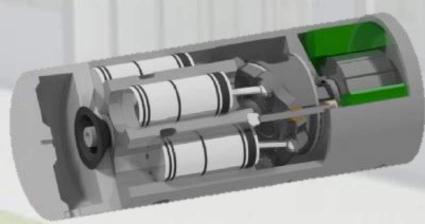
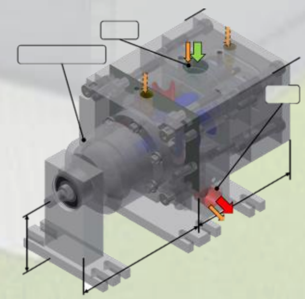
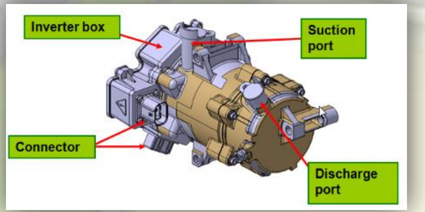
Experimental investigation of four volumetric expanders







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Introduction

State of the art

- Strong **influence of expander** on ORC performance
- (Almost) no experimental comparison of expander in litterature
- **No single technology** identified as **optimal** (cost, efficiency, compactness, working conditions..)
  - ➔3 main technologies (Scroll, Screw, Piston)

Parameter	Scroll	Piston	Screw
Displacement [l/s]	0.76-32	[1.25:75]	[25-1100]
Power [W]	[0.005-14,000] [5]	[0.001-15,000] [5]	[2,000-2e5] [5]
Max. rotational speed [RPM]	10,000 [6]	3000 (swashplate :12,000) [5]	21,000 [5]
Built-in volume ratio	[1.5-4.2] [5]	[2-14] [5]	[?-8] [7]
Maximum pressure [bar]	~40	70 [8]	-
Max. temperature [°C]	250 [8]	560 [9]	-
Two-phase flow handling	yes	low	yes
Isentropic efficiency [%]	87 [10]	70 [11]	84 [12]

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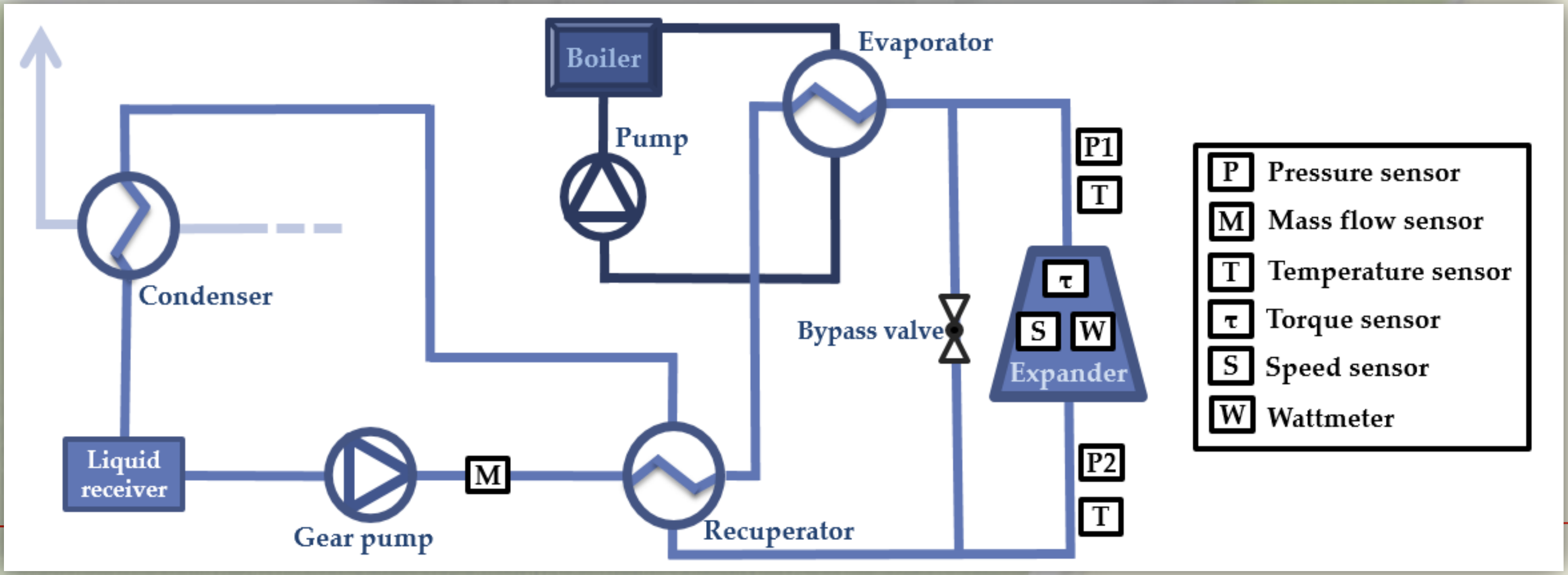
Experimental setup

Hydraulic scheme

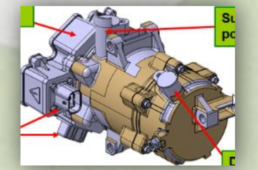
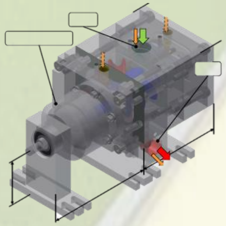
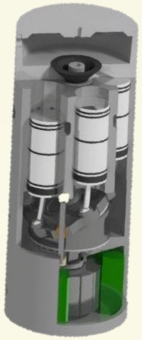
- Test-rig : **3 kWe** ORC (SUN2POWER)
- Fluid : **R245fa** and ~5% oil (but not for piston)
  - **Constant speed scroll** : Asynchronous generator connected to the grid (cst rotationnal speed)
  - **Variable speed scroll**: AC/DC convertor + variable resistor
  - **Piston** : Asynchronous generator with four quadrants variable-frequency drive
  - **Screw** : Air-cooled Eddy-current brake



Experimental setup

Expanders

Parameter	Scroll expanders (constant speed/ variable speed)		Screw expander	Piston expander
Swept volume [cm^3]	20.2	12.74	19.96	195
Volume ratio [-]	2.2	2.19	2.5	4.74
Maximum inlet temperature [°C]	140	130	140	250
Maximum inlet pressure [bar]	28	25	16	40
Rotational speed range [RPM]	3,000	[800-8,000]	20,000	[1,000-4,000]
Nominal shaft power [W]	2,277	2,000	2,000	4,000

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Experimental results

Operating conditions

- Piston → high pressure and temperature allowed
- Piston → higher shaft power
- Screw → Higher rotationnal speed
- Exhaust pressure of the expander limited by pressure drop

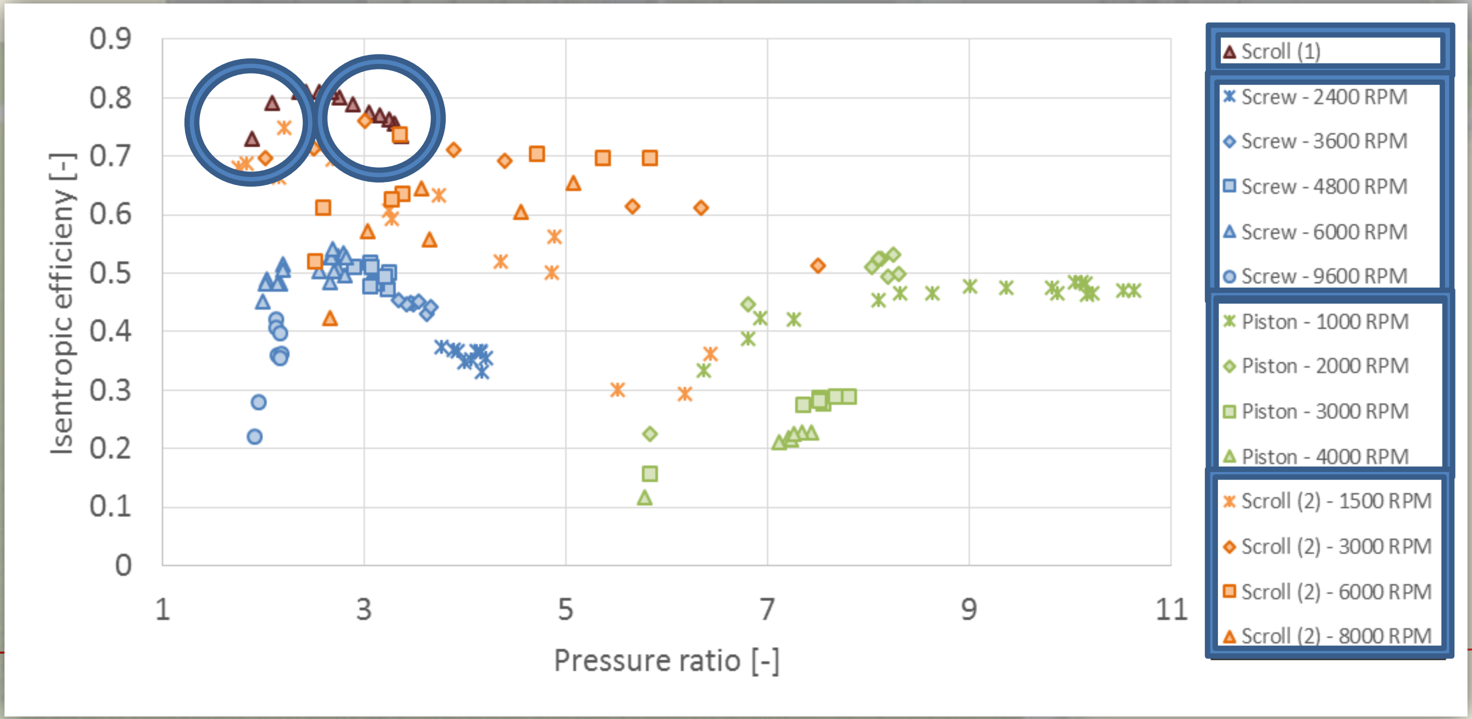
Parameter	Scroll (Copeland/Valeo)		Piston	Screw
Pressure ratio [-]	1.8-3.37	1.4-7.4	6.2-10.6	1.9-4.17
Flow [kg.s^{-1}]	0.77-0.127	0.014-0.07	0.0273-0.104	0.0290-0.137
Supply temperature [°C]	122-133	122-133	118-153	75-130
Highest shaft power [W]	1706	1544	2700	1292
Rotational speed [RPM]	3000	1137-7920	1000-4000	500-12450

Experimental results

Isentropic efficiency

$$\eta_s = \frac{\dot{W}_{sh}}{\dot{m}_r\left(h_{exp,su} - h_{exp,ex,s}\right)}$$

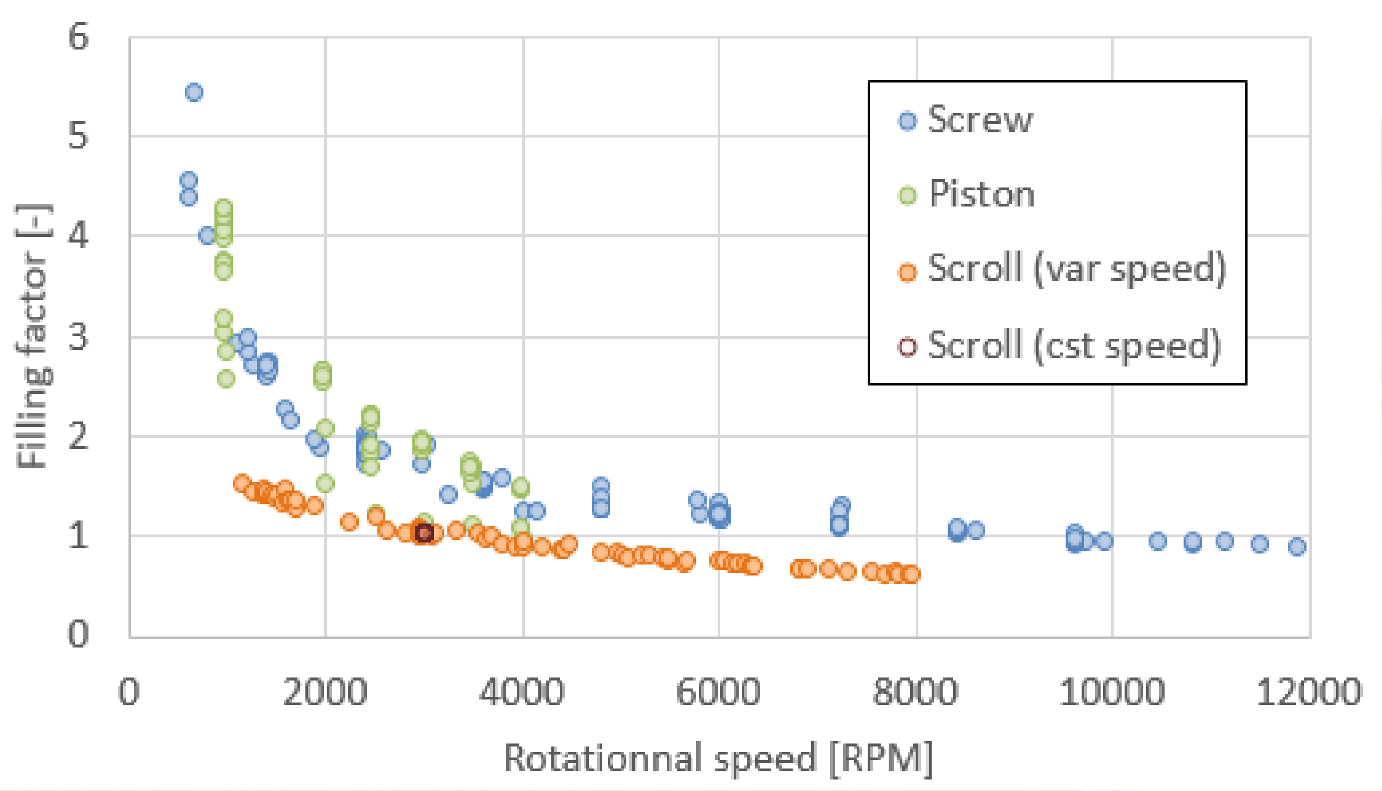
- Same trend for each technology
  - Low pressure ratio → over-expansion losses
  - High pressure ratio → under-expansion, mechanical losses and pressure drops
- Higher scroll efficiency
- Low efficiencies because of test-rig limitations (pressure drops, mass flow rate…)



Experimental results
Filling factor

- Scroll constant speed → ~Constant
- Var speed scroll, screw and piston → FF decrease with speed and increase with Rp

$$FF = \frac{\dot{V}_{meas}}{\dot{V}_{th}}$$



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Semi-empirical model

Important note

Important note

Perfectly objective comparison between different types of expanders not possible :

- Different level of maturity for expanders
- Not an expander sized for the test-rig (mass flow, pressure and temperature affect the performance of the expanders (not necessarily in the same way for each one).
- Sizing fluids for those expanders are not the one used in this ORC (R245fa).
- Nominal working conditions in terms of pressure and temperature are different for each technology (higher pressure and temperature for the piston for example).

<u>BUT:</u>

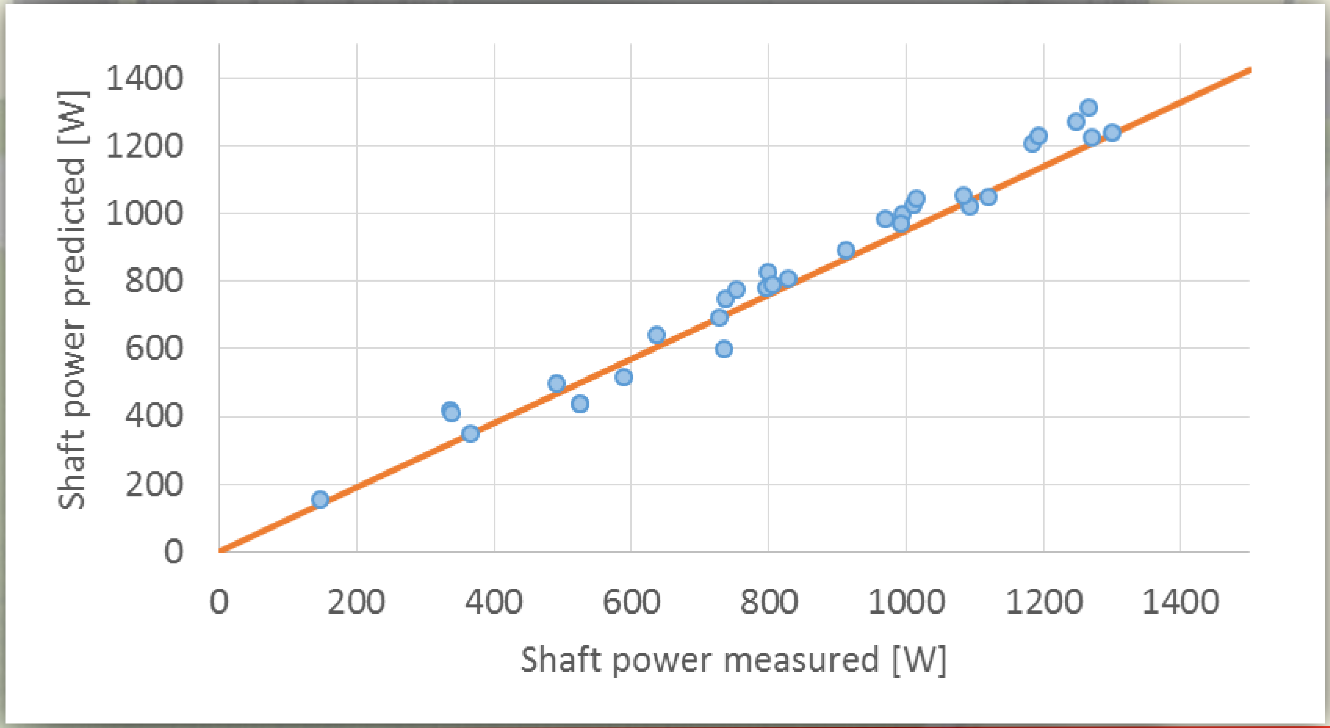
- No such a comparison in litterature
- Same test-rig and fluid
- Semi-empirical models calibrated to predict optimal performance
  - Same formalism for each technology
  - Low number of parameters
  - Fast cpu time
  - Extrapolation capabilities

Semi empirical model

Advantages

Semi-empirical model

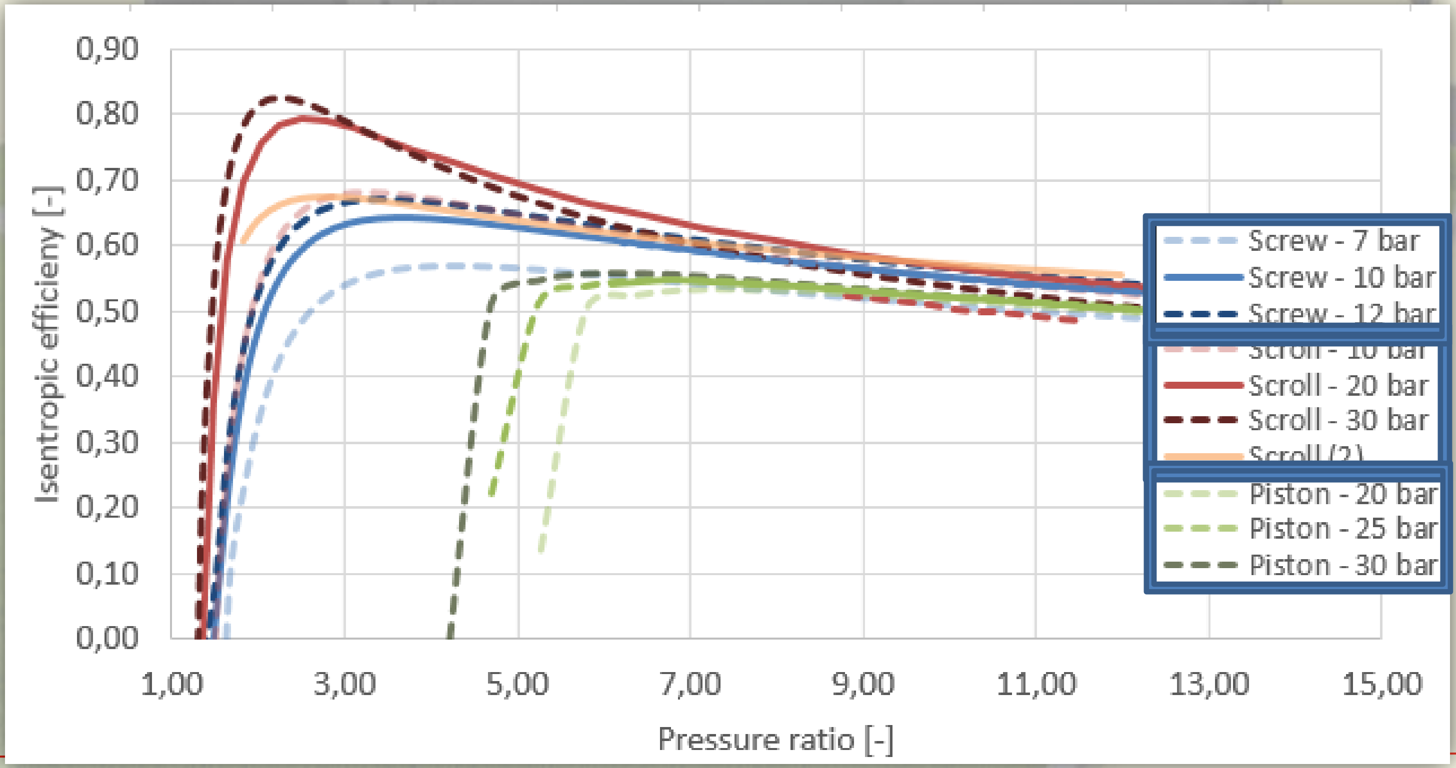
- Low CPU time + robust + extrapolation + general formalism
- Supply DP, mechanical losses, leakage, under(over)-expansion, heat transfers
- Calibration of 7 parameters based on experimentation
- Performance extrapolation with speed optimisation



Semi-empirical model

Assumptions

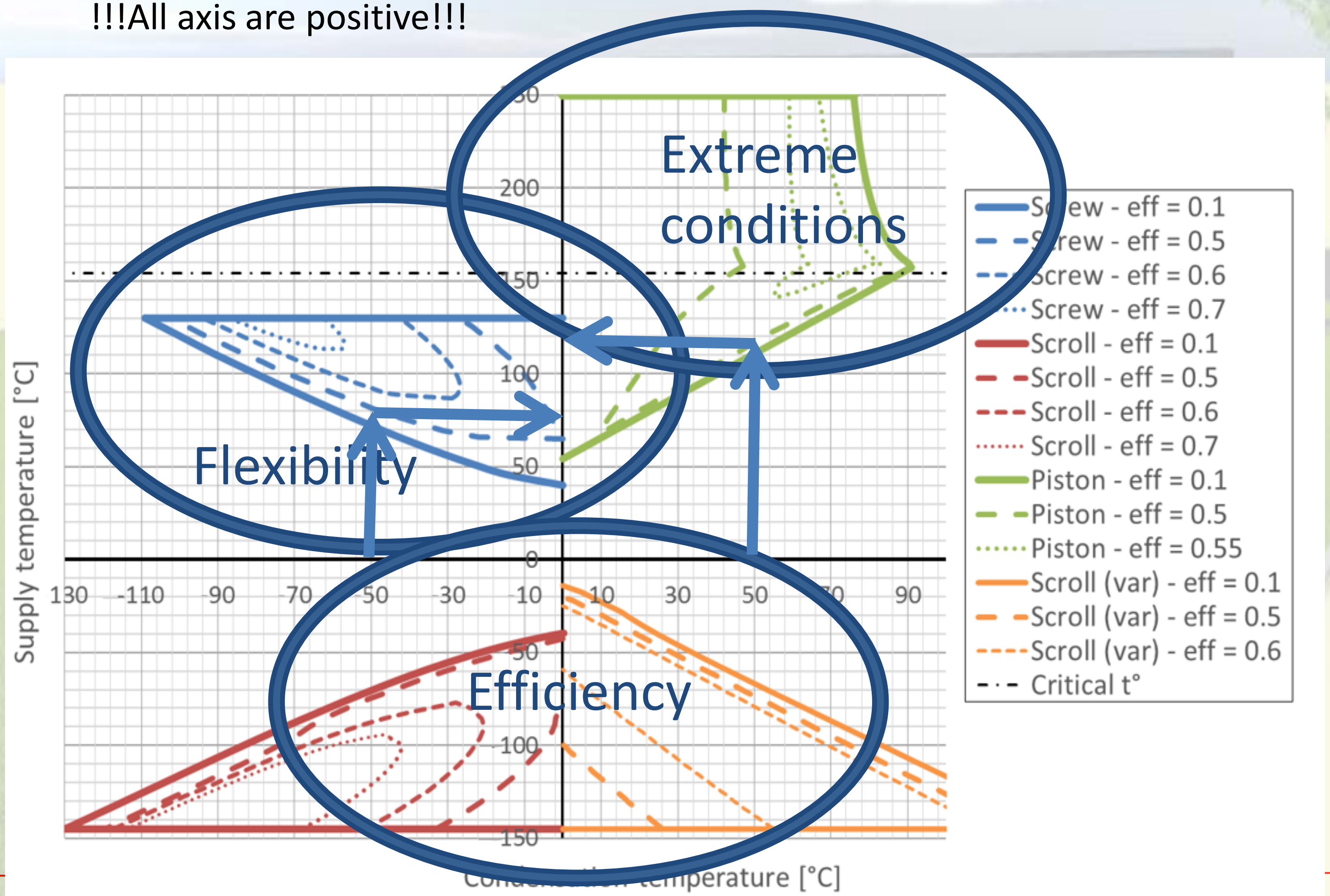
- Larger range of pressure ratio explored
- Larger efficiency for the screw
- Rather constant efficiency for the piston



Semi-empirical model

Operating maps

Optimal performance of a machine for a given condensation and evaporation temperature
!!!All axis are positive!!!



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Conclusion

	Power	High Pressure and temperature	Wet expansion	compactness	flexibility	Efficiency
Piston	<<	+	+	+	+	+
Screw	>>	-	+++	++	+++	+
Scroll	<<	-	+++	+	++	++

1. Screw expander minimum power ~10 kW → wrong!
2. Scroll expander are the best because of higher isentropic efficiency → wrong!
3. Piston expander not interesting because of low efficiency → wrong!
4. Not a single volumetric expander technology is the optimal solution!

Perspectives

- Maturity of technology
- Other technologies: Vane, Wankel, vane
- Economic considerations

Semi-empirical model

Important note

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Thank you!

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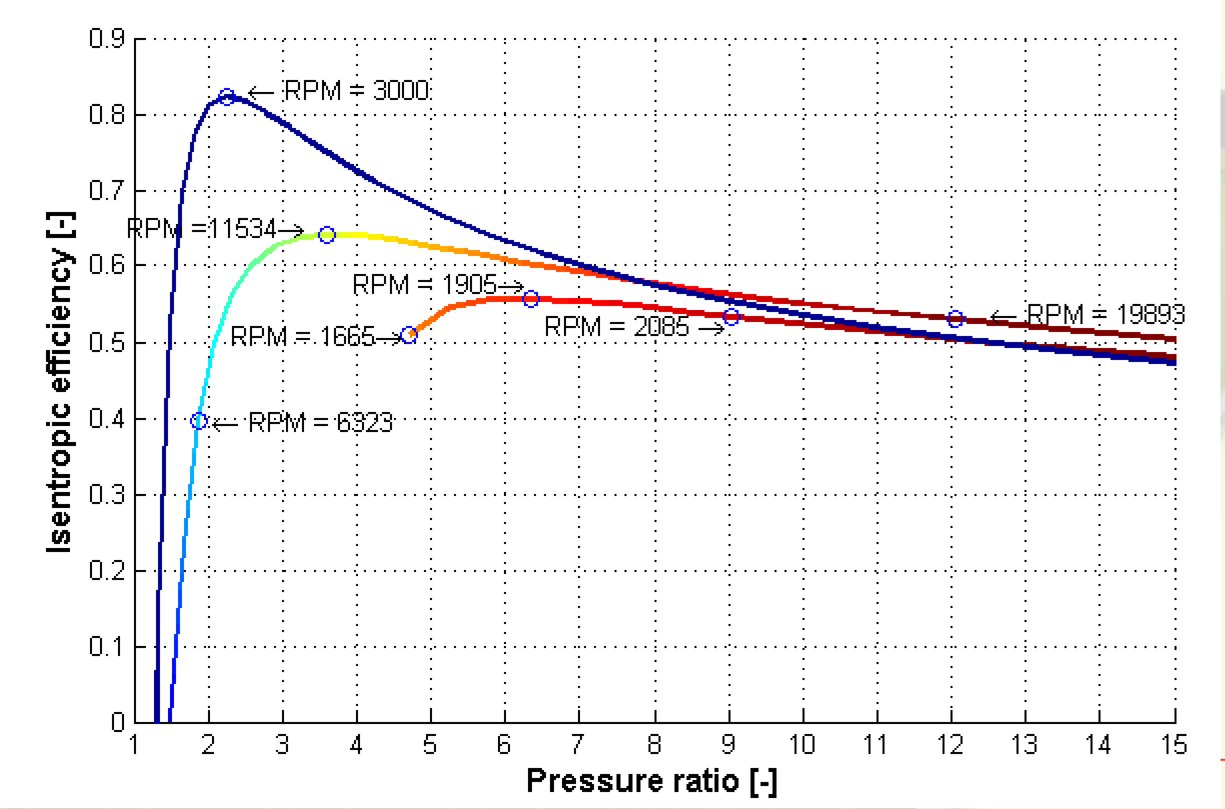
Open source papers ➔ http://orbi.ulg.ac.be

Semi-empirical models

Extrapolation

- Optimal conditions not reached on the test-rig ➔ model to extrapolate
  - Oh = 5 K (Tamb=25° C)
  - RPM optimised
  - Rp adjusted with $P_{exp,ex}$



10 bar
30 bars