International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-03, June 2018

Exergy Analysis of Trigeneration System using Simple Gas Turbine cycle and Vapour Absorption System

Sukirti Patel, M.Tech scholar, RIT Rewa, India, suki2392@gmail.com

Pushparaj Singh, Asso.Professor, RIT Rewa, India

Abstract: This scientific work is based upon trigeneration system in which all the three forms i.e. heating, cooling and power generation take place altogether. In general it is combined cooling heating & power (CCHP) system which utilizes waste of heat which is further utilized in conventional power plants to provide energy (heat). It also produces chilled water that can be used for cooling by using vapor absorption system.

The whole system is made up of three different units i.e. simple gas turbine cycle, heat recovery steam generator and vapour absorption system. Combined 1st law and 2nd law approach have been used for this analysis. Maximum exergy destruction have found inside the combustion chamber and heat recovery steam generator. Computational analysis also is used in order to evaluate the effect of pressure ratio, pressure drop inside the combustor, TIT (turbine inlet temperature) and evaporator temperature in each component during exergy destruction. First law efficiency, second law efficiency and electrical to thermal energy ratio depend upon pressure ratio. As pressure increases, 1st law efficiency of Trigeneration and cogeneration decreases but electrical to thermal energy ratio and 2nd law efficiency increases with the same. Trigeneration system gives 20-40% higher efficiency than cogeneration cycle. The presented work is a preliminary thermodynamic analysis for energetic and exergetic efficiencies with different combinations.

Keywords:* *Cogeneration, Exergy, Gas turbine, Heat recovery, Trigeneration, vapour absorption.

I. INTRODUCTION

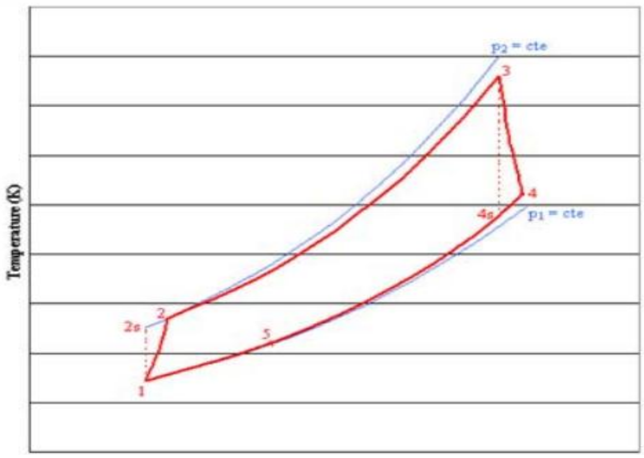
Trigeneration and cogeneration are two different systems. Cogeneration is basically involving generation of two different form of energy i.e. heating and power simultaneously. When cogeneration is used in combination with cooling system such as vapour absorption system then it will be termed as trigeneration system, where combined heating, cooling, and power production take place. Trigeneration is to be remarked as **"hat-trick of the energy industry"** because of its extreme benefits .This plant has huge impacts over natural resources it is also helpful in reducing fuel as system runs on very high productivity. Electricity which is generated through trigeneration plant is mostly used by the local bodies therefore the distribution and transmitting is almost zero. For domestic and industrial applications where various kind of energy is needed, this turns out to be a very effective energy saving system. The very well organized utilization of initial energy can be possible only by these cogeneration plants which have capability to generate power, cooling and heating simultaneously, having probability of output ratio of single energy pass. There will be high demands for some purpose like AC or cooling in various devices. Arju Sencan et al. (2004) in their work Energy analysis of a single-effect lithium bromide/water absorption system for cooling and heating applications is presented. The paper by **[1]**S. Aphornratana et al.(1995) provided an easy to follow description of the second law (of thermodynamics) method as applied to a single-effect absorption refrigerator cycle. **[3]**A. Khaliq et al. (2004) studied, to use the second-law approach for the thermodynamic analysis of the reheat combined Brayton/Rankine power cycle**. S**.C. Kaushik et al.(2003) describes thermodynamic evaluation of combustion gas turbine cogeneration system with reheat. . The effects of process steam pressure and pinch point temperature used in the design of heat recovery steam generator and reheat on energetic and energetic efficiencies have been investigated. From the results obtained in graphs it is observed that the power to heat ratio increases with an increase in pinch point, but the first-law efficiency and second-law efficiency decreases with an increase in pinch

 DOI : 10.18231/2454-9150.2018.0390

point. The power to heat ratio and second-law efficiency increases significantly with increase in process steam pressure, but the first-law efficiency decreases with the same. It has been clear that the most of the studies in the above cited literature have been conducted using the first law of thermodynamics or energy balance approach.

II. METHODOLOGY

The gas turbine cycle that we are using in this analysis is simple gas turbine cycle or known as Brayton cycle. In this cycle first of all air get compressed in the compressor increasing its pressure and temperature. After compressed air is then entered into the combustion chamber where under high temperature pressurized air get mix up with the fuel (the fuel used here is methane because it has highest calorific value). The mixture of fuel and air is then expanded in the turbine where power is produced with the help of heat. The heat that come out of turbine as stack gas is then utilized in HRSG (heat recovery steam generator) to produce process heat $\dot{Q}_p$. The stack gas coming out of HRSG is sent to the generator of vapor absorption system in order to produce cooling effect. The following expression was used to find out the different values required to show the variation of efficiency of trigeneration at different compressor pressure ratio and different turbine inlet temperature.



Entropy (kJ/kgk)

Fig 3.Temperature Entropy diagram for Brayton cycle (simple gas Turbine)

2.1. Thermodynamic formulation:

(a) Expression for power output:

The net power output of a cycle is given by,

$\dot{w}_{net} = (\dot{m}_a + \dot{m}_f)(h_3 - h_4) - \dot{m}_a(h_2 - h_1)$

Eq. (1) may be written as

$\dot{w}_{net} = (\dot{m}_a + \dot{m}_f)c_p(t_3 - t_4) - \dot{m}_a c_p(t_2 - t_1)$

Compressor isentropic efficiency

$\eta_c = \frac{Isentropic\ work\ input}{actual\ work\ input}$

$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$ (3a)

Turbine isentropic efficiency

$\eta_T = \frac{Actual\ work\ output}{Isentropic\ work\ output}$

$\eta_T = \frac{T_3 - T_4}{T_3 - T_{4s}}$

The electrical power output of the system is given by,

$\eta_g = \frac{\dot{W}_{el}}{\dot{w}_{net}}$

$\dot{W}_{el} = \eta_g \dot{w}_{net}$ (6)

Where η_g is the mechanical to electrical conversion efficiency.

(b) Expression for energy input:

The total heat input to the cycle is given by

$\dot{Q}_{in} = \dot{m}_a[(1+A)h_3 - h_2]$

$= \dot{m}_a c_p[(1+A)\,T_3 - T_2]$

Where A is fuel to air ratio.

$e_{in} = q_{in} - T_0 \Delta S$

$= q_{in} - \frac{T_0 . q_{in}}{T_{in}}$

$= q_{in}[1 - \frac{T_0}{T_{in}}]$

Where q_{in} = specific heat input

e_{in} = specific exergy

T_{in} = fuel input tem.

T_0 = fuel output tem.

(c) Fuel utilization efficiency (first law or energetic efficiency):

The ratio of all the useful energy extracted from the system (electricity, process heat, and cold) to the energy of fuel input is known as the fuel utilization efficiency which is also known as the first law efficiency or energetic efficiency,

 DOI : 10.18231/2454-9150.2018.0390

$$\eta_1 = \frac{(\dot{W}_{el} + \dot{Q}_P + \dot{Q}_E - \dot{Q}_{SP})}{\dot{Q}_f}$$

(d) Electrical to thermal energy ratio (first law or energetic efficiency):

The cost effectiveness of any Trigeneration system is directly related to the amount of power it can produce for a given amount of process heat and cold needed. Thus the electrical to thermal energy ratio (RET) is an important parameter used to assess the performance of such a system.

$R_{ET} = (\frac{\dot{W}_{el}}{\dot{Q}_P + \dot{Q}_E})$

R_{ET} = electrical to thermal energy ratio

(e) Second law efficiency (exergetic efficiency):

The second law efficiency is:

$\eta_{||} = \dot{W}_{el} + (\dot{E}_P + \dot{E}_E)/\dot{E}_f$(22)

$\dot{W}_{el}$= exergy content of electrical power

$\dot{E}_P$= exergy content of process heat

$\dot{E}_f$ =exergy content of fuel input

$\dot{E}_E$=exergy content of cold

(f) Turbine expansion ratio:

The turbine expansion ratio may be expressed in terms of the compressor compression ratio and pressure drop to be used in each of the heat transfer device involved in gas turbines.

Pressure drop factor $= \frac{outlet\ pr.}{inlet\ pr.}$

$\beta = \frac{p_{out}}{p_{in}}$

$\beta = 1 - \frac{p_{in} - p_{out}}{p_{in}}$

$= 1 - (\frac{\Delta p}{p})$

The quantity $(\frac{\Delta p}{p})$ is known as relative pressure drop factor.

(g) Refrigeration or cold production:

The amount of cold produced ($\dot{Q}_E$) may be obtained after applying the energy balance on evaporator as:

$\dot{Q}_E = \dot{m}_r(h_9 - h_8)$

$= \dot{m}_E(h_c - h_d)$(15)

Exergy of refrigeration = $\frac{refrigeration\ capacity}{coefficient\ of\ performance\ of\ carnot\ refrigeration\ cycle}$

$\dot{E}_E = \dot{Q}_E(\frac{T_0 - T_E}{T_E})$

III. RESULT AND ANALYSIS

In the present work the effects of pressure ratio across the compressor (π_c), turbine Inlet temperature (TIT), percentage pressure drop(%)on the first law efficiency and also the ratio of electrical to thermal energy (RET) is obtained by energy balance approach or the first law analysis of the cycle. Despite that, the exergy destruction or thermodynamic losses in each component, and the second law efficiency of the Trigeneration cycle have also been investigated under the exergy-balance approach or the second law analysis of the cycle. Using the above equation and properties the following values and graph were obtained.

3.1. Effect of Compressor pressure ratio on first law, second law efficiency of Gas turbine, cogeneration and Trigeneration cycle:

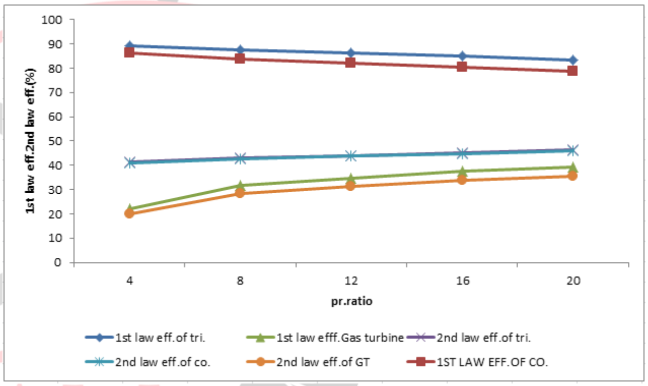
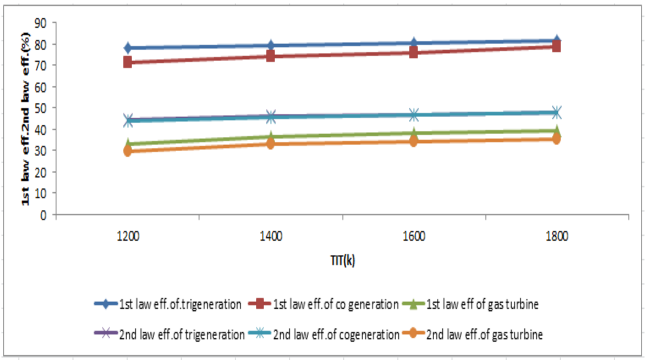


Fig.3.1 shows that with increase of pressure ratio the first law efficiency of trigeneration and first law efficiency of cogeneration decreases but first law efficiency and second law efficiency of gas turbine increases as pressure ratio increases also second law efficiency of cogeneration increases with pressure ratio.

3.2 Effect of Variation of Turbine inlet Temp. on First law Efficiency, Second law Efficiency:

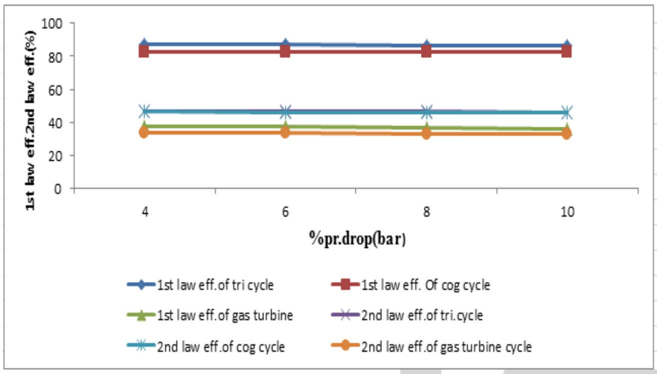


 DOI : 10.18231/2454-9150.2018.0390

ISSN : 2454-9150 Vol-04, Issue-03, June 2018

Fig.3.2 shows that with increase of turbine inlet temperature first law efficiency of trigeneration and first law efficiency of cogeneration increases but first law efficiency and second law efficiency of gas turbine first increases and then decreases with little amount.

3.3 Effect of variation of % pressure drop on First law efficiency, second law efficiency:



It is observed that the first and second law efficiencies for all three cycles is more or less independent of pressure drop, only second law efficiency of the gas turbine slightly decreases when the pressure drop increases.

3.4. Effect of Variation of TIT on electrical to thermal energy ratio:

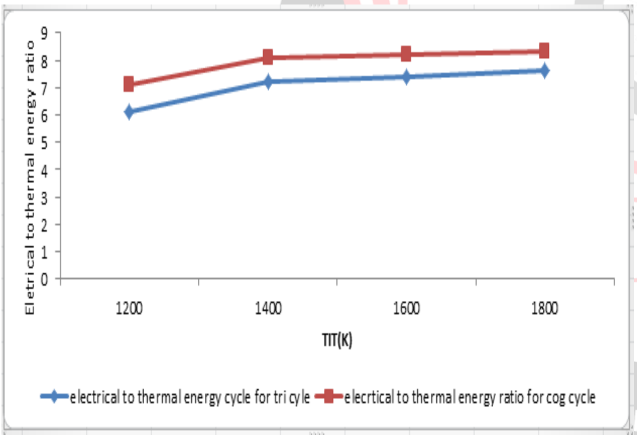


Fig.3.4 shows that with increase of turbine inlet temperature electrical to thermal energy ratio of trigeneration cycle and cogeneration cycle first increases and then decreases with the same.

3.5. Effect of Variation of Pressure ratio on Electrical to Thermal Energy ratio:

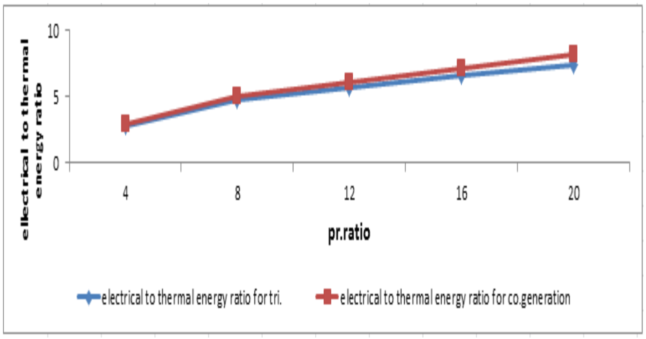
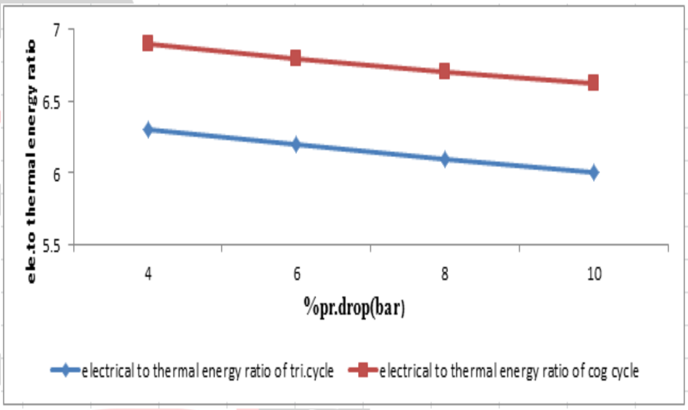


Fig.3.5 shows that with increase of pressure ratio electrical to thermal energy ratio for trigeneration and cogeneration cycle first increases and then slightly bends downward and then increases slightly.

3.6. Effect of Variation of % Pressure drop on Electrical to Thermal Energy Ratio:



Above graph shows that with increase of pressure drop electrical to thermal energy ratio of trigeneration and cogeneration cycle decreases.

IV. DISCUSSION

On the basis of graph shown above following result is calculated:

The result shows that as the pressure ratio (π_c) increases the compressor work increases, raising the temperature at compressor outlet. Increase in pressure ratio also increases the turbine work. The network output first increases and then decreases, as at high pressure ratio compressor work increases rapidly. As the pressure ratio increases the air temperature at the inlet of combustion chamber increases which results in decreasing heat that was added to the cycle. Hence, as π_c increases, the first law efficiency of the gas turbine cycle increases. The second law efficiency is slightly less effective than the first law efficiency of the gas

 DOI : 10.18231/2454-9150.2018.0390

ISSN : 2454-9150 Vol-04, Issue-03, June 2018

turbine cycle. The first law efficiency of cogeneration cycle is higher than first law efficiency of gas turbine cycle because the gas turbine exhaust is utilized to produce the process heat. The second law efficiency for cogeneration cycle is higher than the second law efficiency for gas turbine cycle but the difference between the second Law efficiency for cogeneration cycle and gas turbine cycle is less as compared to the difference between the first law efficiency of both.

The first law efficiency of trigeneration cycle is higher than the first law efficiency of cogeneration cycle and the first law efficiency of cogeneration cycle is higher than the first law efficiency of gas turbine cycle. This is because the stack gas is utilized to produce the cold in the same plant. The second law efficiency for trigeneration cycle is slightly higher than the second law efficiency for cogeneration cycle because exergy associated with cooling load is very small. The electrical to thermal energy ratio (RET) for cogeneration and trigeneration cycle increases as the net work output Increases but process heat decreases and cooling load remains same with increase in pressure ratio.

It is found that the first law efficiency increases with the increase in TIT. This is because increasing TIT leads to significant increase in net work output and insignificant increase in heat addition of cycle. It is noticed that the 1st law efficiency is slightly less than 2nd law efficiency. As compare to the 1st law efficiency, the difference between 2nd law efficiency for gas turbine, cogeneration and trigeneration is less. It is observed that the first and second law efficiencies for all three cycles is more or less independent of pressure drop but only second law efficiency of the gas turbine slightly decreases when the pressure drop increases.

V. SCOPE FOR FUTURE WORK

1. Turbine inlet temperature, combustion chamber, specific fuel consumption, HRSG and T_{max} are important parameter for such system.So these parameters can be optimized and find such a combination at which η_{TR} should be maximum.

2. The exergy destruction in each component can be reduced in order to improve the trigeneration efficiency.

3. Individual component efficiency can be improved in order to increase overall efficiency.

4. For all systems, one has to decide best combination of performance to achieve high trigeneration efficiency and according to all three requirements (Power, Heat, Cooling) choosing best system.

VI. CONCLUSION

On the basis of calculations the following conclusions are made:

As the pressure ratio increase the first law efficiency of cogeneration and Trigeneration decreases but the second law efficiency and electrical to thermal energy ratio for these systems increases with the same.

Effect of pressure ratio on first law efficiency,

- For the pressure ratio 4 bar, the first law efficiency of Trigeneration is 89.4045%, and when the pressure ratio is 20 bar then$\eta_{I(tri)}$= 83.3167%.
- For the pr.ratio 4 bar, $\eta_{I(cog)}$= 86.1478% and it decreases when pr.ratio is 20 bar i.e. $\eta_{I(cog)}$ = 78.7280%
- For the pressure ratio 4 bar $\eta_{I(G.T)}$= 21.8775% and efficiency of gas turbine increases when pr.ratio is 20 bar i.e. $\eta_{I(GT)}$= 39.4463%

Effect of pressure ratio on second law efficiency,

- When pr.ratio = 4bar, $\eta_{II(tri)}$= 41.0116%, and it increases when the pr.ratio=20 bar i.e. $\eta_{II(tri)}$= 46.2732%
- When pr.ratio = 4 bar, $\eta_{II(cog)}$= 41.0116%, and the second law efficiency of cogeneration cycle is increase when pr.ratio=20 bar i.e. $\eta_{II(cog)}$ = 45.9424%
- When the pr.ratio= 4 bar, $\eta_{II(G.T.)}$= 19.7665%, and the second law efficiency of gas Turbine increase when pr.ratio=20 bar i.e.$\eta_{II(G.T.)}$= 35.5263%.

The first law efficiency, electrical to thermal energy ratio, and second law efficiency of cogeneration and Trigeneration increases with the increase in turbine inlet temperature.

Effect of turbine inlet temperature on first law efficiency and second law efficiency,

 DOI : 10.18231/2454-9150.2018.0390

ISSN : 2454-9150 Vol-04, Issue-03, June 2018

- For the TIT=1800K, first law efficiency of Trigeneration is higher, its value is $\eta_{I(tri)}$ = 81.7868%
- For the TIT=1800K, second law eff. of Trigeneration is higher, its value $\eta_{II(tri)}$ = 47.8269%
- For the TIT=1800K, first law eff. of cogeneration is higher, its value,

  $\eta_{I(cog)}$ = 78.7030%
- For the TIT=1800K, second law eff. of cogeneration is higher, its value $\eta_{II(cog)}$ = 47.6050%

The first law efficiency, electrical to thermal energy ratio, and second law efficiency of gas turbine, cogeneration and Trigeneration cycles are not at all affected with the pressure drop in combustion chamber and HRSG. Maximum exergy is destroyed during the combustion and steam generation process; it represents over 80% of the total exergy destruction in the overall system. The exergy destruction in combustion chamber and heat recovery steam generator decreases significantly with the increase in pressure ratio but increases significantly with the increase in turbine inlet temperature.

REFERENCES

[1] S. Aphornratana and I. W. Eames, Thermodynamic analysis of absorption refrigeration cycles using the second law of thermodynamics method, International Journal of Refrigeration, Elsevier,4(1995) 244- *252*, 1995.

[2] Arzu Sencan, Kemal A. Yakut, Soteris A. Kalogirou, Exergy analysis of lithium bromide/water absorption systems, Renewable Energy, Elsevier, 30 (2005) 645–657.

[3] A. Khaliq, S.C. Kaushik, Second-law based thermodynamic analysis of Brayton/Rankine combined power cycle with reheat, Applied Energy, Elsevier, 78 (2004) 179–197.

[4] A. Khaliq, S.C. Kaushik, Thermodynamic performance evaluation of combustion gas turbine cogeneration system with reheat, Applied thermal Energy, Elsevier, 24 (2004) 1785–1795.

[5] J. Bassols, B. Kuckelkorn, J. Langreck, R. Schneider, H. Veelken, Trigeneration in the food industry, Applied Thermal Engineering 22 (2002) 595–602 Elsevier.

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

[7]. G. Tamm, D.Y. Goswami, S. Lu, A.A. Hasan, Theoretical and experimental investigation of an ammonia–water power and refrigeration thermodynamic cycle, Solar Energy 76 (2004) 217–228,Elsevier.

[8]Mohammad Ameri, Ali Behbahaninia, Amir Abbas Tanha, Thermodynamic analysis of a tri generation system based on micro-gas turbine with a steam ejector refrigeration system, Energy 35 (2010) 2203-2209,(Elsevier).

[9]. Arora, C.P., Refrigeration & Air conditioning, third ed. Tata McGraw-Hill Education

[10].Manohar Prasad.A course in Refrigeration and Air Conditioning, second ed., new age international pub.

 DOI : 10.18231/2454-9150.2018.0390