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Efficient Energy Conversion in the Pulp and Paper Industry

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RÉSUMÉ

This report measures the actions performed in 2005 and the actions planned for 2006 within the framework of the project *Efficient Energy Conversion in the Pulp and Paper Industry*. Data reconciliation models of the steam and condensate networks and of the process of *Borregaard Schweiz a.g* have been developed. An additional model of the sulphur loop has been also elaborated. Data reconciliation has been used to reconciliate data from different sources. From this analysis, a list of required measurements has been developed and will be implemented in the process. Several performance indicators have been calculated: one of the most important is the condensate recovery rate, evaluated at 31.4%. A systematic analysis method has been developed to identify sections where condensate could be recovered and the places where it is not feasible. It has been put in evidence that it would be possible to increase the rate of recovered condensate. Condensate recovery is an immediate energy saving when considering the efficiency of the steam distribution system. From the developed method, a systematic definition of the hot and cold streams in the process is being developed in order to compute the minimum energy requirement of the process. Evaluating the minimum energy requirement of the process from the data available will prepare also the preliminary definition of the energy savings opportunities.

The national and international collaborations constitute also an important part of this project. The project is done in close collaboration with the engineers of *Borregaard Schweiz a.g* and with the support of the *Bonnard et Gardel* engineering company. In addition to the systematic analysis of the process plant, the energy efficiency analysis allows the engineers of *Borregaard* to define road maps and procedures for energy savings measures on their plant. By developing a collaborative project with a Canadian consortium (*E^3PAP*), the *EPFL* researchers profits from the expertise of the specialists of the *Centre de Recherche en Ingénierie du Papier* of the *Ecole Polytechnique de Montréal*.

AVERTISSEMENT - WARNING

Buts du projet

The goal of the project is to develop a comprehensive computer aided methodology for analysing the integration of utility systems and energy conversion technologies in the pulp and paper industry. The goal of the methodology is the identification of energy savings options considering process integration and thermo-economic optimisation techniques. The project is realised in the frame of a collaboration with a Canadian consortium that will study in more details the aspects of eco-industrial clusters and the integration of energy conversion technologies like heat pumps. The Swiss consortium focuses his contribution on the development of process integration methods for studying the integration of energy conversion systems like steam network, combined heat and power, rational use of water, biomass valorisation technologies and the integration of by-product valorisation processes. The methods developed are applied and validated on two test cases, one in Switzerland on the plant of *Borregaard Schweiz a.g*., a sulfite pulp and paper process and one in Canada on a Kraft pulp mill.

The goals for this first year were to make a review of the energy analysis studies in the pulp and paper industry (task 1 as described in [1]), to get the energy picture of *Borregaard Schweiz a.g.* (task 2) and to start defining its process minimum energy requirements (task 3.1). The goal of this report is to present the **task 1 – Review of the energy analysis in the pulp and paper industry, the task 2 – Data collection for the pulp and paper processes and partly the task 3 – Definition of the process minimum energy requirements. An additional task**, initially not included in [1], **the sulphur loop modelling and analysis,** is also presented in this report.

Travaux effectués et résultats acquis

1. METHODOLOGY

The methodology used is the following:

- Make a general review of the energy analysis studies in the pulp and paper industry
- Collect pertinent and available data, archived by the mill. At this stage, no sample campain has been done in the mill. Therefore a data reconciliation method has been applied to obtain a consistent picture of the process energy consumption
- Identify and characterise the mill sectors that are considered as steam or condensate users and producers
- Establish the steam and condensate return networks using the information collected in the 2 precedent steps
- Review the PIDs[1] of the mill and establish a simplified BFD of the pulp making process
- Establish the thermodynamic model of the process by integration of the models of the steam and condensate networks and the energy conversion processes; interrelate all the models together
- Make a process data analysis and data reconciliation with the perspective of defining the key performance indicators of the process energy efficiency and the process energy requirements

[1] A list of abbreviations is available in section 3 of the report

- Model and analyse the sulphur loop of *Borregaard Schweiz a.g*. process and its integration with the energy system
- Develop a methodology to define the process requirements from the data available: generate the load profiles of the utility system, the thermodynamic and technological requirements of the process as a function of the operating scenarios, compute the MER of the *Borregaard Schweiz a.g*. process.

2. WORK REALISED

2.0 Literature review

In addition to the references given in [1], a general review of the literature has been done. Publications, conferences, books have been regrouped around three research dimensions:

- The one related to the computer aided methodology for analysing the integration of utility systems and energy conversion technologies. Special attention is given on the work done by UMIST, Chalmers and KTH.
- The one related to the rational use of energy in the pulp and paper industry (calcium bisulfite, kraft and thermo-mechanical processes).
- The third dimension relates to new technologies to save and to rationally convert energy

A preliminary list of references is available in Appendix A. Summaries and state of the art report are also in constant progression.

2.1 Data collection

During the first period of the project, the study of the *Borregaard* plant has been the major target. It concerned the data collection in order to define the energy requirement of the process and define the efficiency of the energy conversion system. The first steps of the data collection are the definition of the thermodynamic data to model the process biomass[2] (wood, fibre, lignin, ...) thermodynamic properties, the identification of the available process data and the development of the process flow diagram. A data reconciliation model of the process and the utility system has been developed. This method is used to reconcile data collected from various sources (on-line and off-line measurements, process data sheets, ...) in order to obtain a consistent picture of the process energy that verifies the heat and mass balances.

Borregaard Schweiz a.g. has furnished, amongst other things, to *EPFL* a general process diagram [Appendix B], a plan of the mill [Appendix C], a detailed process description [2], a steam distribution diagram [3]. Data sheets on *Excel* have also been obtained from the mill. The main file used for the work on the utility system, *Energy BCH.xls* [4], contains monthly values of steam produced by the boilers, the steam consumption by the departments and also data about the energy consumption. Relevant PIDs have also been furnished by the mill [5] and used to construct the BFD

[2] A waste and biomass database has partly been used to define components [9]

of the process. A lot of information has also been transmitted verbally by *Esten Nordal*, the engineer in charge of the *EECPPI* project at *Borregaard Schweiz a.g.*

2.2 Sectors and departments of the mill

For the analysis of the steam and condensate network of the mill, the mill is divided into sectors and departments (see Fig. 1)

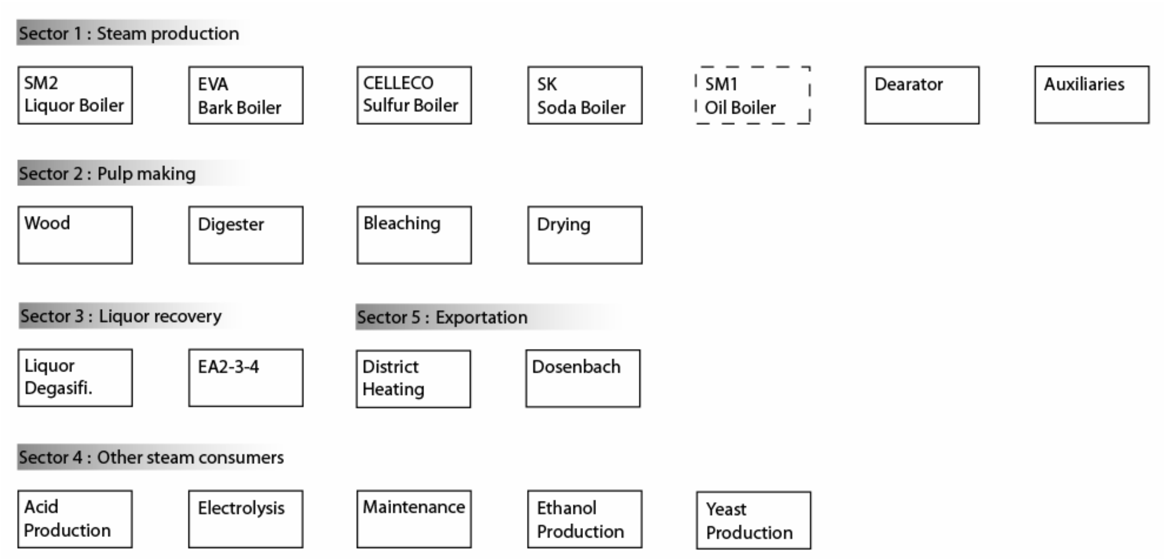


Fig. 1. Sectors and departments of the mill

The nomenclature used in the mill has been conserved, in particular the technical names of the boilers, digesters, evaporators, etc.

The mill has been divided in 5 sectors: the steam production sector (Sector 1), 2 process sectors, pulp preparation (Sector 2) and waste liquor management (Sector 3), the other steam consumers sector (Sector 4) and the steam exportation sector (Sector 5). Each of these 5 sectors has one or several departments as seen on Fig. 1. The sectors 2, 3, 4 and 5 are steam consumers.

The sector 1, steam production, included the working boilers, the dearator and auxiliaries. The steam is produced by 4 boilers burning liquor (*SM2*), sulphur (*Celleco*), waste biomass (*EVA*) and natural gas (*Soda Kessel*). A boiler of lower capacity (*SM1*) is burning heavy fuel oil and is used mainly to absorb the steam demand variation and when *SM2* isn't working. Steam is produced at 2 pressure levels (44 and 5 bar) and uses a back pressure turbine to produce mechanical power (about 12% of the plant electricity is produced by CHP using the steam of the recovery boilers). About 30% of the 5 bar steam is imported from the domestic waste incineration plant near by (*Kebag*). Steam is used as direct injection in the process or in heat exchangers.

The dearator, whose main function is to purge the air from the water returned to the boilers, is also considered as being part of the steam production sector. This equipment has also the function of preheat the collected condensate and the make-up water used to maintain the production and distribution steam system. In the department "Auxiliaries", the following equipments have been regrouped: the turbines (*BBC*, *EW* and *KKK*), the steam accumulator (acts as a buffer between the steam production and the steam consumption), the auxiliary condenser (used when the steam production is exceeding the steam consumption), the pressure-relief valves and the turbo-pump.

The sector 2 contains the digesting, bleaching and drying steps. The cooking chemistry of the calcium bisulphite process can be founded in Appendix [D]. The departments of sectors 3, 4 and 5 are explicit on Figure 1. It is important to notice that *Borregaard Schweiz a.g.* has already realised a certain degree of integration with the neighbouring community because of the steam exportation for district heating and for the storage building of *Dosenbach*.

2.3 Utility network and process models

The flow diagrams of the steam and condensate return are presented in Appendix E. The diagrams included all the departments and/or equipments producers or consumers of steam. It included also the condensate return and losses. A set of relevant data is also shown on the diagrams (temperature, pressure, composition, flowrate). The same strategy is used for the flow diagrams of the pulp making process [Appendix F]. The generic definition of each unit that consumed steam is presented in Table 1 below. It is also illustrated graphically in Appendix E.

Table. 1. Steam consumers (2003)

Steam consumer	**%***
Digester department	21.6
Drying	19.8
EA2	17.7
Alcohol expulsion	10.7
Treatment. EOP (Line 1+2)	6.5
Ethanol production	6.1
Bleaching	4.7
EA3	3.5
Waste liquor degasification 1+2	2.4
Treatment E (Line 1)	1.9
Yeast production	1.8
Rectification	1.0
Production acid	0.7
Electrol.	0.4
District heating	0.3
Waste liquor degasification 3	0.3
EA4	0.3
Dosenbach (exportation)	0.1
Maintenance	0.07
Lignotech	0.01

*Percentage steam consumed/total steam consumed

A macro representation of the mill is shown below (see Fig. 2.). The wood, water and chemical products used in the process and the amount of electricity and thermal energy involved show the importance of the energy integration of the process. The process integration in pulp and paper production is a very important topic since waste streams valorisation (lignin, biomass) and chemicals recycling interact with the production processes to satisfy the system requirement. Furthermore, by-products such as bioethanol is being produced in the process.

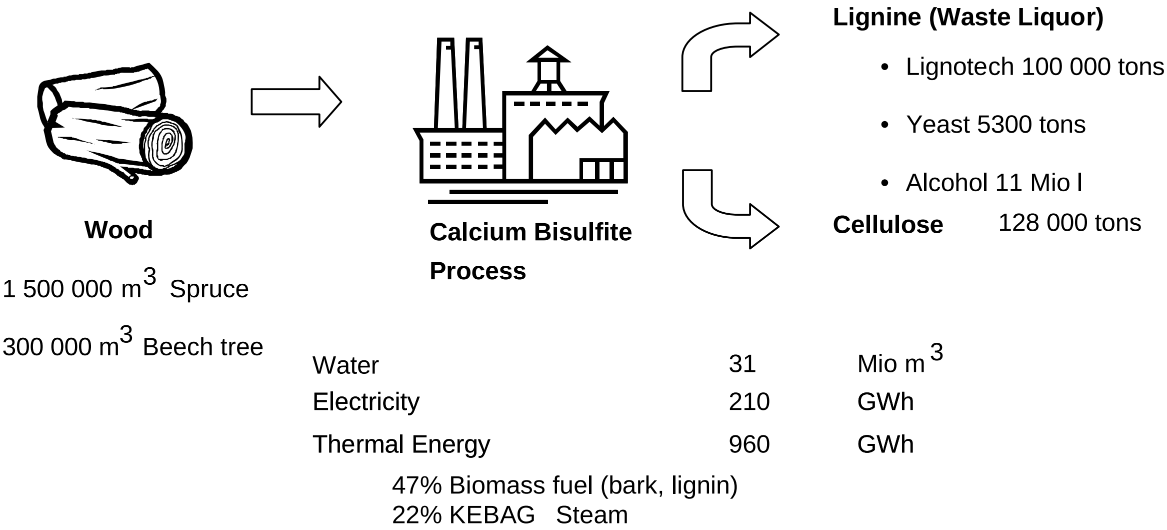


Fig 2. Macro representation of *Borregaard Schweiz a.g* for 2003

Modelling

To establish the model, the process has been divided into several sub-systems and a list of assumptions [Appendix G] is combined with the available measurements set to solve the full process model. The use of data reconciliation allows here to integrate data from varying sources: on line measurement, manual accounting or specification sheets. The interest of this approach is the possibility of working with redundant information. The mill is then more consistent with the modelling tool. A sensitivity analysis will allow to validate the assumptions and to determine the necessary additional data or measurements to be collected by trading-off the level of details and the data collection effort. The model is developed using a commercial software (*Belsim Vali*). The models have been developed considering the 2003 data. Data reconciliation using on line data available will be applied after the analysis of the available and required sensors. To give an idea of the level of details of the developed model, the table 2 summarizes the number of equations and measurements or assumptions for the steam and condensate networks models and the process model (including the sulphur loop as described in section 2.4) (see Table 2).

Table. 2. Number of equations and measurements for *Belsim* models

Number of Units	215
Number of Equations	1182
Number of Unmeasured Variables	1166
Number of Constants	452
Number of Measured Variables	118

By developing the process model, the process requirements are being defined. This is done by describing the thermodynamic requirement of the process operations (what is the energy required to perform the processing steps?) that will be compared with the way the energy requirement is satisfied in the present process. This analysis will be used to perform an exergy analysis of the different process operations and to apply process integration techniques that will allow to identify the possible energy recovery by heat exchange and to define the minimum energy requirement target in terms of resources consumption and define the potential for combined heat and power production. In our study, the process energy requirement will be deduced from the steam network model. The energy savings options will be established considering the utility network integration.

Key performance indicators validation

From the results of the models, energy key performance indicators have been derived (see Table 3 to 7), they define some figures of the “energy picture”.

The following table summarizes the steam production of *Borregaard Schweiz a.g.* in 2003.

Table 3. Steam production (2003)

Boiler	**Production**	
	%	$t/t_{cellulose}$ [3]
Own production		
SM1+SM2	42.2	3.2
Soda	17.6	1.3
Eva	7.7	0.6
Sulphur	2.4	0.2
Steam bought		
Incinerator (*KEBAG*)	30.2	2.3
Total	**100%**	**7.6**

The total own production refers to the steam production based on the use of the on-site boilers, the balance is obtained from the *KEBAG* steam import.

Condensate return

Steam is used in three different forms in the mill : steam condensation in a heat exchanger with condensate return, steam condensation in a heat exchanger without condensate return, steam injection in the process streams. Therefore only a part of the steam is recovered under the form of condensate and recirculated to the boilers. Condensate is recovered only from the bleaching section (80%), the drying section (100%) and the alcohol distillation section (80%). The overall condensate return is evaluated at 31.4%. This corresponds to 45% of the water going to recovery boilers (mainly SM2, SM1). Make-up water (55%) completes the water supply of the recovery boilers. The other boilers are supplied only with fresh water. A part of these losses could be re-

[3] The production is estimated at 128 000 tons of cellulose (chemical use, plastic moulding, pulp) for 2003 [4] & [Appendix B]

covered by recovering steam condensate that are not used as direct heating. By defining the three types of steam usage, it is possible to increase the condensate that could be recovered. The energy saving corresponds to 326 kJ per extra kg of condensate returned to the boiler and additional saving would be obtained from the decrease of the demineralised water production.

Steam produced in the boilers

The load and efficiency of boilers are summarized below

Table 4. Load and efficiencies of boilers (2003)

Boiler	**Load**		**Efficiency**[1]
	kW	kW/$t_{cellulose}$	%
SM2[2]	38 733	2651	81.9
Soda	14 817	1014	87.8
Eva	5661	387	65.0[3]
Sulphur	1253 (*Source J.Luterb*)	86	N/D

[1] The efficiencies have been found assuming a percentage of residual O2 in the fumes of 5%. This would require an additional measurement of the oxygen content to confirm this value.

[2] Since *SM1* is used only 400 h/y, it has been neglected in this analysis

[3] The efficiency of the *EVA* is questionable, verification of the thermodynamic properties is under way and additional temperature measurements are required.

The energy sources used in the mill are summarized below

Table 5. Energy sources (2003)

	t/y	GWh
Natural gas	5247	80
Heavy oil[1]	8655	111
Liquor burned in SM2	122 819	401
Bark for EVA	18 221	54
Steam bought from KEBAG	288 023	213
Liquor burned in Soda Kessel	20 316	86
Sulphur	7796	17
Total Energy		962

[1] Used in SM2 and EVA boilers

Energy bill

Electricity used in the mill is supplied by a third partie (*AEK*) and partly produced on the site by combined heat and power production. The following table summarizes the consumption, production of electricity in the mill.

Table 6. Electricity production and bought for 1 year (2003)

Electricity	**%**
Own Production	11.9
Bought electricity (*AEK*)	88.1

Natural gas, oil and steam (from the domestic waste incinerator *KEBAG*) are also bought. For each resource, a cost (confidential) is related.

The developped methodology for defining the key performance indicators remains to be validated by a sensitivity analysis. This analysis will consist in defining the list of sensitivity assumptions based on the systematic analysis of the assumptions set. From this analysis a set of additional measurement will be defined and a measurement campaign will be realized.

2.4 Modelling of the sulphur processing and recycle loop

Due to its high interaction with the process energy, the model of the sulphur processing & recycle loop has been developed and integrated in the steam, condensate and process models. As for the data collection done for the utilities and process models, *Borregaard Schweiz a.g.* has produced useful documents to elaborate the sulphur loop. The two most important were a report fragment on sulphur done by an *ETHZ* student [6] and a schematic of the cleaning process of the combustion gas in the mill [7].

The model of the sulphur processing & recycle loop has been built in 4 section: sulphur combustion in the boiler *Celleco*, the enrichment and absorption columns (*RGR)*, the pulp making installation and the sulphur recovery system. A general schema of the 4 sections can be seen on Fig. 3.

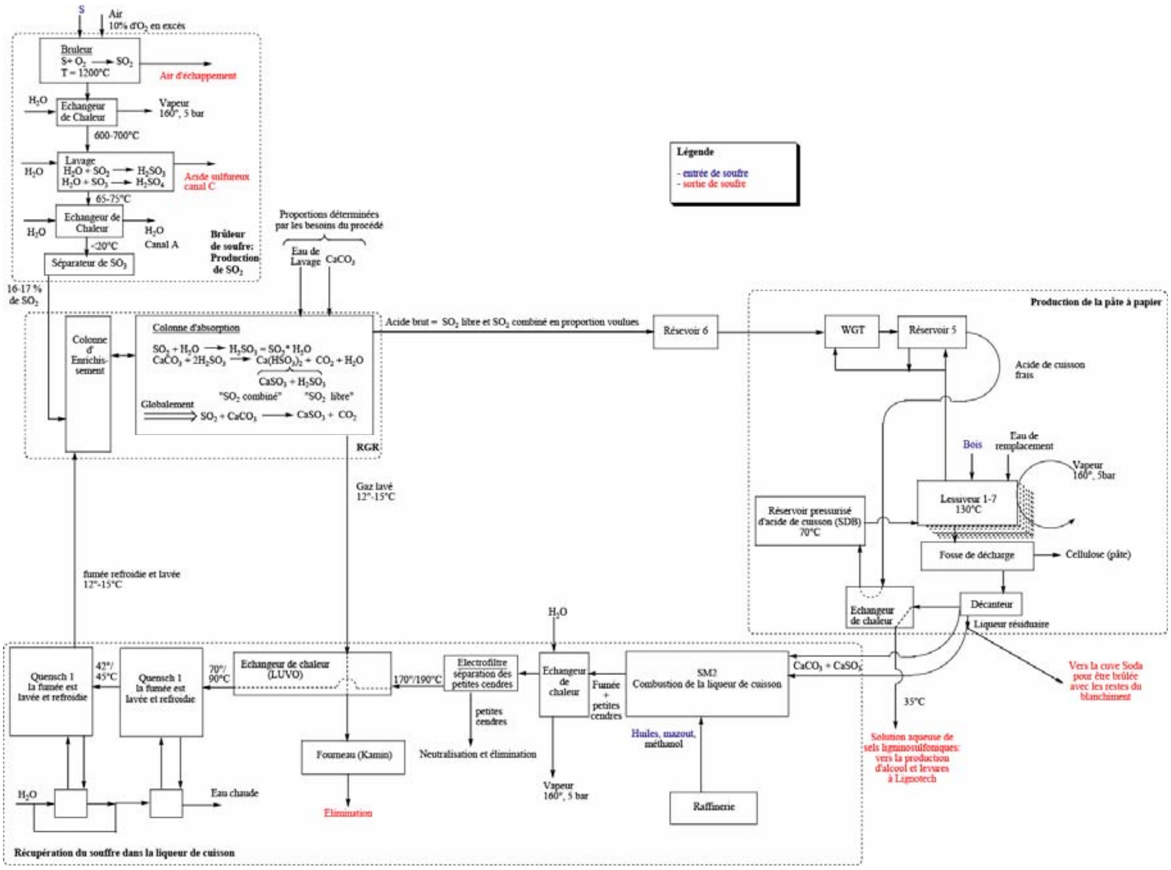


Fig. 3. Sulphur processing and recycle loop

Figure 4 below presents the same schema than Figure 3, but the figure includes sulphur mass balances of the plant i.e. the different chemical forms under which sulphur enters and leaves the process. Sulphur enters the loop at 0.898 t/h, while 0.693 t/h is distributed in other parts of the mill or simply eliminated. It means that 0.175 t/h is recycled in the sulphur loop, this correspond to 19% of the sulphur injected. The overall energy balance is being also prepared.

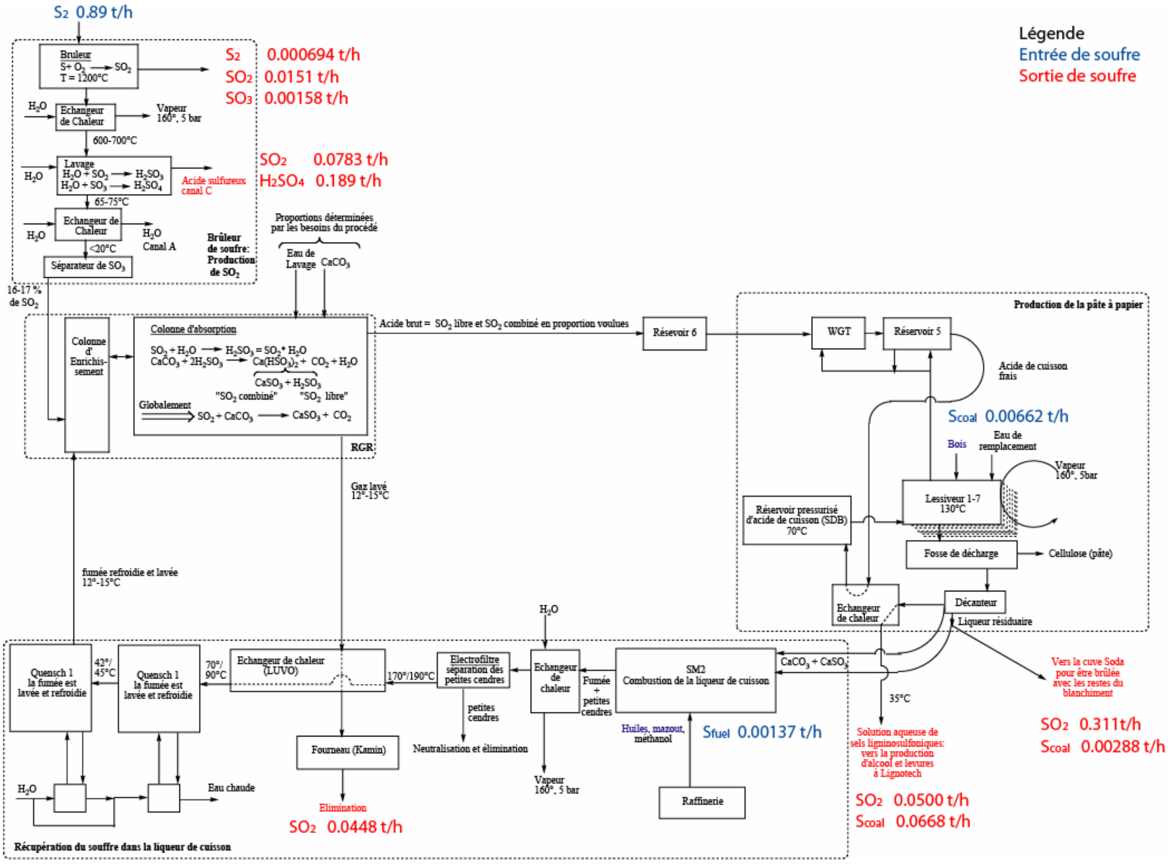


Fig. 4. Sulphur processing and recycle loop analysis

2.5 Definition of the process minimum energy requirements

As described in [1], this task is the

> *development of a methodology to define the process requirements from the data available. This method will aim at generating the load profiles of the utility system, the thermodynamic and the technological requirements of the process as a function of the operating scenarios. This method will incorporate the rational use of water in the energy optimisation target. The methodological development will be integrated into the software tool EASY.*

The identification of hot and cold streams of *Borregaard Schweiz a.g.* is under preparation. This stream identification and classification is based on the dual representation of the technological and thermodynamic requirement of the process. Each requirement is defined as the heat and temperatures required for the thermodynamic conversion in the process. It is also represented as the temperature enthalpy profile required to perform the transformation. For example, heating a stream by steam injection is presented in two ways: the temperature increase of the stream vs. the production of the injected steam. Both have the same overall balance but feature different energy

savings opportunities. This definition is made systematically for heating and cooling requirement of the process.
Special attention on how steam is used in the mill (as described in section 2.3) is also detailed at this step. A non-neglectable energy recovery potential has to be taken into account with the condensate return. Even the condensate streams that are not recovered can be used, for example to preheat some process streams nearby.

Finally, two conference presentations [10,11] on the dual representation of the minimum energy requirement in pulp and paper processes have been done this year.

3. ABBREVIATIONS

BG	Bonnard & Gardel
BFD	block flow diagram
CHP	combined heat and power
EASY	Energy Analysis and SYnthesis of industrial processes
EECPPI	Efficient Energy Conversion in the Pulp and Paper Industry
EPM	Ecole Polytechnique de Montréal
EPFL	Ecole Polytechnique Fédérale de Lausanne
ETHZ	Eidgenössische Technische Hochschule Zürich (Swiss Federal Institute of Technology Zurich)
LENI	Laboratoire d'Energétique Industrielle
MER	minimum energy requirement
PID	process and instrumentation diagram

Collaboration nationale

In this section, short contribution summaries have been given by two partners of the *EECPPI* project (*Borregaard Schweiz a.g.* and *Bonnard & Gardel)* and are included below.

Contribution of *Borregaard Schweiz a.g.* in 2005

Borregaard Schweiz AG is located in Riedholz nearby Solothurn. The name of the company was formerly *Atisholz AG*, but in 2003 it was taken over by *Borregaard*, a member of the Norwegian *Orkla* group. *Borregaard* is specialized in wood chemistry. They are providing wood-based products for use in chemicals, food, pharmaceuticals etc. *Borregaard*'s main products are chemical cellulose, lignin, ethanol, vanillin, yeast and yeast extracts.

The mill in *Riedholz* is a wood refinery where timber and wood chips are used as raw material and after several production stages are different products like cellulose, ethanol, yeast and lignin-lye manufactured. Beside the production lines there are also plants providing necessary chemicals (sodium liquor etc) water and energy. There are plants for waste handling from the production and also plants for waste recovery and by-products like bark, sludge and lye into energy. All together, this makes a rather complex network.

In the last years, *Borregaard Schweiz* has focused more on energy issues. The reasons are:

- Energy is a major cost factor in plants like this one. Good energy management is crucial for maintaining competitiveness.
- Most of the plants are rather old and there are probably significant potentials with new technologies and mindsets.
- The increasing energy prices the last years have made energy savings even favourable.

Several kinds of activities related to energy savings are going on throughout the mill. For example, project of replacing old equipment and processes with low energy efficiency, avoiding or reducing energy losses (better isolation and monitoring, optimizing production recipes, optimizing the mill wide network of energy distribution and energy recovery and optimizing use of external sources.

The *EECPPI* project is, for *Borregaard*, a way to control and improve how the thermal energy is manufactured in the boiler plants, how the different energy sources are distributed and where they are used and finally the recovery of energy and where this secondary energy is used. The system analysis allows to obtain the overall picture of the plant energy and helps defining consistent performance indicators.

Borregaard's contributions so far in the program have been to provide different kind of information:

- General information like flowsheets, lay-out drawings and process descriptions.
- Historical information about production and consumption of raw materials and energy.
- Specific technical information like composition of process media and accuracy of equipment for measurement.

Borregaards participants have also had several meetings with EPFL where technical subjects, findings and progress have been discussed.

Contribution of *Bonnard & Gardel* in 2005

Bonnard & Gardel (*BG* in short) is a 51-years-old engineering company, employing over 100 engineers, with headquarters in Lausanne. *BG* is structured in domains "Transports and Infrastructure", "Water and the Environment", and "Complex Buildings", for which *BG* provides multidisciplinary consultancy and engineering services. Of these, expertise in energy management, optimisation and engineering is strengthening.

Within the *EECPPI* project, *BG* shall provide support related to practical aspects such as measurement /data acquisition (if needed), and achieve preliminary feasibility studies of identified energy savings options, and validation of the methodology by providing feedback to the academic team at *EPFL*. Participation of *BG* aims at widening its field of energy integration and engineering activities to Pulp and Paper Industries.

In 2005, *BG*'s contribution has remained modest, restricted to its participation to meetings at Borregaard, and some advice concerning the modelling of the steam system. This has been also the opportunity to get a first insight into the software *Belsim Vali.*

In 2006, the work will develop along with the elaboration by the other participants of potential energy savings options; *BG* might eventually also contribute in the field of the valorisation of biomass "waste" by producing ethanol.

Collaboration internationale

The *EECPPI* project is realised in the frame of collaboration with a Canadian consortium (E^3PAP[4]) that will study in more details the aspects of eco-industrial clusters and the integration of energy conversion technologies like heat pumps. A general description of the associated Canadian project can be found below. An updated and progress report [8] about the project can be consulted in Appendix H.

General description of the E^3PAP project

Objective

The objective of the E^3PAP project is to establish that it can be technically feasible and cost effective to integrate Canadian pulp and paper mills in eco-industrial clusters by the retrofit of advanced thermal cycles for enhanced energy efficiency. E^3PAP focuses on two components of such a cluster, the mill supplying energy and the surrounding community using it. The economics will be assessed in terms of infrastructures required versus energy savings and environmental benefits achievable for both mill and community. The technology to be implemented in the mill will be trigeneration combined with new types of absorption heat pumps.

Context

An eco-industrial cluster consists of manufacturing and service businesses located in relative proximity of each other and that cooperate with each other and with the local community to share resources efficiently and for mutual economic and environmental benefits. Shared resources may include information, energy, water, infrastructure and habitat. The implementation of an eco-industrial cluster involves complex technical, social, economic and political issues. This case study, the first of its kind to our knowledge, will be focused on technical and economic issues for clusters involving a pulp and paper (P&P) mill as its energy supplier. The project will determine, *(i)* the potential for the Canadian P&P mills to achieve high energy efficiency while creating power and heat producing capacity by the retrofit of new cost effective and environmentally friendly technologies and, *(ii)* the capability of surrounding communities to use the available energy in a manner which is also cost effective.

[4] Novel Technologies for Energy Efficiency and Eco-Industrial Clusters in the Pulp and Paper Industry: a Feasibility Study [12]

Approach

E^3PAP will essentially consist of a case study in three parts:

a) An in depth process energy analysis in a partner mill to quantify several technically feasible options resulting in a significant reduction or elimination of fossil fuel consumption, upgrading waste heat to useful temperature levels, cooling critical streams, liberating high pressure steam and, creating a potential for exporting power, hot water and low pressure steam. The concomitant environmental benefits such as, reduction of greenhouse gas (GHG) emissions and of thermal pollution of receptor water streams will also be quantified.

b) A web-based survey of Canadian pulp and paper mill communities or towns to identify, characterise and quantify the potential uses of exportable power and heat produced by the mills. The methodology to be used in the Canada-wide survey will first be validated on a small scale using the community in which the partner mill is located. This community will also be the object of a special detailed study.

c) An optimal design from the standpoint of cost effectiveness of an energy upgrading and converting system based on the results of the first two parts of the case study. The system will include a trigeneration unit with an absorption heat pump of type-I and a stand alone heat transformer (type-II pump).

Transfer of knowledge and technology to industry

The most important contribution of the project will be to establish a solid data base on the potential for eco-industrial clusters in Canada using innovative thermal technologies. These technologies are new types of thermally driven absorption heat cycles that can use waste heat and do not contribute to GHG emissions. Novel heat pumps designs and usage conditions will be proposed. The design and capital equipment cost will be determined in a case study and communicated to the industry. The increased potential for exportable power and heat achievable by the implementation of those technologies will be characterized and used in subsequent large scale feasibility and demonstration projects.

Benefits to the Canadian industrial and scientific communities

Key benefits to the Canadian industry will be: *(i)* availability of new technologies to upgrade waste heat and produce exportable green heat and power; *(ii)* reduced fossil fuel consumption and, *(iii)* improved environmental performance (Kyoto protocol compliance and thermal pollution of water streams). The proposed project will also create new production and commercial opportunities for manufacturers of thermal systems and will consolidate international R&D initiatives in a new emerging field. Paprican, and the ACE will play a key rote in technology transfer.

Partner Mill

Papiers Fraser, usine de pâte de Thurso, Qc; this mill produces commercial bleached kraft pulp.

Project team

All engineering and scientific disciplines required to successfully execute the work have been assembled in an international multidisciplinary team. The pertinent expertises and past experiences of the team members are:

Browne **(Paprican)**: P&P manufacturing technologies and energy efficiency.

Kajl **(École de technologie supérieure)**: district heating, vapour systems control and measurements.

Legros **(École Polytechnique)**: transport and mass exchange phenomena, separation operations (adsorption-desorption).

Maréchal **(École Polytechnique Fédérale de Lausanne)**: process analysis, novel industrial energy systems, energy integration.
Paris **(Project coordinator, École Polytechnique):** P&P process analysis, novel industrial energy systems, energy integration.
Trépanier (**École Polytechnique)**: tools and methods for on-line web-based surveys, data analysis.
Ziegler **(Technical University of Berlin)**: fundamentals of heat, project leader exchanges and devices, AHPs.
Costa **(École Polytechnique)**: formally from ZAE Bayern and research associate in the PACAS project since 2002 is a specialist of design, analysis and operation of absorption cycles.
A ***specialist of survey techniques*** will also be added to the team as a consultant to advise on all questions concerning the formulation, validation and execution of a survey questionnaire.

Work done in this project by the *EECPPI* team

- Elaboration of the first progress report of the E^3*PAP* project [12]
- Supervision of two exchange students:
  - Martino Minotti (diploma thesis, October to February 2005, *EPM* (Canada))
  - Adriana Cakembergh (learning of *Belsim Vali*, November 15th to December 15th 2005, *EPFL* (Switzerland))

Project duration: 3.5 years (planned starting date: June 1st, 2004)

Évaluation de l'année 2005 et perspectives pour 2006

With the goal of identifying energy savings scenarios for *Borregaard Schweiz a.g.*, several tasks have been planned and well explained in [1]. For 2005, the work done followed quite well the work schedule. The task 1, 2 and 3.1 as described in Chapter 1 have to be accomplished by the end of January 2006 which correspond at the month 12 (M12) of the project. An additional task, the sulphur loop modelling analysis has also been included in the 2005 planification. To resume the work done:

- The task 1, the review of the literature, has been done but is always updated according to the different articles published and conferences presented along the year. The deliverable for this task, a report of the state of the art, is being completed and will constitute one of the main chapter of the PhD thesis
- The task 2, the data collection for *Borregaard Schweiz a.g.*, has been completed. A set of data has been collected from a set of PIDs and several documents furnished by the mill. Data reconciliation models of steam and condensate network and of the general process have been constructed on the platform *Belsim Vali*. Because of the high level of assumptions for some parts of the models, a sensitivity analysis is being performed to validate the assumptions and to determine the necessary additional data or measurements to be collected. Key performance indicators for the plant have been developed to help defining targeting monitoring measures.
- The task 3, the definition of the process minimum energy requirements using process integration techniques is under process. The identification of the *Borregaard* process hot and cold streams has already started. It will allows to generated composite curves of the process and with the help of the dual representation, express by its MER. An update report will be done by the end of January (M12) to expose the results obtained for this task.

- An additional task, the modelling of the sulphur loop has been also performed. It will be particularly useful when elaborating energy savings options and to better understand the environmental balance of the plant.

Taking into account all the work that has been done in 2005, the next steps of the project for 2006 are the following:

- Complete the methodology for defining the minimum energy requirement of the *Borregaard Schweiz a.g.* process. The methodological development will be integrated into the software tool *EASY* under development at *LENI* (task 3 as described in [1])
- Complete the sensitivity analysis to validate the assumptions and organize the sampling campaign at the mill to collect the additional measurement required.
- Using the data of the energy picture and the minimum energy requirement computation, identify preliminary energy savings opportunities with the help of *Borregaard* and *Bonnard et Gardel* engineers.
- Identify the most promising energy saving options and evaluate them thermo-economically

Références

[1] Maréchal, F., ***Efficient Energy Conversion in the Pulp and Paper Industry***, École Polytechnique Fédérale de Lausanne, Requête d'aide financière au programme de R&D OFEN, 2005

[2] ***Prozessbeschreibung Damfversorgung und Rauchgasreinigung***, Internal document of *Borregaard Schweiz a.g*, received on 10/02/05

[3] ***CA-Dampfversorgung***, Internal document of *Borregaard Schweiz a.g*, received on 10/02/05

[4] ***Energy BCH.xls***, Internal *Excel* file of *Borregaard Schweiz a.g*, received on 10/02/05

[5] ***Digester section***, PID R2 45\02 02 0044m, 07/12/94
Drying, PID R1 60\03 02 0216, 07.07.97 and PID R1 60\02 02 0223a, 17/09/97
EOP Delignification (digester) section PID A0 50\01 02 0026, 08/02/91
Evaporation plant Soda Kessel, PID 19997044/51-Z-001, last revision *as built* 08/11/00
General plan of the mill with steam distribution, PID RO 15\01 03 0267, 24/01/01
Pulp preparation (screening, cleaning, thickening), PID R2 45\01 02 0170, 07/11/95 and PID R2 45\01 02 0176, 07/11/95
Soda Kessel, PID B11199-06-99-3110-01000-04, last revision *as built* 28/11/00

[6] ***Stoff-und Energiebilanzierung der Zellstoffherstellung***, Internal document of *Borregaard Schweiz a.g*, received on 22/07/05

[7] ***Rauchgasreinigung (RGR)***, Internal document of *Borregaard Schweiz a.g*, received on 10/02/05

[8] Paris, J., ***Efficacité énergétique et réduction des émissions de gaz à effet de serre dans l'industrie papetière par incorporation de systèmes avancés de pompes à chaleur à absorption***, Deuxième rapport d'avancement au PSIIRI du MDERR du Québec, 2005

[9] ***Waste and biomass database***, www.phyllis.nl, consulted on 23/05/05

[10] Brown, D., Périn-Levasseur, Z., Maréchal, F. and J. Paris, ***Une nouvelle méthode d'analyse thermique et son application aux procédés papetiers***, Congrès annuel ATIP, Annecy 2005

[11] Brown, D., Périn-Levasseur, Z., Maréchal, F. and J. Paris, ***Dual Representation of the Minimum Energy Requirement of a Process Application to P&P Processes***, CSChE Annual Meeting, Toronto 2005

[12] Périn-Levasseur, Z., N. Bouzayani, A. Costa and J. Paris**, *Novel Technologies For Energy Efficiency and Eco-Industrial Clusters In The P&P Industry: A Feasability Study***, Projet E^3PAP, Rapport d'avancement 1, École Polytechnique 2005

Appendices

Warning Appendices B, C, E, F, G, H will be only available on the paper report because of their large format and/or because of their confidential status

Appendix A Preliminary literature review

- A Guide to Energy Savings Opportunities in the Kraft Pulp Industry. PAPTAC (2000).
- AF Publication (in Swedish), Models for energy conservation in pulp and paper manufacturing. Stockholm, 1978.
- Airola K., “Optimizing Power and Heat: There are numerous opportunities to save money and energy in the recovery island and paper mill power plants” PPI Pulp and Paper International, 46 (2), 31-33 (2004)
- Bengtsson, C., “Novel Process Integration Opportunities in Existing Kraft Pulp Mills with Low Water Consumption, Doktorsavhandlingar vid Chalmers, Tekniska Hogskola, 2134 (2004)
- Bengtsson, C., R. Nordman, T. Berntsson, “Utilization of Excess Heat in the Pulp and Paper Industry – a Case Study of Technical and Economic Opportunities”, Pulp and Paper Canada, 22, 1069-1081 (2002).
- Bengtsson, C., Nordman, R. and Berntsson, T. “Utilization of Excess Heat in the Pulp and Paper Industry – a Case Study of Technical and Economic Opportunities”, Applied Thermal Engineering, 22:9, 1069-1081 (2002).
- Bengtsson, C., Karlsson, M., Berntsson, T. and Söderström, M., “Coordination of Pinch Technology and the MIND Method – Applied to a Swedish Board Mill”, Applied Thermal Engineering, 22:2, 133-144 (2001).
- Browne, T.C., Francis, D.W. and Towers, M.T., Energy cost reduction in the pulp and paper industry: an overview. Pulp Paper Can. 102(2):T34-T38 (2001).
- Confidential: Bengtsson, C. T. Berntsson, “Novel Designs for Energy Efficient Heat Exchanger Networks in Kraft Pulp Mills”
- Bhuyan P.K., Nath S.N., Roy A.K., “Energy Conservation in Utility Area of Pulp and Paper Industry”, IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association, 14 (3), 29-33 (2002)
- Chahbani, M.H., J. Labidi and J. Paris, "Modeling of Adsorption Heat Pumps with Heat Regeneration", Applied Thermal Engineering, 23, (2-3), 431-47 (2004).
- Chiba S., “Steam Saving in Paper Making Process - Steam Saving by Raising the Temperature of Pulp Slurry using Hot Water and Recycling White Water from Paper Making Process”, Kami Pa Gikyoshi/Japan Tappi Journal, 58:5, 20-26 (2004)
- Dylke, E., C. Folkestad, T. Retsina and I. Savvakis, “Thermal Optimization Study at Prince George”, Pulp and Paper Canada, 104, (9), 215-217 (2003).
- Energy Cost Reduction in the Pulp and Paper Industry, Browne, T.C. tech. ed., Paprican (1999).
- Energy Conservation Opportunities, 4 volumes, PAPTAC (1992, 1993, 1994, 2001).
- Energy Monitoring Report, Year ended 31 December 1999, CPPA.

- Francis, D.W., M.T. Towers and T.C. Browne, “Energy Cost Reduction in the Pulp and Paper Industry – An Energy Benchmarking Perspective, Pulp and Paper Research Institute of Canada (2004)
- Garner J.W., “Energy Conservation Practices Offer Environmental and Cost Benefits”, Pulp and Paper, 76 (10), 53-56 (2002).
- Gemci, T. and Ozturk, A., “Exergy Analysis of a Sulfide Pulp Preparation Process in the Pulp and Paper Industry”, Energy Convers. Mgmt, 39, (16-18), 1811-20 (1998).
- Gong, M., “Exergy Analysis of a Pulp and Paper Mill”, Int. J. Energy Res, 29, (79-93) (2005).
- Hill, K.C., D. Vijh, R. Boudreau, “Rendement amélioré du système vapeur de la sécherie”, Les Papetières du Québec, 14-18 (Mai/Juin 2003).
- Karojärvi, R., Liimatainen, H. and Tapio, M., Impact of advanced co-generation methods on energy demand in mechanical pulping. First EcoPaperTech, an International Conference on Papermaking and Paper-Machine Technology: 303-314 (1995).
- Kilponen L., Ahtila P., Parpala J., Pihko M.Improvement of pulp mill energy efficiency in an integrated pulp and paper mill (2001) Proceedings ACEEE Summer Study on Energy Efficiency in Industry, 1, Pages 363-374.
- Kuisma K., “Energy Savings through Advanced Steam Balancing”, Paper Technology, 43 (1), 45-47 (2002).
- Kumana J.D., “Pinch Analysis for Process Energy Optimization”, Energy Engineering: Journal of the Association of Energy Engineering, 99 (4), 18-41 (2002).
- Kaya, A., Keyes, M.A., “Energy Management Technology in Pulp, Paper and Allied Industries”, Automatica, 19:2, 111-130 (1983).
- Lafourcade, S., J. Labidi, R. Koteles, C. Gélinas and P. Stuart, “Thermal Pinch Analysis with Process Streams Mixing at a TMP-newsprint Mill”, Pulp and Paper Canada, 104, (12), 309-311 (2003).
- Lähepelto, J., Rational use of energy in the Finnish paper industry — The sustainable paper energy research programme. Das Papier 51(6A):V200-V203 (1997).
- Linnhoff, M. Introduction to Pinch Technology (1998)
- Mathur R.M., Thapliyal B.P., Goel A., Tyagi S., Kulkarni A.G., “Process Integration through Pinch Analysis: A Concept”, IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association, 14 (3), 99-102 (2002).
- Möllersten, K., Yan, J. and Westermark, M., “Potential and Cost-Effectiveness of CO2 Reductions through Energy Measures in Swedish Pulp and Paper Mills”, Energy, 28:7, 691–710 (2003).
- Nguyen K.L., Hoadley A., “Design and Management of Water Circuits of a Closed Integrated Kraft Pulp Mill”, APPITA Annual General Conference, 479-487 (2003).
- Nilsson, L.J., Larson, E.D., Gilbreath, K.R. and Gupta, A., “Energy Efficiency and the Pulp and Paper Industry,” American Council for an Energy-Efficient Economy, Berkeley, CA (1995).
- Nygaard, J., Energy aspects on mechanical pulp, chemical pulp and recycled fibres. International Mechanical Pulping Conference:17-27 (1997).
- Périn-Levasseur, Z., Rodríguez-Toral, M. A., Rivero, R., Paris, J., Network Pinch Analysis in PIECE, a Process Integration Program for North American Mobility in Higher Education, Proceedings of the ECOS 2004 Conference, ISBN: 968-489-027-3, 3, 1379 – 1388, Guanajuato, Mexico (2004).

- Persson, B., Drying section: The least developed part of the paper machine. Nordisk Cellulosa 5(5):75-77 (1988).
- Pyykko J., Haag D., “Balancing Steam Demand and Steam Generation in Industrial Power Plants and Steam Networks”, Instrumentation, Control, and Automation in the Power Industry, Proceedings, 45 (ISA 421), 83-92 (2004).
- Ravagnani, M.A.S.S, Silva, A.P, Arroyo, P.A. and Constantino, A.A., “Heat Exchanger Network Synthesis and Optimisation Using Genetic Algorithm”, Applied Thermal Engineering, 25:7, 1003-1017 (2005).
- Saini N.S., Kaul S.K., “Co-generation and Developments in the Utility Areas of Pulp and Paper Industry”, IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association, 14 (3), 25-28 (2002).
- Sarimveis, H.K. et al, “Optimal Energy Management in Pulp and Paper mills”, Energy Conversion and Management, 44:10, 1707–1718 (2003).
- Savu, E., S. Sarrailh, F. Maréchal et J. Paris, « Fermeture des circuits dans un procédé de désencrage : Analyse et simulation », P&P Can., 105, (2), 28-33, (2004).
- Savulescu L., Poulin B., Hammache A., Bedard S., “Water and Energy Savings at a Kraft Paperboard Mill Using Process Integration”, Annual Meeting - Technical Section, Canadian Pulp and Paper Association, Preprints, C (2001).
- Schroderus S., Ma H., Munger L., Peters N., “Practical Aspects of Energy Conservation in Pulp and Paper Mills”, Pulp and Paper Canada, 103 (4), 36-39 (2002).
- Smook, G.A., Handbook for Pulp and Paper Technologists, 3rd Edition. Canada: Angus Wilde Publications. 425p. (2002).
- Talja, R., Kerttula, R. and Karlsson, M., Future paper production line concepts regarding energy and environmental aspects. Das Papier 51(6A):V203-V207 (1997).
- Wising, U., T. Berntsson and P. Stuart, "The Potential for Energy Savings when Reducing Water Consumption in a Kraft Pulp Mill", Applied Thermal Engineering, 25:7, 1057-1066 (2005).
- Wising, U., Process Integration in Model Kraft Pulp Mills Technical, Economic and Environmental Implications, Doktorsavhandlingar vid Chalmers Tekniska Hogskola, (2019), 1-80 (2003)
- Wising U., Berntsson T., Asblad A., “Energy consequences in minimum effluent market kraft pulp mills” Tappi Journal, 1:11, 30-32 (2002)
- Wising U., Berntsson T., Asblad A., “Usable excess heat in future kraft pulp mills”, Tappi Journal, 1:11, 27-29 (2002).

Appendix B General Process Diagram (*available only on paper*)

Appendix C Plan of the mill (*available only on paper*)

Appendix D Cooking chemistry of the calcium bisulfite process (*in French*)

La caractéristique de ce procédé est la défibration chimique du bois par l'acide sulfureux (H_2SO_3) et la dissolution à l'aide d'une base cationique des sels ligninosulfoniques formés, ce qui empêche la décoloration de la pâte. Le mélange d'acide et de base dans lequel le bois sera défibré est appelé liqueur de cuisson. L'acide sulfureux est généralement produit sur place à partir de la combustion du soufre qui est caractérisée par la réaction suivante:

$$1/2S_2 + O_2 \rightarrow SO_2 \qquad (1)$$

Le dioxide de soufre produit est ensuite absorbé dans de l'eau pour former de l'acide sulfureux :

$$SO_2 + H_2O \rightarrow H_2SO_3 = SO_2 \bullet H_2O \qquad (2)$$

Des études par spectroscopie Raman du Dioxyde de soufre en solution[5] montre qu'il est essentiellement présent sous forme de molécules libres de SO_2, la forme acide n'étant présente qu'en faible quantité. Toutefois, les propriétés réactionnelles présentes dans le procédé au bisulfite sont celles de l'acide. Par conséquent, les deux formes de notation décrites dans l'équation (2) sont correctes. La base cationique utilisée dans le procédé acide est le calcium. Celui-ci est introduit dans l'eau sous forme de calcaire. Il peut ensuite réagir avec l'acide sulfureux pour donner du bisulfite de calcium :

$$CaCO_3 + 2H_2SO_3 \rightarrow Ca(HSO_3)_2 + CO_2 + H_2O \qquad (3)$$

Le bisulfite de calcium est en réalité composé de deux formes de SO_2 en solution :

$$Ca(HSO_3)_2 \rightarrow \underset{\text{"}SO_2\text{ combiné"}}{CaSO_3} + \underset{\text{"}SO_2\text{ libre"}}{H_2SO_3} \qquad (4)$$

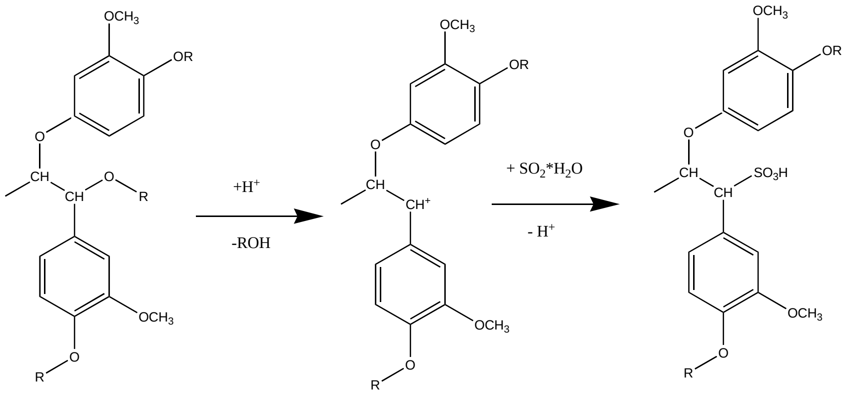
La réaction globale peut donc être écrite comme étant :

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_3 + H_2O + CO_2 \qquad (5)$$

[5] Hermann Müller, « *Ullmann's Encyclopedia of Industrial Chemistry*»,6th Edition, p. 660, Chapter on Sulfur Dioxide, Vol 34, Wiley, 2003.

Le H_2SO_3 est dit « libre » car il se trouve justement sous la forme de molécule de SO_2 en solution. Le taux de SO_2 libre et combiné est ajusté empiriquement afin d'optimiser le procédé.

La liqueur de cuisson qui est mise en contact avec le bois à une température dépassant 110°C réagit avec la lignine présente dans le bois. La lignine est présente dans le bois sous sa forme polymérisée. La formule d'un monomère de Lignine est $\mathbf{C_9H_{8.3}O_{2.7}(OCH_3)_{0.97}}$[6]. La lignine se clive tout d'abord par hydrolyse en monomère plus soluble. Une molécule d'acide sulfureux réagit ensuite avec un monomère de lignine pour former une molécule d'acide ligninosulfonique :



Cet acide peu soluble est solubilisé par la base. Le calcium réagit avec deux molécules d'acide ligninosulfonique pour former des sels ligninosulfoniques solubles dont la formule est $\mathbf{C_{20}H_{24}CaO_{10}S_2}$.

La cellulose, autre constituant majeur du bois, résiste relativement bien à la liqueur de cuisson. Néanmoins, l'hémicellulose peut se convertir en sucres solubles par hydrolyse, ce qui diminue le rendement. La lignine est responsable de la couleur foncée, indésirable, dans la pâte. L'acide de cuisson, en réagissant avec celle-ci défibre le bois et fait passer la lignine en solution aqueuse et ainsi la sépare de la pâte insoluble essentiellement constituée de cellulose.

Appendix E Flow diagrams of the steam and condensate return (*available only on paper*)

Appendix F Flow diagrams of the pulpmaking process (*available only on paper*)

Appendix G List of assumptions for the *Belsim Vali* models (*available only on paper*)

Appendix H Energétique et réduction des émissions de gaz à effet de serre dans l'industrie papetière par incorporation de systèmes avancés de pompes à chaleur à absorption - Deuxième rapport d'avancement au PSIIRI du MDERR du Québec, 2005 (*available only on paper*)

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[6] Formule pour le bois de l'espèce *Picea Abies* : S. Y. Lin, « *Ullmann's Encyclopedia of Industrial Chemistry*»,6th Edition, p. 510, Chapter on Lignin, Vol 19, Wiley, 2003. Ce n'est pas l'espèce de bois utilisé ici mais, la formule ne varie pas de manière significative d'un bois à l'autre.