ALMA MATER STUDIORUM

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THERMODYNAMIC INVESTIGATION ON DIFFERENT ORC CONFIGURATIONS

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Abstract - aim of the work

The Organic Rankine Cycle (ORC) is an emerging technology for power generation and heat recovering from different thermal sources. The ORC adopts a simple thermodynamic concept, based on the use of organic fluids as working medium with a strong influence on the cycle performance. Common and innovative applications: biomass power plants, wasted heat recovery from industrial process and ICE flue gases, geothermal, solar desalinization and waste-to-energy power plants.

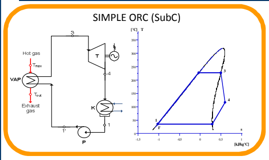
This poster represents a **PRELIMINARY NUMERICAL STUDY TO ASSESS THE RELEVANCE OF THE CYCLE LAYOUT, OF THE MAIN CYCLE PARAMETERS AND OF THE WORKING FLUID ON THE ORC PERFORMANCE.**

To improve the recovery efficiency and the net power output of the SIMPLE ORC, different cycle modifications are evaluated, such as SUPERHEATED, RECUPERATED, RIGENERATIVE , SUPERCRITICAL and THEIR COMBINATIONS.

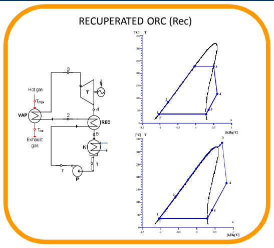
A parametric analysis has been carried out at different hot source temperatures to identify the best operating condition in terms of thermodynamic and recovery efficiency, power output and volumetric expansion ratio.

ORC thermodynamic investigation

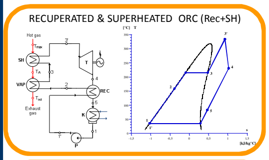
SIMPLE ORC (SubC)



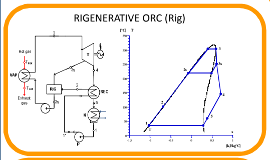
RECUPERATED ORC (Rec)



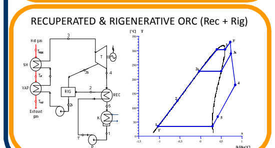
RECUPERATED & SUPERHEATED ORC (Rec+SH)



RIGENERATIVE ORC (Rig)



RECUPERATED & RIGENERATIVE ORC (Rec + Rig)



ORC CYCLE LAYOUT

Fluid	type	Tc [°C]	pc[bar]	T lim min[°C]	T lim max[°C]
MD3M	Siloxane	355.25	9.96	6.85	400
MD2M		326.25	11.79	32.85	400
MDM		290.94	14.15	-108.15	400
benzene	Aromatic	289.01	48.98	5.85	350
toluene		318.65	41.06	12.85	400
p-xylene		343.08	35.11	34.85	330
isobutane	HC	135.05	36.50	-108.15	135
isopentane		187.25	33.90	-53.15	187
butane		152.01	37.97	-91.15	400
PP2	Fluorinate	221.85	20.60	0.00	600
PP5		291.85	17.88	0.00	400
R134a	Refrigerant	101.06	40.56	-63.15	101
R245fa		154.05	36.40	-73.15	227

ORGANIC FLUIDS

ORC efficiency: $\eta = \frac{P}{Q} = \eta_O \frac{h_{3'} - h_4}{h_{3'} - h_2}$

Heat recovery factor: $\varepsilon = \frac{Q}{Q_{max}} = \frac{T_{max} - T_{out}}{T_{max} - T_{min}}$

Recovery efficiency: $\eta_{rec} = \frac{P}{Q_{max}} = \eta \cdot \varepsilon$

Turbine specific work: $W = \eta_O (h_{3'} - h_4)$

ORC power: $P = \dot{m}_{ORC} W$

Expander volumetric ratio: $VER = v_4 / v_{3'}$

Overall Perf. Index: $PI = \frac{1}{4}\left(\frac{\eta}{\eta_{max}} + \frac{\eta_{rec}}{\eta_{rec\_max}} + \frac{P}{P_{max}} + \frac{VER_{min}}{VER} \right)$

Common constraints:

$T_{3'} = T_{max} - \Delta T_{min}$

$T_3 \le T_{max} - \Delta T_{min}$

$T_k \ge T_{k\_min} = 35°C \quad or \quad p_k \ge p_{k\_min} = 0.01 bar$

Specific constraints for each layout configuration:

e.g., for SIMPLE ORC:

$p_{max} = \min(p_c ; p_{lim})$

Degrees of freedom:

evaporation temperature
&
pinch point position

THERMODYNAMIC INPUT, CONSTRAINTS DEFINITION & PERFORMANCE INDEXES

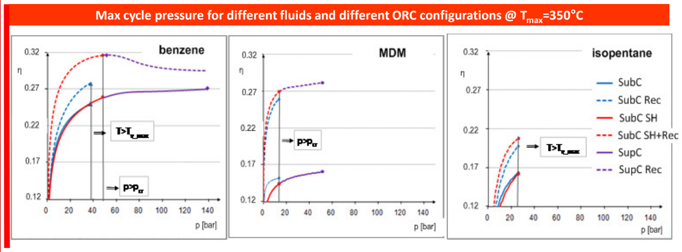
Common assumptions:

T_k [°C]	33
ΔT_{min} [°C]	50
pinch [°C]	10
T_{min} [°C]	15
m_{gas} [kg/s]	1
η_{is} [-]	0.75
ε_{rec} [-]	0.80
Δp [%]	3

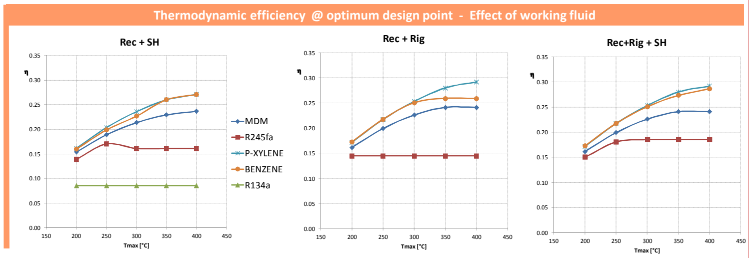
THERMODINAMIC ANALYSIS & DESIGN OPTIMIZATION (evap. Temp. & pinch) with IN HOME DEVELOPED SOFTWARE BASED ON *FluidProp Database*

Results overview

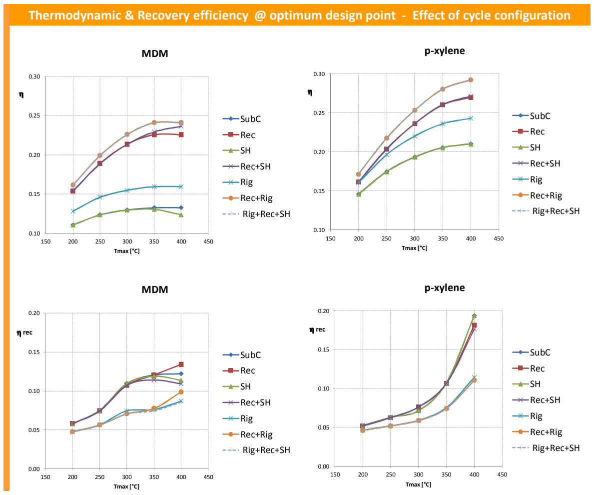
Max cycle pressure for different fluids and different ORC configurations @ T_{max}=350°C



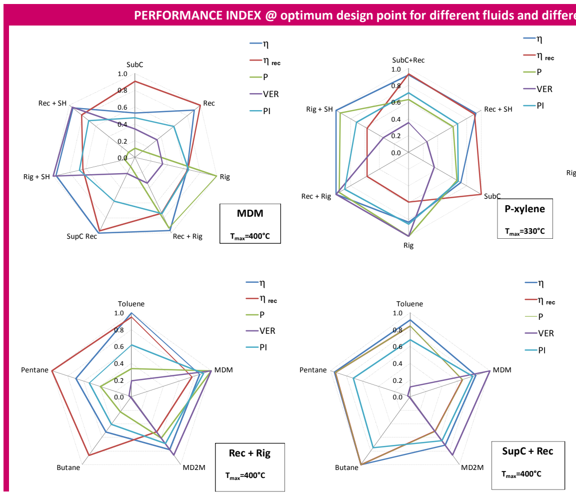
Thermodynamic efficiency @ optimum design point - Effect of working fluid



Thermodynamic & Recovery efficiency @ optimum design point - Effect of cycle configuration



PERFORMANCE INDEX @ optimum design point for different fluids and different ORC configurations



Future developments

- Investigation on potential unexploited thermal sources suitable for ORC;
- ORC application to selected cases of heat recovery from promising thermal sources;
- Overall performance index analysis.

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