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Exergetic Analysis sustainability Index (ESI) On Gas Turbine Compressor Package (GTCP) At Pt. Pertamina Gas Negara (PGN) Pagardewa Station

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Abstract:
Gas Turbine Compressor Package (GTCP) adalah turbin gas berfungsi sebagai penggerak kompresor sebagai beban dimana kompresor ini berfungsi untuk menaikkan tekanan gas sehingga gas tersebut mampu dialirkan menuju unit-unit penerimaan gas. Untuk mendapatkan hasil optimal dalam pengoperasian GTCP diperlukan analisis terhadap parameter-parameter yang berpengaruh didalam sistem GTCP, dimana dalam hal ini parameter yang berpengaruh tersebut adalah rasio kompresi pada kompresor. Pada penelitian ini digunakan analisis exergy untuk dapat mengetahui kerugian exergy pada kondisi operasi disetiap sub-sistem pada GTCP. Setelah melakukan analisis exergy pada kondisi operasi kemudian dilakukan modifikasi pada parameter rasio kompresi untuk dapat mengetahui hubungan antara rasio kompresi dengan eksergi yang dimusnahkan, efisiensi exergetic, dan kerja bersih GTCP, dimana dalam hal ini modifikasi rasio kompresi adalah senilai 16,5:1 sebagai model A yang merupakan rasio kompresi desain , 9:1 sebagai model B yang merupakan rasio kompresi dibawah kondisi operasi dan 13:1 sebagai model C yang merupakan rasio kompresi diatas kondisi operasi. Setelah didapat hasil analisis exergy pada kondisi berbagai permodelan tersebut dilakukan analisis Exergetic Sustainability Index (ESI) sehingga didapat nilai rasio tekanan yang menunjukan nilai ESI, Environtmental Effect Factor dan Kerja Bersih optimal yaitu pada model C dengan rasio kompresi sebesar 13:1

***Key Word**: GTCP; Exergy; Rasio Kompresi; Exergetic Sustainability Index; ESI; Environmental Effect Factor.*

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I. Introduction

PT. PGN Pagar Dewa Station, which plays an important role in the gas distribution business in Indonesia, has gas turbine equipment as one of the supporting utilities in distributing gas in the transmission pipeline network to all end-users, both in the power generation industry, ceramics industry and other commercial users. PT. PGN uses the gas turbine to drive the compressor in a system called the Gas Turbine Compressor Package (GTCP) to compress gas from the PT. Conoco Philips and PT. Pertamina to Java Island.

For enhancement efficiency with appropriate so needed results capable analysis _ tell availability actual energy (exergy) , losses exergy , causes , as well as the location . Analysis exergetic sustainable index is analysis system thermal in a manner qualitative used _ For measure quality from a process and can applied to the GTCP used by PT. PGN Stations Pagardewa For identify source inefficiency , determine location , and size exergy losses that occur so that can determined condition Work the most optimal equipment .

For condition Work the most optimal equipment in operation GTCP , then need done analysis more in-depth on parts of the GTCP as well as do modifications to the operating parameters . Optimization is the process for get conditions , ie values from the variables , which gives minimum values or maximum from function objective

II. Methodology

In this study, exergy analysis calculations will be carried out on the processes in each sub- system in the GTCP and the exergy dissipated into the environment at design and operating conditions as well as dooptimization with give modifications to the ratio compression and temperature especially at the turbine inlet on the GTCPso that got explanation showing connection between ratio compression, turbine inlet temperature, compressor inlet temperature , exergy destroyed , efficiency exergetic , and work net so that the right strategic steps are obtained to obtain optimum operating conditions that show maximum or minimum function according to needs.

To overcome the limitations caused by the lack of points that are given measuring instruments on the GTCP and situations where the value is not yet known, an analysis of the first law of thermodynamics will be carried out to complete the required data.

To be able to determine the specific enthalpy and specific heat values for each air and gas composition needed in the first law of thermodynamics analysis and exergy analysis in GTCP, a tool is needed in the form of a calculator properties of air and gas as well as a table of properties tool.

Besides completeness of the data, the accuracy of the data is also required when do analysis and optimization exergy on GTCPespecially in the combustion chamber . Therefore, any calculations based on the molar mass composition, whether on the side of the air entering the combustion chamber, fuel, or flue gas resulting from combustion, will usedata from the readings of measuring instruments

Analysis of the First Law of Thermodynamics

The design and operation data obtained from the control room are arranged to be placed at each point on the flowchart so that conditions at each unknown point can be identified. These data are then processed using the Microsoft Excel program worksheet to carry out calculations of the first law of thermodynamics analysis in every unknown condition. Furthermore, the calculated data is arranged in tabular form and then displayed in the form of a T-s diagram. From the T-s diagram, the parameters of temperature and compression ratio are obtained in the design and operating conditions of the GTCP system.

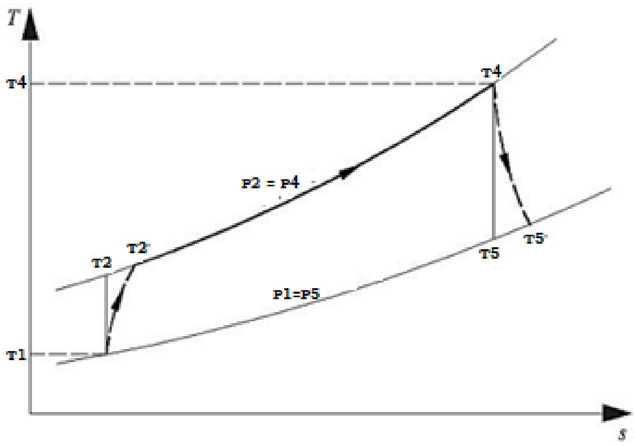

Figure 1. T-s GTCP system diagram of PT PGN Pagardewa Station

Exergy Analysis and ESI Analysis on sub-systems in GTCP

After getting all the parameters needed, the data will be carried out by an exergy analysis process for each sub-system in the GTCP system. The exergy analysis performed on the design and operation data will yield the exergy output at each point and the exergy annihilated for each sub-system and its relationship to work net and compressor under design and operating conditions. The value of the exergy equilibrium rate at GTCP is as follows :

$$[(\dot{E}_C - \dot{E}_{DC}) + \dot{W}_C] + [(\dot{E}_{CC} - \dot{E}_{DCC})] + [(\dot{E}_T - \dot{E}_{DT}) - \dot{W}_{Nett} - \dot{E}_L] = 0 \qquad \text{(II.1)}$$

After the data from the exergy analysis is obtained, modifications will be made by providing variations on the influential parameters, in this case pressure with the maximum value limit that exists in the manufacturing design data.

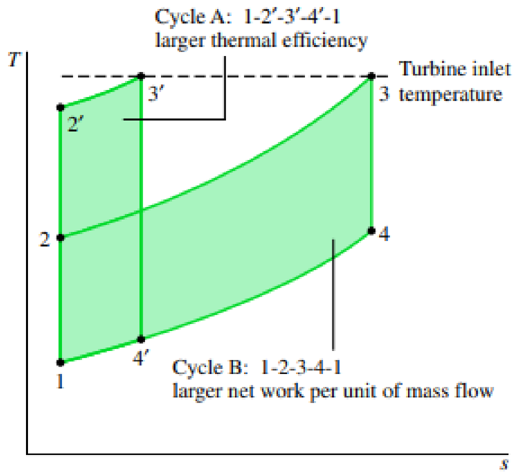

Figure 2. T-s diagram on modification of compression ratio with unchanged turbine inlet temperature (Source: Moran, 2006)

After getting results analysis exergy on each modification variations in the influential parameters the so results modification will made in tabular data form with various modeling .
the tabular data Then done ESI for can know influence from modifications to GTCP parameters .

$$\lambda = \frac{1}{\gamma_{Eef}} \qquad \text{(II.2)}$$

$$\gamma_{Eef} = \frac{\tau}{\eta_{\varepsilon}} \qquad \text{(II.3)}$$

$$\tau = \frac{\dot{E}_{DTotal}}{\dot{E}_{in}} \qquad \text{(II.4)}$$

III. Description System

Technical specifications

Table 1GTCP PT PGN Pagardewa Station Technical Specifications

Description	Information
Compressor Type	Axial Flow
Compressor number of stages	14
Compressor Compression Ratio	16, 5 : 1
Compressor Inlet air flow (nominal)	26.2 kg/sec (57.7 lbs /sec)
Combustion Chamber Type	Annular
ignition	Torches
Number of fuel injectors	12
Gas Producer Turbine Type	reaction
Number of stages	2
Maximum speed	15,200rpm
Output Power	7690 kW (10,300 HP)
Heat rate exhaust	10,340 kJ/kWh (7,310 Btu/kWh)
Flow exhaust	95630 kg/d (210,830 lb /h)
Turbine inlet temperatures	495 ^{0}C (920 ^{0}F)

Source GTCP Manufacturing data record, Solar Turbines Taurus-70

Table 2GTCP Fuel System Technical Specifications

Description	Information
Gas Fuel System	Natural Gas, Propane
Acceptable Gas Fuels	Conventional or SoLoNOx
Minimum/Maximum Gas Fuel Supply Pressure	1860 to 2760 kPag (270 to 400 psig)
Minimum Flow rate	1950 kg/ hr (4297 lbm /d)
Minimum/maximum Fuel Supply Temperature	-40 ^{0}C to 93 ^{0}C (40 ^{0}F to 200 ^{0}F)
Maximum Operating Pressure	3447 kPag (500 psig)
Maximum Operating Temperature	93 ^{0}C (200 ^{0}F)

PT PGN's GTCP Operation Data at Pagardewa Station

Table 3PT PGN's GTCP Operation Data at Pagardewa Station

Parameter	units	Mark
T_1	^{0}F	85,20
T_4	^{0}F	1391,11
T_5	^{0}F	219.94
P_2	psig	150,10
Flow Compressors	mscfd	72.54
T_{Fuel}	^{0}F	110.9652
P_{Fuel}	psig	759,2429
$T_{Sales\ Gas\ 2}$	^{0}F	103.88
P Gas $_{Sales\ 1}$	Psig	1.03

Table 4GTCP Fuel Composition of PT PGN Pagardewa Station

Type	Percentage
Methane	81.2829
Ethane	5.7772
Propane	1.3930
i -butane	0.2678
n-butane	0.3893
i -pentane	0.1608
n-pentane	0.1230
n-hexane	0.2051
N_2	1.2166
CO2	9.1146
H2O	0.0690
H2S	0.0007
AMOUNT	100

IV. Analysis and Discussion

Analysis of the First Law of Thermodynamics

The purpose of analyzing the first law of thermodynamics is to complete the operating data that has been obtained during data collection at the research location and as a basis for exergy analysis calculations.Placing the points that become parameters will make it easier to analyze and assist in completing the operating data that has been obtained during data collection at the research location.

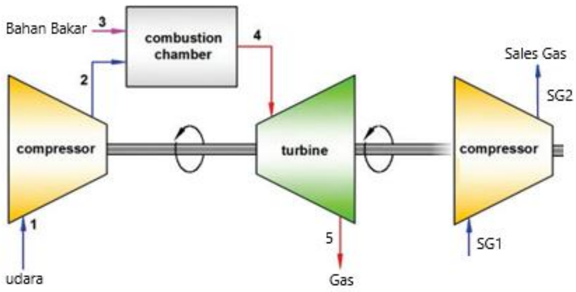

Figure 3 PT PGN Pagardewa Station GTCP flowchart

So that the values obtained from each point in the GTCP system of PT PGN Pagardewa station are as follows.

Table 5. The value at each point in the GTCP system

Point	T(^{0}C)	P(bar)	$\dot{m}$ (kg/s)	C p (kJ/kgK)	H(kW)
1	29,556	1.01325	23.77	1.005	7231,298228
2	324,407	11.362	23.77	1.05	14914,12638
2'	330,723	11.362	23.77	1,051	15086,11833
3	43.8695	52.3479	1.5	2.06	979,590255
4	755,0611	11.362	25,27	0.88441700	22979,71378
5	270.4131	1.01325	25,27	0.87555383	12026,46745
5'	299.1191	1.01325	25,27	0.87962735	12720,50279

Table 6. The value of each sub-system on the GTCP system

State		$\dot{W}$or$\dot{Q}$(kW)
Work Compressor ($\dot{W}_C$)	H $_2$ -H $_1$	7854,820104
Combustion chamber($\dot{Q}$)	H $_4$ - (H $_2$ +H $_3$)	6914.005194
Work turbine ($\dot{W}_{Turbin}$)	H5 - H4	10259,21099
Work Nett($\dot{W}_{Nett}$)	(H $_5$ -H $_4$)-(H $_2$ -H $_1$)	2404,390885

Exergy analysis on GTCP

The purpose of analyzing exergy in GTCP is For can know exergy values at each point in the GTCP and exergy destroyed in each sub- component in the GTCP.

Table 7.Exergy value at each point in GTCP

Point	$\dot{E}_{physics}$(kW)	$\dot{E}_{chemistry}$(kW)	$\dot{E}_{physics + chemistry}$(kW)
1	58.50198384	0	58.50198384
2	7205,755363	0	7205,755363
2'	7367,087275	0	7367,087275
3	18.31598252	70504,34181	70522,65779
4	15944,5778	1763,158626	17707,73643
5	5229,464497	1763,158626	6992,623124
5'	5878,281976	1763,158626	7641,440602

Table 8.Exergy Loss value for each sub- system in GTCP

Sub- system		Exergy Loss (kW)
Compressor ($\dot{E}_{DC}$)	$\dot{W}_C - \dot{E}_{2^*}$	649.0647404
Combustion Chamber($\dot{E}_{DCC}$)	$\dot{E}_{2^*} + \dot{E}_3 - \dot{E}_4$	60182,00864
Turbine ($\dot{E}_{DT}$)	$\dot{E}_{5^*} + \dot{W}_{nett} + \dot{W}_C - \dot{E}_4$	192.9151628
wasted to environment($\dot{E}_L$)	$\dot{E}_{5^*}$	7641,440602

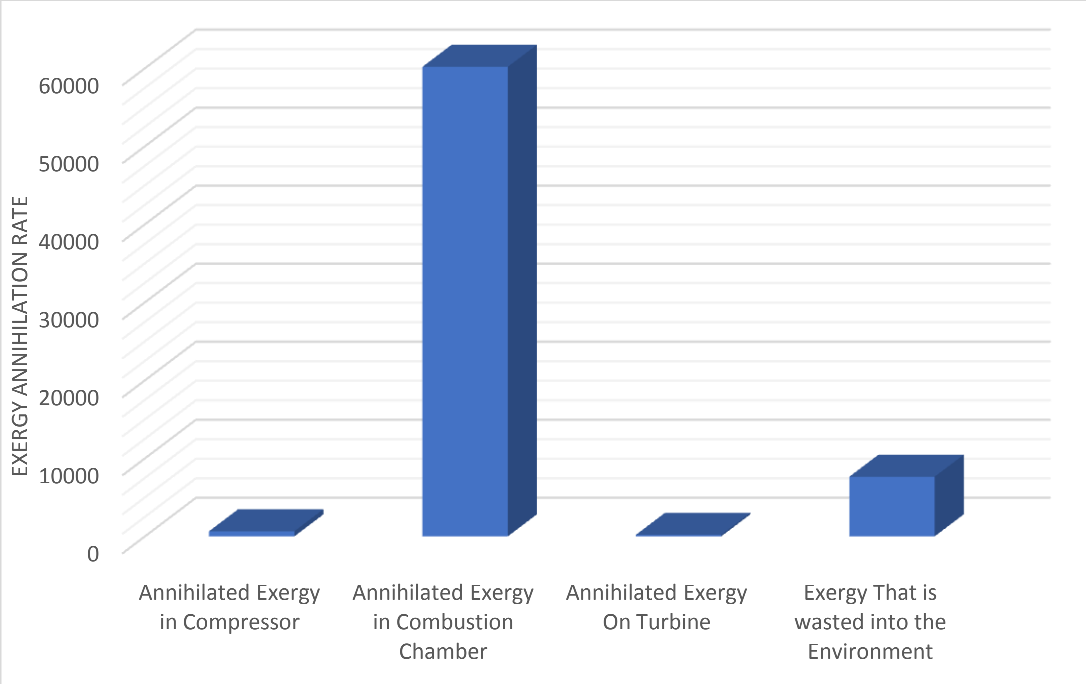

Figure 4 Graph of Exergy Loss Rate at GTCP PT PGN Pagardewa Station

From the chart above, we can see that the GTCP component that has the greatest exergy loss rate is exergy destroyed in the combustion chamber, followed by exergy discharged into the environment through the chimney and then exergy destroyed in the compressor and finally exergy destroyed in the turbine.

Modifications to the GTCP system

Modifications to PT PGN's GTCP Pagardewa station were carried out by providing variations in the compression ratio variable. The compression ratio in the design specifications is 16.5:1 (sixteen point five to one) where in operating conditions the compression ratio can be calculated as 11.2:1 (eleven point two to one). This research was conducted by calculating the compression ratio modeling above and under operating conditions. By modifying the compression ratio parameter with a target that the temperature of the combustion gas entering the turbine is constant according to the operating conditions, the values of each point in the GTCP system of PT PGN Pagardewa station are obtained with various models as follows.

Table 9 Values at each point on the GTCP Model A system with compression ratio conditions according to design conditions.

Point	T(^{0}C)	P (bar)	ṁ (kg/s)	Cp (kJ/kgK)	H (kW)
1	29,556	1,01325	23,77	1,005	7231,298228
2	390,433469	16,718625	23,77	1,06626003	16818,52369
2’	401,181713	16,718625	23,77	1,06883961	17132,28565
3	43,8695	52,3479	1,05	2,06	685,7131785
4	755,0611	16,718625	24,82	0,88441700	22570,49846
5	215,116350	1,01325	24,82	0,87026651	10546,56046
5’	247,966308	1,01325	24,82	0,87434265	11308,8413

Table 10The value at each point on the GTCP Model B system with a compression ratio under operating conditions is 9:1

Point	T(^{0}C)	P(bar)	ṁ (kg/s)	Cp (kJ/kgK)	H(kW)
1	29,556	1.01325	23.77	1.005	7231,298228
2	289.4253	9.11925	23.77	1.042766574	13944,3081
2'	293.9527	9.11925	23.77	1.043762603	14069,95345
3	43.8695	52.3479	1,7	2.06	1110,202289
4	755,0611	9.11925	25,47	0.884417007	23161,58726

5	304.4327	1.01325	25,47	0.880811034	12957,64021
5'	330,4521	1.01325	25,47	0.880751401	13540,44876

Table 11The value at each point on the GTCP Model C system with a compression ratio over operating conditions
is 13:1

Point	T(^{0}C)	P(bar)	ṁ (kg/s)	Cp (kJ/kgK)	H(kW)
1	29,556	1.01325	23.77	1.005	7231,298228
2	348.8766	13.17225	23.77	1.05628638	15617,79911
2'	356.7774	13.17225	23.77	1.05818259	15844,56626
3	43.8695	52.3479	1,3	2.06	848.978221
4	755,0611	13.17225	25.07	0.88441700	22797,8403
5	248.6593	1.01325	25.07	0.87441908	11438,94025
5'	278.9724	1.01325	25.07	0.87778062	12149,98488

By obtaining the value of each point on the GTCP of PT PGN Pagardewa station, a comparison of the T-s diagrams of each model can be made so that through Figure 5 it can be seen that with a change in the compression ratio, there is also a change in other parameters at the PT PGN GTCP station Pagardewa..

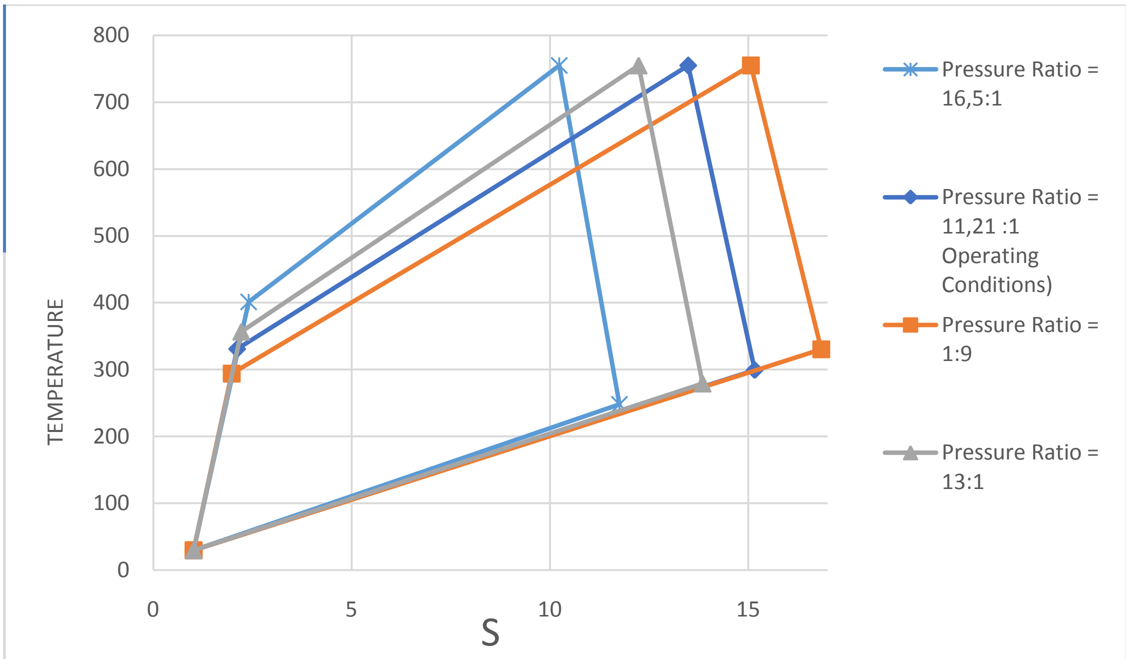

Figure 5 . T-s PT PGN Pagardewa Station GTCP diagram under operating conditions and under modified compressor pressure ratio conditions

Exergy analysis of the results of modifications to the GTCP system

By changing the parameters from the modification of the compression ratio, exergy analysis is then carried out on each model to be able to make a comparison of each model as follows.

Table 12Exergy values at each point in GTCP Model A

Point	$\dot{E}_{physics}$(kW)	$\dot{E}_{chemistry}$(kW)	$\dot{E}_{physics + chemistry}$(kW)
1	58.50198384	0	58.50198384
2	8957,22078	0	8957,22078
2'	9246,806109	0	9246,806109
3	2.677956017	49353,03927	49355,71722
4	15654,81847	1731,760867	17386,57934
5	3936,185683	1731,760867	5667,94655
5'	4650,409235	1731,760867	6382,170102

Table 13Exergy Loss Value for each sub-system in GTCP Model A

Sub- system		Exergy Loss (kW)
Compressor ($\dot{E}_{DC}$)	$\dot{W}_C - \dot{E}_{2^*}$	943.7666431
Combustion Chamber($\dot{E}_{DCC}$)	$\dot{E}_{2^*} + \dot{E}_3 - \dot{E}_4$	41215,94399
Turbine ($\dot{E}_{DT}$)	$\dot{E}_{5^*} + \dot{W}_{nett} + \dot{W}_C - \dot{E}_4$	257,2479203
wasted to environment($\dot{E}_L$)	$\dot{E}_{5^*}$	6382,170102

Table 14.Exergy values at each point in GTCP Model B

Point	$\dot{E}_{physics}$(kW)	$\dot{E}_{chemistry}$(kW)	$\dot{E}_{physics + chemistry}$(kW)
1	58.50198384	0	58.50198384
2	6307,931266	0	6307,931266
2'	6423,770014	0	6423,770014
3	25.26621652	79904,92072	79930,18694
4	16073,35973	1777,113186	17850,47291
5	6050,892224	1777,113186	7828.00541
5'	6622,513179	1777,113186	8399,626365

Table 15Exergy Loss Value for each sub-system in GTCP Model B

Sub- system		Exergy Loss (kW)
Compressor ($\dot{E}_{DC}$)	$\dot{W}_C - \dot{E}_{2^*}$	530,7239509
Combustion Chamber($\dot{E}_{DCC}$)	$\dot{E}_{2^*} + \dot{E}_3 - \dot{E}_4$	68503,48404
Turbine ($\dot{E}_{DT}$)	$\dot{E}_{5^*} + \dot{W}_{nett} + \dot{W}_C - \dot{E}_4$	170.2919478
wasted to environment($\dot{E}_L$)	$\dot{E}_{5^*}$	8399,626365

Table 16Exergy values at each point in GTCP Model C

Point	$\dot{E}_{physics}$(kW)	$\dot{E}_{chemistry}$(kW)	$\dot{E}_{physics + chemistry}$(kW)
1	58.50198384	0	58.50198384
2	7850,54626	0	7850,54626
2'	8059,358606	0	8059,358606
3	11.36574852	61103,7629	61115,12865
4	15815,79588	1749,204066	17564,99994
5	4713,962978	1749,204066	6463,167044
5'	5384,269777	1749,204066	7133,473843

Table 17 Exergy Loss Value for each sub-system in GTCP Model C

Sub- system		Exergy Loss (kW)
Compressor ($\dot{E}_{DC}$)	$\dot{W}_C - \dot{E}_{2^*}$	762.7217668
Combustion Chamber($\dot{E}_{DCC}$)	$\dot{E}_{2^*} + \dot{E}_3 - \dot{E}_4$	51609,48731
Turbine ($\dot{E}_{DT}$)	$\dot{E}_{5^*} + \dot{W}_{nett} + \dot{W}_C - \dot{E}_4$	216,3293246
wasted to environment($\dot{E}_L$)	$\dot{E}_{5^*}$	7133,473843

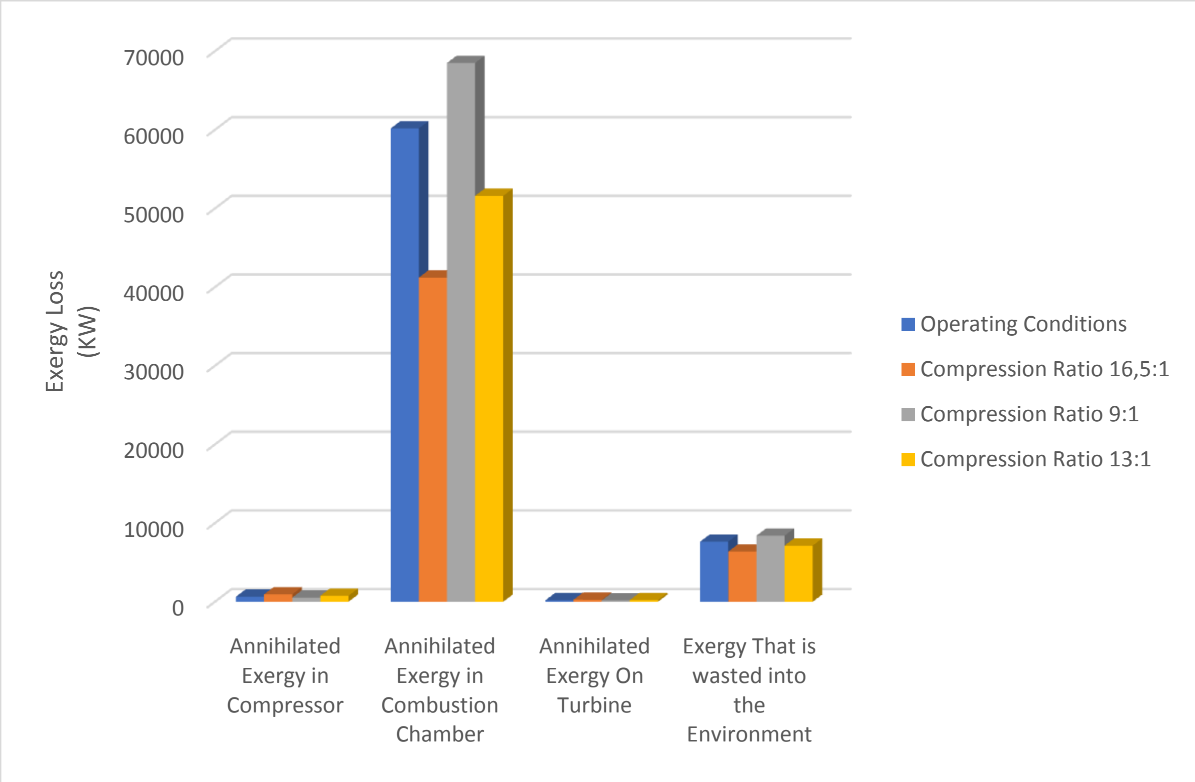

Figure 6 T-s Graph of Exergy Loss Rate for each model at GTCP PT PGN Pagardewa Station

Exergetic Sustainability Index (ESI) analysis on GTCP

From the results of the exergy analysis under operating conditions and various modification models to PT PGN's GTCP Pagardewa Station, an ESI analysis is carried out where the higher the ESI value, the smaller the reduction in resources, be it reductions in fuel use, man-power, and so on. In addition, environmental effect calculations will also be carried out, where the environmental effect factor shows the level of environmental damage caused by exergy losses in a system. The lower the value of the Environmental Effect Factor, the lower the level of environmental damage, but the greater the unit cost needed to achieve it.

Table 17Exergetic Sustainability Index (ESI) analysis on GTCP

Condition	$\dot{E}_{DTotal} + \dot{E}_{L}$	$\dot{E}_{in}$	τ	η_{ε}	γ_{Eef}	λ
Operation	68665,42915	113770,0146	0.603545	0.10752	5.61308	0.17815
Model A	48799,12866	97210,24924	0.501995	0.16492	3.91803	0.25522
Model B	77604,1263	120722,7256	0.642829	0.10435	6.16001	0.16233
C model	59722,01225	106059,1126	0.563101	0.11576	4.86418	0.20558

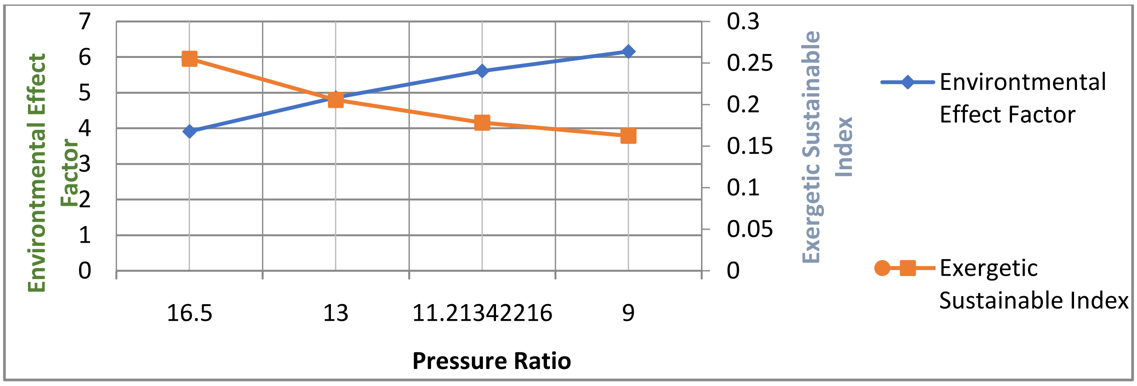

Figure 7. Relationship between ESI and Environmental Effect Factor with Compression Ratio at PT PGN Pagardewa's GTCP

The ESI value which is an indicator in the Quality of a process must also be related to the output power in terms of PT PGN Pagardewa's GTCP is Work Net($\dot{W}_{nett}$) to drive the compressor as a load to distribute gas to customers, where the relationship between ESI and Net Work is detailed in the table following.

Table 18Relationship between ESI and Net Work ($\dot{W}_{nett}$)

Condition	$\dot{W}_{nett}$ (kW)	λ
Operation	2404,391	0.17815
Model A	1360.67	0.25522
Model B	2782,483	0.16233
C model	2034,587	0.20558

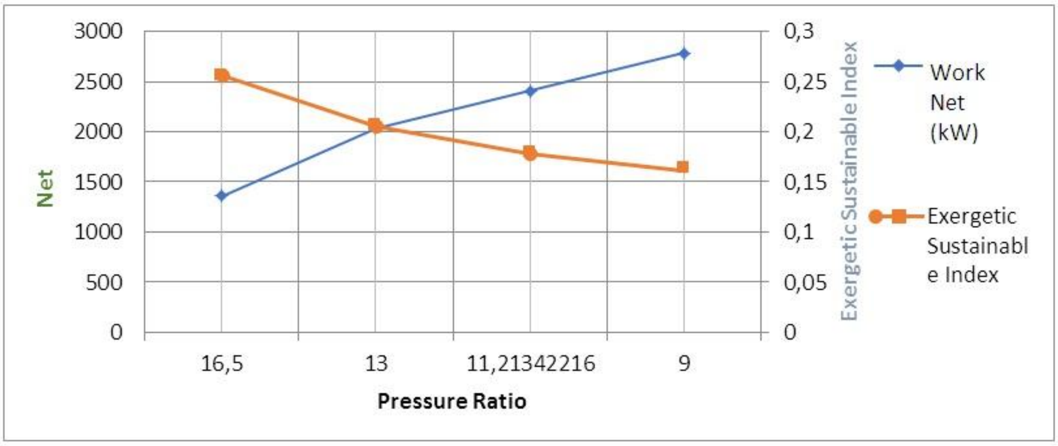

Figure 8. Relationship between ESI and Work Netwith Compression Ratio at PT PGN Pagardewa's GTCP

V. Discussion

Conclusion

Based on the results of processing operating condition data obtained from the control room of PT PGN Pagardewa station and modification of the compressor pressure ratio, it can be concluded:

1. The greater the compression ratio, the higher the ESI value which indicates that the better the quality of the ongoing process.
2. The greater the compression ratio, the lower the value of the environmental effect factor which indicates that the less environmental damage occurs due to exergy losses in the system.
3. With the ESI analysis of the modified modeling of the compression ratio parameter, the optimal pressure ratio value which shows the ESI value, Environment Effect Factor and optimal Clean Work is model C with a pressure ratio of 13:1.
4. The results of the exergy analysis show that the largest exergy losses in each model occur in the combustion process in the combustion chamber followed by exergy losses to the environment.
5. The exhaust gas in GTCP which is lost to the environment through the chimney still has a large enough exergy value to be reused either as a pre-heater before entering the combustion chamber, you can also use a WHRB (Waste Heat Recovery Boiler) or HRSG (Heat Recovery Steam) Generator.

Suggestion

To get more accurate results in calculations using operating conditions, accurate data is needed so that calibration of the equipment used in measuring operating conditions is required.

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