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System and Component Modelling for an Efficient 10kWe ORC Utilising a Turbo-Expander

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Introduction

Small-scale (10kWe) low temperature ORC systems have not been explored within the literature, but present a significant research opportunity. For these systems it's important to optimise the complete cycle in terms of the thermodynamics and individual component behaviour. For the expander an efficient, well-designed radial turbo-expander is the most suitable choice to bridge an observed gap between scroll- and screw expander based cycles, despite high costs concerned with high speed generators or high speed reduction gearboxes.

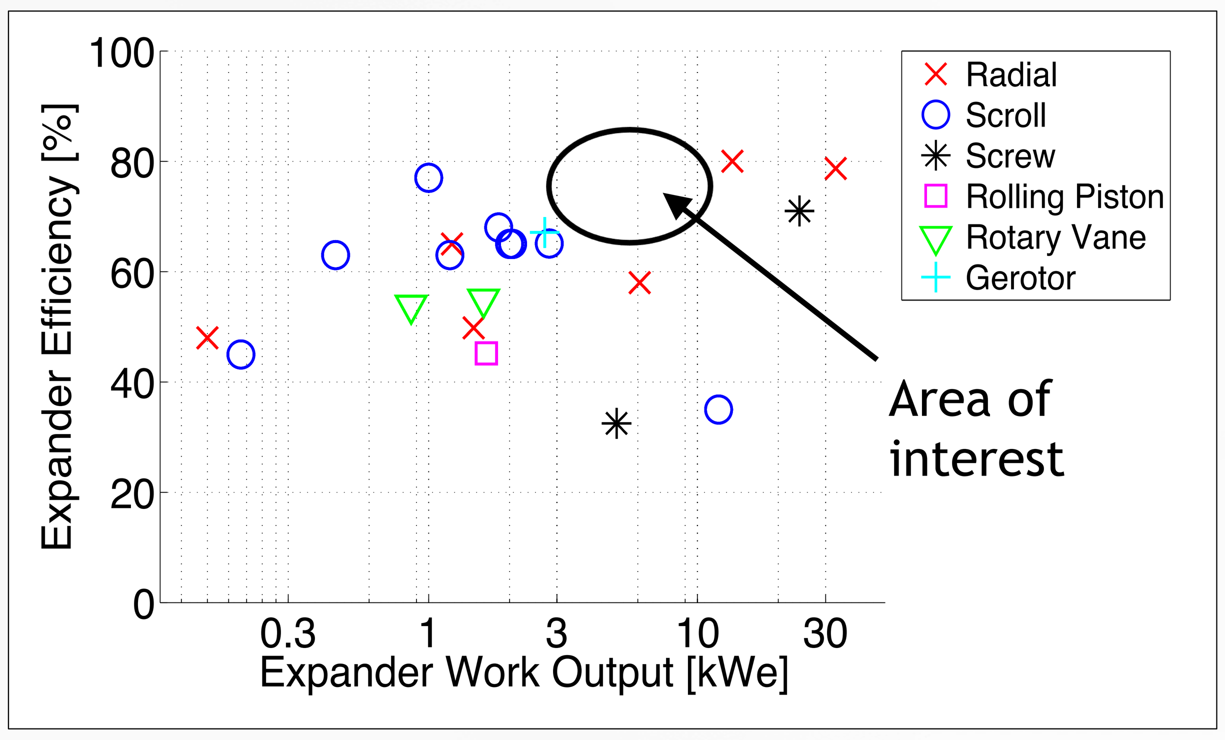

Figure 1 - Review of Experimental ORC Studies

System Modelling

- Steady state system analysis tool developed
- REFPROP utilised for real fluid properties
- Modular structure with separate sizing and optimisation models
- LMTD heat exchanger models with pressure drop design checks
- Radial expander sizing model using specific speed - specific diameter
- Digitised expander and pump characteristics for design and off-design characteristics

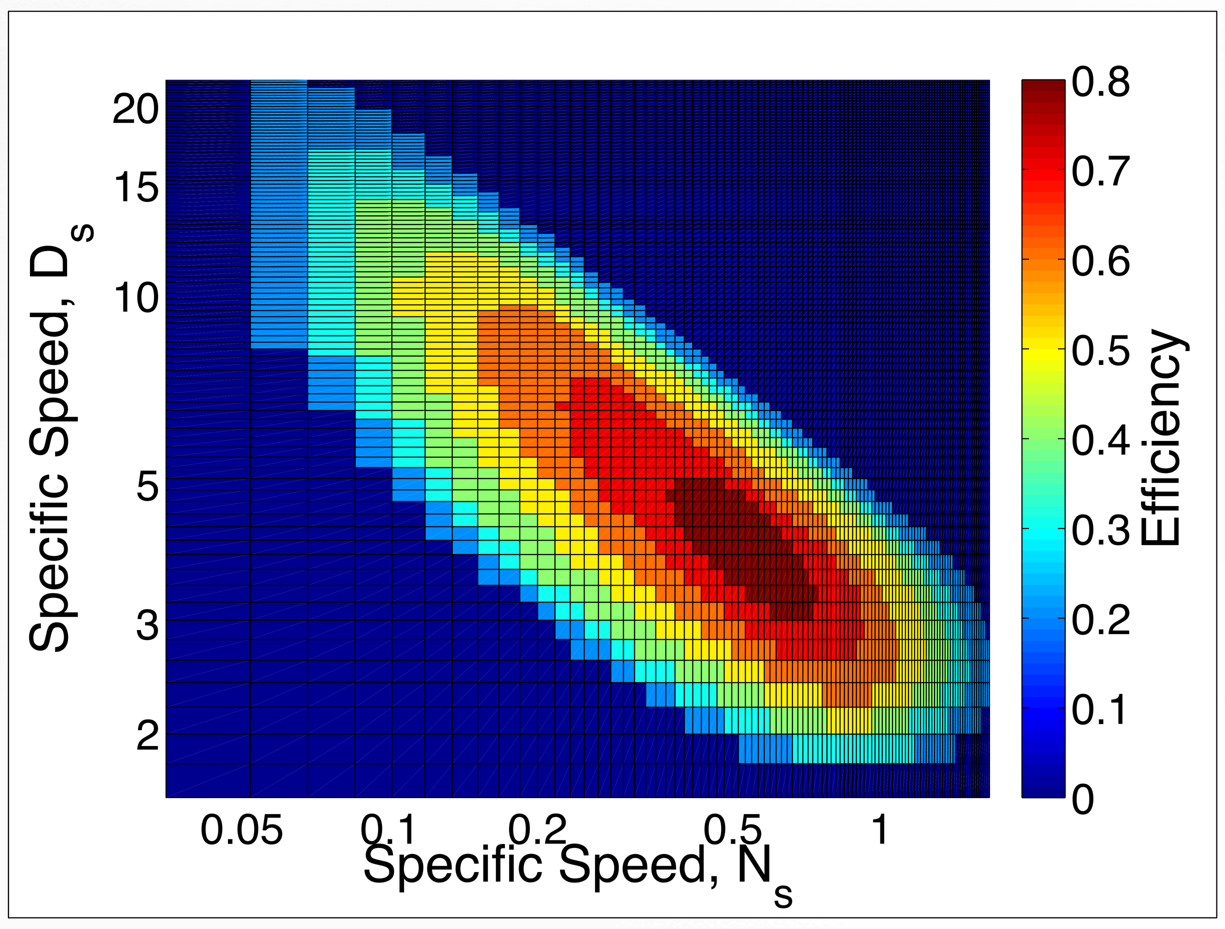

Figure 2 - Digitised Specific Speed - Specific Diameter Efficiency Contour

Optimisation

- MINUIT optimiser used for multi-objective minimisation of defined objective functions
- Cycle optimisation for a known set of components requires a maximum return on investment, and therefore maximum power production
- Sizing optimisation requires a trade-off between performance and complexity
- Objectives for multi-objective function ranked using a binary matrix
- Reference factors required for objective scaling

$$\min f(\mathbf{x}) = a_1 \left[\frac{W_{\mathrm{n,ref}}}{W_{\mathrm{n}}}\right] + a_2 \left[\frac{A_{\mathrm{e}}}{A_{\mathrm{e,ref}}}\right] \cdots + a_3 \left[\frac{A_{\mathrm{c}}}{A_{\mathrm{c,ref}}}\right] + a_4 \left[\frac{N}{N_{\mathrm{ref}}}\right]$$

	Net Work	Rotational speed	Evaporator area	Condenser area	Σ 1's	Normalised	Importance factor
Net Work	X	1	1	1	3	4	0.4
Rotational speed	0	X	0	0	0	1	0.1
Evaporator area	0	1	X	1	2	3	0.3
Condenser area	0	1	0	X	1	2	0.2
				TOTAL		10	1

Results & Discussion

- Optimal working fluid with the lowest objective function value is R11
- Thermodynamic results suggest that the optimisation is driven by favorable component design aspects such as heat transfer area, and expander rotational speed
- Condensation pressure needs to be considered as it impacts the complexity of the system
- Despite R11 having the lowest objective function it is important to consider environmental properties, availability, safety and impact on system design, which can point towards alternative optimal fluids
- Selection of a suitable working fluid can facilitate a larger diameter, reducing rotational speed and therefore reducing system complexity
- R245fa found to be a good compromise between performance, availability and safety, hence confirming its suitability for low temperature applications and has been selected for a planned experimental test rig
- A more detailed 1D through-flow model will result in a more detailed rotor design which will be matched to a commercially available turbocharger shaft to reduce costs

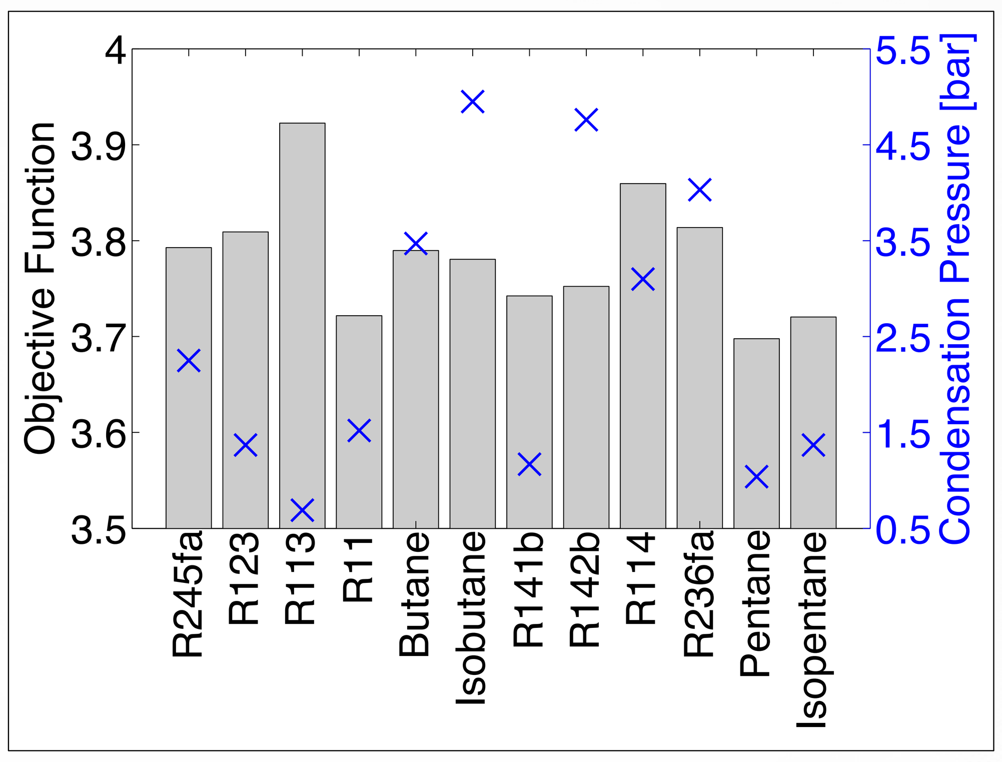

Figure 3 - Objective Function Output from Optimisation Study

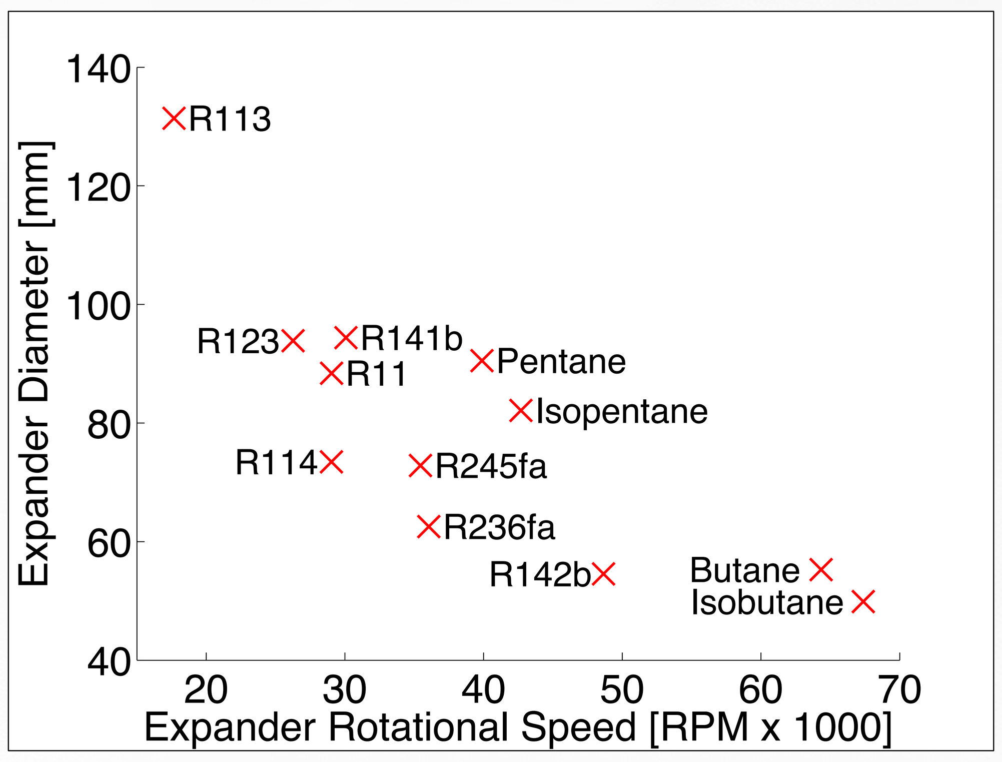

Figure 4 - Expander Design Output from Optimisation Study

Future Work

- Development of 1D through-flow radial expander rotor and stator design model
- Sourcing and construction of turbocharger shaft and test rig
- Experimental expander characterisation and model validation

References

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[2] - Kang, S.H., 2012. Design and experimental study of ORC (organic Rankine cycle) and radial turbine using R245fa working fluid. *Energy*, 41(1), pp.514-524

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