Screw Expanders in ORC applications, review and a new perspective
ASME ORC 2015 Brussels
Paper ID: 45 Henrik Öhman, Per Lundqvist
Content

1. Re-view, leading to new opportunities?
2. 2-phase expansion modeling
3. Implications on ORC systems optimization
4. New perspectives
5. Conclusions
### Re-view: Many shapes and forms

<table>
<thead>
<tr>
<th>Main types</th>
<th>Many variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin Screw</td>
<td><img src="image1.png" alt="Twin Screw" /></td>
</tr>
<tr>
<td>Triple Screw</td>
<td><img src="image2.png" alt="Triple Screw" /></td>
</tr>
<tr>
<td>Inverted Female</td>
<td><img src="image3.png" alt="Inverted Female" /></td>
</tr>
<tr>
<td>Herring Bone</td>
<td><img src="image4.png" alt="Herring Bone" /></td>
</tr>
</tbody>
</table>
Re-view of Twin Screw Expanders

1930's
• Dry Entry/Dry Exit
• Air-, Steam- and Industrial gas expansion

1940's
• Dry Entry/Mixed Exit
• Steam- and humid air expanders

1950's
• 2- and 3-phase expansion
• Air+ Oil, Air+Water+Ice (Wagenius, Schibbye)

1960's
• First ORC applications
• Automotive (Minto), AirCond (Linde)

1970's
• Liquid Expansion, water
• Geothermal water direct expansion (McKay)

1990's
• Liquid Expansion, heated refrigerant
• Trilateral Flash Cycles (Smith)

2000's
• Liquid Expansion, cooled refrigerant
• Expressor, Phase Separator (Brasz, Öhman)

2010's
• Mixed Entry/Mixed Exit + Oil
• Efficiency correlation (Öhman, Lundqvist)

A NEW PERSPECTIVE ON OPPORTUNITIES WITH ORC’s?
Re-view: 1960’s ORC applications gain momentum

Automotive propulsion
Solar heat + combustion
Oil injected Twin Screw

Solar Powered Pumping Stations
Off-grid water pumping
Oil injected Twin Screw
2-phase expansion modeling?

Dynamic flashing

Spontaneous condensation

# 2-phase expansion modeling?

<table>
<thead>
<tr>
<th>Physics</th>
<th>Comment</th>
<th>Models</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid state conditions</td>
<td>Needed at all positions</td>
<td>Quasi-static</td>
<td>Non quasi-static</td>
</tr>
<tr>
<td>Spontaneous condensation</td>
<td>Instable sub-cooled gas</td>
<td>Non-validated (vol, expansion)</td>
<td>Primary impact</td>
</tr>
<tr>
<td>Dynamic flashing</td>
<td>Instable super-heated liquid</td>
<td>Non-validated (vol, expansion)</td>
<td>Primary impact</td>
</tr>
<tr>
<td>Time constants</td>
<td>Damping effects</td>
<td>Undefined</td>
<td>Differs by order of magnitude</td>
</tr>
<tr>
<td>Coupled effects</td>
<td>Condensation/flashing interaction</td>
<td>None available</td>
<td>Strongly coupled</td>
</tr>
<tr>
<td>Impact of lubricant</td>
<td>Distortion of saturation temp + solubility</td>
<td>Equilibrium models</td>
<td>Strongly time + system dependent</td>
</tr>
</tbody>
</table>
## 2-phase expansion modeling: ORC system

<table>
<thead>
<tr>
<th></th>
<th>Physics based models</th>
<th>Correlation models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat exchange</td>
<td>Available</td>
<td>Available</td>
</tr>
<tr>
<td>ORC process states</td>
<td>Available</td>
<td>Available</td>
</tr>
<tr>
<td>Pump efficiencies</td>
<td>Available</td>
<td>Available</td>
</tr>
<tr>
<td>Adiabatic Expansion</td>
<td>Not available</td>
<td></td>
</tr>
<tr>
<td>Efficiency (mixed flow)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Physics based models

\[
\psi_{2\,\text{phase}} = \frac{d\eta_{\text{ad}}}{dX_{\text{entry}}} = -0.15 \cdot \eta_{\text{ad,peak}} + 0.09
\]

\[
\eta_{\text{ad}}(X_{\text{entry}}) = \eta_{\text{ad,peak}} + \psi_{2\,\text{phase}} \cdot (1 - X_{\text{entry}}) \cdot 10
\]

(Öhman, Lundqvist 2013)

### Correlation models

![Graph showing data points for different models]
Implications on ORC systems optimizations: Variable expansion entry vapor fraction

Saturated Liquid, TFC
Variable Vapor Fraction, ORC
Saturated Gas, ORC
Super Heated Gas, ORC

NH3
R245fa
R134a

Öhman, Lundqvist 2014
New perspectives: Importance of fluid choice?

Simulated ORC for WHR of Marine diesel jacket cooling water (Öhman, Lundqvist 2014)

Envelope of optimized efficiency $f(\text{Exp}, \text{Entry Vapor Fraction})$ vs. Utilization.
3 different fluids
3 different lumped efficiency classes
FoC Corr is a comparative correlation for real units (Öhman, Lundqvist 2013)
New perspectives: Optimization on vapor fraction?

Max Net Power Out = Max efficiency

HEXs [K/kW/kWe]

NPO[kWe]

Max Cost Efficiency

Sensitivity to Expansion Entry Vapor Fraction on NPO and Cost Efficiency

WHR from Pulp factory (Öhman 2011)

(R245fa, Utilization=0.75, Reversible Cycle, Irreversible heat transfer)
Conclusions

Physics based “mixed flow” Screw Expander modeling are not yet suitable for application performance predictions.

Correlation of “mixed flow” performance allows for ORC systems optimization by process simulation.

The perspective of “Variable Mixed Flow Screw Expander Entry” offers:

- **An alternative** to trans-/supercritical, Multi-staging and Zeotropic blends
- Opportunities for improved ORC cost efficiency
Thank You!

Henrik Öhman, Per Lundqvist
henrik@hohman.se