Energy efficiency in industrial steam production and distribution

Workshop Energy-efficiency
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Dries Maes
Flemish Institute for Technological Research
Belgium

Structure

1) Working with steam?
2) To Determine the cost of steam
3) Different points and ideas to save energy in a steam system
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Working with steam in the industry?

Different heat transport fluids are available
- Water
  - no transition to steam allowed
  - temperatures are not too high: ± 150°C
- Thermal oil
  - specific composition of the oil for long lifetime
  - higher boiling temperatures so higher operating temperatures.
- Steam
  - Specific use of latent energy in the fluid
  - High heat transfer gives smaller heat exchangers
- Water: 4,000 W/m²°C
- Oil: 1,500 W/m²°C
- Steam: > 10,000 W/m²°C
Working with steam in the industry?

- **Benefits of higher pressure:**
  - The steam has a higher temperature
  - The volume is smaller, the distribution pipes are smaller.
  - It is possible to distribute at high pressure and to relax steam prior to application. The steam thus becomes dryer and reliability is higher.
  - a more stable boiling process in the boiler.
  - ...

- **Benefits of lower pressure:**
  - There is less loss of energy at boiler level and in the distribution
  - The amount of remaining energy in the condensate is relatively small.
  - Leakage losses in the pipe system are lower.
  - ...

!! Working with steam also has implications for safety, reliability, costs, lifespan of the equipment... !!!
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The cost of steam?

Different factors:

- \( C_F \) Fuel
- \( C_W \) Water supply
- \( C_{BFW} \) Feed water treatment (includes softening, clarification..)
- \( C_P \) Feedwater pumping power
- \( C_A \) Combustion air fan
- \( C_R \) Sewer charges for boiler blowdown
- \( C_D \) Ash disposal costs
- \( C_E \) Environmental emissions management and control cost (includes additives)
- \( C_M \) Maintenance materials and labour
The cost of steam

- Fuel costs are normally by large the most important costs:
  \( C_G = 1.1 \times C_F \)

- What does this cost mean?
  - average cost
  - no effect of different pressure levels
  - no effect of marginal consumption
  - no effects of regulation or intermediate electricity production
  - ....

Average versus marginal costs of steam

**Average cost**  
= Total operating cost / Total Steam  
= \( C_O/S \)

**Marginal cost**  
= Marginal production cost / Marginal quantity of Steam Consumption  
= \( \Delta C_O/\Delta S \)

Very different approach, but more correct for the evaluation of energy saving measures
The cost of steam: via marginal costs, example

- Marginal cost is highly variable
- Picture differs for every steam pressure level
- Cost shows influences of varying efficiencies, turbines, pressure-reducing valves,...
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Different ways to save energy in a steam system

- Use economisers to pre-heat feedwater
- Install an air pre-heater
- Prevent scale deposits on heat transfer surfaces. Ensure deposits are regularly removed on the waterside of boilers
  - Minimize boiler blowdown
  - Recoverable heat from boiler blowdown
  - Minimize boiler short cycling losses
- Consider installing high-pressure boilers with backpressure turbine generators for the production of electricity or for rotating installations
  - Implement a control and repair programme for steam traps
  - Install insulation on steam pipe and condensate return pipes
- Installation of removable insulating pads on valves and fittings
- Collect condensate and return it to the boiler for re-use
- Re-use of flash steam
- Use of flash steam on the premises or through recovery of condensate at low pressure
- ...
1) Implement a control and repair programme for steam traps

- Steam systems without regular inspection often have defective steam traps
- Without inspection, after 3 to 5 years, 30% of all steam traps need repair or replacement
- Normally, a distribution system should have less than 5% of defective steam traps.
- Critical traps:
  - High pressure steam traps
  - Traps connected to expensive or critical equipment.

Function of steam traps

- Prevent the steam to pass.
- Evacuate the condensate (once all the energy has been used)
**Different operation modes for steam traps**

<table>
<thead>
<tr>
<th>Description</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>OK</td>
<td>All right</td>
</tr>
<tr>
<td>ES</td>
<td>Steam escaping</td>
</tr>
<tr>
<td>LK</td>
<td>Leaks</td>
</tr>
<tr>
<td>FC</td>
<td>Fast cycle</td>
</tr>
<tr>
<td>FX</td>
<td>Fixed</td>
</tr>
<tr>
<td>SB</td>
<td>Submerged</td>
</tr>
<tr>
<td>OO</td>
<td>Out of order</td>
</tr>
<tr>
<td>NT</td>
<td>Not tested</td>
</tr>
</tbody>
</table>

**Related costs of escaping steam**

- Amount of escaping steam can be huge.
- Defective trap represents large losses
- Example:
  - leakage
  - standard application
  - operating pressure difference : 15 bar
  - losses : 16,650 € per year
- If not simply leaking, but full Blow-through : 66,570 € per year
- These costs easily justify a control programme for steam traps.
2) High pressure boilers and turbines to produce low-pressure steam

- The intervention is large. Economic yield can be equally large.
- This is applicable if:
  - continuous steam supply is necessary
  - or continuously steam is being reduced in pressure by PRV’s
- Alliance with electricity providers is often possible.
Steam is used at this point.

Steam is prepared at higher pressure (100 bar)

Expansion of the steam over a turbine to produce electricity

Steam is used at this point.
Example

- Situation:
  Boiler needs to be replaced:
  - 25 tonnes/h of steam
  - at 15 barg
  - efficiency 74%
  - 6,500 hours per year operating time

Options:
1) Replace by equivalent boiler of better quality
2) Replace by high-pressure boiler and back-pressure turbine

Example

a) Yearly operating cost of the old boiler:
\[
\frac{6500 \text{ h/year} \times 2459 \text{ kJ/kg} \times 25 \text{ t/h} \times 3.8 \text{ €/GJ}}{0.74 \times 1000} = 2.051.836 \text{ €/year}
\]

b) Operating cost of the new boiler (new boiler equivalent with the old one, option 1)
\[
\frac{6500 \text{ h/year} \times 2459 \text{ kJ/kg} \times 25 \text{ t/h} \times 3.8 \text{ €/GJ}}{0.80 \times 1000} = 1.898.041 \text{ €/year}
\]
Example

c) High pressure boiler, yearly operating cost (option 2)
\[
\frac{6500 \text{ h/year} \times (3017.5 \text{ - } 335) \text{ kJ/kg} \times 25 \text{ t/h} \times 3.8 \text{ €/GJ}}{0.80 \times 1000} = 2.070.555 \text{ €/year}
\]
Steam is overheated to 330°C to make energy available for the turbine

d) Amount of electricity generated by the turbine
\[
\frac{6500 \text{ h/year} \times 150.9 \text{ kJ/kg} \times 25 \text{ t/h}}{0.97} = 7.022 \text{ MWh/year}
\]
Annual gain is equivalent to 351.106 €/year

This compensates largely for the higher operating cost

Practically

- Turbines can be interesting when:
  - high operation load during the year
  - large use of lower pressure steam
  - energy prices have an important role (collaboration with electricity providers can be interesting)
  - not the first measure to be taken, but can be considered when high energy efficiency has been achieved by other measures.
3) Minimising Blowdown and recuperation of Blowdown energy

- **Blowdown**: necessary discharge of boiler water to
  - reduce concentration of salts in the boiler water
  - remove suspended particles in the boiler water
- Blowdown percentages depend largely on the quality of fresh water preparation.
Deconcentration blowdown

Minimising Blowdown?

- TDS (Total dissolved salts) concentration needs to be controlled.
- Example: initial blowdown rate is 8%
- Boiler:
  - 25 bar
  - 5,500 hours a year.
  - 25 tonnes of steam per hour
  - boiler efficiency 82%
  - Gas: 5 €/GJ
  - Freshwater 1,3 €/ton
  - Discharging 0,1 €/ton
Minimising Blowdown?

- Automatic blowdown control reduces blowdown rate from 8% to 6%.
- 8% -> 2,08 t/h
- 6% -> 1,5 t/h
- Gains: $\frac{578 l/h \times 5500 h \times 553.1 kJ/kg \times 5 \text{€/GJ}}{0.82 \times 1000.000} = 1072 \text{€/year}$
- Water savings: 4,451 €/year
- Total: 15,172 €.

Recuperation of energy from Blowdown

<table>
<thead>
<tr>
<th>Recovered energy from blowdown losses, in MJ/h [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blowdown rate</strong></td>
</tr>
<tr>
<td>% of boiler supply</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>1%</td>
</tr>
<tr>
<td>2%</td>
</tr>
<tr>
<td>4%</td>
</tr>
<tr>
<td>6%</td>
</tr>
<tr>
<td>8%</td>
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<tr>
<td>10%</td>
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</tbody>
</table>

[1] These quantities have been determined based on a boiler supply of 10 tonnes/h, an average temperature of the boiler water = 20°C, and a recovery efficiency of 88%.
Solubility of oxygen in water in function of the temperature

Solubility of oxygen (ppm)

Water temperature (°C)

Mission 6.2: Energy Efficiency

Dries Maes, STE
VITO, Mol
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Conclusions

- Much more interventions are possible
- Raising energy prices make several interventions economically interesting
- Good set-up of priorities necessary among different interventions (economic yield of interventions may interact)
- Definitively a good idea to look into any existing steam system.

Thank you

Dries Maes

VITO, Flemish Institute for Technological Research
Boeretang 200
2400 Mol
Belgium
+32/14/33.58.27
Dries.maes@vito.be