

# ANALYSIS OF AQUA-AMMONIA POWER CYCLES FOR COGENERATION APPLICATIONS

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**Abstract.** It is shown that the use of an aqua-ammonia absorption power cycle as bottoming cycle for a cogeneration plant may result in an economic advantage. Two absorption power cycles were investigated - a Rankine cycle and a Kalina cycle. In order to establish a consistent comparison these cycles were optimized using as goal function the exergoeconomic unitary cost of the electricity produced by both the cogeneration plant and the absorption cycle. The Zoutendijk method of feasible directions was used for this optimization. Obtained results show that when the Rankine cycle is used the generated net power increases in 3.18% and the unitary cost of electricity diminishes in 3.06%. For the case of Kalina cycle the corresponding obtained values were 3.26% and 3.14%, respectively.

**Keywords.** Absorption power cycles; Exergoeconomic analysis; Exergoeconomic optimization.

## 1. Introduction

Judging from economic and environmental considerations it becomes evident how important it is to improve the efficiency of thermo-energetic systems, particularly in power and refrigeration cycles. One way of achieving this objective is by using absorption cycles.

Conventional cycles use a pure substance as a working fluid. When a pure substance undergoes a constant pressure phase change its temperature also remains constant. On the other hand, when absorption mixtures are used as a working fluid, a constant pressure phase change occurs with changes in composition of each phase, resulting in temperature variations. This behavior allows for a reduction in the temperature difference between the hot and cold streams flowing through an evaporator, diminishing the irreversibilities associated to the heat transfer process.

The aqua-ammonia mixtures have been used in the industry for over a 100 years as a working fluid for refrigeration systems. Its use in power cycles is a relatively recent one, being proposed initially by Kalina (1983). Literature reports a great deal of publishing about absorption cycles for power generation. Ibrahim (1996) presented an energetic analysis of three absorption power cycles with the purpose of evaluating the maximum work that can be obtained from two streams at different temperatures. Ibrahim & Klein (1996) presented a comparative study of Kalina and Maloney-Robertson cycles focusing on energetic aspects. Nag & Gupta (1998) presented an exergetic analysis of a modified Kalina cycle. In the works of Dejfors, Thorin & Svedberg (1998) and Johnsson & Yan (2001) energy analyses of aqua-ammonia absorption power cycles used in cogeneration plants are presented.

What is presented in this work is a comparison between the Rankine and Kalina absorption power cycles (Figure 1), used as bottoming cycles for the cogeneration plant described in the CGAM problem definition (Valero et al., 1996). The studied system is shown in Figure 2. For this comparison an exergoeconomic optimization was made, aiming to diminish the cost of total generated power. The exergoeconomic analysis was based on the exergetic cost theory (Lozano & Valero, 1993).

Anywhere in this paper  $T$  is referred to temperature,  $p$  to pressure,  $\dot{m}$  to mass flow,  $\dot{W}$  to power,  $\dot{Q}$  to heat transfer,  $h$  to specific enthalpy,  $s$  to specific entropy,  $e$  to specific exergy,  $\eta$  to isentropic efficiency,  $y$  to ammonia mass fraction,  $I$  to irreversibility rate,  $\varepsilon$  to exergetic efficiency and  $\Delta T_{\ln}$  to the log mean temperature difference.

## 2. Aqua-ammonia Properties

For the evaluation of aqua-ammonia thermodynamic properties it was followed, mainly, the development given by Jordan (1996) based on the work of Ziegler & Trepp (1984). The latter authors used the fugacity concept while Jordan, in his work, recalculated the coefficients in the original equations to match the chemical potential concept. This reevaluation was made utilizing the experimental data given by Gillespie et al. (1983). The chemical potential concept allows the use of equations based in Gibbs free energy, which give easy ways to calculate other thermodynamic properties. In order to appropriately model the aqua-ammonia mixture, the Gibbs free energy equation is composed by three terms: one that represents the Euler's theorem; one representing that ideal solution model; and another one that represents the excess Gibbs energy term, which allows better fit in liquid regions.

One remarkable characteristic of the chemical potential concept is the possibility of using the concentration of ammonia (or water) in the mixture found in saturation points to determine the mixture phase. This is done by comparing the ammonia concentration in the mixture with the corresponding values in the saturation points. Figure 2 shows a temperature-concentration diagram for an aqua-ammonia mixture (with ammonia concentration in the x-axis) where can be seen three points (A, B and C) corresponding to a mixture in liquid, liquid-vapor and vapor phases, respectively.

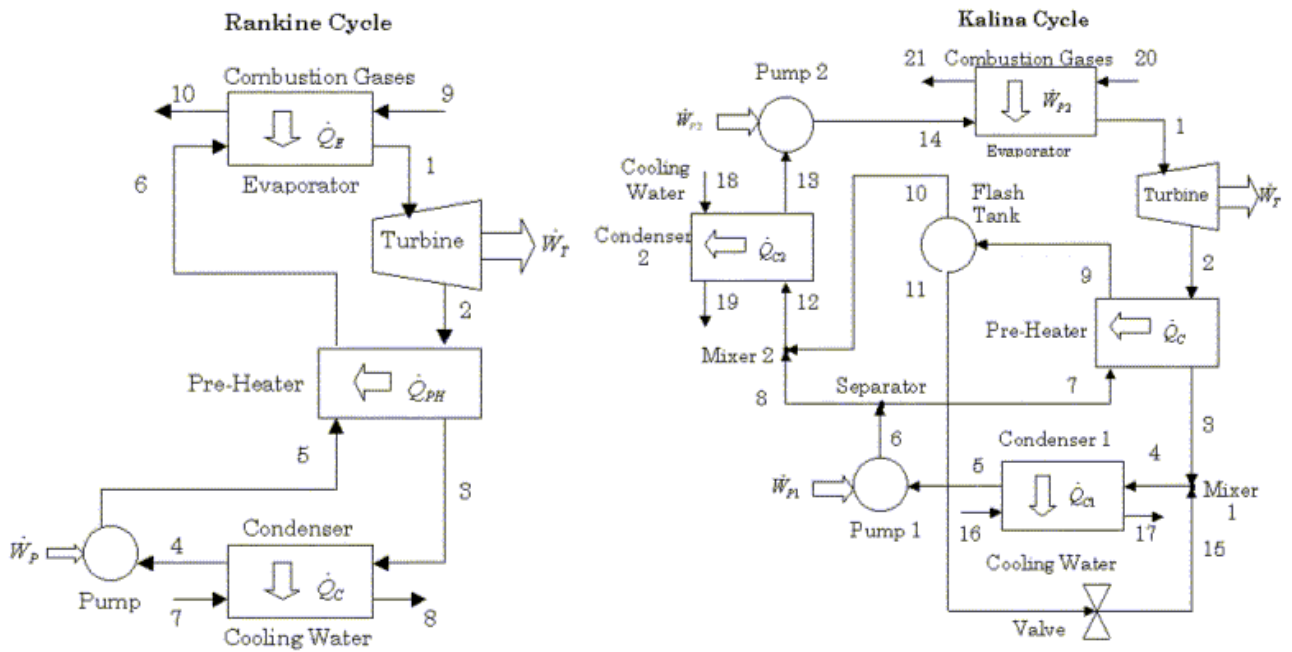


Figure 1 – Rankine and Kalina absorption power cycle.

It can also be seen the corresponding values for the molar fractions in the saturation points. By comparison with these points and the molar fraction of the three points the phase is determined. Additionally, the quality of the mixture can be expressed as a function of the mass fractions of the components by this way:

$$x = \frac{y - y_{sat.liq.}}{y_{sat.vap.} - y_{sat.liq.}} \quad (1)$$

where  $x$  is the quality of the saturated mixture and  $y$  is the mass fraction of ammonia inside mixture.

Despite the fact that the phase determination and the quality concept described here are as simple as to a pure substance, none of the thermodynamic properties routines reported in the searched literature includes them.

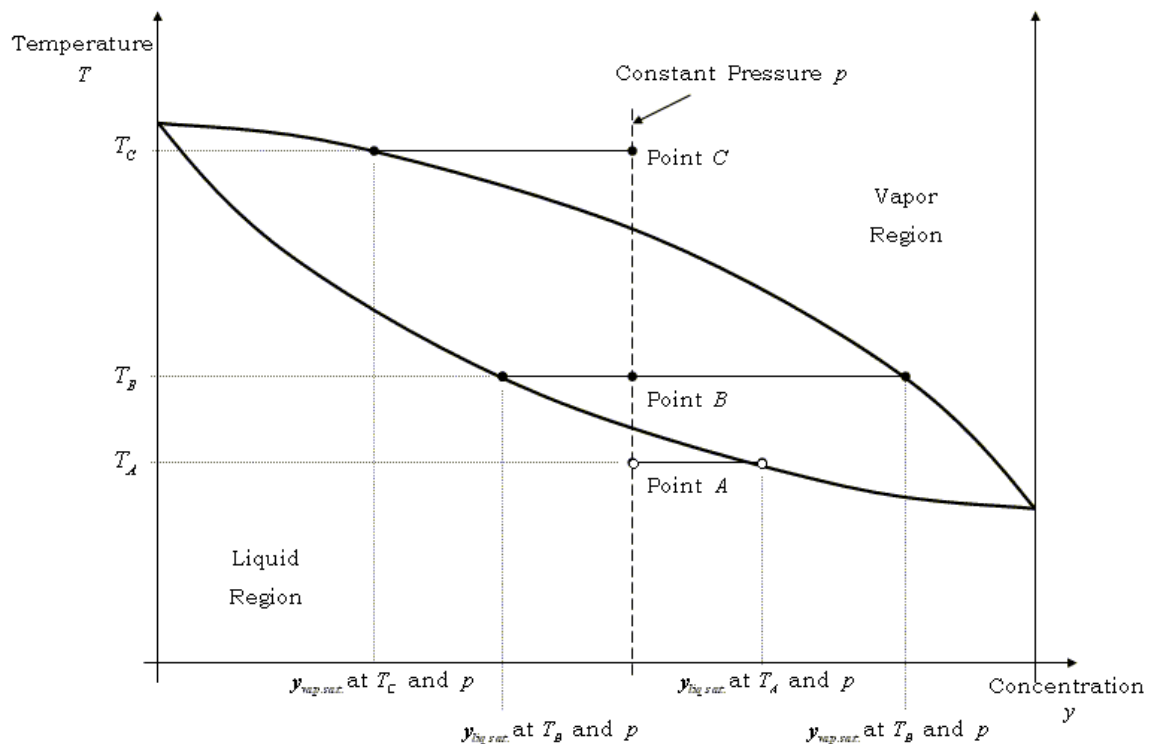


Figure 2 – Temperature-concentration diagram for an aqua-ammonia mixture.

In the analysis of thermoenergetic systems involving mixtures it is necessary to evaluate the chemical exergy of each state the system pass through. To take into account the chemical exergy is important since the mixture composition varies and, consequently, the chemical exergy of the mixture also varies. It is worth mentioning that the evaluation of chemical exergy is unnecessary in the case of cycles using pure substances as working fluids. The chemical exergy is evaluated by:

$$\bar{e}_i^{CH} = \bar{e}_{0,i}^{CH} + RT_0 \ln \bar{y}_i \quad (2)$$

where  $\bar{e}_i^{CH}$  is the molar specific exergy,  $\bar{e}_{0,i}^{CH}$  is the standard chemical exergy,  $R$  is the universal gas constant,  $T_0$  is the reference environment temperature and  $\bar{y}_i$  is the molar fraction of the component  $i$ .

### 3. Absorption Cycles Analysis

For a thermodynamic analysis of Rankine and Kalina cycles the following hypotheses were assumed: steady state operation; there is no stray heat transfer from any component to its surroundings; constant combustion gases specific heats; constant cooling water specific heat; negligible head loss in pipelines; the reference environment corresponds to the model proposed by Szargut, Morris & Steward (1988); kinetic and potential energy effects are negligible.

The following are the hypothesis assumed for the economical analysis: the absorption cycle fuel cost is the cost of combustion gases leaving the steam generator of the cogeneration plant (Figure 3); the purchased equipment costs ( $PEC$ ) are obtained from equations shown in Table 1; the operation and maintenance costs are negligible; the external economic assessment in each unit is calculated this way:

$$\dot{Z}_k = \frac{PEC_k}{t} \quad (3)$$

where  $PEC_k$  is the purchased equipment cost of equipment  $k$  and  $t$  is the operating time per year.

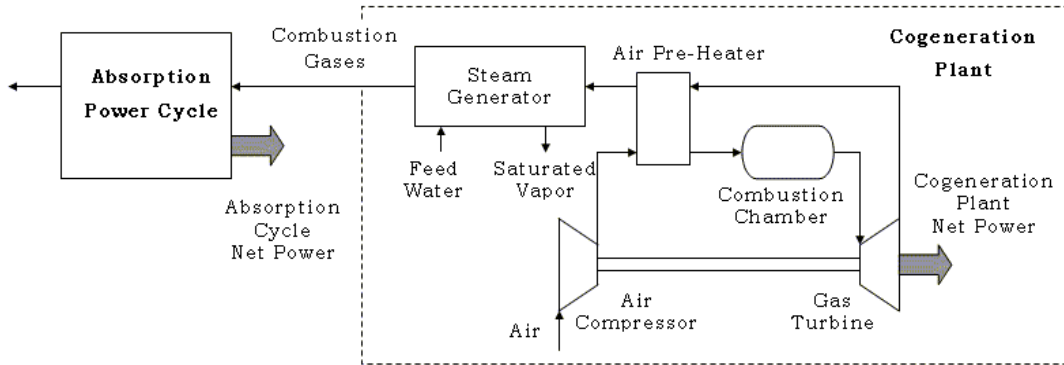


Figure 3 – Combined system cogeneration plant-absorption power cycle.

Table 2 shows the equations used for the energy and exergy analyses of absorption cycles. It is worth mentioning that in order to define meaningful second law efficiencies the condenser was associated to the pump forming an only unit, as it is recommended by Tsatsaronis (1993). Tables 3 and 4 show the data used for the exergoeconomic analysis.

Table 1 – Equations for economic model.

PUMP	$PEC = \left( \frac{C_{11} \dot{m}}{C_{12} - \eta_P} \right) \left( \frac{p_2}{p_1} \right) \ln \left( \frac{p_2}{p_1} \right)$	$C_{11} = 50 [$/(\text{kg/s})]$ $C_{12} = 0,9$
TURBINE	$PEC = \left( \frac{C_{31} \dot{m}}{C_{32} - \eta_T} \right) \ln \left( \frac{p_2}{p_1} \right) \left[ 1 + e^{(C_{33} T_1 - C_{34})} \right]$	$C_{31} = 5000 [$/(\text{kg/s})]$ $C_{32} = 0,92$ $C_{33} = 0,05 [\text{K}^{-1}]$ $C_{34} = 50$
HEAT EXCHANGERS	$PEC = C_{41} \left( \frac{\dot{Q}}{U \Delta T_{\ln}} \right)^{0,6}$	$C_{41} = 5000 [$/(\text{m}^2)]$ $U = 1000 [\text{W}/\text{m}^2\text{K}]$
Values adapted from Valero et al. (1996) for the case of an aqua-ammonia absorption cycle.		

Table 2 – Equations for energy and exergy analysis.

ENERGY ANALYSIS		EXERGY ANALYSIS	
RANKINE ABSORPTION CYCLE			
Turbine	$\dot{W}_T = \dot{m}_1(h_1 - h_2)$ $s_{2s} = s_1$ $h_2 = h_1 - \eta_T(h_1 - h_{2s})$	Turbine	$\dot{I}_T = \dot{m}_1(e_1 - e_2) - \dot{W}_T$ $\varepsilon_T = \dot{W}_T / \dot{m}_1(e_1 - e_2)$
Pre-Heater	$\dot{Q}_{PH} = -\dot{m}_1(h_2 - h_3) = \dot{m}_1(h_3 - h_6)$	Pre-heater	$\dot{I}_{PH} = [\dot{m}_1(e_2 - e_3) + \dot{m}_1(e_5 - e_6)]$ $\varepsilon_{PH} = \dot{m}_1(e_5 - e_6) / \dot{m}_1(e_2 - e_3)$
Condenser	$\dot{Q}_C = -\dot{m}_1(h_3 - h_4) = \dot{m}_7 c_{p7}(T_7 - T_8)$	Condenser-Pump	$\dot{I}_C = [\dot{m}_1(e_3 - e_4) + \dot{m}_7(e_7 - e_8)]$ $\dot{I}_P = \dot{m}_1(e_4 - e_5) - \dot{W}_P$ $\varepsilon_{CP} = \frac{[\dot{m}_7(e_7 - e_8) + \dot{m}_1(e_4 - e_5)]}{[\dot{m}_1(e_3 - e_4) + \dot{W}_P]}$
Pump	$\dot{W}_P = \dot{m}_1(h_4 - h_5)$ $s_{5s} = s_4$ $h_5 = h_4 - (h_4 - h_{5s}) / \eta_P$		
Evaporator	$\dot{Q}_E = -\dot{m}_1(h_6 - h_1) = \dot{m}_9 c_{p9}(T_9 - T_{10})$	Evaporator	$\dot{I}_E = [\dot{m}_1(e_6 - e_1) + \dot{m}_9(e_9 - e_{10})]$ $\varepsilon_E = \dot{m}_1(e_6 - e_1) / \dot{m}_9(e_9 - e_{10})$
KALINA ABSORPTION CYCLE			
Turbine	$\dot{W}_T = \dot{m}_1(h_1 - h_2)$ $s_{2s} = s_1$ $h_2 = h_1 - \eta_T(h_1 - h_{2s})$	Turbine	$\dot{I}_T = \dot{m}_1(e_1 - e_2) - \dot{W}_T$ $\varepsilon_T = \dot{W}_T / \dot{m}_1(e_1 - e_2)$
Pre-Heater	$\dot{Q}_{PH} = -\dot{m}_1(h_2 - h_3) = \dot{m}_7(h_7 - h_9)$	Pre-heater	$\dot{I}_{PH} = [\dot{m}_1(e_2 - e_3) + \dot{m}_7(e_7 - e_9)]$ $\varepsilon_{PH} = \dot{m}_7(e_7 - e_9) / \dot{m}_1(e_2 - e_3)$
Mixer 1	$\dot{m}_1 + \dot{m}_{11} = \dot{m}_4$ $\dot{m}_1 y_1 + \dot{m}_{11} y_{11} = \dot{m}_4 y_4$ $\dot{m}_1 h_3 + \dot{m}_{11} h_{15} = \dot{m}_4 h_4$	Mixer 1	$\dot{I}_{M1} = [(\dot{m}_1 e_3 + \dot{m}_{11} e_{15}) - \dot{m}_4 e_4]$ $\varepsilon_{M1} = \dot{m}_4 e_4 / (\dot{m}_1 e_3 + \dot{m}_{11} e_{15})$
Condenser 1	$\dot{Q}_{C1} = -\dot{m}_1(h_4 - h_5) = \dot{m}_{16} c_{p16}(T_{16} - T_{17})$	Condenser 1-Pump 1	$\dot{I}_{C1} = [\dot{m}_4(e_4 - e_5) + \dot{m}_{16}(e_{16} - e_{17})]$ $\dot{I}_{P1} = \dot{m}_4(e_5 - e_6) - \dot{W}_{P1}$ $\varepsilon_{CP1} = \frac{[\dot{m}_{16}(e_{16} - e_{17}) + \dot{m}_4(e_5 - e_6)]}{[\dot{m}_4(e_4 - e_5) + \dot{W}_{P1}]}$
Pump 1	$\dot{W}_{P1} = \dot{m}_4(h_5 - h_6)$ $s_{6s} = s_5$ $h_6 = h_5 - (h_5 - h_{6s}) / \eta_{P1}$		
		Separator	$\dot{I}_S = [\dot{m}_4 e_6 - (\dot{m}_7 e_7 + \dot{m}_8 e_8)]$ $\varepsilon_S = (\dot{m}_7 e_7 + \dot{m}_8 e_8) / \dot{m}_4 e_6$
Flash Tank	$\dot{m}_7 = \dot{m}_{10} + \dot{m}_{11}$	Flash tank	$\varepsilon_{FT} = (\dot{m}_{10} e_{10} + \dot{m}_{11} e_{11}) / \dot{m}_7 e_9$ $\dot{I}_{FT} = [\dot{m}_7 e_9 - (\dot{m}_{10} e_{10} + \dot{m}_{11} e_{11})]$
Mixer 2	$\dot{m}_8 + \dot{m}_{10} = \dot{m}_1$ $\dot{m}_8 y_4 + \dot{m}_{10} y_{10} = \dot{m}_1 y_1$ $\dot{m}_8 h_8 + \dot{m}_{10} h_{10} = \dot{m}_1 h_{12}$	Mixer 2	$\dot{I}_{M2} = [(\dot{m}_8 e_8 + \dot{m}_{10} e_{10}) - \dot{m}_1 e_{12}]$ $\varepsilon_{M2} = \dot{m}_1 e_{12} / (\dot{m}_8 e_8 + \dot{m}_{10} e_{10})$
Condenser 2	$\dot{Q}_{C2} = -\dot{m}_1(h_{12} - h_{13}) = \dot{m}_{18} c_{p18}(T_{18} - T_{19})$	Condenser 2-Pump 2	$\dot{I}_{C2} = [\dot{m}_1(e_{12} - e_{13}) + \dot{m}_{18}(e_{18} - e_{19})]$ $\dot{I}_{P2} = \dot{m}_1(e_{13} - e_{14}) - \dot{W}_{P2}$ $\varepsilon_{CP2} = \frac{[\dot{m}_{18}(e_{18} - e_{19}) + \dot{m}_1(e_{13} - e_{14})]}{[\dot{m}_1(e_{12} - e_{13}) + \dot{W}_{P2}]}$
Pump 2	$\dot{W}_{P2} = \dot{m}_1(h_{13} - h_{14})$ $s_{14s} = s_{13}$ $h_{14} = h_{13} - (h_{13} - h_{14s}) / \eta_{P2}$		
Evaporator	$\dot{Q}_E = -\dot{m}_1(h_{14} - h_1) = \dot{m}_{20} c_{p20}(T_{20} - T_{21})$	Evaporator	$\dot{I}_E = [\dot{m}_1(e_{14} - e_1) + \dot{m}_{20}(e_{20} - e_{21})]$ $\varepsilon_E = \dot{m}_1(e_{14} - e_1) / \dot{m}_{20}(e_{20} - e_{21})$
Valve	$h_{11} = h_{15}$	Valve	$\dot{I}_V = \dot{m}_{11}(e_{11} - e_{15})$ $\varepsilon_V = \dot{m}_{11} e_{15} / \dot{m}_{11} e_{11}$

Table 3 – Data for thermodynamic analysis.

TEMPERATURE	Condenser inlet	298.15 K
	Condenser outlet	320 K
	Evaporator inlet	427 K
	Evaporator outlet	350 K
SPECIFIC HEATS	Cooling water	4183 J/kgK
	Combustion Gases	1240 J/kgK
ISENTROPIC EFFICIENCY	Turbine	0.9
	Pump	0.85

Table 4 – Cogeneration cycle data (from Bejan, Tsatsaronis & Moran (1996)).

COMBUSTION GASES MASS FLOW	$\dot{m}_{CP}$	91.28 kg/s
COGENERATION PLANT NET POWER	$\dot{W}_{CP}$	30 MW
COGENERATION PLANT POWER COST	$\dot{C}_{CP}$	67.53 \$/MW·h
COMBUSTION GASES COST	$\dot{C}_F$	0.0020363 \$/s

#### 4. Exergoeconomic Optimization

The Zountendijk method of feasible directions was used to optimize the absorption power cycles. For this optimization the cost of the net power produced by the combined system formed of the cogeneration plant and the absorption cycle ( $C_t$ ) was chosen as the goal function. This cost was calculated through the following expression

$$C_t = \frac{\dot{W}_{CP} C_{CP} + \dot{W}_{net} C_{AC}}{\dot{W}_{CP} + \dot{W}_{net}} \quad (4)$$

where  $\dot{W}_{CP}$  is the net power produced by the cogeneration plant;  $\dot{W}_{net}$  is the net power generated by the absorption cycle;  $C_{CP}$  is the unitary cost of the net power produced by the cogeneration plant [\$/MW·h] and  $C_{AC}$  is the unitary cost of the net power produced by the absorption cycle [\$/MW·h].

The parameters that have been changed to optimize Rankine and Kalina absorption cycles are shown in Table 5.

Table 5 – Optimization variables for the absorption cycle.

	RANKINE CYCLE	KALINA CYCLE
TEMPERATURE	$T_1$ (Turbine inlet) $T_3$ (Condenser inlet) $T_4$ (Pump inlet)	$T_1$ (Turbine inlet) $T_5$ (Pump 1 inlet) $T_9$ (Flash tank inlet) $T_{13}$ (Pump 2 inlet)
PRESSURE	$p_1$ (High pressure) $p_2$ (Low pressure)	$p_1$ (High) $p_2$ (Low) $p_6$ (Intermediary)
AMMONIA MASS FRACTION	$y_1$	$y_1$ (Basic) $y_4$ (Intermediary)
MASS FLOW	$\dot{m}_1$	$\dot{m}_1$ (Basic)

To make convergence easier in the optimizing process, dimensionless variables having the same order of magnitude were defined dividing pressure and temperature variables by reference values ( $p_{ref} = 2 \times 10^6$  Pa and  $T_{ref} = 300$  K).

## 5. Results

Figure 4 shows the goal function convergence. In order to reach converged solution of the Rankine cycle 43 iterations and 254 evaluations of the goal function were needed, while in the case of Kalina cycle 20 iterations and 229 evaluations of goal function were necessary.

Figure 5 shows the variation of the absorption cycles net power during the convergence to optimized solution. It may be noticed that in the case of Rankine cycle the final value resulted approximately twice the initial trial value, while in the case of Kalina cycle the final value resulted approximately 25% bigger than the initial value.

During the optimization process the turbine pressure ratio increased and the turbine mass flow decreased (in comparison to initial values). It is worth noting that the increase in the turbine pressure ratio increases the produced power as well as the turbine purchase cost. On the other hand, the lower the turbine mass flow the smaller the produced power and the turbine purchase cost. The obtained final values of the turbine pressure ratio and of the turbine mass flow are those that guarantee the better cost-benefit relation as defined by the goal function.

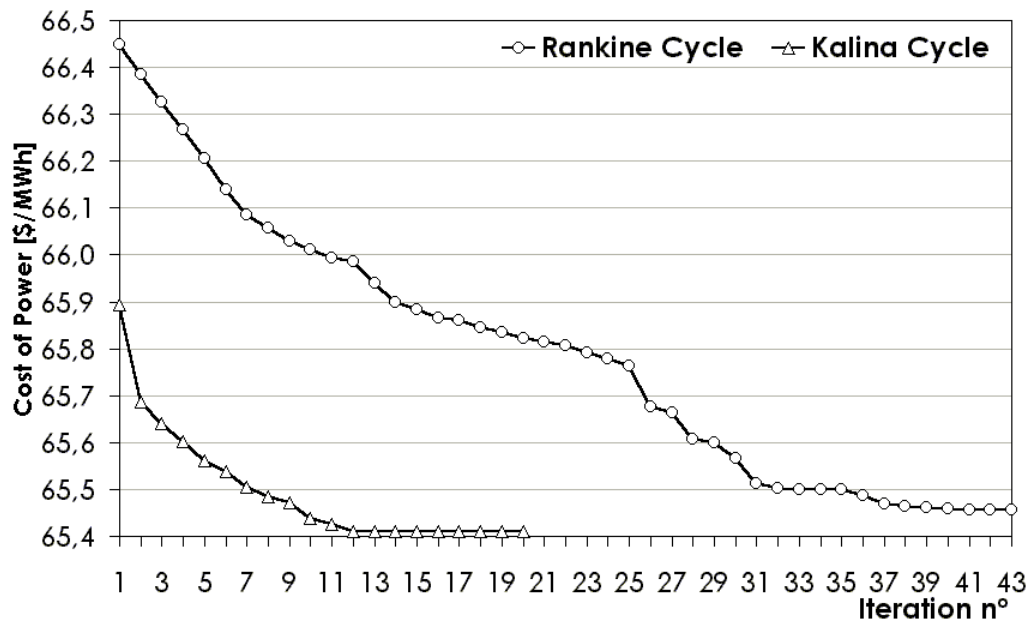


Figure 4 – Target function convergence.

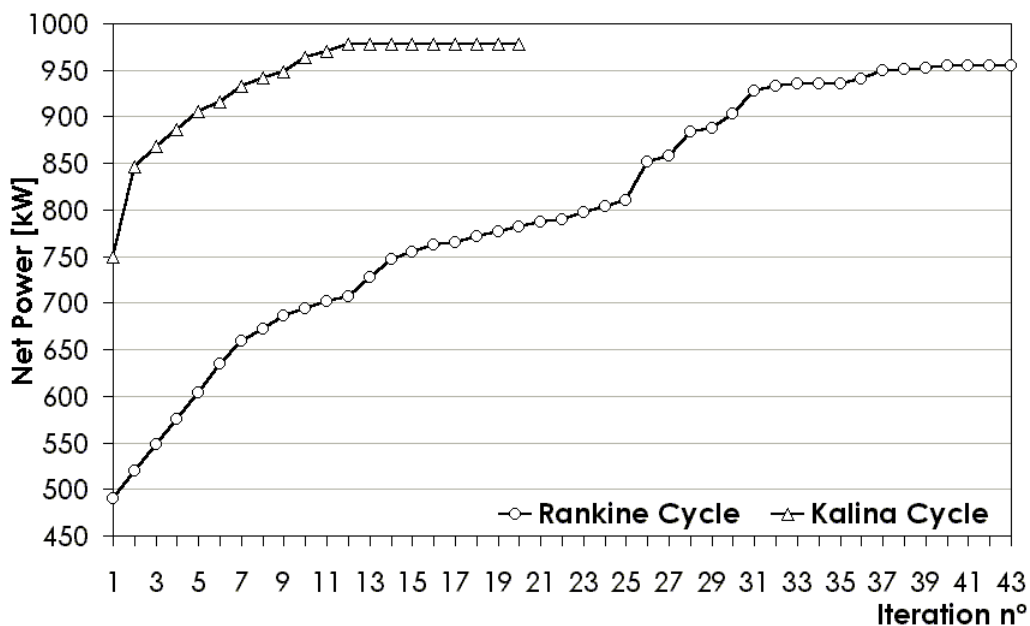


Figure 5 – Net power produced by absorption cycles.

Values shown in Table 6 correspond to main thermodynamic states of the optimized Rankine absorption cycle and the values in Table 7 are the relevant performance parameters for this cycle. It is interesting to notice that during the optimization process the irreversibilities increased in some components and decreased in others. In the case of the turbine the irreversibility almost doubled while in the evaporator the irreversibility decreased to approximately 23% of its initial value. During the optimization process the total cycle irreversibility decreases significantly going from 1226kW to 778kW while the energy and exergy plant efficiencies almost doubled.

Table 6 – Data for optimized Rankine cycle.

TEMPERATURE [K]	$T_1$	421.77
	$T_2$	389.62
	$T_3$	325.232
	$T_4$	308.19
	$T_5$	308.40
	$T_6$	345.00
	$T_7$	298.15
	$T_8$	320
	$T_9$	427
	$T_{10}$	350
PRESSURE [kPa]	$p_1$	2177.67
	$p_2$	1176.74
MASS FLOW [kg/s]	$\dot{m}_1$	9.92
	$\dot{m}_7$	84.90
	$\dot{m}_9$	91.28
AMMONIA MASS FRACTION	$y_1$	0.862
NET POWER [kW]	$\dot{W}_{net}$	955.32

Table 7 – Irreversibilities and efficiencies for optimized Rankine cycle.

		INITIAL	FINAL
IRREVERSIBILITY [kW]	$\dot{I}_T$	42.793	83.597
	$\dot{I}_{PH}$	396.971	455.911
	$\dot{I}_{C1}$	174.357	97.778
	$\dot{I}_{P1}$	1.860	3.937
	$\dot{I}_E$	609.993	137.121
	$\dot{I}_{Total}$	1225.973	778.344
EXERGETIC EFFICIENCY	$\varepsilon_T$	92.16%	92.16%
	$\varepsilon_{PH}$	48.40%	63.61%
	$\varepsilon_{CP1}$	58.30%	62.60%
	$\varepsilon_E$	69.56%	93.16%
CYCLE EFFICIENCY	$\eta$	5.63%	10.96%
	$\varepsilon$	24.48%	47.65%

Tables 8 and 9 are similar to Tables 6 and 7 and show the obtained results for the case of the optimized Kalina cycle. It may be noticed that exergy destruction is smaller in the Kalina cycle than in the Rankine cycle.

Table 8 – Data for optimized Kalina cycle.

TEMPERATURE [K]	$T_1$	421.64
	$T_2$	368.42
	$T_3$	323.51
	$T_4$	325.69
	$T_5$	303.81
	$T_6$	303.60
	$T_7$	303.60
	$T_8$	303.60
	$T_9$	352.54
	$T_{10}$	352.54
	$T_{11}$	352.54
	$T_{12}$	334.05
	$T_{13}$	308.52
	$T_{14}$	308.41
	$T_{15}$	326.44
PRESSURE [kPa]	$p_1$	1048.807
	$p_2$	216.997
	$p_6$	648.957
MASS FLOW [kg/s]	$\dot{m}_1$	4.11
	$\dot{m}_4$	14.15
	$\dot{m}_7$	11.47
	$\dot{m}_8$	2.68
	$\dot{m}_{10}$	1.42
	$\dot{m}_{11}$	10.05
	$\dot{m}_{16}$	61.06
	$\dot{m}_{18}$	23.60
	$\dot{m}_{20}$	91.28
AMMONIA MASS FRACTION	$y_1$	0.587
	$y_4$	0.394
	$y_{10}$	0.952
	$y_{11}$	0.315
NET POWER [kW]	$\dot{W}_{net}$	977.875

In Table 10 is made a comparison between the combined system (cogeneration plant plus absorption cycle) and the original cogeneration plant. This table shows that the use of an absorption power cycle as bottoming cycle reduces the power cost while increases the net power production.

## 6. Conclusions

In the presented study the absorption Rankine and Kalina bottoming cycles for a cogeneration plant were analyzed and compared. These absorption cycles make it possible to produce additional power by recovering the energy contained in the combustion gases stream that leaves the cogeneration plant at a relatively low temperature (427K). For the comparison to be consistent, both these cycles were optimized. The obtained results show that the Rankine cycle allows for a net produced power increase of 3.18% (going from 30MW to 30.96MW) and for a reduction in net power



cost of 3.07% (going from 67.530\$/MW·h to 65.457\$/MW·h). In the case of the Kalina cycle the generated power increased in 3.26% (going from 30MW to 30.978MW) and the net power cost decreased in 3.14% (going from 67.530\$/MW·h to 65.409\$/MW·h).

Table 9 – Irreversibilities and efficiencies for optimized Kalina cycle.

IRREVERSIBILITY [kW]	$\dot{I}_T$	89.696
	$\dot{I}_{PH}$	188.229
	$\dot{I}_{M1}$	0.530
	$\dot{I}_{C1}$	90.110
	$\dot{I}_{P1}$	3.475
	$\dot{I}_S$	0
	$\dot{I}_{FT}$	0
	$\dot{I}_{M2}$	22.377
	$\dot{I}_{C2}$	69.944
	$\dot{I}_{P2}$	0.832
	$\dot{I}_E$	224.323
	$\dot{I}_V$	67.058
	$\dot{I}_{Total}$	756.576
EXERGETIC EFFICIENCY	$\epsilon_T$	91.82%
	$\epsilon_{PH}$	73.46%
	$\epsilon_{M1}$	99.85%
	$\epsilon_{CP1}$	56.64%
	$\epsilon_S$	100.00%
	$\epsilon_{FT}$	100.00%
	$\epsilon_{M2}$	94.50%
	$\epsilon_{CP2}$	46.65%
	$\epsilon_E$	88.81%
	$\epsilon_V$	68.44%
CYCLE EFFICIENCY	$\eta$	11.22%
	$\epsilon$	48.78%

Table 10 – Net power and cost of generated power.

	Net power cost [\$/MWh]		Net power [MW]	
Cogeneration Plant	67.530	-	30.000	-
Cogeneration Plant + Rankine Cycle	65.457	-3.07%	30.955	+3.18%
Cogeneration Plant + Kalina Cycle	65.409	-3.14%	30.978	+3.26%

It is important to point out that besides the evaluated economic advantage the use of bottoming absorption cycles makes it possible to reduce exhaust gas temperature from 427K to 350K, thus diminishing the environmental impact resulting from the plant operation.

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