Process Integration in the Pulp and Paper Industry

The Role of process Integration for Greenhouse Gas Mitigation in Industry
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Industrial Systems Optimization
CanmetENERGY
CanmetENERGY is the principal performer of federal non-nuclear energy science & technology (S&T):
- Fossil fuels (oil sands and heavy oil processing; tight oil and gas);
- Energy efficiency and improved industrial processes;
- Clean electricity;
- Buildings and Communities; and
- Bioenergy and renewables.

Areas of Focus:
- Oil sands & heavy oil processes
- Tight oil & gas
- Oil spill recovery & response

Areas of Focus:
- Buildings energy efficiency
- Industrial processes
- Integration of renewable & distributed energy resources
- RETScreen International

CanmetENERGY Three Scientific Laboratories across Canada

Devon

Areas of Focus:
- Buildings & Communities
- Industrial processes
- Clean fossil fuels
- Bioenergy
- Renewables

Varennes

Ottawa
CanmetENERGY-Varennes

*Industrial Systems Optimization (ISO) Program*

- CanmetENERGY’s ISO Program focuses on innovative facility-wide optimization techniques (i.e. systems approach):
  - Improve plants design and operation;
  - Effective introduction of new technologies;
  - Achieve efficient use of energy and natural resources with reduced environmental impacts;
  - **Pulp and paper**, refineries, oil sands, agrifood;
  - Four main areas:
    - Heat Management
    - Cogeneration Optimization
    - Advanced Data Analytics
    - Biorefinery
CanmetENERGY-Varennes
Industrial Systems Optimization (ISO) Program

Research
Knowledge
Industrial projects

SYSTEM ANALYSIS SOFTWARE

INTEGRATION
Identify heat recovery opportunities in your plant

EXPLORER
Discover the power of data to improve operation

COGEN
Maximize revenues from cogeneration systems

I-BIOREF
Evaluate biorefinery strategies

SERVICES

TRAINING
Attend workshops with world class experts

KNOWLEDGE
Access to publications and industrial case studies

Knowledge Transfer
Pulp and Paper Industry Context

- Pulp and paper industry is in an on-going transformation to increase profitability:
  - **Lower production costs** → Energy efficiency, Reduce cost of GHG emissions, Reduce the number of operating lines or shut down unprofitable mills
  - **Increase annual revenues** → Install new turbines and produce additional "green" power
  - **Diversify production** → Change product grade; Add biorefinery technologies

**Optimized energy integration is essential** to reduce operating costs, lower GHG emissions, add new revenues and prepare pulp and paper mills for the low-carbon economy
Applying Process Integration in P&P Industry

- Pulp and paper processes are complex and already integrated:
  - Numerous operations interconnected through energy and water networks
  - Numerous recycle loops
- Strong interactions between energy and water systems:
  - Cooling water becomes process water
  - Non-isothermal mixing (pulp line, water tanks)
Applying Process Integration in P&P Industry

- Complex interactions with the steam and power system
- In some countries, seasonal effects and large share of biomass use as fuel;
- Large amounts of waste heat rejected: effluents, exhausts, flue gas, vents
- Retrofit projects are becoming increasingly complex as most of "easy to find" projects are already implemented
- Limited capital available for energy projects
- Many constraints make energy optimization even more difficult:
  - Production schedules
  - Equipment availability and performance
  - Process variability
  - Fuel and power prices
  - Contractual constraints
  - Environmental constraints

Using process integration techniques is quite challenging in P&P mills: heat recovery, energy-water interactions, use of biomass as fuel, electricity contracts, process variability
Process Integration in Pulp and Paper Industry

Canadian Experience

- **Natural Resources Canada** has been promoting supporting the use of Process Integration in Canadian industries

- Since 2004, 81 PI studies in various industry sectors across Canada with 46 PI studies in pulp and paper

- PI studies performed by a small number of specialized organizations (consultants, industry and government research organizations) and few other studies done by universities

- **PI tools used:**
  
  Mill simulation, Pinch Analysis, Cogeneration optimization, KPIs, Data Analytics

Results and impacts on energy efficiency and GHG emissions

Download the report from NRCan’s website
Typical results:

Operating cost reductions from 1 to 4 M$/yr per mill (fuel savings and/or additional electricity sales)

10 to 20% process steam savings

$: Canadian dollars

Legend:

- PI study in pulp and paper mill

46 PI studies in Canadian pulp and paper mills between 2004 and 2017
**PI in Retrofit Situations in Canadian Pulp and Paper Mills**

**Results and Impacts**

<table>
<thead>
<tr>
<th>Process integration: Results and impacts 2004-13</th>
<th>Pulp and paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of PI studies included</td>
<td>19</td>
</tr>
<tr>
<td>Fuel savings</td>
<td></td>
</tr>
<tr>
<td>Implementation rate (fuel saving measures)</td>
<td>4,105 TJ/year</td>
</tr>
<tr>
<td>Increase</td>
<td>65%</td>
</tr>
<tr>
<td>Increased power generation</td>
<td>54 MWe</td>
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<tr>
<td>Direct GHG reductions</td>
<td></td>
</tr>
<tr>
<td>Total GHG reductions (direct + indirect)</td>
<td>174,720 tonnes/year</td>
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<tr>
<td></td>
<td>231,370 tonnes/year</td>
</tr>
<tr>
<td>Fuel cost savings</td>
<td></td>
</tr>
<tr>
<td>Revenue from power generation</td>
<td>$22 million/year</td>
</tr>
<tr>
<td>Other cost savings or additional revenue</td>
<td>$35 million/year</td>
</tr>
<tr>
<td>Total monetary impacts (energy related + others)</td>
<td>$0 million/year</td>
</tr>
<tr>
<td></td>
<td>$57 million/year</td>
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<tr>
<td>Average payback period</td>
<td>1.4 year</td>
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</table>

Kraft (9), TMP (6), Tissue (3), Other (1)
Cogeneration (10), No cogeneration (9)
Market pulp (7), Integrated (8), Paper, board and tissue only (4)

Impacts from projects actually implemented + projects scheduled for being implemented soon

Indirect GHG reductions: from additional power generation and electricity saving measures
PI in Retrofit Situations in Pulp and Paper Industry

Lessons learned and Typical Opportunities

- Improvement opportunities can be found in all departments and utility system, all P&P processes, both large and smaller mills
- A successful retrofit PI study results in a set of projects presented in a clear action plan to improve the plant’s energy performance over time:

1. **Make-up water and turbine condensate return:**
   - Reduce steam at the deaerator through turbine condensate and make-up water preheating
   - Increase condensate return and recover flash steam losses

2. **Water - energy network:**
   - Rearrange water network to reduce overflows, overflow coldest water sources,
   - Reduce detrimental NIMs and increase the water tank temperatures towards steam savings
3. **Heat exchanger network:**
   - Increase heat recovery in existing exchangers: relocation, stream distribution, add surface area, improve cleaning strategies
   - Recover waste heat in effluents, exhausts, vents
   - Add new process exchangers

4. **Utility system:**
   - Optimize boiler operating strategies to maximize economic benefits from process steam savings (fuel savings or power generation)
   - Better exploit flexibilities in electricity contracts
   - Improve header control strategies to reduce pressure fluctuations and reduce steam let-down

5. **Heating and Ventilation:**
   - Building heating using waste heat; improve glycol loop controls
1. Pinch analysis used to identify heat sources and sinks, energy targets, inefficient heat transfers, but data extraction can be challenging

2. Approach based on the Grid Diagram has limitations due to:
   - Water tanks with multiple inlets and outlets;
   - Complex splits and mixing;
   - Bypasses and Recirculations.

    Flowsheet-based data input needed

3. Energy-water interactions and non-isothermal mixing points

    New approach developed
Process Integration in Pulp and Paper Mills

*Lessons learned in retrofit situations*

4. Variability in operations affects process performance (locally and in other units)
   ➔ Operation analysis and improvement using Advanced Data Analytics

5. High share of biomass fuel use but quality highly variable year-round
   ➔ Management of fuel quality

6. Contract complexity for "green" electricity from Cogeneration
   ➔ Several constraints on different time periods

7. Limited available capital for energy projects, often in competition with production projects
   ➔ Short vision may limit opportunities for greater savings in the future; Prioritize larger projects that can be implemented in phases according to budget availability
Process Integration in Pulp and Paper Industry
Approach Combining Several Systems Analysis Tools

Innovation Through Integrated Solutions

- **EXPLORATION**
  - Operation Analysis & Improvement

- **INTEGRATION**
  - Heat Integration
  - Technology Integration
  - Utility Systems Optimization
  - Water Network

- **COGEN**
  - Anaerobic treatment
  - Gasification
  - Biorefinery
  - CO₂ capture
Heat Recovery in Pulp and Paper Industry

*Long term vision and phased implementation – Kraft mill*

Each opportunity has specific implications to the long term network retrofit.
Heat Recovery in Pulp and Paper Industry

*Long term vision and phased implementation – Kraft mill*

1. **Path 1: Short term vision**
   - **Implementation**: up to 2 Phases
   - **Savings**: 750,000 $/year fuel savings

2. **Phase 1**
   - Water Treatment
   - Evap Surf Cond
   - Warm Water Tank
   - Demin Water Tank
   - Deaerator
   - Boiler Feed Water
   - Process Hot water

3. **Phase 2**
   - Reduced Waste Heat
   - Dedicated Water Tank
   - Condensate
   - Cold Mill Water
Heat Recovery in Pulp and Paper Industry

**Long term vision and phased implementation – Kraft mill**

- **Water Treatment** → **Evap Surf Cond** → **Warm Water Tank** → **Demin Water Tank** → **Deaerator** → **Boiler Feed Water**
- **Cold Mill Water** → **Evap Surf Cond** → **Warm Water Tank** → **Dedicated Water Tank**

- **Path 2: Long term vision**
  - Implementation: up to 4 Phases
  - 1,500,000 $/year fuel savings

- **Phase 1**: Steam Savings
- **Phase 2**: Steam Savings
- **Phase 3**: Steam Savings
- **Phase 4**: Natural Resources Canada
Objective: increase refiner dilution water temperature to generate more steam
Segregate white water network to reach a temperature as high as possible (+80°C)
Process Integration in Pulp and Paper Industry

Advanced Data Analytics (Data Mining)

- Valuable process knowledge is hidden in historical database
  - Large amount of data is available in mills
  - Difficult to fully understand the links and interactions between data
- Data mining techniques can help extract this knowledge
  - Statistical analysis to explain process variability and improve operation
  - Statistical models to maintain performance over time
Process Optimization using Advanced Data Analytics

**Brown Stock Washing (BSW) – Kraft mill**

- Identify best operating conditions in BSW considering interactions with evaporators, recovery boiler, bleaching and heat recovery network:
  - Key aspect to optimize resources utilisation (energy, water, chemicals)

![Diagram of BSW process](image)

- What is the optimal dilution factor?
- How to reduce weak black liquor concentration variability?
Process Integration in Pulp and Paper Industry

Utility systems optimization

Most cogeneration systems are not used in an optimal way
A detailed model of the utility system is used and the optimal steam path that minimizes the total operating cost is determined: optimize existing system and maximize economic benefits from steam savings.

Benefits will be maximized year-round by considering contractual, operational and environmental constraints on different time periods.
Process Integration in Pulp and Paper Industry

Concluding remarks

- Process Integration is key to design highly-efficient pulp and paper mills
- In retrofit situations, **steam and water savings of 10 to 20%** are possible cost-effectively. **Increased power generation** is also typical
- Large energy savings can be obtained at low-cost by reducing process variability and improving control strategies
- **Challenges** to perform retrofit PI studies successfully include:
  - Complex water-energy interactions making classical pinch difficult to apply
  - Many heat recovery projects already implemented
  - Process operating conditions having an impact on energy consumption should be challenged in order to maximize savings
  - Risk that biomass-based cogeneration systems shift mill priority towards increased power generation rather than fuel savings and GHG reductions
- Develop a **long term vision for project implementation**:
  - Permits a gradual implementation that mitigate the implication of short-term modifications over long-term high impact solutions
Process Integration in Pulp and Paper Industry

**Concluding remarks**

- Possible solutions for large GHG reductions should be analyzed using process integration to maximize benefits and reduce the cost:
  - Lime kiln and flash dryer: gasification, anaerobic treatment, lignin precipitation, cogeneration
  - CO$_2$ capture

- R&D program for pulp and paper - Current and future work at CanmetENERGY
  - Improved retrofit method in complex configurations (mixing, recycling, tanks) based on path and bridge approaches
  - Improved multiperiod algorithm for utility systems
  - Data Analytics for key P&P equipment/process
  - Technology options to reduce GHG in lime kiln and flash dryer
  - Pathways for improving TMP and kraft mill performance
  - Analysis of biorefinery pathways for integration at existing mills
Process Integration R&D Program at CanmetENERGY: Current and Future Work

- Improved multiperiod algorithm for utility systems
  - Contractual constraints on different time periods
  - Start-up/shut-down/maintenance of major equipment

- Improved heat integration software
  - **One change at a time**: Path based algorithm for the identification of new and relocated Hx (NLP and MINLP formulations)
  - **Multiple changes at a time**: creating new paths requiring more than one new Hx to complete the path using MINLP formulation (bridge method used as a basis to generate new paths)
  - Flowsheet data input instead of grid diagram to handle complex mixing between several streams, recycling, loops and splitting without remixing
  - Tools and strategies to reduce impacts of fouling
  - Engineering heuristics
  - Impact of flow variation on Hx performance
Process Integration R&D Program at CanmetENERGY: Current and Future Work

- Predefined models with associated documentation to performed advanced data analytics of key P&P equipment/processes
  - Evaporators, lime kiln, biomass boilers (including biomass supply and management systems), refiners, etc.
- Analysis of biorefinery pathways and how mill existing assets can evolve to reduce implementation costs, notably by debottlenecking key process equipments
- Possible solutions to reduce fossil fuel usage in lime kiln and flash dryers
  - Gasification, anaerobic treatment systems, lignin precipitation, cogeneration...
- Detailed pathways with associated calculations tools to improve TMP and kraft mill energy performance cost-effectively: making lesson learned from PI more easily accessible
Thank You!

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