2015 INTERNATIONAL WORKSHOP ON ENVIRONMENT AND ALTERNATIVE ENERGY

"Increasing Space Mission Ground Infrastructure Resiliency through Sustainability"

Being held at:

ESA's ESAC Facility, Madrid, Spain – November 10 - 13, 2015

FUNDAÇÃO LUSO-AMERICANA

DESIGN, MODELING, CONSTRUCTION AND EXPERIMENTAL CHARACTERIZATION OF A GAS-FIRED HEAT-EXCHANGER SET FOR A MICRO-CHP SYSTEM BASED ON AN ORGANIC RANKINE CYCLE

João Pereira*, Jorge André, Ricardo Mendes, Eduardo Costa, João Carvalho and José Ribeiro.

* PhD student in Sustainable Energy System at MIT Portugal Program in University of Coimbra

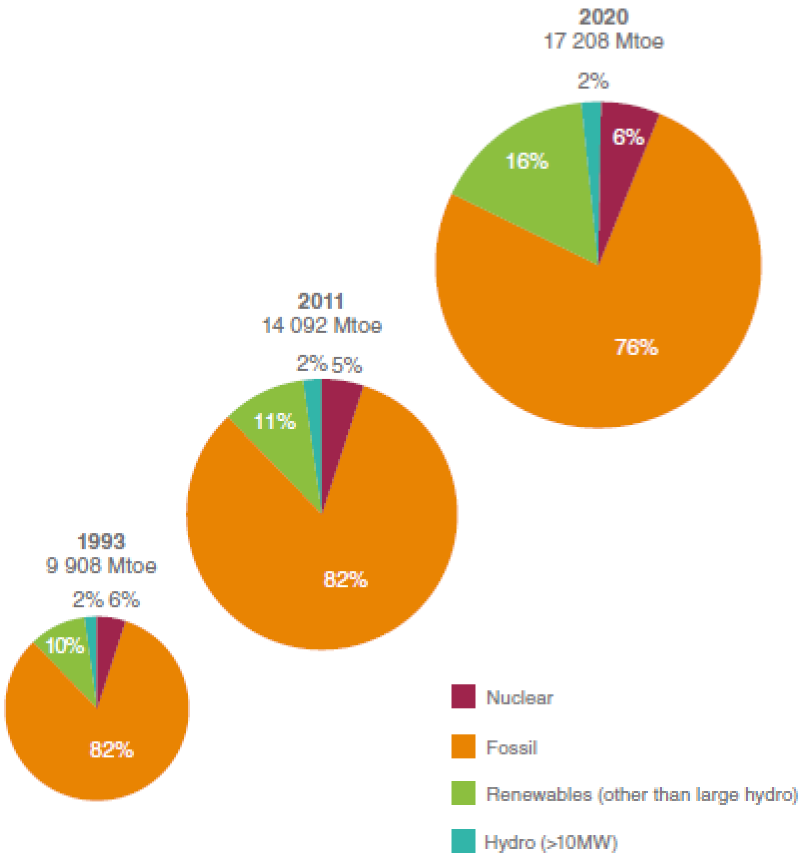
MOTIVATION

Reference: World Energy Council, *World Energy Resources - 2013 Survey*. 2013

	1993	2011	2020	% Growth 1993–2011
Population, billion	5.5	7	8.1	27%
GDP				
Trillion USD	25	70	65	180%
TPES Mtoe	9 532	14 092	17 208	48%
Coal Mt	4 474	7 520	10 108	68%
Oil Mt	3 179	3 973	4 594	25%
Natural Gas bcm	2 176	3 518	4 049	62%
Nuclear TWh	2 106	2 386	3 761	13%
Hydro Power TWh	2 286	2 767	3 826	21%
Biomass Mtoe	1 036	1 277	1 323	23%
Other renewables* TWh	44	515	1 999	n/a
Electricity Production/year				
Total TWh	12 607	22 202	23 000	76%
Per capita MWh	2	3	3	52%
CO_2 emissions/year				
Total CO_2 Gt	21	30	42	44%
Per capita tonne CO_2	4	4	n/a	11%
Energy intensity koe, 2005 USD	0.24	0.19	n/a	-21%

* Includes figures for all renewables, except Hydro

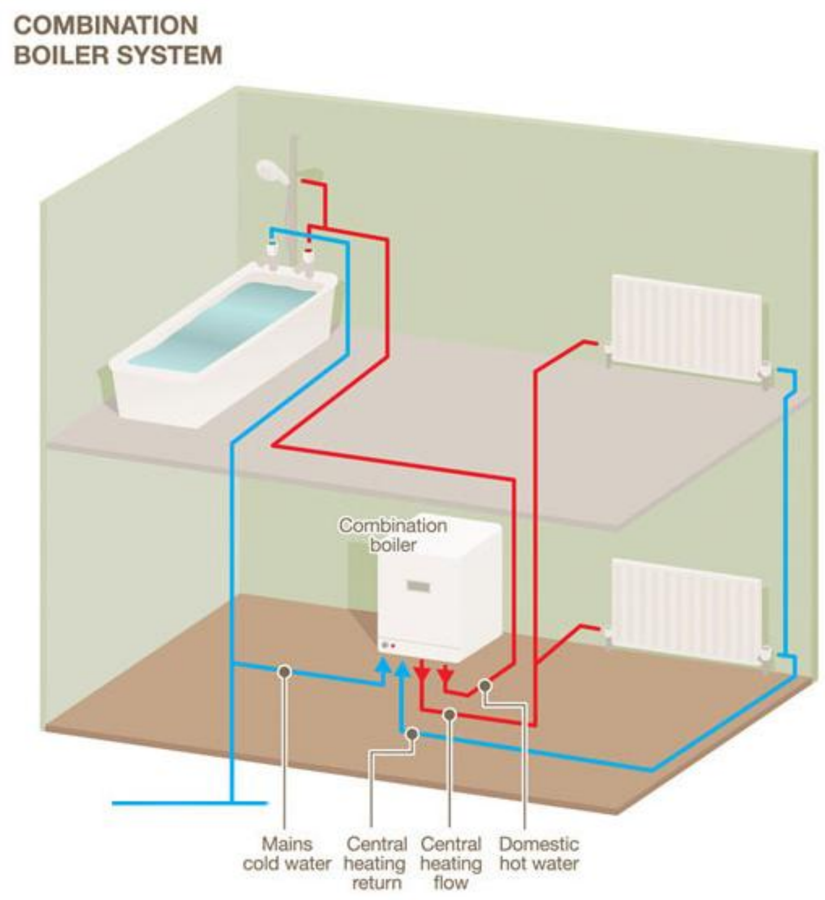
Total Primary Energy Supply by resource

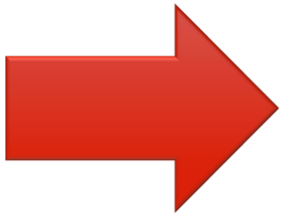


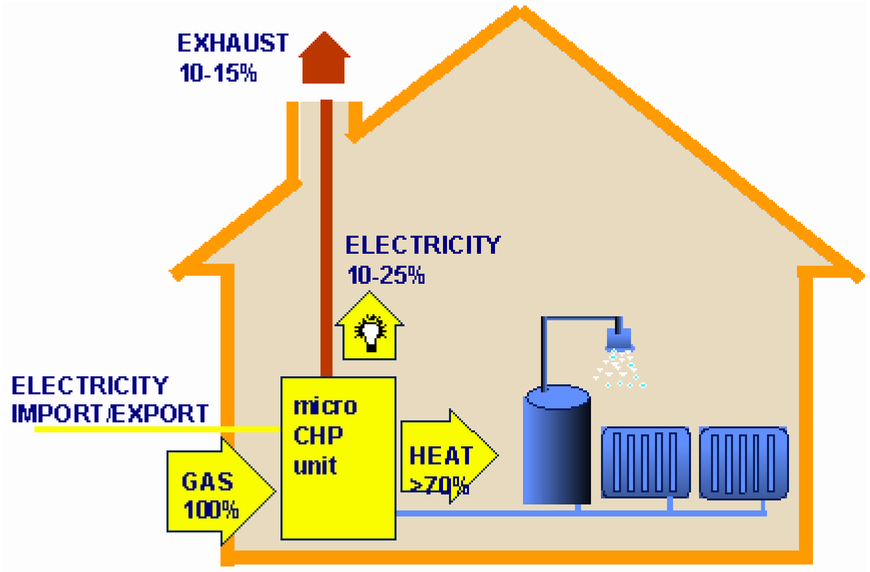
HEBE PROJECT

FEDER Funds through the program COMPETE: QREN-POFC-COMPETE-23101

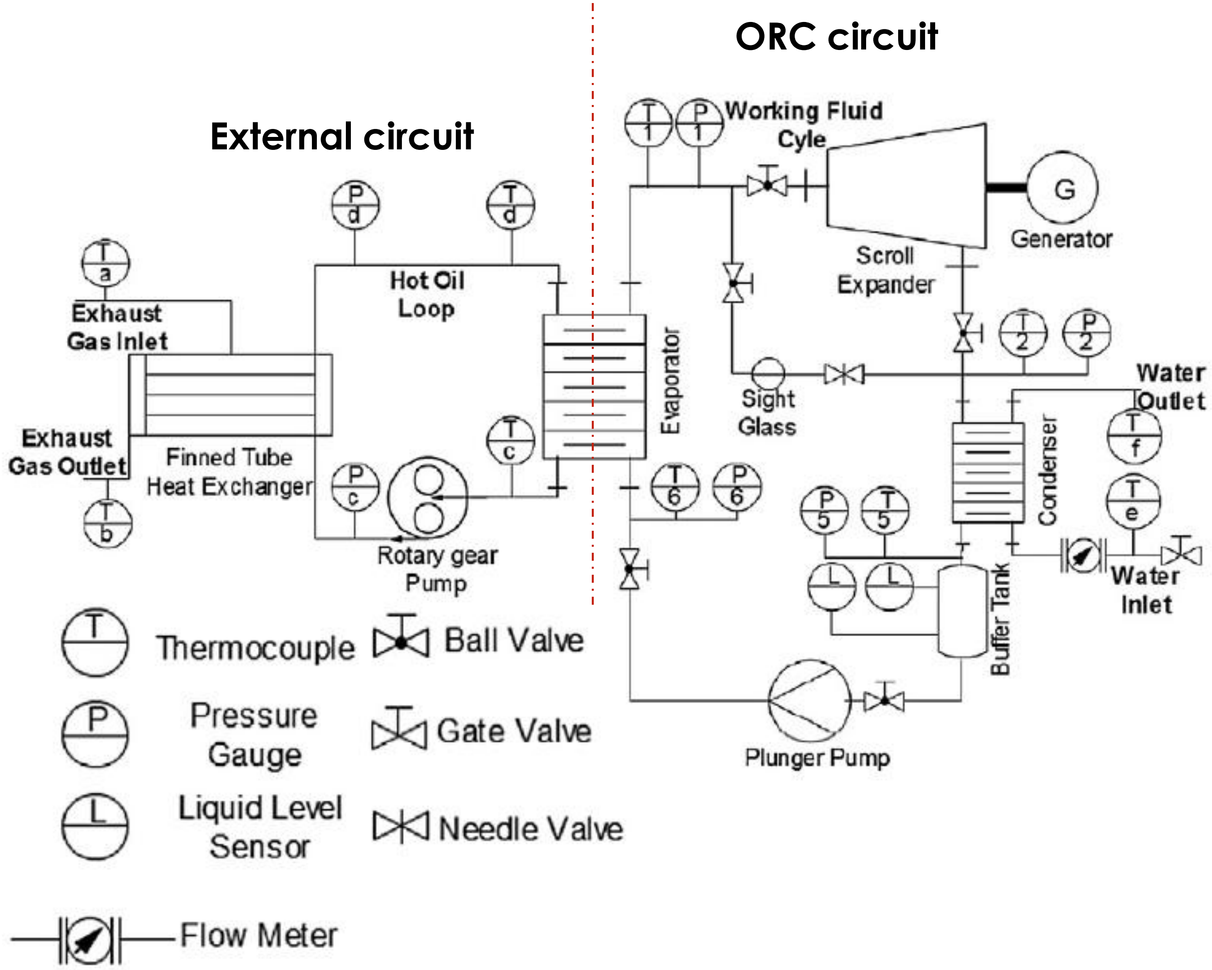
WORK OVERVIEW







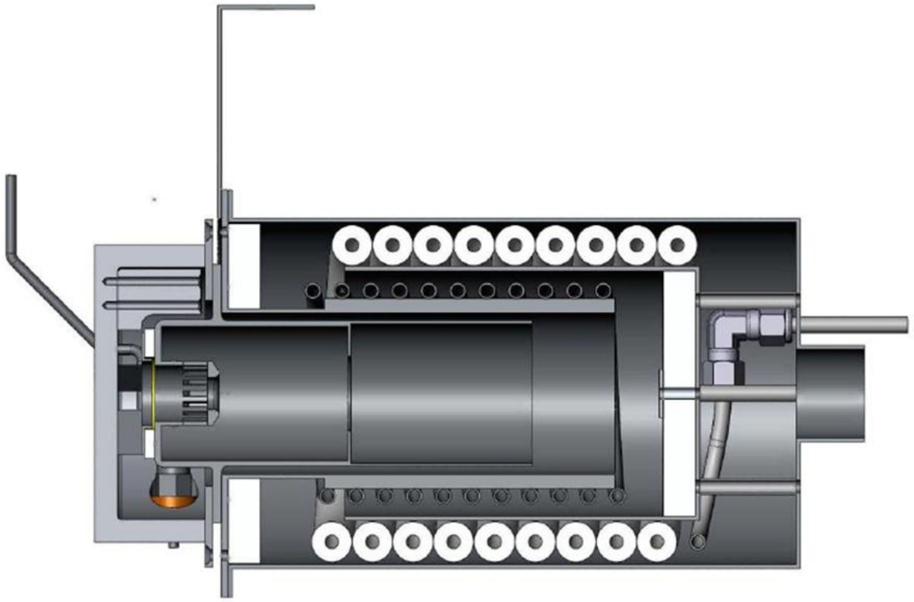
WORK OVERVIEW



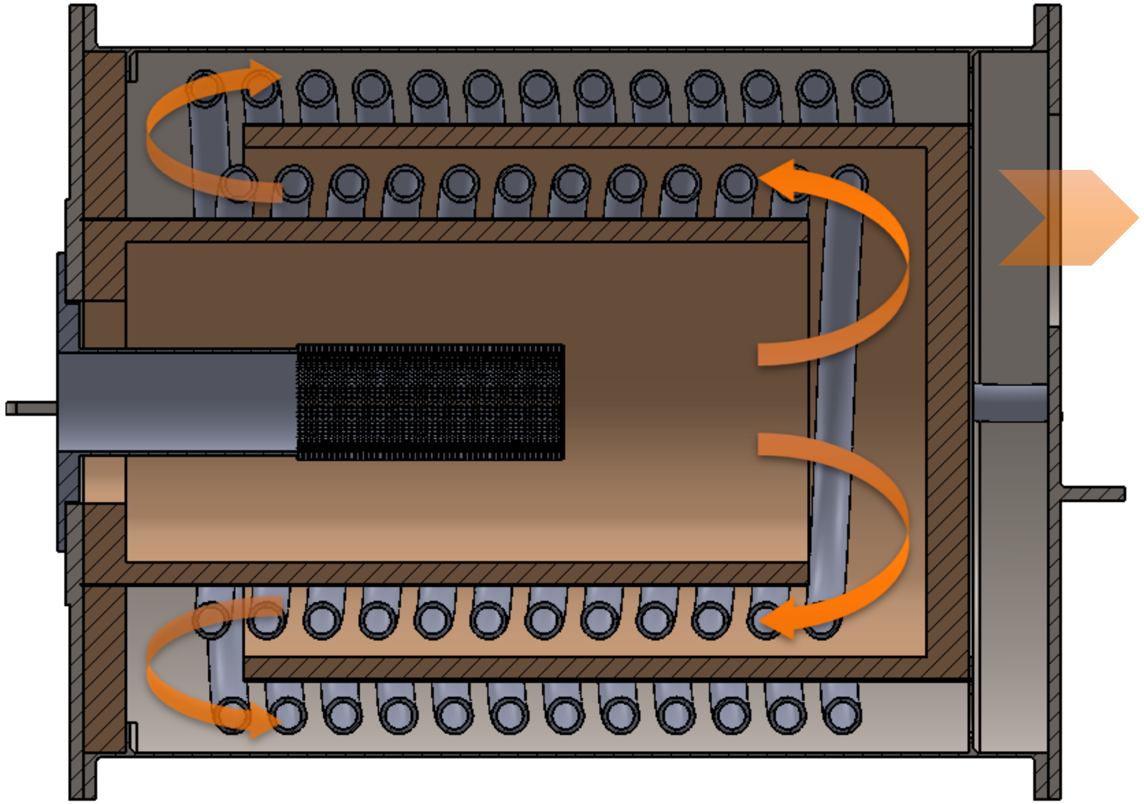
Why not try a direct process?

1ST EVAPORATOR PROTOTYPE

REQUIREMENTS AND WORKING PRINCIPLE



Reference: ECR International. Research, Development and Demonstration of Micro-CHP Systems for Residential Applications-Phase I. 2011.



1^{ST} EVAPORATOR PROTOTYPE

MODELING

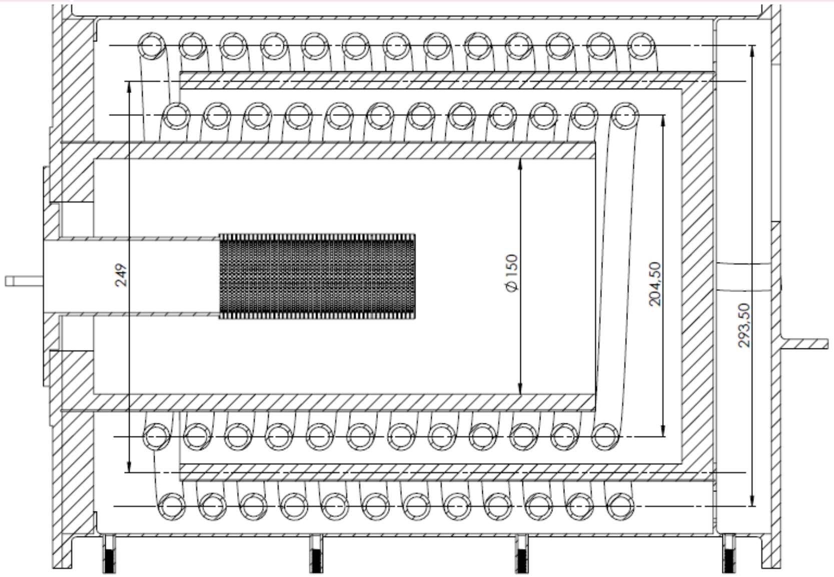
Micro-CHP Hebe	Comercial limitations	Combustion model
Working fluid selection	Tube dimensions (D_e, D_i) and properties (k_t)	Composition of the combustion gases
Working fluid temperatures ($T_{f,in}$, $T_{f,out}$)	Burner nominal power ($\dot{Q}_c$)	Combustion gases temperatures ($T_{g,in}$, $T_{g,out}$)
Working fluid mass flow rate ($\dot{m}_f$)	Burner dimensions	Combustion gases mass flow rate ($\dot{m}_g$)
Required power ($\dot{Q}_f$)		

$$A_{ht}(L_t, D_e) = (\boldsymbol{NTU}, U_{ht}, C_{min})$$

→ NTU $\left(\frac{Cmin}{Cmax}, \varepsilon\right)$, where $\varepsilon\ (\dot{Q}_f, \dot{Q}_c)$

→ $U_{ht}\ (h_h, R_w(k_t), h_c)$, where $h_x\ (Re_x, Nussel_x, k\ (T_x, p_x), D_x)$

→ $C_{min/max}\ (cp(T_x, p_x), \dot{m}_x)$



Final output: $L_t = 19{,}4\ [m]$ given ≅ 24 coils

1ST EVAPORATOR PROTOTYPE

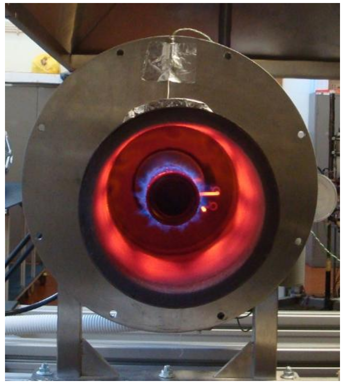
CONSTRUCTION & ASSEMBLY

Model		RX 35 S/PV	RX 70 S/PV	RX 110 S/PV
Burner operation mode		Modulating (with variable speed)		
Modulation ratio at max. output		7 ÷ 1	8 ÷ 1	8 ÷ 1
Servo-motor	tipe	--		
Servo-motor run time	s	--		
Heat output	kW	5 - 35	9 - 70	14 - 110
Heat output	Mcal/h	4,3 - 30,1	7,7 - 60,2	12 - 94,6
Working temperature	°C min./max.	0/40		

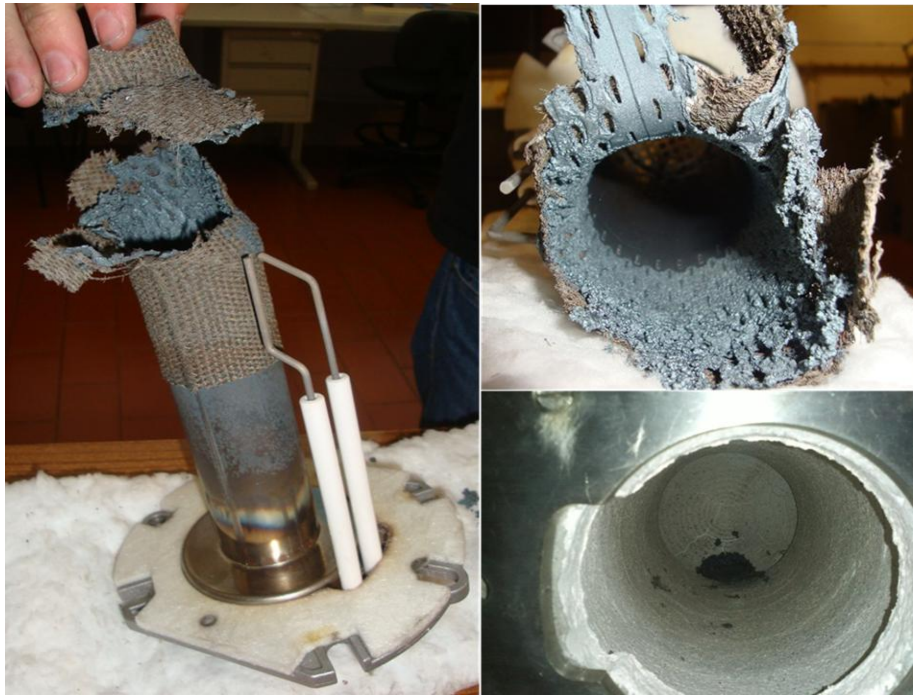
1ST EVAPORATOR PROTOTYPE

COMMISSIONING

1st stage

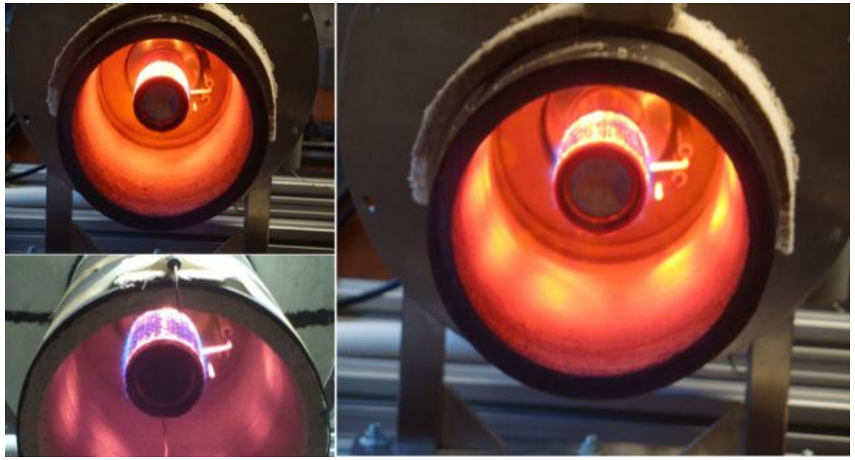


2nd stage

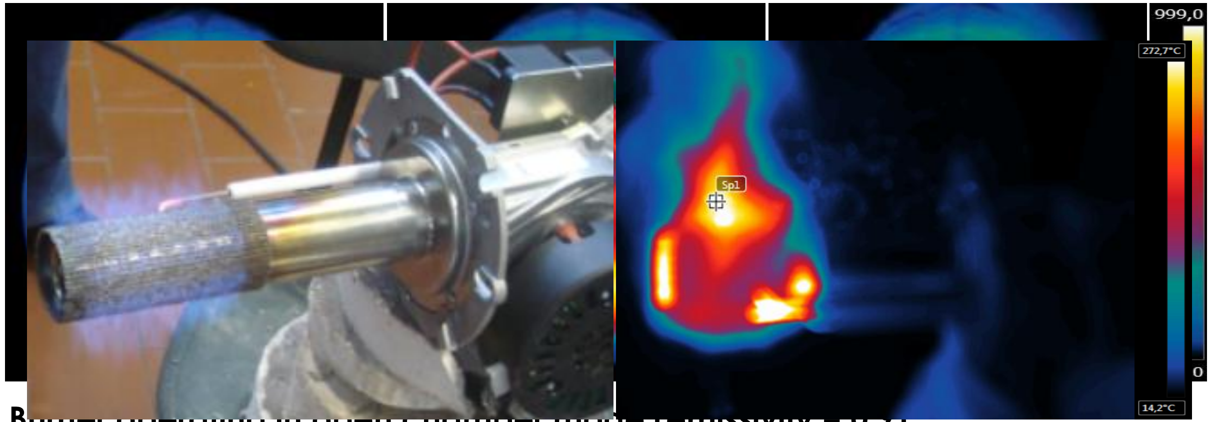


1ST EVAPORATOR PROTOTYPE

COMMISSIONING



Burner manufacturer contact



Burner operating in open chamber mode (emissivity = 0,7)

Left picture: nominal power of 30% (Sp1 = 789.1 °C and Sp2 = 958.1 °C);

Middle picture: nominal power of 50% (Sp1 = 827.2 °C and Sp2 = 1006 °C);

Right picture: nominal power of 70% (Sp1 = 861.2 °C and Sp2 = 1025.2 °C).

Burner operation without surrounding (emissivity = 0.9):

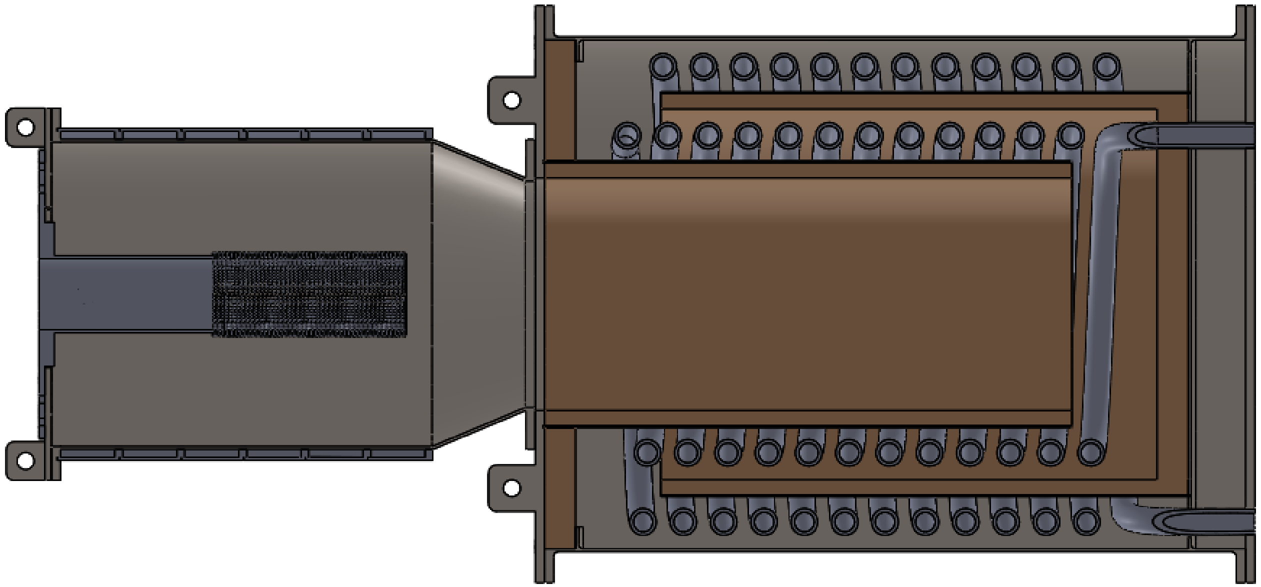
Left picture: nominal power of 50% - regular picture;

Right picture: nominal power of 50% - thermal picture (Sp1 = 267.8 °C).

1ST EVAPORATOR PROTOTYPE

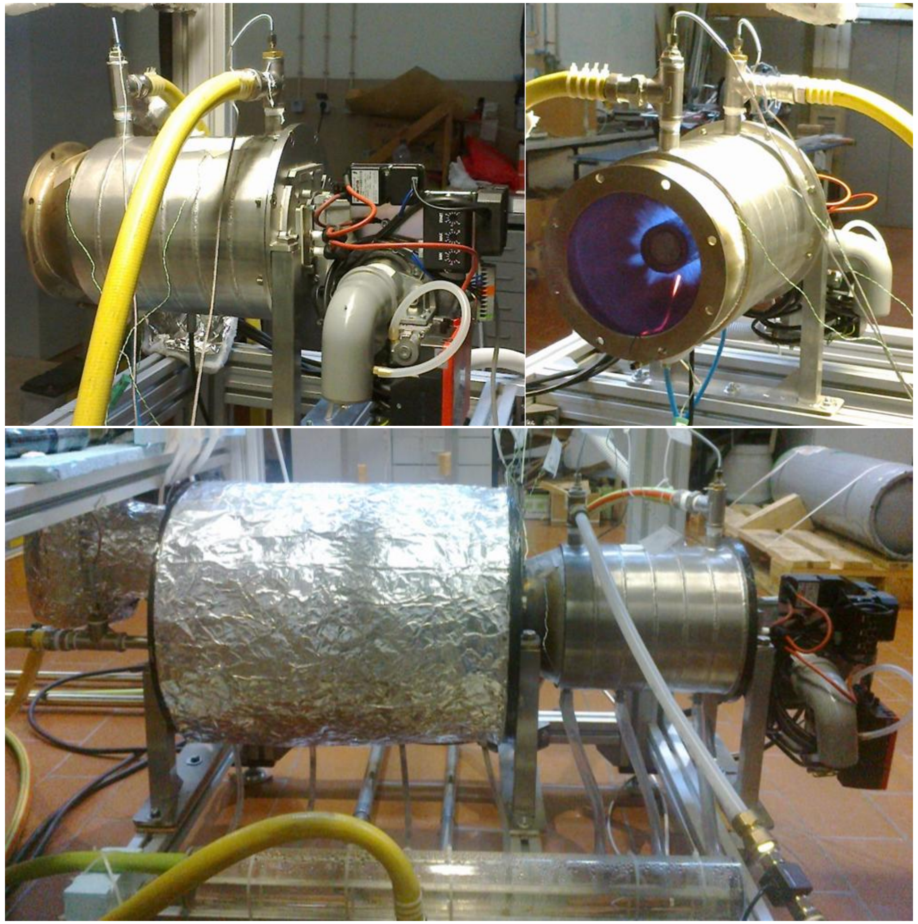
EVAPORATOR CONTINGENCE SOLUTION

- Burner changing?
- Remove the inner cylinder of ceramic material?
- Creating a cold surrounding?



1ST EVAPORATOR PROTOTYPE

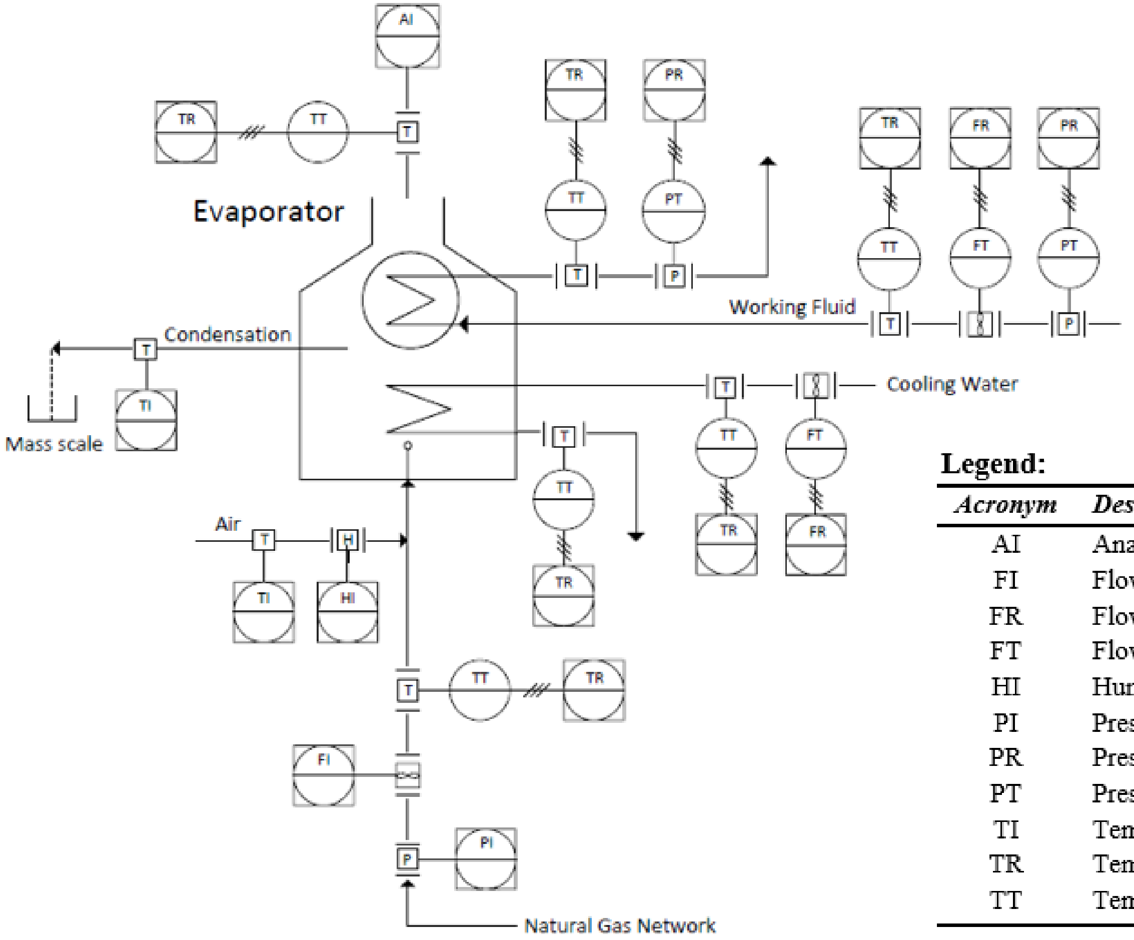
CONSTRUCTION AND COMMISSIONING



1ST EVAPORATOR PROTOTYPE

TEST BENCH AND ACQUIRED DATA

Measured parameters	Sensor-type	Operation limits	Uncertainty
Working and cooling fluid **mass flow rate**	Vaned turbine flowmeter (infra-red sensor)	20 bar; 25 L/min	+- 2%
Working and cooling fluid (in and out), natural gas and condensate water **temperatures**	RTD PT100	-50 to 500 °C	B class;
Flue gas and flame **temperatures**	Mineral insulated Type 'K' Thermocouple	-40 to 1100°C	+- 0,75%
Working fluid **pressure** (in and out)	Relative pressure transducers	Inlet: 0 to 25 bar; -40 to 120°C; Outlet: 0 to 20,7 bar; -73 to 149°C	Inlet: +- 0,25% FS; Outlet: +- 0,25% linearity, hysteresis and repeatability combined
Natural gas **pressure**	Capsular pressure gauge	0 to 60mbar; -20 to 65 ° C	Class 1,0 according to EN 837-3
Natural gas **flow rate**	Diaphragm gas meter	0 to 1,5 bar; -25 to 55°C	Class 1.5 according to EN1359
Combustion products	Dry flue gas analyzer with a non-dispersive infrared sensors for O_2, CO_2, CO, HC and NO	O_2: 0 to 25%; CO_2: 0 to 20%; CO: 0 to 10%; HC: 0 to 10000pmm; NO: 0 to 5000ppm	O_2: 0,01%; CO_2: 0,02%; CO: 0,1%; HC (range 1ppm to 2000ppm): 1pmm; HC (range 2000ppm to 10000ppm): 10ppm; NO: 1ppm
Condensate water, from combustion, **mass**	Compact Toploading Balance	0 to 6000g	+- 0,1g



Legend:

Acronym	*Description*
AI	Analysis indicator
FI	Flow rate indicator
FR	Flow rate recorder
FT	Flow rate transmitter
HI	Humidity indicator
PI	Pressure indicator
PR	Pressure recorder
PT	Pressure transmitter
TI	Temperature indicator
TR	Temperature recorder
TT	Temperature transmitter

1ST EVAPORATOR PROTOTYPE
EXPERIMENTAL METHODOLOGY

With water as working fluid (in a open cycle):

Burner nominal percentage: 10%, 20%, 40%, 50%, 70%, 90% and 100%;

Working fluid mass flow rate: 0,1 kg/s, 0,15 kg/s and 0,2 kg/s;

Cooling water (CW) mass flow rate: 0,1 kg/s;

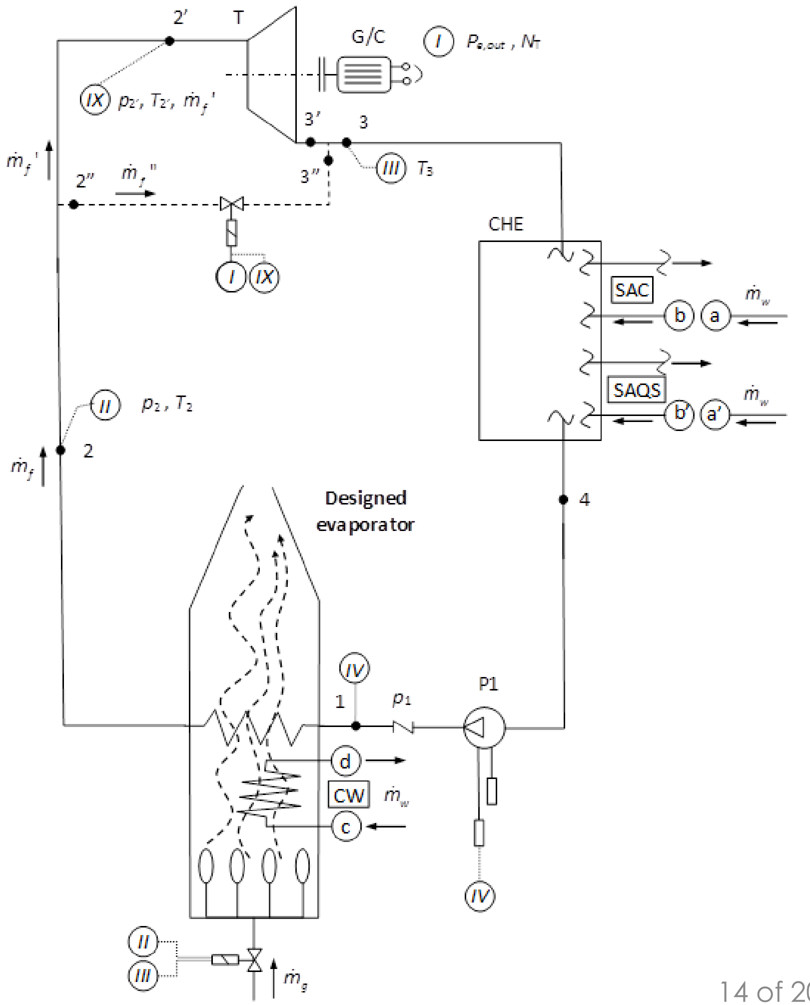
With R245fa as working fluid (as a micro-cogenerator system):

Burner nominal percentage: 18%, 21%, 23%, 25%, 27% and 30%;

Working fluid mass flow rate: adjusted on-site (P1 rotation speed);

Cooling water (CW) mass flow rate: 0,1 kg/s;

Time trial: 300 seconds/trial



1ST EVAPORATOR PROTOTYPE
CHARACTERIZATION

1st **Unknown stoichiometric coefficients (x_a, x_b, x_c):**

$$x_{ng}\left(Fuel_{ng}\right) + x_a\left(O_2 + 3{,}76\ N_2\right) + x_{hum}\ H_2O \rightarrow x_b\left(x_{CO_2}CO_2 + x_{CO}CO + x_{O_2}O_2 + x_{N_2}N_2\right) + x_c\ H_2O$$

2nd **Combustion power:**

$$\dot{Q}_{comb} = \Sigma_P\left(\dot{n} \times \left(\bar{h}_f^o + \Delta\bar{h}\right)\right)_P - \Sigma_R\left(\dot{n} \times \left(\bar{h}_f^o + \Delta\bar{h}\right)\right)_R$$

3rd **Flue losses:**

$$\dot{Q}_{flue} = \sum\left(\dot{n}_P \times \Delta\bar{h}_P\right)$$

4th **Power absorbed by any water circuit:**

$$\dot{Q}_w = \dot{m}_w \times cp_w \times \Delta T_w$$

5th **Power absorbed by the working fluid:**

$$\dot{Q}_f = \dot{m}_f \times \Delta h_f$$

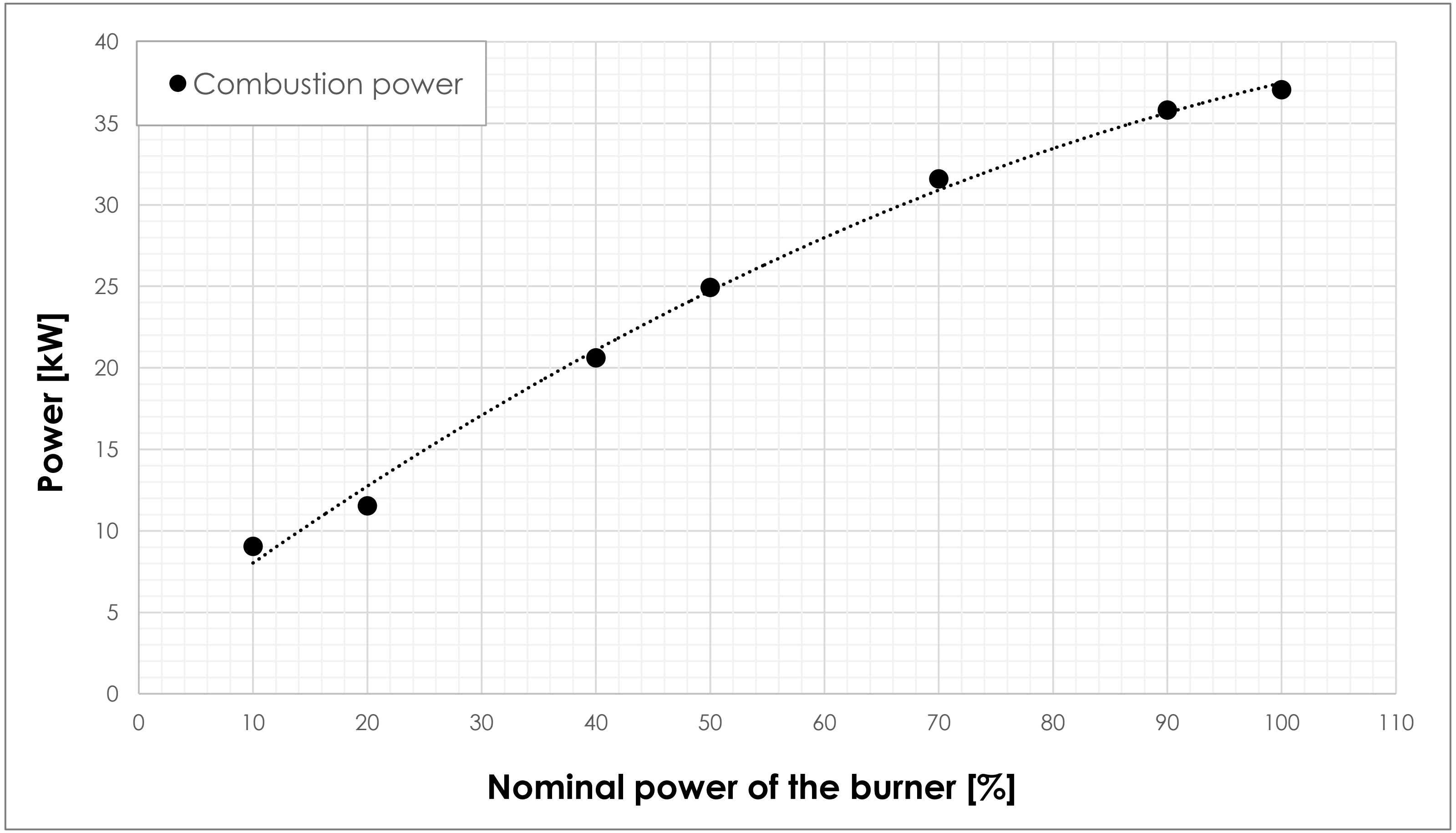
∧

Working fluid overheating degree:

$$\Delta T_{vap} = T_{f,out} - T_{sat}\left(p_{f,out}\right)$$

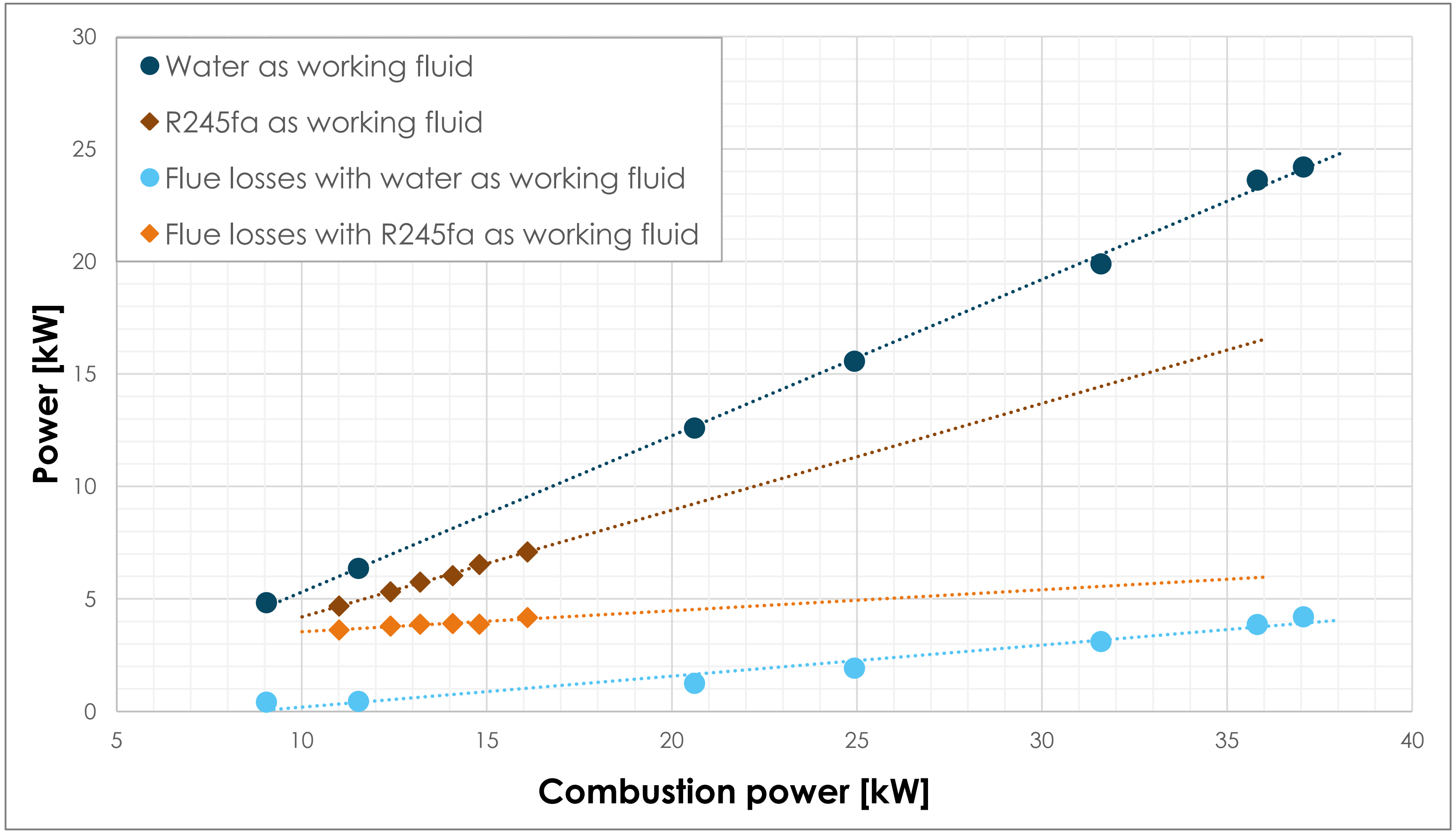
1ST EVAPORATOR PROTOTYPE

RESULTS



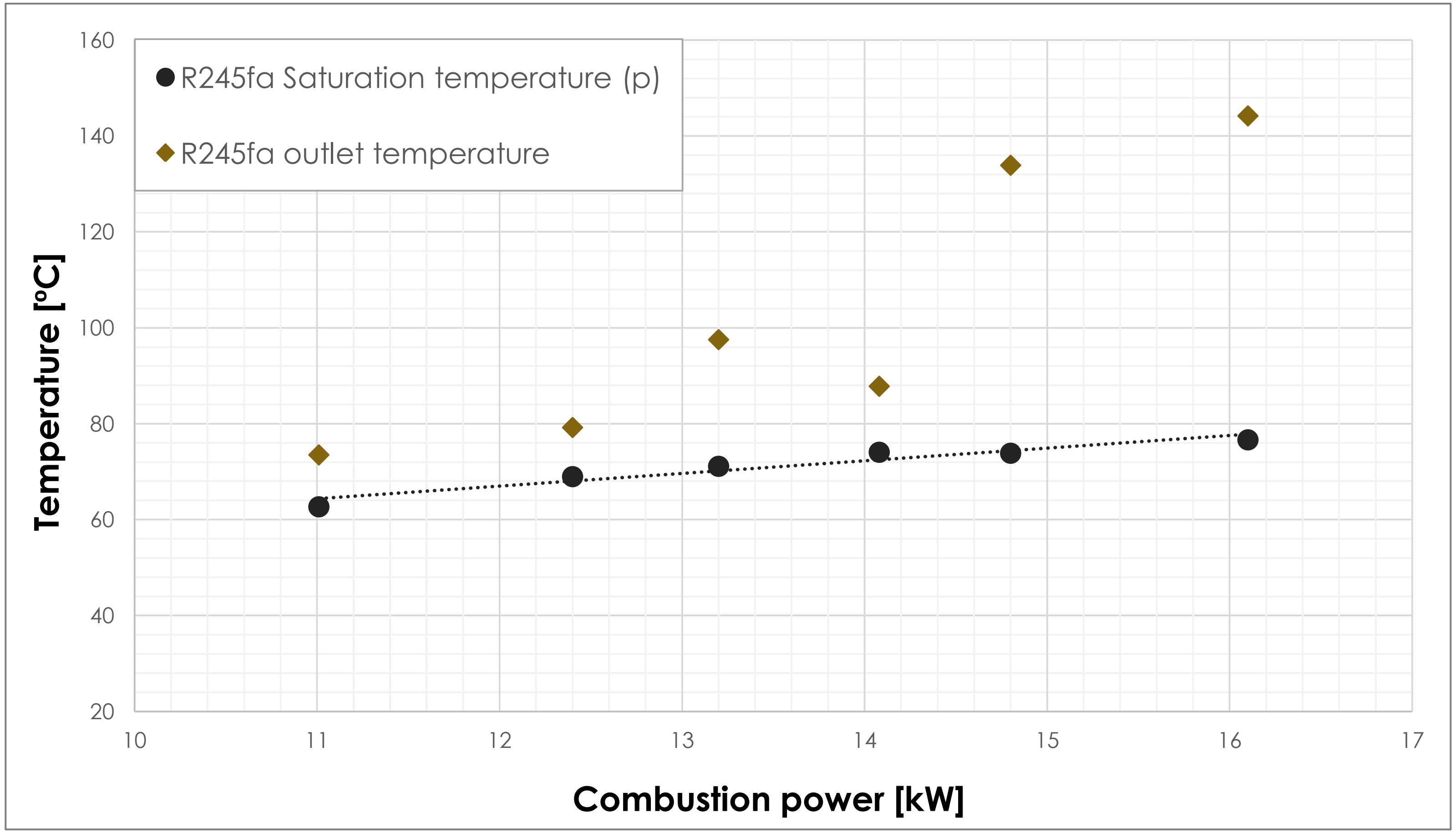
1ST EVAPORATOR PROTOTYPE

RESULTS



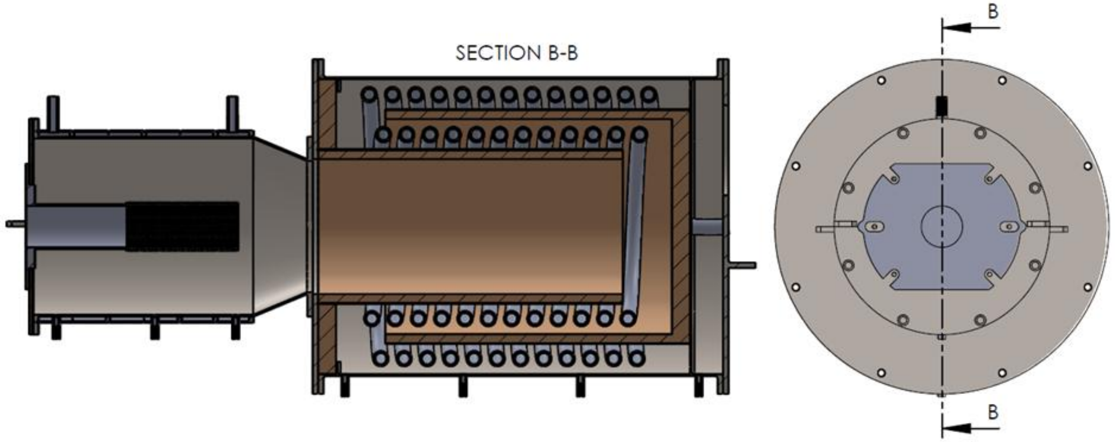
1ST EVAPORATOR PROTOTYPE

RESULTS



1ST EVAPORATOR PROTOTYPE

CONCLUSIONS



- Direct vaporization is possible.
- This particular evaporator has:
  - High thermal inertia (response time);
  - Low global efficiency;
  - Promotes accumulation of vapor bubbles on the inside of the helical heat-exchanger;

THANK YOU FOR YOUR ATTENTION

João Pedro Pereira