prices, and the obligation to reduce CO_2 emissions, there's a push for the replacement of fossil fuels in lime kilns. Forecasting the price of oil and natural gas is difficult, but with the recent ratification of the Paris Agreement by a majority of countries, the world has now a clearer vision of its future regarding climate change mitigation.

Therefore, a key challenge for the pulp industry will be to replace fossil fuels with other cleaner and more sustainable fuel alternatives. Since pulp mills have access to biomass waste in various forms (e.g. bark, chip screening fines, and sawdust), it makes sense to utilize these biomass materials as fuel. This was highlighted by Pöyry in a presentation that identified bark gasification as a potential opportunity to fire lime kilns in softwood pulp mills [1]. Similarly, according to CEPI [2], a 10% reduction in CO_2 can be achieved by replacing natural gas or fuel oil with biomass fuels in lime kilns in Europe.

Aside from biomass gasification, there are other fuels and technologies available, such as wood powder, biomass derived tall oil and pitch oil, lignin, and methanol combustion. Quite often, these alternatives require unique conditions at the mill (e.g., certain industries nearby, fuel availability, and costs). The latest trends still favor gasification. Bark is available at low cost and the gasification process is flexible. After debarking the pulp wood, bark needs only to be dried. The gasification process is flexible because it can accommodate various fuels with different properties and can separate most of the Non Process Elements (NPE) contained in the bark fuel so that it does not contaminate the lime cycle.

Gasification is a proven technology. ANDRITZ has four installation references from the 1980s. From 2010 on, there has been a renewed interest in lime kiln gasifiers and ANDRITZ has three additional reference plants: Metsä Fibre Joutseno in Finland, Zhanjiang Chenming Pulp & Paper and Chenming Shouguang Meilun pulp mill, both in China.

METHODS

The methodology to replace fossil fuel with biomass is the application of the ANDRITZ Carbona Circulating Fluidized Bed (CFB) biomass gasification plant technology for generating a biomass derived gas to fuel a pulp mill lime kiln.

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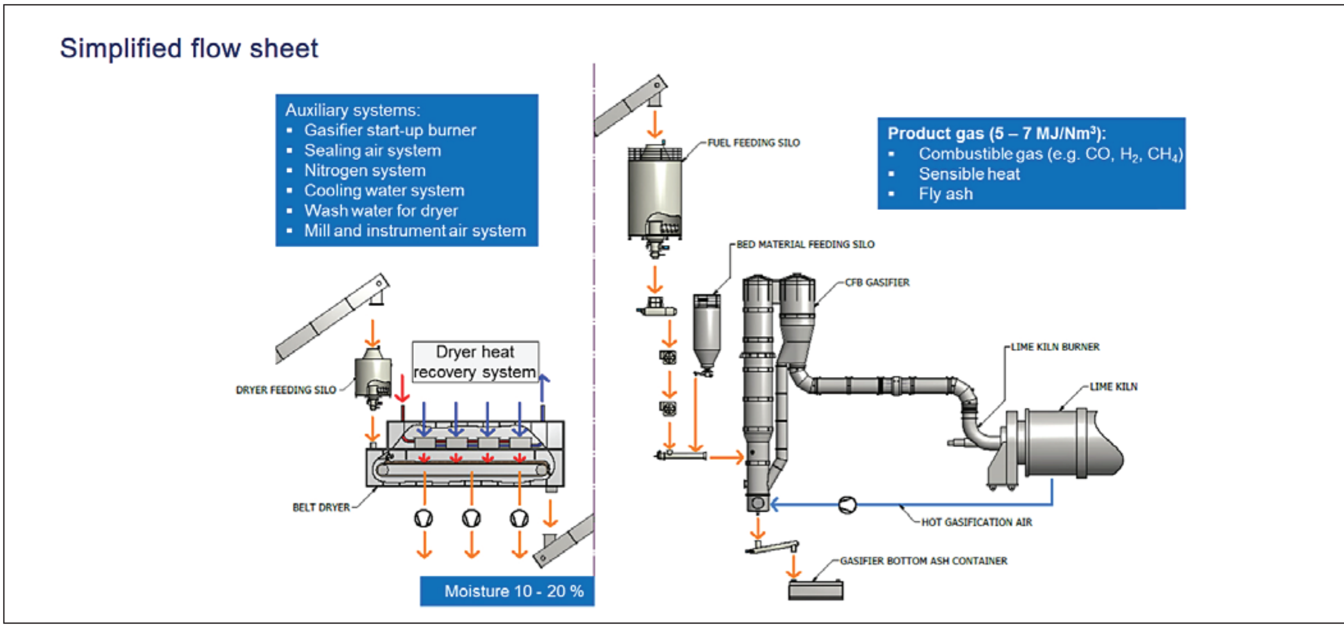

Figure 1. Simplified gasification process flow from dryer to lime kiln

Figure 1 shows a simplified process flow diagram of the gasification plant that includes the following key equipment: belt dryer; gasifier with fuel and bed material feeding; ash removal; and product gas duct connected to a multi-fuel lime kiln burner.

Belt Dryer

The wet biomass mixture is conveyed from the woodyard to a buffer silo before the dryer. Woody biomass is typically dried to about 85-90%-w dryness for gasification. Belt drying is the preferred technology because it can utilize low temperature waste heat readily available in a typical pulp mill to minimize operating costs. Various sources of low quality heat can be found such as hot filtrates, condensates, heat recovered from the lime kiln flue gas, and low-pressure steam if needed. With this technology, the drying temperature is below the de-volatilization temperature of wood fuel, which minimizes Volatile Organic Content (VOC) and odors from the exhaust air of the dryer.

The dried biomass is then conveyed to the gasification plant.

CFB Gasification Plant

Gasification is a process of various thermo-chemical reactions of woody biomass with air under sub-stoichiometric conditions. The energy in the product gas consists of the following: (a) 80% chemical heat (5-7 MJ/Nm^3), which represents the combustible components of the gas and includes mainly CO, H_2, CH_4 with some hydrocarbons; (b) 15% sensible heat; and (c) 5% fly ashes including unreacted fine char from the biomass. All of these transfer energy through further combustion inside the kiln [3].

The plant is composed of the gasifier reactor with cyclone(s) and gas duct (refractory-lined vessels), fuel and bed material feeding, bottom ash discharge, and gasification air supply equipment.

The gasifier is an air-blown CFB gasifier operating at atmospheric pressure. Bed material, usually limestone, is used to facilitate fluidization. Gasification air is introduced from the bottom of the gasifier through a grid which ensures proper air distribution in the gasifier. Taken from the kiln's sector cooler, the gasification air is hot, which reduces fuel consumption, increases product gas quality, and improves lime cooling with a simple concept. A UNIFLOW-type cyclone is used to separate entrained solids from the gas flow. Solids containing unreacted fuel char and circulating bed material are returned to the gasifier through a return pipe (dipleg) to maximize fuel conversion. These solids (fuel ash, unreacted bed material, NPE) are partly removed through the bottom ash discharge. If additional removal is needed, a second cyclone with a fly ash removal system can be installed before the lime kiln. The hot fuel gas is fed to the lime kiln burner via the gas duct.

A key issue in the planning of a gasification plant is to ensure that the biomass will be representative of the design fuel. Samples should be taken and analyzed for fuel properties, ash content, particle size, and moisture.

Fuel flexibility is a key feature of CFB technology. By weight, the biomass feed is a much smaller fraction than the hot solids (e.g., bed material and fuel ash) circulating in the gasifier reactor. Due to the large amount of hot bed material, CFB gasifiers are less sensitive to variations in fuel quality, such as heat value and moisture. The incoming fuel particles are quickly dispersed into the large mass of bed solids, which rapidly transfer heat to the fuel particles without any significant drop in temperature [3]. As a result, the control of the gasification process is stable, the quality of the product gas is uniform, and the combustion process in the lime kiln can be controlled by similar means as is done with conventional fuels.

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Figure 2. Multi-fuel burner in Zhanjiang

Multi-Fuel Lime Kiln Burner

The burner is located at the center of the firing hood and is pointed approximately along the axis of the kiln. The burner has two primary air zones – axial and radial. By varying the primary air flow to the zones, the flame can be shaped for optimum heat transfer and emissions. The kiln burner is air-cooled and the primary air tube is designed to allow the burner to be operated without the use of a water-cooled jacket or a refractory coating. Figure 2 shows the burner in Zhanjiang.

Application of Method

ANDRITZ has two plants in full production: Metsä-Fibre in Joutseno, Finland, started in 2012 and Zhanjiang Chenming Pulp & Paper in China, started in 2014. Figures 3 and 4 highlight the key characteristics of these two plants. More recently, ANDRITZ received a repeat order from Chenming at its Shouguang Meilun greenfield pulp mill, which will start in 2018.

Figure 5 shows the Joutseno gasification plant with the lime kiln in the background. Figure 6 shows the Zhanjiang Chenming gasification plant with its second cyclone and product gas duct.

Highlight:
Replace natural gas in an existing lime kiln (600 t/d).

Fuel handling, belt dryer, complete gasification plant (fuel feeding, gasifier, cyclone, ash handling, gas duct) and multi-fuel lime kiln burner.

- CFB gasifier capacity: 48 MW
- Operates with 100% biomass derived gas
- Fuel: Bark (pine, spruce, birch) from debarking
- Dryer evaporation: 12 t/h
- Dryer heat sources: mill filtrates and LP steam

Figure 3. Metsä Fibre, Joutseno

Highlight:
Replace heavy fuel oil in an existing lime kiln (800 t/d).

Key equipment for fuel handling, belt dryer, gasification plant (fuel feeding, gasifier, cyclones, ash handling, gas duct) and multi-fuel lime kiln burner.

- CFB gasifier capacity: 65 MW
- Operates with 100% biomass derived gas
- Fuel: Eucalyptus bark and chip screening fines
- Dryer evaporation: 19 t/h
- Dryer heat sources: condensates, lime kiln flue gas, LP steam

Figure 4. Zhanjiang Chenming

Figure 5. Joutseno

Figure 6. Zhanjiang

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RESULTS AND DISCUSSIONS

Based on experience gained from the projects at Joutseno and Zhanjiang, the key challenges for biomass gasification in kraft pulp mills can be summarized as:

- ✓ Replacing fossil fuel with biomass
- ✓ Providing steady heat without disturbances in the kiln operation
- ✓ Avoiding accumulation of NPE and their reaction with burnt lime
- ✓ Providing a satisfactory economic payback

• Replacing fossil fuels (natural gas or heavy fuel oil) with biomass

In both mills, Joutseno and Zhanjiang, the lime kilns operate at full capacity with 100% biomass derived gas. At Joutseno, natural gas was replaced by the gasification of Nordic barks (pine, spruce and birch) and in Zhanjiang, heavy fuel oil was replaced by gasification of eucalyptus chip screening fines. The plants are equipped with multi-fuel kiln burners which can easily and rapidly switch to fossil fuel as a back-up.

When the gasification plant goes online, the lime kiln operation is already stable. The switch between the fuels is done gradually. The biomass feed is increased while the oil or natural gas is reduced. In case of a gasification plant shutdown, the back-up fuel will take over almost immediately without any disturbances to the process and ensure high availability of the lime kiln.

The lime kiln operational efficiency is high as well as with the gasification plant. And so are the upstream processes (e.g., fuel feeding, ash handling, dryer and wood processing area), which are designed with specific buffers. This high efficiency was confirmed by Metsä Fibre in Joutseno in a recent press release where they are near to their 100% fossil-fuel free lime kiln operation target [4].

• Providing steady heat supply without disturbances to the kiln operation

The wet fuel from the wood yard typically varies in moisture content. To a large extent, the dryer can uniformly regulate the moisture content of the biomass. However, fuel heating values may differ (e.g., ratio of different species in the fuel mix, sand and impurities content in the bark, etc.) which affects the overall ash content. To ensure a steady heat supply to the lime kiln, these variations are controlled through the gasification air flow which will change according to fuel quality.

With biomass gasification, the lime kiln flue gas flow will increase. On existing lime kilns, there might be a need to replace the induced draft fan. Compared with conventional fossil fuels, the feeding end temperature is slightly higher because of the higher gas flow inside the kiln.

• Avoiding accumulation of NPE and their reaction with burnt lime

Key issues related to impurities in the lime mud are filtration properties and the kiln availability. Therefore, monitoring of critical NPE such as silica (Si), magnesium (Mg), aluminum (Al), iron (Fe), manganese (Mn), and phosphorus (P) is essential. [5]

The ash of biofuels represents an additional source of NPE when compared to conventional sources. The NPE concentration in the lime mud circulation must be minimized so that there's no accumulation or reaction with the re-burned lime. To ensure good filtration of lime mud and high dry solids, concentration of SiO_2, Al_2O_3, and MgO in the lime mud should not exceed 0.5%.

Silica content may originate from the fuel or from the soil when sand particles are picked up with the logs. If so, there are means to remove substantial amounts of sand with log-washing equipment.

Typically, pulp mills operate with a lime cycle opening between 2-5% to ensure low NPE in lime mud.

Measured data and operational experiences show that certain NPE can be removed with the gasifier bottom ash. This decreases the amount of impurities sent to the kiln with the product gas and, as a result, reduces the need for additional opening of the lime cycle. Removal efficiency with bottom ash is always specific to the process and the biomass type. With very high ash content in the biomass, additional removal of NPE can be achieved with a secondary cyclone. In the recausticizing plant, efficient NPE removal can be best achieved with precoat-free green liquor filters.

At Joutseno, the mill reported a change in the lime color when natural gas was replaced with wood bark derived gas, but it did not cause any disruption in production, nor lead to any accumulation of NPE in the process. [6]

At Zhanjiang, the mill is constantly monitoring the quality of the burnt lime. The plant is equipped with a second cyclone because the mill originally planned to use eucalyptus bark with high ash and silica content.

• Providing a satisfactory economic payback

There are many variables which will affect the payback time of a gasification plant investment. As is often the case, the variables are unique to the specific mill and the actual costs are known to the mill alone. However, the following variables seem to be the most significant: lime kiln capacity, price of replacement fossil fuel, price or internal cost of biomass, co-firing if needed, capital investment required, and the cost of make-up lime.

Gasification plants of **capacities** between 25–110 MW typically offer the most attractive payback. This roughly corresponds to a lime kiln capacity of 300–1,200 t/d. The future **price of fossil fuels** is virtually impossible to forecast, since it responds to both macro events (global and national) as well as local conditions (taxation and subsidies). However, at current oil prices (Q1-2017), a satisfactory payback can be achieved. **Costs of biomass** vary significantly between pulp mills (e.g., availability, sourcing, and opportunity costs for alternative uses). For the modernization of existing lime kilns, there might be a need for fossil fuel **co-firing**. This will depend on various factors such as the condition of the lime kiln, design load of the kiln, future capacity requirements, and biomass heat value (MJ/kg). To some extent, a high biomass heating value will produce a higher flame temperature and, therefore, will reduce the need to compensate with fossil fuel co-firing. As mentioned earlier, additional contaminants and NPE introduced by the biomass (SiO_2 and others) need to be extracted so as not to increase the **lime cycle opening**

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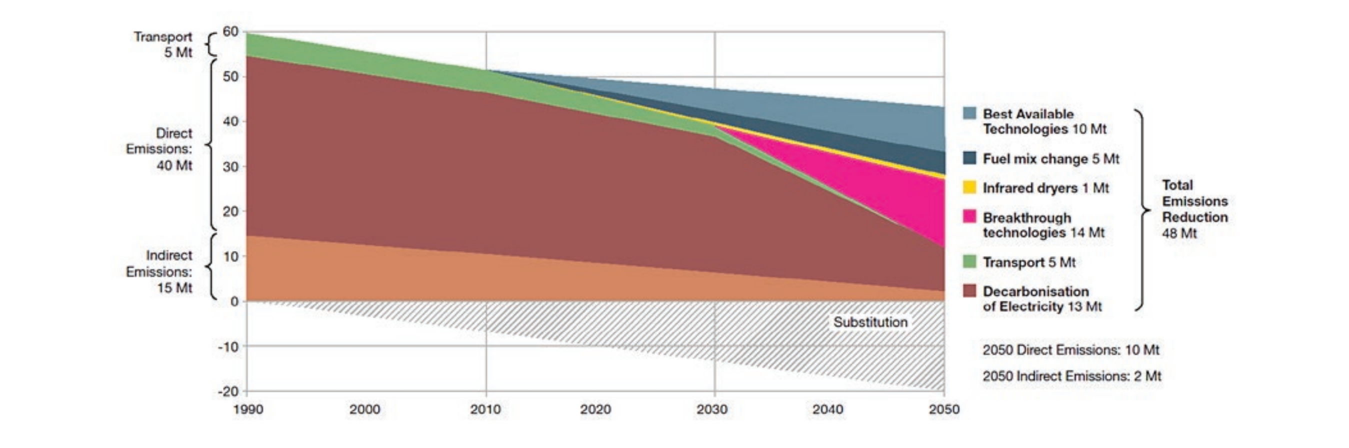

Figure 7. **Projections of European pulp and paper emission reductions (in million tons) [2]**

excessively. These costs will be reflected in the needs for replacement of make-up lime when compared to lime kiln firing with conventional fuels and landfill costs of the lime mud.

There are also other parameters to consider, albeit less significant such as: cost of electricity, manpower costs, and bed material (limestone) costs.

Finally, an important parameter is **carbon dioxide price**. Currently, this may or may not play a significant role in feasibility calculations, but there's a strong political push to reduce greenhouse gas emissions. The latest manifestation for this was with the ratification of the Paris Agreement in October 2016 where a majority of countries pledged to reduce greenhouse gas emissions.

This is important because emissions from fossil fuel combustion of lime kilns in the pulp industry are significant. They vary between 50–300 kg CO_2/metric ton of unbleached pulp with a median of 100 kg CO_2/ton [6]. The variations depend mainly on the type of mill (unbleached vs. bleached) and the type of fuel (natural gas vs. fuel oil). Although outdated, for the USA in 1995, the fossil fuel derived CO_2 emissions from kraft mill lime kilns represented about 7% of the pulp and paper industry's total direct emissions of fossil CO_2 [7]. More recently, CEPI estimated that switching from fossil fuels to bioenergy in lime kilns could reduce European kraft pulp mills emissions by 3–4 Mt CO_2 by 2050, or about 10% of the 34 Mt CO_2 emissions reductions they identified (Figure 7) [2] (*note: the value 10% excludes breakthrough technologies that have not yet been developed*).

CONCLUSION

There are two fundamental drivers for replacing fossil fuel firing in lime kilns in the kraft pulping industry: 1) high fossil-fuel prices, and 2) the desire/need to reduce CO_2 emissions. With current fuel oil prices (Q1-2017), a satisfactory payback can be achieved with a lime kiln biomass gasification concept that significantly lowers the carbon footprint of pulp mills.

A key challenge for gasification is to target 100% fossil fuel replacement. Metsä Fibre recently informed that it has replaced around 95% of natural gas on an annual basis with biomass (bark) derived gas to their lime kilns. In both mills, the lime kilns operate at full capacity with 100% biomass derived gas. The flexibility of a CFB gasifier ensures a steady heat supply to the lime kiln and does not create disturbances to the lime kiln and chemical recovery process. The combustion process in the lime kiln can be controlled by similar means as it's done with conventional fuels.

Gasification is a proven technology. Beginning in the 1980s, ANDRITZ installed four reference systems. More recently, two modern gasification plants are operating at full production (Metsä Fibre in Joutseno, Finland, and Zhanjiang Chenming Pulp & Paper in China). A new plant is on order and is scheduled to start up in 2018 (Chenming Shouguang Meilun). There are other alternatives to gasification, but conditions favor gasification because of low bark costs and its ability to reduce excess NPE in the lime cycle. ■

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