ORC Waste Heat Recovery system using kiln exit and cooler vent air
VDZ Jahrestagung, Düsseldorf; September 27-28, 2012 Markus Hepberger
Agenda

A. Introduction - WHR in cement
B. Organic Rankine Cycle
C. ORC application in Untervaz plant
D. Conclusion
Waste Heat Recovery (WHR) in cement

- WHR in cement was introduced more than 20 years ago (Japan)
- Momentary “state-of the-art” in Japan and China, rolling out in other Asian regions:
  - Thailand, India, Pakistan, Taiwan, Vietnam, etc.
  - More than 525 WHR systems are in operation worldwide (2009) [3]
  - Most of them are based on Water-Steam Rankine Cycle (WSRC) [3]
- Only few WHR applications in cement in Europe and Americas

Heat Balance of a Dry Cement Kiln
Total Energy input 3000-3500 GJ/tclic

~ 35% of input heat is available for drying and power production
kiln exhaust temp : 290-390°C
cooler exit temp : 250-350°C
Availability of heat for power production

- Exhaust kiln heat is used for raw material drying (1st priority)
- Remaining waste heat can be used for material and fuel drying, heating and power production
- Typical power production from waste heat is 30 – 45 kWh/t\textsubscript{clinker}\textsuperscript{*1)}

which is up to 30% of the power consumption of a cement plant\textsuperscript{[3]}

\*1) based on gross kWel
Pre-condition for power production from waste heat in cement

- **High** electricity price
- Availability of waste heat
  - Moderate raw material moisture & coal moisture
  - No other drying requirement
  - *kiln size / gas volume*
- Government / local regulations and incentives
  - $CO_2$: CDM, carbon tax, renewable power index, etc.

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Specific Organic Rankine Cycle features

- Invented more than 30 years ago
- Use low temperature boiling working fluid (organic fluids or refrigerants)
- Heat transferred by an intermediate circuit (small gas to liquid heat exchangers)
- For “low” source temperatures applications (100 - 300 °C)
- Turbine on one temperature & pressure level, thus simpler design (In some cases no gearbox between turbine and generator)
Application of Organic Rankine Cycle (ORC)

- Many applications in geothermal, biomass and small power supply system (gas pipeline)
- Several waste heat sources on different temperature levels can be collected and “homogenised”
- Higher thermodynamic efficiency compared to water-steam at turbine inlet temperatures below ~200 °C
- Only ~ 5 ORC WHR applications in cement (Germany, India, Morocco, Romania, Switzerland) [3]

Cement kiln waste-heat power production application based on ORC technology
Specific advantages of ORC based WHR systems in cement kiln applications

Organic Rankine Cycle

- Turbine inlet temperature 150 - 220 C
- Use of complete cooler exit gas volume at low temperature (~280 C) and high variations (150 - 350 C)
- Smaller heat-exchanger surface due to higher temperature difference and no evaporation

Water-Steam Rankine Cycle

- Turbine inlet temperature > 350 C (superheated steam)
- Two pressure level turbine for better use of cooler gas
- Mid air tab to increase gas temperature > 380 C
- Part of exit gas (~ 150 C) is lost for power generation
Why ORC based WHR systems are probably better suited for European cement plants?

- Higher raw material moisture (typically: 3.5 - 6% in northern Europe up to 10%)
- Smaller kilns (typically: 1’500-3’000 tpd_{cli})
- Efficient use of complete cooler heat (no losses)
- Simpler integration, smaller heat-exchanger surface area (no cooler tab modification, uses complete volume and temp range)
- Space limitations ask for small footprint (mostly plant upgrades, no new plants, smaller boilers)
- Fully automated operation required (mature countries have high labour cost)
- Low maintenance effort required (no water make-up system)
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Untervaz has a history in power production from waste heat; first system commissioned 1981– de-commissioned 2005

- Exhaust heat from pre-heater only (kiln with planetary cooler)
- Water-steam based with low pressure turbine, 7 bar, 1000 kW_{el}
- Low boiler and turbine efficiency (8-12 kWh/t_{cli}),
- Issues with boiler fouling/clogging (dust), by-pass losses due to not tight dampers
Boiler / gas heat-exchanger design and dust cleaning technology is key in cement WHR applications

- Untervaz WHR boiler was not adequately designed
  - vertical gas flow, not sufficient tube inter-space
  - not adequate cleaning system
- Other kiln gas heat-exchanger applications (e.g. district-heating) suffer from similar deficiencies

Finned tube heat-exchanger with soot-blower cleaning

(after re-start of kiln) (several weeks of operation)

- Other ORC WHR systems in cement run on clean cooler exhaust gas only (e.g. Lengfurt, Grasim)
Untervaz WHR system scheme

- Preheater Heat exchange
- WHR I
- Pressured Water
- Evaporator Preheater
- ORC Turbine & Generator
- Isobutane
- Air Cooled Condenser (ACC)
- WHR II
- Clinker Cooler Heat exchanger
- ~290 °C
- Kiln
- ~5 MW th
- ~10 MW th
- 170 °C
- 370 °C
- 150 °C
- ORC WHR System, 2012-08-15

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Untervaz WHR system installation

- Preheater gas gas tie-in
- Cooler gas gas tie-in
- Cooler gas heat-exchanger
- Preheater gas heat-exchanger
- Preheater gas booster-fan
- Air cooled condenser
- ORC fluid Heat-exchangers
- Turbine-generator
- ORC fluid tanks
Key features of Untervaz WHR system

- Horizontal gas-flow pre-heater HEX bare tubes with dust
- Gas tie-in with tight vertical sliding gate shut-off dampers
Key features of Untervaz WHR system

- Booster fan to minimize losses and avoid backlash to kiln system
- Air Cooled Condenser ACC to save water
Key features of Untervaz WHR system

• Vertical gas-flow cooler HEX with cyclone de-duster
  ▶ Compact design
  ▶ Booster fan and tight slide gates inhibit by-pass losses
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Conclusions

• ORC based WHR systems are an alternative to conventional water-steam based systems

• The challenge of operating heat-exchangers in a dust loaded gas stream is the same for both WHR technologies
  » One can profit from vast experiences made in Asia.

• ORC WHR system are economically the better solution for:
  » Smaller applications of 1-3 MWel
  » Lower and multiple temperature sources
  » In cases fully automatic operation is required

• ORC system must be designed to maximize overall efficiency
  » Available heat stream utilization versus thermodynamic efficiency
  » Smaller units must be more efficient to be economical
THE END

• Source / Literature Reference
• Appendix
Literature References


[3] Dr. Joachim Harder, OneStone Consulting Group, Trends in power generation from waste heat in cement plants; ZKG International (No-5-2011)


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