EVALUATION OF HEAT TRANSFER CORRELATIONS FOR FLOW CONDENSATION IN PLATE HEAT EXCHANGERS AND THEIR IMPACT ON THE DESIGN OF ORGANIC RANKINE CYCLE SYSTEMS

Ji Zhang*, Enrico Baldasso, Roberta Mancini, Brian Elmegaard, Fredrik Haglind

***Technical University of Denmark, jizhang@mek.dtu.dk**

Presenter: Nishith Babubhai Desai (Technical University of Denmark, nbdes@mek.dtu.dk)

1. Introduction

Main goals of the paper:

- Evaluate the predictive performances of existing condensation heat transfer correlations – experimental analysis

- Evaluate the impact of using different condensation heat transfer correlations on ORC design – numerical simulation

1. Introduction

In order to achieve the goals, the following tasks has been accomplished:

1. Obtain a dataset of experimental data

2. Compare the experimental and predicted values

3. Evaluate the required heat transfer area for the condenser

4. Evaluate the attainable power output from an ORC unit

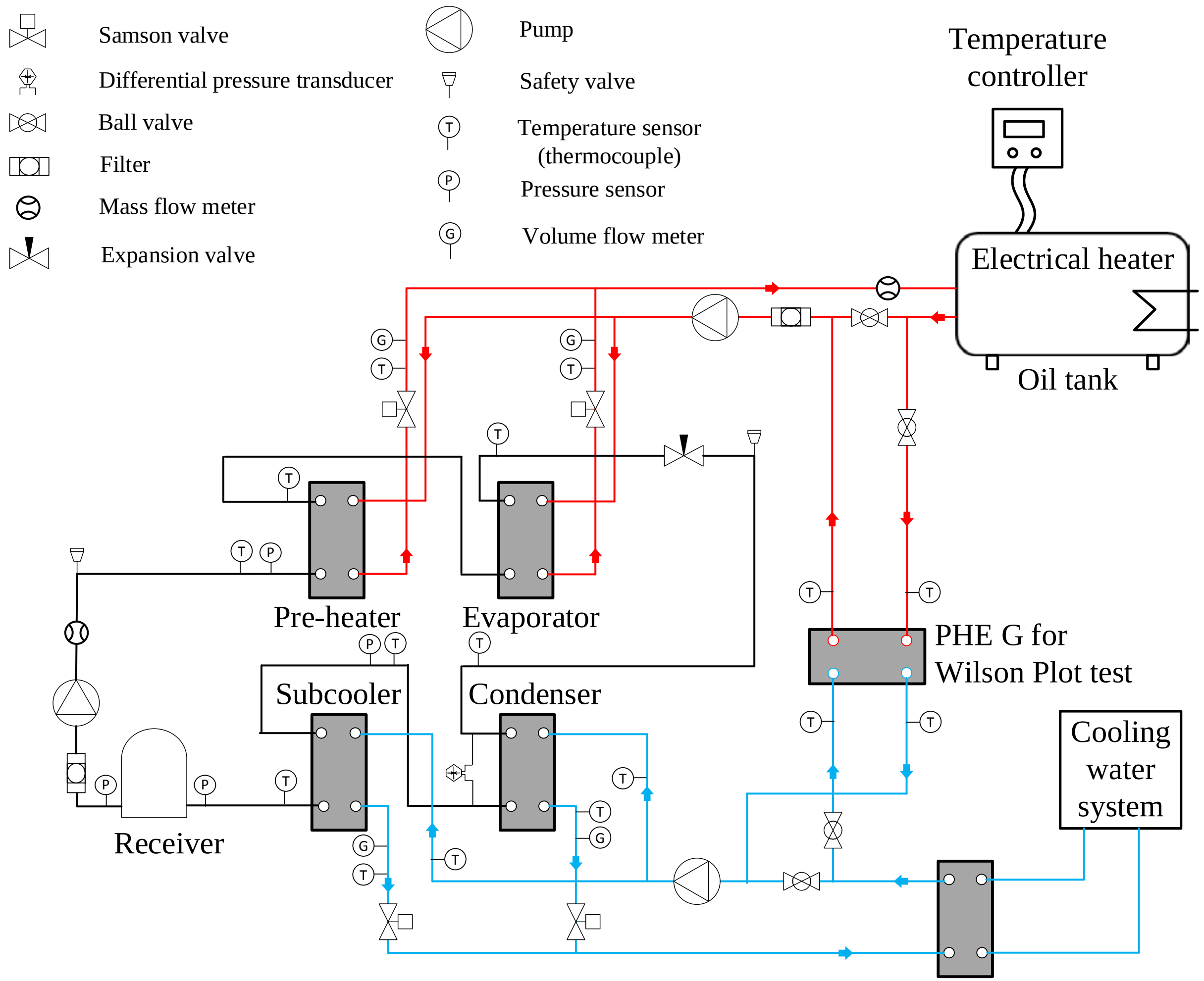
1. Introduction

Five alternative condensation heat transfer correlations:

- Yan et al. (1999)
- Han et al. (2003)
- Kuo et al. (2005)
- Longo et al. (2015)
- Zhang et al. (2019)

2. Methods - Experimentation

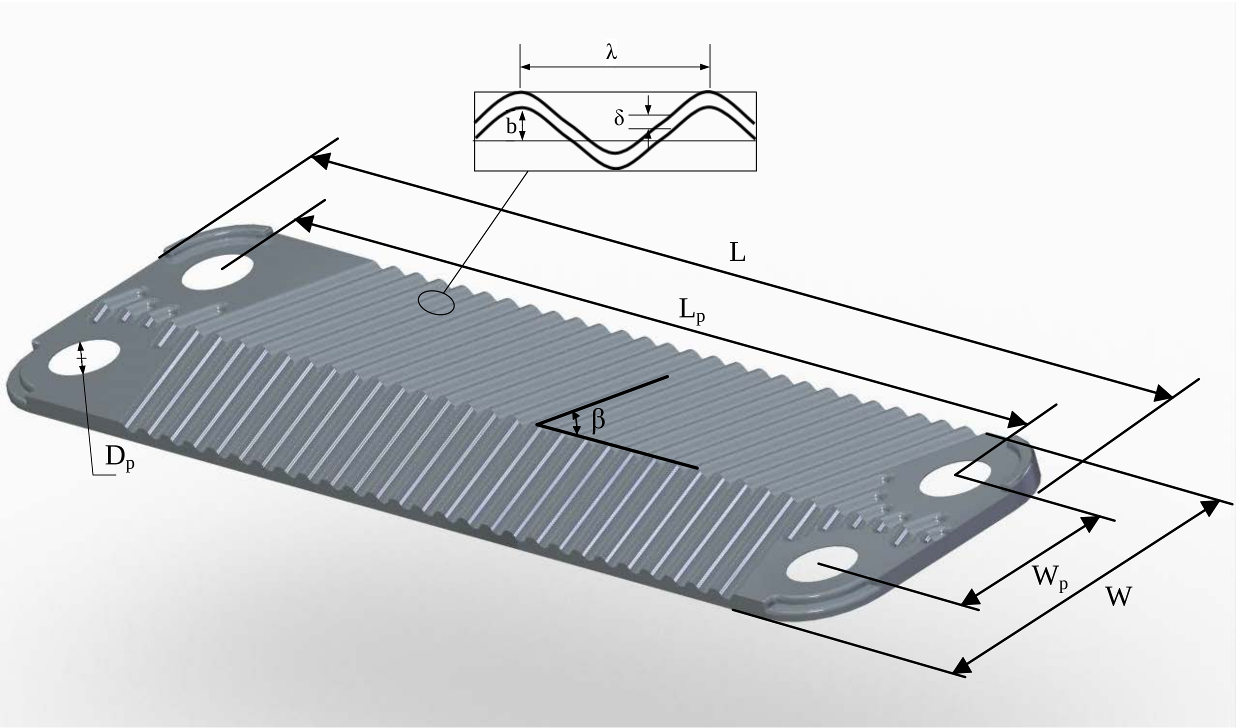
Test facilities



2. Methods - Experimentation

Geometry of PHE:

Parameters	Values
Length L (mm)	317
Width W (mm)	76
Port-to-port length L_p (mm)	278
Port-to-port width W_p (mm)	40
Diameter of inlet/outlet port D_p (mm)	36
Chevron angle β (°)	65
Corrugation pitch λ (mm)	7
Amplitude of corrugation b (mm)	1
Hydraulic diameter D_h (mm)	3.4



2. Methods - Experimentation

Working conditions :

- Working fluids: R134a, R236fa, R245fa, R1234ze(E), R1233zd(E), propane and isobutane
- Saturation temperatures: 30, 40 and 50 ºC
- Inlet of condenser: superheat degree within 5 K
- Outlet of condenser: vapor quality between 0 and 0.05.
- Mass fluxes:12–83 kg/m^2s

2. Methods - Simulation framework

1. A waste heat recovery case study (Haglind et al., 2017)

Heat source		**Heat sink**	
Inlet temperature (ºC)	85	Inlet temperature (ºC)	18.5
Mass flow rate (kg/s)	35	Mass flow rate (kg/s)	35
ORC unit		**PHE condenser**	
Working fluid	R245fa	Port diameter (plate width < 0.25) (m)	0.015
Condenser sub-cooling (ºC)	6.5	Port diameter (plate width ≥ 0.25) (m)	0.05
Turbine isentropic efficiency	0.91	Chevron angle (º)	25
Pump isentropic efficiency	0.3	Thermal conductivity (W/m·K)	16.2
Generator efficiency	0.98	Corrugation thickness (m)	0.0005

2. Methods - Simulation framework

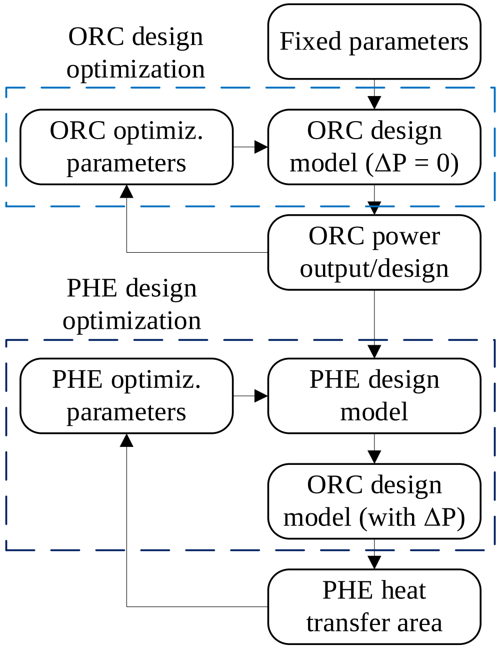
2. Simulation framework including models for the ORC unit and the PHE condenser

- PHE models: one-dimensional PHE models discretized along the flow direction (Mancini et al., 2018 and Mancini et al., 2019a)

- ORC models: a zero-dimensional model previously described and validated in Andreasen et al. (2014)

2. Methods - Simulation framework

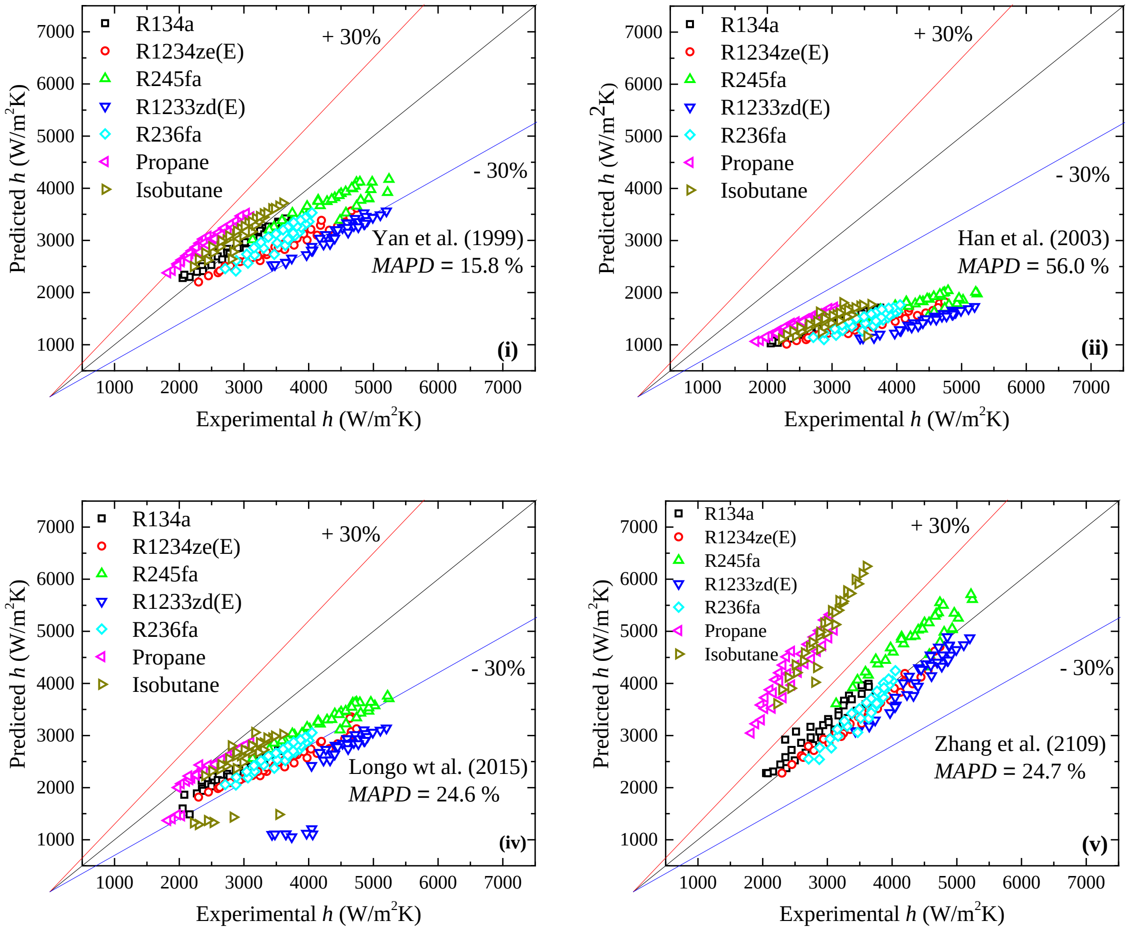
3. Optimization of PHE design: Estimate the impact of using different heat transfer correlations on condenser design



A sketch of the two-step optimization procedure

4. ORC off-design performance: Assess the impact of using different heat transfer correlations on ORC performance

3. Results - Predictive performance evaluation



Mean absolute percentage deviation:

$$\text{MAPD} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{data_{i,pred}-data_{i,exp}}{data_{i,exp}}\right| \times 100\%$$

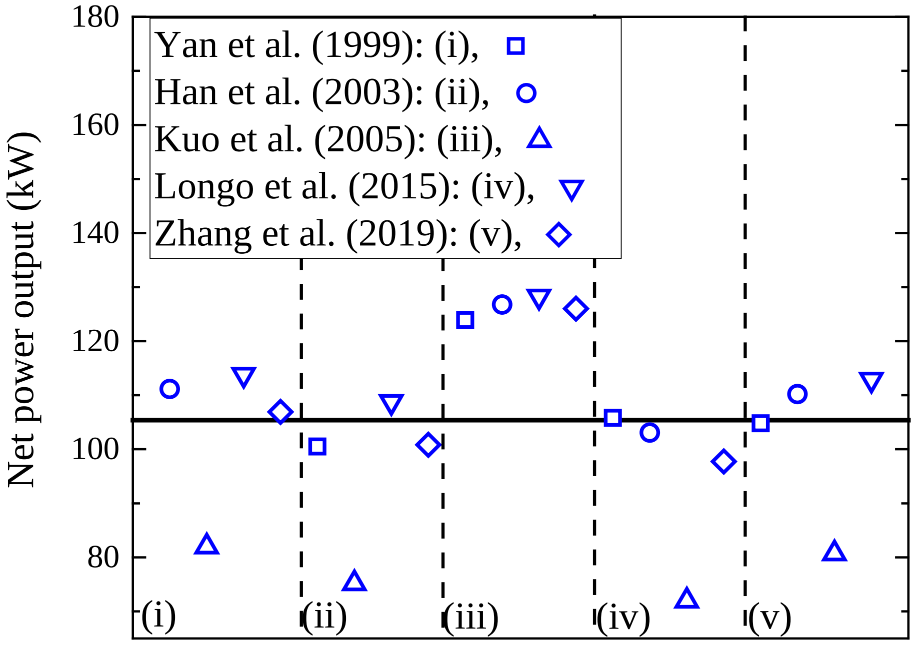
The Yan et al. (1999) and Longo et al. (2015) correlations provide the best and second best predictions with the MAPDs of 15.8 % and 24.6 %, respectively.

3. Results - Condenser and ORC design

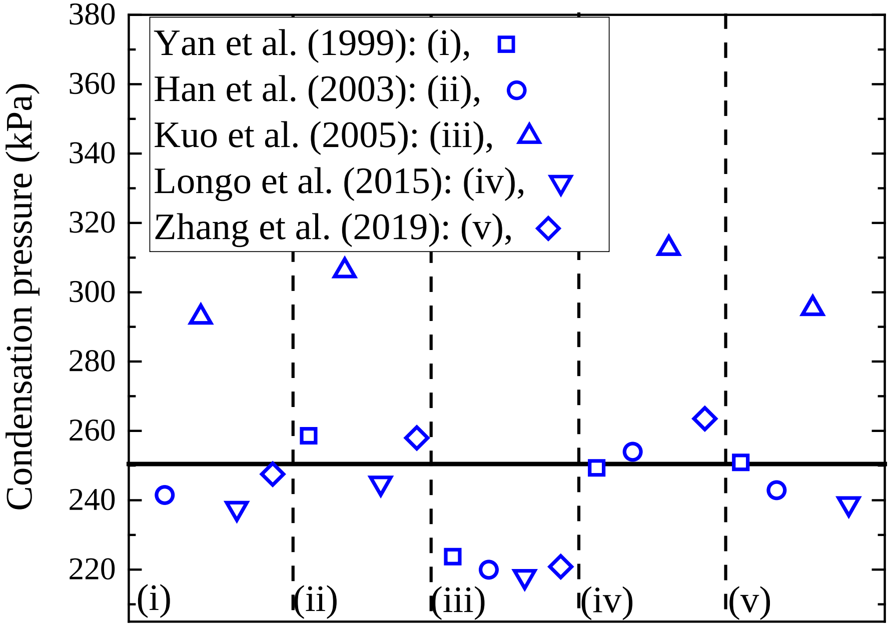
Required heat transfer area for the condenser:

Correlation	Yan et al. (1999)	Han et al. (2003)	Kuo et al. (2005)	Longo et al. (2015)	Zhang et al. (2019)
A_{tot} (m^2)	85.4	78.4	132	75.8	83.8
$A_{desuperheater}$ (m^2)	13.11	13.26	12.59	13.36	13.11
$A_{subcooler}$ (m^2)	3.95	4.01	1.96	4.05	3.95
$A_{condensation}$ (m^2)	68.29	61.09	117.06	58.39	66.73
Plate width (m)	0.35	0.34	0.40	0.34	0.34
Plate length (m)	0.53	0.51	0.70	0.50	0.52
Length/width	1.5	1.5	1.8	1.5	1.5
Number of channels	200	200	200	200	200
Chevron angle	35	35	35	35	35
Pressure drop of working fluid (kPa)	19.2	17.3	29.4	16.2	18.3
Inlet velocity of working fluid (m/s)	4.0	4.0	4.0	4.0	4.0
Pressure drop of sink (kPa)	10.4	9.77	14.7	9.58	10.2
Inlet velocity of sink (m/s)	0.21	0.21	0.21	0.21	0.21
$\dot{W}_{net}$ (kW)	105.0	105.0	104.7	105.0	105.0

3. Results - Condenser and ORC design



Impact on net power output



Impact on condensation pressure

Conclusions

- Based on the 237 data points, the results suggest that the Yan et al. (1999) correlation shows best prediction with a mean absolute percentage deviation of 15.8 %.

- The use of alternative heat transfer correlations affected both
  i) the estimated condenser heat transfer area varying between 75.8 m^2 and 132 m^2
  ii) the predicted ORC power output varying between -7.2 % and +8 % compared to the target design value

Reference

Yan, Y.-Y., Lio, H.-C., Lin, T.-F., 1999. Condensation heat transfer and pressure drop of refrigerant R-134a in a plate heat exchanger. Int. J. Heat Mass Transf. 42, 993–1006.

Han, D.H., Lee, K.J., Kim, Y.H., 2003. The characteristics of condensation brazed plate heat exchangers with different chevron angles. J. Korean Phys. Soc. 43, 66–73.

Kuo, W.S., Lie, Y.M., Hsieh, Y.Y., Lin, T.F., 2005. Condensation heat transfer and pressure drop of refrigerant R-410A flow in a vertical plate heat exchanger. Int. J. Heat Mass Transf. 48, 5205–5220.

Longo, G.A., Righetti, G., Zilio, C., 2015. International Journal of Heat and Mass Transfer A new computational procedure for refrigerant condensation inside herringbone-type Brazed Plate Heat Exchangers. Int. J. Heat Mass Transf. 82, 530–536.

Zhang, J., Kærn, M.R., Ommen, T., Elmegaard, B., Haglind, F., 2019. Condensation heat transfer and pressure drop characteristics of R134a, R1234ze(E), R245fa and R1233zd(E) in a plate heat exchanger. Int. J. Heat Mass Transf. 128, 136–149.

Haglind, F., Mondejar, M.E., Andreasen, J.G., Pierobon, L., Meroni, A., 2017. Organic Rankine cycle unit for waste heat recovery on ships (PilotORC) - Final Report, Tech. rep. Department of Mechanical Engineering, Technical University of Denmark (DTU). Copenhagen, Denmark.

Mancini, R., Zühlsdorf, B., Kjær Jensen, J., Brix Markussen, W., Elmegaard, B., 2018. Deriving guidelines for the design of plate evaporators in heat pumps using zeotropic mixtures. Energy 156, 492–508.

Mancini, R., Zühlsdorf, B., Aute, B., Markussen, V., Elmegaard, B., 2019a. Performance of heat pumps using pure and mixed refrigerants with maldistribution effects in plate heat exchanger evaporators. Int. J. Refrig.

Andreasen, J.G., Larsen, U., Knudsen, T., Pierobon, L., Haglind, F., 2014. Selection and optimization of pure and mixed working fluids for low grade heat utilization using organic rankine cycles. Energy 73, 204–213.

Thank you for your attention!

More questions: jizhang@mek.dtu.dk