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OTTI

Experimental performance of a chemisorption chiller driven by hot water with temperature up to 75 °C

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Background

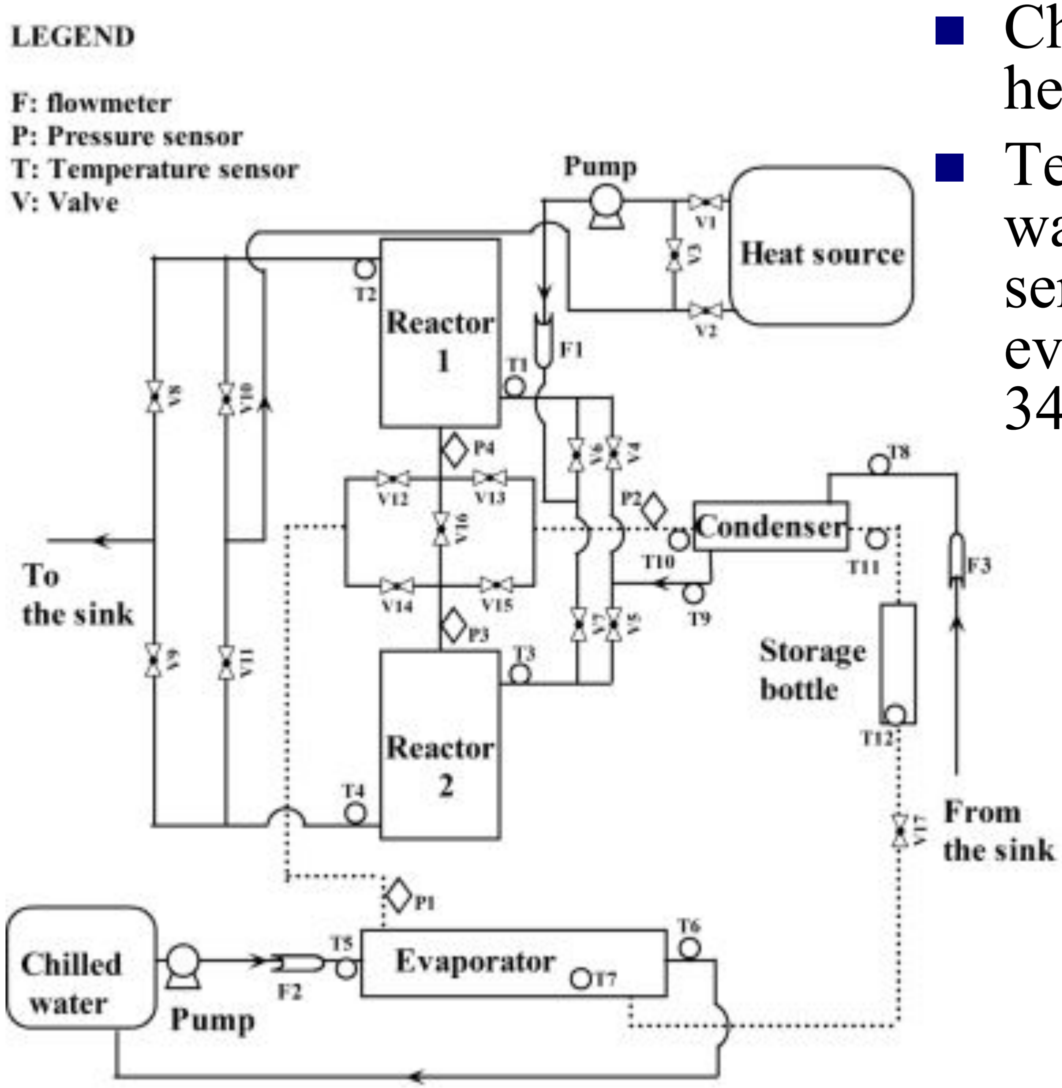
- Sorption chillers are an alternative to produce cooling power from solar energy or recovered waste heat
- Alternatives include machines with liquid-vapor absorption, solid-vapor physical adsorption and solid-vapor chemical adsorption
- Liquid-vapor absorption and solid-vapor physical adsorption are commercially available with optimum operation temperature above 80 °C
- Machines driven with lower temperatures fluids may show the following advantages:
  - Allow higher efficiency in the solar collectors for solar driven systems
  - Allow multiple stages of heat recovery when driven by waste heat

Objectives

- Analysis of cooling power and COP of a chemical adsorption (chemisorption) chiller that used NaBr impregnated in expanded graphite as composite sorbent and ammonia as refrigerant under different operational conditions.

- The results were used to assess the expected performance of this chiller when used in a solar cooling system or when integrated as bottom chiller in a cogeneration plant with a gas turbine and GAX ammonia-water absorption chiller at top cycle.

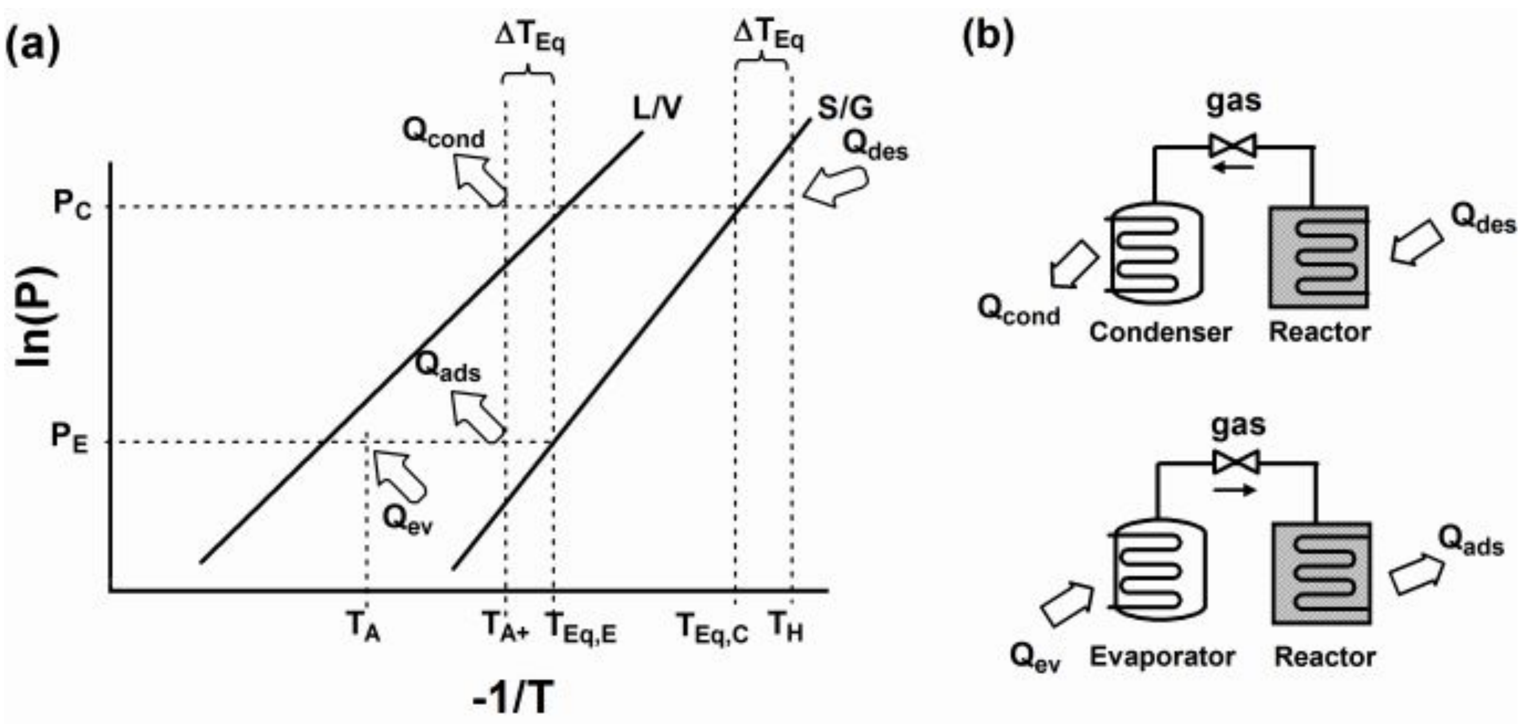
Description of the system



- Chemisorption chiller with four heat exchangers.
- Temperature, pressure and water mass flow measured by sensors, with signals recorded every 6 seconds by an Agilent 34772a data logger.

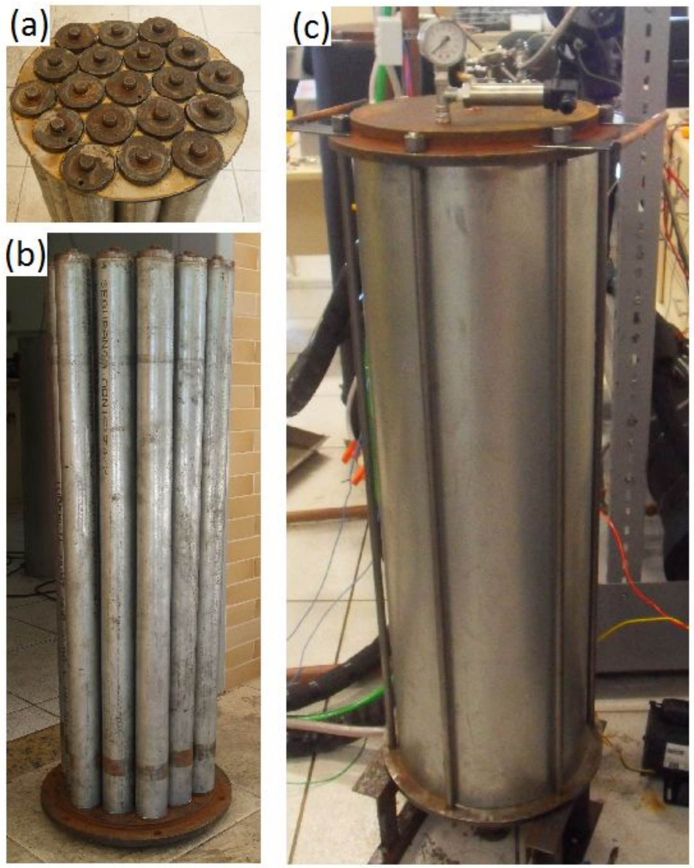
Description of the system

- While one reactor was being heated and desorbing refrigerant to the condenser, the other reactor was being cooled and adsorbing refrigerant from the evaporator.



Description of the system

- The reactors with consolidated composite sorbent made from NaBr impregnated in expanded graphite.
  - The preparation of the composite sorbent included expansion of the expandable graphite at temperatures between 700 °C and 750 °C, followed by the mixture of the expanded graphite to a salt solution.
  - Slurry dried at 130 °C for a period between 6 and 12 h, depending on the amount of slurry to be dried.
  - Proportion between salt and expanded graphite equal to 3:2.
  - Salt in the composite sorbent reacted with ammonia, according to

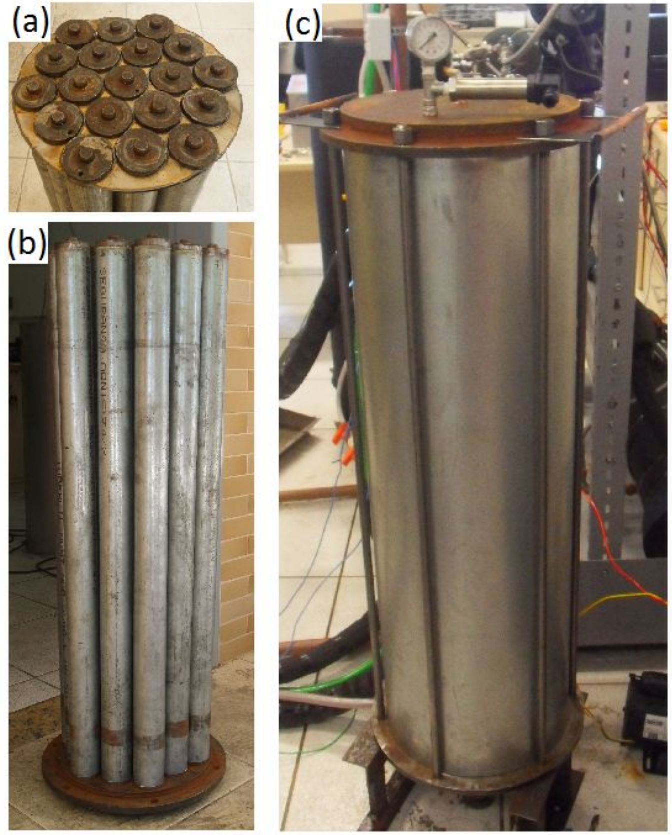


$$NaBr + 5.25NH_3 \Leftrightarrow NaBr \cdot 5.25NH_3 + 5.25\Delta H_R$$

Description of the system

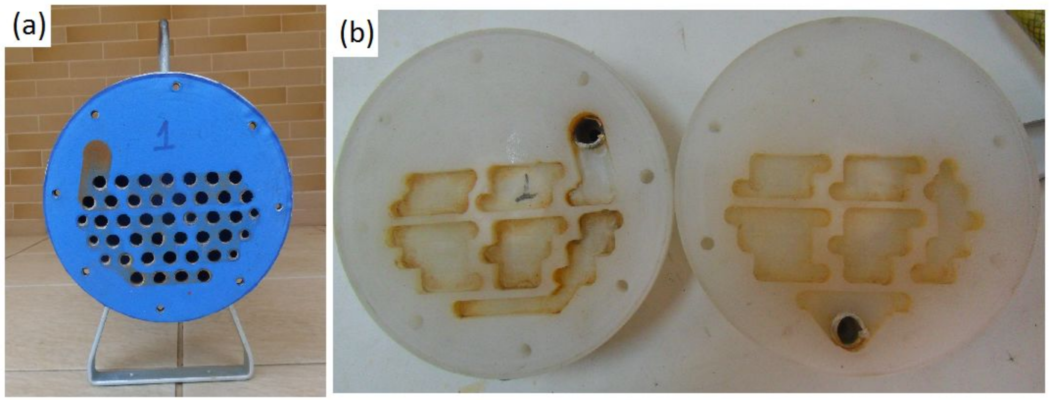
Table 1. Constructive characteristics of each reactor.

Heat exchange area (m^2)	2.81
Mass of tubes (kg)	82.5
Total metallic mass (tubes, shell, cover, etc.) (kg)	140
Inner diameter of the tubes (m)	0.055
Number of tubes	19
Inner diameter of the shell (m)	0.31
Number of baffles	1
Mass of dry composite adsorbent (kg)	9.4
Thickness of the adsorbent layer (m)	8.4×10^{-3}
Length of the adsorbent inside the tube (m)	0.81



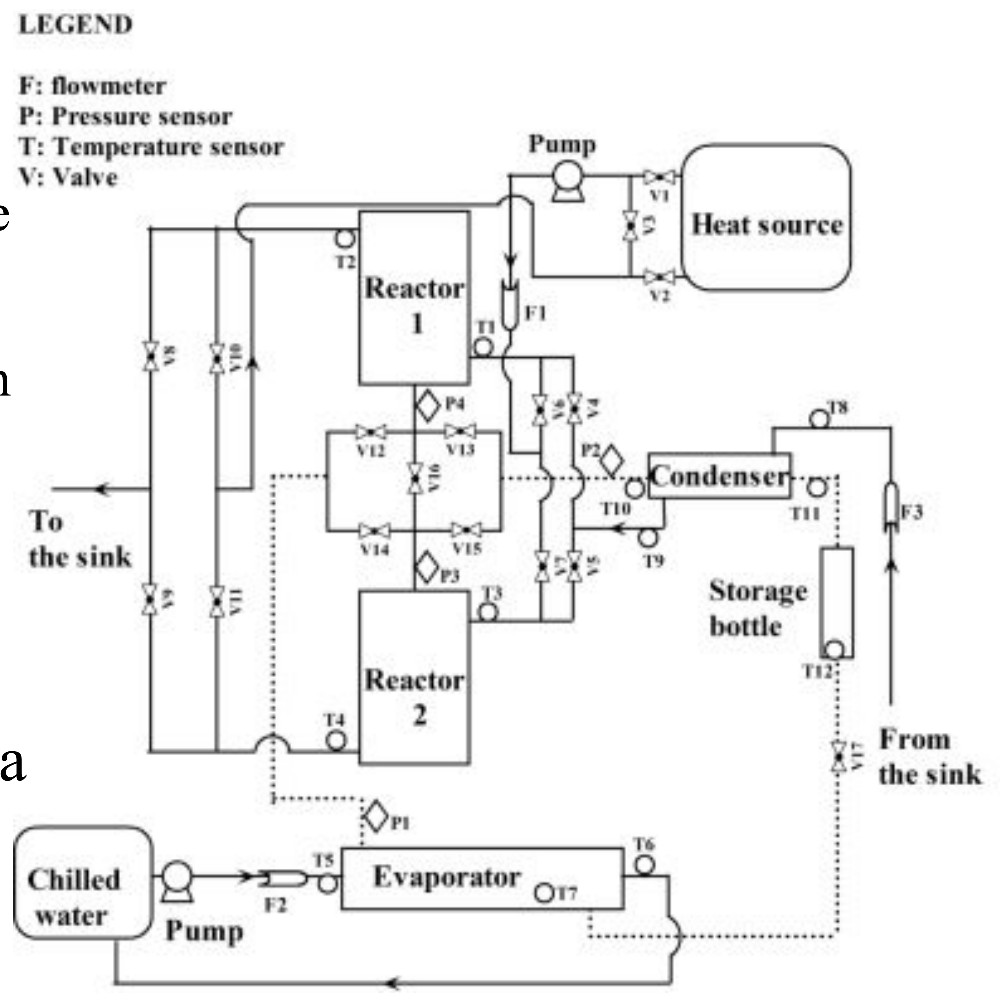
Description of the system

- Condenser and the evaporator were also shell-and-tube heat exchangers.
- **In the condenser:** refrigerant condensed inside the tubes and water flowed through the shell.
- **In the evaporator:** the refrigerant evaporated in the shell, around the tubes, and water flowed in multiple passes, inside the tubes.
  - Evaporator was only partially filled with tubes.



Experimental procedures

- Experiments at selected operation conditions of
  - Inlet hot water temperature in the reactor ($T_{Source,In}$)
  - Inlet cold water temperature in the evaporator ($T_{Ev,In}$)
  - Cycle time (the heating and the cooling period of the reactors with same length of time).
- All cycles with heat and mass recovery.
- Experimental data to assess the expected overall performance for solar cooling system and in a cogeneration plant with two types of chiller.



Experimental procedures

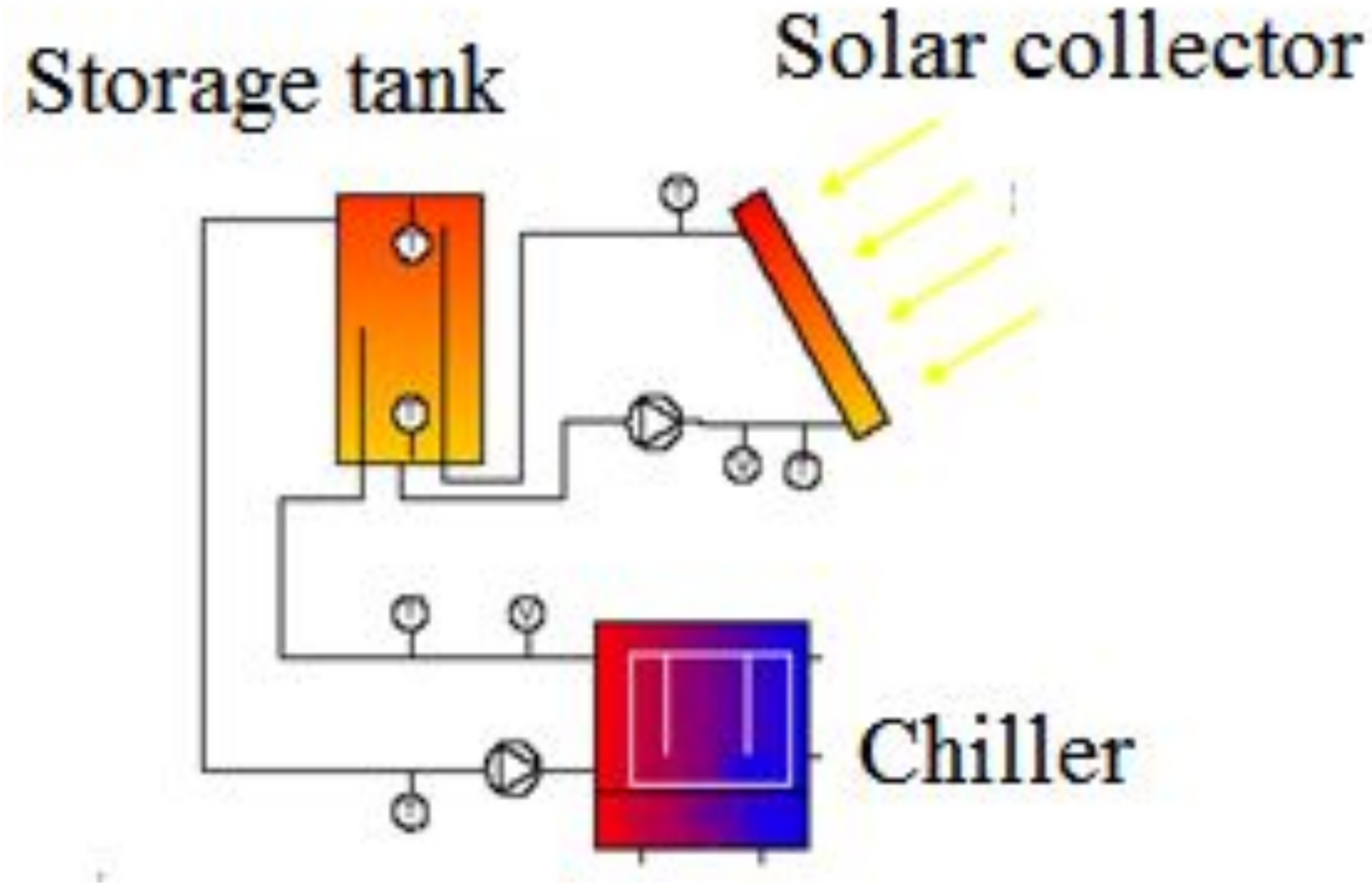
- In the solar air conditioning system
  - Hot water heated in two solar panels model *Col-4x8-NL-SG1-SH10US* from the Enerworks Inc.

TECHNICAL INFORMATION	
ISO Efficiency Equation [NOTE: Based on gross area and (P)=Ti-Ta]	
SI UNITS:	η= 0.762 - 3.27870(P/G) - 0.01290(P^2/G)

Incident Angle Modifier							
θ	10	20	30	40	50	60	70
Kτα	1.00	1.00	1.00	1.00	0.96	0.84	0.31

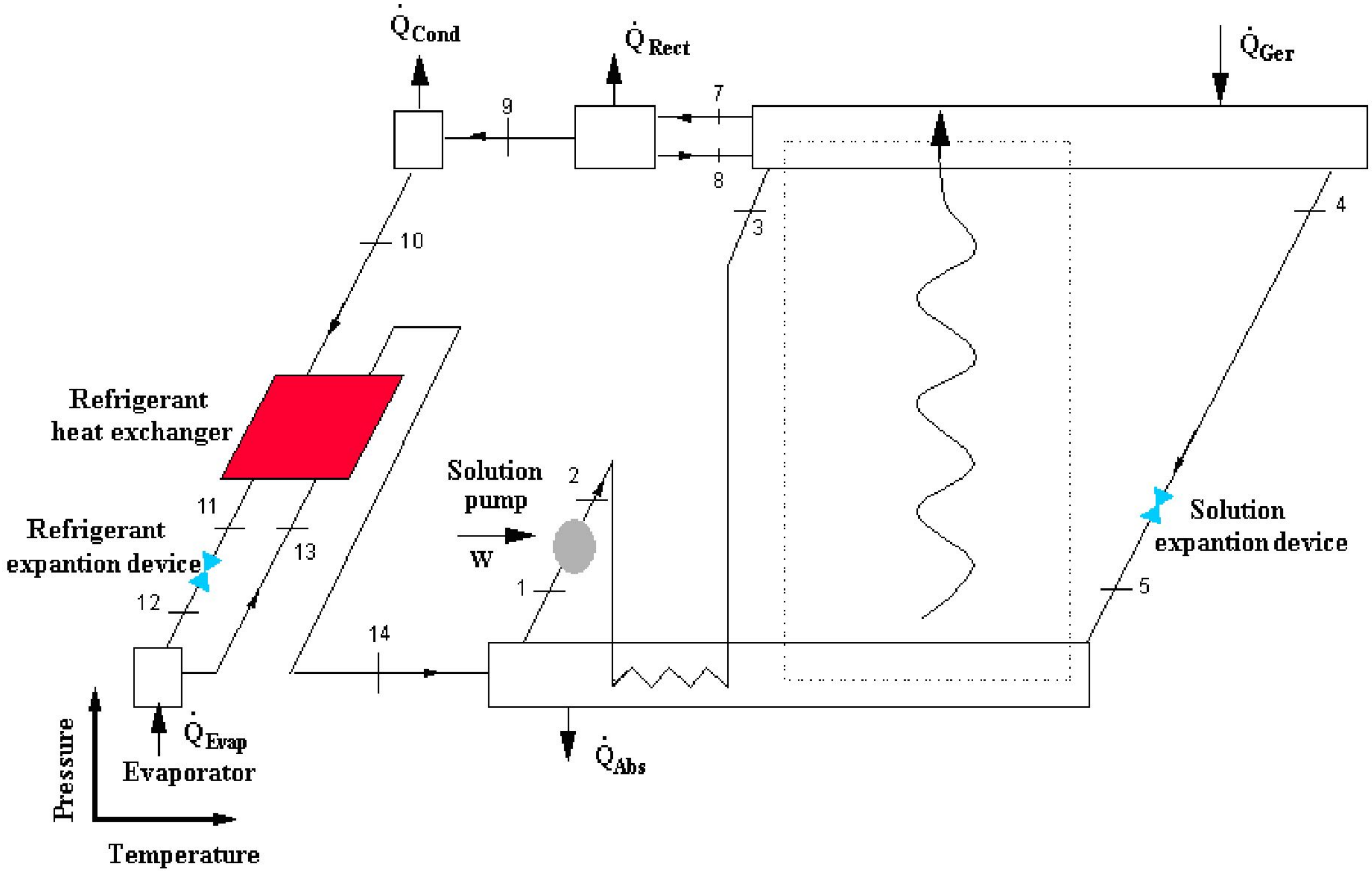
COLLECTOR SPECIFICATIONS	
Gross Area:	2.873 m²
Net Aperture Area:	2.691 m²
Absorber Area:	0.000 m²

  - Operate in Florianópolis (27.5954° S, 48.5480° W), Brazil
    - panels tilted 37 °
    - SWERA weather data to assess the amount of heat received by the solar collectors
      - monthly collector efficiency
      - monthly solar coefficient of performance (COP_{Sol})
  - Water stored in a 700 L insulated water tank.
  - The system with no auxiliary heat, and water from the tank was supplied to the chiller when the temperature of the former reached 65 °C.


Storage tank
Solar collector
Chiller

Experimental procedures

- **Bottom chiller in a cogeneration plant with a gas turbine and GAX ammonia-water absorption chiller as top chiller**
  - Gas turbine type Capstone C30LP with rated electricity power of 28 kWe, but actual electricity power of 26 kWe
    - Experimental results from the literature showed that when the electricity power was 26 kWe, the exhaust gas temperature was 306 °C
  - Performance of the GAX ammonia-water absorption chiller was calculated through a numerical model as available in the literature, and simulated in the software EES.
  - The operation conditions for the NH_3-H_2O chiller were as follows:
    - Evaporation temperature of 8 °C
    - Condensation temperature and minimum absorption temperature of 33 °C
    - Internal heat exchangers with efficiency of 0.7
    - Pump with isentropic efficiency of 0.9
    - Maximum temperature in the generator of 188 °C which was 10 °C below the steam temperature produced at 1.5 MPa in one of the boilers that used the waste heat from the gas turbine.



Q̇Cond
Q̇Rect
Q̇Ger
9
7
8
10
3
4
Refrigerant
heat exchanger
Solution
pump
2
W
11
13
Refrigerant
expantion device
1
Solution
expantion device
5
12
14
Q̇Evap
Evaporator
Q̇Abs
Pressure
Temperature

Performance indicators

- Important performance indicators are as follows:

$$\dot{Q}_{Cool} = \frac{\sum_{i=1}^{n} \left[\Delta t \rho_W \dot{V}_{Evap} Cp_W \left(T_{Ev,In} - T_{Ev,Out} \right) \right]_i}{t_i}$$

$$COP = \frac{\sum_{i=1}^{n} \left[\Delta t \rho_W \dot{V}_{Ev} Cp_W \left(T_{Ev,In} - T_{Ev,Out} \right) \right]_i}{\sum_{i=1}^{n} \left[\Delta t \rho_W \dot{V}_{Source} Cp_W \left(T_{Source,In} - T_{Source,Out} \right) \right]_i}$$

  - T_{In} and T_{Out} measured with RTD 1/10 DIN class with uncertainty at 0 °C of 0.03 °C + uncertainty of 0.06 C in data logger
  - $\dot{V}$ measured with flow meters FPR301 and FPR204 (Omega Engineering, Inc.), with uncertainty of 3.2×10-3 L/s + uncertainty, respectively of 2.8×10-5 L/s and 8.8×10-4 L/s in data logger.

Results

Influence of cycle time under different $T_{Ev,In}$ and $T_{Source,In}$

COP and cooling power under different operation conditions.

Cycle time (min.)	$T_{Ev,In}$ (°C)	$T_{Sink,In,Cnd}$ (°C)	$T_{Sink,In,Rect}$ (°C)	$T_{Source,In}$ (°C)	COP	$\dot{Q}_{Cool}$ (W)
68	12.0±0.2	27.4±0.1	29.1±0.7	69.9±1.8	0.28±0.3	930±50
78	12.0±0.1	28.0±0.1	29.5±0.7	69.9±1.3	0.27±0.3	840±50
88	12.0±0.1	28.4±0.1	29.9±0.8	70.0±1.4	0.32±0.3	880±50
68	12.0±0.2	27.5±0.1	29.0±0.9	75.0±1.4	0.27±0.3	940±50
68	15.1±0.1	28.4±0.1	29.7±0.4	65.0±1.4	0.32±0.3	910±50
78	15.1±0.1	27.9±0.1	29.5±0.5	65.0±1.1	0.36±0.3	1080±50
68	15.1±0.2	28.9±0.1	30.5±0.6	70.0±1.3	0.31±0.3	1050±50
78	15.0±0.1	27.6±0.1	29.6±0.7	69.9±1.4	0.34±0.3	1200±60
88	15.1±0.1	27.8±0.1	29.6±0.7	70.0±1.1	0.36±0.3	1130±50
68	15.1±0.2	28.3±0.1	30.0±0.8	75.1±1.8	0.28±0.3	1080±60

Results

Influence of $T_{Source,In}$ under different $T_{Ev,In}$ and cycle time

COP and cooling power under different operation conditions.

Cycle time (min.)	$T_{Ev,In}$ (°C)	$T_{Sink,In,Cnd}$ (°C)	$T_{Sink,In,Rect}$ (°C)	$T_{Source,In}$ (°C)	COP	$\dot{Q}_{Cool}$ (W)
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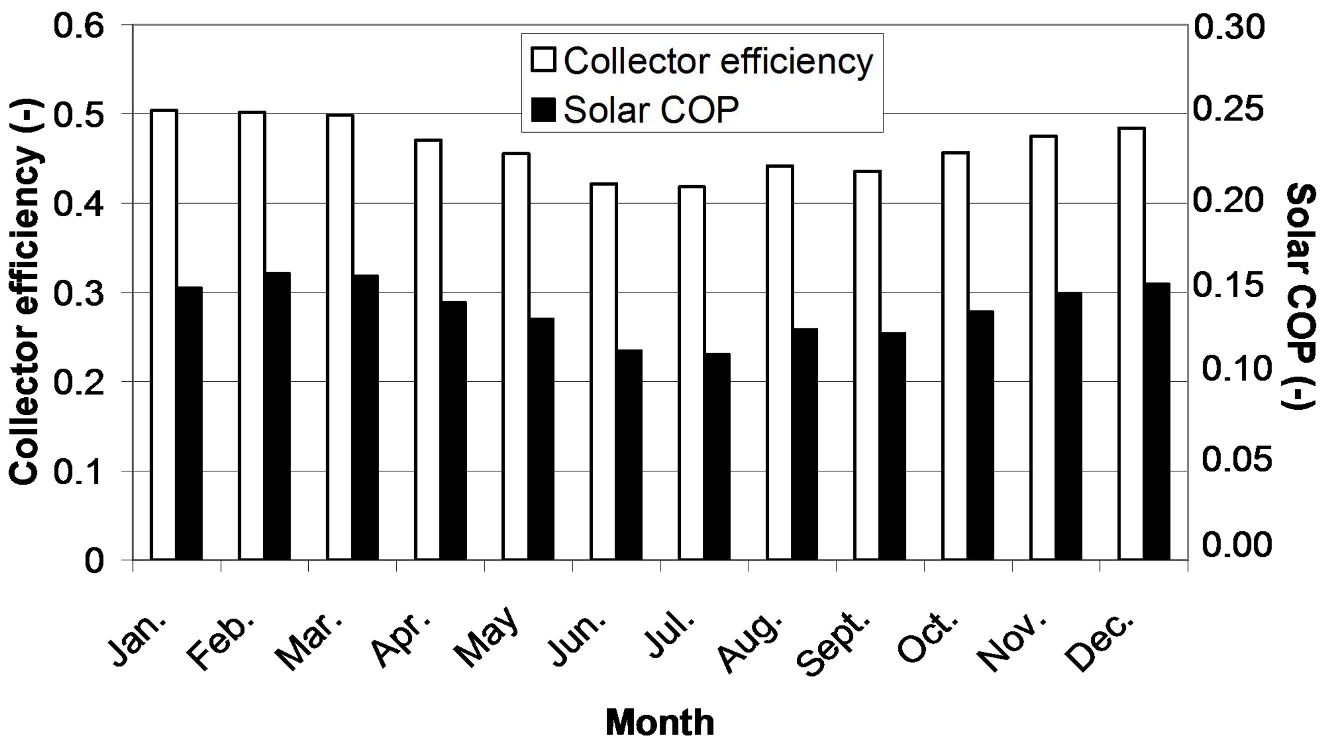
Results

- The increase of cycle time increased COP by 14 % to 16 %
- 78 min cycle led to minimum values of cooling power when $T_{Ev,In}$ = 12 °C, but to maximum values when $T_{Ev,In}$ = 15 °C.
- Differences between the maximum and minimum cooling power obtained in similar conditions with exception of the cycle time, ranged from 11 % to 14 %.
- From these results, it is suggested that cycles with 88 minutes are preferred if COP should be maximized.

Results

- In a **solar air conditioning system in Florianópolis**
  - Monthly solar COP from 0.12 to 0.16
  - Highest solar COP obtained in February (21 MJ/m²/day) and the lowest one in July (13.8 MJ/m²/day).



Monthly collector efficiency and solar COP of an air conditioning system in the city of Florianópolis, Brazil.

Results

COP and cooling power under different operation conditions.

Cycle time (min.)	$T_{Ev,In}$ (°C)	$T_{Sink,In,Cnd}$ (°C)	$T_{Sink,In,Rect}$ (°C)	$T_{Source,In}$ (°C)	COP	$\dot{Q}_{Cool}$ (W)
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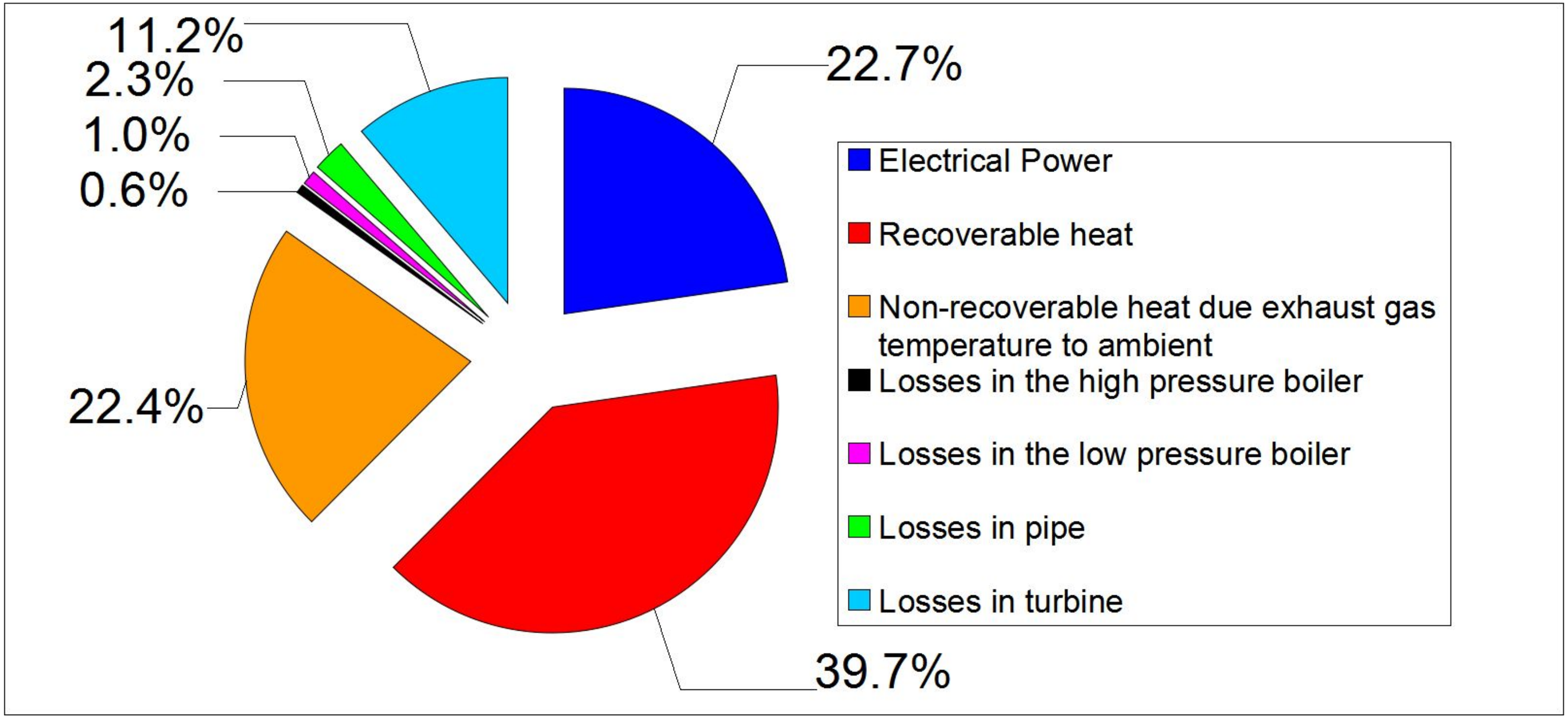
Results

- **In a cogeneration system**



Results

- Recover of 45.4 kW (39.7 %) of the combustion power, if it was used directly in another process.
- When used as source for an absorption GAX chiller (COP = 1.48) and for the chemisorption chiller (COP = 0.36)
  - Cooling power production of 35.7 kW
  - total recovered power was 31 % from the combustion power (78.6 % from the possible recovery)
- If absorption GAX chiller (COP = 0.71)
  - Total recovered heat was 19 % from the combustion power
- Regardless the technology used to recover heat
  - 22.4 % of the heat cannot be recovered
    - discharge temperature of the gas (120 °C).

Conclusion

- Design and construction of a chemisorption chiller that can be driven by hot water from 65 °C.
  - Maximum cooling power (1200 W) with cycle time of 78 min. and $T_{Source,In}$ of 70 °C
  - Maximum COP (0,36) with cycle time of 88 min. and $T_{Source,Inc}$ of 70 °C or 78 min. and $T_{Source,In}$ of 65 °C
- If applied to a solar air conditioning system in Florianópolis , Brazil (daily irradiation between 13.8 and 22.4 to $MJ/m^2/day$)
  - Solar COP between 0.12 and 0.16
- If applied as bottom chiller in a cogeneration system with gas turbine
  - Total heat recovered for coooling production between 19 and 31 % of the input energy, depending on the COP of the top cycle chiller
  - 22,4 % of input energy cannot be recovered regardless the technology

Acknowledge

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Thank you for your attention!