Techno-economic Survey and Design of a Pilot Test Rig for a Trilateral Flash Cycle System in a Steel Production Plant


*Spirax Sarco, **Brunel University, ***Tata Steel
Beaumont Estate Hotel in Windsor, Thursday 20th April,
Agenda

Opportunity

Technology

Application

Development

Results
The Opportunity

Potential Theoretical Global Waste Heat estimated to be 68.2 TWh

63% occurs below 100°C

Estimated heat recovery potential for industrial sector lies in the region 10-20TWh (36-71PJ)

Largest heat recovery potential in Iron and Steel
Existing Technology - ORC
Existing Technology - ORC

Shaft Power ORC and Thermal Power (1MW Stream)

- ORC power out (kW)
- kW Thermal
Existing Technology - ORC
Trilateral Flash Cycle
Trilateral Flash Cycle

Shaft Power TFC and Thermal Power (1MW Stream)

Heating Temperature

Power kW

Thermal Power kW

- kW Thermal
- TFC power out (kW)
### Tata Steel Application

<table>
<thead>
<tr>
<th>Application</th>
<th>Flowrate (m³/h)</th>
<th>Inlet Temperature (°C)</th>
<th>Outlet Temperature (°C)</th>
<th>Thermal Power of Waste Stream (kW)</th>
<th>Number of Hours Running</th>
<th>MWh per year generated</th>
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<td>Tata Steel Heat Source A</td>
<td>33,820 (gas)</td>
<td>250</td>
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- **Typical Heat Recovery Opportunity**
  - 833+ MWh Potential Generation

- **Large modifications required**
  - Undesirable payback
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- Local cooling water available
- Commercially attractive location
- Opportunity for low-temp application
- Diversion of streams required
- Currently unmetered
Tata Steel Design Specifics

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<tr>
<th>Stream</th>
<th>Flowrate (kg/s)</th>
<th>Inlet Pressure (bara)</th>
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<th>Inlet Temperature (°C)</th>
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<tr>
<td>Waste heat stream</td>
<td>10.39</td>
<td>4</td>
<td>3.5</td>
<td>70</td>
<td>24</td>
</tr>
<tr>
<td>Refrigerant stream</td>
<td>31.4</td>
<td>5.47</td>
<td>1.18</td>
<td>66</td>
<td>19</td>
</tr>
<tr>
<td>Condensing water stream</td>
<td>90.85</td>
<td>4</td>
<td>3.5</td>
<td>12</td>
<td>17</td>
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100kW Electrical Power Generation
Thermodynamic Modelling

\[ \dot{m}_{\text{hot}} c_{p,\text{hot}} (T_8 - T_9) = \dot{m}_{\text{wf}} (h_B - h_A) \]

\[ \dot{m}_{\text{cold}} c_{p,\text{cold}} (T_{11} - T_{10}) = \dot{m}_{\text{wf}} (h_D - h_C) \]

\[ \eta_{\text{pmp}} = \frac{h_3 - h_2}{h_4 - h_2} \]

\[ \eta_{\text{exp}} = \frac{h_5 - h_6}{h_5 - h_7} \]

\[ \eta_{\text{cy}} = \frac{\dot{m}_{\text{wf}} (h_5 - h_6 - (h_4 - h_2))}{\dot{m}_{\text{hot}} c_{p,\text{hot}} (T_8 - T_9)} \]

\[ \eta_{\text{tot}} = \eta_{\text{cy}} \eta_{\text{mech}} \eta_{\text{el}} \]
Thermodynamic Modelling

![Graphs showing electrical power output and temperature differences for various refrigerants](image-url)
Pilot Test Rig System Design
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Pilot Test Rig System Design
Pilot Test Rig Development

- Twin-screw TFC Expander
- Plate HX Heater
Initial Testing

- Electrical Power Output (kW) vs. Thermal Power Input (kW)
Conclusion

Thermodynamic model created

Commercial business cases reviewed and Tata Steel demonstration site chosen

TFC system designed, built and run successfully

Preliminary tests demonstrate ability to reach $6.2kW_e$ from $141.8kW_t$

Limitation in the control system

Further development under I-ThERM