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Thermodynamic analysis of combined power, heating and cooling in a tri-generation system-A Review

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Abstract

The proposed combined power, heating and cooling in a trigeneration system is bases of optimal utilization of energy addressing the environmental issues because the design of tri-generation system is an alternative way of improved energy use in cascade refrigeration system using ejector. Savings of energy can be observed by using intercooler as cascade condenser. The combination of an ejector and a mechanical compressor in a cascade refrigeration system is technically viable due to no-cost thermal energy supplied to the system in terms of industrial waste heat or any renewable thermal source. The evolution of new hybrid systems has also enabled the heat pump to perform efficiently with wider applications. By incorporating a heat pump to a tri-generation system allowed a better humidity and temperature controls with achievable COP as high as possible. Heat pump brings about even greater opportunities for enhancing energy efficiency. From thermodynamic point of view, the combination of organic Rankine cycle with absorption chilling machine in this tri-generation system is found to be to be more efficient, because the flue gas from heat recovery steam generator to be used as a heat source for vapour absorption refrigeration system.
Keywords: Tri-generation cycle, Thermodynamic modeling

1. Introduction

One of the most important and much needed concerns shown by the researchers' world over is related to energy on which researches are being focused e.g. optimal use of energy, new or renewable sources of energy and reuse or recovery of waste energy in a tri-generation cycle. The main motive of this work is to recover and use waste heat from an energy consuming system. The present study focuses on energy analysis, exergy analysis and heat transfer analysis of combined power and ejector refrigeration cycle integrated in a tri-generation cycle with various refrigerants both ultra-low GWP and zero ODP refrigerants.

1.1 Tri-generation cycle

Tri-generation is one of the most promising technologies allowing the efficient simultaneous production of heat, cooling and power with potential technical, economic and environmental benefits. Using different working fluids in the Rankine cycle for heat and power generation in addition to investigating the use of new efficient and environmentally friendly working fluids; integrating thermal units with tri-generation systems to improve the overall efficiency[2].
A comprehensive thermodynamic modeling is reported of a tri-generation system for cooling, heating (and/or hot water) and electricity generation. This tri-generation system consists of a steam turbine cycle, gas turbine cycle, and organic Rankine cycle (ORC), a single-effect absorption chiller and a vapor compression cycle. Energy and exergy analyses, environmental impact assessments and related parametric studies are conducted, and parameters that measure environmental impact and sustainability are evaluated. The exergy efficiency of the tri-generation system is found to be higher than that of typical combined heat and power systems or gas turbine cycles. [3] Tri-generation is the simultaneous production of heating, cooling and electricity from a common energy source, utilizes the waste heat of a power plant to improve overall thermal performance, essentially utilizing the 'free' energy available via the waste energy. [4]
The thermodynamic modeling of the tri-generation cycle considered is divided into three parts: topping cycle (power

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cycle), bottoming cycle (Refrigeration cycle) and heating cycle. Thermodynamic analysis is used to determine the temperature profile, input and output enthalpies, exergy flows, environmental impacts, exergy destructions and exergy efficiencies [5].

1.2 Vapour compression cycle

In the vapor compression cycle, first of all vapor is compressed to a super-heated fluid, further cooled and condensed at constant pressure. Then refrigerant is allowed to throttle to a lower pressure by irreversible process, as a result producing a combination of liquid and vapor. Finally, at constant pressure liquid is evaporated. Heat rejected from refrigeration air conditioning plants is of low grade quality [1].

1.3 Vapor absorption refrigeration

Vapor absorption is the one of the ordinary method to produce the refrigeration effect. This system is used for domestic as well as industrial refrigeration plant. The commonly used refrigerant in this system is ammonia. The vapor absorption system uses heat energy instead of mechanical energy as in vapor compression refrigeration system. The main components used in the absorption system are absorber, pump, generator, pressure reducing valve. This system can be used in the combined cycle as bottoming cycle to recover the low grade waste heat for useful purpose.

1.4 Supercritical CO2 Cycle

Supercritical CO2 means that it is held at and above its critical temperature and pressure state. If both the temperature and pressure is increased from standard atmospheric temperature and held at and above the critical point, which results it acquires the properties that lies between the gas and the liquids. After that critical point CO2 behaves like supercritical carbon dioxide. Supercritical carbon dioxide cycle has smaller capital cost as comparison to steam Rankine cycle due to smaller size and it has higher Efficiency, which means that for the same heat input electricity production increases [8].

1.5 Organic Rankine cycle (ORC)

Organic Rankine cycle use the organic, high molecular mass with liquid vapor phase change or boiling point occurring at low temperature than water steam phase change. Heat can be recovered from the low temperature sources like biomass, solar pond, geothermal energy, industrial waste heat that can be used to operate organic Rankine cycle. Organic Rankine cycle is very much similar to steam Rankine cycle but with organic working fluids with low boiling point and critical points. If working pressure of the organic fluid above its critical pressure and heated to supercritical state then the cycle is known by supercritical organic Rankine cycle. [10]

1.6 Ejector Refrigeration cycle

The ejectors along with any vacuum pump create the low pressure (vacuum) at the inlet of the first ejector; can be used to remove the condensed steam from the system. Exhaust gas enters the ejector as primary flow; the primary flow enters the ejector at relatively high pressure and its pressure decreases while its velocity increases when flowing through the nozzle. Flows inside the ejector can be treated as steady and one-dimensional [11].

1.7 Working fluids

In the low temperature rankine cycle, selection of the working fluids is the key important parameter. There are heat transfer inefficiencies due to low temperature are highly injurious. Inefficiency is highly dependent upon the operation conditions and thermodynamic characteristics of the working fluids. To recover low grade waste heat, fluids with low boiling points than water are generally preferred. Refrigerants and hydrocarbons can be efficiently used in the low temperature ORC system. There are various characteristics of the working fluids like isentropic saturation vapor curve, low freezing point and stability at high temperature, heat of vaporization and density should be very high, impact on environment should be low, Safety precautions, easy available and low cost, pressure range lies between the working limit. Supercritical carbon dioxide can be operated by high temperature generating systems, but if we increase the temperature above the certain limit then metallurgical losses may occur. This system composes a generator to vaporize working fluid, a turbine which produces power, an ejector which is interconnected to evaporator to generate a low pressure area in evaporator as primary fluid from turbine expands through ejector, a condenser and a pump to complete the cycle and return the fluid to generator. It was shown that turbine inlet and outlet pressures, and condenser and evaporator temperatures have significant effects on turbine outlet power, refrigeration output and exergy efficiency of the system. [17]. In the low temperature Rankine cycle, selection of the working fluids is the key important parameter. To recover low grade waste heat, fluids with low boiling points than water are generally preferred. Refrigerants and hydrocarbons can be efficiently used in the low temperature ORC system. [19] In this study, R-123 and zeotropic mixture is selected as the working fluid. R-123 is a dry fluid and has remarkable thermodynamic performance and seems to be a suitable economic choice [30].

2. Literature Review

Kaushik et al. [1] presented an investigation of the feasibility of the heat recovery from the condenser of a simple vapor compression refrigeration system through a Canopus heat exchanger which acts as an auxiliary condenser between the compressor and condenser components. Results were compared for different working fluids and found that heat recovery factor of the order of 2.0 and 40% of condenser heat can be removed through the Canopus heat exchanger. Huang et al. [2] proposed a combined cycle refrigeration system (CCRS) that comprised a conventional refrigeration & air-conditioning system using mechanical compressor (RAC/MC) and an ejector cooling system (EJC) and observed that the COP of a CCRS is significantly higher than a single stage refrigeration system. Improvement in COP can be as high as 18.4% for evaporating temperature at -50C. The developed prototype of combined cycle refrigeration system (CCR was tested and experimental results shown that at evaporator temperature (Te) = 268.5 K, the COP is improved by 14% for a CCRS and concluded that the CCRS using the ejector cooling cycle as the bottom cycle of the RAC/MC is viable. Minciuc et al. [3] proposed a tri-generation plants based on gas turbine or internal combustion engine with absorption chilling machine and thermodynamic analysis has been carried out for the case of tri-generation with an absorption chilling machine for the best energetic performance of tri-generation and also analyzed the dependence of different technical criteria. It was observed that a certain case of a tri-generation plant, the dependence of the energetic performance of tri-generation on different technical criteria has also important for performance point of view. Herna et al. [4] Proposed a new process focused towards a more efficient use of energy, is nowadays highly desirable. And developed the design of a system of tri--generation as an alternative way of improved energy use in cogeneration systems and observed that the savings are decrease of the fuel fed to the turbo-generation equipment. A detailed analysis is also carried out by him for regenerative-cycle cogeneration system and a new tri-generation system showing their benefits as well as the operation criteria for both processes. Calva et al. [5] mainly focused on tri-generation system where a gas turbine is used as a prime mover for power production and cooling is generated by a typical compression–refrigeration system. The selection of the gas turbine that minimizes the heat losses to the ambient while supplying the required power can be readily accomplished by superimposing the turbine exhaust gas temperature profile to the process streams profile in a Temp vs enthalpy curve and developed thermodynamic model which helps to simulate the main components of the system and permits a fast and interactive way to design the optimum tri-generation system using the performance data of commercial gas turbines. Ouadha et al. [6] computed components exergetic losses by operating at constant evaporating temperature of -300C and condensation temperatures of 300C, 400C, 500C and 600C with two natural substitutes of HCFC22,(i.e. propane (R-290) and ammonia (R-717) as working fluids in the system. Arora and Kaushik [7] proposed a detailed exergy analysis of an actual vapour compression refrigeration (VCR) cycle for computing coefficient of performance (COP), exergy destruction, exergetic efficiency and efficiency defects for R-502, R-404A, and R-507A. The efficiency defect in condenser is highest and lowest in liquid vapour heat exchanger for considered refrigerants. Yingjie Xu et al. [8] presented a performance analysis of low-temperature absorption–compression cascade refrigeration system (LACRS), In the system, low-grade heat of absorption system is used to sub- cool the compression system which can obtain cold energy at −100 °C. and found that as low-grade cooling capacity from the of absorption system is provided to the compression system , high-grade cooling capacity increases, compressor power consumption decreases, and the COP of the compression system therefore increases.

Lazzaretto et al. [9] proposed a systematic and general methodology for defining and calculating exergetic efficiencies and exergy related costs in thermal systems. Thus, a direct link between the definitions of fuel and product for a component and the corresponding costing equations is established. In particular, the paper shows how to obtain detailed definitions of exergetic efficiencies using separate forms of exergy (thermal, mechanical and chemical) and how, according to these definitions, to conduct an evaluation of costs associated with all the exergy streams entering and exiting a system component. Wang et al. [10] proposed a combined power and refrigeration cycle which combines the Rankine cycle and the absorption refrigeration cycle. This combined cycle uses a binary ammonia–water mixture as the working fluid and produces both power output and refrigeration output simultaneously with only one heat source and observed that the heat source temperature, environment temperature, refrigeration temperature, turbine inlet pressure, turbine inlet temperature, and basic solution ammonia concentration have significant effects on the net power output, refrigeration output and exergy efficiency of the combined cycle. A parameter optimization is also carried out by means of genetic algorithm to reach the maximum exergy efficiency and found that the optimized exergy efficiency is 43.06%. Yapıcı et al. [11] studied the thermal performance of the ejector refrigeration system using ejectors with cylindrical mixing chamber at operating conditions with choking in the mixing chamber. The performance of the experimental system is determined by using six configurations of ejector and R-123 as working fluid in the system. The numerical computation is performed over a range of the ejector area ratio from 6.5 to 11.5 at the compression ratio 2.47 and found that the experimental coefficient of performance of the system rises from 0.29 to 0.41, as the optimum generator temperature increases from 83 to 1030C. Similar results were also found in the parametric study when the efficiencies of the nozzle and diffuser are taken as 0.90. Yiping Dai et al. [12] proposed a new combined power and refrigeration cycle, which combines the Rankine cycle and the ejector refrigeration cycle and found that the biggest exergy loss due to the irreversibility occurs in heat addition processes, and the ejector causes the next largest exergy loss and observed that the turbine inlet pressure, the turbine back pressure, the condenser temperature and the evaporator temperature have significant effects on the turbine power output, refrigeration output and exergy efficiency of the combined cycle. The optimized exergy efficiency is 27.10% under the given condition. Wang et al. [13] proposed a new combined power and refrigeration cycle for the cogeneration, which combines the Rankine cycle and the ejector refrigeration cycle by adding an extraction turbine between heat recovery vapor generator (HRVG) and ejector and observed that the condenser temperature, the evaporator temperature, the turbine inlet pressure, the turbine extraction pressure and extraction ratio have significant effects on the turbine power output, refrigeration output, exergy efficiency and exergy destruction in each component in the combined cycle. It is found that the biggest exergy destruction occurs in the heat recovery vapor generator, followed by the ejector and turbine. Dai et al. [14] proposed a new combined power and refrigeration cycle, which combines the Rankine cycle and the ejector refrigeration cycle. This combined cycle produces both power output and refrigeration output simultaneously and results shown that the biggest exergy loss due to the irreversibility occurs in heat addition processes, and the ejector causes the next largest exergy loss. It observed that the turbine inlet pressure, the turbine back pressure, the condenser temperature and the evaporator temperature have significant effects on the turbine power output, refrigeration output and exergy efficiency of the combined cycle. The optimized exergy efficiency is 27.10% under the given condition. Chaer et al. [15] set up a test rig for a tri-generation system to investigate the system performance and application feasibility. The rig was composed of three modules, a power component containing a micro turbine, a refrigeration unit consisting of an absorption chiller with gas pipe connection, and a supermarket section containing a display cabinet. The system model has been has been developed to validate the test results to predict the system performance at different operating and design conditions, such as varied ambient temperature, fuel flow rate and pressure ratio etc and found that the performance analysis is formulated by the system model can contribute significantly to the optimal component and system designs in various practical applications. Khaliq [16] is proposed conceptual tri-generation system based on the conventional gas turbine cycle for the high temperature heat addition while adopting the heat recovery steam generator for process heat and vapuor absorption refrigeration for the cold production. Combined first and second law approach is applied, and computational analysis is performed to investigate the effects of overall pressure ratio, turbine inlet temperature, pressure drop in combustor and heat recovery steam generator, and evaporator temperature on the exergy destruction in each component, first law efficiency, electrical to thermal energy ratio, and second law efficiency of the system and observed that the maximum exergy is destroyed during the combustion and steam generation process; which represents over 80% of the total exergy destruction in the overall system. Al-Sulaiman et al. [17] studied energy analysis of a tri-generation plant based on solid oxide fuel cell (SOFC) and organic Rankine cycle (ORC) is conducted. The physical and thermodynamic elements of the plant include an SOFC, an ORC, a heat exchanger for the heating process and a single-effect absorption chiller for cooling and obtained results show that there is at least a 22% gain in efficiency using the trigeneration plant compared with the power cycle (SOFC and ORC) and found that the maximum efficiency of the tri-generation plant is 74%, heating cogeneration is 71%, cooling cogeneration is 57% and net electricity is 46%, and also found that the highest net power output that can be provided by the trigeneration plant considered in this study is 540 kW and, the highest SOFC-AC power is 520 kW.

Marquesa et al. [18] proposed a novel Tri-generation application of energy technologies which simultaneously produces heat, refrigeration and electricity. To illustrate the usefulness of the criterion, a tri-generation pilot plant set up in an office building was studied. A theoretical model was developed an expression for the calculation of the thermodynamic performance of a generic tri-generation using , first-law analysis which involved an energy conversion ratio and newly defined heating-to-cooling and electric-to-cooling load ratios to usual system component thermodynamic parameters (such as coefficient of performance or prime mover thermal efficiency). Kavvadias et al. [19] mainly focused on the problem of optimal design of tri-generation plants and discusses the factors that affect the operation and the feasibility of investment. The effect of various operation parameters and energy tariffs structures are studied and the performance of a tri-generation plant is presented and evaluated versus the investment size. A new operation strategy is being introduced and examined along with three existing strategies and results are incorporated with various economical and performance indices that characterized the system, with reference to a case of a commercial hospital building. Zheng et al. [20] proposed a cycle combines the organic Rankine cycle and the ejector refrigeration cycle. The ejector is driven by the exhausts from the turbine to produce power and refrigeration simultaneously. A simulation was carried out to analyze the cycle performance using R245fa as the working fluid. A thermal efficiency of 34.1%, an effective efficiency of 18.7% and an exergy efficiency of 56.8% can be obtained at a generating temperature of 395 K, a condensing temperature of 298 K and an evaporating temperature of 280 K. Simulation results show that the proposed cycle has a big potential to produce refrigeration and most exergy losses take place in the ejector. Vidal et al. [21] performed a double stage solar ejector cooling cycle is using the TRNSYS-EES simulation tool and the typical meteorological year file containing the weather data of Florianopolis, Brazil. The first stage is performed by a mechanical compression system with R134a as the working fluid, while the second stage is performed by a thermally driven ejector cycle with R141b. The thermo-economical optimization is carried out with respect to the intercooler temperature and the flat plate solar collector area, for given specific costs of the auxiliary energy and electric energy, the capital cost of the collectors, ejector cooler, and the capital cost of equivalent mechanical compression cooler. Ameri et al. [22] proposed a new configuration of Micro-gas turbine cogeneration and tri-generation systems, with a steam ejector refrigeration system and Heat recovery Steam Generator.

Performance evaluation of this system with respect to Energy Utilization Factor (EUF), Fuel Energy Saving Ratio (FESR), thermal efficiency, and pinch point temperature difference, net power to evaporator cooling load and power to heat ratio is carried out. It has been shown that by using the present cogeneration system, one can save fuel consumption from about 23% in summer up to 33% in winter in comparison with separate generation of heating, cooling and electricity. Ghaebi et al. [23] the energy, exergy and thermo economic analysis of a combined cooling, heating and power (CCHP) system has been performed. Computational analysis is performed to investigate the effects of below items on the fuel consumption, values of cooling, heating and net power output, the first and second laws efficiencies, exergy destruction in each of the components and total cost of the system. These items include the following: air compressor pressure ratio, turbine inlet temperature, and pinch temperatures in dual pressure HRSG, pressure of steam that enters the generator of absorption chiller and process steam pressure. Al-Sulaiman et al. [24] exergy modeling is used to assess the exergetic performance of a novel tri-generation system using parabolic trough solar collectors (PTSC) and an organic Rankine cycle (ORC). Four cases are considered: electrical-power, cooling-cogeneration, heating cogeneration, and tri-generation. In this tri-generation system a single-effect absorption chiller is utilized to provide the necessary cooling energy and a heat exchanger is utilized to provide the necessary heating energy. This study reveals that the maximum electrical-exergy efficiency for the solar mode is 7%, for the solar and storage mode is 3.5%, and for the storage mode is 3%. Alternatively, when tri-generation is used, the exergy efficiency increases noticeably. The maximum tri-generation-exergy efficiency for the solar mode is 20%, for solar and storage mode is 8%, and for the storage mode is 7%. Maa et al. [25] studied a new combined cooling, heat and power (CCHP) system driven by the SOFC is proposed to perform the tri-generation by using ammonia–water mixture to recover the waste heat of exhaust from the SOFC-GT. The CCHP system, whose main fuel is methane, can generate electricity, cooling effect and heat effect simultaneously. Results indicate that the overall energy conversion efficiency exceeds 80% under the given conditions, and it is also found that the increasing the fuel flow rate can improve overall energy conversion efficiency, even though both the SOFC efficiency and electricity efficiency decrease. Moreover, with an increased compressor pressure ratio, the SOFC efficiency, electricity efficiency and overall energy conversion efficiency all increase. Ammonia concentration and pressure entering ammonia–water turbine can also affect the CCHP system performance. Huicochea et al. [26] analyzed theoretically the thermodynamic performance of a tri-generation system formed by a micro turbine and a double-effect water/LiBr absorption chiller. A thermodynamic simulator was developed using Mass and energy balances of the main components of the cooling system were obtained with water lithium bromide solution as working fluid. The results demonstrated that this system represents an attractive technological alternative to use the energy from the micro turbine exhaust gases for electric power generation, cooling and heating produced simultaneously. Moya et al. [27] experimentally determined the efficiency and viability of the performance of an advanced tri-generation system that consists of a micro gas turbine in which the exhaust gases heat hot thermal oil to produce cooling with an air cooled absorption chiller and hot water for heating and DHW. The micro gas turbine with a net power of 28 kW produces around 60 kW of heat to drive an ammonia/water air-cooled absorption chiller with a rated capacity of 17 kW. The modeling performance of the tri-generation system and the electrical modeling of the micro gas turbine are presented and compared with experimental results. Finally, the primary energy saving and the economic analysis show the advantages and drawbacks of this tri-generation configuration. Popli et al. [28] analyzed the integration of a tri-generation scheme within a NGPP that utilizes waste heat from gas turbine exhaust gases to generate process steam in a Waste Heat Recovery Steam Generator (WHRSG). Part of the steam generated is used to power double-effect water–lithium bromide (H2O–LiBr) absorption chillers that provide gas turbine compressor inlet air-cooling. The results indicate that the tri-generation system could recover 79.7 MW of gas turbine waste heat, 37.1MW of which could be utilized by three steam-fired H2O–LiBr absorption chillers to provide 45MW of cooling at 5 _C. This could save approximately 9 MW of electric energy required by a typical compression chiller, while providing the same amount of cooling. In addition, the combined cycle generates 22.6MW of additional electrical energy for the plant, while process heating reduces furnace oil consumption by 0.23 MSCM per annum. Mansouri et al. [29] studied the effect of HRSG pressure levels on exergy efficiency of combined cycle power plants is investigated. The results show that the losses due to heat transfer in the HRSG and the exhaust of flue gas to the stack in a triple pressure reheat combined cycle are less than the other cases. From the economic analysis, it is found that increasing the number of pressure levels of steam generation leads to an increase for the total and specific investment cost of the plant for about 6% and 4% respectively. The net present value (NPV) of the plant increases for about 7% for triple pressure reheat compared to with the double pressure CCPP. Therefore, the results of economic analysis show that it is economically justifiable to increase the number of pressure levels of steam generation in HRSG.Wang et al. [30] proposed a new combined cooling, heating and power (CCHP) system to produce cooling output, heating output and power output simultaneously. This proposed system combines a Brayton cycle and a transcritical CO_2 refrigeration cycle with ejector-expansion device, which uses solar energy as the heat source to reduce fossil fuel consumption and alleviate environmental problems. A mathematical model is developed to simulate the new CCHP system with transcritical CO2 driven by solar energy under steady-state conditions, and the thermal efficiency and exergy efficiency are used to evaluate the system performance. The results indicate that increasing turbine inlet pressure and ejector inlet temperature could lower the efficiency of the system, and increasing turbine back pressure and turbine inlet temperature could elevate the efficiency of system.

Farshi et al. [31] a combined ejector-double effect absorption cycle is a good choice to make effective use of heat sources at this temperature range for refrigeration purposes. In this study, detailed exergo-economic analyses are performed for series flow double effect and combined ejector double effect systems in order to investigate and compare the influence of various operating parameters on investment costs of the overall systems and product cost flow rates. In addition, the proportion of component costs in the overall systems costs and exergo-economic results are obtained. The results show that the combined cycle operates more economically compared to the double effect system. Fontalvo et al. [32] presented a comprehensive exergy analysis of a combined power and cooling cycle which combines a Rankine and absorption refrigeration cycle by using ammonia water mixture as working fluid. The results showed that total exergy destruction decreases when pressure ratio increases, and reaches a maximum at $x = 0.5$, when ammonia mass fraction is varied at absorber. The effect of rectification cooling source (external and internal) on the cycle output was investigated, and the results showed that internal rectification cooling reduces the total exergy destruction of the cycle. Abed et al. [33] proposed a combined cycle for the production of power and refrigeration simultaneously. The cycle can be driven by low grade heat sources such as solar, geothermal and waste heat sources. There are three important conflicting objectives namely, turbine work (Wt), cooling capacity (Qc) and thermal efficiency (ηth) which have been selected to find the best possible combination of these performance parameters. Optimization has been carried out by varying turbine inlet pressure, superheated temperature and condenser temperature as design variables. Among optimum design parameters, a trade-off point is selected; it has been shown that some interesting and important relationships can be discovered among optimal objective functions and decision variables involved, consequently. Kshirsagar et al. [34] Combined vapor compression-ejector refrigeration system is proposed which uses the waste heat of condenser of simple vapor compression system and this heat is utilized to drive the binary ejector refrigeration system. Thermal design of this combined vapor compression ejector refrigeration system (VCR-VER) is based on energy and mass conservation in each component. The system performance is first analyzed for the on design conditions. The results show that the COP is improved by 3.086% for the proposed system. The system is then analyzed for variation of four important variables. The system analysis shows that this refrigeration system can effectively improve the COP by the ejector cycle with the refrigerant which has high compressor discharge temperature.

Habibzadeh et al. [35] presented the thermodynamic study of a thermal system which combines an organic Rankine cycle (ORC) and an ejector refrigeration cycle. Their effect on the thermal efficiency, the total exergy destruction, the total thermal conductance and the entrainment ratio of the ejector is calculated and analyzed. Further results are then obtained by varying either the inlet pressure of the pump (or, equivalently, the evaporation temperature) or the inlet pressure of the turbine. They show that these variables can be optimized to get a minimum total thermal conductance. R141b has the lowest optimum pressure and smallest total thermal conductance for both these optimum conditions. On the other hand, R601a has the highest thermal efficiency and lowest total exergy destruction in both optimum cases.

Al-Sulaiman et al. [36] presented the thermo economic optimization formulations of three new tri-generation systems using organic Rankine cycle (ORC): SOFC-tri-generation, biomass-tri-generation, and solar-tri-generation systems. A thermo economic modeling is employed using the specific exergy costing (SPECO) method while the optimization performed using the Powell's method to minimize the product cost of tri-generation (combined, cooling, heating, and power). The results help in understanding how to apply the thermo economic modeling and thermo economic optimization to a tri-generation system. Hua et al. [37] an ammonia water absorption cycle for power and chilling output cogeneration from mid/low-grade waste heat was analyzed and optimized, which is a modified Kalina cycle adding an evaporator and a sub-cooler to realize the chilling effect. The results show that there are matching basic and work concentration pairs for a higher efficiency. The smaller circulation multiple and greater chilling fraction are favorable to the efficiencies but restricted respectively by heat transfer constraint of recuperator and the demand. The calculation example with the turbine inlet parameters set at 195 _C/2.736 MPa and the cooling water inlet temperature set at 25 _C with chilling fraction of 0.5 shows that the thermal efficiency and exergy efficiency reach up to 16.4% and 48.3%, about 24.24% and 8.16% higher than those of an ammonia water power cycle under identical condition. Gogoi et al. [38] presented the exergy analysis of a combined reheat regenerative steam turbine (ST) based power cycle and water–LiBr vapor absorption refrigeration system (VARS). Exergetic efficiency of the power cycle and VARS, energy utilization factor (EUF) of the combined system (CS) and irreversibility in each system component are calculated. The effect of fuel flow rate, boiler pressure, cooling capacity and VARS components' temperature on performance, component and total system irreversibility is analyzed. Among the VARS components, exergy destruction in the generator is the highest followed by irreversibility contribution of the absorber, condenser and the evaporator. Jradi et al. [39] Tri-generation is one of the most promising technologies allowing the efficient simultaneous production of heat, cold and power with potential technical, economic and environmental benefits. This paper provides a comprehensive review of the latest developments in the field of combined cooling, heating and power generation. Recent tri-generation supporting mechanisms, prime movers, cooling technologies, system configurations, fuels and renewable energy resources employed are presented and discussed Gaurav and Rajkumar

[40] presented a comparison of energy and exergy analysis for R-134a, R-152a, R-290, R-600 and R-600a in refrigerator. This paper analyzes the domestic refrigerator with alternative refrigerants for computing coefficient of performance, exergy destruction ratio, exergy efficiency and efficiency defect. Yi Chen et al. [41] proposed a new absorption–compression refrigeration system to produce cooling energy at -30 °C to -55 °C.A power generation subsystem using an ammonia–water mixture as the working fluid, an ammonia–water absorption refrigeration subsystem, and a CO2 compression refrigeration subsystem.

Esfahani et al. [42] evaluated conventional and advanced exergy and exergo-economic analyses for a multi-effect evaporation– absorption heat pump (MEE–ABHP) desalination system. Advanced exergy and exergo-economic analyses were each conducted to identify the components with the greatest influences and evaluate the realistic economic improvement potential of the system. Parameter optimizations were achieved using genetic algorithm (GA) for each objective functions to find the optimal operation conditions with minimization of the overall avoidable exergy destruction and cost rates of the system, separately Overall, it was found that the best optimal operation conditions can be achieved by minimization of OAC Sadeghi et al. [43] a two-dimensional model is developed for the ejector. Energy, exergy and exergo economic analysis performed for the proposed system using the MATLAB software. In addition, considering the exergy efficiency and the product unit cost of the system as objective functions, a multi-objective optimization is performed for the system to find the optimum design variables including the generator, condenser and evaporator temperatures. The optimization results are obtained as a set of optimal points and the Pareto frontier is plotted for multi-objective optimization. The results of the optimization show that ejector refrigeration cycle is operating at optimum state based on exergy efficiency and product unit cost when generator, condenser and evaporator works simultaneously. Cimsit et al. [44] presents the thermo-economic optimization of LiBr/H2O-R134a compression-absorption cascade refrigeration cycle. The detailed exergy-based thermo-economic analyses, thermo-economic evaluation with exergo-economic variables and thermo-economic optimization by using non-linear simplex direct search method has been performed for the cascade refrigeration cycle. This analysis points out that the evaporator equipage and solution heat exchanger should be designed carefully according to the exergo-economic factor values. The exergetic efficiency and minimum cost of objective function are determined as 7.30% and 4.05 ($/h) for the optimum case of sample application. Chen et al. [45] presented the evaluation of the ejector refrigeration system from three levels: energy analysis, conventional exergy analysis and advanced exergy analysis. Five environmentally friendly working fluids, namely R600, R600a, R601a, R1233zd (E) and R1234ze (E), are used to compare their performance and working characteristics in the system. The ejector efficiencies have considerable influence on the system performance, and a 0.1 increase in ejector efficiency could lead to the increase of system exergy efficiency from 1.38% to 10.33%. The pump efficiency has insignificant influence the system performance, but a 0.1 increase in the pump efficiency results in a 7.37% decrease in exergetic improvement potential ratio of the pump. Bilir Sag et al. [46] an experimental studied were conducted on vapor compression refrigerators using R134a refrigerant for the purpose of achieving energy recovery and decreasing the effects of irreversibility. The coefficient of performance of the ejector refrigeration system and the amount of irreversibility and efficiency of each of its components were determined and compared with those of a basic vapor compression refrigeration system of the same cooling capacity under the same external conditions. It was found that the ejector expander system exhibited a lower total irreversibility in comparison with the basic system. When the ejector was used as the expander in the refrigeration system, the coefficient of performance was higher than in the basic system by 7.34–12.87%, while the exergy efficiency values were 6.6–11.24% higher than in the basic system. Yan et al. [47] proposed a new ejector enhanced auto-cascade refrigeration cycle using R134a/R23 refrigerant mixture. In the new cycle, an ejector is used to recover part of the work that would otherwise be lost in the throttling processes. The simulation results show that both the coefficient of performance and exergy efficiency of the new cycle can be improved by 8.42–18.02% compared with those of the basic cycle at the same operation conditions as the ejector has achieved pressure lift ratios of 1.12–1.23. The results show that for the new cycle, the achieved performance improvement over the basic cycle is also dependent on the mixture composition and the vapor quality at the condenser outlet. The optimum mixture composition of both cycles may be fixed at about 0.5 under the given evaporating temperature. Wang et al. [48] presented a multi-objective optimization of a combined cooling, heating and power system (CCHP) driven by solar energy. Two objective functions, namely the average useful output and the total heat transfer area, were selected to maximize the average useful output and to minimize the total heat transfer area under the given conditions. NSGA-II (Non-dominated Sort Genetic Algorithm-II) was employed to achieve the final solutions in the multi-objective optimization of the system operating in three modes, namely power mode, combined heat and power (CHP) mode, and combined cooling and power (CCP) mode. Results also indicated that the multi-objective optimization provided a more comprehensive solution set so that the optimum performance could be achieved according to different requirements for system. Tashtoush et al. [49] studied the performance of the ejector cooling cycle is investigated at critical mode, where, the effects of ejector geometry, refrigerant type, and operating condition are considered. The solar generator temperature ranges are 80–100^{0}C. The operating temperature of evaporator range is 8–12^{0}C and the optimal condensation temperature is in the range of 28–40^{0}C. It is found that constant-pressure mixing ejector generates higher backpressure than constant-area mixing ejector for the same entrainment ratio and COP. The type of ejector is selected based on the performance criteria of the critical backpressure and choking condition of the primary flow, the so called EJ2 type ejector meets the criteria. The COP is found to be in the range of 0.59–0.67 at condenser backpressure of 24 bar due to higher critical condenser pressure and higher generator temperature. Yanga et al. [50] proposed cogeneration system consists an organic Rankine cycle and a refrigeration cycle, connected by an ejector. The performance of the combined cycle is analyzed when the system running in different working fluids, including pure working fluids, R245fa and R600a, and zoetrope mixtures, R245fa/R600a. Results show that the mixtures generate more refrigeration than pure working fluids, and they have better performance under certain conditions. Besides, the effect of some thermodynamic parameters, including evaporator temperature, condenser temperature, boiler temperature and turbine outlet temperature, on the performance of the system is studied. Tan et al. [51] an auto-cascade ejector refrigeration cycle (ACERC) is proposed to obtain lower refrigeration temperature based on conventional ejector refrigeration and auto-cascade refrigeration principle. The study shows that refrigerant mixture composition, condenser outlet temperature and evaporation pressure have effects on performance of ACERC. The theoretical results also indicate that the ACERC can achieve the lowest refrigeration temperature at the temperature level of 300C. The application of zeotropic refrigerant mixture autocascade refrigeration in the ejector refrigeration cycle can provide a new way to obtain lower refrigeration temperature utilizing low-grade thermal energy.

Nesreddine et al. [52] A novel two-stage cascade refrigeration system, combining a sub-critical CO2 mechanical vapor compression loop (lower stage) and a gas-gas ejector loop using R245fa (upper stage), was developed. The system, designed to deliver a cooling capacity of 15 kW at an evaporating temperature of -20 °C was thermally driven by low grade industrial waste heat. In the present work an experimental investigation was performed in order to study the thermal performance of the cascade system. The tests covered the following ranges of the governing parameters: the upper stage condensation temperature varied from 25 to 35^{0}C, the lower stage evaporation temperature ranged from -15 to -25^{0}C, the ejector primary mass flow rate was set to 0.33 kg/s, and the temperature of the heat source was kept constant at 80 °C. Kaynakli et al. [53] studied energy and exergy analysis is performed on a double effect series flow absorption refrigeration system with water/lithium bromide as working fluid pair. The refrigeration system runs on various heat sources such as hot water, hot air and steam via High Pressure Generator (HPG) because of hot water/steam and hot air are the most common available heat source for absorption applications but the first law of thermodynamics may not be sufficient analyze the absorption refrigeration system and to show the difference of utilize for different type heat source. From the analyses it is observed that exergy destruction of the HPG increases at higher temperature of the heat sources, condenser and absorber, and lower temperature of the HPG, LPG and evaporator. This destruction is maximized when hot air heat source is used and minimized with utilizing hot water heat source. Baghernejad et al. [54] study a comprehensive thermodynamic modeling and multi-objective exergo-economic optimization of a new integrated SOFC-tri-generation system is carried out to determine the optimum decision parameters, accounting for exergetic, economic and environmental factors. Results of optimal designs are obtained as a set of multiple optimum solutions, called the Pareto optimal solutions. This new approach shows that by selecting final optimum solution, the tri-generation unit cost of products reduced by 13.88% and exergy efficiency increased from 62.85% in the base case to 64.5% in the optimum case. Also, the optimization results demonstrate that fuel cost, exergy destruction cost and environmental impacts (CO2 emissions cost) are reduced by 17.54%, 17.05% and 18.22% respectively; although these are achieved with 8.03% increase in the capital investment cost. Karellas et al. [55] presented the thermodynamic modeling and economic analysis of a micro-scale tri/co-generation system capable of combined heat and power production and refrigeration, based on the joint operation of an Organic Rankine Cycle (ORC) and a Vapor Compression Cycle (VCC). The performance of the system is assessed for subcritical operation pressures for the organic medium R245fa. Investigations on the effect of various parameters, such as condensation and evaporation temperatures on the system performance are carried out. The impact of superheating and installing a recuperator is also examined. In a base case scenario (evaporation temperature at 90 _C without superheating) assuming an overall 50 kWth heat input and a cooling load of 5 kWh (during the summer), the net electric efficiency is 2.38%, with an electricity output equal to 1.42 kWh and a heating output of 53.5 kWth. The exergy efficiency of the ORC was estimated at about 7%. Borui et al. [56] a novel combined cooling, heating and power organic Rankine cycle (CCHP–ORC) system installed with heat pumps is presented in this paper. The CCHP–ORC system using zeotropic mixtures is first discussed, and this work is focused on selecting optimal zeotropic mixtures and determining the component concentration that gives a better performance. The evaluation index net output power, heating capacity, refrigerating capacity, coefficient of performance (COP), economic thermal efficiency and exergy efficiency were calculated with the changing evaporation temperature under the condition of ejector coefficient 0.2. The ejector coefficient and evaporation temperature had been analyzed as independent variables. The results showed that R141b/R134a, R141b/R152a and R123/152a have a higher COP and exergy efficiency than others. By analyzing the component concentration of the optimized three kinds of zeotropic mixtures, it can be inferred that a mixture of dry and wet working fluids is more suitable for the system.

Bellos et al. [57] an innovative tri-generation system which uses low temperature level heat sources is analyzed and optimized. This system is consisted of an absorption heat pump and a steam turbine which consumes a part of the produced steam in the generator. This system is able to produce electricity, heating, cooling and hot water, covering the typical energy needs of buildings. The final results proved that the exergetic efficiency is about 72% and the electrical output close to 9 kW, when a heat input of 100 kW is given. By selecting the proper parameters, the outputs of the system can be distributed according to the building energy demands, something very important for the sustainability of this system. Oliveira et al. [58] a technical and economic study has been conducted in this work in order to increase the efficiency of electricity production, and thus reduce fuel consumption and polluting gas emission from Internal Combustion Engines. For such a purpose, two Organic Rankine Cycle sets were suggested. The first one is facing deployment in water shortage areas (Organic Rankine Cycle using a cooling tower for the condensing system) and another one with the water supply condenser being made by the urban water net. Both simulated systems were able to increase electricity production by almost 20% when toluene was the working fluid. The economic analysis was based on the Engineering Chemical Cost Plant Index model which showed that the financial return from the implementation of the Organic Rankine Cycle system can occur in six years. Thus, it is noted that the Organic Rankine Cycle system can be installed in areas where there is no water abundance and without much yield loss. Yang et al. [59] presented a novel combined power and ejector-refrigeration cycle using zeotropic mixture is proposed. The turbine exhaust from the organic Rankine cycle entrains the vapor from the ejector-refrigeration cycle. It is found that the cycle exergy achieves a maximum value of 10.29% with mixture isobutene /pentane (40%/60%), and the thermal efficiency gets a maximum value of 10.77% with mixture isobutene /pentane (70%/30%). The temperature glide in the evaporator achieves a maximum value of 15.09 K with mixture isobutane/pentane (80%/20%). The parametric analysis shows that the cycle performs better in lower condenser temperature.

Nemati et al. [60] presented a comprehensive energy, exergy, exergo-economic and environmental comparison between carbon dioxide, ethane and nitrous oxide as the refrigerants of a two-stage ejector-expansion trans-critical refrigeration cycle is carried out. It is observed that the compressors operating pressure and temperature levels in the cycle for ethane are lower than other refrigerants, which leads to higher system safety and lifetime. Furthermore, the highest COP and exergy efficiency in a wide range of gas cooler temperature belongs to the ethane. The nitrous oxide refrigerant has the lowest product unit cost, which is about 4.2% lower than that of the ethane refrigerant with the highest product unit cost. Therefore, ethane is the most preferable refrigerant from energy and exergy aspects and nitrous oxide is suitable based on exergo-economic viewpoint. Rashidi et al. [61] two new power and cooling cogeneration systems based on Kalina cycle (KC) and absorption refrigeration cycle (AC) are proposed and studied from thermodynamic and economic viewpoints. The performance and economic aspects of both proposed systems are analyzed and compared with the stand alone KC. A parametric analysis is conducted to evaluate the sensitivity of efficiencies and the generated power and cooling quantities to the key operating variables. The results showed that, thermal efficiency and total annual costs decreased by 5.6% and 8% for KPCC system but increased 4.9% and 58% for KLACC system, respectively. Since the power-cooling efficiency of KLACC is 42% higher than KPCC it can be applied where the aim is cooling generation without considering economic aspects. Zhang et al. [62] proposed a Power-generation systems based on organic Rankine cycles (ORCs) employed in the conversion of thermal energy from low temperature heat sources to power. The study considers, beyond variations to the geometric design of the ejector, also the role of changing the external conditions across this component and how these affect its performance. It is found that some operating conditions, such as a high pressure of the secondary and discharge fluid, lead to higher energy losses inside the ejector and limit the performance of the entire system. Yingjie Xu et al. [63] presented a novel absorption compression cascade refrigeration system, which can reach an evaporating temperature of −170°C. Theoretical and experimental investigations were carried out over the evaporating temperature ranging from −100 to −170°C and operating parameters were given. At the evaporating temperature of −170 °C when AS provided a low-grade cooling capacity of 164.8 W to CS, a decrease of 2.5°C in CS evaporating temperature or an increase of 32.3 W in high-grade cooling capacity of CS were observed.

Chopra et.al. [64] Presented Energy and exergy analysis of a two-stage refrigeration system having an intercooler is performed. The COP of such a system is found to be increased by 4 to 5%, and calculated to be approximately 3.24. Heat recovery through the intercooler proved to be beneficial as the COP of the system is improved along with heat recovery of 20 kJ/s. Megdouli et al. [65] presented hybrid vapor compression refrigeration (HVCR) system, which combines vapor compression refrigeration (VCR) system and an ejector refrigeration (ER) system, was developed. The waste heat energy from the gas cooler in the VCR system is applied as driven source towards ER system. The results indicate that for the same cooling capacity, the coefficient of performance (COP) of the HVCR system shows 25% higher COP and the total mechanical power consumption is reduced by 20% than that of conventional VCR system, respectively. The performance characteristics of the proposed cycle show its application potential in cooling and air-conditioning. Zhiwei Ma et al. [66] proposed a detailed thermodynamic modeling method of an ejector for ejection refrigeration system. In this model, the primary flow in the ejector was assumed to fan out from the nozzle without mixing with the secondary flow in a certain downstream distance. The present study developed empirical correlations of the hypothetical throat area to aid further modeling. The ratio of the hypothetical throat area to the mixing area was correlated with two dimensionless variables: one was the ratio of nozzle throat area to the mixing area, and the other one was the primary and secondary flow pressure ratio. The model has been validated by the measured primary mass flow rates and the critical back pressures. Eldakamawy et al. [67] presented a Conventional and compression-enhanced ejector refrigeration systems were investigated numerically using regular and retrograde refrigerants. The numerical model was developed and validated with previous experimental data of both types of working fluids. Energy and exergy analysis were performed to examine system performance and compare between the selected refrigerant candidates. Retrograde refrigerants were found promising with both versions of ejector cycles, when two case studies of an air conditioning application and an indoor ice rink were considered. The butene series showed superior coefficient of performance and exergy efficiency, especially the isomers cis-2-butene and 1-butene. Junjiang Bao et al [68] proposed a transcritical power and ejector refrigeration cycle (TPERC) to improve temperature matching between the heat source and working fluid. Based on the modeling of the TPERC system, a comparison of working fluids and the effects of system parameters on the cooling capacity, work output, thermal efficiency and exergy efficiency are discussed. The results show that of the seven working fluids selected, R1234ze has the largest thermal efficiency and exergy efficiency, principally due to having the highest critical temperature. At the identical turbine back pressure, condensing temperature and evaporation temperature, the turbine inlet temperature and its corresponding generation pressure have little impact on thermal efficiency. Ahmadzadeh et al. [69] presented a novel solar driven combined power and ejector refrigeration system (CPER) of 50 kW power capacity composed of an ORC (organic Rankine cycle) and an ejector refrigeration system is investigated. Thermodynamic performance of the proposed CPER system is evaluated and a thermo-economic analysis is conducted using the SPECO (specific exergy costing) method. A parametric study showed the effects of condenser temperature, evaporator temperature, generator pressure, turbine back pressure and turbine extraction ratio. The genetic algorithm optimization analysis is conducted which shows 25.5% improvement in thermal energy, 21.27% in exergy efficiency, and 7.76% reduction in the total cost of the CPER system. The results reveal that the performance of the CPER system is considerably improved at higher temperatures of generator and evaporator. Nami et al. [70] studied on geothermal driven dual fluid organic Rankine cycle is presented in this paper using conventional and advanced exergy analysis methods to provide information about system components interactions. The conventional exergy analysis reveals that, low pressure vapor generator (LPVG), high pressure vapor generator (HPVG) and condenser (COND) are the most important component by 38.11, 29.98 and 15.93% of the total exergy destruction rate, respectively. Despite the conventional exergy analysis results, advanced exergy shows that only 15% of the COND exergy destruction is avoidable which includes 7% of system avoidable exergy destruction rate. Dixit et al [71] in this paper a two stage hybrid absorption compression refrigeration system utilizing LiBr-H2O as working fluid is proposed. The hybrid system is compared thermodynamically with the conventional two stage absorption refrigeration system and it is found that the former can be operated at lower generator temperature and performs better than the latter. The heat exchangers are designed to estimate the size and cost of the system. The objective of thermo economic optimization is the minimization of annual cost of system, which includes investment costs and exergy fuel costs. The optimized hybrid system has COP of 0.43 and exergetic efficiency of 11.68%. The optimization results in the reduction of heat exchangers area from 79.61 m^2 to 71.96 m^2 and annual cost of operation of hybrid system by 5.2%. Wang et al. [72] Exergo-economic analysis is performed for a novel combined SCRB/ARC (supercritical CO_2 recompression Brayton/absorption refrigeration cycle) in which the waste heat from the SCRBC is recovered by an ARC for producing cooling. Parametric analysis is conducted to investigate the effects of the decision variables on the performance of the SCRB/ARC cycle. The results show that the largest exergy destruction rate occurs in the reactor, while the components in the ARC have less exergy destruction. The reactor and turbine are the first and second important components from exergo-economic aspects. When optimization is based on the exergo-economics, the first and second law efficiencies and the total product unit cost of SCRB/ARC are 26.12% higher, 2.73% higher and 2.03% lower than those of the SCRBC. Patel et al. [73] presented the thermo-economic optimization of the waste heat based organic Rankine cycle powered cascaded vapor compression-absorption refrigeration system. Organic Rankine cycle with dry organic working fluid is used as a power generating cycle to provide input to the vapor compression refrigeration system. Moreover, the high temperature organic working fluid at the expander outlet is used to supply thermal need of the vapor absorption refrigeration system. Optimization results reveal that the annualized cost of the present system is decreased by about 12% compared to the base case. Moreover, the simple payback period and break-even point are reduced to 4.50 years and 3.48 years, respectively. The results of comparative economic study, between the present and stand-alone vapor compression refrigeration systems, show that the higher value of electricity price and the lower value of discount rate are favorable for the selection of the present system. Chen et al. [74] performed the analysis of a two-stage mechanical compression–ejector cooling cycle. In the proposed cooling system the compression process is realized in two stages: by a mechanical compressor as the first stage and by an ejector as the second stage. Ammonia (R717) is investigated as the working fluid for the cooling system in the present study. The influence of the middle pressure and evaporating and condensing temperatures on the characteristics of the cooling system is analyzed. Based on the obtained results a pilot small-scale two-stage refrigeration unit with cooling capacity of 10 kW intended for application in micro-tri-generation systems is designed.

Mishra et al. [75] proposed two method either to opt for advance technology or go for optimum use of present resources which could be made possible by reducing the losses, it can be curbed at small level like switching off appliances when not in use, at large scale it can be done my making modification in the present cycle used for power production. This paper mainly deals with the reduce the work input of gas turbine plant in auxiliary equipment, mostly in air compressor by reducing the work input through intercooling and utilizing same heat energy for useful purpose using vapor absorption system. Mishra [76] performed the thermodynamic analysis of three stages cascade vapor compression refrigeration systems using eco-friendly refrigerants used for low temperature applications. The effect of thermal performance parameters (i.e. approaches, condenser temperature, and temperature variations in the evaporators) on the first law thermal performances COP System and also in terms of second law efficiency of the cascade system (exergetic efficiency) and System exergy destruction ratio (SEDR) have been optimized thermodynamically using entropy generation principle. It was observed that the best combination in terms of R1234ze-R134a- R404a gives better thermal performance than using R1234yf-R134a-R404a. Similarly other combination in terms of R1234ze-R134a-R404a gives better thermal performance than using R1234ze-R1234yf-R404a.

3. Results and Discussion

The present paper mainly deals with thermodynamic analysis of tri-generation system. The Mathematical modeling of the combined power, heating and cooling cycle for computing exergy efficiency, thermal efficiency and exergy destruction rate of various system components and using performance parameters like improvement potential, coefficient of performance (COP), waste heat recovery and irreversibility ratio can be obtained . Effect of recompression is also analyzed in the combined cycle and performance through mathematical modeling of the combined cycle is obtained. The various aspect of use of waste heat from intercooler of an ejector refrigeration cycle in a tri-generation cycle in terms of working parameters like ejector inlet condition, turbine inlet pressure, the condenser temperature and evaporator temperature on the system performance is investigated.

3. Conclusion

The following conclusions were drawn.

1. Energy and exergy analysis of power and ejector vapor compression cascade refrigeration cycle is also important for predicting it thermal performances..
2. Thermodynamic modeling of power, vapour absorption refrigeration cycle combined with heating cycle based on organic Rankine cycle helps for finding exergy losses in the components. When maximum exergy destruction in that component was observed than that component can de redesigned for minimum exergy destruction.
3. Energy and exergy analysis of a combined power and ejector-vapor compression cascade refrigeration cycle using alternative refrigerants help for reducing global warming and ozone depletion

References

[1] S.C. Kaushik, M.Singh "Feasibility and Design for Heat Recovery from a Refrigeration System with a Canopus Heat Exchanger" Heat Recovery Systems and CHP., Vol-15 (1995) 665-673.

[2] B.J. Huang, V.A. Petrenko, J.M. Chang, C.P.Lin, S.S.Hu "A combined cycle refrigeration system using ejector-cooling cycle as the bottom cycle" International Journal of Refrigeration., Vol-24 (2001) 391-399.

[3] E. Minciuc, O. Le Corre, V. Athanasovici, M. Tazerout, I. Bitir "Thermodynamic analysis of tri-generation with absorption chilling machine" Applied Thermal Engineering., Vol-23 (2003) 1391-1405.

[4] J. Herna, N.Santoyoa, S. Augusto, N.Cifuentesb "Trigeneration: an alternative for energy savings" Applied Energy., Vol-76 (2003) 219-227.

[5] E. T. Calva, M. P. Nunez, M.A. Toral "Thermal integration of tri-generation systems" Applied Thermal Engineering., Vol-25 (2005) 973-984.

[6] Ahmed Oudha, Mohammed En-Nacer, Omar Imine, "Exergy Analysis of Two- Stage Refrigeration Cycle Using Two Natural Substitutes Of Hcfc22" International Journal of Exergy., Vol-2 (2005) 14-30.

[7] Akhilesh Arora, S.C Kaushik "Theoretical Analysis of Vapour Compression Refrigeration System with R502, R404a, and R507a", International Journal of Refrigeration, Vol-3 (2008) 998-1005.

[8] Yingbai Xie, Ganglei Sun, Liyong Lun "Thermodynamic Analysis of CO2 Supercritical Two-Stage Compression Refrigeration Cycle, International Journal of Refrigeration and Air-Conditioning, Vol-904 (2008) 2390-2396.

[9] A. Lazzarettoa, G. Tsatsaronis "SPECO: A systematic and general methodology for calculating efficiencies and costs in thermal systems" Energy., Vol-31 (2008) 1257-1289.

[10] J. Wang, Y. Dai, L. Gao "Parametric analysis and optimization for a combined power and refrigeration cycle" Applied Energy., Vol-85 (2008) 1071-1085.

[11] R. Yapıcıa, H.K. Ersoya, A. A. lua, H.S. Halkacıa, O. Y. Itb "Experimental determination of the optimum performance of ejector refrigeration system depending on ejector area ratio" International Journal of Refrigeration., Vol-31 (2008) 1183-1189.

[12] Y. Dai, J. Wang, L. Gao "Exergy analysis, parametric analysis and optimization for a novel combined power and ejector refrigeration cycle" Applied Thermal Engineering., Vol-29 (2009) 1983-1990.

[13] J. Wang, Y. Dai, Z. Sun "A theoretical study on a novel combined power and ejector refrigeration cycle" International Journal of Refrigeration., Vol-32 (2009) 1186-1194.

[14] Y. Dai, J. Wang, L. Gao "Exergy analysis, parametric analysis and optimization for a novel combined power and ejector refrigeration cycle" Applied Thermal Engineering., Vol-29 (2009) 1983-1990.

[15] I. Chaer, Y.T. Ge, N. Suguartha "Performance evaluation of a tri-generation system with simulation and experiment" Applied Energy., Vol-86 (2009) 2317-2226.

[16] A. Khaliq "Exergy analysis of gas turbine tri-generation system for combined production of power heat and refrigeration" International Journal of Refrigeration., Vol-32 (2009) 534-545.

[17] F. A. Al-Sulaiman , I. Dincer, F. Hamdullahpur "Energy analysis of a trigeneration plant based on solid oxide fuel cell and organic Rankine cycle" International Journal of Hydrogen Energy., Vol-25 (2010) 5104-5113.

[18] R. P. Marquesa, D. Haconb, A. Tessarolloc, J. A. Parisec "Thermodynamic analysis of tri-generation systems taking into account refrigeration, heating and electricity load demands" Energy and Buildings., Vol-42 (2010) 2323-2330.

[19] K.C. Kavvadias, A.P. Tosios, Z.B. Maroulis "Design of a combined heating, cooling and power system: Sizing, operation strategy selection and parametric analysis" Energy Conversion and Management., Vol-51 (2010) 833-845.

[20] B. Zheng, Y.W. Weng "A combined power and ejector refrigeration cycle for low temperature heat sources" Solar Energy., Vol-84 (2010) 784-791.

[21] H. Vidal, S. Colle "Simulation and economic optimization of a solar assisted combined ejector–vapor compression cycle for cooling applications" Applied Thermal Engineering., Vol-30 (2010) 478-486.

[22] M. Ameri, A. Behbahaninia , A. A. Tanha "Thermodynamic analysis of a tri-generation system based on micro-gas turbine with a steam ejector refrigeration system" Energy., Vol-35 (2010) 2203-2209.

[23] H. Ghaebi1, M. Amidpour, S. Karimkashi, O. Rezayan "Energy, exergy and thermo economic analysis of a combined cooling, heating and power (CCHP) system with gas turbine prime mover" International Journal of Energy Research., Vol-35 (2011) 697-709.

[24] F. A. Al-Sulaiman, I. Dincer, F. Hamdullahpur "Exergy modeling of a new solar driven tri-generation system" Solar Energy., Vol-85 (2011) 2228-2243.

[25] S. Maa, J. Wanga, Z. Yana, Y. Daia, B. Lua " Thermodynamic analysis of a new combined cooling, heat and power system driven by solid oxide fuel cell based on ammonia–water mixture" Journal of Power Sources ., Vol-196 (2011) 8463-8471.

[26] A. Huicochea, W. Rivera, G. G.Urueta, J. C. Bruno, A. Coronas "Thermodynamic analysis of a tri-generation system consisting of a micro gas turbine and a double effect absorption chiller" Applied Thermal Engineering., Vol-32 (2011) 3347-3353.

[27] M. Moya, J.C. Bruno, P. Eguia, E. Torres, I. Zamora, A. Coronas "Performance analysis of a trigeneration system based on a micro gas turbine and an air-cooled, indirect fired, ammonia-water absorption chiller "Applied Energy., Vol-88 (2011) 4424-4440.

[28] S. Popli, P. Rodgers, V. Eveloy "Trigeneration scheme for energy efficiency enhancement in a natural gas processing plant through turbine exhaust gas waste heat utilization" Applied Energy., Vol-93 (2012) 624-636.

[29] M. T. Mansouri, P. Ahmadi, A. G. Kaviri, M. N. Jaafar "Exergetic and economic evaluation of the effect of HRSG configurations on the performance of combined cycle power plants" Energy Conversion and Management., Vol-58 (2012) 47-58.

[30] J. Wang, P. Zhao, X. Niu, Y. Dai "Parametric analysis of a new combined cooling, heating and power system with transcritical CO2 driven by solar energy" Applied Energy., Vol-94 (2012) 58-64.

[31] L. G. Farshi, S.M.S. Mahmoudi, M.A. Rosen, M. Yari, M. Amidpour "Exergo-economic analysis of double effect absorption refrigeration systems" Energy Conversion and Management., Vol-65 (2013) 13-25.

[32] A. Fontalvo, H. Pinzon, J. Duarte, A. Bula, A. G. Quiroga, R.V. Padilla "Exergy analysis of a combined power and cooling cycle" Applied Thermal Engineering., Vol-60 (2013) 164-171.

[33] H. Abed, K. Atashkari, A. Niazmehr, A. Jamali "Thermodynamic optimization of combined power and refrigeration cycle using binary organic working fluid" International Journal of Refrigeratin., Vol-36 (2013) 2160-2168.

[34] S. D. Kshirsagar, M. M. Deshmukh, "Thermal Design & Performance Of Combined Vapor Compression-Ejector Refrigeration System Using R600a" International Journal of Engineering Research and Applications., Vol-3 (2013) 2248-9622.

[35] A. Habibzadeh, M.M. Rashidi, N. Galanis "Analysis of a combined power and ejector-refrigeration cycle using low temperature heat" Energy Conversion and Management., Vol-65 (2013) 381-391.

[36] F. A. Al-Sulaiman, I. Dincer, F. Hamdullahpur "Thermoeconomic optimization of three trigeneration systems using organic Rankine cycles: Part I – Formulations" Energy Conversion and Management., Vol-69 (2013) 189-208.

[37] J. Hua, Y. Chen, Y. Wang, A.P. Roskilly "Thermodynamic analysis of ammonia water power/chilling cogeneration cycle with low-grade waste heat" Applied Thermal Engineering ., Vol-64 (2014) 483-490.

[38] T.K. Gogoi, K. Talukdar "Exergy based parametric analysis of a combined reheat regenerative thermal power plant and water–LiBr vapor absorption refrigeration system" Energy Conversion and Management., Vol-83 (2014) 119-132.

[39] M. Jradi, S. Riffat "Tri-generation systems: Energy policies, prime movers, cooling technologies, configurations and operation strategies" Renewable and Sustainable Energy Reviews., Vol-32 (2014) 396-415.

[40] Gaurav, Raj Kumar "Performance Analysis of Household Refrigerator with Alternate Refrigerants "International Journal of Innovative Research in Science, Engineering and Technology", Vol-3 (2014) 19-53.

[41] Yi Chen, Wei Han, Liuli Sun, H. Jin "A New Absorption–Compression Refrigeration System Using a mid-Temperature Heat Source for Freezing Application" International Conference on Applied Energy, Vol-75 (2015) 560-565.

[42] I. J. Esfahani, S.C. Lee, C.K. Yoo "Evaluation and optimization of a multi-effect evaporation –absorption heat pump desalination based conventional and advanced exergy and exergoeconomic analyses" Desalination. Vol-359 (2015) 92-107.

[43] M. Sadeghi, S.M.S. Mahmoudi, R. K. Saray "Exergoeconomic analysis and multi-objective optimization of an ejector refrigeration cycle powered by an internal combustion (HCCI) engine" Energy Conversion and Management., Vol-96 (2015) 403-417.

[44] C. Cimsit, I. T. Ozturk, O. Kincay "Thermo-economic optimization of LiBr/H2O-R134a compression absorption cascade refrigeration cycle" Applied Thermal Engineering., Vol-76 (2015) 105-115.

[45] J. Chen, H. Havtun, B. Palm "Conventional and advanced exergy analysis of an ejector refrigeration system" Applied Energy., Vol-144 (2015) 139-151.

[46] N. B. Sag, H.K. Ersoy, A. Hepbasli, H.S. Halkaci "Energetic and exergetic comparison of basic and ejector expander refrigeration systems operating under the same external conditions and cooling capacities" Energy Conversion and Management., Vol-90 (2015) 184-194.

[47] G. Yan, J. Chen, J. Yu "Energy and exergy analysis of a new ejector enhanced auto-cascade refrigeration cycle" Energy Conversion and Management., Vol-105 (2015)509-517.

[48] M. Wang, J. Wang, P. Zhao, Y. Dai "Multi-objective optimization of a combined cooling, heating and power system driven by solar energy" Energy Conversion and Management., Vol-89 (2015) 289-297.

[49] B. Tashtoush, A. Alshare, S. Al-Rifai "Performance study of ejector cooling cycle at critical mode under superheated primary flow" Energy Conversion and Management., Vol-94 (2015) 300-310.

[50] X. Yanga, L. Zhaoa "Thermodynamic analysis of a combined power and ejector refrigeration cycle using zeotropic mixtures" The 7th International Conference on Applied Energy – ICAE2015., Vol-75 (2015) 1033-1036.

[51] Y. Tan, L. Wang, K. Liang "Thermodynamic performance of an auto-cascade ejector refrigeration cycle with mixed refrigerant R32 + R236fa" Applied Thermal Engineering., Vol-84 (2015) 268-275.

[52] H. Nesreddine, A. Bendaoud, Z. Aidoun, M. Ouzzane "Experimental investigation of an ejector-compression cascade system activated with low-grade waste heat" ICR Yokohama, Japan., August (2015) 16 - 22.

[53] O. Kaynakli, K. Saka , F. Kaynakli "Energy and exergy analysis of a double effect absorption refrigeration system based on different heat sources" Energy Conversion and Management., Vol-106 (2015) 21-30.

[54] A. Baghernejad, M. Yaghoubi, K. Jafarpur "Optimum power performance of a new integrated SOFC-tri-generation system by multi-objective exergo-economic optimization" Electrical Power and Energy Systems., Vol-73 (2015) 899-912.

[55] S. Karellas, K. Braimakis "Energy–exergy analysis and economic investigation of a cogeneration and trigeneration ORC–VCC hybrid system utilizing biomass fuel and solar power" Energy Conversion and Management., Vol-107 (2016) 103-113.

[56] X. Borui, Z. Li, W. Li, "Optimization of mixed working fluids for a novel tri-generation system based on organic Rankine cycle installed with heat pumps" Applied Thermal Engineering ., Vol-94 (2016) 754-762.

[57] E. Bellos, C. Tzivanidis, K. A. Antonopoulos "Parametric investigation and optimization of an innovative tri-generation" Energy Conversion and Management., Vol-127 (2016) 515-525.

[58] R. d. Oliveira, A. R. Sotomonte, C. J.R. Coronado, M. A.R. Nascimento "Technical and economic analyses of waste heat energy recovery from internal combustion engines by the Organic Rankine Cycle" Energy Conversion and Management., Vol-129 (2016) 168-179.

[59] X. Yang, N. Zheng, L.Zhao, S. Deng, Z.Yu "Analysis of a novel combined power and ejector-refrigeration cycle" Energy Conversion and Management., Vol-108 (2016) 266-274.

[60] A. Nemati, H. Nami, M. Yari, F. Ranjbar, H. R. Kolvir "Development of an exergo-economic model for analysis and multi-objective optimization

[61] of a thermoelectric heat pump" Energy Conversion and Management ., Vol-130 (2016) 1-13.
[62] J. Rashidi, P. Ifaei, I. J. Esfahani, A. Ataei, C. K. Yoo "Thermodynamic and economic studies of two new high efficient power-cooling cogeneration systems based on Kalina and absorption refrigeration cycles" Energy Conversion and Management., Vol-127 (2016) 170-186.
[63] K. Zhang, X. Chen, C. N. Markides, Y. Yang, S. Shen "Evaluation of ejector performance for an organic Rankine cycle combined power and cooling system" Applied Energy., Vol-184 (2016) 404-412.
[64] Yingjie Xu , G. Chen, Q. Wangb, X. Han, N.Jiang, S. Deng "Performance Study on a Low-Temperature Absorption–Compression Cascade Refrigeration System Driven by Low-Grade Heat" Energy Conversion and Management, Vol-119 (2016) 379-388.
[65] Chopra Kapil, R.S. Mishra Energy, Exergy and Sustainability Analysis of Two-stage Vapour Compression Refrigeration System. *Journal of Thermal Engineering* 1 (4), 440-445, 2015. 2, 2015. K. Megdouli, B.M. Tashtoush, E. Nahdi, M. Elakhdar, A. Mhimid, L. Kairouani "Performance analysis of a combined vapor compression cycle and ejector cycle for refrigeration cogeneration" International Journal of Refrigeration., Vol-74 (2017) 517-527.
[66] M. Zhiwei, B. Huashan, A. P. Roskilly "Thermodynamic modeling and parameter determination of ejector for ejection refrigeration system" International Journal of Refrigeration., Vol-75 (2017) 117-128.
[67] M. H. Eldakamawy, M. V. Sorin, M. Brouillette "Energy and exergy investigation of ejector refrigeration systems using retrograde refrigerants" International Journal of Refrigeration., Vol-78 (2017) 176-192.
[68] J. Bao, Y. Lin, H. Gaohong "Working fluids comparison and thermodynamic analysis of a transcritical power and ejector refrigeration cycle (TPERC)" International Journal of Refrigeration., Vol-82 (2017) 262-272.
[69] A. Ahmadzadeh, M. R. Salimpour, A. Sedaghat "Thermal and exergo-economic analysis of a novel solar driven combined power and ejector refrigeration (CPER) system" International Journal of Refrigeration., Vol-83 (2017) 143-156.
[70] A. Nemati, H. Nami, M. Yari "A comparison of refrigerants in a two-stage ejector-expansion trans-critical refrigeration cycle based on exergo-economic and environmental analysis" International Journal of Refrigeration., Vol-70 (2017) 349-364.
[71] M. Dixit, A. Arora, S.C. Kaushik "Thermodynamic and thermo-economic analyses of two stage hybrid absorption compression refrigeration system" Applied Thermal Engineering., Vol-113 (2017) 120-131.
[72] S. Wang, C. Wu, X. Feng, J. Li "Energy, exergy and exergo-economic analyses of a combined supercritical CO2 recompression Brayton/absorption refrigeration cycle" Energy Conversion and Management. Vol-148 (2017) 360-377.
[73] B. Patel, N. B. Desai, S. S. Kachhwaha "Optimization of waste heat based organic Rankine cycle powered cascaded vapor compression-absorption refrigeration system" Energy Conversion and Management. Vol-154 (2017) 576-590.
[74] G. Chen, O. Volovyk, V. Ierin "Performance analysis of a two-stage mechanical compression–ejector cooling cycle intended for micro-trigeneration system" International Journal of Refrigeration., Vol-81 (2017) 33-40.
[75] R.S Mishra, M. Agarwal "Thermodynamic analysis of vapour absorption system using waste heat of gas turbine plant with intercooling" International Journal of Research in Engineering and Innovation., Vol-1 (2017) 13-24.
[76] R.S Mishra " Thermal modeling of three stage vapor compression cascade refrigeration system using entropy generation principle for reducing global warming and ozone depletion using eco-friendly refrigerants for semen preservation" International Journal of Research in Engineering and Innovation., Vol-1 (2017) 22-28.