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A LITERATURE REVIEW OF MODIFICATION KALINA CYCLE APPLICATIONS AND ADVANCEMENTS

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ABSTRACT
This literature review examines the applications and advancements of the Kalina cycle in the context of renewable energy growth. The Kalina cycle, an improvement on the traditional Rankine cycle, offers enhanced efficiency for power generation from low-grade heat sources. This review synthesizes recent research on Kalina cycle implementations in geothermal, solar thermal, and most waste heat recovery applications, such as industry, diesel engines, and marine engines, as well as contributions to the augmenting power, desalination process, and the field of cosmic space. Also, studying a binary solution as the working fluid and the reason for selecting the ammonia-water mixture; additionally, discussion of the issues of corrosion and material compatibility. Finally, mention the correlation core of thermodynamic properties for analysis of the Kalina cycle. The findings indicate that while the Kalina cycle shows promise for improving renewable energy utilization, further research and development are needed to address efficiency, cost, and implementation barriers.

Keywords: Modified Kalina cycle, renewable energy, combine cycle, low-temperature source, ammonia-water fluids.

NOMENCLATURE

CO_2	Carbon dioxide	OKCS	Original Kalina Cycle System
COP	Coefficient of performance	ORC	Organic Rankine Cycle
CH_4O-H_2O	Methanol/water mixture	OTEC	Oceanic Thermal Energy Conversion
C_2H_6O-H_2O	Ethanol/water mixture		
C_3H_8O-H_2O	Propanol/water mixture	RC	Rankine cycle
GT	Gas Turbine	S	Entropy (kJ/kg. K)
HE	Heat exchanger	TLC	Trilateral cycle
HRVG	Heat Recovery Vapor Generation	Tdp	Dew point Temperature (℃)
		Tbp	Bubble point Temperature (℃)
KC	Kalina Cycle	TPC	Top Cycle
KFC	Kalina flash cycle	W_{net}	Net output power (kW)
LiBr	Lithium bromide solution	$\dot{W}$	Rate of work output (kW)
MKCS	Modified Kalina cycle system	x	Ammonia Mass Fraction
NH_3/H_2O	Ammonia/water mixture		(Ammonia Mass Concentration)

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INTRODUCTION

Kalina cycle occupies an advanced and effective position in converting effective energy in many engineering applications and supporting this shift towards more sustainable energy due to its ability to be compatible with many energy sources, including low-temperature such as geothermal and solar heat, recovering waste heat from factories and engines, and striving for clean energy without greenhouse gases emissions. Thus, this review took it upon itself to demonstrate the importance of Kalina cycle, its use, and the possibility of integrating it into many engineering applications to provide a nearly comprehensive database for researchers and students, as well as potential and guide future innovations and implementations. Despite many promising advantages for sustainability and the environment, renewable energy cannot be cost-competitive with crude oil in all places because of problems with low-capacity factors and energy instability. Therefore, the researchers focus on promoting this aspect of clean energy **(Li et al., 2020)**. To promote renewable energy prosperity by exploiting low-grade heat sources. Kalina cycle, invented by Alexander Kalina in the 1980s, has emerged as a promising alternative to the traditional Rankine cycle for such applications **(Zhang et al., 2012)**. **(Victor et al., 2013)** presented an overall overview of the latest research on Kalina cycle applications and advancements in the context of renewable energy growth. Kalina cycle uses a pair solution, typically an ammonia solution (NH_3/H_2O), which allows for better fitting with the waste heat and sink of the cycle, resulting in improved thermodynamic efficiency compared to the Rankine cycle. Besides the above, this review is a clear study and concise analysis of several subjects. like comparing the Kalina cycle to other energy cycles, its applications, and how well it uses its intended purpose; the pros and cons of using a binary solution as the working fluid; and the challenges of material compatibility between cycle components and this binary solution. Understanding the essential thermodynamic properties and their correlations is crucial for finding solutions to these challenges.

2. BASIC COMPONENTS AND WORKING PRINCIPLE

2.1 Kalina cycle fundamentals

Kalina cycle is an adjusted Rankine cycle that uses a binary working fluid, typically an ammonia solution. The basic configuration of the Kalina cycle includes a boiler, turbine, condenser, pump, and separator **(Momeni et al., 2016)**. The key distinction from the Rankine cycle is the use of a separator to create two streams with different ammonia concentrations, allowing for better temperature matching in heat exchange processes. **(Zare and Mahmoudi, 2015)** explained a Kalina cycle leverages the non-isothermal phase change of the binary working fluid to improve heat recovery efficiency. During the evaporation and condensation process, the temperature of the binary solution changes, unlike the constant temperature phase shifting of pure fluids in the Rankine cycle. Finally, these features give strength to the Kalina cycle.

2.2 Binary solution properties

Two solutions combine to form the binary solution system, which possesses the desired properties for successful system operation. The binary mixture system holds the qualities of the two fluids. Here below are the pros of the binary solution system **(Srinivas T, 2023)**:

1. A binary mixture system can run with a low-grade heat source.

2. The varying temperature is where the phase shift takes place. As a result, the working fluid and low heat source have an excellent temperature match, which reduces entropy formation compared to a single fluid system.

3. The binary mixture system is adaptable and can be used in cogeneration systems to produce cooling and power.

4. It works better with renewable energy sources, like geothermal, biomass, and solar thermal.

5. Its suitability as working fluids for refrigeration applications **(Li et al., 2024)**.

2.2.1 Type of a binary solution as the working fluid

There are several pairs of working fluids utilized in Kalina cycle that have been explored in research and specialized applications, including NH_3-H_2O, LiBr-H_2O, CH_4O-H_2O, C_2H_6O-H_2O, and C_3H_8O-H_2O, etc, every pair consists of refrigerant and absorbent. This binary fluid comes back benefits more than a single fluid in cycles by allowing for a closer temperature match between the working fluid and the heat source, which increases energy efficiency. This improves energy efficiency and power output, making the Kalina cycle a future technology for several heat source applications **(Meftahpour et al., 2024)**. The fluid properties, miscibility of ingredients, and favorable temperature gradient (temperature difference between boiling point and dew point, which phase changes with variable temperature in zeotropic mixtures) are considered for mixture fluid selection **(Eller et al., 2017)**. Experimental investigation shows the LiBr-H_2O systems are superior to conventional NH_3-H_2O systems in terms of COP and cooling capacity, suggesting a more efficient alternative for air conditioning and refrigeration applications **(Shaban et al., 2024)**.

2.2.2 The reason ammonia-water is as a working fluid

As previously mentioned, Kalina Cycle utilizes ammonia water-working fluid, making it unique because it includes at least two distinct ingredients, each having a different boiling point. Ammonia's lower boiling point compared to water allows for efficient power generation from low-temperature heat sources. Given that, a two-ingredient mixture solution allows for ratio changes in different areas of the system and can boil and condense at various temperatures, which affects cycle performance and is a key parameter in cycle optimization **(Fergani et al., 2016)**. Consequently, **(Wang et al., 2013)**. found that the optimal ammonia mass fraction varies depending on the heat source temperature, ranging from 0.8 to 0.9 for heat source temperatures between 100°C and 200°C. They observed that higher ammonia concentrations generally lead to better cycle performance at lower heat source temperatures. It leads to improving thermodynamic efficiency. Additionally, some features below **(Thorin, 2000)**,**(Victor et al., 2013)**:

1. The mixture solution is a new working fluid with unique properties. Ammonia's molecular weight (17.03074 g/mol) is quite similar to that of water's (18.0157 g/mol).

2. The mixture solution has high miscibility at low temperatures.

3. Higher coefficients of heat transfer.

4. Ammonia-containing water does not freeze; each concentration of ammonia in the solution has a specific freezing point.

5. The solution has varying boiling point and dew point temperatures.

6. Fewer flammable and dangerous than ORC working fluids. and it is self-alert

7. The ammonia has a high latent heat of evaporation.

8. Both are ecologically benign and available components of nature. Ammonia is an environmentally favorable substitute because of its minimal potential to cause global warming **(Sanchuli et al., 2024)**.

9. No deposits occur in the mixture solution under the operation condition **(Naden Robinson et al., 2018)**.

3. WORKING FLUID ISSUES AND MATERIAL COMPATIBILITY

The use of ammonia-water mixtures in Kalina cycles presents challenges related to material compatibility. Ammonia can be corrosive to certain metals, necessitating the use of special materials in system components **(Shan and Nihaj, 2020)**. Researchers have studied this topic,**(Murugan and Subbarao, 2008)** mentioned that can increase system costs and limit the widespread adoption of Kalina cycle technology. Therefore, it is not recommended to use an ammonia solution at greater temperatures (400℃). NH_3 gets uneasy at higher temperatures, resulting in nitride erosion.

(Whittaker, 2009) investigated the Kalina Cycle Geothermal Power Plant in Husavik, Iceland, for erosion problems in 2009. Despite mild steel and aluminum being commonly regarded as dangerous materials for Kalina Cycle Systems, the investigation indicates that certain stainless steels (304, 316, nitronic 60, and duplex) and 6Al-4V titanium do not appear to corrode. **(Marston, 1990)** proved that regarding the turbine's design, it may be necessary to change some of the materials because copper-based alloys are prone to corrosion when exposed to ammonia. Future research should focus on developing more compatible materials and coatings to mitigate these issues. Additionally, the environmental impact of potential ammonia leaks must be carefully considered. Researchers are exploring alternative working fluid mixtures that could offer similar thermodynamic advantages with reduced ecological risks **(Harris, 2021)**.

4. COMPARISON WITH OTHER CYCLES

4.1 Kalina cycle vs. Rankine cycle

The Kalina and Rankine cycles are both thermodynamic cycles used for converting thermal energy into mechanical work, but they differ significantly in their working principles, efficiency, and applications. **(Aksar et al., 2022)** The Rankine cycle utilizes the water vapor as a working fluid, in contrast, the Kalina cycle utilizes ammonia solution as the working fluid, which allows for a variable boiling point and better thermal matching with heat sources. The Kalina cycle is an adjustment of the Rankine cycle to exploit low temperatures of waste heat. Typically, an ammonia-water mixture; allows for better fitting between the heat source and sink compared to pure fluids used in conventional Rankine cycles. **(Zhang et al., 2020)** studied a Kalina cycle, which enlists an ammonia solution as the working fluid, offers higher thermal efficiency compared to traditional Rankine cycles in applications involving low-temperature heat recovery below 200°C.

4.2 Kalina cycle vs. organic Rankine cycle

Kalina cycle is often compared to the Organic Rankine Cycle (ORC) due to their similar applications in low-temperature heat recovery. **(Bombarda et al., 2010)** compared the performance of Kalina and ORC systems for waste heat recovery from diesel engines. They concluded that while the Kalina cycle showed slightly higher efficiency in some cases, the difference was not significant enough to justify its higher complexity compared to the ORC. However, other studies have found more substantial advantages for the Kalina cycle.**(Eller et al., 2017)** compared Kalina and ORC systems for geothermal power plants and reported that the Kalina cycle could achieve up to 25% higher power output than the ORC for certain temperature ranges.

4.3 Kalina cycle vs. trilateral cycle

Trilateral cycle is another opponent to the Kalina cycle for low-degree heat restore. **(Yari et al., 2015)** thermodynamics and exergoeconomics of three power-generating systems, TLC, ORC, and KCS, as shown in figures 1, 2, and 3, respectively, are used to study and compare their performance. The results showed that each cycle outperformed the others, but under certain conditions. Additionally, the optimal conditions for thermodynamic analysis differed from those for exergoeconomic analysis. In the case of the Kalina system, for 0.60, 0.75, and 0.90 ammonia concentrations, the net output power is maximized for a particular value of turbine inlet pressure. This value is different from the turbine inlet pressure, which offers a low cost.

5. INTEGRATION KALINA CYCLE WITH OTHER SYSTEMS AND APPLICATIONS

5.1 Contribution to cooling and power

The increasing global demand for energy and cooling has led to the development of innovative systems that can efficiently provide both power and either cooling or heating. **(Chen et al., 2018)** studied a combined system that includes a Kalina cycle to produce parallel power and refrigeration (PPR-KC), to exploit more heat resources recovered from the boiler. A parallel branch of the working fluid is split at the exit of the mixer, and it treats generation, pumping, condensation, and rectification pre-evaporation for cooling. The results indicated the optimum work concentration is 0.5, and the optimum basic concentration is adjusted with different split fractions.

Under specific temperatures and pinch temperature differences, the PPR-KC achieves a comprehensive power recovery efficiency of 27.2%, higher than previous cogeneration cycles. **(Seckin et al., 2020)** proposed a new mutual power and refrigeration system. The combined system consists of two cycles: the Kalina cycle (KC) with ammonia solution as working fluids for power and the ejector refrigeration cycle (ERC) with R-134a as a working medium for cooling.

Temperature and pressure at the turbine entry were looked at to observe how they affected the system's performance. The outcome was that thermal and exergy efficiencies increased to reach 10% and 70%, respectively, with an increase in the maximum pressure from 25 bars to 40 bars. Also, when raising the turbine entrance temperature from 115 to 140℃, it increases to reach 7% and 41% consecutively.**(Meftahpour et al., 2024)** studied Kalina cycle system (KCS) as combined to produce power and heat (CHP) along with a gas turbine (GT) cycle and a single-pressure heat restore steam generator (HRSG). The results indicated the system's energy and exergy efficiency increased from 53.60% to 54.31% and an ascent from 50.59% to 51.27%, respectively. and investigated the average kidney cost of the system. The outcomes reveal this cost does not compare to the improvement of the environment.

5.2 Kalina cycle for lunar power applications

The unique environmental conditions on the Moon—such as strong volatility, temperature, shortage of atmosphere, and prolonged periods of darkness—demand innovative solutions. One promising approach is using thermodynamic cycles that can efficiently harness available resources. traditional power generation systems, such as fossil fuel-based systems, are unsuitable for lunar applications due to their high mass, volume, and energy requirements**(Saraf et al., 2019)**. Also, suggested traditional power systems, such as solar panels and nuclear reactors, have been extensively studied and deployed. but still unsuitable due to the harsh lunar environment. The Kalina cycle, a thermodynamic cycle that utilizes an ammonia solution-working fluid, has garnered significant attention due to its adaptability and high efficiency in low-grade heat recovery **(Kulkarni et al., 2020)**.

(Harris et al., 2021) investigated and compared the Kalina cycle with the other energy cycles, for medium-sized bases, the expected launch costs of a Kalina cycle system are lower than those of a photovoltaic system. Because a Kalina cycle has higher system thermodynamic efficiency across a range of operating temperatures, it requires a lower thermal heat sink than a Brayton cycle. Lower launch and equipment costs are associated with a smaller heat sink. A nuclear-powered system is less expensive for medium- and large-scale power demands. Heat source longevity and safety are the advantages of a Kalina-cycle system over a nuclear-powered system. The lifespan of a nuclear-powered system is only 12 to 15 years before a new nuclear core is required. In conclusion, compared to rival systems, an ammonia-water thermodynamic power system performs better.

5.3 Kalina cycle with desalination application

The integration of the Kalina Cycle with reverse osmosis desalination presents a promising approach to enhance freshwater production while optimizing energy efficiency. This combination leverages the waste heat from the Kalina Cycle to drive desalination processes, particularly through humidification-dehumidification, **(Rostamzadeh et al.,**

2020) focused on a solar-powered combined electricity and desalination system using a humidification-dehumidification (HDH) method, which utilizes waste heat low-temperature from the Kalina Cycle in the HDH system can produce approximately 4.96 m³ of distilled water per day, alongside generating 10.45 kW of net electricity.

(Behnam et al., 2022) proposed a new triple-generation cycle based on low-temperature geothermal resources, integrating the Kalina cycle with moisture cycles and moisture removal for power, heat on, and drinking water generation at the same time. The system uses an evaporative condenser for the Kalina cycle and a humidifier and heater for the HDH cycle. **(Prikhodko et al., 2024)** studied and presented a technological investigation for utilizing low heat for water heating and extracting electricity in the seawater desalination cycle. The suggested diagram couples the Kalina cycle and reverse osmosis desalination plant cycle, using heated water for water treatment and producing electricity for pump driving. executed on geothermal resources close to the ocean.

5.4 Applications in geothermal power generation

Geothermal energy has been one of the primary areas of application for the Kalina cycle due to its ability to utilize low to medium-temperature heat sources efficiently. Several studies have investigated the performance of modified Kalina cycle systems in geothermal power plants. **(Coskun et al., 2014)** investigated and contrasted three power cycles in Turkey's Kutahya–Simav region that are driven by medium-temperature geothermal heat sources. Finding the most efficient method of using the geothermal resource through these cycles under the same circumstances—such as the maximum turbine inlet pressure—was the aim. The findings indicate that the Kalina cycle yields the highest power production, energy, and exergy efficiency, followed by the binary and mixed cycles. The Kalina cycle had the highest energy efficiency, about 10.6%, and the exergy efficiency, about 59.3%, while the other reached 6.9% and 38.5%, respectively.

(Prananto et al., 2017) investigated in a Kalina cycle (KCS11), the waste saline discharged to the ground in the Wayang Windu geothermal power plant was utilized as a subcycle. It served as a source of heat. The Kalina cycle uses ammonia solution as a working fluid. Changes in the thermodynamic analysis parameters, such as the ammonia concentration going from 0.82 to 0.88 and the feed water brine pressure going from 20 to 37 bar, affected how well the cycle worked. The results show that the power plant generates the maximum power at an optimal ammonia mass fraction of 0.86 with 32 bar of feed water pressure. About 48 kg/s of waste brine from the power plant generates about 1734 kW of power at 13.20% energy efficiency. With 53.04 and 20.66 kW of consumption from the feed water pump and condenser fan, respectively, the system's gross energy was 16.6030 kW.

5.5 Solar thermal power applications

The application of modified Kalina cycle systems to solar thermal energy has been an area of growing interest, particularly for concentrated solar power (CSP) plants. **(Zare et al., 2017)** studied the integration of Parabolic Trough Solar Collectors (PTSC) with a new Kalina cycle layout that is appropriate for using high-temperature heat sources is presented and examined. According to the findings, energy cycle units can meet thermal efficiencies of around 64%, whereas the overall power plant can meet thermal efficiencies of about 14%. Therefore, in the clean energy sector, the Kalina cycle (KC) is an effective substitute for the traditional or organic Rankine cycles.

(Qu et al., 2018) proposed concentrating photovoltaic/Kalina cycle system includes twin core parts: the concentrating photovoltaic subcomponent and the Kalina cycle subcomponent, which serves as an absorption chiller. This system is designed to extract waste heat from photovoltaic cells and convert it into power by lowering the turbine's outlet pressure in the Kalina cycle instead of traditionally increasing the turbine entry temperature. They studied the impact of parameters, specifically the photovoltaic temperature, on the thermal performance of a cycle. The results show that at a heat source range of 60–70 °C, the Kalina cycle's thermal efficiency could go up by 2–3% compared to the referenced Kalina cycle. The gross power of the Kalina cycle could go up by 4–5%, the solar power efficiency would reach about 24%, and the photovoltaic efficiency would be about 4.2% without chilling.

5.6 Hybrid heat source applications

Several researchers have explored the potential of hybrid solar-geothermal systems utilizing modified Kalina cycles. **(Sun et al., 2022)** studied a combined system of solar and geothermal wells in Sabalan, utilizing the Kalina Cycle, Rankine Cycle, and Flash Cycle as a green and promising energy generation system that can provide several types of usable energy. The outcomes reveal an increase in the level of power generation; the overall electricity extract of the power cycle is at about 26.1 MW. Thermal efficiency was 24.9%, and exergy efficiency was about 53.4% of the energy cycle.

(Madhesh et al., 2024) studied the sequential system of Kalina and organic Rankine cycles to produce refrigeration and green hydrogen to utilize the heat recovery from a hybrid solar/biogas heat source. It is presented for its ability to produce refrigeration only or in coupling with hydrogen provision. The results show that utilizing the recovered heat more effectively to make cooling and green hydrogen, along with setting up the system so that it works at its best, can lead to a low total cost, an energy use ratio of 0.76, and a second law efficiency of 21.56%.

6. WAST HEAT RECOVERY IMPLEMENTATIONS

The ability of Kalina cycle to efficiently utilize low-grade heat resources has made it an attractive option for waste heat recovery applications in various industries.

6.1 Industrial applications

6.1.1 Steel industry applications

(Salemi et al., 2022) suggested a new Kalina-based waste heat recovery system for electric arc furnaces used in the steel industry. It would be used at the 1.38 Mt/year MIDREX plant in Iran. The modified cycle incorporated a two-stage expansion process and an internal heat recuperation mechanism. The simulations showed that the proposed system could achieve a thermal efficiency of 26.7% and recover up to 76.5% of the waste heat. This means the Kalina cycle with an ammonia solution makes more than 2000 kW of electricity from heat recovery.

6.1.2 Sugar factory's power plant applications

(Singh, 2020) investigated combining the Kalina cycle with a 16 MW sugar factory's bagasse-fired power plant in India, which loses 6.34% of fuel energy and 5.20% of fuel exergy through the flue gases. To convert some of this waste heat into power, the integrated plant's net power output increased by 375.2135 kW, which raised the cogeneration's thermal and exergy efficiencies by 0.3819% and 0.3150%, consecutively.

6.2 Marine applications

A Kalina cycle has also shown promise for waste heat restoration in marine applications. **(Fan et al., 2024)** studied how the low thermal efficiency of oceanic thermal energy conversion (OTEC) can be improved by introducing a solar pool to preheat hot seawater as a conventional cycle at an output temperature of 86 °C, and comparative analysis is done with solar pond-assisted OTEC systems using the Kalina cycle. The results show that the exergy efficiency of the thermoelectric module gets better with the Kalina cycle at 75°C, which is the best temperature for extraction. Also, systems that use the Kalina cycle have less CO_2 emissions of power at 0.98 kg/kWh, which is lower than the conventional OTEC emission rate of 10.7 kg/kWh. **(Larsen et al., 2014)** researched the Split-cycle, a unique Kalina cycle designed to recover exhaust heat from large marine engines. Additionally, they contrasted the Kalina cycle's performance with that of the organic Rankine cycle systems, a traditional cycle utilized for big ship waste heat recovery. According to their calculations, for normal marine engine exhaust gas temperatures, the Kalina cycle might produce up to 23% more power than the ORC. Additionally, reheating can boost energy efficiency between 3.4% and 5.9%.

6.3 Diesel engines applications

(Bombarda et al., 2010) suggested a modified Kalina cycle configuration specifically for diesel engines with an electrical power of 8900 kW waste heat restoration. They also compared the thermodynamic performances of an organic Rankine and Kalina cycles. Results show the gross power for the Kalina and the ORC cycle was 1615 kW and 1603 kW, respectively.

7. CORRELATION CORE OF THERMODYNAMIC PROPERTIES FOR ANALYSIS OF MODIFIED KALINA CYCLE

The literature review that a deep understanding of the thermodynamic properties and their correlations is essential for the effective analysis and optimization of modified Kalina cycles. The modified Kalina cycle, with its unique thermodynamic characteristics, opportunity to achieve higher efficiencies and lower emissions compared to conventional cycles. By examining the correlations between key thermodynamic properties—such as enthalpy, entropy, and specific heat—this review aims to provide a comprehensive understanding of how these properties influence the performance of modified Kalina cycles. Furthermore, the review will highlight recent research efforts aimed at refining these correlations to better predict cycle behavior under varying operating conditions.

7.1 The thermodynamic T-x diagram and T-s diagram

Figures 4, 5; depict the original Kalina cycle system on the T-x diagram, T-s diagram, and schematic of the original Kalina cycle system (OKCS) illustrated in Figure 3, consecutively. The OKCS includes a heat recovery vapor generator, separator, expander, expansion valve, mixer/absorber, condenser, and motor pump. The state of the working fluid through OKCS at the separator entry (region 7) is liquid-vapor. The separator well separates the liquid-vapor mixture solution into saturated vapor "strong solution" (region 1) and saturated liquid "weak solution" (region 8). The strong solution exits from the upper hole of the separator toward the turbine and enters the expanded to turn the generator to produce power. while the weak solution exits from the lower hole of the separator to enter the throttling valve to reduce pressure and temperature by the valve during the isenthalpic process (region 9), and then mixes with the turbine output solution (region 2) to re-shape the NH_3/H_2O working fluid again (region 3). The working fluid is completely condensed to a liquid state by the air condenser with a low temperature and low pressure (region 4), then the working fluid is sucked by the pump motor for pumping to a high-pressure level (region 5), thus circulating the working fluid through the HRVG again.

The (T-s) is a graph of the main relationship of thermodynamics of the system's state, in which the temperature and its corresponding entropy are restricted. To study the extent to which thermal energy can be converted into mechanical work and thus determine the system's efficiency due to atoms' characteristics in their tendency to become irregular over time. So, we notice an increase in entropy at any point in the Kalina cycle with an increase in temperature, which affects the possible results negatively or positively.

7.2 Enthalpy-mass fraction diagram

The enthalpy-concentration graph is shown in Figure (6); the graph is included in terms of ammonia concentration and pressure levels. The dew point curve is a function of ammonia mass fraction in the vapor phase (Tdp) and pressure. The bubble point curve is a function of the ammonia mass fraction and pressure in a liquid phase (Tbp). A two-phase (liquid-vapor state) of working fluid is between these two curves. The enthalpy-concentration plot of the ammonia-water mixture is useful for energy efficiency calculations for a Kalina power system. The enthalpy value of the mixture of liquid and vapor is higher at high pressures than at low pressures. The enthalpy value goes down as the ammonia concentration rises along both curves.

7.3 The T-P diagram

(Ravindra and Winter, 2003) explained the temperature vs. pressure (T-P) diagram serves as an important tool in understanding the thermodynamic behavior of various fluids, including gases, and liquids. This diagram provides a vision of phase changes, stability, and the effects of varying conditions on fluid properties. The need for schemes of T-P is evident under varying temperature and pressure conditions, aiding in the understanding of their facilitation of the known change points, such as boiling point and freezing point.

(Hua and Roskilly, 2014) utilized the T-P diagram of the proposed cycle, exploited industrial waste heat from 200 C to 450 C. The authors explained the system has triple levels of pressure: low pressure (pl), mid pressure (pm), and high pressure (ph). The mid-pressure allows it to match the recuperator's temperature with the temperature of the ammonia solution. The cycle triple stages also allow more freedom of the concentration of the ammonia solution. Consequently, three key concentrations in the cycle are realized by the separator and absorber.

8. SUGGESTION FORFUTURE WORK

There are several recommendations for the future:

1. Continuous updates to the literature review will ensure that emerging technologies and adjustments are integrated, maintaining a creation, an evaluation, and a comparison.

2. Research indicates that continuous modifications to the cycle, such as using new working fluids or new components like a heat exchanger, can further improve performance and exergy efficiency.

3. There is a lot of waste heat in working life applications and we suggest integrating Kalina cycle with these applications.

9. CONCLUSION

This literature review has provided a comprehensive overview of recent advancements in modified Kalina cycle systems across various applications. The studies examined demonstrate the potential of these systems to achieve higher efficiencies and better utilization of low to medium-temperature heat sources compared to conventional power cycles.

1. Modified Kalina cycles can offer significant efficiency improvements over organic Rankine cycles for geothermal power plants, particularly for heat source temperatures above 120°C.

2. Waste heat recovery applications in industries such as cement and steel production have shown promising results, with overall thermal efficiencies reaching up to 26.7%.

3. Modified Kalina cycles can be a successful alternative to other energy cycles and offer significant efficiency, like lunar energy and desalination applications.

4. Kalina Cycle's integration with renewable energy sources offers a sustainable solution for energy efficiency and greenhouse gas mitigation. This technology, combined with renewable sources like solar, geothermal, and hybrid solar-geothermal systems, has demonstrated potential for increased annual electricity production and improved thermal efficiencies.

5. Advanced cycle configurations, such as split-cycle and dual-pressure systems, have shown the ability to further enhance performance and adapt to various heat source characteristics.

6. The ammonia-water mixture enhances energy extraction from low and medium enthalpy heat sources, making it suitable for waste heat recovery. Also, the closed-loop nature of Kalina cycle results in zero emissions, contributing to cleaner energy production.

7. It is important to know and study some relationships between the properties of the working fluid of the cycle, such as T-x, T-s, and h-x, before suggesting and studying any modification of Kalina cycle integrating with a low degree of heat source.

Future research should focus on environmentally friendly working fluid mixtures and simplifying system designs to overcome challenges in modified Kalina cycle systems, despite advancements in technology.

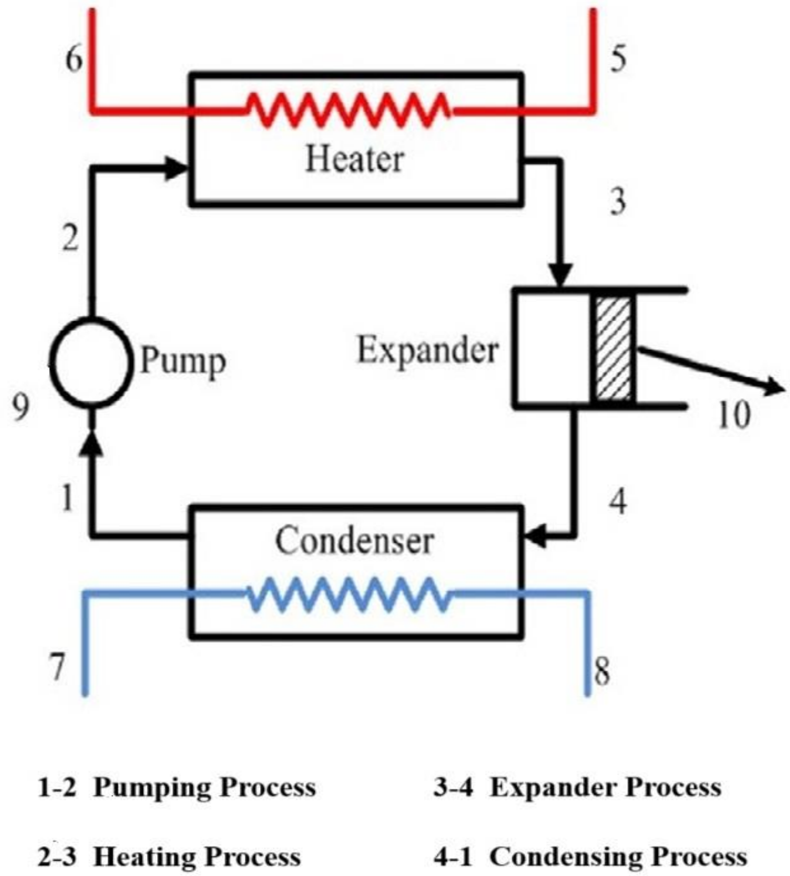

Fig. 1**.** The diagram for simple trilateral cycle (TLC) **(Yari et al., 2015)**.

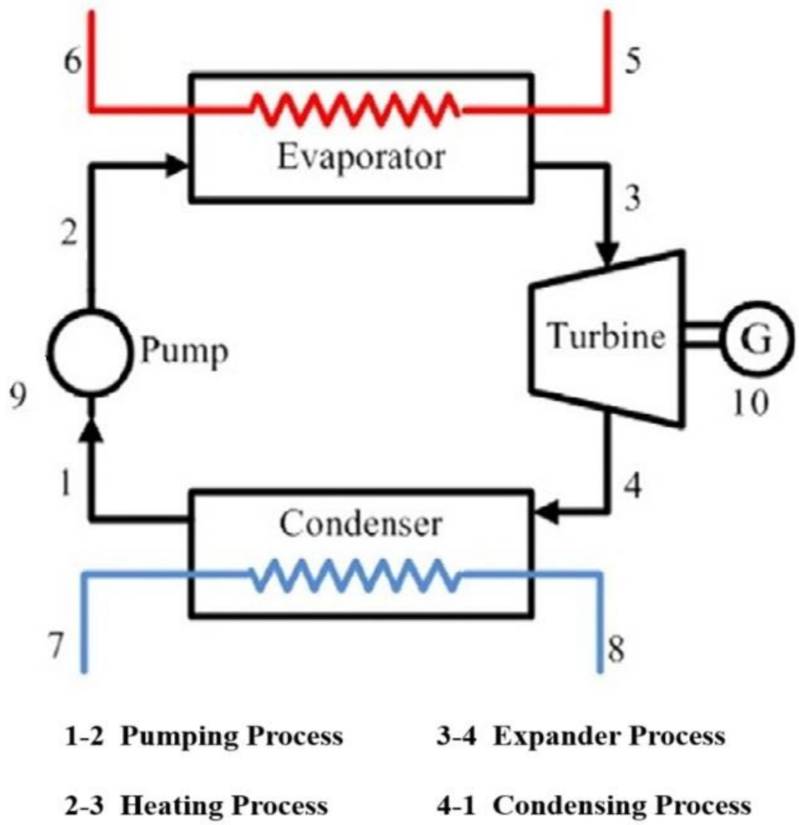

Fig. 2**.** The diagram for simple ORC **(Yari et al., 2015)**.

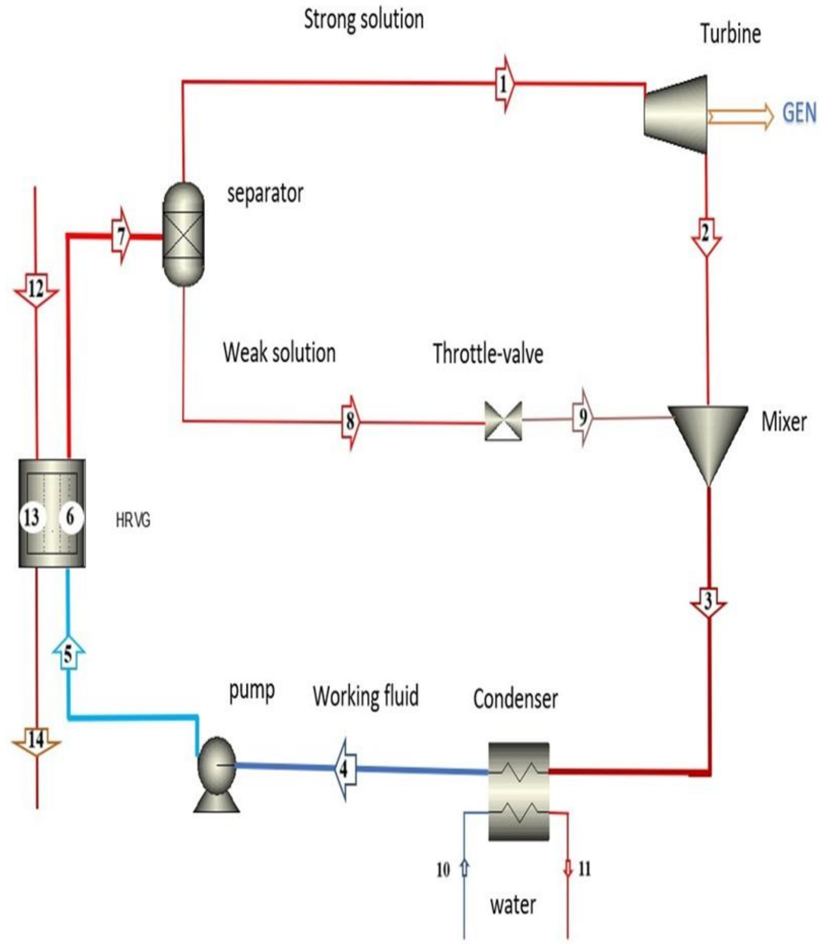

Fig. 3. Original Kalina cycle system **(Nassir and Shahad, 2022).**

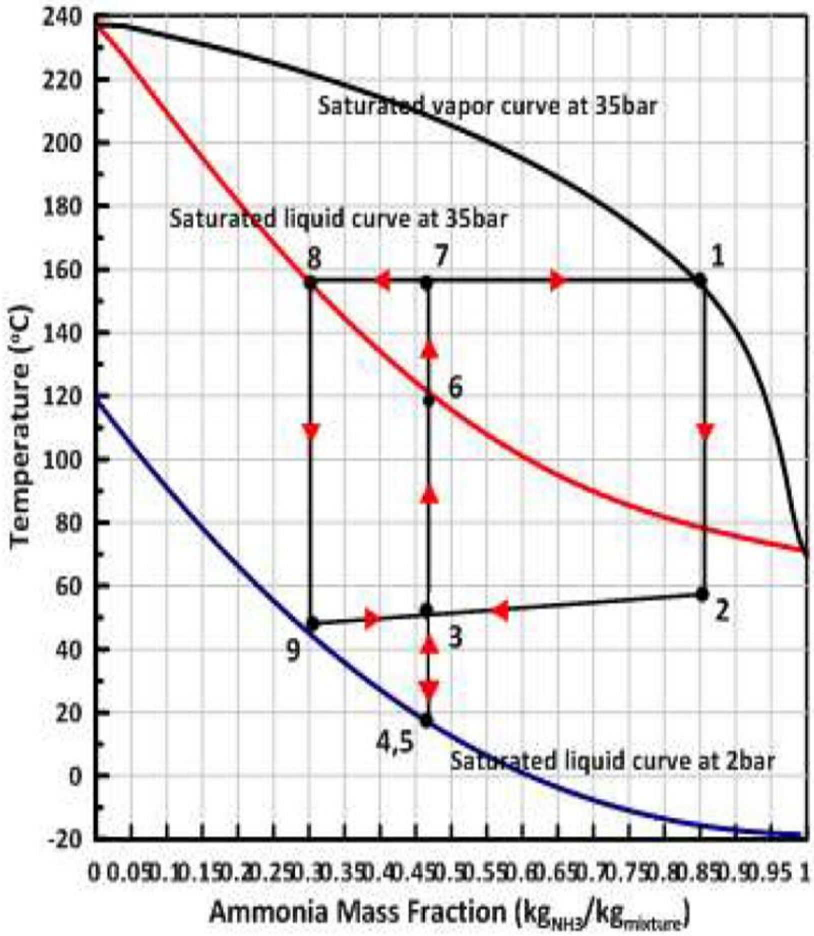

Fig. 4. Temperature vs Ammonia Mass Fraction Diagram of SKCS
at Pmax=35 bar, Pmin=2 bar, X=0.85 and DF=0.3, **(Nassir and Shahad, 2023)**.

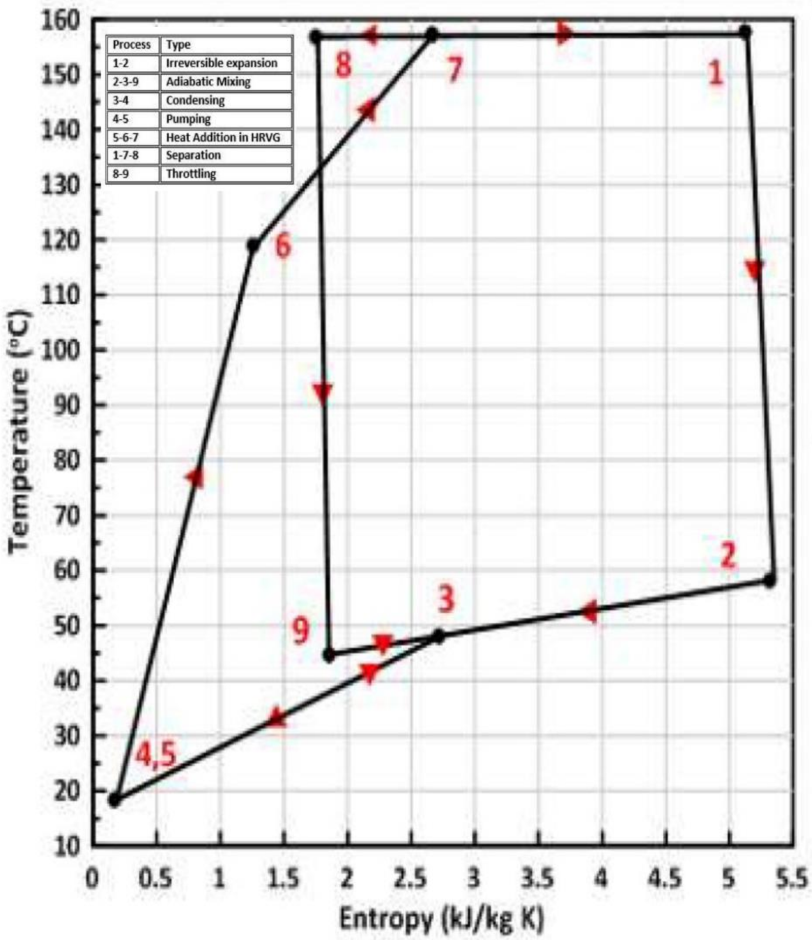

Fig. 5**.** Temperature vs entropy of simple Kalina cycle diagram at Pmax=35 bar, Pmin=2 bar, x=0.85 and DF=0.3, **(Nassir and Shahad, 2023)**.

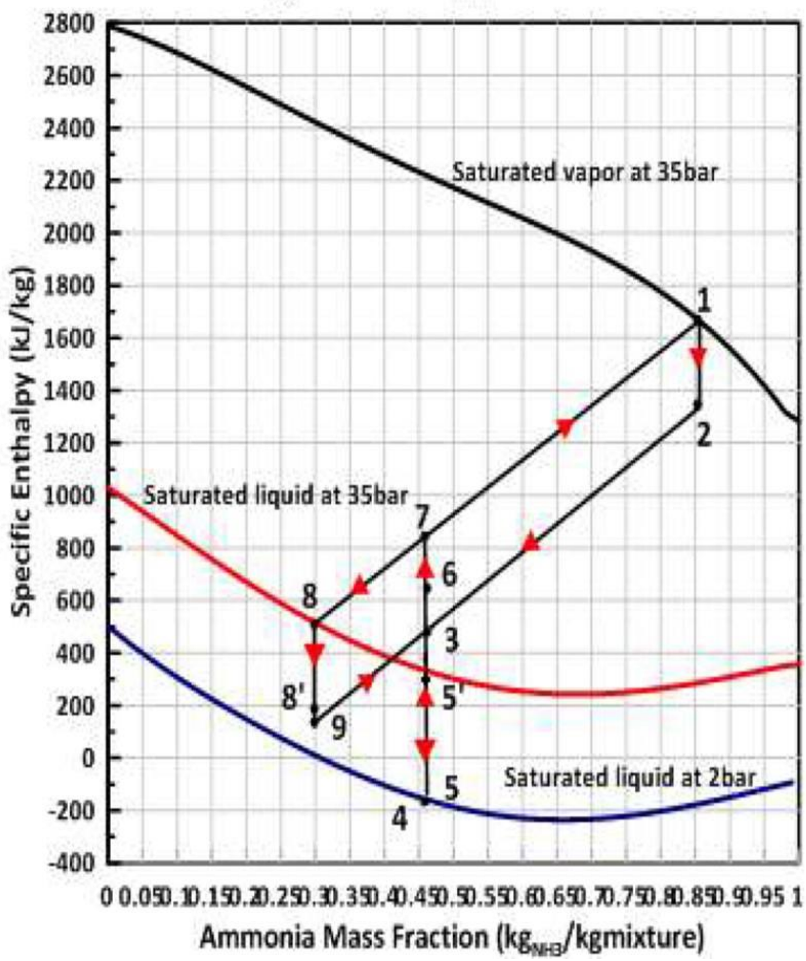

Fig. 6. Temperature vs Enthalpy of Modified Kalina Cycle Diagram at Pmax=35 bar, Pmin=2 bar, x=0.85 and DF=0.3, **(Nassir and Shahad, 2023)**.

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