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Options In Kalina Cycle Systems

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Abstract

Cooling needs are increasing rapidly at hot climatic countries with increased global warming. Some commercial units and industries need more amount of cooling than the power such as cold storage, shopping complex etc. The existed vapor compression refrigeration (VCR) system demands electricity for its operation which is more expensive. The available combined power and cooling cycle (Goswami cycle) operates with ammonia-water mixture as working fluid having low cooling due to the saturated vapor at the inlet of evaporator. It also demands high ammonia concentration at turbine inlet to get cooling effect and suitable only at low sink temperature (10-12 °C). In this work, a new cooling cogeneration cycle has been proposed and solved to generate more cooling with adequate power generation from single source of heat with two options in working fluids i.e. ammonia-water mixture and LiBr-water mixture. The resulted cycle energy utilization factor (EUF), plant EUF, specific power, specific cooling and solar collector area are 0.27, 0.10, 15 kW, 220 kW and 10 m^2/ kW for ammonia-water mixture plant and 0.82, 0.33, 25 kW, 180 kW and 3 m^2/kW for LiBr-water mixture plant respectively..

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Keywords: Aqua-Ammonia, LiBr-Water, Cooling, Cogeneration, Solar thermal etc.

1. Introduction

It is difficult to erect conventional power plants to meet the increased power and cooling loads due to its exhaustive in nature. Decentralized power system, waste heat recovery and cogeneration system etc. are the alternative routes to solve this problem. In cooling cogeneration (common plant for power and cooling) a considerable save in power consumption is due to generation of cooling without electrical input.

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It is not possible to operate a steam power plant at low temperature heat source but steam can be generated in a low temperature and low pressure operated by LiBr-H_2O based vapor absorption refrigeration (VAR) system with a high coefficient of performance (COP) compared to aqua ammonia mixture. If the configurations of power and cooling are clubbed together, it is possible to generate power and cooling with low temperature heat source. This type of integration of power and cooling increases the overall system performance.

Many analyses on externally integrated power and cooling cycle in both theoretical and experimental shows an improvement in efficiency with the integration. Xu et al. [1] modified the Kalina cycle system to achieve both power and cooling. But it demands 0.999 ammonia concentration to get the cooling effect. In this cycle, a low temperature of saturated ammonia vapor is obtained at the exit of the turbine and it is used for refrigeration purpose. Srinivas and Reddy [2] developed a cooling cogeneration cycle by coupling the KCS and VAR system without changing the base cycles. They divided the working fluid which is common to both power cycle and cooling cycle to meet the demand. High turbine inlet concentration maximizes the cooling output when the cooling requirement is high. The rectification with internal and external cooing is analyzed by Fontalvo et al. [3] and concluded that the internal cooling reduces the irreversibility and increases both first and second law efficiency. Jawahar et al. [4] resulted 225 kW of cooling and 80 kW power from aqua ammonia based integrated system. They attained a maximum combined thermal efficiency of 35-45% and coefficient of about 0.35 at the optimum conditions. Lopez-Villada et al. [5] made the simulation for the split cycle for three working pair of NH_3/H_2O, $NH3/LiNO_3$ and NH_3/NaSCN with the option in split ratio. The comparison shows that the first law efficiency is less than the Goswami cycle but having the option of choosing the power to cooling ratio and also suitable for different absorption pair. The development performance studies of combined power and cooling cycle working at both LiBr-water and aqua-ammonia pair is the main objective.

2. Working Principle

The KCS plant can convert into combined power and cooling cycle by simply adding the condenser which leads to triple pressure. The common cycle for both aqua-ammonia and LiBr-water cooling cogeneration cycle is shown in the Fig.1. The binary fluid cycle is the separation of absorbent and refrigerant at the source temperature and the mixing of these two at sink temperature. A saturated vapor is generated in the boiler/generator and undergoes a subsequent superheating process. The superheated vapor expands in the mixture turbine to generate power from high pressure (HP) to intermediate pressure (IP). The IP is determined from the sink temperature. It is condensed in a condenser from wet vapor to saturated liquid condition. The condensate liquid cools after rejecting heat to low temperature vapor at subcooler. The subcooled liquid throttles to low temperature from condensing pressure to the sink pressure.

Depending upon the operational conditions, the exit temperature of throttling may be negative or positive cooling temperature. Since the state is above the saturated liquid condition, there is no practical issue of crystal formation at negative temperature for aqua-ammonia which is severe problem in case of LiBr-water mixture. The throttled and low temperature liquid mixture can absorb the heat from the surroundings from evaporator coils. The evaporator exit temperature is fixed to analyze the other operational parameters. The mixture (absorbent+refrigerant) liquid solution is pumped to HP through solution heat exchanger. Dephlegmator is used to increase the concentration of ammonia vapor and it is not necessary for LiBr-Water cycle. The hot fluid from solar concentrating collectors is used to generate wet vapor and superheated vapor at generator and superheater respectively. The liquid mixture will absorb the vapor from the evaporator due to low temperature maintained at absorber by rejecting heat to circulating water. These processes repeat in cycle and generate power and cooling. Without the condenser at the exit of the turbine called as KCS cycle I.e. the proposed cycle can operate KCS plant as well as combined power and cooling cycle suitable for hot climatic countries.

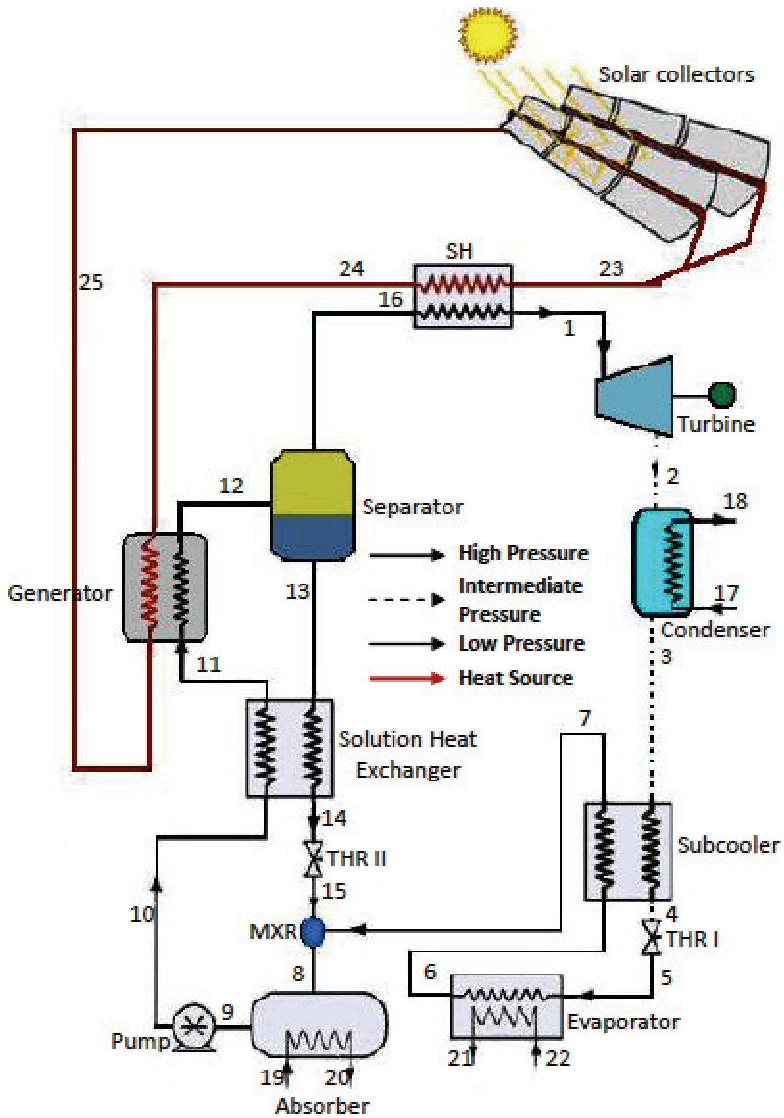

Fig.1 Schematic layout of common (LiBr-water and aqua-ammonia) cooling cogeneration cycle.

3. Results and Discussions

The aqua-ammonia and LiBr-Water cooling cogeneration cycle are simulated by fixing the beam and global radiation of 700 and 960 W/m^2. The separator temperature of 80-200 °C and cooling water temperature of 24-30 °C are varied and the performances are analyzed. The cycle power efficiency of the LiBr-Water cooling cogeneration is as high as 3-13% where as it s low of 1-6.5% for aqua-ammonia cooling cogeneration cycle as shown in the Fig. 2. The working temperature and pressure is different for both the cycle. At the low temperature of 90 °C itself the LiBr-water cooling cogeneration cycle starts operating but high temperature of 140 °C is required for the operation of aqua-ammonia cooling cogeneration cycle due to its turbine and cooling working pressure. At high strong solution concentration and low sink temperature the aqua-ammonia cycle will operate at low separator temperature.

The COP of the cycle should not change when it is integrated with another cycle. Fig. 2 (b) shows the COP of the proposed cooling cogeneration cycle and it is in the range of 0.46-0.54 for the aqua-ammonia cycle and 0.74-0.82 for the LiBr-water cycle. Maximum cooing water temperature for LiBr-water cycle is 30 °C due to requirement of low sink pressure for the cooling. Operating at high sink temperature is made possible by increasing LiBr concentration in the water.

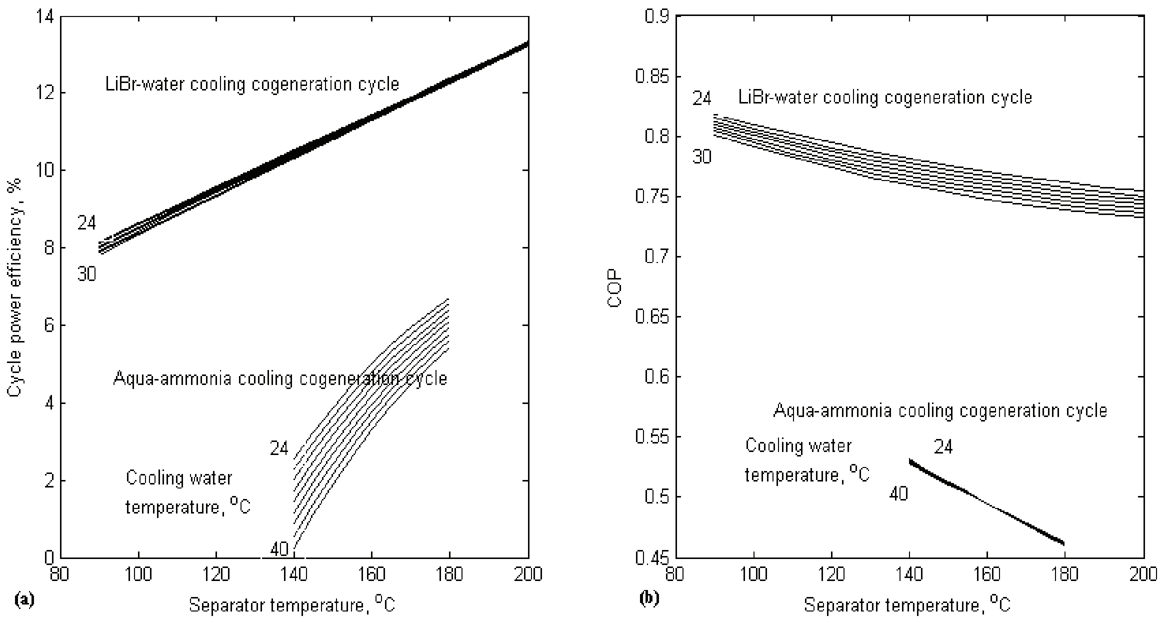

Fig. 2. Performance of (a). Cycle power efficiency and (b). COP of cooling cogeneration cycle

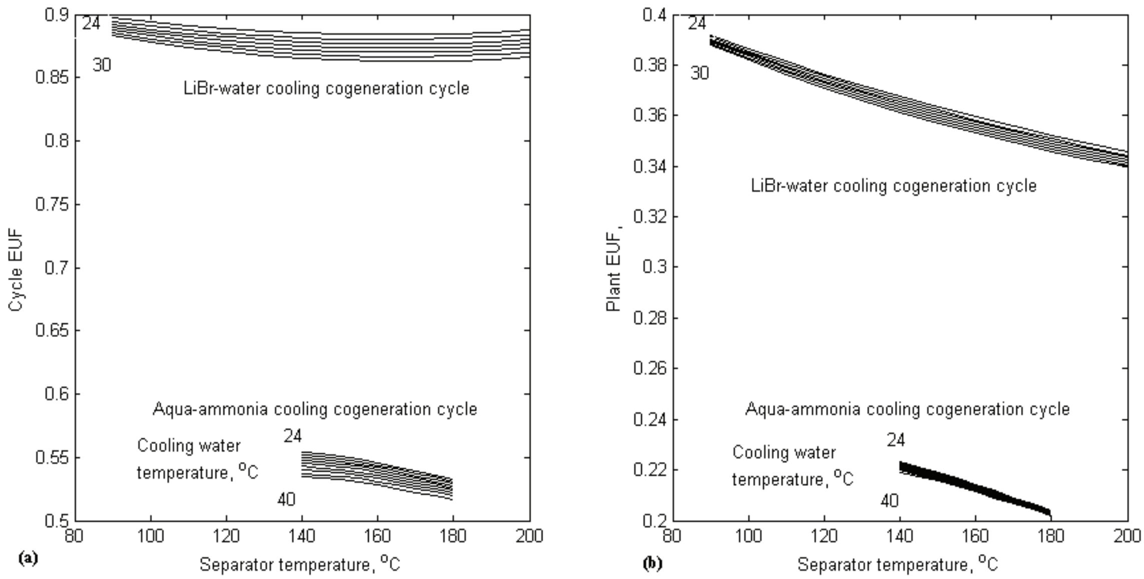

Fig. 3. (a) Cycle Energy Utilization Factor and (b) Plant Energy Utilization Factor of the cooling cogeneration cycle.

The performance of the combined power and cooling are expressed in Energy Utilization Factor (EUF) due to two different outputs. The cycle and plant EUF are studied to find the optimum working condition of the proposed cooling cogeneration and it is shown in the Fig.3. In case of LiBr-water working pair the cooling output is high compared to the aqua-ammonia pair because of its high latent heat of refrigerant. Hence both the cycle and plant EUF is high for LiBr-water working pair. Vijayaraghavan and Goswami [9] showed more than 0.25 cycle EUF and Wang et al. [10] resulted 20.45% of cycle thermal efficiency from integrated plant. The current model results high compared to existing combined power and cooling cycle at maximum separator temperature and concentration due to more cooling output. The cycle and plant EUF for the LiBr-water cooling cogeneration 0.86-0.9 and 0.34-0.38 respectively are obtained and for aqua-ammonia cycle lies in the range of 0.52-0.56 of cycle EUF and 0.2-0.22 of plant EUF achieved. But both the cycle EUF increases when the cooling water temperature/sink temperature is low.

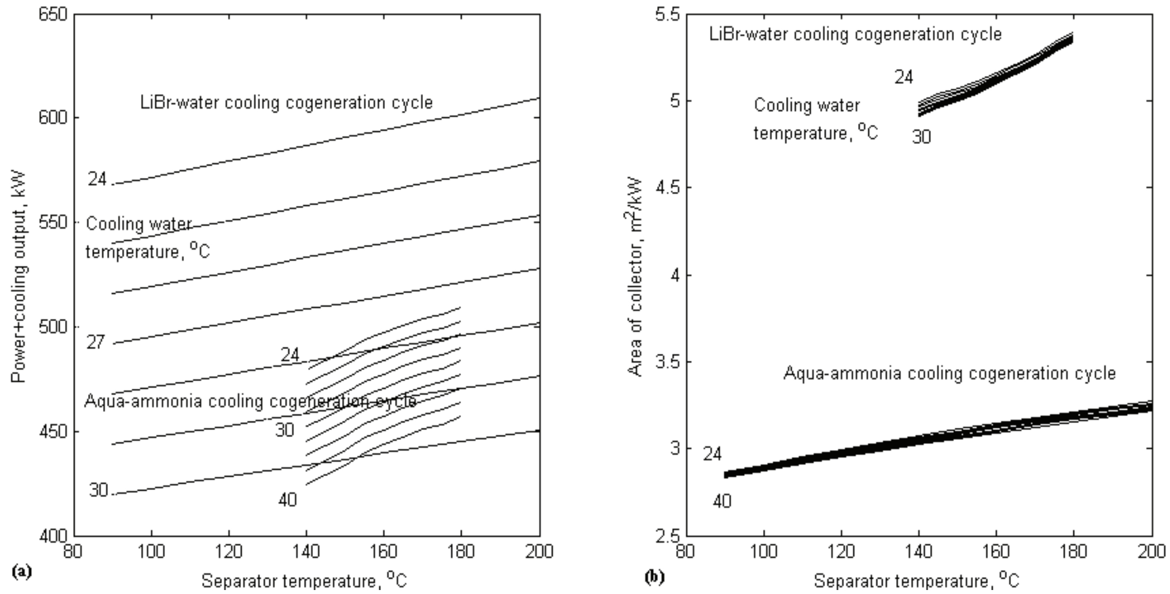

Fig.4 Comparisons of aqua-ammonia and LiBr-water cooling cogeneration cycle on (a) power+cooling output and (b) area of collector.

Fig.1 (a) shows the combined power and cooling output of both aqua-ammonia and LiBr-water cooling cogeneration cycle and Fig.1 (b) shows the solar collector area required for the operation of the cycle with respect to separator temperature and cooling water temperature. The cogeneration output (power+cooling) shows increment with respect to separator temperature for both aqua-ammonia and LiBr-water mixture but is decreased by increasing the cooing water temperature. The LiBr-water cycle will able to operate for the separator temperature range of 80-200 °C and aqua-ammonia cycle will operate within the range of 140-180 °C. Maximum cogeneration output of 610 kW is produced for the LiBr-water cycle at separator and cooling water temperature of 200 and 24 °C respectively. The LiBr-water cycle will produce the cooling temperature more than 4 °C due to its ice formation in the evaporator whereas the aqua-ammonia cycle will produce both negative and positive cooling temperature. The solar collector area requirement for the operation for the aqua-ammonia cogeneration cycle is less due its operating temperature range and it requires maximum of 3.3 m^2/kW but for the LiBr-Water cycle more than 5 m^2/kW as shown in the Fig.1(b). High separator temperature consumes more solar collector area and it is less for low cooling water temperature for both aqua-ammonia and LiBr-Water cooling cogeneration cycle.

Table. 1 Comparisons of cooling cogeneration cycle for 100 TR of refrigeration

Description	Aqua-Ammonia cogeneration cycle	LiBr-Water cogeneration cycle
Separator temperature, °C	150	150
Strong solution concentration, kg/kg	0.422	0.65
Weak solution concentration, kg/kg	0.258	0.555
Vapor fraction	30	16
Turbine concentration, kg/kg	0.883	0
Evaporator temperature, °C	-7.36	6
Pump load, kW	10.61	0.04
Absorber heat load, kW	940.21	464.94
Solution heat exchanger heat load, kW	48.92	109.81
Heat load in generator, kW	1119.8	466.74
Heat load in dephlegmator, kW	128.75	----
Heat load in superheater, kW	15.08	2.77
Condenser heat load	569.44	329.03
Sub cooler heat load, kW	8.70	6.05
Turbine power output, kW	28.95	51.16
Cooling output, kW	350.49 (100 TR)	349.85 (100 TR)
COP	0.30	0.75
Cycle power efficiency, %	2.55	11.40
Cycle Energy Utilization Factor	0.32	0.86
Plant Energy Utilization Factor	0.13	0.35

Table.1 shows the comparisons of LiBr-water and aqua-ammonia cooling cogeneration cycle at fixed cooling output of 50 TR with 150 °C of separator temperature and 30 °C of atmosphere temperature. More than double of vapour fraction is required for the aqua-ammonia compared to LiBr-water working fluid for producing the same cooling output. 15.21 kW and 26.27 kW of additional power are produced for aqua-ammonia and LiBr-water cycles. The generator load and absorber load are high for aqua-ammonia cycle for the same separator and cooling water temperature. The cycle EUF and plant EUF also high for the LiBr-Water cogeneration cycle compared to the aqua-ammonia cycle whereas the evaporator temperature of aqua-ammonia is -8 °C and for LiBr-water is 6 °C.

4. Conclusion

The comparison study of solar combined power and cooling cycle working with aqua-ammonia and LiBr-water pair are analyzed at different cooling water temperature. The LiBr-water mixture shows better performance in terms of power and cooling output and ammonia water mixture shows better performance in terms of solar collector area and cooling temperature. Maximum cogeneration output of 610 and 510 kW are produced for LiBr-water and aqua-ammonia cooling cogeneration cycle respectively. Aqua-ammonia cooling cogeneration cycle has been recommended for industrial use where the cooling requirement is below 0 °C such as cold storage, medicine etc. LiBr-Water cooling cogeneration cycle is suggested for domestic and commercial applications where the cooling requirement is above 0 °C such as refrigeration and air conditioning systems.

Acknowledgements

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