KTH ROYAL INSTITUTE
OF TECHNOLOGY

ON HIGH LEVEL EVALUATION AND COMPARISON OF ORC POWER GENERATORS

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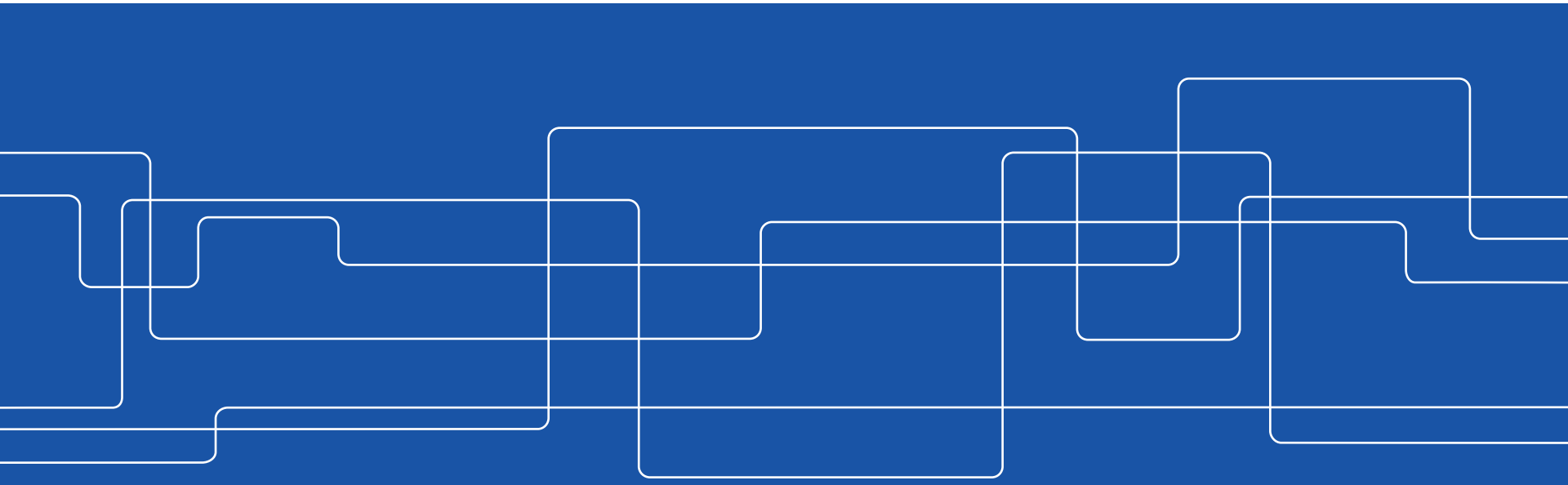

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Inadequate terms of merit?

- Room for ”over-optimistic” or ”under-ethical” market players
- Unrealistic customer expectations
- Investors find ”plenty of reasons to wait”
- Customers ”do not understand”

$\Rightarrow$ Entry barriers to the market

No matter if technology is mature if communication is immature!

Criteria for useful terms of merit

- Cannot violate theory
- Explainable and acceptable to practitioners
- Free of bias from relevant boundary variations
- Show ”primary good” in a dimensionless manner

Conventional terms of merit for ORC power generators

Carnot efficiency	$\eta_c = 1 - T_2/T_1$	Irrelevant
Thermal efficiency	$\eta_{th} = \dot{W}/\dot{Q}_1$	Biased
Exergy efficiency	$\eta_{ex} = \dot{W}/\left[\dot{m}_1 \cdot \left(e_{1,entry} - e_{1,exit}\right)\right]$	Ambiguous
Exergy efficiency	$\eta_{ex} = \dot{W}/\left[\dot{m}_1 \cdot \left(e_{1,entry} - e_{1,exit}\right) + \dot{m}_2 \cdot \left(e_{2,entry} - e_{2,exit}\right)\right]$	Iteration Non-intuitive

Dimensionless scale, Utilization

Chosen limit for use of first law potential

$$\psi_U = \dot{Q}_1 / \dot{Q}_{CA}$$

where

$$\dot{Q}_{CA} = \dot{m}_1 \cdot Cp_1 \cdot \left(T_{1,entry} - T_{CA}\right) = \frac{\left(T_{1,entry} - T_{CA}\right)}{\alpha_1}$$

Common exit temperature of source and sink assuming a reversible power process => Curzon-Ahlborn temperature

Integrated Local Carnot Efficiency
=> *reversibly available thermal efficiency*

Max Power Cycle:

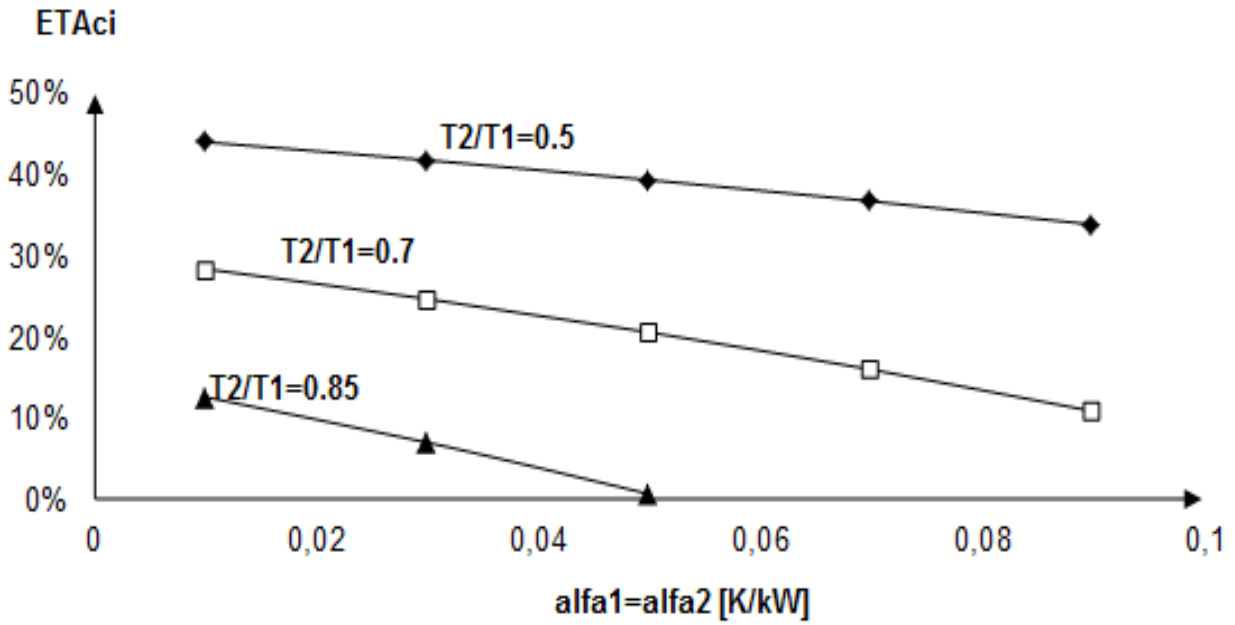
Reformulated from (Ibrahim & Klein 1996)

$$\dot{W} = \int_0^{\dot{Q}_1} \left(1 - \frac{T_{2,l}}{T_{1,l}}\right) \cdot d\dot{Q}_1$$

Numerical solution using local Carnot cycles *Öhman & Lundqvist 2013*

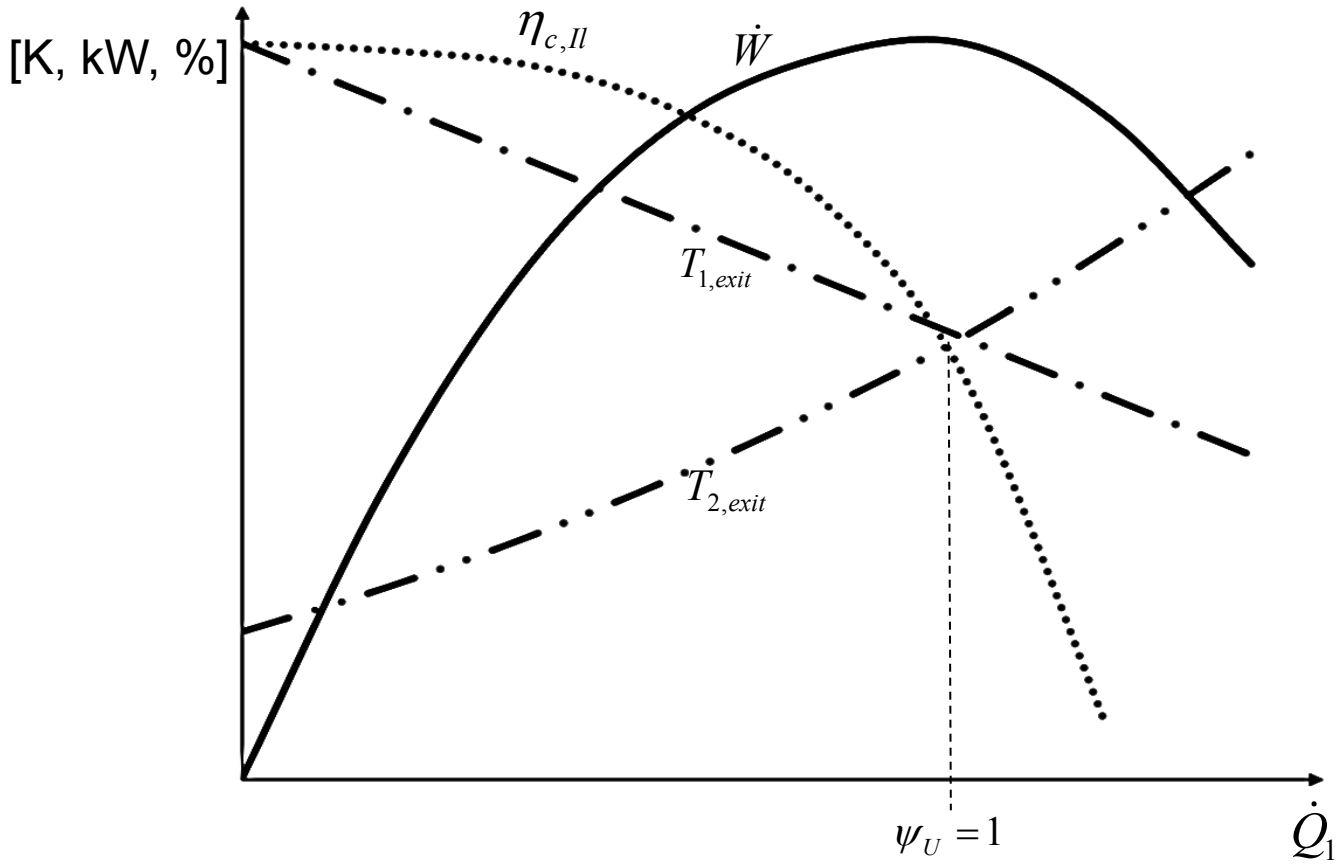
$$\eta_{c,II} = \frac{1}{n} \cdot \sum_{i=1}^{n} \left(1 - \frac{T_{2,l}}{T_{1,l}}\right)$$

Reversible sensitivity to ”finiteness”



Öhman & Lundqvist 2013

Schematic relationships, reversible



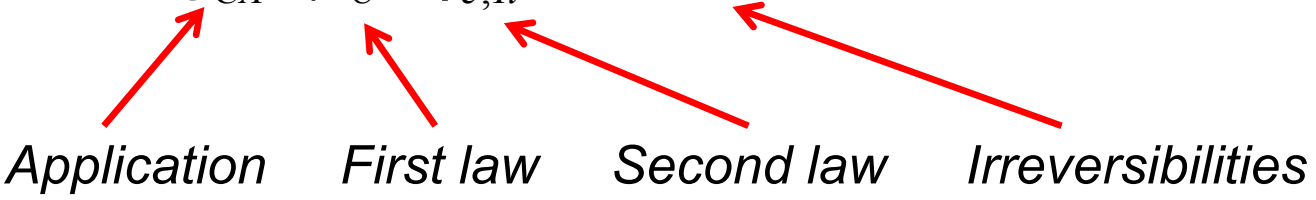
Fraction Of Carnot

Compilation of all irreversibilities of a power generator

$$FoC(\psi_U) = \frac{\eta_{th}(\psi_U)}{\eta_{c,Il}(\psi_U)}$$

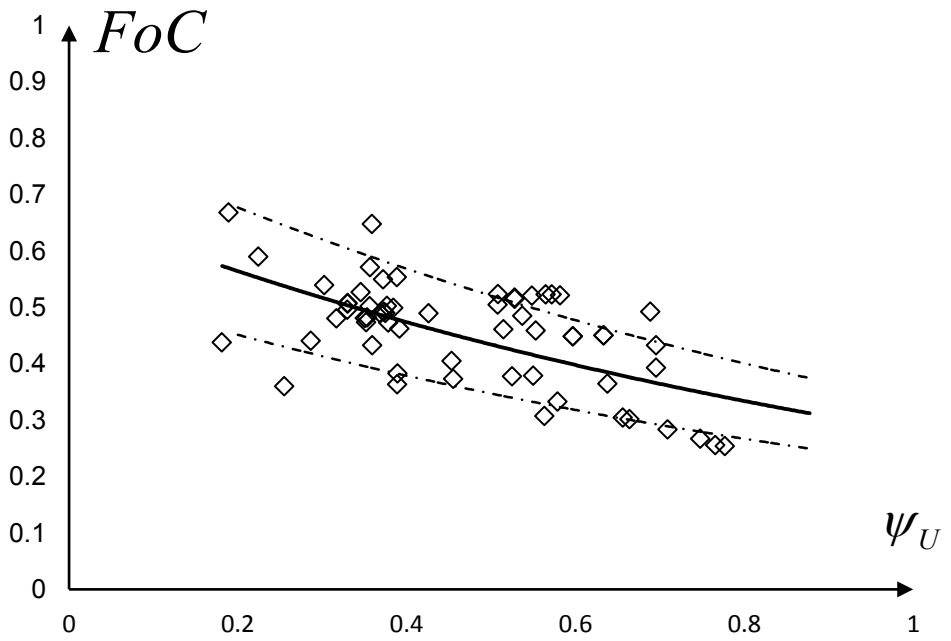
thus net output power is

$$\dot{W} = \dot{Q}_{CA} \cdot \psi_U \cdot \eta_{c,Il} \cdot FoC$$



Öhman & Lundqvist 2014

Normative Reference, empirical non-biased



Real unit performance + marketing data

Nominal power range: 0.2kW to 5MW

Source temperature range: 300˚C to 61.5˚C

Different cycles and fluids

Conclusions

ORC industry and academy needs improved terms of merit

Semi-empirical data can provide such terms of merit

We propose FoC based on $\eta_{c,II}$ as term of merit for efficiency of ORC power generators

We propose development of non-biased Normative References for more effective regulation and technological advancement

Future work

Increase reference database with measured data

Introduce Non-biased Normative References to regulatory bodies

Sub-divide Normative References to application niches for improved accuracy

Thank you!

Please send your makro-data on real ORC units to:

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