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RESEARCH ARTICLE

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EXERGY ANALYSIS ON BRAYSSON CYCLE WITH REAL GASES

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ABSTRACT

The present study was made to evaluate the performance of Braysson cycle. Braysson cycle is a hybrid gas turbine, combination of Brayton cycle and Ericsson cycle. The hybrid gas turbine is proposed based on the Brayton cycle at high temperature heat addition and low temperature heat rejection at Ericsson cycle. The performance was evaluated in terms of thermal efficiency, exergy losses and specific power output.

Energy and exergy analysis was carried out on Braysson cycle and Brayton cycle. The analytical formula was derived for energy efficiency, specific power output, exergy losses of each component, and the exergy efficiency. The influence of various parameters on the performance of the Braysson cycle and Brayton cycle were analyzed. The analysis was carried out using working fluids such as Air, Carbon dioxide, Ethane, Methane, Natural gas. Considering air as working fluid results are validated with literature. The results are compared for different working fluids under same working conditions. From the results is observed that losses are minimum and efficiency high in Braysson cycle than that of Brayton cycle

Keywords— Braysson cycle, real gases, exergy analysis.

INTRODUCTION

Combined-cycle plants are more popular due to higher thermal-efficiency. A development in the search for higher thermal-efficiency of conventional power plant has been the introduction of combined-cycle plants. This is leading to the development of gas turbines dedicated to combined-cycle applications, which has been a subject of great interest in recent years, because of their relatively low initial costs, and the short time for their construction.

First law and second law analysis of gas turbine power plant is performed by Tara Chand et al., [1]. The performance of a gas turbine power plant was evaluated by conducting en ergy and exergy analyses on each component of the system. A parametric study was carried out on energy and exergy efficiency. Second-law thermodynamic analysis was performed on Brayton/Rankine combined power cycle with reheat system and analyzed component wise air as working fluid by Khaliq and Kaushik [2].An analytical expression was derived for specific power output, thermal efficiency, exergy degradation for the cycle. Ersayin and Ozgener [3] carried out the performance analysis of combined cycle power plants using new energy resources with higher utilization for higher efficiency. Exergy analysis for combined regenerative Brayton and inverse Brayton cycles was performed by Zhang et al., [4].They performed exergy analysis on joined regenerative Brayton and reverse Brayton cycles; and the biggest exergy destruction area is resolved. Junlin Zheng et al. [5] performed the exergy analysis on Braysson cycle with air as working fluid and evaluated the performance of Braysson cycle in terms of exergy efficiency , specific power output and exergy losses. Frost at al [6] proposed a cycle with two conventional gas turbine cycles Brayton and Ericsson cycle where high temperature heat addition is takes place in Brayton cycle and low temperature heat rejection takes place in Ericsson cycle named it as Braysson cycle which is an alternative to conventional combined gas and steam power plant.

In present work aims thermodynamic analysis of Braysson cycle the hot exhaust gases are expanded in bottom cycle (Ericsson) to a very low temperature and pressure about 0.04bar. After expansion to a very low pressure the heat rejection process takes place at constant temperature through multistage intercooled compression process, by heat pipe technology. And the efficiency of Braysson cycle will depend up on the efficiency of heat pipe technology.

In present work the analysis is carried out with real gases as working fluids such as Air, Carbon dioxide, Ethane, Methane, Natural gas .And evaluating the performance of the cycle with these gases under different operating conditions.

Assumption used in this Analysis

The following assumptions are used for the present investigation.

[1]. The effect of fuel addition on mass flow rate is neglected.

[2]. Losses in all rotating components are neglected.

[3]. The isentropic efficiency of gas turbine [η_T] and compressor [η_C] is taken as 95%, combustion efficiency [η_{CH}] as 90%, and mechanical efficiency as [η_M] as 98.5%.

[4]. For all gases the inlet temperature is taken as 293 K.

[5]. The gas properties for different gases at temperature 293 K is as follows,

Gas	C_p(kJ/kg k)	$\gamma=C_p/C_v$
Air	1.01	1.4
Carbon dioxide	0.844	1.279
Ethane (C2H6)	1.75	1.187
Methane(CH4)	2.22	1.304
Natural Gas	2.34	1.27

First Law Analysis of Braysson Cycle

Process 1-2

Work supplied to compressor

W_{1-2}=m cp (T_2-T_1) kJ.

Process 2-3

Heat supplied in combustion chamber

Q_{2-3} =m Cp (T_3-T_2) kJ.

Process 3-4

Work done by turbine

W_{3-4} =m Cp (T_3-T_4) kJ.

Process 4-5

Work done by turbine

W_{4-5} =m Cp (T_4-T_5) kJ.

Process 5-1

Work supplied to isothermal compressor is

W_{5-1} = T_1*R ln (P_1/P_5) kJ.

Top Cycle Efficiency (Brayton Cycle)

$$\eta = 1 - \frac{1}{(\Psi)^{(\Upsilon-1)/\Upsilon}}$$

Bottom cycle efficiency (Ericsson cycle)

$$= 1 - \frac{\ln\left(\frac{1}{\psi^{(\Upsilon-1)/\Upsilon}} * t\right)}{\frac{1}{\psi^{(\Upsilon-1)/\Upsilon}} * t - 1}$$

Ideal Braysson cycle efficiency is

$$\eta_{BS} = \eta_B + \eta_E - \eta_B * \eta_E$$

Second Law Analysis of Braysson Cycle

Process 1-2'

The air compressed isentropically 1 to 2 .the actual compression occurs in the process 1-2'.

The compressor efficiency

$$\eta_C = \frac{\text{Isotropic work}}{\text{Actual work}}$$

$$= \frac{h_2 - h_1}{h_{2'} - h_1}$$

$$= \frac{T_2 - T_1}{T_{2'} - T_1}$$

$$=\frac{(T_2/T_1)-1}{(T_{2'}/T_1)-1}$$

$$(T_{2'}/T_1)=\frac{(\Psi)^{(\Upsilon-1)/\Upsilon}-1}{\eta_C}+1$$

Irreversibility of a process is

$I = W_{Max} - W_{Actual}$

In the case of compressor W Max is the actual work and W actual is isentropic work.

$I_{1-2}{}^{1} = T_o\,(S_2{}^{1} - S_1)$

$= T_1\,[Cp\ \ln(T_{2'}/T_1) - R\ \ln(P_{2'}/P_1)]$

We know $(P_2{}^{1} = P_2)$

$= T_1 * Cp\ [\ln((\Psi^{(\Upsilon-1)/\Upsilon}-1)/\eta_C + 1) - (\Upsilon - 1/\Upsilon)\ \ln(\Psi)]$

(To=T1 surrounding temperature)

Process 2^1-3:

Process 2^1 to 3 is a heat addition process. In combustion process two types of losses occur.

1. Losses due to imperfect combustion
2. Losses due to conversion of energy

Combustion efficiency

$$\eta_{CH} = \frac{\text{Energy Released in combustion}}{\text{Chemical energy of fuel}}$$

$$(CH)_{Energy} = \frac{Cp\,(T_3 - T_{2'})}{\eta_{CH}}$$

1. Irreversibility due to imperfect combustion

$I^1\ 2^1$-3 = Chemical energy of fuel –Energy Released in combustion

$= (CH)_{Energy} - Cp\,(T_3 - T_{2'})$

$$=\frac{Cp\,(T_3 - T_{2'})}{\eta_{CH}} - Cp(T_3 - T_{2'})$$

$= Cp\,(T_3 - T_2{}^{1})\,[(1/\eta_{CH}) - 1]$

$= Cp * T_1\,[(T_3/T_1) - (T_{2'}/T_1)][(1/\eta_{CH}) - 1]$

$= Cp * T_1\,[t - ((\Psi^{(\Upsilon-1)/\Upsilon} - 1)/\eta_C + 1)]\,[(1/\eta_{CH}) - 1]$

2. Irreversibility due to conversion of energy

$I^2{}_{2'-3} = W_{Max} - W_{Min}$

$= T_o\,(S_3 - S_2{}^{1})$

$= T_1 * Cp\ \ln(T_3/T_{2'})$

$= T_1 * Cp\ \ln[(T_3/T_1) * (T_1/T_{2'})]$

$= T_1 * Cp\ [\ln(t) - 1/\Psi^{(\Upsilon-1)/\Upsilon} - 1)\ /\ \eta_C + 1))]$

Total irreversibility in process

$I_{2'-3} = I^1{}_{2'-3} + I^2{}_{2'-3}$

Process 3-4^1

Ideal expansion takes place isentropically during process 3 to 4.

Actual expansion follows process 3 to 4'

Turbine efficiency $\eta_T = \frac{h_3 - h_{4'}}{h_3 - h_{4'}}$

$$=\frac{T_3 - T_{4'}}{T_3 - T_4}$$

$$=\frac{1-[T_{4'}/T_3]}{1-[T_4/T_3]}$$

$(T_4/T_3) = 1 - [1 - (T_{4'}/T_3)]/\eta_T$

From figure we know that $T_4{}^{1} = T_1$ and $T_3/T_1 = \tau$

$T_4/T_3 = 1 - [1 - (1/t)]/\eta_T$

$= 1 - (1/\eta_T) - 1/(t * \eta_T)$

Irreversibility of a process is

$I = W_{Max} - W_{Actual}$

$I_{3-4}{}^{1} = T_o\,(S_3 - S_4{}^{1})$

$= T_1\,[Cp\ \ln(T_4{}^{1}/T_3) - R\ \ln(P_4{}^{1}/P_3)]$

We know that $P_4{}^{1} = P_4 = P_1$

$= T_1 * Cp\ [\ln[1 - (1/\eta_T) - 1/(t * \eta_T)] - [(\Upsilon - 1/\Upsilon)\ \ln(P_1/P_3)]]$

$= T_1 * Cp\ [\ln[1 - (1/\eta_T) - 1/(t * \eta_T)] + [\ln(t)]$

$= T_1 * Cp\ [\ln(1/t) - \ln(1 - (1/\eta_T) - (1/(t * \eta_T))]$

Process 4^1-1

The process 4^1-1 is a multi-stage inters cooled compression. In each stage a small amount of pressure rise takes place during this temperature raise is negligible. So during this irreversibility is zero.

Irreversibility during process I 4^1-1 =0

Total Irreversibility in the cycle=0

$I = I_{1-2}{}^{1} + I_{2}{}^{1}{}_{-3} + I_{3-4}{}^{1} + I_{4}{}^{1}{}_{-1}$.

Specific work done

$W_s = \eta_M\,W_{3-4}{}^{1} - W_{1-2}{}^{1} - W_{4}{}^{1}{}_{-1}$

$= \eta_M * Cp * (T_3 - T_{41}) - Cp * (T_{21} - T_1) - T_1 * R\ \ln(P_1/P_4{}^{1})$

$= \eta_M\ Cp * T_4{}^{1}\ [((T_3/T_4{}^{1}) - 1] - Cp * T_1\,[(T_2{}^{1}/T_1) - 1] - T_1 * Cp\,[(\Upsilon - 1)/\Upsilon]\ \ln(P_1/P_4{}^{1})$

We know that $P_1/P_4{}^{1} = (P_1/P_3)/(P_3/P_4{}^{1})$

$(P_1/P_3) = (P_1/P_2) = \Psi$ and $T_4{}^{1} = T_1$, $(T_3/T_4{}^{1} = t)$

$\ln(P_1/P_4{}^{1}) = \ln(P_1/P_3) * \ln(P_3/P_4{}^{1})$

$(P_3/P_4{}^{1}) = [T_3/T_{4'}]^{\Upsilon/\Upsilon-1}$

$W_s = \eta_M\ Cp * T_1\ [t-1] - Cp\ T_1 + T_1 * Cp\ [\ [\ [\ (\Upsilon - 1)\Upsilon]\ \ln(\Psi) + \ln(1 - (1/\eta_T) - 1/(t * \eta_T))]$

Cycle exergy efficiency

$$\eta_{BS} = \frac{\text{Specific power output}}{\text{Chemical energy of fuel}}$$

$$=\frac{W_S}{(CH)_{Energy}}$$

$$=\frac{W_S}{Cp\,(T_3 - T_{2'})/\eta_{CH}}$$

$$=\frac{\eta_{CH}\,(W_S)}{Cp(T_3 - T_{2'})}$$

$$= \frac{\eta_{CH}(W_S)}{Cp * T_1[(T_3/T_1) - (T_{2'}/T_1)]}$$

$$= \frac{\eta_{CH}[\eta_M[t-1] - [(\Psi^{(\Upsilon-1)/\Upsilon}) - 1] + [[(\Upsilon-1)\Upsilon]\ln(\Psi)] + \ln(1-(1/\eta_T) - 1/(t*\eta_T))]}{[t - (\frac{\Psi^{(\Upsilon-1/\Upsilon)}-1}{\eta_C} + 1)}$$

RESULTS AND DISCUSSIONS

First law efficiency

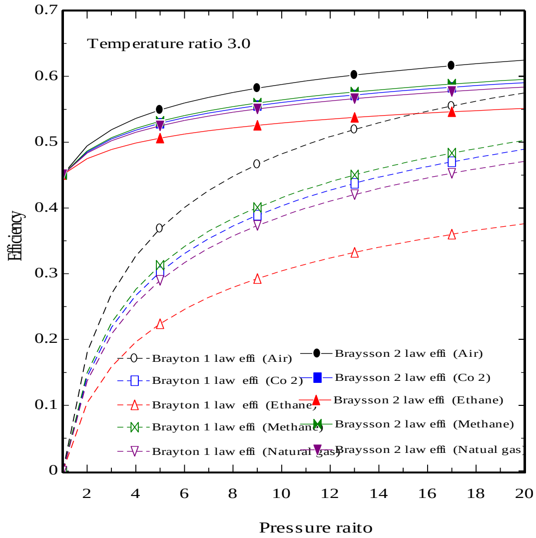

Fig.1 First law efficiency of Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio.

First law efficiency of Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio is analyzed by fig.1.The efficiency of Braysson cycle is greater than Brayton cycle because in Braysson cycle utilizing the hot exhaust gasses from Brayton cycle are expanded in bottom cycle (Ericsson cycle). The first law efficiency of cycle with methane as working fluid is having high efficiency compared to all other working fluids. Since first law efficiency is a function of temperature ratio and value of ratio of specific heats (γ).

Second law efficiency

The second law efficiency of Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio and pressure ratio 3.0 varying with temperature ratio is analyzed from fig 2 and fig 3.In both cases the second law efficiency of Braysson cycle is greater than Brayton cycle and in both cases the second law efficiency of cycle with working as Methane having high efficiency compared to all other gases. The value of efficiency increases with increase in temperature ratio at constant pressure ratio because maximum value of component efficiency is achieved at constant or low range of pressure ratios.

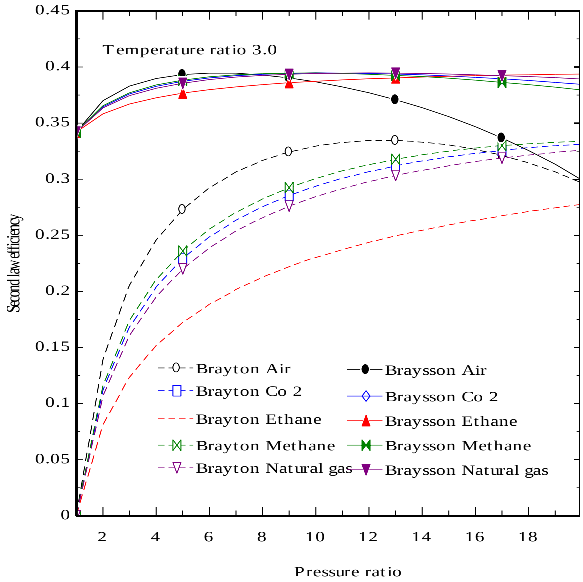

Fig.2 Second law efficiency of Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio.

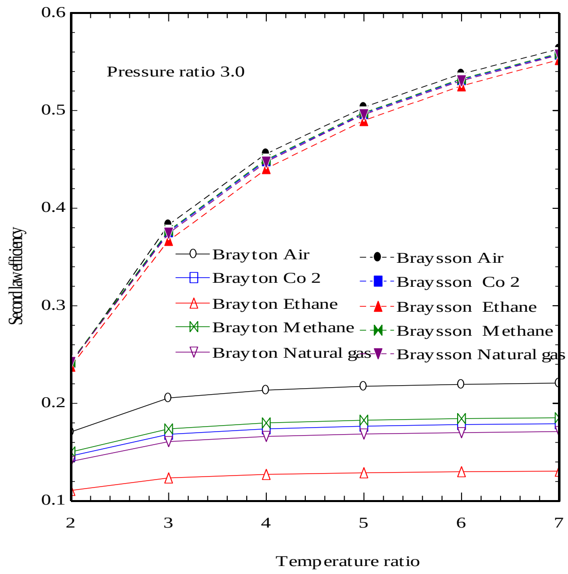

Fig.3 Second law efficiency of Braysson cycle and Brayton cycle at pressure ratio3.0 varying with temperature ratio.

Specific power output

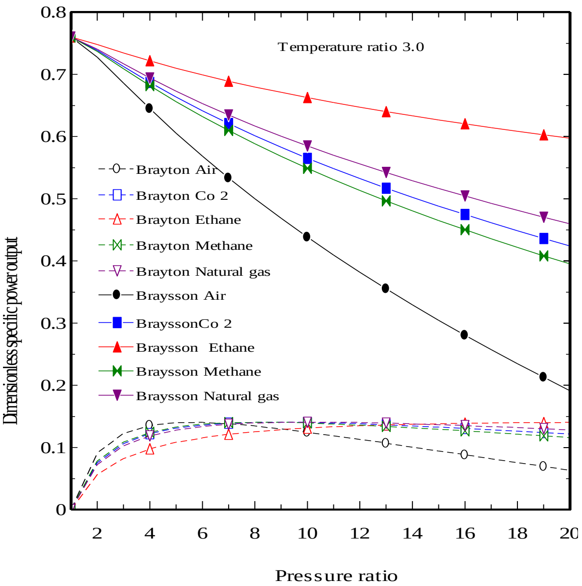

Fig.4 Dimensionless specific power output of Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio.

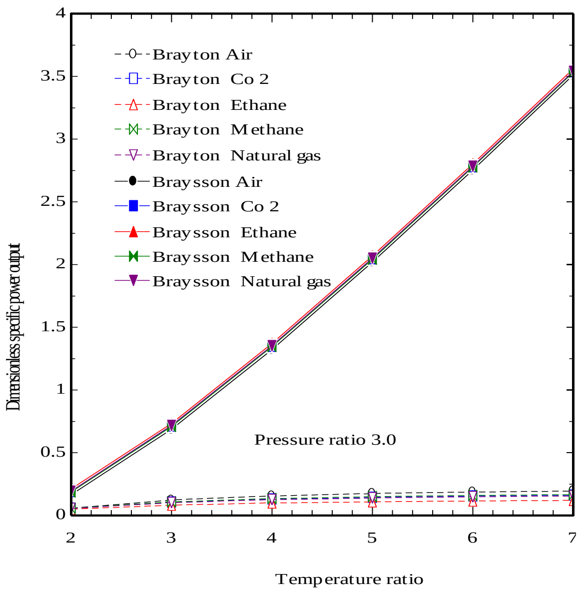

Fig.5 Dimensionless specific power output of Braysson cycle and Brayton cycle at pressure ratio 3.0 varying with temperature ratio.

The dimensionless specific power output of Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio and at pressure ratio 3.0 varying with temperature ratio are analyzed by fig 4 and fig 5.The specific power output of Braysson cycle is greater than that of Brayton cycle. The specific power output in Braysson cycle is decreases continuously with increase in pressure at constant temperature ratio and increases continuously with increase in temperature at constant pressure. And also in both cases the specific power output of Braysson cycle with Ethane as working fluid is having high value compared to all other working fluids.

Dimensionless exergy losses

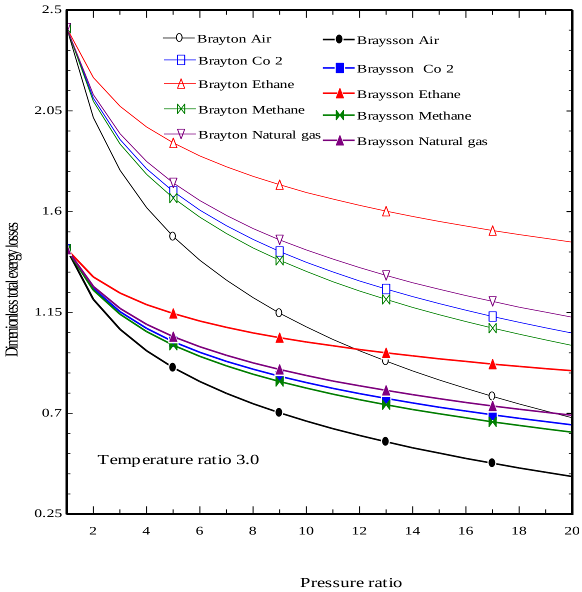

Fig.6 Dimensionless exergy losses in Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio.

Dimensionless exergy losses in Braysson cycle and Brayton cycle at temperature ratio 3.0 varying with pressure ratio and at pressure ratio 3.0 varying with pressure ratio are analyzed by figures 6, 7.In both cases the exergy losses are high in Brayton cycle compared to Brayton cycle because the exergy losses are function of temperature ratio in Brayton cycle the hot exhaust gases are expanded to a very low temperature in bottom cycle so the losses are minimum in case of Braysson cycle. It is also observed that the losses are decreases with increase in pressure and increases with increase in temperature ratio.

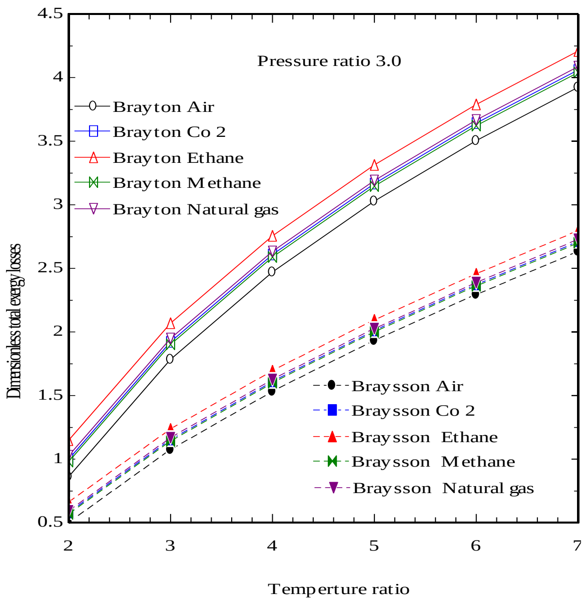

Fig.7 Dimensionless exergy losses in Braysson cycle and Brayton cycle at pressure ratio 3.0 varying with temperature ratio.

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