Augmented Kalina Cycle Using Renewable Energy as Input for Power Generation

Manam Ahmad and Md Mizanur Rahman

***Abstract*—Kalina cycle is an idealized thermodynamic cycle that generates power using a binary mixture as a working substance. Depending on the application, the Kalina Cycle increase power plant efficiency by 10% to 50% over the Organic Rankine Cycle. The relative advantage of the Kalina cycle rises when operating temperatures are reduced and Kalina cycle is generating by mixture. Kalina cycle is identified as a bottoming cycle that demonstrates improved efficiency. Ammonia-water mixture is high-energy than a single component. Producing electricity of the inlet turbine and the temperature of the separator increase the performance of the cycle. It may be more effective to use the Kalina cycle for concentrating renewable energy sources such as solar power plants that use direct steam production to enhance heat exchange efficiency, and therefore, increase total system performance. This research attempts to build a Kalina cycle system, which will help to transform the natural source from sunlight to energy. Python open-source software has been used to design and implement the Kalina cycle. The suggested cycles include various types of solar collectors and extra heat recovery technologies. Systems uses a medium temperature heat source to analyze the Kalina cycle for different system characteristics and to conduct parametric research to determine which input temperature, ammonia concentrations, separator temperatures yield the optimal energy production. The Kalina cycle of binary plants generates 30% to 50 % more power for a provided heat source. With the Kalina cycle as a bottoming cycle for a cogeneration plant, the exhaust gas temperature has been reduced from 427 K to 350 K, which reduces the environmental impact.**

***Index Terms*—Kalina, organic, renewables, solar.**

I. Introduction

In the production of energy and cogeneration, the electricity market is growing at the same time. Conventional oils are quickly depleting. Efforts are being made to identify alternative fuels that will satisfy the growing need for oil. Various sources of non-conventional resources, such as geothermal energy, solar thermal energy, wind energy, and biomass are now being used to address emission challenge and increasing demand [1], [2]. Low-grade heat energy at low temperatures will not only offset the energy crisis we face; it can also simultaneously resolve the problem of global pollution by stopping excess heat from discharging into the atmosphere. Rankine Cycle is the first candidate to use this low-temperature heat capacity since the Rankine Cycle has the maximum performance of the traditional power conversion cycle [3], [4]. But the Rankine cycle has inferior performance for operation at low temperatures. Other cycles have been suggested to derive power from this low-temperature waste heat, namely the Organic Rankine Cycle (ORC) and the Kalina Cycle. Kalina suggested a modern thermodynamic power cycle named the Kalina Cycle to use low-temperature heat to pursue the use of a binary mixture (ammonia-water) to absorb low-temperature heat and to use excess heat effectively [5]–[7]. For low-temperature heat recovery over other periods, the binary mixture's non-azeotropic action renders this cycle very formidable [8]. This paper carries out a thermodynamic study of this cycle for low-temperature applications. The Kalina cycle is known as one of the alternatives of the organic Rankine cycle. The Kalina method allows it more common to be built and applied with the convenience and equivalent components of the mixtures and its environmentally sustainable companion. To transform the natural supply from the sun to productive function, this work suggests a modern, optimized Kalina cycle.

II. Methodology

Energy consumption rates is growing day by day due to a growing population at a high pace. Thus, along with high-grade heat, low-grade heat conversion has received significant attention in the recent past. Solar thermal is a possible source of low-grade heat. Various technologies have been documented in the past to turn low-grade heat into electricity, as well as the Kalina cycle [9].

The new Kalina cycle is designed to produce binary vapor with the aid of a solar collector (Fig. 1). In the first stage, the superheated ammonia water mixture vapor spreads into the binary mixing turbine producing electricity [10]. The expanded mixture with a higher concentration of ammonia is condensed in the condenser after partial condensation at the heat exchanger level. The electricity supplied to the heat exchangers (HE1, HE2 and HE3) has been energized by additional moving energy from renewable heating systems.

Increased output results against increased turbine flow. Partial evaporation is improved in an evaporator with a renewable energy source. The Parabolic Concentration Collector and the Flat Plate Collector have been designed to provide an effective heat source. The independent liquid concentration of the separator drum is moved to Mixer and Tank. The mass and energy balance equations for different components are given below.

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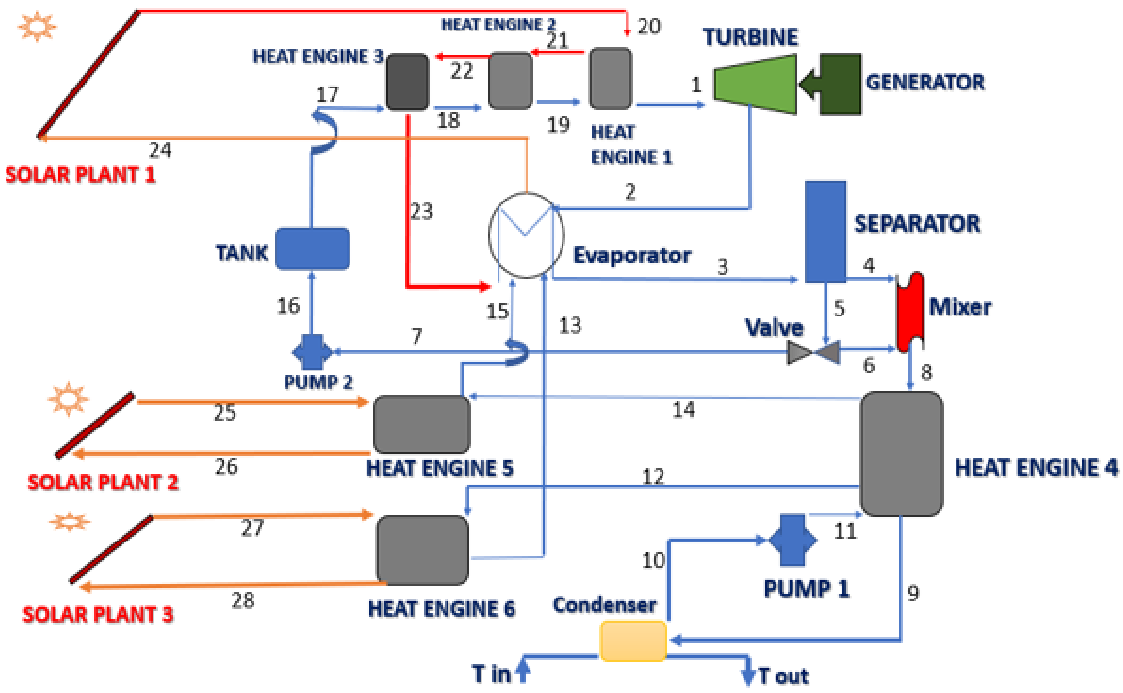

Fig. 1. New Kalina cycle with 3 solar system.

Dryness Fraction,

$$F = \frac{x_3 - x_5}{x_4 - x_5} \quad (1)$$

Mass at Separator,

$$\dot{m}3 = \frac{m8(x\dot{8} - x5)}{x3 - x5} \quad (2)$$

Separator Vapor Mass,

$$\dot{m}4 = \mathrm{F} \times \dot{m}3 \quad (3)$$

Separator Liquid Mass,

$$\dot{m}5 = (1 - \mathrm{F}) \times \dot{m}3 \quad (4)$$

Enthalpy at Heat Engine 5,

$$h8 = \frac{(m4 \times h4) \dot{+} (\dot{m}6 \times h6)}{\dot{m}8} \quad (5)$$

Mass at the First Solar Collector,

$$\dot{m}_{23} = \frac{\dot{m}1(h1 \dot{-} h18)}{Cp(T20 - T22} \quad (6)$$

Turbine Work,

$$\dot{W}T = \dot{m}1(h1 - h2)Meff \times Geff \quad (7)$$

Heat Supplied by the First Solar Collector,

$$Q\dot{s}1 = \dot{m}1(h1 - h19) + \dot{m}19(h19 - h18) + \dot{m}18(h18 - h17) \quad (8)$$

Heat Supplied by the Second Solar Collector,

$$\dot{Q}s2 = \dot{m}15(h15 - h12) \quad (9)$$

$$\dot{Q}s3 = \dot{m}13(h13 - h12) \quad (10)$$

Total Heat Supplied,

$$\dot{Q}s = Q\dot{s}1 + \dot{Q}s2 + \dot{Q}s3 \quad (11)$$

Energy Efficiency,

$$\eta = \frac{\dot{W}nett}{\dot{Q}s} \times 100 \quad (12)$$

Efficiency Ratio,

$$Efficiency\ Ratio = \frac{(\eta)kc}{(\eta)carnor} \times 100 \quad (13)$$

Exergy at inlet to the vapor turbine,

$$EX_1 = h_1 - [T_0 \times s_1] \quad (14)$$

Entropy of the heat exchanger inlet HE3,

$$S_{23} = C_{pw} \times \log(\frac{T_{23}}{T_0}) \quad (15)$$

Exergy of hot fluid,

$$E_{hf} = \dot{m}_{23}[h_{23} - (T_0 \times S_{23})] \quad (16)$$

III. Results and Discussion

Plant and cycle characterization and the influence of concentration on plant efficiency are presented here. Each one of the outcomes was tallied and analyzed visually.

A. Effect for Inlet Temperature and Ammonia Concentration of Turbine

The Fig. 2 shows the impacts of turbine inlet temperature and ammonia concentration of condensers on cycle efficiency. The system performance optimizes at the 50-bar turbine input pressure with an optimal concentration of ammonia at condenser at 0.87. With an increase in ammonia concentration at condenser from 0.80 to 0.90, the efficiency of the suggested binary mixture cycle improves for the proposed Kalina system.

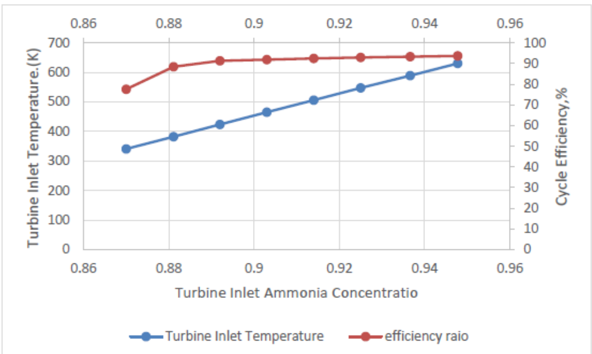

Fig. 2. The cycle efficiency with the impact of ammonia concentration at turbine exhaust condenser at 50 bar inlet pressure.

Fig. 3 shows that back work ratio was affected by turbine inlet temperature and ammonia concentration. It shows that the ammonia concentration 0.83-0.87 gives inlet temperature in the range 350-400 K and back work ratio in the range 0.1-0.2. But when the turbine inlet temperature at 700 K and ammonia concentration at 0.82 gives back work ratio to 1.2.

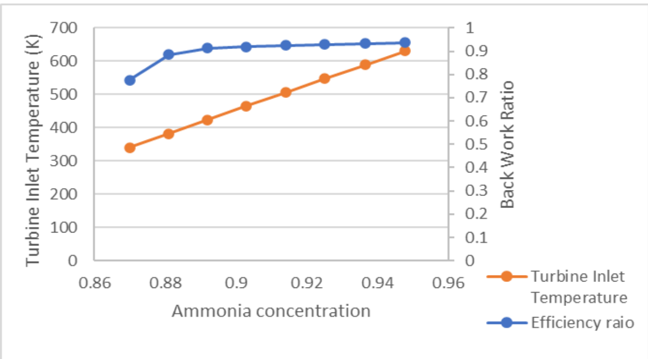

Fig. 3. Back Work Ratio with the impact of ammonia concentration and turbine inlet temperature at 50 bar inlet pressure.

IV. Effect for Outlet Temperature and Ammonia Concentration of Turbine

The relationship between turbine outlet pressure and outlet temperature and the effects on cycle efficiency and ammonia concentration in condensers is investigated. With an ideal concentration of ammonia at a condenser at 0.87, the system's performance is optimized at 50 bar turbine output pressure with an optimal concentration of ammonia. It is found that increasing the ammonia content at condenser from 0.80 to 0.90 percent results in an improvement in the efficiency of the proposed binary mixture cycle for the Kalina system. Fig. 4 shows that outlet temperature of turbine and ammonia concentration severely influence the Kalina cycle efficiency. We can see that 320 K-480 K of outlet temperature with 0.82-0.88 ammonia concentration increase the cycle efficiency until 470 K. The cycle efficiency is high (55%) while the turbine outlet temperature is at 470 K. The Fig. 5 shows the effect of ammonia concentration and turbine outlet temperature on back work ratio.

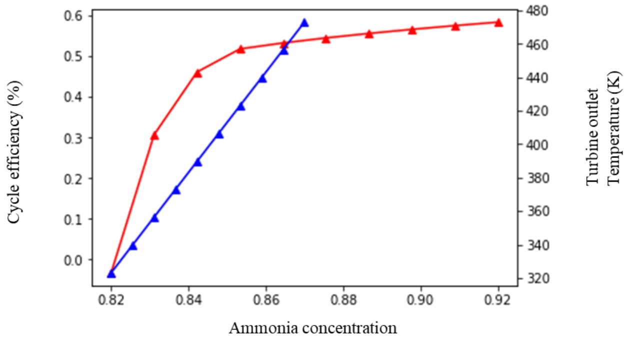

Fig. 4. KPS Kalina Cycle efficiency with the impact ammonia concentration at turbine exhaust turbine at 50 bar outlet pressure.

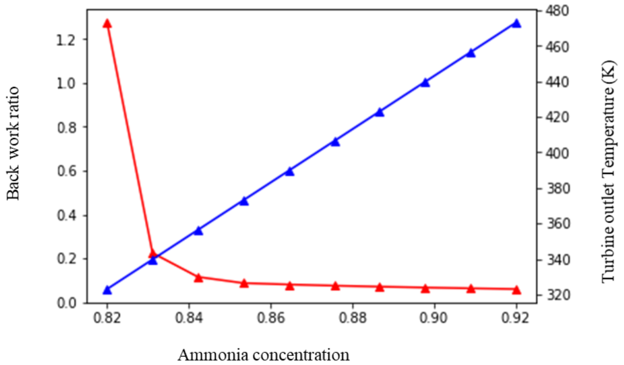

Fig. 5. KPS back work ratio with the impact of ammonia concentration at turbine exhaust condenser at 50 bar Outlet pressure.

V. Effect for Inlet Temperature and Ammonia Concentration of Condenser

All instances show a variation in exergy losses in the Kalina cycle components throughout a range of ammonia concentration at condenser and separator temperatures, with the highest exergy loss at the turbine and lowest exergy losses at condensers and separators. Because of the increased hot source temperature, the losses in the turbine are greater. When the ammonia concentration is high and the condenser and separator inlet temperatures are high, the losses are reduced. According to a survey of the literature, most power systems suffer from greater exegetic loss in high temperature components.

Table I shows the effects of condenser inlet temperature and ammonia concentration on plant efficiencies. Results show that solar plant 1 produce lower efficiency than other solar plants in a particular temperature. The solar plant 3 produces more efficiency with ammonia concentration between 0.80-0.94.

TABLE I: CONDENSER INLET TEMPERATURES EFFECT ON SOLAR PLANT EFFICIENCY

Inlet Temperature of Condenser (K)	Condenser ammonia concen-tration	Solar Plant 1 efficiency (%)	Solar Plant 2 efficiency (%)	Solar Plant 3 efficiency (%)
303	0.89	12.39	14.87	18.59
305.22	0.89	25.05	30.06	37.57
307.44	0.90	31.32	37.58	46.98
309.67	0.90	31.46	37.75	47.19
311.88	0.91	31.45	37.74	47.18
314.11	0.91	31.40	37.68	47.10
316.33	0.92	31.35	37.62	47.03
320.77	0.92	31.31	37.57	46.97

VI. CONCLUSION

A redesigned power production configuration is suggested to use more solar energy with additional collector and thermodynamically analyzed from the perspective of first law and second law analysis. Parametric research is performed, revealing important empirical relationships in performance development of the suggested system. It is found that when the temperature to the separator rises, the cycle generates more vapor, increasing ammonia concentration to the turbine, resulting in improved performance. However, the optimal condenser evaporator outlet temperature values from turbine and ammonia concentration vary. Results showed that energy efficiency improves at 0.95 ammonia concentration at condenser. The parametric research also indicates the improved condenser output minimizes at 85°C evaporator outlet temperature and 0.9 ammonia concentration. Having determined the parameters, the suggested system maximized plant efficiencies at low turbine outlet temperature and low turbine input temperature. Exergy degradation in turbine peaks with 60% of the proposed power cycle and reduces with higher ammonia concentration at a condenser of 0.94 and separator inlet temperature of 80°C with 30%. Using extra solar recovery system requires less input for optimum performance. In researching new system performance, the difficulty is to find the diversity of parameters. The key parameters are ammonia, temperature, and pressure.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

MA conducted the research, collected data, analyzed results, and wrote the first version of manuscript; MMR generated the idea and wrote final version of the paper; all authors had approved the final version.

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