International Interdisciplinary Congress on Renewable Energies, Industrial Maintenance, Mechatronics and Informatics
Booklets

RENIECYT Registro Nacional de Instituciones y Empresas Científicas y Tecnológicas 1702902 CONACYT

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Title: Assessment of an Organic Rankine Cycle and a Kalina Cycle for a Single Source of Low-Enthalpy Geothermal Heat

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Editorial label ECORFAN: 607-8695
BCIERMMI Control Number: 2022-01
BCIERMMI Classification (2022): 261022-0001

Pages: 12
RNA: 03-2010-032610115700-14

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Assessment of an Organic Rankine Cycle and a Kalina Cycle for a Single Source of Low-Enthalpy Geothermal Heat

Introduction

Methodology

Results

Conclusions

References

Introduction

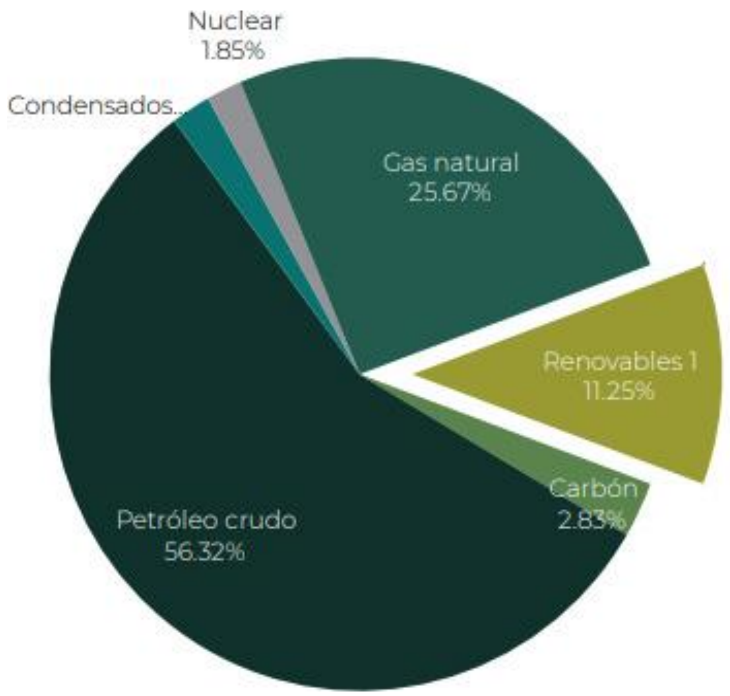


Figure 1 Production of Primary Energy in Mexico. *Source: (SENER, 2021).*

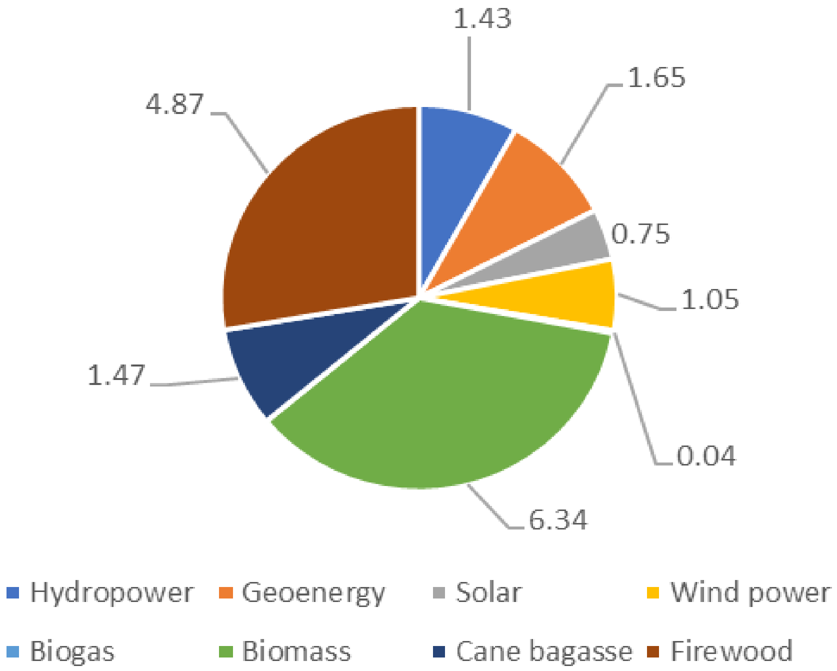
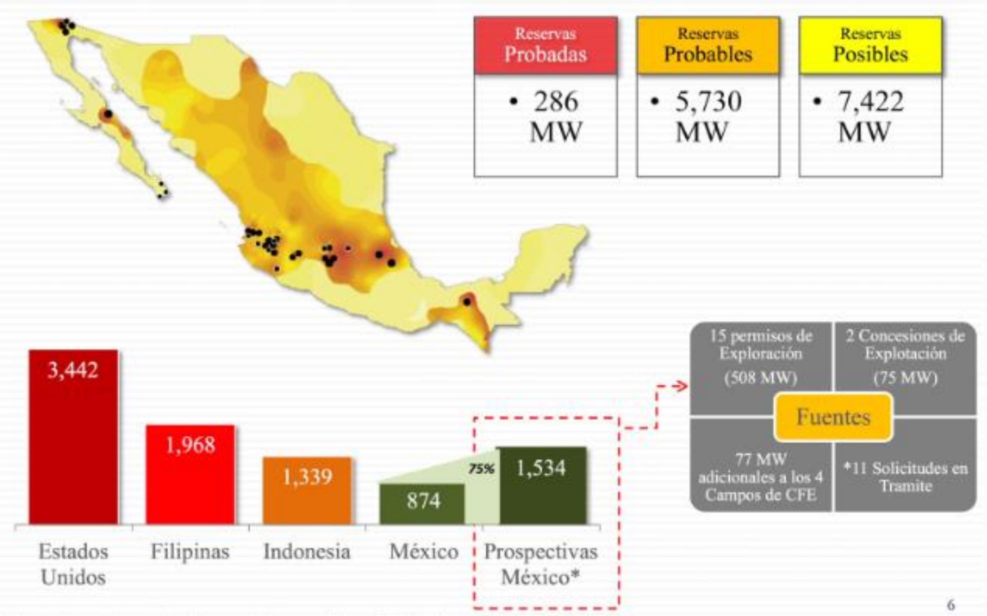


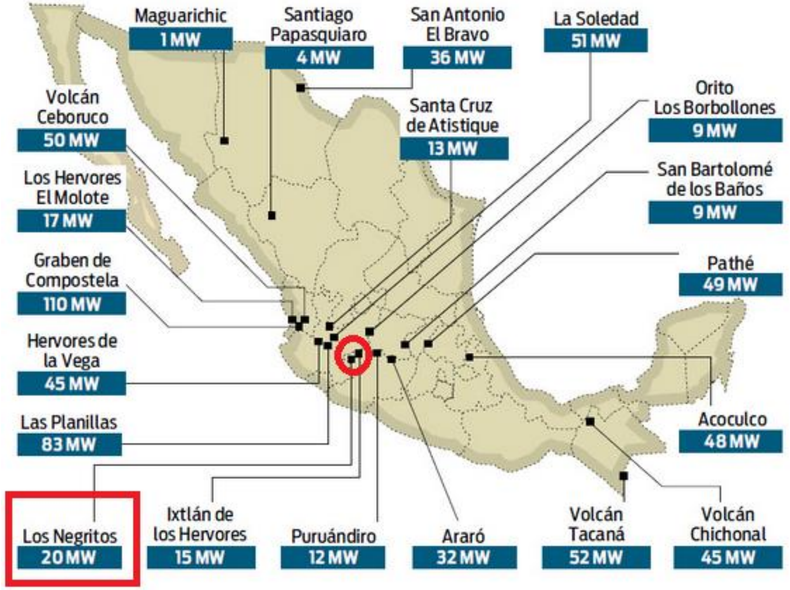
Figure 2 Contribution of Renewable Energies. Source: *(SIE, 2022)*

Campo	Capacidad (MW)	
	Instalada	Operando
Cerro Prieto, BC	570.0	570.0
Los Azufres, Mich.	247.8	224.8
Los Humeros, Pue.	120.4	80.4
Las Tres Vírgenes, BCS	10.0	10.0
Domo San Pedro, Nay.	35.5	25.5
Total	983.7	910.7

Campos Geotérmicos de México bajo explotación actual. Fuente: CFE



Potencial Geotérmico en Energía Geotérmica. Fuente: SEMARNAT



Desglose Potencial Geotérmico. Fuente: CFE

Methodology

Figure 3 Los Negritos, Villamar, Michoacán. *Source: Google Earth Adaptation*

Figure 4 Spring, Los Negritos. *Source: Author's File*

Figure 5 Mud Volcano, Los Negritos. *Source: Author's File.*

Figure 6 Geothermal Manifestation, Los Negritos. *Source: Author's File.*

Methodology

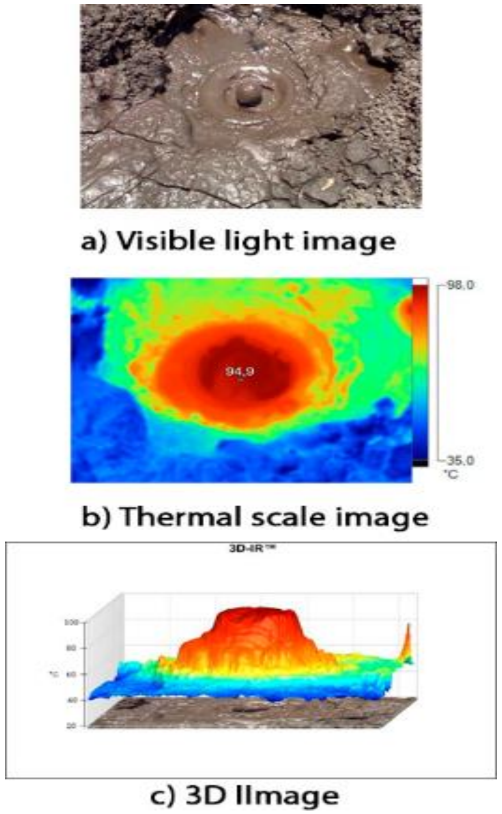


Figure 7 Primary Plain, Los Negritos. *Source: Author's File*.

Table 1 Conditions and Considerations for the ORC and Kalina Cycle Simulations

Temperature of the geothermal source	92 °C
Temperature difference in the steam generator	10 °C
Temperature difference in the condenser	10 °C
Isentropic efficiency of the steam turbine	85 %
Isentropic efficiency of the pump	80 %
Efficiency of the electric generator	96 %
Effectiveness of the steam generator	100 %
Effectiveness of the heat exchanger inside the greenhouse	70 %
Effectiveness of the regenerator (Kalina)	70 %
Mass flow rate of the geothermal fluid	1 kg/s

Methodology

Table 2 Equations used for the ORC and Kalina cycle simulations (eqn. 1–15)

Equipment	Equation	No.
Pump (OCR)	$W_P = \dot{m}_{WF}(h_2 - h_1)$	1
	$eff_P = \frac{h_{2s} - h_1}{h_2 - h_1}$	2
Pump (Kalina)	$W_P = \dot{m}_{WF}(h_3 - h_2)$	3
	$eff_P = \frac{h_{3s} - h_3}{h_3 - h_3}$	4
Evaporator (OCR)	$\dot{Q}_{in} = \dot{m}_{WF}(h_3 - h_2)$	5
Evaporator (Kalina)	$\dot{Q}_{in} = \dot{m}_5(h_5 - h_4)$	6
Turbine (OCR)	$W_T = \dot{m}_{WF}(h_3 - h_4)$	7
	$eff_T = \frac{h_3 - h_4}{h_3 - h_{4s}}$	8
Turbine (Kalina)	$W_T = \dot{m}_6(h_6 - h_{10})$	9
Condenser (OCR)	$Q_{CON} = \dot{m}_{WF}(h_4 - h_1)$	10
Condenser (Kalina)	$Q_{CON} = \dot{m}_1(h_1 - h_2)$	11
Electric Generator (ORC y Kalina)	$W_{EG} = (W_T - W_P) * ef_{EG}$	12
Mass Balance	$\sum \dot{m}_{in} - \sum \dot{m}_{out}$	13
Energy Balance	$\sum \dot{E}_{in} - \sum \dot{E}_{out}$	14
Thermal Efficiency	$eff_{th} = \frac{W_T - W_P}{\dot{Q}_{in}}$	15

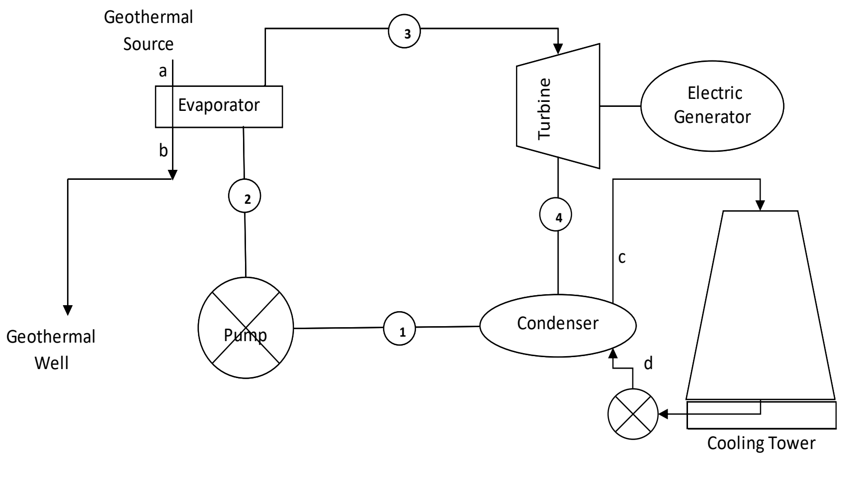


Figure 8 General outline of the organic Rankine cycle

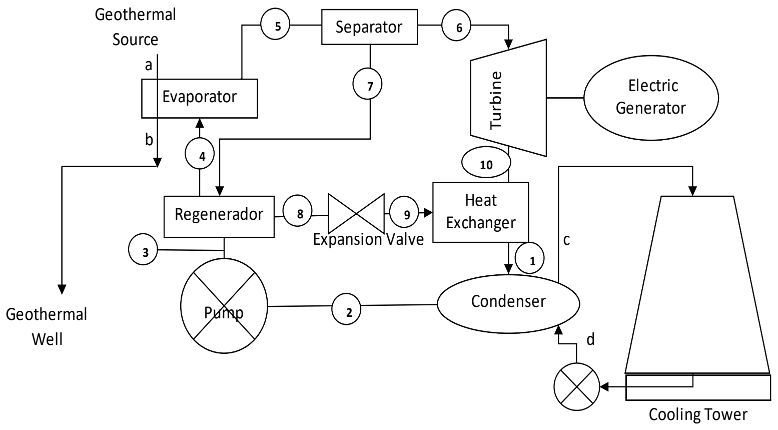


Figure 9 General outline of the Kalina cycle

Results

Table 3 Comparison of the results of the Kalina cycle simulation in terms of pressure, concentration, and efficiency obtained

Pressure (bar)	x (Concentration of ammonia in the mixture)	Efficiency of Kalina cycle (%)
10	0.48	6.612
	0.58	4.868
	0.68	2.714
	0.78	1.052
20	0.48	-3.509
	0.58	1.99
	0.68	6.75
	0.78	6.215
30	0.48	-18.7
	0.58	-10.93
	0.68	-5.445
	0.78	6803

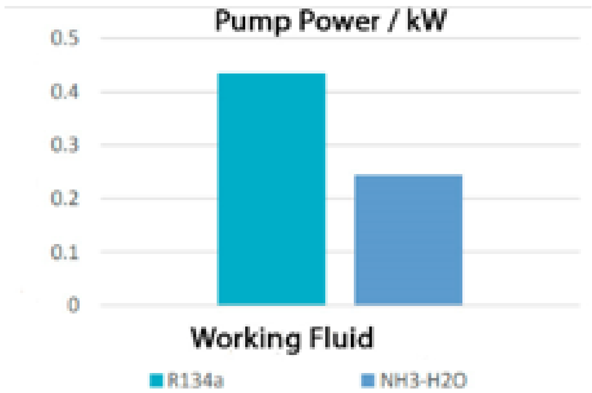
Table 4 Simulation results of the ORC

No.	P(MPa)	T(°C)	h(kJ/kg)	s(kJ/kg K)
1	0.7487	29.00	92.13	0.3432
2	1.265	29.38	92.68	0.3435
3	1.265	82.00	312.6	1.025
4	0.7487	64.00	301.6	1.025

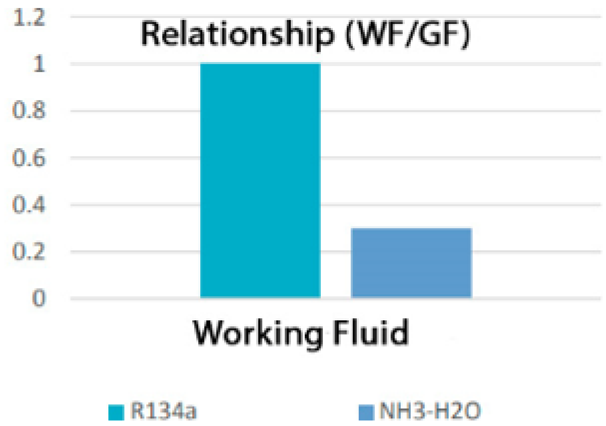
Table 5 Simulation results of the Kalina cycle

P = 10bar x=0.48							
No	h (kJ/kg)	P (bar)	Quality (Q.)	s (kJ/kg K)	T (K)	v (m^3/s)	x (kg/kg)
1	152.8	3.175	0.1351	1.127	315.4	0.06462	0.48
2	-109.8	3.175	0	0.2801	302.1	0.00120	0.48
3	-108.8	10	-0.001	0.2808	302.2	0.0012	0.48
4	39.48	10	-0.001	0.7463	335.2	0.00124	0.48
5	321.4	10	0.1381	1.555	355.1	0.02354	0.48
6	1472	10	1	4.893	355.1	0.1628	0.9722
7	137	10	0	1.02	355.1	0.00123	0.4011
8	-35.06	10	-0.001	0.5076	316.6	0.00117	0.4011
9	-35.06	3.175	0.00304	0.5101	315.7	0.0026	0.4011
10	1325	3.175	0.965	4.977	310.7	0.4468	0.9722

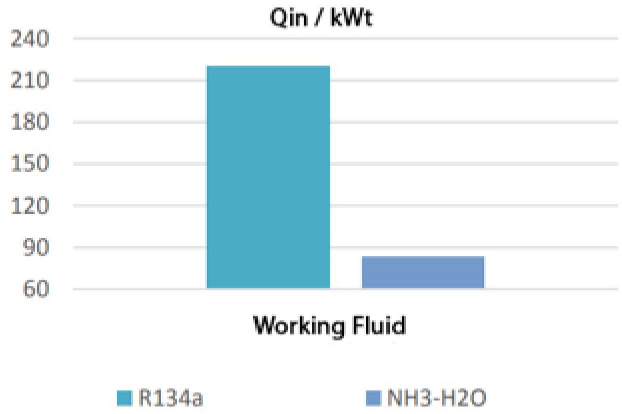
Results



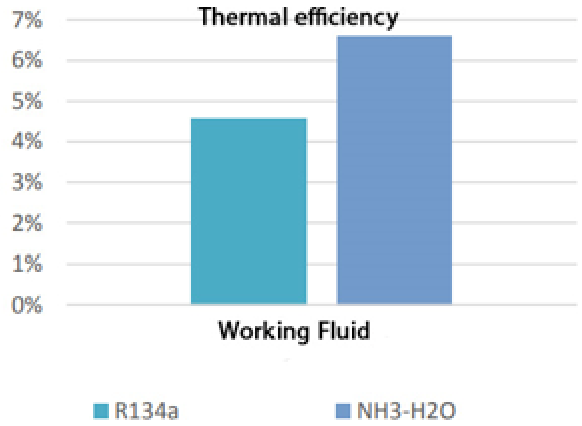
Graphic 1 Power demanded by the pump



Graphic 2 Mass flow rate of the working fluid in relation to the geothermal fluid

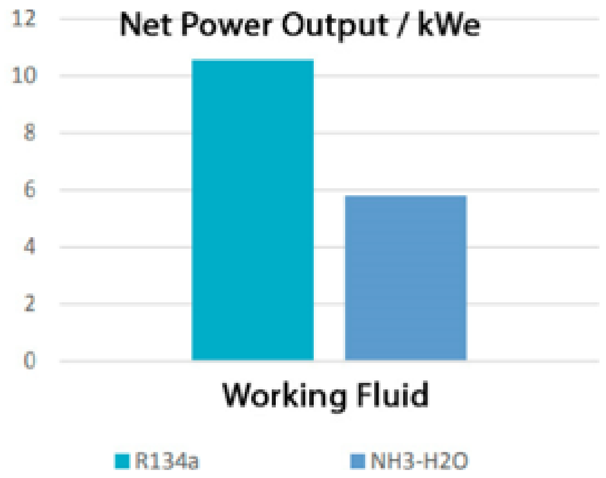


Graphic 3 Heat supplied in the steamer



Graphic 4 Thermic efficiency obtained for the ORC and Kalina cycle

Results



Graphic 5 Net power output for both cycles

In the case of the net power output of both cycles and the efficiency obtained respectively, it can be observed that while the Kalina cycle's efficiency (6.61%) was higher than the ORC's efficiency (4.58%), the power output does not behave in the same way (10.54 kWe and 5.77 kWe, respectively), as observed in Graphic 4 and 5.

Conclusions

The analysis indicates that these types of electric power generation plants are possible alternatives for low enthalpy sources, as in the case of the town of Los Negritos, Michoacán. Also, it was detected that while the Kalina cycle has higher thermic efficiency than the ORC cycle, the net power output was greater for the latter.

This is attributed to the temperature difference in the steamer; on the cycle side, it is higher for the ORC than for the Kalina. That said, the heat used by the ORC in the steamer is considerably greater than what is used in the Kalina cycle. More exhaustive studies of the analyzed conditions are needed in order to determine the benefits of these cycles.

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