THERMODYNAMIC STUDY OF RENEWABLE BASED TRIGENERATION CYCLE

Manish Kumar [1,*],H.Chandra [2,*],Raghwendra Banchhor [3],Arun Arora [4]
[1,3,4] Department of Mechanical Engineering, Bhilai Institute of Technology, Durg (C.G.) India
[2] Department of Mechanical Engineering, VEC Lakhanpur, Sarguja Vishwavidyalaya Ambikapur (C.G.) India

ABSTRACT

The aim of the paper is to summarize thermodynamic study of a renewable based trigeneration cycle. Renewable energy (RE) sources can be integrated to serve autonomous tri-generation combined cooling, heating and power (CCHP) systems, so that the advantages of zero environmental emissions as well as higher energy efficiencies in generation and consumption are realized simultaneously. The provision of a sustainable energy supply is one of the most important issues facing humanity at the current time, and solar thermal power has established itself as one of the more viable sources of renewable energy. The results showed the configurations that utilize steam extraction with a lower temperature and pressures were more efficient. For power and fresh water cogeneration, utilizing the condensation steam to integrate multi effect distillation with a power cycle was thermodynamically more efficient than the integration of thermal vapor compression-multi effect distillation using extraction steams. Integrated Rankine cycle-multi effect distillation configuration was found to be very competitive with the direct supply of electricity to reverse osmosis systems, particularly at higher fresh water productions.

Keywords: Brayton cycle, Rankine cycle, Kalina cycle, Renewable energy, Thermodynamic Analysis

1. INTRODUCTION

One of the way to decrease the global primary energy consumption and the corresponding greenhouse gas emissions is the application of the combined cooling, heating and power generation technologies, known as trigeneration system. Tri-generation is the production of electricity, heat and cooling in the one process. Typically this means a gas fired generator producing electricity and heat with the exhaust heat going to an absorption chiller which produces chilled water and hot water for air conditioning or alternatively the heat is used to heat a swimming pool. The ratio of electricity produced and exhausts heat for the absorption chiller and then the ratio of cooling to heating can be varied to meet the specific site requirements.To integrate solar energy into trigeneration system producing electricity, heating and cooling according to the exergetic, economic and environmental targets is explained by [2].With the increasing development of science and technology, demand for energy is surging at an unprecedented pace. Considering the growing consumption of conventional primary energy (coal, petroleum, natural gas) and environment-related concerns, recovering low temperature heat sources has become an inevitable option to solve the energy and environment problem [3].The Kalina cycle was introduced in 1984 [4] as an alternative to the conventional Rankine cycle to be used as a bottoming cycle for combined cycle power plants. It uses a mixture of ammonia and water as its working fluid, instead of pure water as in the case of a steam Rankine cycle. The composition of the ammonia-water mixture could be varied by changing the ammonia mass fraction which is defined as the ratio of the mass of ammonia in the mixture to the total mass of the mixture. Since its introduction, several usesfor the Kalina cycle have been proposed such as in a geothermal power plant, for waste heat recovery, in solar power plants, etc. to analyze and optimize a solar assisted gas turbine system. Parabolic trough collectors are used in order to supply a part of the demanded heat input, reducing the natural gas consumption and leading to an environmental friendly system is discussed in [5]. Energetic performance comparison of three trigeneration systems is presented in [6]. The systems considered are SOFC-trigeneration, biomass-trigeneration, and solar-trigeneration systems. This study compares the performance of the systems considered when there is only electrical power and the efficiency improvement of these systems when there is trigeneration. Different key output parameters are examined: energy efficiency, net electrical power, electrical to heating and cooling ratios, and (GHG) GHG (greenhouse gas) emissions. A novel solar building cooling heating and power (BCHP) system driven by solar energy and natural gas is proposed in [7].

2. SYSTEM DESCRIPTION

The examined system is depicted in Fig. 1 and it includes compressor, turbine, generator, combustion chamber and PTC field. Air with atmospheric conditions (state point 1) enters in the system and its pressured increases with simultaneous temperature increase (state point 2) in the compressor. This pressurized air continues in the solar collector field where it warms up with a small penalty in its pressure level (state point 3). The next device is the combustion chamber where the temperature of the pressurized air reaches its maximum value (state point 4). The turbine is the next device where the pressurized air is expanded up to atmospheric pressure and useful work is produced. This work is converted into electricity in the generator which is in the same shaft with the turbine and the compressor. Table 1 includes the main parameters of the examined system. More specifically, the isentropic efficiencies for turbomachinery, the mechanical and the other efficiencies, as well as the ambient situation and the fuel properties are given. It is essential to state that the fuel in this system is nature gas [5].

Table 1: System parameter[5]

Parameters	Symbols	Value	Ref.
Turbine isentropic efficiency	$\eta_{is,T}$	0.90	[1]
Compressor isentropic efficiency	$\eta_{is,C}$	0.85	[1]
Mechanical efficiency	η_m	0.98	[30]
Generator efficiency	η_{GEN}	0.97	[31]
Combustion chamber efficiency	η_b	0.98	[29]
Stoichiometric air-fuel ratio	μ_α	17	[32]
Lower heating value of fuel	H_u	$48 \cdot 10^6$ J/kg	[1]
Maximum cycle temperature	T_4	1400 K	–
Air mass flow rate	m_a	50 kg/s	–
Molecular mass of air	M	28.96 kg/kmol	–
Gas constant	R_C	8314 J/kg K	–
Ambient temperature	T_{am}	288.15 K	–
Ambient pressure	P_{am}	1.01315 bar	–

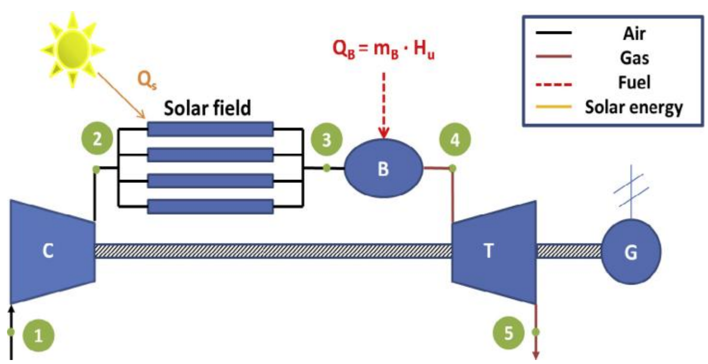

Fig. 1 The examined system [5]

In comparison with the existing Rankine cycle plants, an integrated solar system offers three principal advantages:

a) First, solar thermal energy can be converted to electric energy at a higher efficiency.
b) Second, the incremental unit cost for the larger steam turbine in the integrated plant is less than the overall unit cost in a solar-only plant.
c) Third, an integrated system does not suffer the thermal inefficiencies associated with the daily startup and shutdown of the steam turbine.

The most efficient method for converting solar thermal energy to electric energy is to withdraw feed water from the heat recovery steam generator downstream of the second stage (highest temperature) feedwater economizer, produce high pressure saturated steam, and return the steam to the heat recovery steam generator for superheating and reheating by the gas turbine exhaust. Fig. 2 shows a schematic diagram of the integrated solar-trigeneration system considered in this study which is located in Yazd, Iran and is not yet completed. This figure shows that the trigeneration system consists of four main units:

a) A power generation unit, which is known as the plant's prime mover, such as an integrated solar combined cycle system with parabolic solar trough collector.

b) A cooling unit, such as a single-effect absorption chiller.
c) A heating unit, such as a heating process heat exchanger.
d) An electrical generator.

Within the combined cycle unit of this trigeneration system, the following equipments are used:

a) Two V94.2 gas turbine units with natural gas fuel.
b) Two pressure heat recovery steam generator. The high and low pressure steam conditions were as follows: 84 bar and 507^{0}C and 9 bar and 232^{0}C respectively. A design stack temperature of 113^{0}C is selected to recover as much energy from the turbine exhaust as possible.
c) A no reheat two pressures steam turbine.

The flow in the trigeneration system according to Fig. 2[2] is described briefly as follows. The fluid exits the generator (GEN) at the state 13 as saturated liquid. Next, the condensate extraction pump (CEP) increases the pressure of the saturated liquid (state 14). Then, the working fluid enters the dearator (DEA) of the heat recovery steam generator (HRSG) for the removal of dissolved gases and preheating the fluid. Preheated feedwater is pumped by boiler feed pump (BFP) in a liquid state and exit as superheated vapor at the state's 18 and 24 from low pressure superheater (SHL) and high pressure superheater (SHH), respectively. However a part of working fluid exiting from the economizer (ECO) enters to the solar auxiliary evaporator (SAE) at the state 25 to produce the high pressure saturated steam (state 26). Then the saturated steam return to the heat recovery steam generator for superheating (state 24) by the gas turbine exhaust. Next, the superheated vapor expands through the steam turbine (ST) to produce the mechanical energy. The mechanical energy is used to rotate the electrical generator which is connected to the turbine. Then, the working fluid exits the steam turbine (state 11) and supplies heat to the heating process unit (HPU). The heating process unit rejects heat to supply the heating. After that, the working fluid enters the generator at the state 12 as saturated vapor. The generator absorbs heat to supply the cooling from evaporator (EVAC) for the single-effect absorption chiller. Then, the working fluid exits from the generator again as saturated liquid (state 13).

The solar field considered in this site is comprised of 42 loops and for each loop, six parabolic trough solar collectors of LS-3 type (Kearney, 1999) which are single axis tracking and aligned on a north–south line, thus tracking the sun from east to west. Various design parameters of these collectors are given in Table 1. In this study, numerical results are based on the site design condition with ambient temperature of 25 _C and a relative humidity of 32% and wind speed of 3 m/s. The analysis is carried out on 21 June in Yazd, IRAN at 12:00 noon (LAT). At this hour, solar radiation intensity at the plant site is about 800 W/m2. Therminol VP-1 is used as heat transfer fluid (HTF) in the solar field. Therminol VP- 1 is a synthetic heat transfer fluid with high thermal stability, uniform performance in a wide optimum use range of 12–400^{0}C.

Table 2: LS-3 collector specifications used in the solar-trigeneration system[2].

Aperture area per collector, A_{ap} (m^2)	545	HCE transmittance, τ	0.96
Mirror segments	224	Mirror reflectivity, ρ	0.94
Aperture, w (m)	5.76	Length, L (m)	99
HCE diameter, $D_{c,o}$ (m)	0.07	Concentration ratio	82
Average focal distance (m)	0.94	Peak collector efficiency (%)	68
HCE absorptivity, α	0.96	Annual thermal efficiency (%)	53
HCE emittance, ε	0.17	Optical efficiency, η_r (%)	80

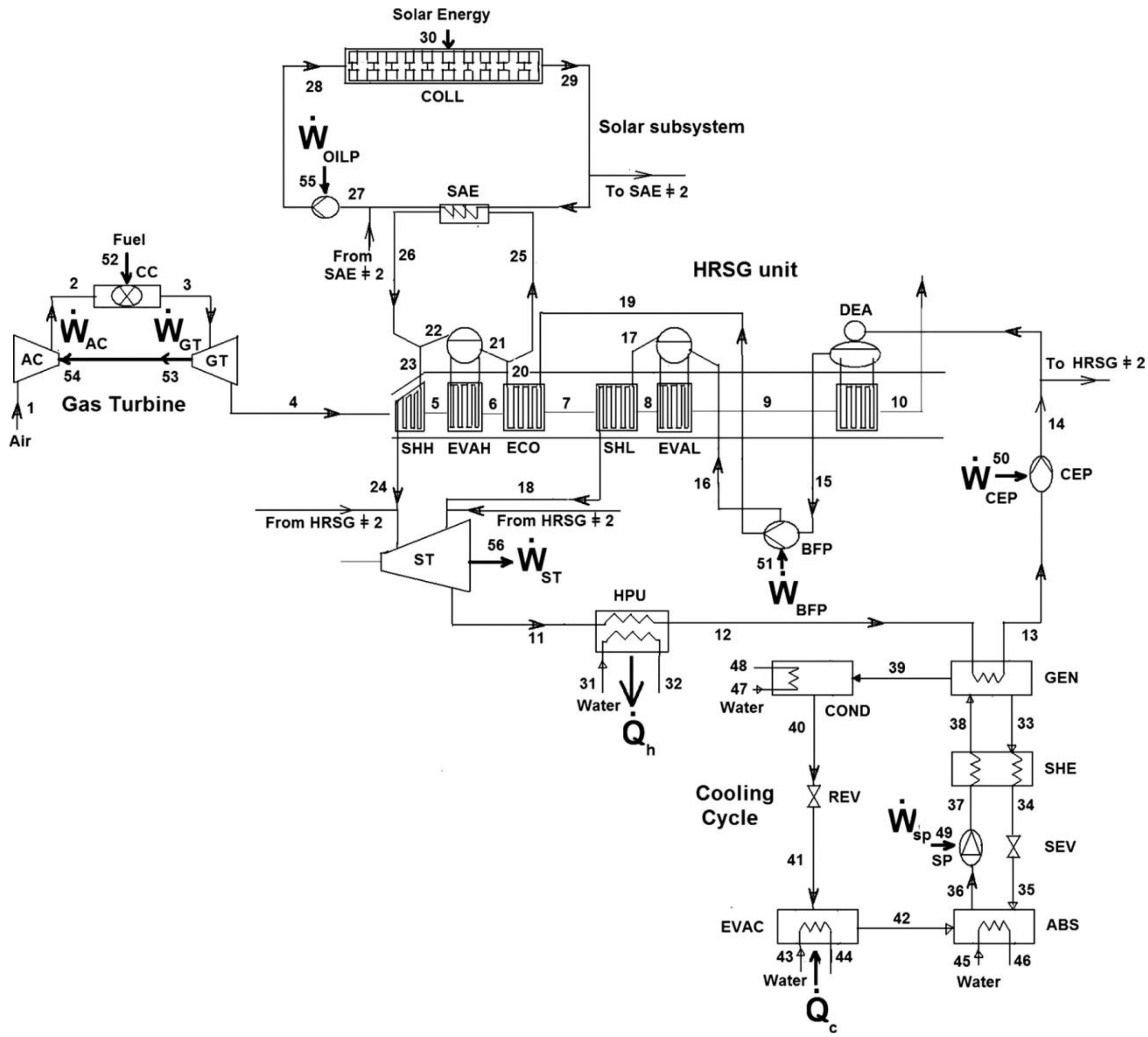

Fig.2 Schematic Diagram Of The Novel Integrated Solar-Trigeneration System [2].

3. CONCLUSION

As the solar shares of the simple-cycle hybrid solar gas-turbine power plants are relatively low, fuel consumption is still a major factor in the levelised cost of electricity. In order to obtain acceptable conversion efficiencies for the simple-cycle configuration, relatively high pressure ratios were selected for the optimized gas-turbines. The addition of a conventional Rankine bottoming-cycle further increases the conversion efficiency of the power block and generates additional electricity from the solar heat supplied to the system. Thus, while combined-cycle configurations allows electricity costs to be reduced, the degree of emissions savings achieved remains relatively modest. In hybrid power plants without storage, the maximum degree of solar integration is limited by the hours during which the Sun is available. Even if an extremely large (and thus extremely costly) solar field was used, which provided full solar heat input during all Sun-hours, certain periods of power plant operation will coincide with times at which no solar input is available.

REFERENCES

[1]. A thesis on Hybrid Solar Gas Turbine Power Plant, A Thermoeconomic Analysis by James D. Spelling (2013).
[2]. A. Baghernejad , M. Yaghoubi , K. Jafarpur, Exergoeconomic optimization and environmental analysis of a novel solar-trigeneration system for heating, cooling and power production purpose, Solar Energy 134 (2016) 165–179.
[3]. Omendra Kumar Singh and S.C. Kaushik. Thermoeconomic evaluation and optimization of a Brayton–Rankine–Kalina combined triple power cycle. Energy Conversion andManagement(Elsevier) 71 (2013) 32–42.
[4]. K Deepak, A.V.S.S.K.S. Gupta. Modeling and analysis of Low Temperature Kalina Cycle System. Journal of Chemical and Pharmaceutical Sciences Issue 2,August 2016 ISSN: 0974-2115.
[5]. Evangelos Bellos , Christos Tzivanidis, Kimon A. Antonopoulos, Parametric analysis and optimization of a solar assisted gas turbine, Energy Conversion and Management 139 (2017) 151–165
[6]. Fahad A. Al-Sulaiman , Feridun Hamdullahpur , Ibrahim Dincer, Performance comparison of three trigeneration systems using organic rankine cycles, Energy 36 (2011) 5741-5754.
[7]. You-Yin Jing , He Bai, Jiang-Jiang Wang , Lei Liu, Life cycle assessment of a solar combined cooling heating and power system in different operation strategies, Applied Energy 92 (2012) 843–853.
[8]. International journal of Science and Research, ISSN(online): 2319-7064, Indea Copernicus Value (2013):6.14, impact factor (2014): 5.611 'Thermodynamic Analysis of Kalina Cycle' MogheesAhmad1, M. N. Karimi
[9]. Arash Nemati, Hossein Nami, Faramarz Ranjbar, Mortaza Yari, A comparative thermodynamic analysis of ORC and Kalina cycles for waste heat recovery: A case study for CGAM cogeneration system, Case Studies in Thermal Engineering 9 (2017) 1–13
[10]. Anish Modi, Fredrik Haglind.Thermodynamic optimisation and analysis of four Kalina cycle layouts for high temperature applications.Applied Thermal Engineering (Elsevier) 76 (2015) 196-205