

EXERGY EVALUATION OF THE COOKING PLANT

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Abstract: Exergy analysis can lead us to improve thermal processes. The pulp and paper industry was chosen for this exergy analysis because of this sector's high energy demand on both electricity and fuel oil. In this paper, the authors present the cooking process, the exergy evaluation of this process and numerical result for a cooking plant.

Keywords: cooking plant, exergy analyze

1. INTRODUCTION

Paper manufacturing includes the processing of wood, recovered paper and paperboard, and other cellulose fibers into thousands of end-use products.

Pulping is the process of reducing wood into a fibrous mass suitable for papermaking, [1]. The process involves breaking the chemical bonds of the raw material through mechanical and/or chemical means in order to liberate the discrete fibers used to make paper. Once the fibers are separated, they are screened, washed to varying degrees, thickened, and sent to pulp storage.

Pulp for paper production is obtained via two classes of processes that differ greatly in principle:

- Mechanical pulping, in which the fibres are separated mainly through mechanical treatment in refiners. Most of the wood thus becomes pulp, including the lignin.
- Chemical pulping, in which the fibres are separated mainly through chemical treatment in either acidic or caustic solutions. These processes aim to separate the lignin from the cellulose fibres.

Chemical pulping is the dominant pulping process used for papermaking today, mainly because it can produce a strong pulp from a wide variety of tree species.

From energy point-of-view the two classes of processes differ greatly. Mechanical pulping consumes electrical energy, which to some extent is recovered as steam and usable lowgrade heat. Only a small fraction of the wood is dissolved in the process. In contrast, about 50% of the wood are dissolved in chemical pulping. The processing of this dissolved organic substance can make a mill self-sufficient in energy and, depending on the type of product, even generate a surplus of steam or electricity. *It is this dissolution of the energyrich lignin fraction from the pulp fibres that makes chemical pulping an interesting candidate for the production of liquid fuels from biomass.*

The dominant process for chemical pulping (at about 90%) is the *kraft process*, sometimes called the sulphate process.

The process starts in the *wood yard* where logs are debarked and cut into wood chips which fed to the *digester*.

2. COOKING PROCESS

In the Kraft process the fibres are liberated in the cooking plant by dissolving the lignin and part of the hemicellulose in the cooking chemical solution (white liquor), which contains sodium hydroxide and sodium sulphide as active chemicals.

The cooking process can be performed either in batch digesters or in a continuous digester.

The digester is essentially a pressure cooker that operates up to 170⁰ C at pressures between 7 and 13bar, figure 1. It is filled with chips, white liquor, and weak black liquor and is heated to cooking temperature. The liquor is re-circulated continuously by pump between digester and surface heat exchanger heating with steam of 15 bar. Condensate which results from heat exchanger is returned to power plant. When the desired residual lignin content is reached, the contents are discharged to a blow tank and the cooking cycle is repeated. The high-pressure mixture of the wood chips and the solution containing the dissolved lignin passes through a pipe and enters tangentially into an atmospheric pressure tank (blow tank) and impacts against a region of the tank called the target plate. The combination of the rapid pressure change and the impact explodes the chips into individual fibers. The pulp, which at this point in the process is referred to as "brownstock," is discharged from the bottom of the blow tank by large rotary rake arms and proceeds to a sequence of equipment that separates the fibers from the chemicals and dissolved lignin. Saturated steam resulting from the blow tank is condensed in a mixed heat exchanger. Warm water which results from this heat exchanger is used in the washing section.

Gases resulting from the chemical reactions in the digester (mercaptans, dimethyl sulfides) exit the top of the digester. Heat of these gases is recovered in the heat exchanger where is obtained warm water which is used in the washing section.

The brownstock is conveyed through pipes to a series of vibrating screens called "knotters." The knotters separate acceptable pulp from bark fragments and inadequately cooked chips. The bark fragments and chips generally become fuel for the hog boiler or go to landfill. The usable brownstock passes through a series of cleaners to separate the wood fibers from the chemicals and lignin.

These cleaners are typically counter-current vacuum drum washers that consist of a washer vat, a rotary drum, and a discharge doctor blade. Countercurrent means that the pulp flows in one direction and the water in the other, an arrangement that conserves water and allows some concentration of the chemicals and lignin into "black liquor." The black liquor flows to the recovery boiler for chemicals recycling and combustion of the lignin.

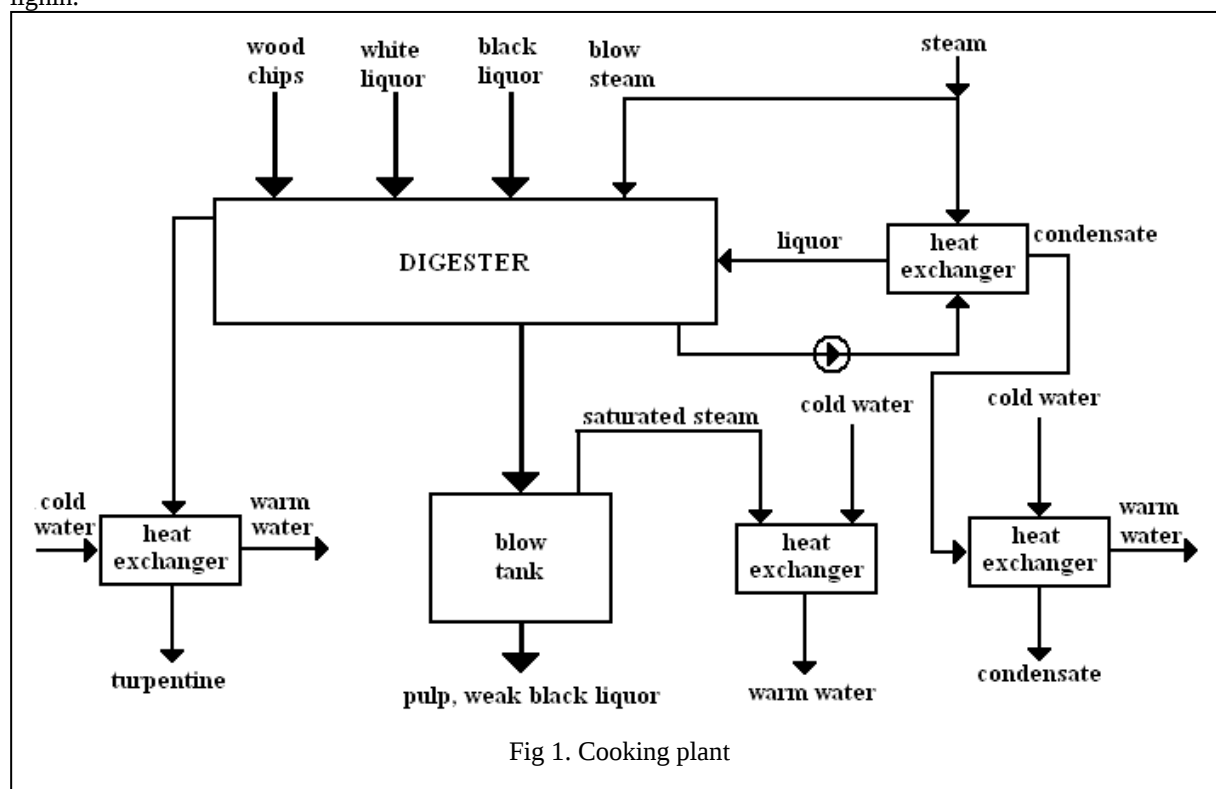


Fig 1. Cooking plant

3. EXERGY EVALUATION OF THE COOKING PLANT

The exergy analysis was realized for the cooking plant in the integrate pulp and paper mill.

Exergy is the maximum amount of work that can be extracted from a system, [2]. Because exergy is defined as the maximum work potential of a material or of a form of energy in relation to its environment, then the environment is specified a reference environment: reference temperature T_0 is 298.15 K and the reference pressure p_0 is 1 atm.

Exergy analysis concerns calculations of E_{in} , E_{out} , and E_{loss} . Expressions that are used to calculate the exergy content of an amount of heat, Q , at T_1 :

$$E^{heat} = Q \left| 1 - \frac{T_0}{T_1} \right| \quad (1)$$

where Q is energy of the transferred heat and $\left| 1 - \frac{T_0}{T_1} \right|$ is exergy factor.

Exergy content of one component at p_1 and T_1 compared to the environment state is following:

$$E^{cm} = (H_1 - H_0) - T_0(S_1 - S_0) \quad (2)$$

where H is the enthalpy and S is entropy.

The exergy input exceeds the exergy output, this unbalance is due to irreversibilities (exergy destruction). The exergy output consists of the utilized output and the non-utilized output, i.e. exergy of waste output (E_{waste}). It is very important to distinguish between exergy destruction caused by irreversibilities and exergy waste due to unused exergy, i.e. exergy flow to the environment. Both represent exergy losses, but irreversibilities have, by definition, no exergy and no environment effects.

By calculating the exergy loss, i.e. destruction and waste, it can visualize possible process improvements.

Table 1. Exergy analysis

Inputs			Outputs		
Name	kJ/kg	%	Name	kJ/kg	%
$E_{in,material}$	238	10,60	$E_{out,material}$	542	24,19
$E_{in,steam}$	1996	89,06	$E_{out,condensat}$	46	2,03
$E_{in,water}$	8	0,35	$E_{out,water}$	143	6,40
			$E_{turpentine}$	0	0,00
			E_{loss}	1511	67,38
E_{in}	2242	100,00	E_{out}	2242	100,00

The biggest part of the inputs of exergy is due to steam for heating and for blowing. The exergy of the pulp and weak black liquor is a quarter from outputs. The warm water with 70 °C and 6.4% from exergy output is used in the washing process. The condensate with 90 °C is returned to the power plant. The losses in the cooking plant is high (67%) and these are due to heat transfer in the heat exchangers, mainly.

Exergy efficiency is defined, as utilized exergy ($E_{utilized}$) (or useful effect of a process) divided by used exergy (E_{used}).

$$\eta_{ex} = \frac{E_{utilized}}{E_{used}} \quad (3)$$

Taking account by the exergy analysis, table1, these exergies are determined as:

$$E_{utilized} = (E_{out,material} - E_{in,material}) + (E_{out,water} - E_{in,water}) + E_{turpentine} \quad (4)$$

$$E_{used} = E_{in,steam} - E_{out,condensat} \quad (5)$$

It result values from the table 2.

Table 2. Exergy efficiency

Name	U.M.	Value
E_{used}	kJ/kg	1951
$E_{utilized}$	kJ/kg	440
E_{loss}	kJ/kg	1510,51
Exergy efficiency	%	22,6

4. CONCLUSIONS

Chemical pulping plants are energy-intensive installations that consume high amounts of energy but at the same time produce steam and electrical power on site by use of regenerative fuels.

The major part of heat energy is consumed for heating different fluids and for evaporating water. Heat energy is also used to accelerate or control chemical reactions.

The exergy analysis allows us to make an evaluation of the useful effect of the process and of the exergy destruction. According to the exergy analysis the losses in the cooking plant are high and are due to the heat transfer in finite temperature difference, mainly. The exergy of the warm water, of the condensate are recovered.

REFERENCES

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