Cooling Cogeneration Cycle

R. Shankar and T. Srinivas*
CO$_2$ Research and Green Technologies Centre, School of Mechanical Engineering,
VIT University, Vellore, Tamil Nadu, India
*e-mail: srinivastpalli@yahoo.co.in
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Abstract—The existed combined power and cooling cycle operates with ammonia–water mixture as working fluid having low cooling due to the vapor at the inlet of evaporator. It also demands high ammonia concentration at turbine inlet to get cooling and suitable only at low sink temperature (10–12°C). 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 results show that an increase in cycle maximum temperature is only supporting the power but not the cooling. A suitable range for separator temperature has been developed and optimized to maximize the total output. From this study, the resulted specific power, specific cooling, cycle power efficiency, cycle coefficient of performance (COP) and cycle energy utilization factor (EUF), plant EUF, and specific area of solar collector are 0.008 kW/m$^2$, 0.11 kW/m$^2$, 2%, 0.28, 0.3, 0.13 and 8 m$^2$/kW for ammonia–water cycle and 0.04 kW/m$^2$, 0.3 kW/m$^2$, 9.5%, 0.7, 0.8, 0.37 and 3 m$^2$/kW for LiBr–water mixture plant respectively.

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INTRODUCTION

In this work, a focus has been made on the development of a new cooling cogeneration cycle that generates power and cooling together with a choice in working fluids. It has been designed and studied thermodynamically to check its feasibility at hot climatic conditions (24–40°C). Development of this kind of plant avoids the repetitive usage of components and results a compact system compared to individual systems integration. Small scale distributed cogeneration units ($\leq$1 MWe) are gaining attention for future power generation systems. Many conventional plants have been developed with combustion of fuel and heat recovery integration [1]. Waste heat from the microturbine or engine exhaust can be used to run single effect absorption chiller [2]. Burns and McDonnell partnered with Austin energy to construct the innovative large scale cogeneration pilot system in the domain plant of Austin [3]. Sun [4] made a cooling cogeneration cycle with mid or low temperature heat source. The experimental results of 15 kW cooling system coupled externally to other cycle saves 17.1% with same output compared to separate power and cooling cycle. Xu et al. [5] modified the Kalina cycle system (KCS) 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. Hasan et al. [6] investigated the combined cycle performance using the solar thermal as heat source and concluded that 77°C is sufficient to achieve second law efficiency of more than 60%. Tamm and Goswami [7] made the experimental investigation of combined power and cooling with ammonia–water mixture. Increase in turbine inlet pressure gives drop in power output and linear increased in refrigeration and thermal efficiency. Martin and Goswami [8] analyzed the cooling effectiveness in the combined cycle. They resulted that the equal amount of work is required per unit of cooling production by achieving the effective COP of 1.1. Vidal et al. [9] bypassed pump flow from generator to rectifier and identified that there is 0.5 kW of irreversibility is reduced when the rectifier temperature is decreased from 112 to 106°C. The exergy effectiveness of 53 and 51% were obtained at the source temperature of 125 and 150°C respectively. Due to the more components in the controlling of separate power and cooling cycle the cost is increased and having more irreversibility. Zheng et al. [10] developed a novel absorption power and cooling cycle and reported 24% of cycle efficiency at a maximum temperature of 350°C. But the cycle proposed is a complex in nature. The optimum operating condition of 2.3 MPa of turbine inlet pressure and 0.42 MPa of turbine exit pressure gives more COP of 0.647 with ammonia concentration of 0.554 [11]. Wang et al. [12] designed a combined power and refrigeration cycle which combines the Rankine cycle and the absorption refrigeration cycle. They reported a cycle efficiency of 20.5% at the source

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temperature of 300°C. Wang et al. [13] also proposed a new combined power and ejector absorption refrigeration cycle, which combines the Rankine cycle and the ejector absorption refrigeration cycle, and could produce both power output and refrigeration output simultaneously. They resulted 21% of thermal efficiency at the source temperature of 300°C. Pouraghajae et al. [14] used the multi objective technique for the Goswami cycle to find the key parameter variation for the performance of the cycle. Zare et al. [15] analyzed the Goswami cycle with gas turbine combined cycle heat recovery system. The thermo economic analysis shows that the unit rate of production cost integrated power and cooling cycle is reduced by 18.6 and 25.9% with first and second law efficiency respectively. Srinivas and Reddy [16] developed a cooling cogeneration cycle by coupling the KCS and vapore absorption refrigeration (VAR) system without changing the base cycles. They divided the working fluid which is common to both power cycle and cooling cycle as per the demand. High turbine inlet concentration maximizes the cooling output, when the cooling requirement is high the rectification process is mandatory. The rectification with internal and external cooling is analyzed by Padilla et al. [17] and concluded that the internal cooling reduces the irreversibility and increases both first and second law efficiency. Jawahar et al. [18] 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 performance of about 0.35 at the optimum conditions. This type of integration of power and cooling increases the overall system performance.

Currently solar thermal energy as a source to a low temperature plant is gaining more momentum [19]. The current cooling cogeneration gains operation energy from the solar concentrating collectors. In the literature a comparative study of proposed cycle with a choice in working fluid has not been available at common ground. The work details the results to highlight the comparative merits and demerits. Thermodynamic property equations for ammonia–water mixture, developed by Ziegler and Trepp [20] have been used to evaluate the proposed ammonia–water cooling cogeneration cycle. LiBr–water mixture properties have been used from the ASHRAE correlations [21] for LiBr–water cooling cogeneration cycle. The developed results are specific power, specific cooling, power cycle efficiency, cycle coefficient of performance (COP), cycle energy utilization factor (EUF), plant EUF, total output and collector specific area.

METHODOLOGY

The process flow diagram for proposed cooling cogeneration cycle has been developed and depicted in Fig. 1. This system can be used for both ammonia–water cycle and LiBr–water cycle. In ammonia–water cycle, ammonia is used as refrigerant and water works as an absorbent. But in LiBr–water cycle, water is a refrigerant and LiBr salt is an absorbent. Therefore in LiBr–water cycle, dephlegmator is bypassed since the refrigerant is pure substance. The superheated vapor (1) generated in boiler and superheater enters in turbine and expands to generate mechanical and so electrical power by expanding from high pressure (HP) to intermediate pressure (IP). The expanded vapor (2) is condensed to a saturated liquid state (3). The condensate subcools (4) after rejecting heat in a subcooler to a low temperature vapor coming from evaporator. The subcooler improves the cooling performance by resulting lower temperature and decreasing absorber load. The subcooled liquid throttles (4–5) to low temperature wet mixture (5) which is able to absorb heat from the surroundings. The throttling process happens from IP to low pressure (LP). In ammonia–water mixture cooling cogeneration cycle, the temperature at exit of throttle is negative. But in LiBr–water cooling cogeneration cycle, the fluid exit temperature is positive to avoid the ice formation which blocks the pipe flow. For thermodynamic study, the evaporator exit (6) temperature is fixed to analyze the effect of other operational parameters. After absorbing the heat in evaporator, the dry vapor (6) receives the heat from subcooler and mixed with the weak solution (18). In LiBr–water mixture, the concentration is defined as the mass fraction of LiBr in a mixture. Therefore, the weak solution at the exit of separator (18) or inlet of mixture is called as strong solution in LiBr–water cycle. The mixing of vapor from evaporator with weak solution in ammonia–water cycle or strong solution in LiBr–water cycle generates heat. This heat has been removed in the absorber similar to condenser and the mixture (8) is condensed into a saturated liquid (9). The liquid solution is pumped (9–10) to HP and supplied to boiler via solution heat exchanger (11–12). In solution heat exchanger, a preheating of liquid takes place to save the heat load in boiler. At the exit of boiler, and in a separating drum, the liquid mass (16) and vapor mass (20) have been separated. In ammonia–water cycle, still there are water traces in the vapor which causes low cooling effect in the evaporator. Therefore, the moisture content (19) in the vapor has been removed by cooling at dephlegmator with liquid solution (23) supplied from pump.

Now the high ammonia concentrated vapor is super heated (22–1) and supplied to the turbine to repeat the cycle. It is not possible to condense the high concentrated vapor supplied from evaporator at the low pressure. Therefore it is diluted with weak solution at the inlet of absorber. Now it is easy to condense the mixture (8) into a saturated liquid (9). Since the weak solution temperature is relative high, it is cooled (16–17) in solution heat exchanger by rejecting heat to pumped solution. At the exit of solution pump, one part of separated liquid (23) flows to dephlegmator to cool the vapor (20) and the rest goes to boiler. The hot fluid generated in solar concentrating collector (31) is