



ORC technology and implementation in different geological contexts

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ENOGIA



MEET Project – Geothermal Winter School – February 2021



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Course Plan

1. Introduction
2. The story of the ORC
3. How does an ORC work?
 - a. Principle of the ORC
 - b. How to select the working fluid?
 - c. What is a regenerative cycle?
 - d. What is an expander machine?
4. How to design an ORC
5. Heat recovery in geothermal context



ENOGIA

ENOGIA designs and produces **Organic Rankine Cycle** micro-powerplants that convert **waste heat** into electrical power.

- **Innovative** company founded in **2009**
- Head office and facilities in Marseilles, France
- **35 employees**
- More than 80 references in **22 countries**
- **Fastest growth** of turnover rate amongst all French cleantechs, winner of Deloitte Technology Fast 50
- **Strategic partnership** with the famous research group
- Welcomes a **strategic shareholder** in 2018



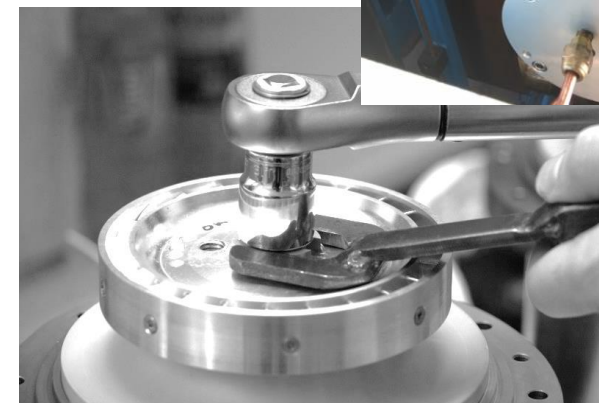
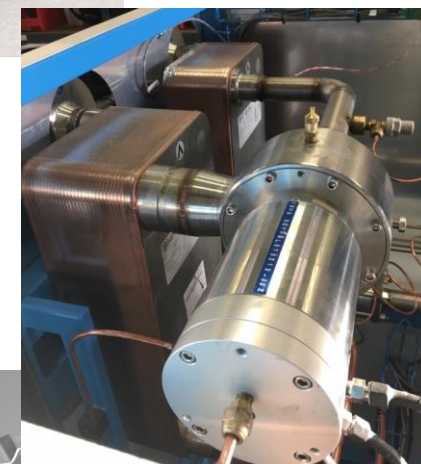
ENOGIA

ENOGIA: turbomachinery experts

- Design from scratch for custom applications:
- → blowers, pumps, turbines...
- Manufacturing and testing

Low temperature, small scale ORC specialists

- Patented high speed turbogenerator, very low footprint
- Hermetic design, no leaks
- No friction, no wear/maintenance
- From 1 to 180 kW
- From 80°C heat sources



1.Introduction

Organic Rankine Cycle systems for large-scale waste heat recovery to produce electricity. Organic Rankine Cycle

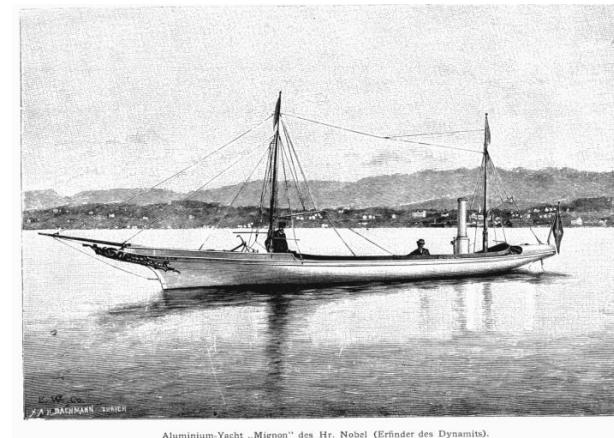
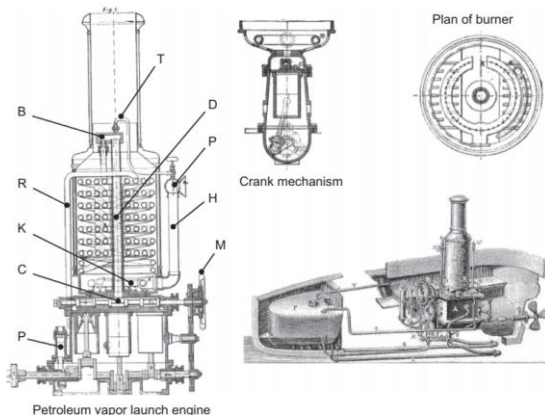
The Organic Rankine Cycles are variants of the water steam cycles, which are used when the hot source is at low or medium temperature.

Under these conditions their performance of the water steam cycles deteriorates, it becomes preferable to use other thermodynamics fluids.

These fluids are derived from organic chemistry (carbonà and can be hydrocarbons, oils, refrigerants,...

2. Story of the ORC

- 1823: Mr. Humphrey DAVY suggest the ORC cycle as an alternative to the steam engine.
- William John Macquorn RANKINE (1820-1872) was a scottish engineer and physicist who worked on thermodynamics and binary cycle theroty between 1849 and 1860
- Around 1850, Verdat DU TREMBLEY built a cascading water steam/ether engine for boats going up the Rhône and name this process « combined steam »
- In 1883, Frank OFELDT was the first to develop a Rankine engine using not water as a working fluid but naphtha

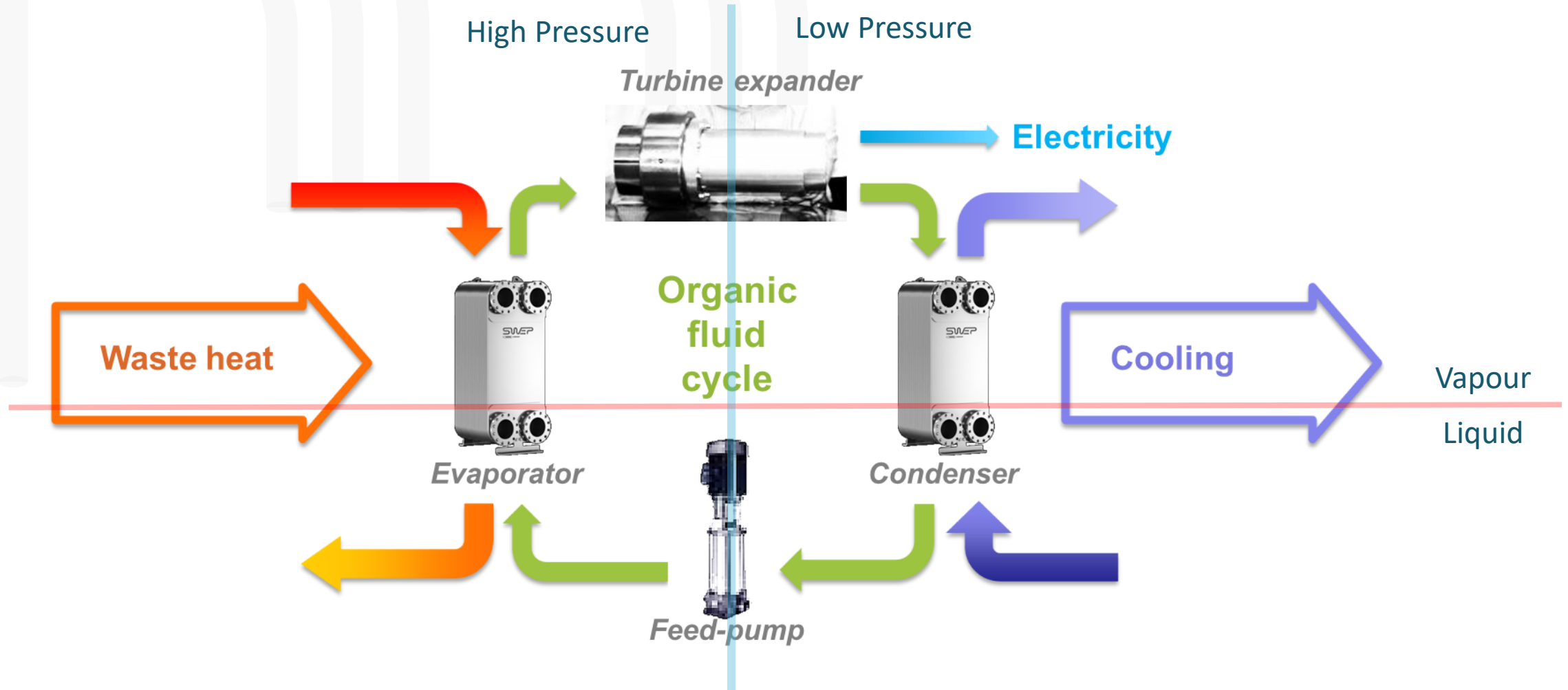


2. Story of the ORC

- In the 1950s, Israeli engineer Lucien Bronicki produced prototypes of ORCs for solar and geothermal applications. In 1965, he founded ORMAT, the current market leader ORC
- In the 1980s, the Politecnico Milano School worked on ORCs under the leadership of Prof. Angelino and Prof. Mario Gaia, who founded Turboden, the European leader
- And in France, Bertin Co. is developing a prototype ORC turbine for the Vignola power plant in Corsica in ORCs



How does an ORC work?



How does an ORC work?

Basic Thermodynamic parameters

- Temperature ($^{\circ}\text{C}$ or $^{\circ}\text{K}$)
- Pressure (Bar)
- Mass flow (Kg/s)
- Volume Flow (m^3/h)
- Specific enthalpy (KJ/Kg)
- Power (KW)
- Specific Heat Capacity (J/KgK)

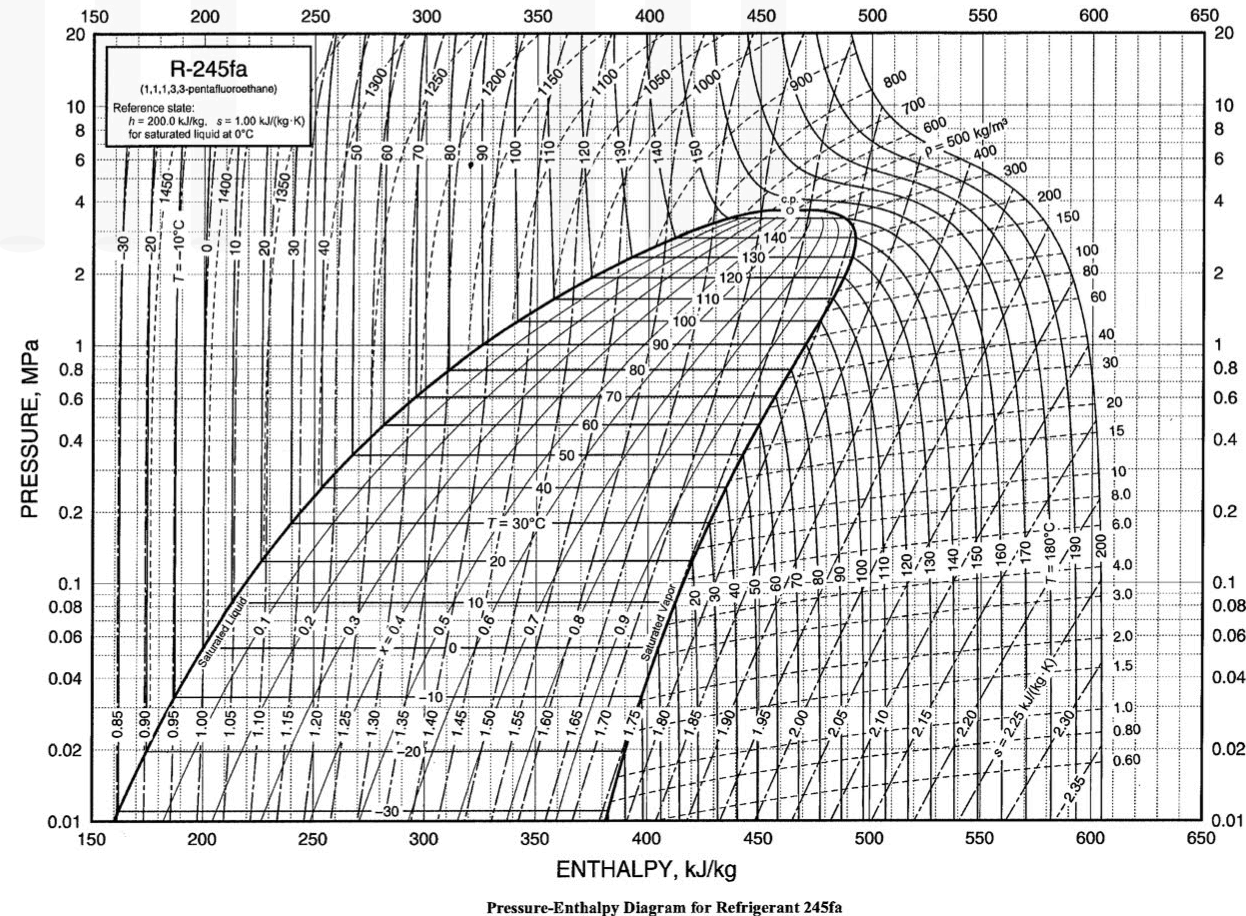
Enthalpy is a thermodynamic potential corresponds to the total energy of a thermodynamic system.

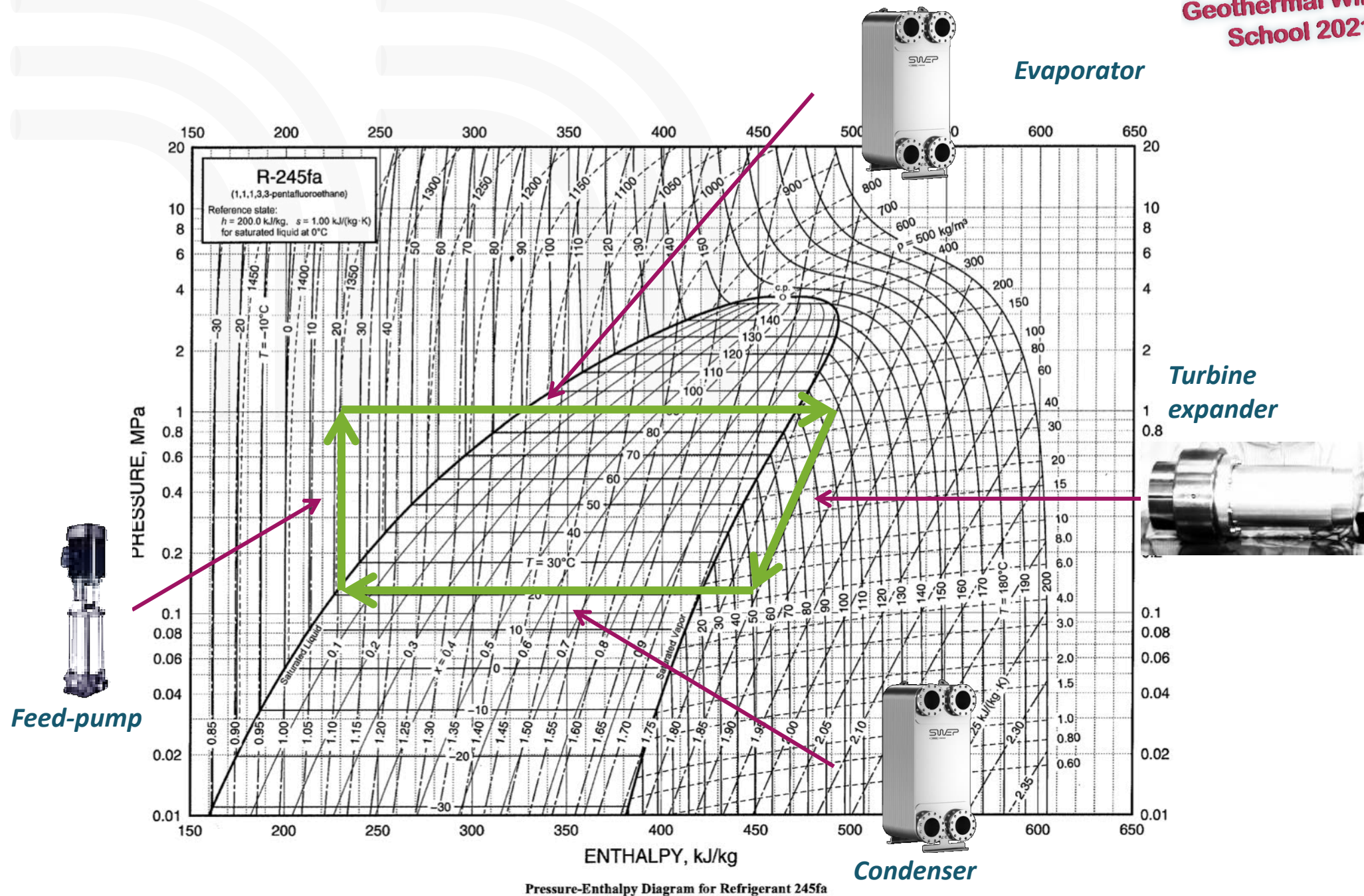
The specific enthalpy is the energy contained in 1 kg of fluid

If you multiply a specific enthalpy by a mass flow, you get a thermodynamic power

How does an ORC work?

Mollier Diagram





How does an ORC work?

Applications



Biogas, Landfill gas

- Enhancement of biogas engine via exhaust, water jacket or both
- Direct biogas to electricity conversion with boiler



Solar

- Solar CHP with CSP field
- Solar CHP with CSP and heat storage



Biomass

- Biomass to electricity
- Biomass CHP
- Isolated site



Geothermal

- Natural hot sources
- Medium temperature wells (from 80 °C)

Renewable Energies



Industrial Waste Heat Recovery

- Process Heat
- Exhaust gases
- Waste steam



Diesel genset

- Efficiency enhancement via exhaust, water jacket or both



Transportation

- Sea and River transportation
- Railroad
- Heavy Duty Trucks



Educational and research

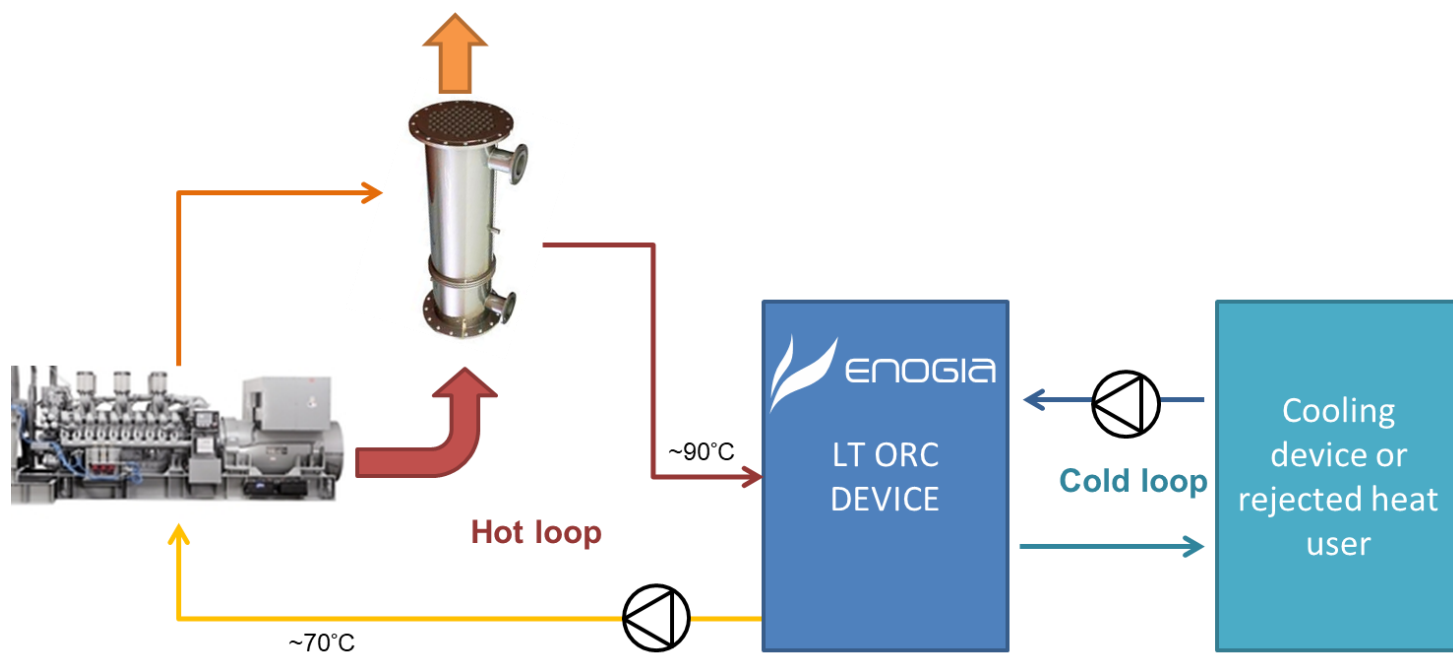
- With boiler simulating heat source

Energy Efficiency

How does an ORC work?

Applications

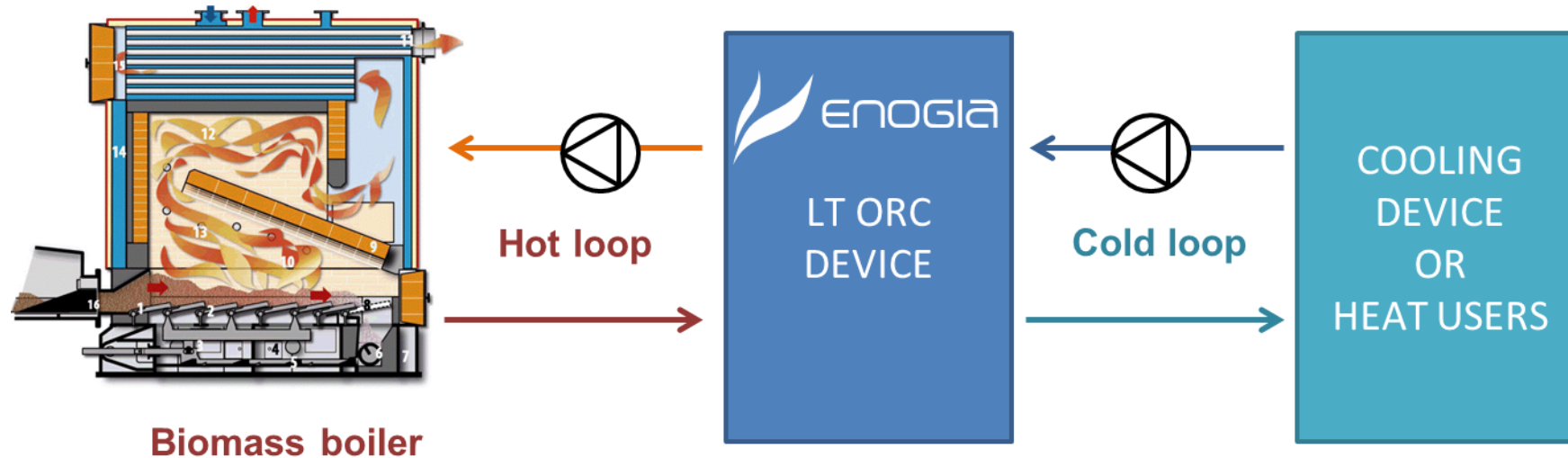
ORC is used to enhance Biogas CHP efficiency using both jacket water and exhaust heat recovery :



How does an ORC work?

Applications

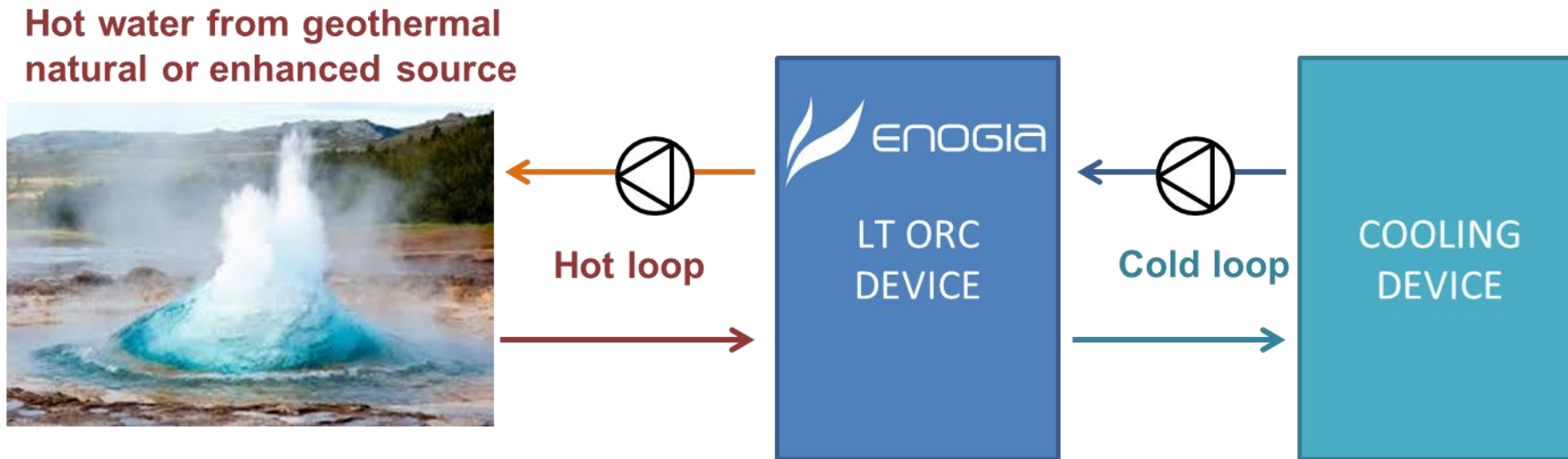
ORC is used to generate electricity from biomass boiler heat or as a bottoming cycle



How does an ORC work?

Applications

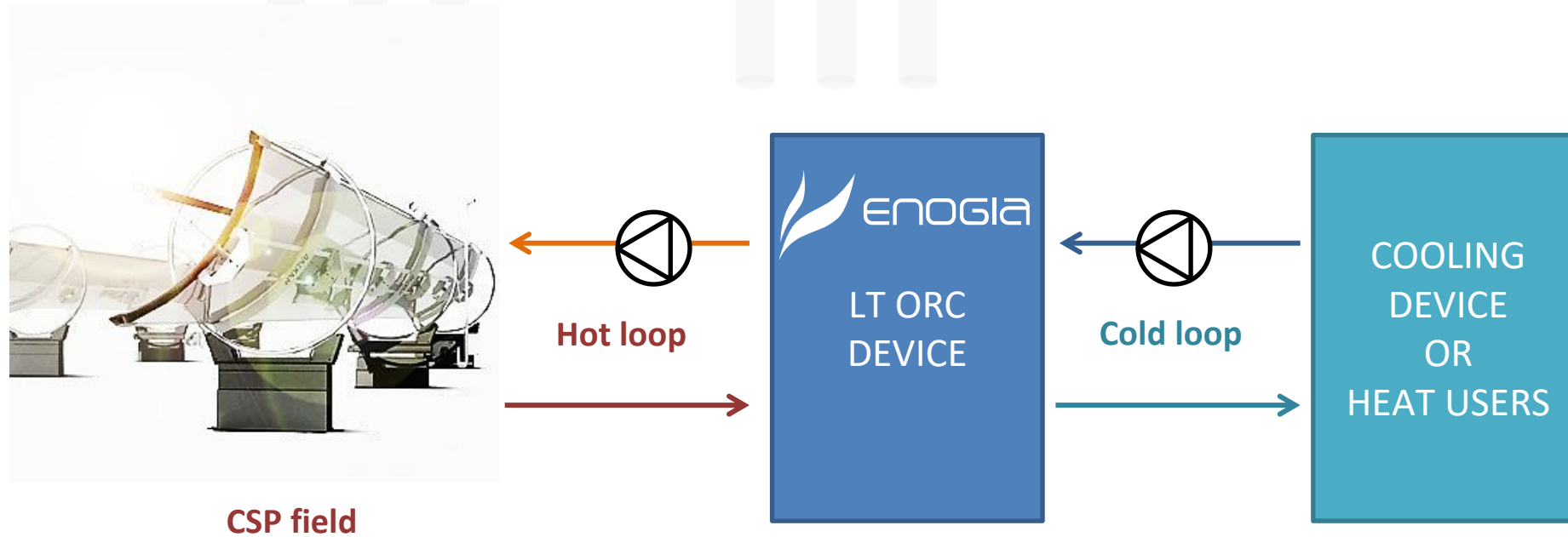
ORC is used to produce electricity from geothermal natural source or geothermal well :



How does an ORC work?

Applications

ORC is used to generate electricity from CSP field :



How to select the working fluids?

In general, four main categories of criteria can be distinguished in all classifications:

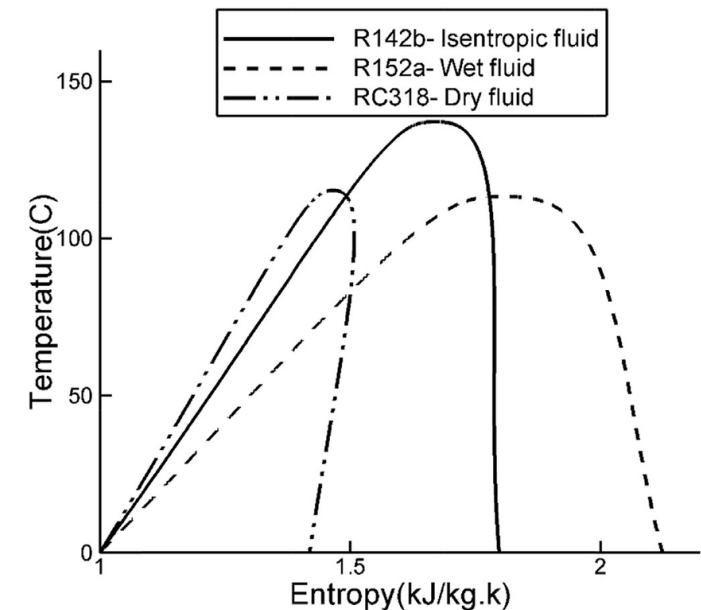
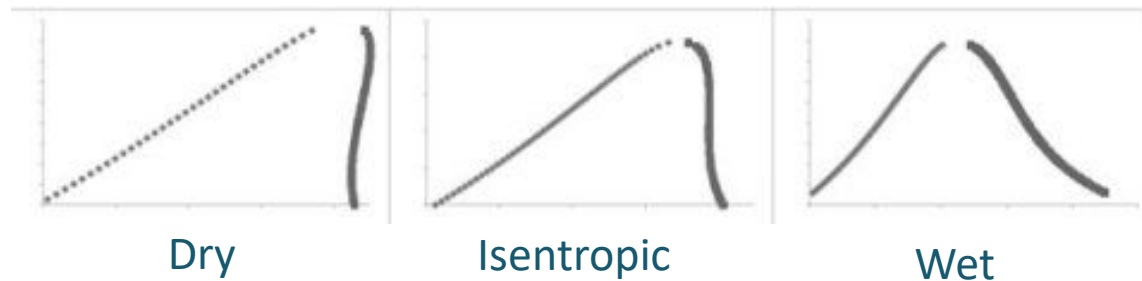
- performance criteria,
- technical and economic criteria;
- Operating limit criteria
- environmental and safety criteria

How to select the working fluids?

There are three types of fluids: dry fluids, isentropic fluids and wet fluids.

This distinction is made by the value of the slope δ on the expansion in the entropic diagram, defined by $\delta = dS/dT$ on the saturation vapor curve

- If $\delta > 0$, dry fluid;
- If $\delta = 0$, Isentropic fluid;
- If $\delta < 0$, Wet fluid;



How to select the working fluids?

Technical and economic criteria:

- Price per Kg
- Implementation

Operating limit criteria:

- Maximum temperature and pressure.
- Partial vacuum acceptable or not

Environmental and safety criteria

- GWP: Global warming potential
- ODP: Ozone Depletion Potential
- Fluid toxicity and flammability

How to select the working fluids?

Exemple

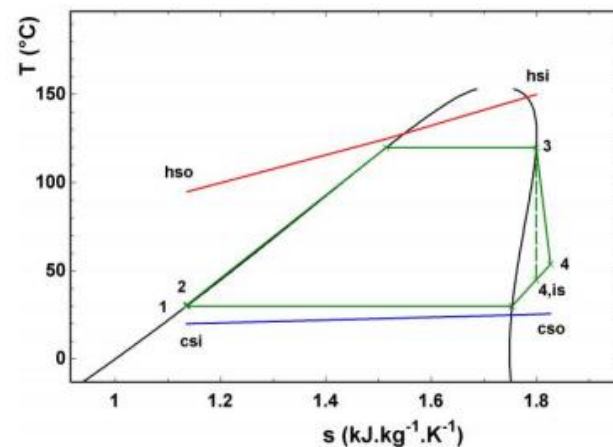
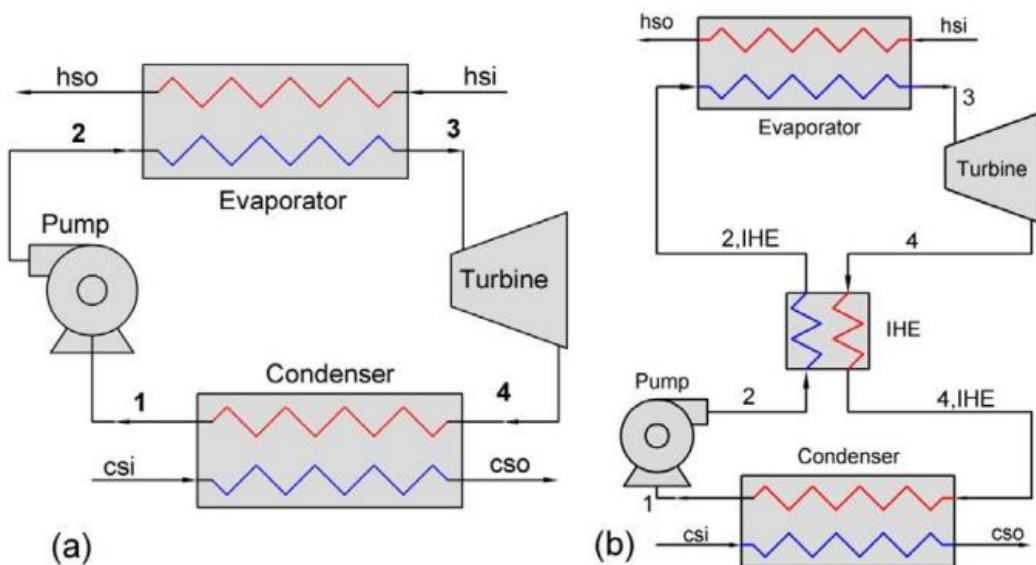
Case:

- Hot loop temperature Inlet: 200 °C
- Cold loop temperature Outlet: 70°C
- Application: production Heat and electricity supply to household

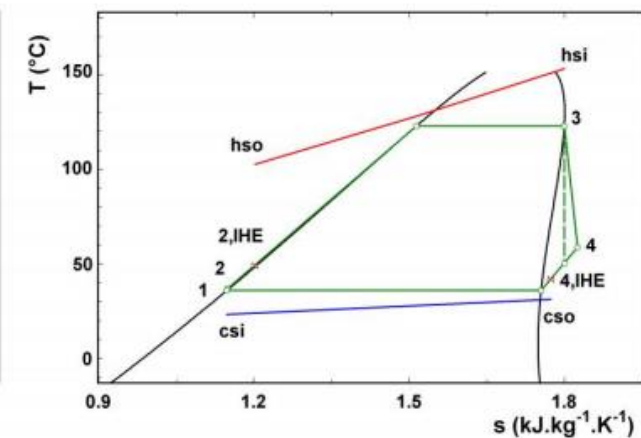
Physical parameter	Novec 649	Cyclopentane	R365mfc
Boiling temperature (° C)	165	188	180
Critical temperature (° C)	168	239	187
Boiling Pressure (Bar)	17,5	22,11	29,08
Superheating (° C)	5	5	5
Condensing temperature (° C)	73	73	73
Condensing pressure (Bar)	2,18	2,1	2,90
Subcooling (° C)	1	3	3
Pressure Ratio	8,02	10,52	10
Mass flow (Kg/s)	0,22	0,05	0,1
Power production (kW)	2,39	2,99	2,73
η_{cycle} (%)	10,85	13,62	12,4
Global Warming Potential	1	11	1110
Ozone Depletion Potential	0	0	0
Atmospheric Lifetime (year)	0.014	0.008	8.6
Flammability/Toxicity	No/Low	High/High	Yes in vapor phase

What is the regenerative cycle

In the case of a "dry fluid", the cycle can be improved using a regenerator: since the fluid has not reached the two-phase state at the end of the expansion, its temperature at this point is higher than the condensing temperature. This higher temperature fluid can be used to preheat the liquid before it enters the evaporator.



(a)

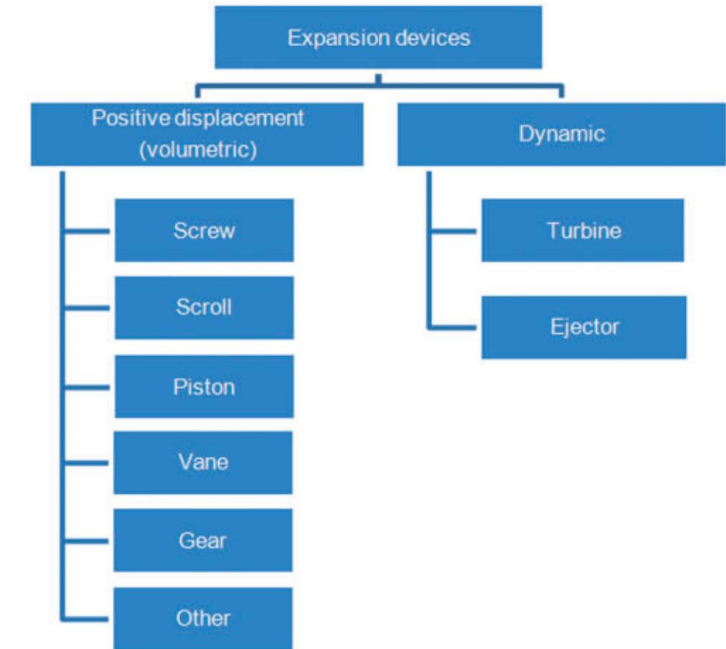


(b)

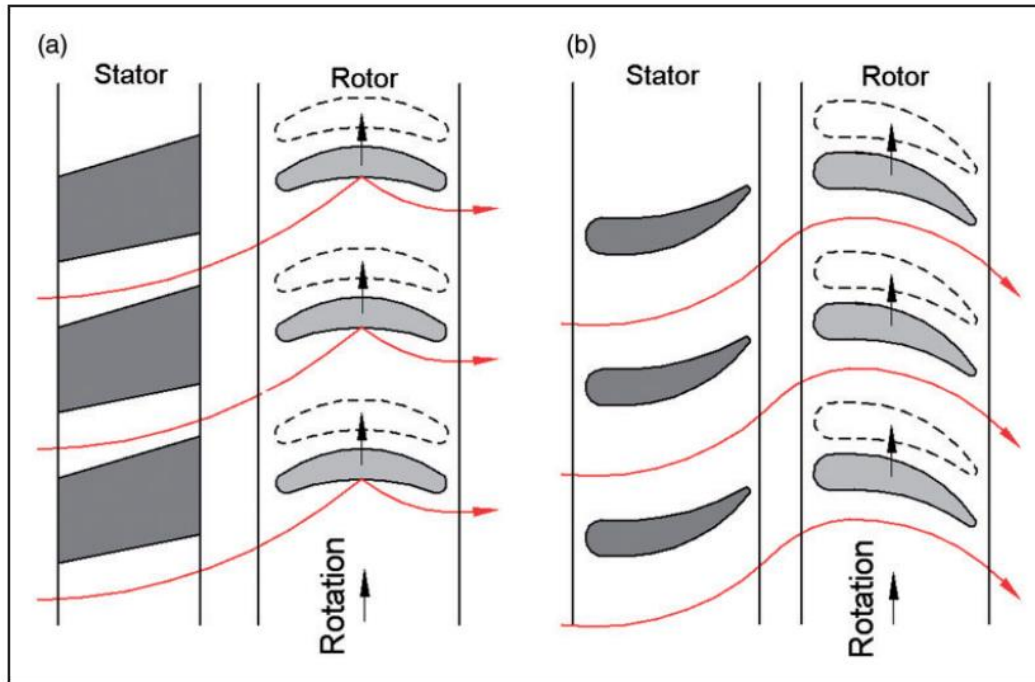
What is an expander machine?

The performance of the an ORC system strongly correlates with that of the expander. The choices of the technology depends on the operating conditions and on the size of the system.

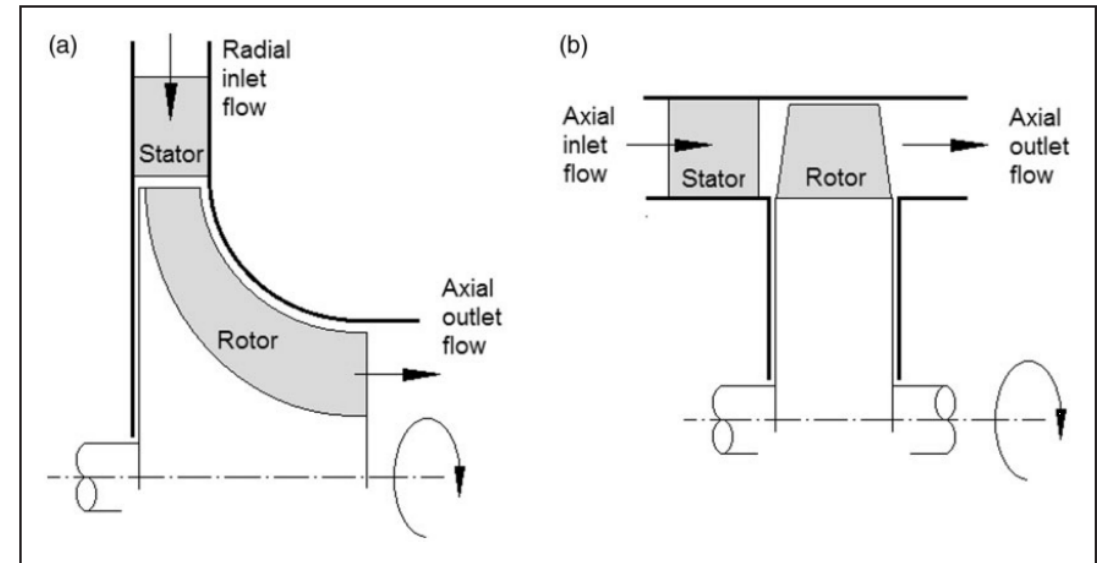
Evaluated feature	Volumetric expanders				Vapor turbines	
	Screw expanders	Scroll expanders	Vane expanders	Piston expanders	Radial	Axial
Efficiency	+++	+++	+	++	+++	++
Size	+	++	++	+	+++	+++
Lubrication	++	++	+	+	+++	+++
Vapor condensation	+++	+++	++	+	+	+
Wear	++	++	+	++	+++	+++
Noise and vibration	++	+	++	+	+++	+++
Simple structure	++	+++	++	++	++	+++
Σ	15	16	11	10	18	18



What is an expander machine? Turbine

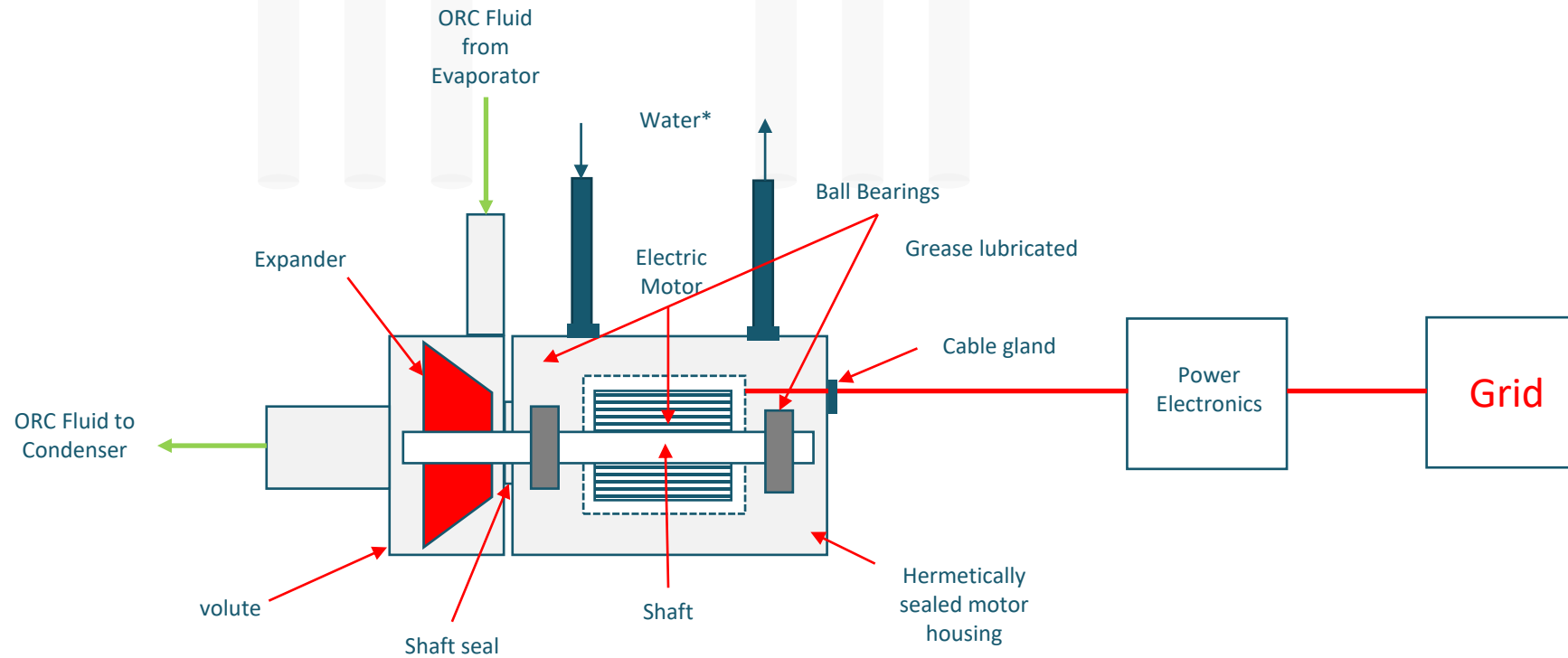


Typical geometries of turbine blades: (a) impulse turbine; (b) reaction turbine.



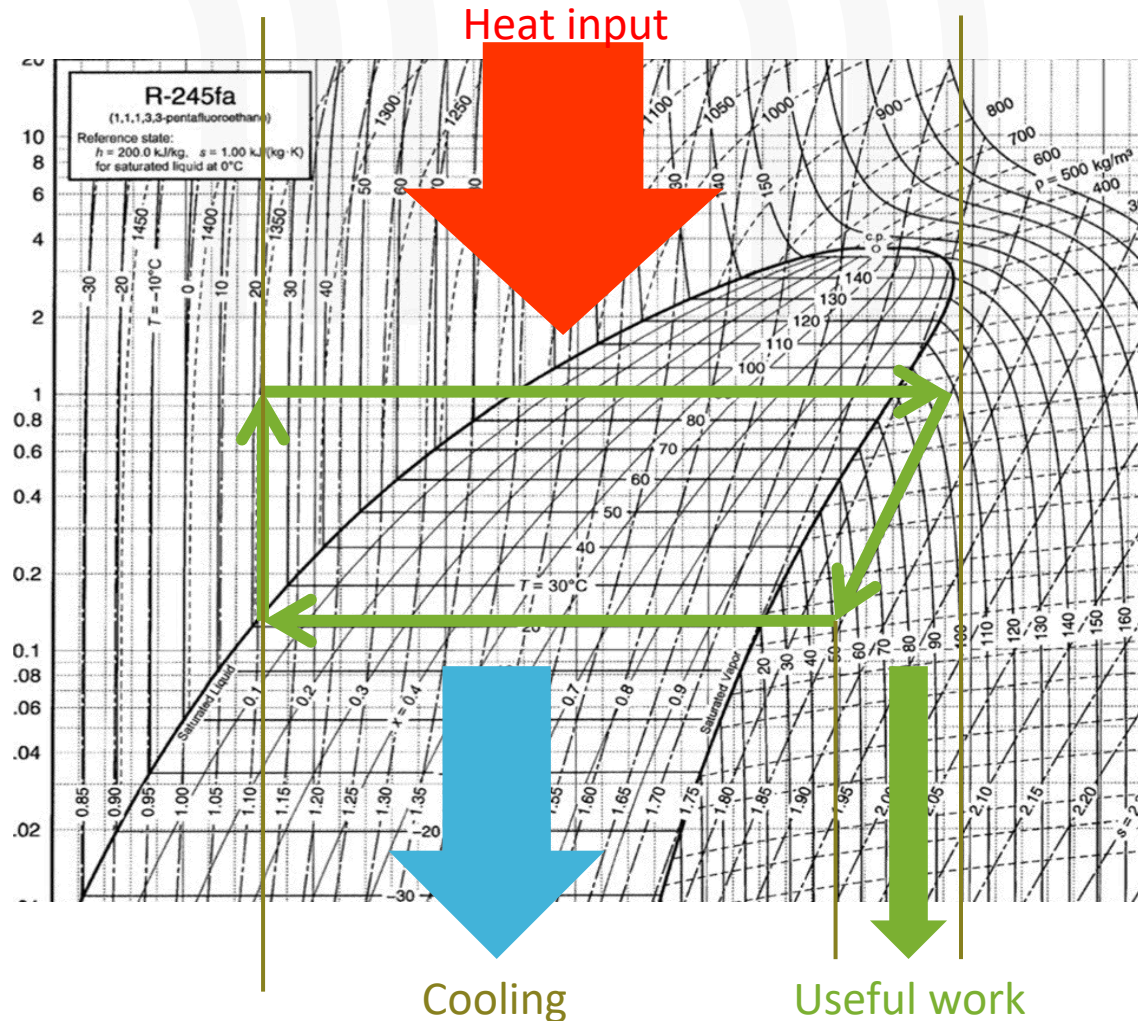
Diagrams showing the flow paths in a radial-flow turbine (a) and an axial-flow turbine (b).

What is an expander machine? Turbine



How to design an ORC?

Isentropic expansion

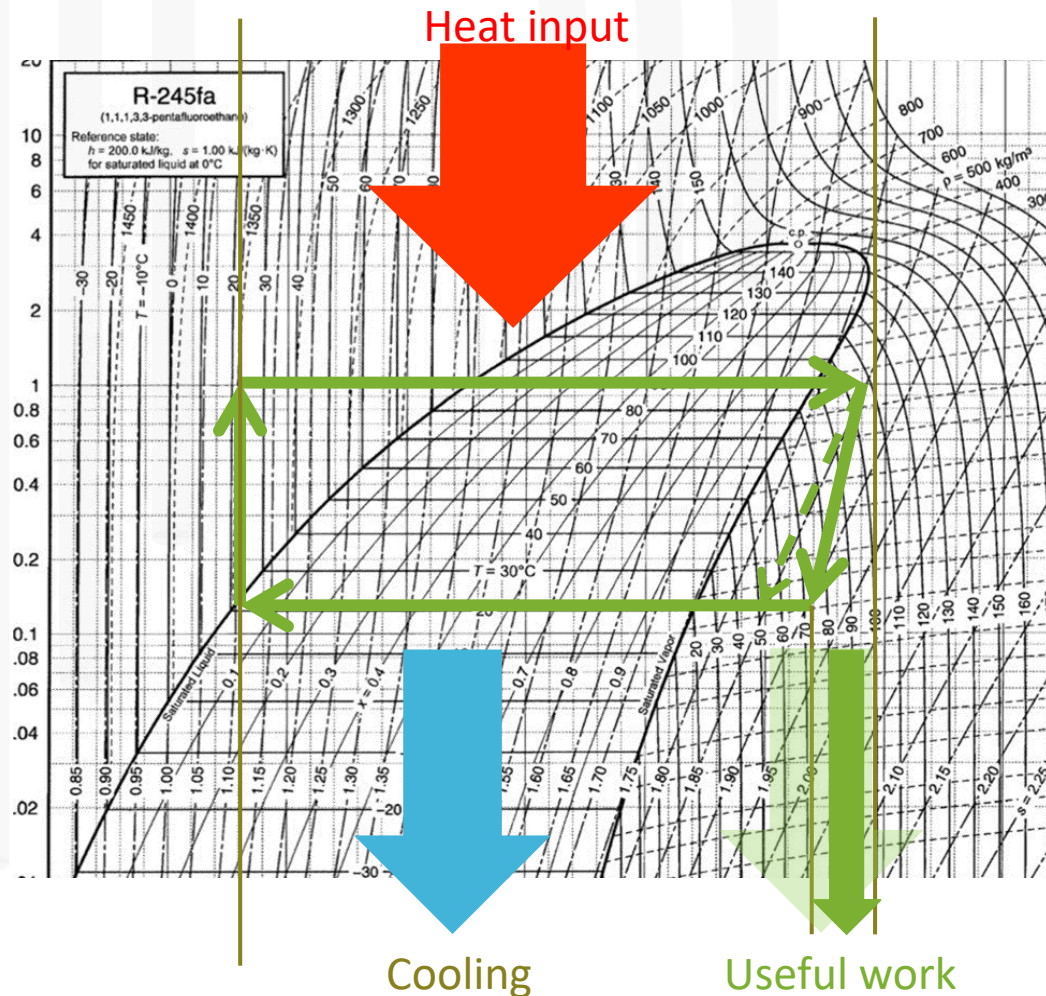


Theoretical cycle efficiency:

$$\frac{\text{Isentropic expansion enthalpy}}{\text{Heating enthalpy}}$$

How to design an ORC?

Real expansion



$$\text{Real Cycle efficiency} = \frac{\text{Real expansion enthalpy}}{\text{Heating enthalpy}}$$

$$\text{Real Cycle efficiency} = \text{Theoretical cycle efficiency} \times \text{Turbine efficiency}$$

$$\text{Turbine efficiency} = \frac{\text{Real expansion enthalpy}}{\text{Isentropic expansion enthalpy}}$$

How to design an ORC?

Exemple

Input from the client:

- 100 kW of the available thermal Power
- 90/70°C inlet/outlet temperature in the hot loop.
- 20/30°C inlet/outlet temperature in the cold loop.
- Fluide R245Fa in the ORC

Hypothesis:

- 55% for turbine efficiency
- Pinch in the evaporator: 2°K
- Pinch in the condenser: 3° K

How to design an ORC?

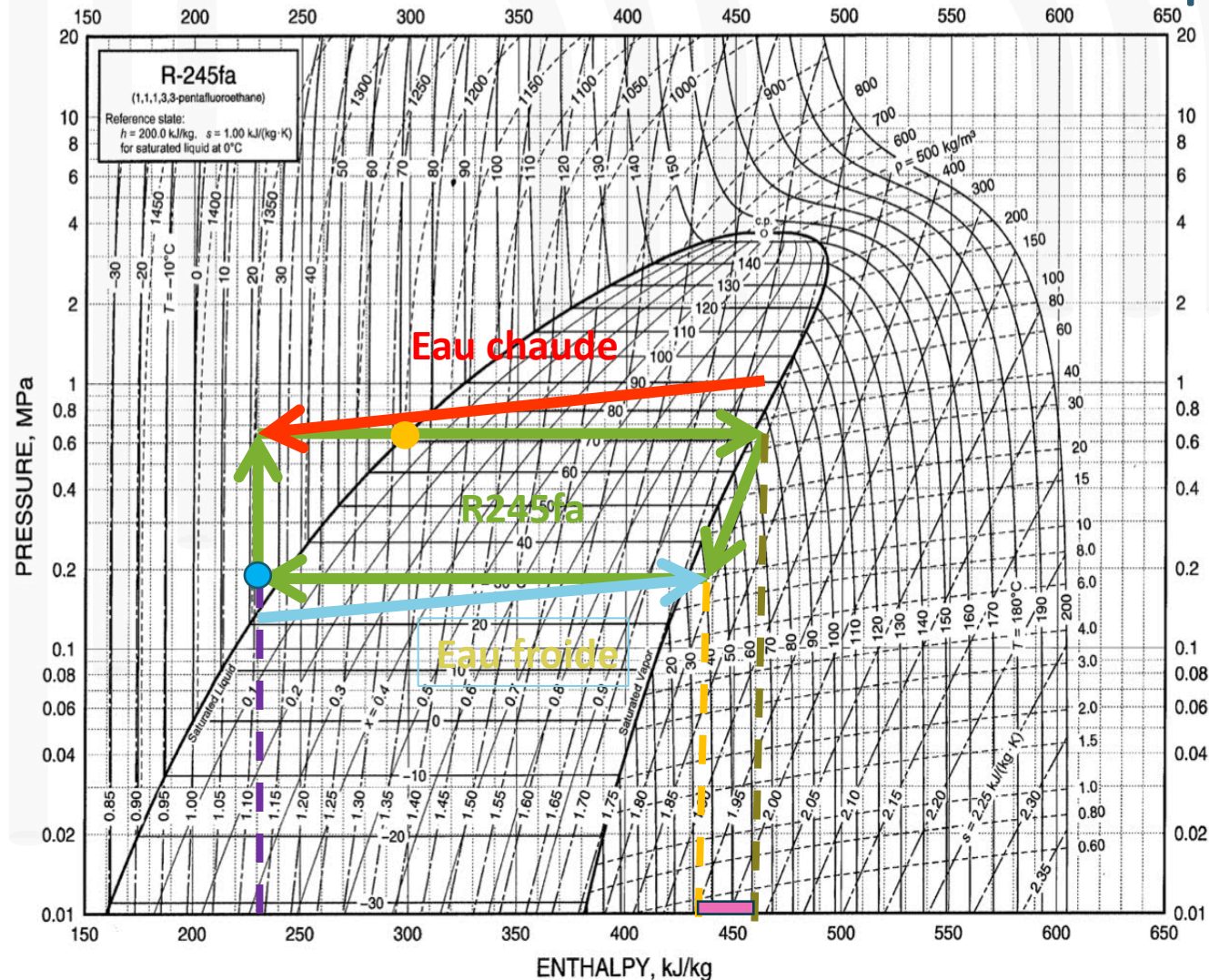
Exemple

Step:

1. Define boiling and condensation temperature and pressure.
2. Calculate the heating enthalpy
3. Calculate the expansion enthalpy
4. Define the theorotical cycle efficiency
5. Calculate the real cycle efficiency
6. Calculate the electrical power output

How to design an ORC?

Exemple



- Boiling Point:
70°C
6 bar
- Condensing point:
33°C
2 bar
- Enthalpy inlet turbine:
456 kJ/kg enthalpie
- Enthalpy outlet the condenser:
243 kJ/kg enthalpie
- Theoretical expansion enthalpie:
21 kJ/kg

How to design an ORC?

Exemple: Calculation

- Heat enthalpy: $456 - 243 = 213 \text{ kJ/kg}$
- Theorotical expansion: 21 kJ/kg
- Theorotical cycle efficiency: $\frac{213}{21} = 10\%$
- Turbine efficiency : 55%
- Real cycle efficiency: $10\% \times 55\% = 5,5\%$
- Electrical output of the ORC: $100 \text{ kW} \times 5,5\% = 5.5 \text{ kW}$

How to design an ORC?

Sensible heat:

- To recover sensible heat to a fluid that is open circuit (an exhaust gas for example, or condensate water from steam) or in a close circuit.

$$P_{th} = n * C_p * Q_m * (T_{in} - T_{out})$$

- n is exchanger efficiency
- C_p is thermal capacity of fluid (4,2 kJ/kg for water, 1,05-1,15 kJ/kg for exhaust gases)
- T_{in} is exchanger inlet temperature
- T_{out} is exchanger outlet temperature
- Q_m is massflow of fluid

How to design an ORC?

Latent heat:

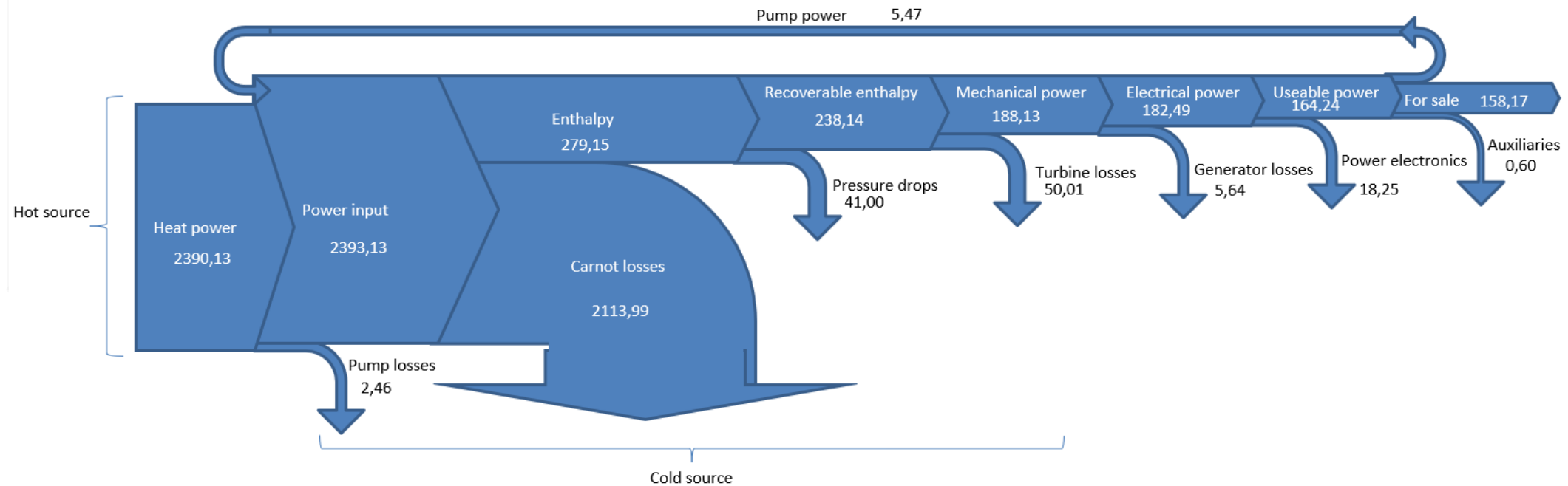
- To recover condensing latent heat, (steam condensing for example)

$$P_{th} = n * Cl * Q_m$$

- n is exchanger efficiency
- Cl is latent heat coefficient
- Q_m is massflow rate

How to design an ORC?

Sankey diagram

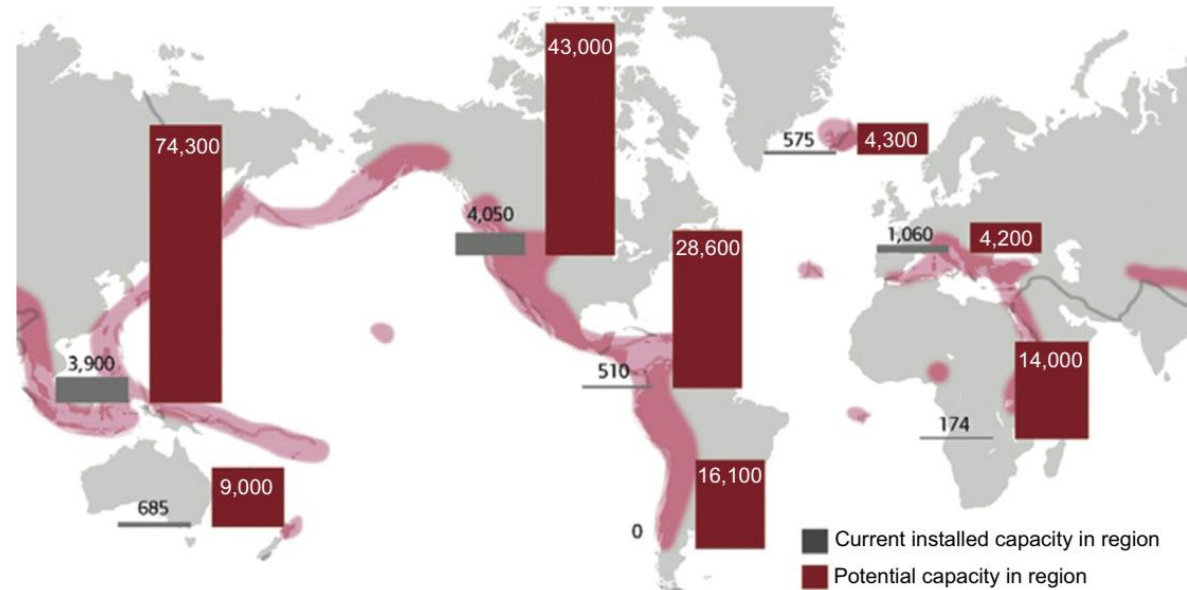


Heat recovery in geothermal context

Among the renewable energy resources, geothermal is the most interesting for reliable base-load energy production. Geothermal power plants are, in fact, characterized by very high annual capacity factor, availability, and reliability. Geothermal power plants exploit a resource that consists of a hot fluid coming from an underground reservoir

Table 14.1 Resources classification according to enthalpy (Dickson and Fanelli, 2004)

Resource name	Temperature range (°C) of classification for the considered references				
	Muffler and Cataldi (1978)	Hochstein (1990)	Benderitter and Cormy (1990)	Nicholson (1993)	Axelsson and Gunnlaugsson (2000)
Low-enthalpy resources	<90	<125	<100	≤150	≤190
Medium-enthalpy resources	90–150	125–225	100–200	–	–
High-enthalpy resources	>150	>225	>200	>150	>190



Heat recovery in geothermal context

Constraints

- A geothermal power plant is a risky and capital-intensive investment
- Geothermal fluids are characterized as a solution of pure water plus dissolved minerals (i.e., Fe, Zn, Cu) and dissolved gases (i.e., H_2CO_3 , H_2S), which varies greatly field by field and well by well,
- Due to some of the chemical components of the geothermal fluid, the exploitation of geothermal resources may cause scaling and corrosion in geothermal plants
- The geothermal environment is critical for the design of electrical components due to the presence of sulfidic components: corrosion of copper electrical equipment in a geothermal environment from hydrogen sulfide contamination.



Rack of material sample on the Chaunoy 40 wells

Heat recovery in geothermal context

- Operate an existing facility. (oil facility).
- For each geology, it is necessary to identify the most resistant and cheapest material.
- Being able to exploit small geothermal wells (Low flow and low temperature) but with a good return on investment



Chaunoy (France)



Grasteinn (Iceland)



Soultz Sous Forêts (France)

Heat recovery in geothermal context

MEET PROJECT

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The Work package 6 (WP6) demonstration of electricity and thermal power generation focused on the following task:

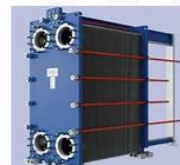
- **Develop a small scale ORC to adress a new market: low temperature and low flow geothermal sources for electricity production.**
- **Demonstrate the feasibility of the heat to power in various geothermal setting.**
- **Assess the most cost-effective pipeline material to transport geothermal brine through the system in order to allow future upscaling of geothermal projects.**



Identify



Analyse



Select



Design &
Manufacture



Demonstrate &
Upscale

Thank you very much for your attention



This work was performed in the framework of the H2020 MEET EU project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792037