Overview of Heat Recovery projects related to the Chemical Cluster in Stenungsund

Professor Simon Harvey
Chalmers University of Technology
Chemical Cluster Stenungsund: Production and emissions 2011

TOTAL Emissions of CO₂ approx. 900 kton/yr
The potential of inter-process heat integration: Opportunities for improving energy efficiency in Stenungsund – Sweden’s largest chemical cluster

Key figures for total site:
- Total CO₂ emissions: ~900 kton/yr
- Total heating demand: 442 MW – 320 MW are covered by internal heat recovery
- Current utility usage for fired boilers: 122 MW
- Can theoretically be reduced to 0 MW through inter-process heat integration!

How this can be accomplished:
- New circulating hot water systems 50-100°C
- Harmonization of utility pressure levels to enable heat exchange between process plant utility systems
- Rebuild steam heaters for 2 bar(g) operation
- Fire process off-gases in different boilers

Substantial opportunities for energy efficiency through Inter-process heat recovery
Detailed design of specific heat recovery systems has been accomplished in a recent study at Chalmers.

Consequences of increased heat recovery with the HW systems on the overall PBP; red squares: Total fixed capital, blue diamonds: PBP.

Detailed design of specific heat recovery systems has been accomplished in a recent study at Chalmers.

Consequences of increased heat recovery with the HW systems on the overall PBP; red squares: Total fixed capital, blue diamonds: PBP.
System 20 can be pre-fitted for extension to System 50 (extra cost 19 MSEK)

Total investment: 199 MSEK

Total hot utility savings: 20.7 MW

Payback period: App. 3.2 years

New HXs: 5
**Total investment:** 598 MSEK (199)

**Total hot utility savings:** 50.8 MW (20.7)

**Pay back period:** App. 3.9 years (3.2)

**New HX:** 32 (5)
Studying competition between internal heat recovery and excess heat export

Lina Eriksson
SP – Energiteknik
Examinator and main supervisor: Simon Harvey
Co-supervisor: Matteo Morandin

Timeframe: September 2013 – December 2015
Part of collaborative project package investigating different aspects of regional district heating

• Other sub-projects:
  – “How district heating market models influence industrial excess heat usage” – SP, Magnus Brolin
  – “Assessment of Sustainability of industrial waste heat - the Stenungsund case” – Chalmers and IVL, Erik Ahlgren and Thomas Ekervall
  – “Analysis of need and demand for sustainable district heating from the large customers” – Business Region Gothenburg, Lars Bern

• Scientific co-ordination of the projects lead by Thore Berntsson
  – Exchange results
  – Use common assumptions
Aim: Promote rational use of industrial excess heat, and provide conditions for creating a sustainable energy system.

The primary goal is to understand:

- Technical feasibility, profitability and environmental impact of the use of excess heat for district heating

- The competition between the production of district heating and opportunities within industry for heat recovery
Two case studies: PREEM Lysekil
Chemical cluster in Stenungsund

1. Identify some different levels of use of excess heat internally for:
   a. Heat recovery within each industry / sub-process
   b. Exchange between industries / sub-processes
   c. Investigate the possibilities for using heat pumps

2. Identify for each level and area of use above:
   a. Quantity and temperature of the remaining excess heat for district heating delivery
   b. Opportunities to increase the delivery of district heat by using heat pumps

3. Evaluate costs and CO2 emissions for the different cases based on some different scenarios for:
   a. Marginal production for district heating (what is replaced)
   b. Marginal production of electricity (what is replaced)
   c. Policy instruments (such as future costs of emitting CO2)
Project outline

4. Identify and include some other technologies:
   a. Biorefinery concepts
   b. Electricity generation with ORC
   c. Drying of biomass
   d. CCS, etc.
   
   Evaluate these in the manner described in step 2 and 3, in terms of economy, CO2 emissions and impact on the possibilities to produce district heating.

5. Find some optimal solutions for utilisation of excess heat with regards to costs and climate impact (CO2) for the different scenarios that were created in step 3.
Potentials estimated using ACLC - Actual Cooling Load Curves
Industrial Excess Heat for District Heating

Comparison of potentials from top-down and bottom-up studies for energy-intensive process industries

Based on the MSc Thesis project conducted by Moa Swing Gustafsson 2013

Professor Simon Harvey
Heat and Power Technology Group
Department of Energy and Environment
Chalmers University of Technology
Background

• In response to EU’s Energy Efficiency Directive: Ongoing legislation changes in Sweden aim to facilitate third party access to DH networks (in particular industrial processes)

• 4.1 TWh/yr of industrial excess heat was delivered to DH networks in Sweden in 2012 (total DH heat delivered 2012: 50 TWh)

• A number of studies indicate that there is a potential for increasing excess process heat recovery for DH delivery
Major study commissioned by the Swedish DH Association (SDHA) in 2009

Statistical data was compiled for excess heat deliveries from industrial plants. This data was related to the corresponding fuel usage for these plants.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Excess heat delivered per unit of fuel usage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp industry</td>
<td>2.8</td>
</tr>
<tr>
<td>Paper industry</td>
<td>3.2</td>
</tr>
<tr>
<td>Chemicals and chemical products</td>
<td>24.3</td>
</tr>
<tr>
<td>Ferrous and non-ferrous metals</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Based on this data it was estimated that the potential for excess recovery for DH purposes is 6.3 TWh/yr compared to 4.1 TWh/yr currently delivered.
Objective of the MSc thesis project

Compare the potentials estimated in the SDHA report with results generated using pinch analysis for case studies in key industrial sectors.

5 industrial plant case studies were studied
- Chemical pulp and paperboard mill
- Chemical pulp mill
- Mechanical pulp and paper mill
- Steel mill
- PVC plant
Brief presentation of Pinch analysis

- Well established tool for analysing heat flows in industrial processes with liquid and gas flows.
- Allows heat recovery targets to be established: Determines minimum cooling and heating demand of a process for a given value of minimum temperature difference allowed in the heat exchangers \((\Delta T_{\text{min}})\)
- Requires the following data for process streams that must be heated or cooled
  - Start temperature
  - Target temperature
  - Mass Flowrate
  - Specific heat capacity
Basics of Pinch Analysis

Process Pinch
Depends on choice of $\Delta T_{\text{min}}$

Maximal internal Heat recovery

Theoretical minimum heating demand

Theoretical cooling demand

Graphically

Heat balances

Hot streams

Cold streams

Q

Energy analysis

Process streams
Grand composite curves

The grand composite curve (GCC) illustrates the net energy flow in each temperature interval.
Estimating the potential for export of excess process heat to a DH network using the GCC

Excess heat is discharged to CW if no other options are available.
Quantification of maximal excess heat recovery

Case 1: DH supply $T_{\text{target}}$ can be reached. All process excess heat can be used for WW production.

Temperature profile for DH water

Slope of line is related to flowrate

$$Q_{DH} = F_w \cdot C_{p,W} \cdot (T_{DH,\text{Supply}} - T_{DH,\text{Return}})$$
Case 2: All process excess heat cannot be delivered to DH network. (DH supply $T_{\text{target}}$ too high)

Utility pinch activated. DH flow is limited by $\Delta T_{\text{min}}$

Cold utility for remaining cooling load
Results presented in the thesis

- DH export potentials estimated from GCCs for 4 different values of $\Delta T_{\text{min}}$

  0 K  5 K  10 K  15 K

  theoretical maximum for reference

- In practice, few processes achieve the energy target. It is also of interest to estimate potentials based on the composite curve of process streams that are cooled in process coolers (ACLC Actual Cooling Load Curve)

- These numbers are compared with the estimates obtained using the SDHA procedure
Limitations and assumptions

• All work based on case studies (pinch analysis studies conducted within our group)

• District heating water temperatures
  - Return temperature: 55°C
  - Supply temperature: 85-105°C

• Required minimum $\Delta T$ between the district heating water and process streams
  - 7 K
Case study 1

Chemical pulp and paperboard mill
Grand Composite Curve $\Delta T=10$
# Results

<table>
<thead>
<tr>
<th>( \Delta T_{\text{min}} )</th>
<th>DH export potentials [MW] for varying DH water supply temperature levels [(^{\circ}\text{C})]</th>
<th>Pinch temperature [(^{\circ}\text{C})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>0 K</td>
<td>28.0</td>
<td>25.6</td>
</tr>
<tr>
<td>5 K</td>
<td>24.2</td>
<td>22.6</td>
</tr>
<tr>
<td>10 K</td>
<td>12.6</td>
<td>12.1</td>
</tr>
<tr>
<td>15 K</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ACLC Estimate</td>
<td>14.3</td>
<td>12.5</td>
</tr>
</tbody>
</table>

SDHA estimate

Pulp: 10.0 MW

Paper: 11.4 MW
Case study 5

PVC plant
Estimated potentials for DH delivery from PVC plant

<table>
<thead>
<tr>
<th>$\Delta T_{\text{min}}$</th>
<th>DH water supply temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85</td>
</tr>
<tr>
<td>0 K</td>
<td>17.6 MW</td>
</tr>
<tr>
<td>5 K</td>
<td>21.5 MW</td>
</tr>
<tr>
<td>10 K</td>
<td>22.2 MW</td>
</tr>
<tr>
<td>15 K</td>
<td>23.0 MW</td>
</tr>
<tr>
<td>ACLC</td>
<td>25.6 MW</td>
</tr>
</tbody>
</table>

SDHA Estimate
13.1 MW
Summary of results
## Estimated potentials for DH export [MW]

<table>
<thead>
<tr>
<th></th>
<th>Case study 1 Chem. P&amp;P mill</th>
<th>Case study 2 Chem. Pulp mill</th>
<th>Case study 3 Mech. P&amp;P mill</th>
<th>Case study 4 Steel works Coking plant</th>
<th>Case study 4 Steel works rest of plant</th>
<th>Case study 5 PVC Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH [°C]</td>
<td>85 105</td>
<td>85 105</td>
<td>85 105</td>
<td>85 105</td>
<td>85 105</td>
<td>85 105</td>
</tr>
<tr>
<td>$\Delta T_{min}$=0</td>
<td>28.0 -</td>
<td>38.2 -</td>
<td>- -</td>
<td>4.4 1.5</td>
<td>14.6 14.6</td>
<td>17.6 -</td>
</tr>
<tr>
<td>$\Delta T_{min}$=5</td>
<td>24.2 -</td>
<td>42.2 -</td>
<td>2.3 -</td>
<td>4.4 1.6</td>
<td>15.0 15.0</td>
<td>21.5 4.6</td>
</tr>
<tr>
<td>$\Delta T_{min}$=10</td>
<td>12.6 11.9</td>
<td>45.5 -</td>
<td>- -</td>
<td>4.5 1.7</td>
<td>15.4 15.4</td>
<td>22.2 5.4</td>
</tr>
<tr>
<td>$\Delta T_{min}$=15</td>
<td>- -</td>
<td>48.9 -</td>
<td>- -</td>
<td>4.5 1.8</td>
<td>16.2 16.2</td>
<td>23.0 7.1</td>
</tr>
<tr>
<td>ACLC</td>
<td>14.3 11.5</td>
<td>- -</td>
<td>- -</td>
<td>11.0 7.2</td>
<td>17.2 17.2</td>
<td>25.6 16.9</td>
</tr>
<tr>
<td>SDHA estimate</td>
<td>10.0-11.4</td>
<td>9.8</td>
<td>1.6-1.8</td>
<td>6.6</td>
<td>6.7 (13.1)</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• The SDHA approach usually underestimates the potential for DH export compared to estimates using pinch analysis

• The potentials based the actual cooling (ACLC) are usually higher since they (often) reflect inefficient use of heat within the process

• "Beauty is in the eye of the beholder". There is no clearcut definition of excess heat

• Even if the "excess heat" at the plant isn’t at a high enough temperature to produce DH it may be beneficial to recover the excess heat available and provide final heating to the required delivery temperature with steam (or other hot utility)
Regional Energy System
Idea: Benefits from an integrated system
RESO, Studied region

Distance approx 50 km
Heating demand approx 7 TWh/year
When the systems are integrated

- The profit for integrating the system is up to 240 MSEK* per year compared to the present system
  - Average: 140 MSEK/year*
  - Payback time: 2-11 years*
- District heating market: 150 – 620 GWh/year*
  - Average: 430 GWh/year*
- Electricity production: 850 – 1360 GWh/year*
  - Average: 1080 GWh/year*

*based on 30 scenarios with different investment possibilities
Lowest cost solution, [GWh]

Gävle Energy
352 7

Sandviken Energy
53 40

Älvkarleby Fjärrvärme
28 0

Heat market
0 515 168 0 0 39

Korsnäs | Karskär Energy
Sandvik
StoraEnso Skutskär
Reasons for the profits when integrating the systems to one system

- The boilers are used in a better way
- It is possible to produce more electricity
- Investments
Influence on each operator, compared to separate systems

*9 scenarios are analyzed in-depth
The boundaries for CO$_2$-emission accounting

- Swedish average electricity mix
- European average electricity mix
- Present marginal production
Reduction of CO₂ emissions, compared to reference scenario

Appendix 3: Presentations from the workshops

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Marginal Coal</th>
<th>Marginal NGCC</th>
<th>Average Swedish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 5</td>
<td></td>
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<tr>
<td>Scenario 21</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Scenario 25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Idea: Benefits from an integrated system
Appendix 3: Presentations from the workshops

Development of a sustainable, competitive society with high security of supply

- Develop a common infrastructure for energy and other resources
- Regional cooperation on infrastructure - Skutskär, Gävle, Sandviken och Hofors, Falun and Borlänge!

Appendix 3: Presentations from the workshops

Development of a sustainable, competitive society with high security of supply

- Develop a common infrastructure for energy and other resources
- Regional cooperation on infrastructure - Skutskär, Gävle, Sandviken och Hofors, Falun and Borlänge!
Excess heat
Projects at Linköping university

Mats Söderström, Energy Systems, Linköping university
Appendix 3: Presentations from the workshops

Contents

- Harvesting
- Quantification
- Systems analysis
- Realization
In this case:

- Measurements using IR camera and thermocouples
- Possible to transfer 0.3 GWh annually to water and air

IR images from cooling bed 1 (CB1) and cooling bed 2 (CB2). The tubes move over the bed in the direction of the arrow. The diagrams to the right of the images show the temperature profile of the cooling bed along the arrow.

Source: Johansson MT, Wren J, Söderström M. Submitted to Applied Energy
Electricity generation from low-temperature industrial excess heat

Excess heat with a temperature below 230 °C

Technology alternatives

Thermo Electric Generator – F2F200W TEG Power
Organic Rankine Cycle – 750 kWel Opcon Powerbox
PCM-motor – 100-200 kWel Exencotech

Excess heat

Cooling water from EAF – ORC
Cooling water from ingot casting – PCM
electricity generation 3,5 GWh

Economy

TEG – not suitable
ORC for temperatures over 80 °C
PCM for temperatures below 80 °C

Källa: Johansson MT, Söderström M,
Electricity generation from low-temperature industrial excess heat – an opportunity for the steel industry.
Excess heat today = ca 35 GWh
Potential excess heat = ca 90 GWh !!
Survey of industry in Örebro och Östergötland counties

- Cooperation with county boards
- Energy intensive industries
- Responses from industries representing 10,5 of 12,5 TWh
- Today 107 GWh of excess heat is used in district heating
- Fig shows unused excess heat 1480 GWh
- 146 GWh in flue gases over 160°C
- Uppscaling to national level - 2TWh

Survey of industry in Gävleborg county

- Cooperation with the county board
- Survey to the energy manager in 58 industries
- Responses from industries representing 9,5 of 11,2 TWh
- Today 220 GWh is used in district heating
- Fig shows unused excess heat 800 GWh
- Over 100 C: ca 300 GWh (water and gases)

Technologies for utilization of excess heat based on the survey of Gävleborg county

Case 1: to district heating

- Water over 95 C
- Gases over 100 C
- Hot material
- Ca 90 GWh to district heating

Case 2: to electricity generation

- Hot material 1000 C  
  TPV
- Gases and water over 80 C  
  ORC
- Water under 80 C  
  PCM – motor
- Ca 25 GWh electricity

Systems analysis

- Based on input data from the Gävleborg survey
- System optimization reMIND
- Energimarket scenarios ENPAC

Results:
- All available excess heat is used
- ORC is not used
- CO2-emissions decrease in all scenarios, decrease depends on what is replaced by the excess heat

Idea: Benefits from an integrated system
Gävleborg county
Thanks!
We also do:

- **Biogas applications in industry – excess heat**
- **Excess heat and policies**