Development of recovery boiler technology

Dr Esa Vakkilainen
Jaakko Pöyry Oy, Vantaa, Finland

Abstract

Recovery technology developed from early inefficient chemical recovery to modern large plants. Early rotary units had to fade when new larger and more reliable units came were available in the 1930’s.

Changes in investment costs, increases in scale, demands placed on energy efficiency and environmental requirements are the main factors directing development of the recovery boiler. This has resulted in use of higher steam parameters and black liquor dry solids.

An example modern Scandinavian mill produces more than 30 MWe for sales with annual pulp capacity of about 600 000 t/a. Already net revenue of around 10 % can be achieved with surplus electricity, bark and wood residue sales. This amount can further be increased with adoption of utility type power plant connections.

Size of pulp lines has increased. In the largest lines we talk about utility sized power production (>100 MWe). Economics of scale means there are currently new economic possibilities to increase the yield of bioenergy.

Introduction

Recovery boilers are built all over the world. The roots of recovery technology are longer than the roots of recovery boilers. Introduction of recovery boilers before the Second World War revolutionized the recovery and led to long development of essentially the same type of equipment, culminating into units that are largest biofuel boilers in the world.

For pulp mills the significance of electricity generation from the recovery boiler has been secondary. The most important factor in the recovery boiler has been high availability. The electricity generation in recovery boiler process and steam cycle can be increased by elevated main steam pressure and temperature or by higher black liquor dry solids. This has been done in the modern Scandinavian units.
Early recovery technology

Figure 1, Early flame oven from late 1800 (Edling, 1981).

Early recovery technology concentrated only on chemical recovery (Deeley and Kirkby, 1967). Chemicals cost money at it was easy to note that recycling these chemicals would improve the profitability of pulp manufacture. Recovery of pulping chemicals could be based on French chemist Nicholas LeBlanc’s process for producing soda at reducing furnace.

Figure 2, Early smelt pot from late 1800 (Edling, 1981).

Recovering small amounts of chemicals was done by hand filling a flame oven with black liquor, Figure 1. Then the clack liquor was dried with flue gases from burning wood. The dried black liquor was scraped to floor, collected and sent to separate smelt pot, Figure 2, for reduction and burning the remaining organics (Rydhholm, 1965). Recovery of chemicals with this type of system was inefficient, chemicals recovery hardly exceeded 60 % (Whitney, 1968).
Hand operated recovery grew more complicated with heat recovery surfaces, Figure 3. Pre-evaporation and scrubbing in a rotary device was invented by Adolph W. Waern (Combustion Engineering, 1949). This improved the heat economy of the recovery system. The hand operation was soon replaced by rotative oven, Figure 4. Then it was a small step to introduce heat recovery equipment as was done with other types of boilers at that time. In 1912 the S-S system (Sundblad-Sandberg) was taken online at Skutskär. In it liquor was sprayed into rotary furnace at 50 % dry solids.

Tampella was among the first manufacturers to build SS-type furnaces, Figure 5. As can be seen there existed sealing arrangement between rotary drum and fixed parts. Preventing unnecessary air flow seemed to be one continuous operating problem. Thus typically the combustion was conducted at very high air ratio leading to inefficient energy use.
The equipment itself remained unchanged, but details were improved on. Smelt dissolving tank was introduced, final smelting was improved on and capacities grew, Figure 6. The use of refractory and rotative oven tended to limit the recovery capacity to 70 … 75 tds/d (Sebbas et al., 1983). Rotary part lengths were 7 … 10 m and diameter about 1.5 m (Swatrz and MacDonald, 1962).

Figure 6, Early SS rotary furnace from about 1945 (Vannerus et al., 1948).

The heat recovery boilers were improved on. In 1930s even LaMont type units were built, Figure 7. The use of rotary furnaces pinnacled in Murray-Waern type units which were successfully built around the world. In these the rotary precombustion was combined with totally water cooled furnace with lower part refractory lined.
Figure 7, LaMont type construction used in Kotka, Moss and Frantsach ~1930 (Edling, 1981).

First recovery boilers

The modern recovery boiler has a few strong ideas that have remained unchanged until today. It was the first recovery equipment type where all processes occurred in a single vessel. The drying, combustion and subsequent reactions of black liquor all occur inside a cooled furnace. This is the main idea in Tomlinson’s work.

Secondly the combustion is aided by spraying the black liquor into small droplets. Controlling process by directing spray proved easy. Spraying was used in early rotary furnaces and with some success adapted to stationary furnace by H. K. Moore. Thirdly one controls the char bed by having primary air level at char bed surface and more levels above. Multiple level air system was introduced by C. L. Wagner.

Recovery boiler also improved the smelt removal. It is removed directly from the furnace through smelt spouts into a dissolving tank. Even the first recovery units employed the use of Cottrell’s precipitator for dust recovery.
Babcock & Wilcox was founded in 1867 and gained early fame with its water tube boilers. It built and put into service the first black liquor recovery boiler in the world in 1929 (Steam, 1992). This was soon followed by a unit with completely water cooled furnace at Windsor Mills in 1934. After reverberatory and rotating furnaces the recovery boiler was on its way.

B&W favored use typically a single black liquor gun at front wall. In larger units additional gun was placed on back wall (Tomlinson and Richter, 1969). They preferred a significant part of the liquor to be sprayed to walls for drying. Boiler bottom was in angle causing smelt to flow quickly out. Hardly any space was reserved for smelt layer in the furnace. Thus this type of boiler was named sloped bottom. Final black liquor evaporation was carried in a direct contact evaporator of venturi scrubber or cyclone type.

The second early pioneer, Combustion Engineering based its recovery boiler design on the pioneering work of William M. Cary, who in 1926 designed three furnaces to operate with direct liquor spraying and Adolph W. Waern and his recovery units. The Murray-Waern recovery units were popular until the fifties.
Figure 9, The first CE recovery boiler 1938 (Combustion Engineering, 1949).

The first CE recovery unit, Figure 9, looks a lot like a modern recovery boiler. Note evaporator scrubber on the left and three drum construction. These recovery boiler constructions soon were licensed and produced in Scandinavia and Japan.

Early on the CE design stressed use of multiple guns in all walls (Tomlinson and Richter, 1969). Boiler bottom was flat with space for smelt layer on top of the whole floor. Thus the name decanting floor. Final black liquor evaporation was carried in a direct contact evaporator of cascade type.

The time was right

Using fibers from annual plants had been superseded by production of pulp from wood. Hugh Burgess and Charles Watt discovered and developed the process of soda pulping of wood getting a patent in 1853. And in 1866 the first soda-based pulp mill “the Manayunk Pulp Works” was in operation. Then in 1879 C.F. Dahl discovered that the addition of sodium sulfide to cooking liquor improved the
pulping process and the properties of final product. The Kraft mill was born when 1885 the Munksjo mill in Sweden started using this process.

The commercial success of Kraft process relied however on development of suitable chemical recovery where sulfate its main makeup chemical could be cheaply reduced to sulfide. It was the development in the period 1928 to 1934 of practical chemical furnaces that greatly lowered the production cost and pawed the way for the large increase in capacity of Kraft pulping (Tomlinson and Richter, 1969).

Aims

The basic aims of recovery boiler design could soon be summarized as; highest possible recovery of chemicals, high efficiency, high utilization of the calorific values in black liquor and highest safety of operation (Hochmuth, 1953). So finally the main process development of the recovery boiler was finished. In the early days the mill engineer was often let to his own devices to evolve a method of burning the black liquor with the sole objective of chemical recovery (Deeley and Kirkby, 1967).

Even though the recovery boiler development has continued these aims have remained the same the past 50 years. Adams et al. (1997) cites that the two main functions of the recovery boiler are to recover inorganic cooking chemicals used in the pulping process and to make use of the chemical energy in the organic portion of the liquor to generate steam for the mill.

Development of recovery boiler design

Spread of Kraft recovery boilers was fast as functioning chemical recovery gave Kraft pulping an economic edge over sulfite pulping (Boniface, 1985). The first recovery boilers had horizontal evaporator surface followed with superheaters and more evaporation. These boilers resembled the state-of-the-art boilers of some 30 years earlier. This trend has continued until today. It is easy to understand when any stop will cost a lot of money the adopted technology tends to be conservative.

The first recovery boilers had severe problems with fouling (Deeley and Kirkby, 1967). Tube spacing wide enough to coal fired boiler had to widened for recovery boilers. This gave satisfactory performance of 5½ days before water wash. Mechanical sootblowers were also quickly adopted. To control chemical losses electrostatic precipitators were soon adopted. So lowering dust losses in flue gases has more than 50 years of practice. The air levels in recovery boilers soon standardized to two. One primary at the char bed level and secondary above the liquor guns.
In the first tens of years the furnace lining was of refractory brick. The flow of smelt on the walls causes extensive replacement and soon designs that eliminated the use of brick were developed. The standard then became the tangent furnace wall. Membrane wall use became widespread in the 60’s.

There have been significant changes in Kraft pulping in recent years (Lindberg and Ryham, 1994, Vakkilainen, 1994b, Ryham, 1992). Combined use of extended cooking, hot alkali extraction and oxygen delignification make it possible to reach kappa numbers as low as 10 before bleaching. This has increased the degree of organic residue recovery. Black liquor properties have reflected these changes, Table 1.

Table 1, Development of black liquor properties (Vakkilainen, 2000).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquor dry solids, kg dry solids/ton pulp</td>
<td>1700</td>
<td>1680</td>
<td>1780</td>
</tr>
<tr>
<td>Sulphidity, Na₂S/(Na₂S+NaOH)</td>
<td>42</td>
<td>45</td>
<td>41</td>
</tr>
<tr>
<td>Black liquor HHV, MJ/kg dry solids</td>
<td>15.0</td>
<td>13.9</td>
<td>13.0</td>
</tr>
<tr>
<td>Liquor dry solids, %</td>
<td>64</td>
<td>72</td>
<td>80</td>
</tr>
<tr>
<td>Elemental analysis, % weight</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>36.4</td>
<td>34</td>
<td>31.6</td>
</tr>
<tr>
<td>H</td>
<td>3.75</td>
<td>3.5</td>
<td>3.4</td>
</tr>
<tr>
<td>N</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Na</td>
<td>18</td>
<td>18.4</td>
<td>19.8</td>
</tr>
<tr>
<td>S</td>
<td>5.4</td>
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<td>6</td>
</tr>
<tr>
<td>Cl</td>
<td>0.2</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>K</td>
<td>0.75</td>
<td>1.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Cl/(Na+K), mol-%</td>
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<td>1.37</td>
<td>2.49</td>
</tr>
<tr>
<td>K/(Na+K), mol-%</td>
<td>2.39</td>
<td>3.10</td>
<td>5.07</td>
</tr>
<tr>
<td>Net heat to furnace, kW/kg dry solids</td>
<td>13600</td>
<td>12250</td>
<td>11200</td>
</tr>
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<td>Combustion air* required, m³/n/kg dry solids</td>
<td>4.1</td>
<td>3.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Flue gas* produced, m³/n/kg dry solids</td>
<td>4.9</td>
<td>4.3</td>
<td>3.9</td>
</tr>
</tbody>
</table>

* At air ratio 1.2

Steam generation increases with increasing black liquor dry solids content. For a rise in dry solids content from 65% to 80% the main steam flow increases by about 7%. The increase is more than 2% per each 5% increase in dry solids. Steam generation efficiency improves slightly more than steam generation itself. This is mainly because the drier black liquor requires less preheating.

There are recovery boilers that burn liquor with solids concentration higher than 80%. Unreliable liquor handling, the need for pressurized storage and high pressure
steam demand in the concentrator have frequently prevented sustained operation at very high solids. The main reason for the handling problems is the high viscosity of black liquor associated with high solids contents. Black liquor heat treatment (LHT) can be used to reduce viscosity at high solids (Kiiskilä et al., 1993).

Two drum recovery boiler

Most of the recovery boilers operating today are of two drum design, Figure 10. Their main steam pressure is typically about 85 bar(a) and temperature 480 °C. The maximum design solids handling capacity of the two drum recovery boiler is about 1700 tds/d. Three level air and stationary firing are employed. Two drum boiler represents one successful stage in a long evolutionary path and signified a design with which the sulfur emissions could be successfully minimized. Main steam temperature was increased to 480 °C using this design.
Two drum recovery boilers are constructed with water screen to protect superheaters from direct furnace radiation, lower flue gas temperatures and to decrease combustible material carry-over to superheaters. The two drum boiler was the first type to use vertical flow economizers, which replaced horizontal economizers because of their improved resistance to fouling.

**Modern recovery boiler**

The modern recovery boiler is of a single drum design, with vertical steam generating bank and wide spaced superheaters. The most marked change around 1985 was the adoption of single drum construction. The construction of the vertical steam generating bank is similar to the vertical economizer. Vertical boiler bank is easy to keep clean. The spacing between superheater panels increased and plateaued at over 300 mm. Wide spacing in superheaters helps to minimize fouling. This arrangement, in combination with sweetwater attemperators, ensures maximum protection against corrosion. There have been numerous improvements in recovery boiler materials to limit corrosion (Ahlers, 1983, Hänninen, 1994, Klarin, 1992, Nikkanen et al., 1989).
A modern recovery boiler, Figure 11, consists of heat transfer surfaces made of steel tube; furnace-1, superheaters-2, boiler generating bank-3 and economizers-4. The steam drum-5 design is of single-drum type. The air and black liquor are introduced through primary and secondary air ports-6, liquor guns-7 and tertiary air-8. The combustion residue, smelt exists through smelt spouts-9 to the dissolving tank-10.

The nominal furnace loading has increased during the last ten years and will continue to increase (McCann, 1991). Changes in air design have increased furnace temperatures (Adams, 1994, Lankinen et al., 1991, MacCallum, 1992, MacCallum and Blackwell, 1985). This has enabled a significant increase in hearth solids loading (HSL) with only a modest design increase in hearth heat release rate (HHRR). The average flue gas flow decreases as less water vapor is present. So the vertical flue gas velocities can be reduced even with increasing temperatures in lower furnace.

The most marked change has been the adoption of single drum construction. This change has been partly affected by the more reliable water quality control. The advantages of a single drum boiler compared to a bi drum are the improved safety and availability. Single drum boilers can be built to higher pressures and bigger capacities. Savings can be achieved with decreased erection time. There is less tube joints in the single drum construction so drums with improved startup curves can be built.

The construction of the vertical steam generating bank is similar to the vertical economizer, which based on experience is very easy to keep clean (Tran, 1988). Vertical flue gas flow path improves the cleanability with high dust loading (Vakkilainen and Niemitalo, 1994). To minimize the risk for plugging and maximize the efficiency of cleaning both the generating bank and the economizers are arranged on generous side spacing. Two drum boiler bank pluggage is often caused by the too tight spacing between the tubes.

The spacing between superheater panels has increased. All superheaters are now wide spaced to minimize fouling. This arrangement, in combination with sweetwater attemperators, ensures maximum protection from corrosion. With increased number of superheaters, the difference in the heat transfer between a clean and fouled surface is less. This facilitates the control of superheater outlet steam temperature especially during start ups. Plugging of the superheaters becomes less likely, the deposit cleaning is easier and the sootblowing steam consumption is low.

The lower loops of hottest superheaters can be made of material, with better corrosion resistance. The steam velocity in the hottest superheater tubes is high, decreasing the tube surface temperature. Low tube surface temperatures are
essential to prevent superheater corrosion. A high steam side pressure loss over the hot superheaters ensures uniform steam flow in tube elements.

**Current recovery boiler**

Recovery boiler evolution is continuing strongly. Maximizing electricity generation is driving increases in main steam pressures and temperatures. If the main steam pressure is increased to 104 bar(a) and temperature 520 °C, then the electricity generation from recovery boiler plant increases about 7%. For design dry solids load of 4000 tds/d this means an additional 7 MW of electricity (Raukola, 2002).

![Image of modern boiler](image)

**Figure 12, One of the most modern boilers, Gruvön (Wallén et al., 2002).**

The current recovery boiler, Figure 12, can be much larger than the previous ones. Boilers with over 200 square meter bottom area have been bought. Largest recovery boilers are challenging circulating fluidized boilers for the title of largest bio-fuel fired boiler.

The superheater arrangement is designed for optimum heat transfer with extra protection to furnace radiation. Mill closure and decreased emissions mean higher higher chloride and potassium contents in black liquor. Almost all superheaters are placed behind the bullnose to minimize the direct radiative heat transfer from the furnace. Increasing superheating demand with increasing pressure decreases the need for boiler bank and water screen arrangement.
The higher main steam outlet temperature requires more heat to be added in the superheating section. Therefore the furnace outlet gas temperature has increased. The alternative is to significantly increase superheating surface and decrease boiler bank inlet flue gas. If boiler bank inlet gas temperature is reduced the average temperature difference between flue gas and steam is also decreased. This reduces heat transfer and substantially more superheating surface is needed. This approach has been abandoned because of increased cost. With increasing dry solids content the furnace exit temperature can safely increase without fear of corrosion caused by carryover.

Increasing recovery boiler main steam temperature affects the corrosion of the superheaters. Designing for higher recovery boiler main steam pressure increases the design pressure for all boiler parts. The recovery boiler lower furnace wall temperatures increase with higher operating pressure. New better but more expensive lower furnace materials are used. The air flow per unit of black liquor burned in the recovery boiler furnace decreases. Therefore the number of air ports will decrease.

**State of the art and current trends**

Recovery boiler design changes slowly. There are however some features that boiler bought today have in common. State of the art recovery boiler has the following features:

- One drum boiler with 3-part superheater and water screen (optional)
- Steam design data 9.2 MPa / 490 °C
- Design for high solids 80+ %DS with pressurised heavy liquor storage tank
- Liquor temperature control with flash tank, indirect liquor heaters eliminated
- HVLC gases are introduced to the boiler
- Low emissions of TRS, SO₂ and particulates
- Flue gas cleaning with ESP (no scrubbers)
- Upper level DCS applied

The design changes occurring can be listed. Current trends for recovery boilers are

- Higher design pressure and temperature due to increasing demands of power generation
- Superheater materials of high-grade alloys
- Further increase in black liquor solids towards 90 % by concentrators using elevated steam pressure
- Burning of biological effluent treatment sludge and bark press filtrate effluent
- Installations with CNCG burner (LVHC gases)
- Dissolving tank vent gases returned to the boiler
- Chloride and potassium removal from fly ash when recovering bleaching filtrates
- Fourth air level for NOx control
Choosing recovery boiler main parameters

As stated the recovery boiler main parameters are often given by the customer to the boiler vendor. So when the recovery boiler purchase is considered these main parameters must be chosen after careful study.

Trends in main parameters

Higher black liquor dry solids generates more steam. Also the main steam parameters (pressure and temperature) can usually be increased from traditional values. Significantly more power generation can be achieved, Figure 13. As can be seen, the change in steam data is as important as about 5 % change in black liquor dry solids.

![Figure 13, Effect of black liquor dry solids and main steam parameters to electricity generation from recovery boiler.](image)

The trend in recent years has been definitely in favor of increased temperatures and pressures. Newest Scandinavian lines, Figure 14, have chosen main steam values in excess of 80 bar and 480 °C (Vakkilainen and Holm, 2000, Wallén et al., 2002). Only a marginal increase in power production is attained with changing the steam temperature from 480 °C to 500 °C if steam pressure is kept constant. The overall mill heat balance should be used to optimize the feed water and flue gas temperatures (Suutela and Fogelholm, 2000).

The maximum steam data can be limited by the ash properties. The first melting curve at the superheater front should be taken into account. Increasing mill closure with high chlorine and potassium decreases melting temperatures. The overall mill heat balance should be used to optimize the feed water and flue gas temperatures.
Figure 14, Newest pulp mills are energy efficient and environmentally friendly, Gruvön (Wallén et al., 2002).

Main steam temperature

Figure 15, Main steam temperature as a function of recovery boiler capacity.
Main steam temperature of recovery boilers is shown in Figure 15 as a function of MCR capacity of that boiler. The average steam temperature increases with size. That is because small boilers tend to have low pressure to reduce specific cost. There are many boilers with main steam parameters higher than 500 °C. Most of them are in Japan.

**Main steam pressure**

![Figure 16](image_url)

**Figure 16, Main steam temperature as a function of recovery boiler main steam pressure.**

Main steam pressure of recovery boilers is shown in Figure 3-4 with corresponding main steam temperature. When looking at the steam pressures we note that increase in main steam temperature is usually accompanied with increase in main steam pressure. Increasing either steam pressure or temperature has only a small effect on back pressure electricity generation.

**Black liquor dry solids**

As fired black liquor is a mixture of organics inorganics and water. Typically the amount of water is is expressed as mass ratio of dried black liquor to unit of black liquor before drying. This ratio is called the black liquor dry solids. If the black liquor dry solids is below 20 % or water content in black liquor is above 80 % the net heating value of black liquor is negative. This means that all heat from combustion of organics in black liquor is spent evaporating the water it contains. The higher the dry solids, the less water the black liquor contains and the hotter the adiabatic combustion temperature.

Black liquor dry solids has always been limited by the ability of available evaporation technology to handle highly viscous liquor (Holmlund and Parviainen,
As technology has evolved so has the final black liquor dry solids. Virgin black liquor dry solids of recovery boilers is shown in Figure 17 as a function of purchase year of that boiler.

![Figure 17, Virgin black liquor dry solids as a function of purchase year of the recovery boiler.](image)

When looking at the virgin black liquor dry solids we note that on average dry solids has increased. This is especially true for latest very large recovery boilers. Design dry solids for green field mills have been either 80 or 85 % dry solids. 80 % (or before that 75 %) dry solids has been in use in Asia and South America. 85 % (or before that 80 %) has been in use in Scandinavia and Europe.

**Maximize your bioenergy potential with new solutions**

Pulp and paper industry faces new era. It is not enough only to cut down emissions. Pulp and paper mills should maximize their bioenergy potential and minimize their electricity consumption (Raukola et al., 2002).

Pulp mills have successfully reduced their energy consumption and at the same time increased electricity generation. Higher black liquor dry solids generate more steam and electricity. But today’s challenge is to have integrated pulp and paper mills that operate totally without auxiliary fuels producing a net surplus of electricity from 100 % biomass fuels.

**Steam generation**

Steam generation will depend on recovery boiler design parameters. A rough estimate can be seen from Figure 18. About 3.5 kg\textsubscript{steam}/kg\textsubscript{BL dry solids} is often used as
a base value. Specific steam production can be used to presize other components in recovery boiler plant.

Both black liquor dry solids and higher heating value affect the steam generation. Also black liquor sulfidity and main steam values affect the steam generation efficiency. For accurate steam generation one should always calculate the mass and energy balances.

![Graph showing specific steam generation kg steam/kg BL dry solids as a function of black liquor higher heating value.](image)

**Figure 18.** Specific steam generation kg\(_{\text{steam}}\)/kg\(_{\text{BL dry solids}}\) as a function of black liquor higher heating value.

**Is gasification the answer**

Industry visions of early nineties that black liquor gasification could within next ten years become a viable alternative have not materialized.

**Table 2.** Effectiveness of converting black liquor HHV into fuel value in net product gas (Grace and Timmer, 1995).

<table>
<thead>
<tr>
<th>Original HHV, MJ/kg bl</th>
<th>14.7</th>
<th>13.3</th>
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</thead>
<tbody>
<tr>
<td>HHV in net gas % of original</td>
<td>55.9</td>
<td>50.7</td>
</tr>
<tr>
<td>HHV in net gas % of original</td>
<td>49.0</td>
<td>42.6</td>
</tr>
</tbody>
</table>

**Commercial processes**
- Chemrec (Kvaerner)
- StoneChem (MTCI)

**Piloted processes**
- ABB
- Tampella
- Conventional RB
Even though there are significant gains to be made, Table 2, there still remains a lot of unresolved issues (Tucker, 2002); finding materials that survive in a gasifier, mitigating increased causticizing load and how to make startup and shutdown. Only time will tell whether higher electricity generation can overcome lower efficiency and higher installation cost.

**Trends in modern mills**

Changes in pulping and bleaching with increased black liquor dry solids have affected the heat and power balance of a modern mill, Table 3.

| Table 3, Heat and power demand of chemical pulp production (Suutela and Fogelholm, 1995). |
|----------------------------------|------------------|------------------|
| Softwood                         | GJ/t             | kWh/t            |
| Unbleached                       | 7.5 – 10.6       | 400 – 490        |
| Unbleached dried                 | 10 – 13.9        | 520 – 630        |
| Bleached                         | 9 – 12           | 540 – 680        |
| Bleached dried                   | 11.5 – 15        | 660 – 800        |
| Hardwood                         |                  |                  |
| Unbleached                       | 7 – 10           | 390 – 500        |
| Unbleached dried                 | 9.5 – 13.2       | 500 – 650        |
| Bleached                         | 8.5 – 11         | 510 – 620        |
| Bleached dried                   | 10.9 – 14        | 630 – 760        |

Energy efficiency has increased both in generating and consumption so that the newest pulp lines produce a surplus of electricity without firing mill bark and wood residues. Reducing the heat consumption in the mill has reduced the back pressure power potential and more and more of power generated is actually condensing power.

**Maximizing bioenergy**

Pulp mill electrical energy production capability has grown in the past years, Table 4. One reason is that in newer larger mills it is more cost effective to apply energy saving technologies. This with positive development in modern cooking has reduced the mill heat consumption by 20%. This has enabled condensing power generation. Increasing condensing power with improved recovery boiler parameters has doubled the electricity generation from a pulp mill.
Table 4, Steam and power balance when bark and wood waste fired.

<table>
<thead>
<tr>
<th></th>
<th>Old</th>
<th>Modern</th>
<th>New</th>
<th>Utility</th>
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<tbody>
<tr>
<td>Dry solids t/Adt</td>
<td>1,7</td>
<td>1,7</td>
<td>1,7</td>
<td>1,7</td>
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<tr>
<td>%ds</td>
<td>65</td>
<td>78</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>GJ/tds</td>
<td>14,3</td>
<td>14</td>
<td>14</td>
<td>14</td>
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<tr>
<td>Heat to steam %</td>
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<td>71,6</td>
<td>74,8</td>
<td>75</td>
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<tr>
<td>Heat gen</td>
<td></td>
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<td></td>
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<tr>
<td>- RB</td>
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<tr>
<td>GJ/Adt</td>
<td>15,5</td>
<td>17,05</td>
<td>17,8</td>
<td>17,9</td>
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<tr>
<td>- RB NCG+sludge</td>
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<td>- PB</td>
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<tr>
<td>Heat to</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>- Process GJ/Adt</td>
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<td>11,47</td>
<td>11,7</td>
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<td>- Power to heat ratio %</td>
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<td>33</td>
<td>38</td>
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<tr>
<td>- BP power GJ/Adt</td>
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<td>3,14</td>
<td>3,9</td>
<td>4,45</td>
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<tr>
<td>- Cond power GJ/Adt</td>
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<td>5,64</td>
<td>5,4</td>
<td>5,05</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- BP power kWh/Adt</td>
<td>850</td>
<td>860</td>
<td>1050</td>
<td>1215</td>
</tr>
<tr>
<td>- Cond power</td>
<td>140</td>
<td>585</td>
<td>575</td>
<td>590</td>
</tr>
<tr>
<td>- Mill power use</td>
<td>800</td>
<td>707</td>
<td>715</td>
<td>735</td>
</tr>
<tr>
<td>- Power sold</td>
<td>190</td>
<td>738</td>
<td>910</td>
<td>1070</td>
</tr>
</tbody>
</table>

Jaakko Pöyry with its clients has been extensively involved in maximizing the profits with new bioenergy production opportunities. This has resulted in new concepts for connection of recovery boiler and turbine. The up-coming Scandinavian lines will have main steam values around 100 bar and 505 °C. In these installations potassium and chlorine removal equipment are definitely needed.

An example modern Scandinavian mill produces more than 30 MWe for sales with annual pulp capacity of about 600 000 t/a. Already net revenue of around 10 % can be achieved with surplus electricity, bark and wood residue sales. This amount can further be increased with adoption of utility type power plant connections.

Size of pulp lines has increased. In the largest lines we talk about utility sized power production (>100 MWe). Economics of scale means there are currently new economic possibilities to increase the yield of bioenergy.

References


