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MODELLING OF GAS TURBINE AND GAS TURBINE EXHAUST AND ITS UTILISATION AS COMBINED CYCLE IN UTILITY SYSTEM

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ABSTRACT: Due to increasing demand for energy and unstable and continuous increase in cost of fossil fuel, attention has been shifted from the traditional power plants to energy generation using gas turbines because of the availability and low cost of its fuel. This led to the need for proper understanding of the gas turbine performance and how the energy from gas turbine can be optimally utilized. Many authors have worked on the modeling of gas turbine performance and optimal utilization of its energy output but they rarely consider different gas turbine configurations and how the configurations can be integrated into utility system. This work will therefore focus on modeling gas turbine and gas turbine exhaust using Aspen HYSYS, taking into account different possible configurations. The objective is to model different configurations of gas turbine maximizing the energy output usage (both power and heat) in a utility system using combined cycle. The results obtained shows that different configuration of gas turbine gives better result compared to simple gas turbine. The improvement is so prevalent most especially if it is integrated with utility system by generating high pressure steam in heat recovery steam generator to be used in steam turbine in form of combined cycle. Better performance of the gas turbine in combined cycle is obtained if multiple steam pressure level is generated in the heat recovery steam generator.

Keywords: Gas Turbine, Configuration, Modelling, Exhaust Energy, Brayton Cycle, Combined Cycle, Utility System

INTRODUCTION

Gas turbine is a heat engine that converts the heat obtained from fuel by the use of compressed hot gas as a working fluid, into mechanical output power either as torque through a rotating shaft or as jet power in the form of velocity through an exhaust nozzle [8]. Gas turbine can be operated in one of these various ways according to their purpose which include the operation for power generation only and for co-generation where it is operated to generate heat and power [5]. For its operation for power generation only, much heat is wasted since the turbine exhaust outlet of the gas turbine is always at high temperature of about 450 – 600^{o}C [13]. In this case, it will be discovered that the efficiency of the turbine is low compared to other operations [9]. Utilising the gas turbine exhaust will reduce the heat wasted to the environment which is currently supplying 10% heat and electricity in Europe [16]. For this purpose, there is therefore the need to model the gas turbine exhaust to determine the amount of heat to be obtained from the exhaust and how the exhaust heat can be adequately utilised.

The operation of a gas turbine is described by Brayton cycle which is a cycle where both compression and expansion processes take place in the same rotating machinery [11]. The cycle is usually presented in form of open cycle as shown in Figure 1. Brayton cycle is evaluated classically using thermodynamic parameters such as temperature, pressure, specific heat, adiabatic compression exponents and efficiency factors where standard conditions are conveniently used for some factors such as 15 ^{o}C for ambient temperature, 1.01325 bar for atmospheric pressure and 60% for relative humidity established by International Standard Organisation (ISO) [3].

In Brayton cycle, air enters the compression chamber and is compressed at constant entropy, fuel is added to it in the combustion chamber and burnt at constant pressure, the hot gases then expand in the turbine at constant entropy and the expansion drives the blade while the remaining heat is rejected to the environment at constant pressure. It can be presented on either a temperature-entropy (T-S) diagram or pressure-volume (P-V) diagram as shown in Figures 2 and 3 respectively.

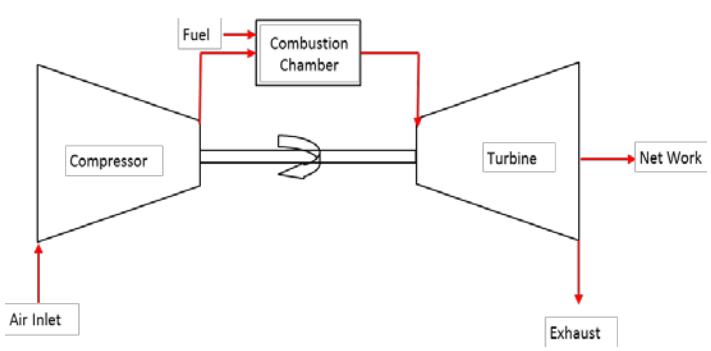

Figure 1: Schematic of a Simple Gas Turbine

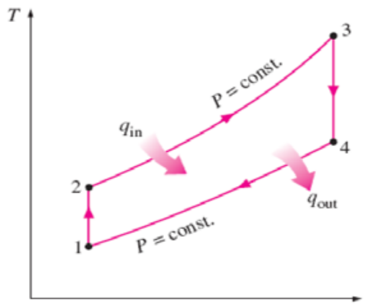

Figure 2: Representation of Brayton Cycle on T-S Diagram

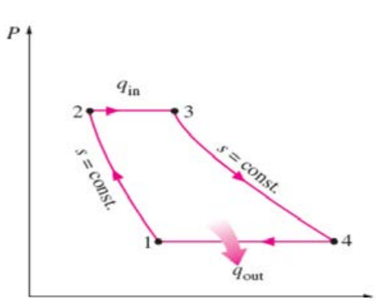

Figure 3: Representation of Brayton Cycle on P-V Diagram

Gas turbine is made up of three major components described as primary modules [7]. The major components are compressors, combustion chamber and the turbine. Compressors are parts of gas turbine that takes in air from the environment and compress it so as to supply it at high pressure to the combustion chamber [7]. The compressor is connected to the turbine by one or two shafts so that the turbine can drive it. About 50 to 60% of the power from the turbine is used for operating the compressor [3]. The combustion chamber is where the air from the compressor is mixed with the fuel supplied to the chamber which is in form of a direct fired heater. 25 to 40% of the air entering the combustion chamber at a velocity of about 122 to 182.88 m/s is used for the combustion process; the remaining is used for cooling and for dilution purpose [7]. For normal operation, the air to fuel ratio is between 45:1 and 130:1 and the compressed air is between a temperature of 200 ^{o}C and 550 ^{o}C due to the compression work done on it which is increased to about 1800 – 2000 ^{o}C by the combustion process. It is then reduced to between 850 ^{o}C and 1700 ^{o}C as the highest allowable temperature by either the excess air (about 60% to 75% inflow air) not used for combustion process, and/or steam injection. Although the amounts can be calculated from material and energy balances, the amount of excess air is a degree of freedom that cannot be established by thermodynamic relation. Consequently, the starting point for the model is to use the published data for full load performance of commercial gas turbines which mostly depend on the turbine inlet temperature as given by [12].

The combustion process is achieved by stoichiometric burning of carbon or hydrogen in oxygen with the release of heat [7]. The turbine is a component that drives the compressor and also provides power for use. The hot air enters the turbine at the temperature of between 850 ^{o}C and 1700 ^{o}C with the speed increasing to around 762 m/s in parts of the turbine [7]. The efficiency of the turbine depends highly on the inlet temperature. It has polytrophic efficiency of between 85% and 95% [6]. The temperature of the exhaust coming out from the gas turbine is between 360 ^{o}C and 610 ^{o}C [7].

There are various configurations of gas turbine all with the intention of improving the performance of the gas turbine. Some common configurations are inlet air cooling, steam injection, reheating, regeneration and intercooling [15, 20,17].

Utility system is an important part of most processes. It provides heating, cooling and also power needed by the process. A typical utility system and its interaction with process is presented schematically in Figure 5. In large processes, the cost of fuel and power is very significant which then calls for the need for proper management of the utility system in order to save energy [19]. There is therefore the need to model the basic elements of the system among which is a gas turbine.

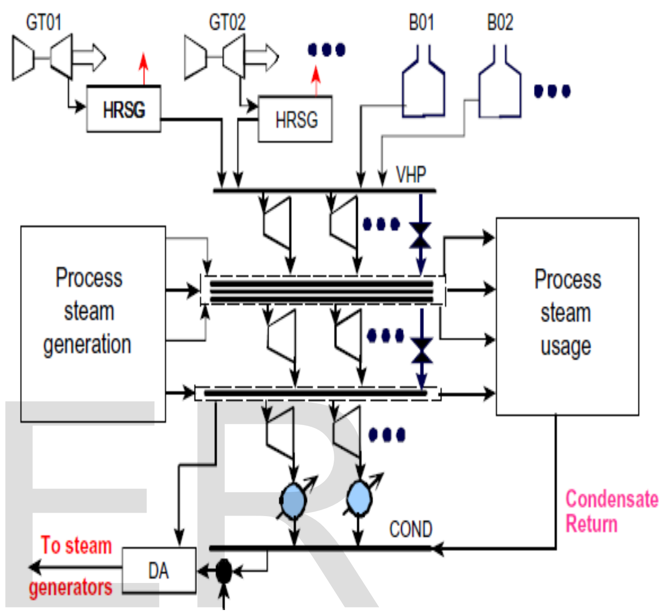

Figure 4: Utility System and its Interaction with a Process [19].

The challenge of constantly enhancing gas turbine performance had drawn a lot of attentions thereby leading to a lot of research. Many works have been done on the modelling of gas turbine with the intention of determining the performance of the gas turbine, integrating the heat of the exhaust into a process and/or using it for some heating purposes. The works are though still useful in predicting the behaviour of gas turbine and gas turbine exhaust, they neglect some important factors that have to do with the configuration of the gas turbine. The work of [17] estimated the performance of gas turbine varying the operating conditions such as the fuel/air ratio, inlet and outlet temperatures and the compressor and turbine efficiencies using MATLAB. Verbanov, Doyle and Smith (2004) gave good model equations for predicting the exhaust temperature of gas turbine which can be used taking into account different configurations so as to give the general behaviour of the gas turbine exhaust. [18] and [2] discovered that by injecting steam into the compressed air, the flow rate of the fluid is increased; therefore the power output from the turbine is increased. They observed that injection of low pressure steam into the combustion chamber of the gas turbine results in low power consumption by the compressor thereby increasing the overall efficiency. Horlock et al (2003) observed that the highest performance of a gas turbine is achieved when the turbine inlet temperature is less than the stoichiometric combustion temperature which gives a limit on the highest temperature required for optimum performance of gas turbine. Intercooling in a multistage compressor gas turbine was found to be more effective when used in a cycle with heat recovery [21]. Calderan et al (1991) discovered that if a process needs process heat to produce high pressure steam, gas turbine is preferred compared to heat engines because open cycle gas turbine rejects high grade heat to the environment compared to the heat rejected by steam turbine to the condenser. The waste heat rejected to the environment can then be used to raise the efficiency to more than 55% [14].

In integrating gas turbine exhaust into utility system, one of the problems is the choice of gas turbine to be used. The choice is therefore dependent on which integration scheme is to be used and also a trade-off between energy and capital [13]. The model of gas turbine where power and heat are considered must determine both the equipment conditions and the condition of the turbine exhaust gases such as temperature and flow rate which will allow us determine the amount of steam to be generated by a heat recovery steam generator (HRSG) [1,19]. The flow rate and the temperature of the gas turbine exhaust are dependent on the amount of fuel and air provided. This work will focus basically on modelling of gas turbine and gas turbine exhaust using Aspen HYSYS and how it can be integrated into utility system in form of combined cycle taking into account the maximum power output from it.

RESEARCH PROGRAMME AND METHODOLOGY

There are different ways of modelling gas turbine and gas turbine exhaust. The accuracy of the results obtained and the accurate prediction of the gas turbine exhaust behaviour depends largely on the method adopted, the information available for using the model and the input data.

In this work, Aspen HYSYS process simulator will be used for modelling the behaviour of gas turbine and gas turbine exhaust under different operating conditions as it is a commercial software found suitable for a variety of steady state modelling application. In this simulation, the following input are provided

- The flow rates, compositions and operating conditions of some streams.
- Inlet air with composition of 21% oxygen and 79% nitrogen and its flow to the compressor.
- The operating conditions such as inlet temperature of about 15 ^{o}C, pressure of 1.01325 bar, polytrophic efficiencies and thermal efficiencies of the various units used in the model building.
- Compressor pressure ratio, fuel to air ratio and percentage of excess air.
- The heat and/or work input where applicable.

When all these are provided, the software can then calculate the flow rate, temperature and composition as well as the heat and work of the outlet streams. There are different fluid packages for different models depending on the correlation involved. For the use with Aspen HYSYS, the equations of state are recommended which Peng-Robinson is found to be more suitable.

Some of the above inputs can be varied obtaining the exhaust conditions for each variation (sensitivity analysis). The following sensitivity analysis will be considered;

- The compressor can be modelled either as a single compressor or in stages to allow for intercooling between the compressors.
- The turbine can be modelled either as a single stage or in stages so as to allow for reheating of the fluid between the stages.
- The compressor inlet air temperature will also be varied to model for inlet air cooling.
- Configuration and integration such as inlet air cooling, reheating, steam injection and regeneration will also be considered and various methods/devices will be integrated with the gas turbine exhaust in order to evaluate the potential use of gas turbine exhaust.

Initial Model Formulation for Validation Purpose

Performance of gas turbine and gas turbine exhausts depend on a number of factors. The modelling of gas turbine and gas turbine exhaust will therefore have many dependent variables. Some of these dependent variables will be fixed for simplicity. The initial model is simulated using a known gas turbine (V94.2 gas turbine) with power rating of 165 MW. The various models for each of the components can be made separately and the overall model for the complete gas turbine simulated combining the various components. The specifications provided for the gas turbine in consideration are pressure ratio of 11.7:1, natural gas is the fuel used, exhaust gas flow of 131.5 kg/s, fuel pressure is considered same as air pressure to avoid back pressure and fuel temperature of 15 ^{o}C. The flow diagram for the simulation of the model is shown on Figure 5

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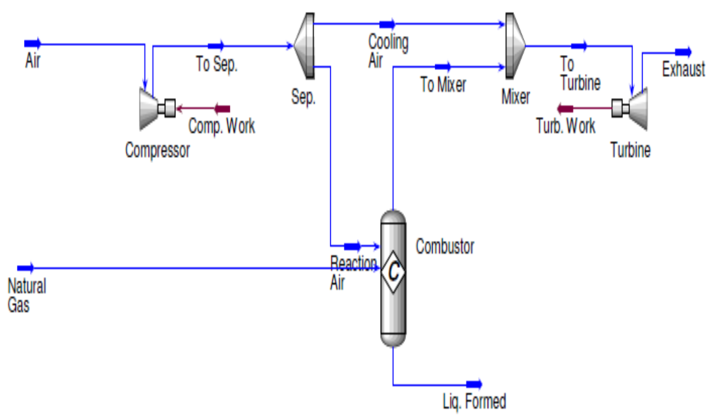

Figure 5: Model Diagram for a Gas Turbine from HYSYS

In this model, the combustion temperature is fixed and regulated by passing certain excess air to the combustion chamber so as to achieve complete combustion of the fuel and consequently minimise NO_x formation. The combustion temperature is therefore intended to be maintained at about 1500 ^oC. The model for the gas turbine is validated with the data obtained from manufacturer of the gas turbine which can then be used for modelling the different configurations. The validation is shown in Table 1.

Table 1: Model Result and Manufacturer's Data for Validation Purpose

	ISO Power Rating (MW)	Pressure Ratio	Exhaust Mass Flow (kg/s)	Exhaust Temperature (^oC)	Net Efficiency (%)
Man. Data	165.00	11.70	526.00	539.00	34.50
Model	165.60	11.70	526.00	539.50	35.17
Error (%)	0.364	0.00	0.00	0.093	1.942

Modelling of Different Gas Turbine Configurations

V92 gas turbine can then be used for the different configurations which are given below.

Inlet Air Cooling: This is where the inlet air entering the compressor is cooled either by evaporative cooling or by absorption chiller. This increases the density of air entering the compressor and consequently increasing the mass flow rate of the air or reducing compressor work. For this study, the ambient air is cooled to different temperatures keeping the mass flow constant. The configuration is modelled between the ambient temperature of 15 ^oC and -15 ^oC with intervals of 5 ^oC each.

Inter-cooling: This is a type of configuration that can be used in gas turbines with multi stage compression. This will improve efficiency of the gas turbine as described in the literature above. In this configuration, the air leaving the compressor is cooled down before entering the next compressor. In this model, different inter-cooling temperature of between 20 ^oC and 226 ^oC are used to bring the temperature to the minimum which is the ambient temperature and the effect of the cooling on the gas turbine exhaust and the cycle efficiency are observed for each cooling temperature. The above temperatures are selected so that the last intercooling temperature should give the low pressure compressor outlet temperature equal to the ambient temperature.

Reheating: This type of configuration is used for gas turbines with multi stage turbines. In this configuration, the gas leaving the high pressure turbine is reheated before entering the low pressure turbine. This is done by injecting fuel in between the two turbines for a combustion process generating heat. In this model, two combustors are used with one for the main combustion process and the other placed between the high and low pressure turbines for reheating purpose. The fuel used in reheating is estimated using a certain percentage of the fuel used in the combustion chamber. In this case, different fuel flow rates are used between 3% and 21% which is the maximum fuel flow rate to give the maximum exhaust temperature. This values selected is as a result of that the exhaust temperature is not intended to get too high considering material of construction as reheating increases the exhaust temperature.

Regeneration: This type of configuration is applied where the exhaust temperature is higher than the temperature entering the combustion chamber. The air leaving the compressor and entering the combustion chamber can be preheated using the exhaust gas so as to reduce the fuel consumption. In this model, the air is preheated with temperature increase of between 20 ^oC and 120 ^oC. The maximum temperature of 120 ^oC used here is the maximum heat the turbine exhaust can provide to maintain its temperature above the compressor exit temperature.

Steam Injection: In this configuration, a certain amount of steam is injected into the combustion chamber so as to increase the flow rate of gas into the turbine and also increase efficiency. In this model, steam to air percentage of between 10% and 90% is used as the ratio is to be less than one.

MODEL RESULTS AND DISCUSSIONS

All the configurations described above are modelled between certain ranges of either temperatures or percentages of some defined variables. The results are presented in form of graphs which shows clearly the relationship between the variables considered for changing conditions. Though there are so many variables that can be obtained from the simulation of the gas turbine models, the objective of this work is to determine the heat content of the exhaust while maximising power output and the methods of integrating it with utility system. Therefore, the only variables considered and presented here are the exhaust temperatures, the net-work output and the efficiency; which take into account the net work done by the gas turbine. The essence of including the efficiency in the result is to avoid the turbine work being compensated by consideration of the turbine exhaust heat content. The heat flow of the exhaust is kept constant for most of the configurations which can easily be used with the exhaust temperatures for easy calculations of the exhaust heat content.

Inlet Air Cooling: The effects of inlet air cooling on the exhaust temperatures and cycle efficiency of the gas turbine are shown in Figures 6 and 7.

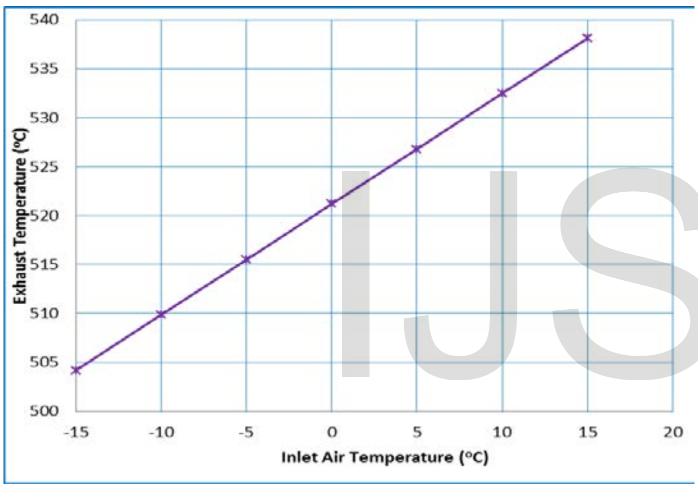

Figure 6: Effect of Inlet Air Cooling on Exhaust Temperature

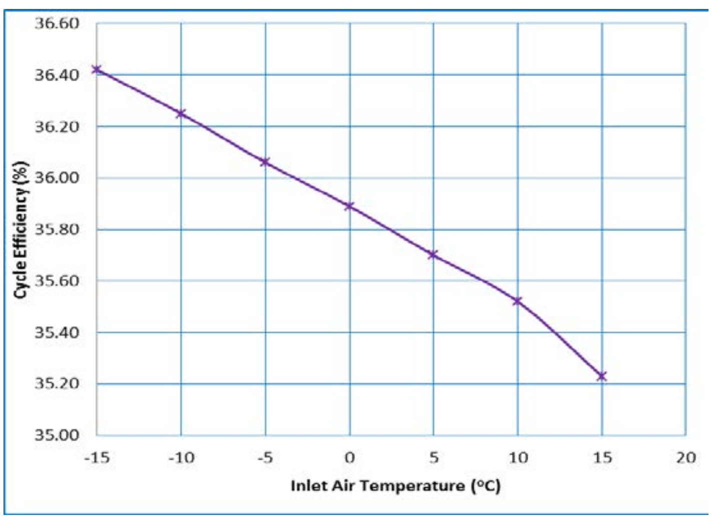

Figure 7: Effect of Inlet Air Cooling on Cycle Efficiency

From the result, it is observed that there is a decrease in the exhaust temperature with lower air intake temperatures meanwhile the efficiency and consequently the power output are found to be lower at ISO condition without inlet air cooling than with inlet air cooling. The power consumption by absorption chiller is about 40 kW for every MW of gas turbine [10]. For this configuration, there is a trade-off between the exhaust temperatures which is intended to be integrated into the utility system and the power output of the gas turbine.

Inter-cooling: The effects of inter-cooling on the exhaust temperature and cycle efficiency are presented in Figures 8 and 9.

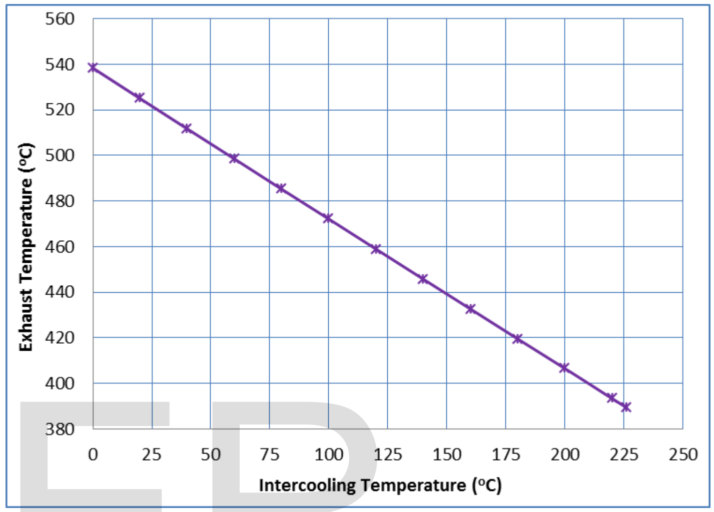

Figure 8: Effect of Inter-cooling on Exhaust Temperature

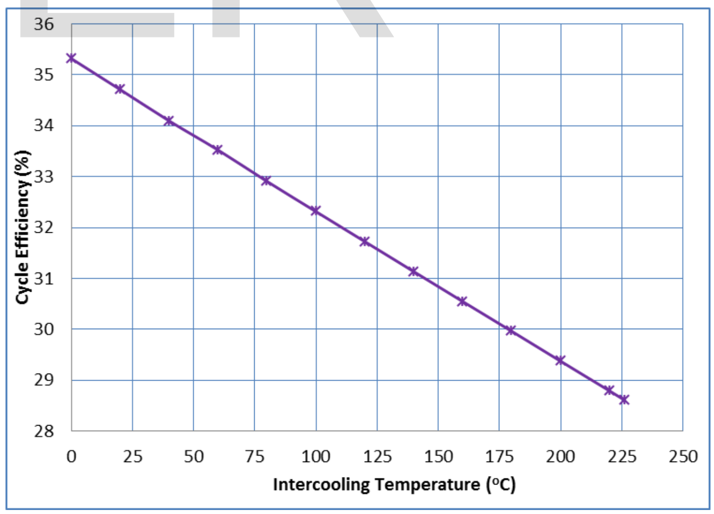

Figure 9: Effect of Inter-cooling on Cycle Efficiency

From the graphs, it can be seen that both the exhaust temperature and the cycle efficiency decrease with air intercooled between the compressors compared to ISO rated gas turbine without intercooling. The advantage of intercooling is that it lowers the work input into the high pressure compressor. Since the temperature outlet of the high pressure compressor will be lower for an intercooled gas turbine compared to ISO rated gas turbine without intercooling, it then opens up an opportunity for regeneration by enhancing high driving force for heat transfer. Therefore intercooling without regeneration and/or reheating will instead lower the efficiency and power output of the gas turbine rather than increasing [1]. There is therefore no benefit in gas turbine configuration that considers only intercooling as explained in the literature. There is need to consider the configuration of intercooling in conjunction with other configurations.

Reheating: The effect of reheating on gas turbine exhaust temperature and the cycle efficiency are presented in Figures 10 and 11

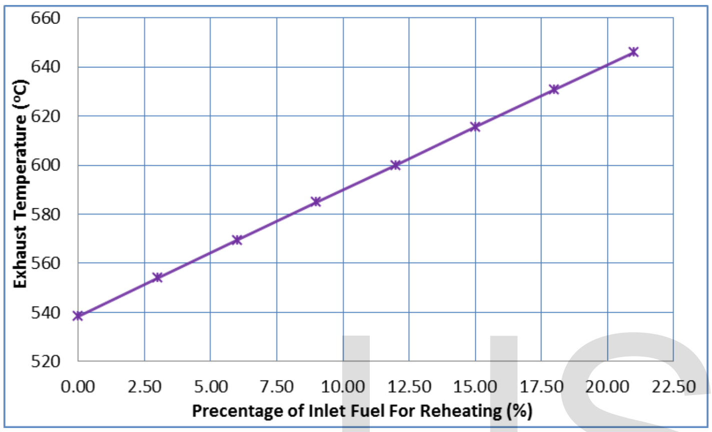

Figure 10: Effect of Reheating on Exhaust Temperature

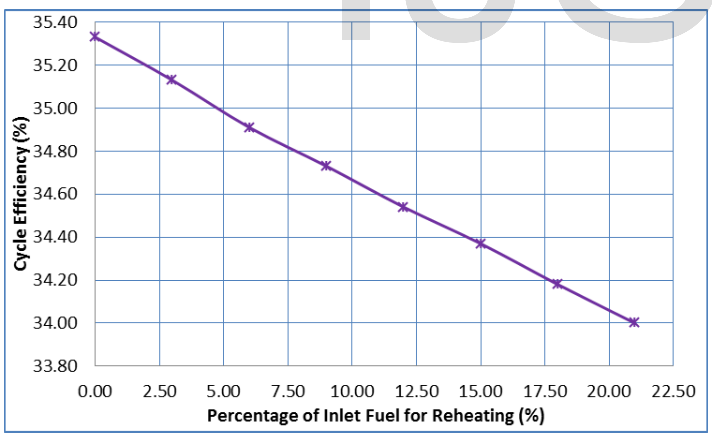

Figure 11: Effect of Reheating on Cycle Efficiency

From the result, the exhaust temperature of the gas turbine is observed to be higher in gas turbine with reheat compared to ISO rated gas turbine without reheat while the cycle efficiency is lower for gas turbine with reheat compared to that without reheat. The cycle efficiency of the gas turbine is reduced because of the additional fuel consumption used in the regenerator. Despite the decrease in the efficiency of the gas turbine, regeneration leads to additional power generation. This can therefore be used where the main concern is the power output. Another benefit of this type of configuration is the high temperature of the exhaust which in this case can be integrated into utility system to increase power generation which may compensate for the additional power consumption.

Regeneration: The effect of regeneration on gas turbine exhaust temperature and the cycle efficiency are presented in Figures 12 and 13.

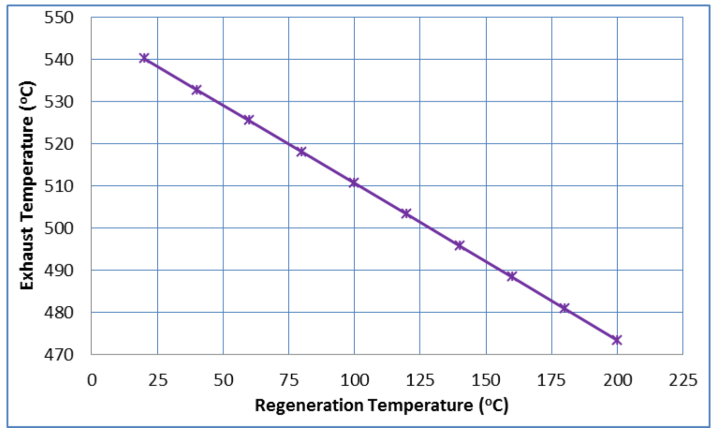

Figure 12: Effect of Regeneration on Exhaust Temperature

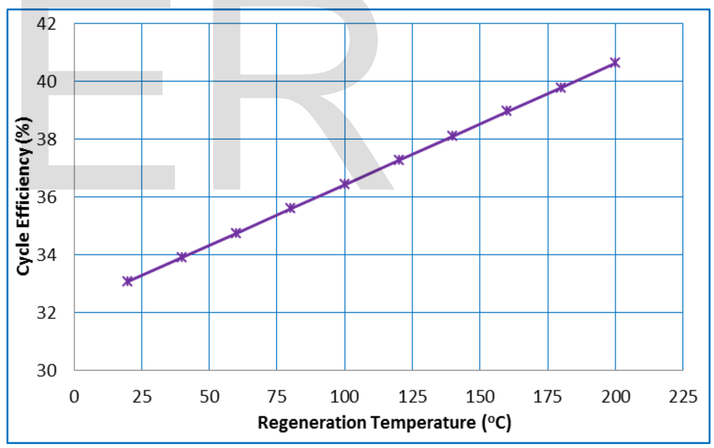

Figure 13: Effect of Regeneration on Cycle Efficiency

The results above show that the exhaust temperature is lower for a gas turbine with regenerator compared to ISO rated gas turbine without regenerator while the cycle efficiency is higher for a gas turbine with regenerator than that without regenerator. The reduction in the temperature of the exhaust is due to some heat from the exhaust being used for the reheating purpose which leads to increase in the cycle efficiency. Regeneration though relevant, is limited by compressor outlet temperature. Regeneration is only possible if the turbine outlet temperature is higher than the compressor outlet temperature so as to provide the driving force for heat transfer. This therefore calls for the need for intercooling within the compressor so as to provide the minimum possible temperature at the exit of the compressor. Regeneration will therefore be better utilised with

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intercooling.

Steam Injection: The model result is plotted on Figures 14 and 15 to demonstrate the effect of steam injection on gas turbine exhaust temperature and its cycle efficiency.

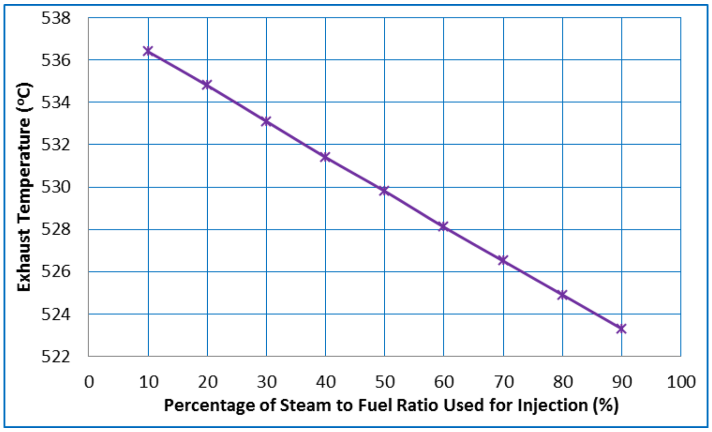

Figure 14: Effect of Steam Injection on Exhaust Temperature

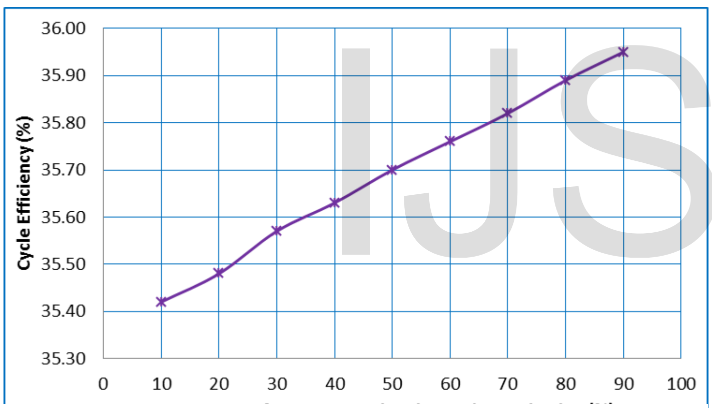

Figure 15: Effect of Steam Injection on Cycle Efficiency

With steam injection, the result shows that the exhaust temperature is lower for a gas turbine with steam injection compared to ISO rated gas turbine without steam injection while the cycle efficiency is higher for a gas turbine with steam injection compared to the one without steam injection. The decrease in the exhaust temperature of the gas turbine is because the steam injected into the combustion chamber reduces the combustion temperature. On the other hand, the cycle efficiency increases due to increase in the mass flow of gas to the turbine as a result of the steam injected into the system compensating for the reduction in turbine inlet temperature thereby increasing the net power output. The steam to be used here can be obtained from the heat recovery team generator (HRSG) using the exhaust gas from the gas turbine.

Gas Turbine Exhaust Integration with Utility System

Gas turbine exhaust contains a lot of energy after generating power from the turbine of the gas turbine. This energy is referred here, to as waste heat since the energy will be wasted to the environment if not utilised. It this research, the heat will be used to generate high pressure steam in heat recovery steam generator (HRSG) which can be used in steam turbine to generate more power. In this case, the steam will be generated at different pressure levels which can then be compared so as to determine which pressure level gives the best performance. For purpose of comparison, a condensing turbine will be modelled here with heat recovery steam generator. The combined cycle efficiency to be calculated here will justify which configuration gives better performance of the gas turbine if the exhaust of the gas turbine is to be utilised. The Aspen HYSYS flow diagram for the combined cycle turbine for one steam pressure and two steam pressure levels is as shown in Figure 16 and 17 respectively.

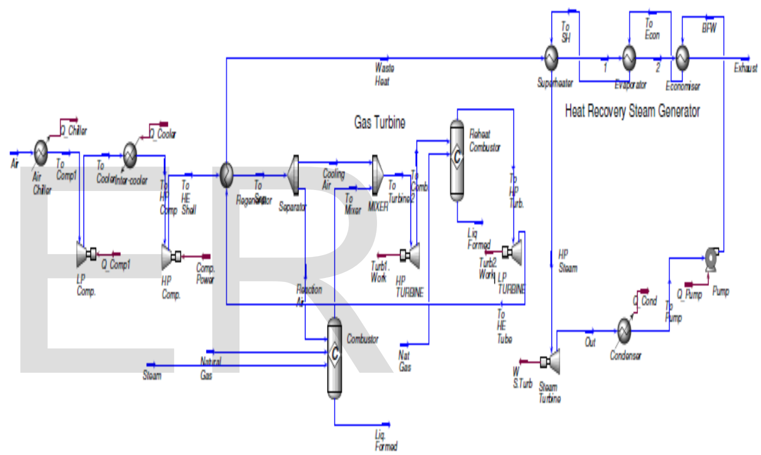

Figure 16: HYSYS Model Diagram for one Steam Pressure Level Combined Cycle Turbine

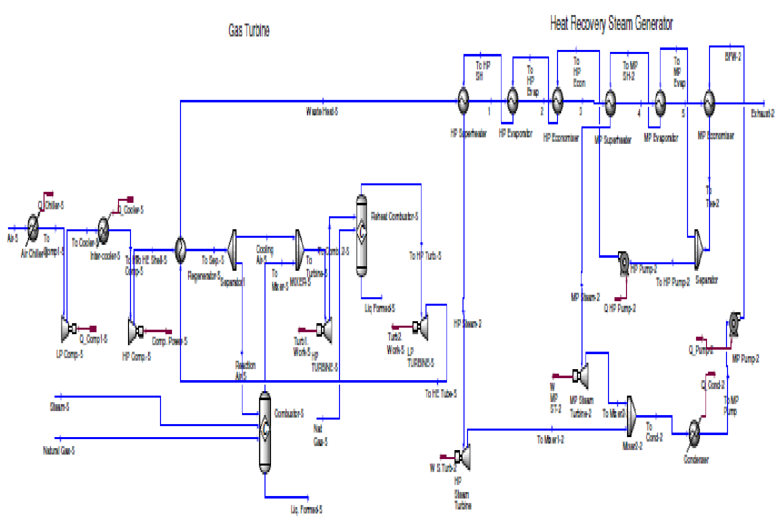

Figure 17: HYSYS Model Diagram for 2 Steam Pressure Levels Combined Cycle Turbine

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The various pressure levels considered here and their superheat temperatures are as follows

i. 50 bar superheated to 300^{o}C
ii. 40 bar superheated to 280^{o}C
iii. 30 bar superheated to 260^{o}C
iv. Two Pressure levels (50 bar at 300 ^{o}C and 20 bar at 240 ^{o}C)

Since we are only interested in the net power output and the combined cycle efficiencies, the results to be presented here are those of the net power output and the combined cycle efficiencies. In all the cases considered here, the exhaust temperatures at the exit of the heat recovery steam generator is below 260 ^{o}C which shows that the sensible heat in the exhaust of the gas turbine has been utilised. The results obtained from the models are as presented in Table 2.

Table 2: Combined Cycle Model Results for Various Configurations of a Gas Turbine

Configuration	Steam Pres.(Bar) / Property	50			40			30			Two Pressure Levels (50 and 20)		
INLET AIR COOLING	Inlet Air Temp. (^{o}C)	-15	0	15	-15	0	15	-15	0	15	-15	0	15
	Gas Turb. Work (MW)	171.50	169.00	168.10	171.50	169.00	168.10	171.50	169.00	168.10	171.50	169.00	168.10
	Steam T. Work (MW)	34.48	36.92	39.37	34.46	36.68	38.99	33.8	35.92	38.10	39.26	41.57	43.91
	Net Work (MW)	205.98	205.92	207.47	205.86	205.68	207.09	205.30	204.92	206.2	210.76	210.57	212.01
	Comb. Cycle Eff. (%)	43.74	43.73	44.06	43.72	43.68	43.64	43.60	43.51	43.79	44.76	44.72	45.02
INTER COOLING	Inter Cool. Temp (^{o}C)	20	100	220	20	100	220	20	100	220	20	100	220
	Gas Turb. Work (MW)	169.40	185.53	201.81	169.40	185.53	201.81	169.40	185.53	201.81	169.40	185.53	201.80
	Steam T. Work (MW)	39.47	40.12	40.74	39.12	39.73	40.19	38.20	38.79	39.38	44.02	44.69	45.34
	Net Work (MW)	208.87	225.65	242.55	208.52	225.26	242.00	207.60	224.32	241.19	213.42	230.22	247.15
	Comb. Cycle Eff. (%)	40.02	41.36	38.33	42.94	41.29	38.24	42.76	41.12	38.11	43.96	42.20	39.34
REHEATING	Perc. Fuel for Reh	3%	12%	21%	3%	12%	21%	3%	12%	21%	3%	12%	21%
	Gas Turb. Work (MW)	170.50	182.50	194.70	170.50	182.50	194.70	170.50	182.50	194.70	170.50	182.50	194.70
	Steam T. Work (MW)	41.73	48.69	55.72	41.23	47.83	54.53	40.15	46.03	52.52	46.16	52.62	59.52
	Net Work (MW)	212.23	231.19	250.42	211.73	230.33	249.23	210.65	228.53	247.22	216.66	235.12	254.22
	Comb. Cycle Eff. (%)	43.76	43.75	43.77	43.66	42.55	39.79	43.43	42.27	39.47	44.67	43.30	40.59
RE-GENERATION	Reg. Temp. (^{o}C)	20	60	120	20	60	120	20	60	120	20	60	120
	Gas Turb. Work (MW)	169.00	182.80	192.00	169.00	182.80	192.00	169.00	182.80	192.00	169.00	182.00	192.00
	Steam T. Work (MW)	38.78	35.53	33.34	38.40	35.35	33.29	37.57	34.72	32.79	43.35	40.24	38.17
	Net Work (MW)	207.78	218.33	225.34	207.40	218.15	225.29	206.57	217.52	224.79	212.35	223.04	230.17
	Comb. Cycle Eff. (%)	44.12	46.36	47.85	44.04	46.33	47.84	43.87	46.19	47.74	45.09	47.36	48.88
STEAM INJECTION	Perc. Steam to Fuel	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
	Gas Turb. Work (MW)	166.80	168.10	169.30	166.80	168.10	169.30	166.80	168.10	169.30	166.80	168.10	169.30
	Steam T. Work (MW)	39.26	38.82	38.38	38.89	38.51	38.13	38.08	37.69	37.35	43.83	43.51	43.18
	Net Work (MW)	206.06	206.92	207.68	205.69	206.61	207.43	204.88	205.79	206.65	210.63	211.61	212.48
	Comb. Cycle Eff. (%)	43.76	43.94	44.10	43.68	43.87	44.05	43.49	43.70	43.88	44.73	44.94	45.12

From the results, it can be observed that there is an improvement in the efficiency of the combined cycle gas turbines for all the configurations when the exhaust heat of the gas turbine is utilised. The improvement depends on the configuration of the gas turbine. As explained in the literature, the efficiency of a gas turbine can get to as high as 70% depending on how the energy from the gas turbine is considered for the calculation of the efficiency.

For all the configurations considered above, it can be observed that simple configuration with regeneration gives better efficiency compared to all other configurations. For power output, it can be observed that reheating gives the highest power output compared to all other configuration but the efficiency is found to reduce because of the additional power consumption for the reheating purpose. In all the configurations, it can be observed that the combined cycle with two pressure levels of steam gives better efficiency and better power output compared to one steam pressure level. This shows that there is much benefit in utilising the exhaust of a gas turbine which gives optimum utilisation.

CONCLUSION

This study was aimed at modelling different gas turbine configurations so as to analyse their effect on the energy content of the gas turbine exhaust while maximising the power output of the turbine. Aspen HYSYS was used for the model where different gas turbine configurations as explained in the methodology were examined. From the model results obtained, the following conclusions were drawn;

Inlet air cooling has positive impact on the power output of a gas turbine but negative impact on the exhaust of the gas turbine. Integrating both the gas turbine and its exhaust with utility system shows that the combined cycle efficiency is improved with inlet air cooling.

Gas turbine with intercooling between two compressors has negative impact on both the power output and the exhaust energy if no additional fuel is used to compensate for the cooling. With additional fuel to compensate for the cooling shows an improvement on the power output but the efficiency drops for every increase in intercooling temperature.

Reheating has positive impact on both the power output and the exhaust heat but the efficiency drops due to increase in fuel used for reheating. There is also no benefit in term of the efficiency of the gas turbine when utilising the exhaust heat of the turbine.

Regeneration has positive impact on both the power output and the efficiency of the gas turbine but negative impact on the turbine exhaust heat. Regeneration is limited by compressor outlet temperature, so it is best used with intercooling which gives improved power output. It also has positive impact on both the power output and the efficiency when used in combined cycle.

Steam injection increases the mass flow of the gas at the turbine section of the gas turbine thereby increasing the power output of the gas turbine even with low combustion temperature. Though it has negative impact on the exhaust heat, the gas turbine efficiency when used in a combined cycle gives better results.

Heat recovery steam generator with multiple steam levels gives better utilisation of the exhaust heat compared to the one with only one steam level.

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