Journal of Applied Engineering and Technological Science
Vol 4(2) 2023: 618-632

THE IMPACT OF COMPRESSOR DEGRADATION ON THE OPTIMIZED FLEET COMPOSITIONS, OPTIMIZED THERMAL EFFICIENCIES, AND THE OPERATIONS & MAINTENANCE COST OF FLEETS OF A REHEAT ENGINE RUNNING ON ASSOCIATED GAS FUEL

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Received : 28 September 2022, Revised: 08 January 2023, Accepted : 14 January 2023
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ABSTRACT
Associated gas is a viable source of fuel for industrial gas turbines, and this is due to its high methane content. This study presents a useful model and methodology to be employed for the optimization of gas turbine fleet composition, thermal efficiency and for the assessment of the impact of compressor degradation on the aforementioned. This methodology serves as a guide to investors and governments for the economic use of this fuel. Turbomatch was used in modeling a 296 mega watt reheat gas turbine engine. The study was done using clean engines and degraded engines of three variations – the optimistic, medium, and pessimistic. Genetic algorithm tool in Matlab was used in optimizing the fleet compositions and thermal efficiencies. The effect of compressor degradation on the optimized fleet composition and thermal efficiencies were also ascertained. Results show that the clean, optimistic, medium, and pessimistic degraded fleets have total operations and maintenance costs to be 1.224, 1.242, 1.265, and 1.297 billion US dollars respectively. Engine degradation resulted to 1.4%, 3.3%, and 5.9% increase in the operations and maintenance costs of the optimistic, medium, and pessimistic degraded fleets respectively.

Keywords : *Energy, Power, Economic Return, Turbomatch, Gas Turbine.*

1. Introduction

Associated gas is a huge source of energy; this is due to its high methane content. Instead of flaring of this energy resource, it could be harnessed as fuel for power and energy generation using gas turbines.Several works have been done on the utilization of associated gas for energy and revenue generation, Zolfaghari et al., (2017) Also, researches on the influence of degradation on the performance parameters of gas turbines have been done(Kurz and Brun, 2009; Allison, 2014; Anosike et al.,2016). Allison et al., (2013) studied the influence of gas turbine degradation on the performance of gas turbines.

Obhuo et. Al., (2020) have worked on the influence of degradation on the economic utilization of associated gas and on the divestment time of redundant units of engines. A lot has also been done in the field of gas turbine maintenance. Carazas et al., (2011) researched availability analysis of gas turbines used in power plants. This author adopted a methodology based on system reliability concepts like functional tree development, reliability and maintainability assessment using a database of historical failure records, and implementation of failure mode and effects assessment to estimate critical components for enhancement of the reliability of the system. 99% and 96% are the results for the reliability assessment for the two turbines, which is an indication of the variation in their systems installation and operation. Tahan et al., (2017) worked on 'performance-based health monitoring, diagnostics and prognostics for condition-based maintenance of gas turbines: a review'. This author reviewed gas turbine engine monitoring approaches. He also identified the causes of engine degradation to have a timely identification of fault. The outcome of the author's research would provide professionals, researchers, and decision-makers working in the field of gas turbine with state of the art knowledge on engine performance-based condition monitoring. Mo et al., (2018) studied 'performance-based maintenance of gas turbines for reliable control of degraded power systems'. This author's research investigated optimal maintenance techniques to reduce the expected maintenance costs. His work proposed a framework that could be used in designing preventive maintenance actions on a gas power plant, which would help to ensure the needed load frequency control performance, thereby preventing sudden load increase.

Optimization of various gas turbine components to have better performance has been studied by many. Knight et al., (2006) carried out economic optimization of gas turbine power generation; findings from the study reveal that the approach led to outstanding financial benefits. The aerodynamic shape of a 2-dimensional axial fan cascade was optimized using genetic algorithm methods (Lotfi, 2006). Oyama and Liou, (2002) and Oyama et al., (2002) researched on redesigning a 4-stage compressor by employing a multi-objective evolutionary algorithm to estimate the optimum total pressure ratio and the overall isentropic efficiency. The estimated design had a 1% increase in the efficiency while the pressure ratio was kept constant (Mitchell, 1996).

Fujita (1996) employed genetic algorithm-based optimization to estimate the optimal solution to the planning problem observed in energy plant configurations. Genetic algorithm was used by Oksuz (2001) to estimate the optimum aerodynamic performance of a turbine cascade. Results from the author’s work show that the highest tangential force was actualized for a higher flow turning, a wider pitch, and a thicker cascade. Associated gas is wasted to flaring in some parts of the world. But this gas is a huge source of energy; this is due to its high methane content. In employing gas turbines for energy generation using this fuel resource, over time, the engines begin to degrade. Also, this fuel resource is gotten from fossil fuel which is fast depleting due to the large usage on industrial scale. So for an energy generation business using associated gas and gas turbines for a period of 20 years, there is the need to optimize the fleet composition and the thermal efficiencies of the engines. There is also the need to evaluate the effect of engine degradation on the optimized fleet composition and thermal efficiencies. The fleet composition is an array of all the units of engines in the fleet together with their operating turbine entry temperatures (TETs), for the entire duration of the project. The optimized fleet composition is the fleet composition that gives the optimum power generation from the fleet. Enginee degradation greatly affects the operations and maintenance cost in the economic use of associated gas using gas turbines, the depth of this effect also needs to be evaluated.

Ighodaro and Osikhuemhe (2019) evaluated the thermo-economic of a heat recovery steam generator combined cycle. In this study, a retrofitted performance assessment of integrating a steam power cycle to the already existing gas turbine cycle in Delta IV power station was assessed. The outcome of the authors’ work showed an additional increase of the power output by 51.5MW, and as a result a 41.85% increment in the overall combined cycle efficiency. Adiofo et al., (2018) studied on thermo-economic assessment of a natural gas liquefaction plant. The simplified version of ConocoPhillips Optimized Cascade process was used in the study. Additionally, the research carried out sensitivity analyses to evaluate market price variations and estimation errors which are as a result of the assumptions used. Jassim, (2015) performed an energy assessment of a gas turbine Brayton cycle which was incorporated to a refrigeration cycle, the outcome gave hope for an increase in the power output with a small decrease in the thermal efficiency. Shayan et al., (2019) did some work on the use of associated gas for energy and revenue generation. A thermo-economic analysis for a trigeneration system incorporated by an absorption chiller, a gas microturbine, and a heat recovery steam generation subsystem was done by Valencia et al., (2019). The outcome of the authors’ work reveals that the combustor of the gas microturbine had the greatest exergy destruction (29.24%), and this was seconded by 26.25% for the generator of the absorption refrigeration chiller. Oyedepo et al., (2018) did thermo-economic and environmental assessment of specific gas turbine power plants in Nigeria, the outcome show that the combustor had the greatest cost of exergy destruction. It was also seen that an increment in the turbine inlet temperature of the gas turbine resulted to a decrease in the cost of exergy destruction. Likewise, Okuma et al., (2022) evaluation on energy and exergy study shows that the boiler experiences the highest exergy efficiency of 59.66% whereas the condenser has the highest energy efficiency of 48.18%.

Obhuo et al., (2020) evaluated the effect of deterioration on the economic use of flare gas and on the divestment time of engines which are redundant. Yao and Yu, (2018) suggested a new power generation system which combined a natural gas expansion plant with a geothermal organic rankine cycle. None of the above cited literatures shows the optimized fleet composition of the alstom GT-26 reheat engine; neither did any give a hint on how to achieve optimized efficiencies in the event of constraint fuel availability. This work has also shown a detailed evaluation of the impact of compressor degradation on the operations and maintenance cost of the GT-26 engine when using associated gas, this is lacking in literatures obtainable in the public domain.

This study stems out of the need to economically maximize the use of associated gas for power/energy generation using gas turbines. The associated gas availability for the project gradually declines over the years of the project as seen in Figure 1.

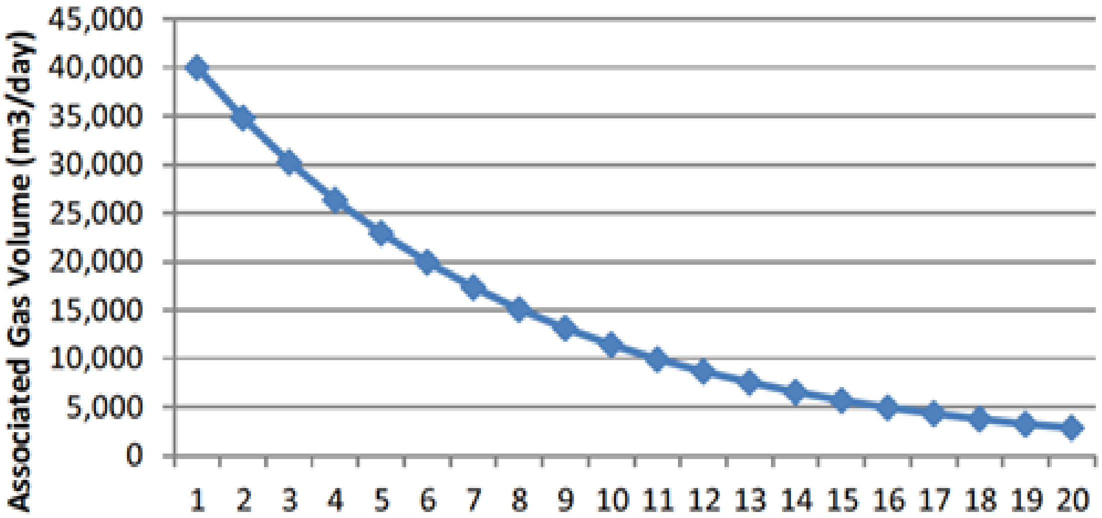


Fig. 1. Associated Gas Resource for The Project (Allison, 2014)

Because the project duration is 20 years, various engine degradation scenarios have been considered – the optimistic (slow degradation), medium, and the pessimistic (fast degradation). The 4th scenario considered is the clean scenario (fleet). Figure 2 shows the extent of degradation experienced by the various degraded scenarios in the different years of the project. In the 1st year of the project, all fleets are clean (zero degradation).

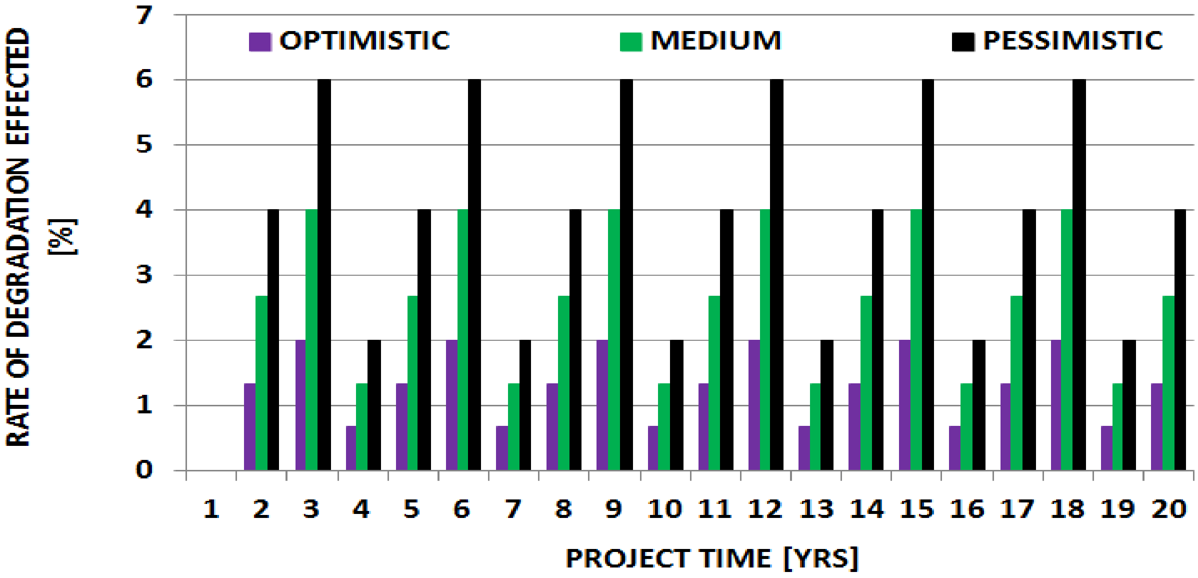


Fig. 2. Rate of Degradation Experienced by The Degraded Scenarios of The Project

Over the years of the project, as a result of the decline in the associated gas availability, some of the units of engines in the fleet would become redundant; all redundant engines are immediately divested for more economic returns.

Cranfield University performance simulation tool, TURBOMATCH was used for the engine performance simulation while Genetic algorithm was used for the fleet composition optimization.

3. Tools and Methodology

3.1 Tools used for the study

Various tools and materials have been used for this study. The performance data for the real engine (Alstom GT-26) were gotten from the public domain (Turbines AG, 2013; Power Engineering International, 2011; Eckardt, 2014). The performance simulations for the study engine (RH296) were done using the Cranfield University in-house FORTRAN-based code (TURBOMATCH) for gas turbine performance simulations (Nikolaidis, 2015; Nkoi, 2014; Pachidis, 2014; Palmer, 1999; Pilidis and Palmer, 2010; Li,2005). The Associated gas and clean natural gas were used as fuel for the performance simulations of the same model engines. Anosike (2014), results showed no significant difference in most of the performance parameters. Also, the same engines were simulated with associated gas of three different degrees of gas quality, the results also showed that there were no significant deviations in the lower heating values (LHV) of the three fuels, similar observation was also made for the power outputs and the thermal efficiencies of the engines (Allision, 2014). Based on the above observations, clean natural gas was used in the actual performance simulation in this study in place of associated gas. Genetic algorithm in Matlab was used for the optimization of the fleet compositions, the total optimized power and the divestment schedule of the fleets. It should be noted that the research was simulation-based; as such the various simulation softwares stated above were employed at various stages of the research.

3.2 Methodology adopted for the study

3.2.1 Gas turbine performance simulations

Gas turbine performance simulations were done for the study engine using the Cranfield University gas turbine performance simulation in-house tool (Turbomatch). These simulations were done at design point and off-design point engine operating conditions. The comparison of the design point results gotten from the simulation and the public domain data for the study engine is as shown in Table 1.

Table 1- RH296 Engine model specifications (Obhuo, 2018)

Parameter	**GT26**	**Engine Model**	**%Diff.**
Exhaust mass flow(Kg/s)	644	660.4	2.55
Exhaust temperature (K)		908.8	−
TET (K)	Not available	1543	−
Shaft power (MW)	296	296	0
Thermal efficiency	0.396	0.396	0
Pressure ratio	33.3	33.3	0
Fuel flow (Kg/s)	Not available	16.4153	−

Gas turbine simulations of the study engine were also done at varying levels of compressor degradation. The levels of degradation implemented for the various years of the project are as shown in Figure 2 above. The results from the gas turbine performance simulation software served as the database for Genetic Algorithm (in Matlab) optimizer. These results are sets of values of fuel flows, power outputs and thermal efficiencies for corresponding values of turbine entry temperatures. This was also done for the degraded fleets by implementing the values shown in Figure 2.

3.2.2 Genetic algorithm optimizations for best fleet composition and maximal thermal efficiencies for the engines

Genetic algorithm in Matlab was used for this optimization. Gas turbine performance simulation results served as the database for the optimizer. Figure 3 below shows the model used for the optimization while Figure 4 shows the optimization flow chart.

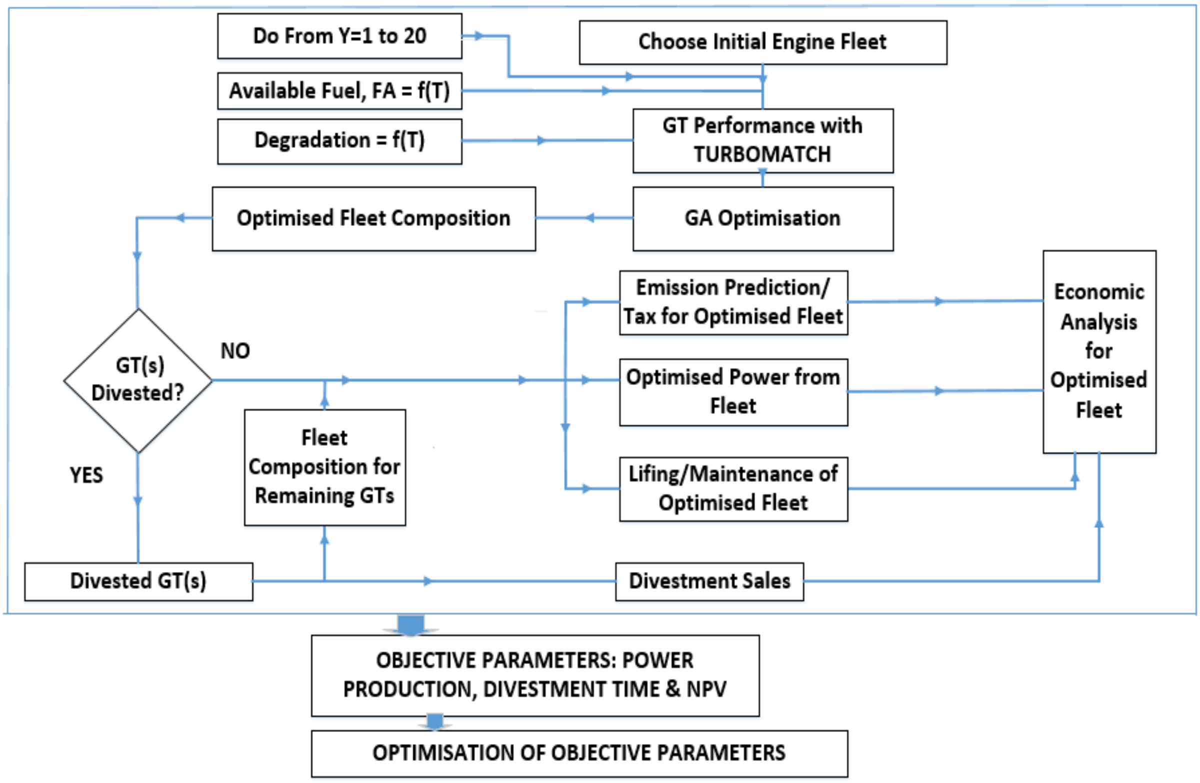


Fig. 3. Methodology employed for the optimization of the fleet compositions and thermal efficiencies of the fleets

As shown in Figure 3, the first step is to choose the initial engine fleet. This is followed by carrying out gas turbine performance simulations using Turbomatch software. This is also done for the degraded engines. The gas turbine performance results from Turbomatch software are fed into Genetic algorithm tool which then optimizes for the best fleet composition and maximal thermal efficiencies for the fleet. The whole process is repeated for the entire duration of the project.

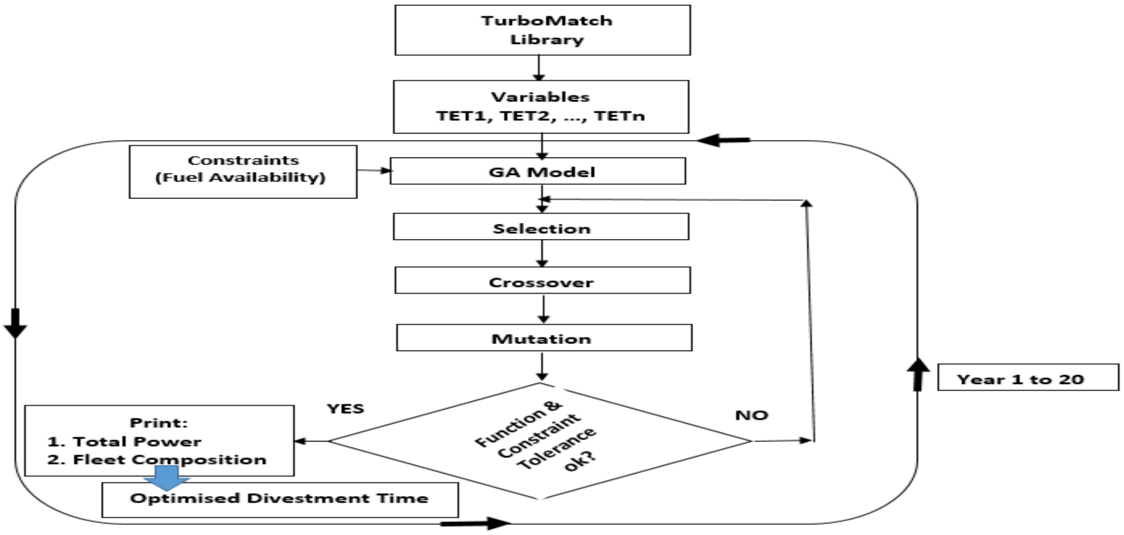


Fig. 4. Flow chart adopted by the optimizer in the optimization of the fleet composition and thermal efficiencies of the study engine using associated gas fuel

As shown in Figure 4, the optimization variables are sets of turbine entry temperatures, while the constraint for the optimization are the fuel availability values shown in Figure 1. The results gotten from the optimization include the optimized fleet compositions and the optimized thermal efficiencies.

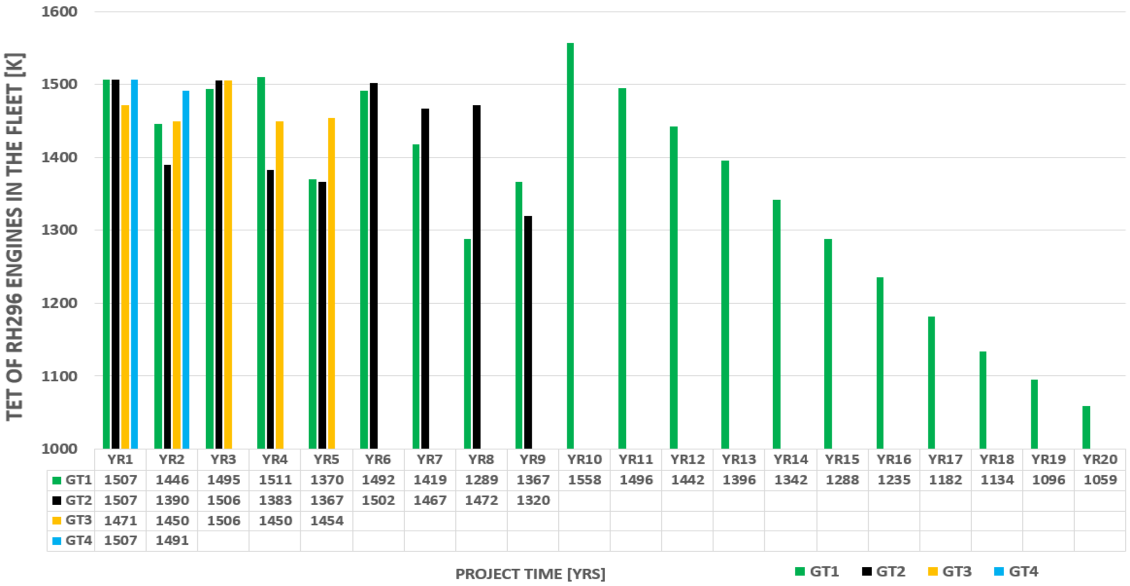
4. Optimization Results

4.1 Optimized fleet compositions

As a result of the time-dependent availability of the associated gas, there is a need for optimization of the power/energy generation from the fleet, which would eventually lead to optimum economic returns. With the optimized fleet compositions, gas turbine operators would derive the maximum power or energy possible from the fleets given. Optimization of the fleet composition is further necessitated by the constraint of depleting associated gas availability.

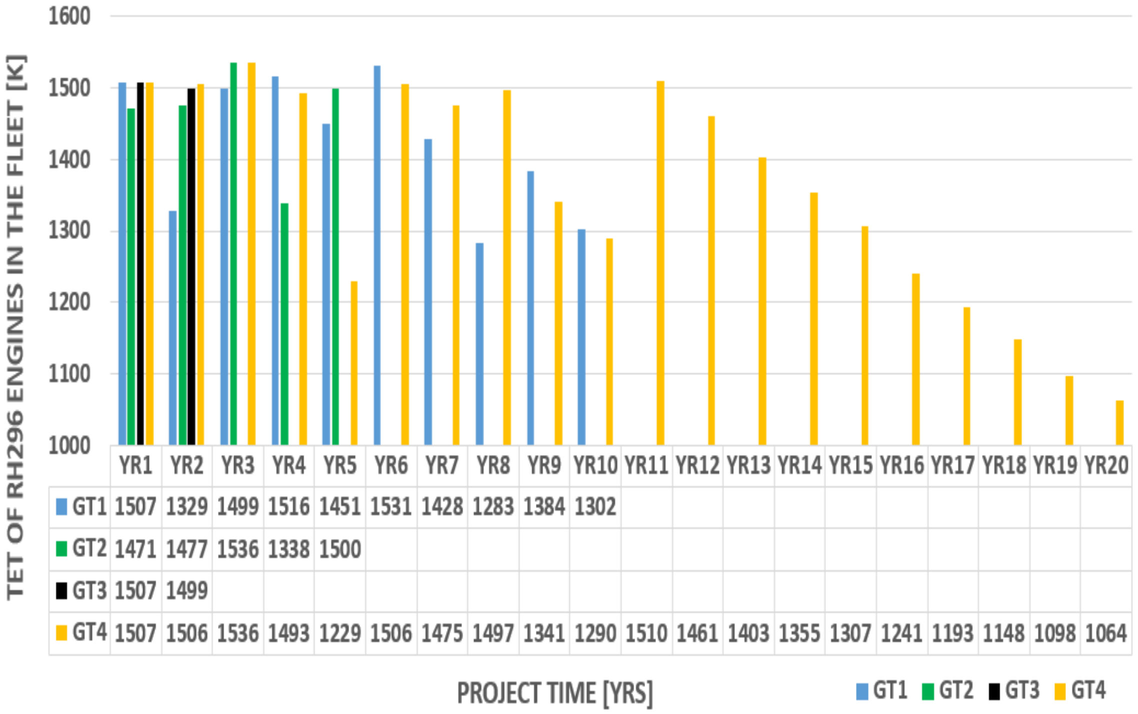
The fleet composition is an array of all the units of engines in the fleet together with their operating turbine entry temperatures (TETs), for the entire duration of the project. The optimized fleet composition is the fleet composition that gives the optimum power generation from the fleet and estimates the optimized divestment time for the redundant units of engines in the fleet. For the entire duration of the project, all the units of engines in the optimized fleet compositions have their corresponding optimized power, optimized efficiency, and optimized fuel consumption. Therefore, the fleet composition results presented below are theoretically and practically useful to gas turbine operators and investors, as they aid higher energy production and enhance economic returns.

Figures 5, 6, 7, and 8 show the optimized fleet compositions for the clean, the optimistic, the medium, and the pessimistic degraded fleets respectively. As can be seen in these figures, the optimized fleet compositions comprise of the units of engines in the fleets and their optimized operating turbine entry temperatures in Kelvin. The empty spaces imply units of engines that have been divested.



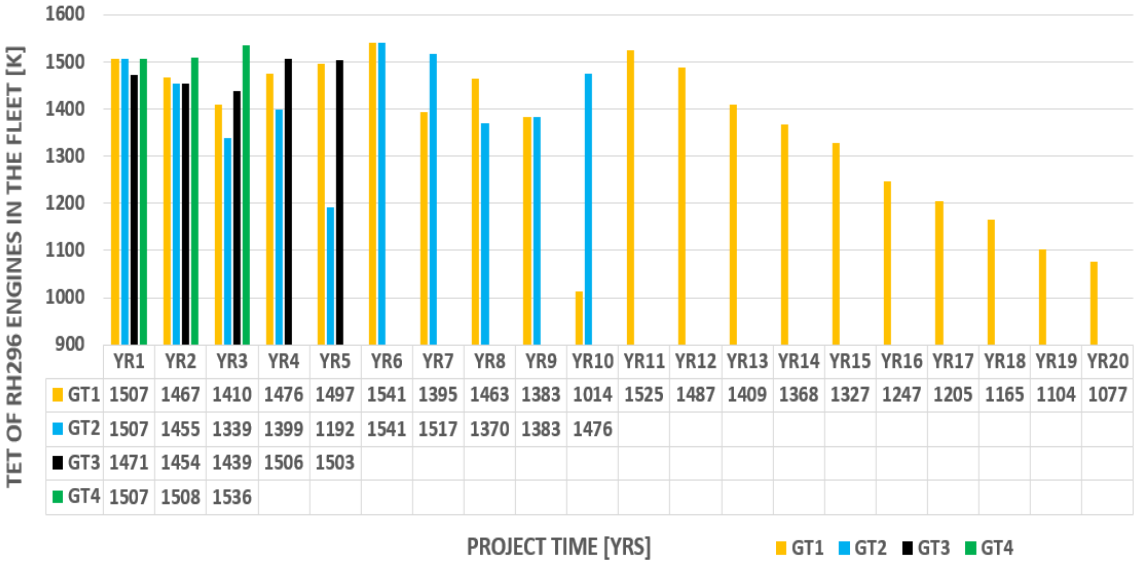
	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
🟩 GT1	1507	1446	1495	1511	1370	1492	1419	1289	1367	1558	1496	1442	1396	1342	1288	1235	1182	1134	1096	1059
■ GT2	1507	1390	1506	1383	1367	1502	1467	1472	1320											
🟨 GT3	1471	1450	1506	1450	1454															
🟦 GT4	1507	1491																		

Fig. 5. The optimized fleet composition for the economic utilization of associated gas (Clean fleet)



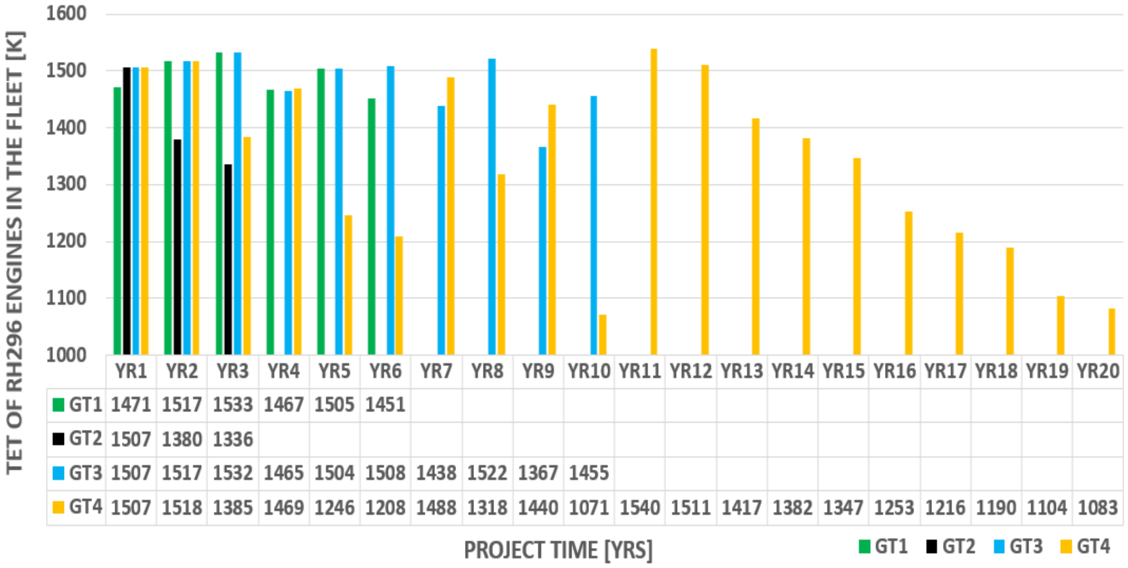
	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
GT1	1507	1329	1499	1516	1451	1531	1428	1283	1384	1302										
GT2	1471	1477	1536	1338	1500															
GT3	1507	1499																		
GT4	1507	1506	1536	1493	1229	1506	1475	1497	1341	1290	1510	1461	1403	1355	1307	1241	1193	1148	1098	1064

Fig .6. The optimized fleet composition for the economic utilization of associated gas (Optimistic fleet)



	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
GT1	1507	1467	1410	1476	1497	1541	1395	1463	1383	1014	1525	1487	1409	1368	1327	1247	1205	1165	1104	1077
GT2	1507	1455	1339	1399	1192	1541	1517	1370	1383	1476										
GT3	1471	1454	1439	1506	1503															
GT4	1507	1508	1536																	

Fig. 7. The optimized fleet composition for the economic utilization of associated gas (Medium fleet)



	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
🟩 GT1	1471	1517	1533	1467	1505	1451														
■ GT2	1507	1380	1336																	
🟦 GT3	1507	1517	1532	1465	1504	1508	1438	1522	1367	1455										
🟨 GT4	1507	1518	1385	1469	1246	1208	1488	1318	1440	1071	1540	1511	1417	1382	1347	1253	1216	1190	1104	1083

Fig. 8. The optimized fleet composition for the economic utilization of associated gas (Pessimistic fleet)

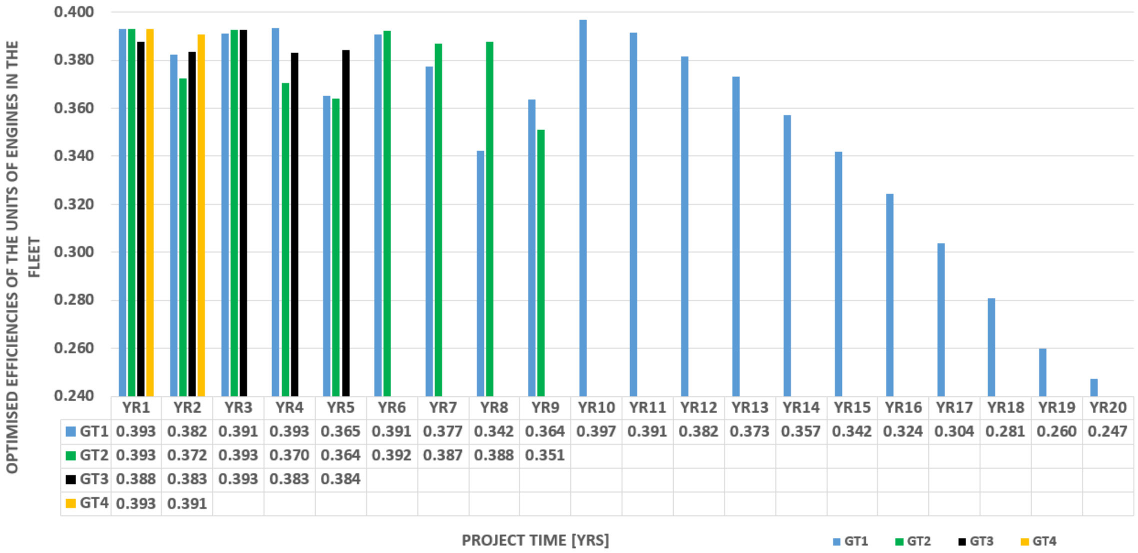
These optimized fleet compositions are the turbine entry temperatures for which the units of engines in the fleet have to be operated to achieve maximal energy given the constraint of fuel availability. On comparing the turbine entry temperatures (TETs) of the units of engines in the various fleets (scenarios), it is observed that at year 1, all fleets have the same optimized operating turbine entry temperatures of 1507K, 1507K, 1507K, and 1471K as given by the optimizer. All the various scenarios have the same fleet composition at year 1 because all the units of engines in the various fleets were operated clean. It also implies that at year 1, the same quantity of optimized power would be realized.Also, comparing the fleet compositions of the degraded fleets and that of the clean fleet, it can be seen that the degraded fleets are operated at higher optimized turbine entry temperatures to fully use the fuel available. As an example, considering year 11, the lone unit of engine left in the fleet has 1540K, 1525K, 1510K, and 1496K as the turbine entry temperatures for the pessimistic, medium, optimistic and clean fleet respectively. A vital observation from the figures is that degradation influences the divestment time of the redundant units of engines in the various fleets. All associated gas investors using gas turbines for power generation need a model to estimate the optimized fleet composition. The model presented in this study is thus very valuable to both investors and governments who are interested in the business of power generation using a similar reheat gas turbine and associated gas as fuel.

4.2 Optimized thermal efficiencies

Obtaining maximal efficiency from a gas turbine is a key factor in the heart of any gas turbine operator or investor. For optimum economic returns from the various fleets, and also due to the constraint of limited and time-dependent availability of the associated gas, the units of engines have to be optimally utilized; their efficiencies have to be optimized as well.

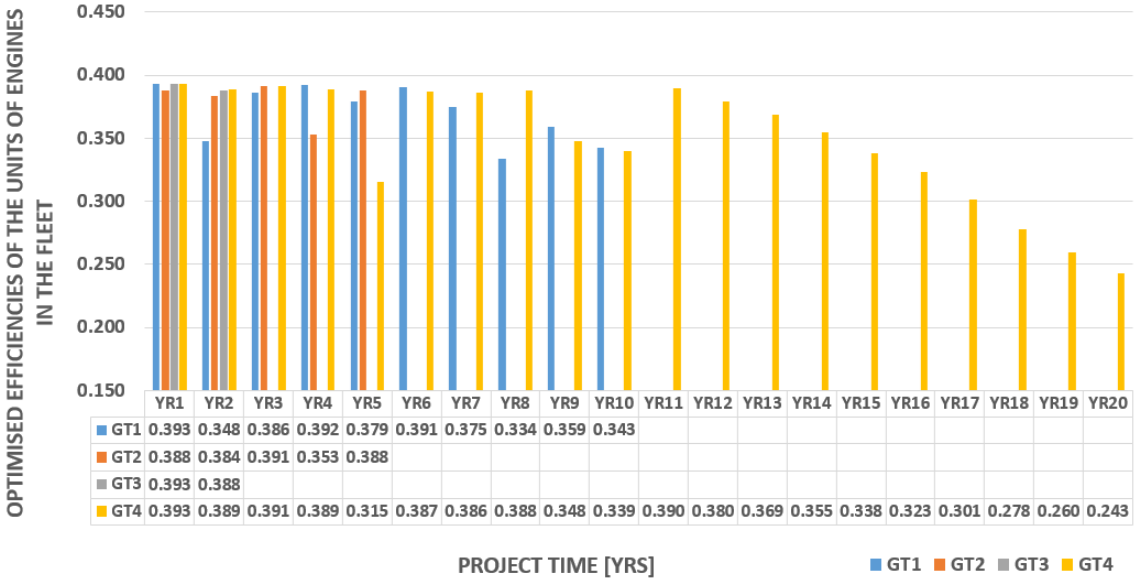
Figures 9, 10, 11, and 12 show the optimized efficiencies for the clean, the optimistic, the medium, and the pessimistic degraded scenarios respectively. As seen from these figures, in the first year all the units of engines in the various fleets have the same optimized efficiencies 0.393, 0.393, 0.393, and 0.388. This is because they were all operated as clean engines in the first year. Considering the results in these figures, it can be seen that generally, the optimized efficiencies decrease over the years of the project, this is as a result of the declining trend in the associated gas availability as shown in Figure 1.

Comparing the optimized efficiencies for the four scenarios presented in Figures 9, 10, 11, and 12; it is observed that the optimized efficiencies follow the trend Clean > Optimistic > Medium > Pessimistic, this is easily observed from the 11th to the 20th year of the project.



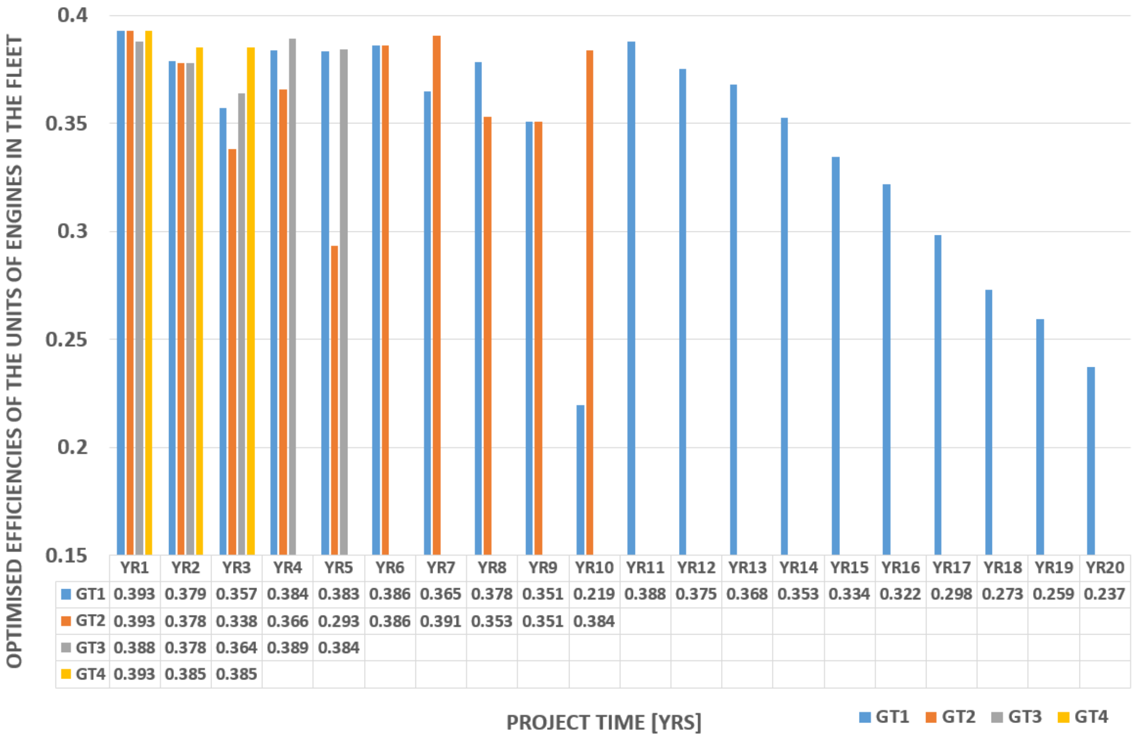
	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
GT1	0.393	0.382	0.391	0.393	0.365	0.391	0.377	0.342	0.364	0.397	0.391	0.382	0.373	0.357	0.342	0.324	0.304	0.281	0.260	0.247
GT2	0.393	0.372	0.393	0.370	0.364	0.392	0.387	0.388	0.351											
GT3	0.388	0.383	0.393	0.383	0.384															
GT4	0.393	0.391																		

Fig. 9. The optimized efficiencies of the units of engines for the economic use of associated gas (Clean fleet)



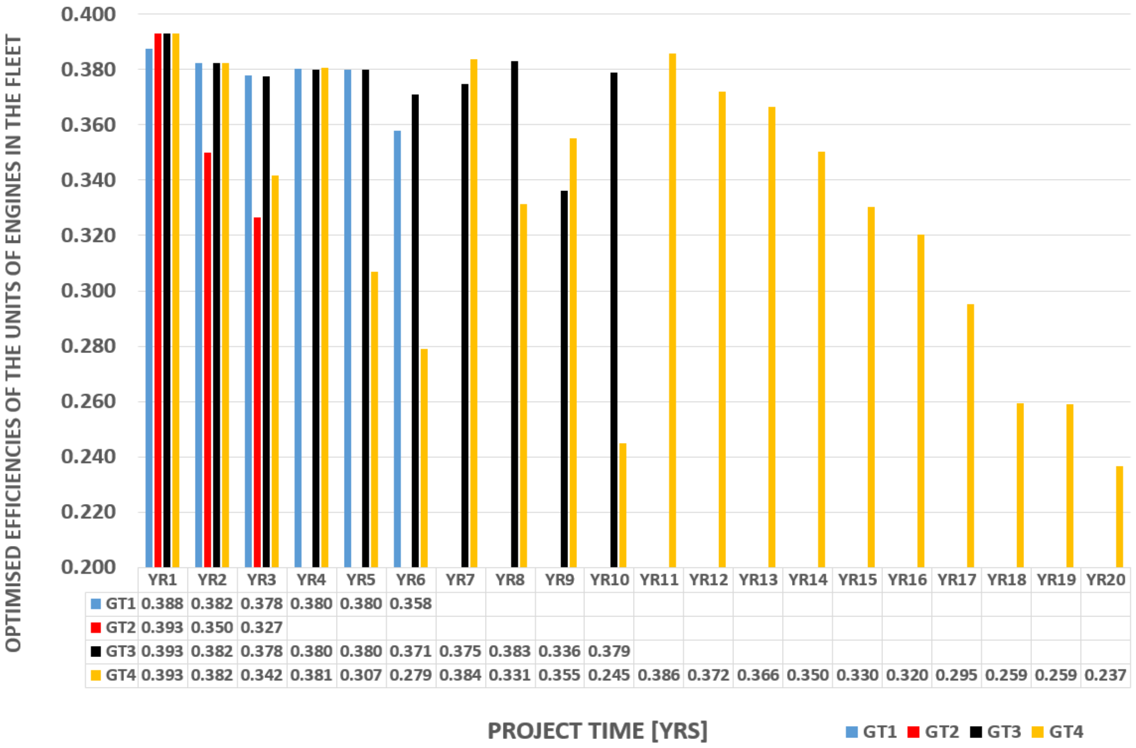
	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
GT1	0.393	0.348	0.386	0.392	0.379	0.391	0.375	0.334	0.359	0.343										
GT2	0.388	0.384	0.391	0.353	0.388															
GT3	0.393	0.388																		
GT4	0.393	0.389	0.391	0.389	0.315	0.387	0.386	0.388	0.348	0.339	0.390	0.380	0.369	0.355	0.338	0.323	0.301	0.278	0.260	0.243

Fig. 10. The optimized efficiencies of the units of engines for the economic use of associated gas (Optimistic fleet)



	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
GT1	0.393	0.379	0.357	0.384	0.383	0.386	0.365	0.378	0.351	0.219	0.388	0.375	0.368	0.353	0.334	0.322	0.298	0.273	0.259	0.237
GT2	0.393	0.378	0.338	0.366	0.293	0.386	0.391	0.353	0.351	0.384										
GT3	0.388	0.378	0.364	0.389	0.384															
GT4	0.393	0.385	0.385																	

Fig. 11. The optimized efficiencies of the units of engines for the economic use of associated gas (Medium fleet)



	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
GT1	0.388	0.382	0.378	0.380	0.380	0.358														
GT2	0.393	0.350	0.327																	
GT3	0.393	0.382	0.378	0.380	0.380	0.371	0.375	0.383	0.336	0.379										
GT4	0.393	0.382	0.342	0.381	0.307	0.279	0.384	0.331	0.355	0.245	0.386	0.372	0.366	0.350	0.330	0.320	0.295	0.259	0.259	0.237

Fig. 12. The optimized efficiencies of the units of engines for the economic use of associated gas (Pessimistic fleet)

4.3 Optimized fuel consumptions

As explained earlier, the fuel for this research (associated gas) is declining in availability, hence the need to maximally utilize it. Figure 13 shows the optimized fuel consumption curve. The superimposing of the fuel consumption curves for the various scenarios on the fuel availability curve shows that the optimization constraint was satisfied during the optimization, fuel resources were maximally utilized.

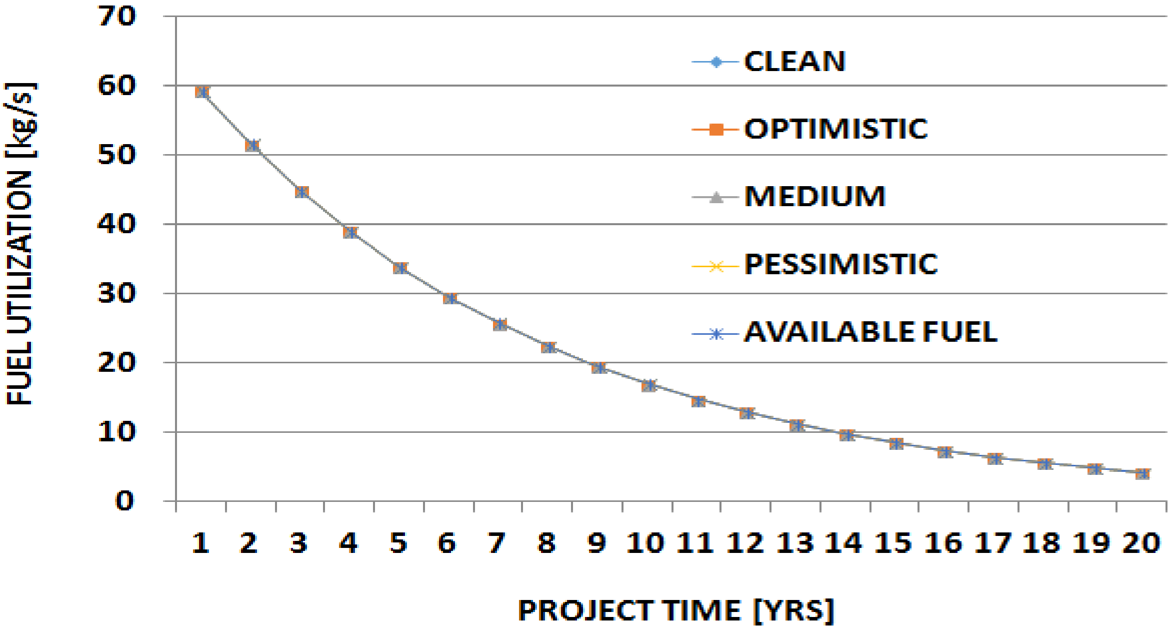


Fig. 13. Fuel availability and fuel usage curves

5. The Operations and Maintenance Costs of The Project

5.1 Total operations and maintenance costs from the various scenarios

Operations and maintenance (O & M) cost is a key element in a gas turbine operations business. In this business of economic utilization of associated gas for power generation using gas turbines, the operations and maintenance costs of the fleets were estimated using the relationship shown in equation 1.

$$Annual_{O\ \&\ M\ Cost} = Fixed_{O\ \&\ M\ Cost} + Variable_{O\ \&\ M\ Cost} + Major_{\ Maintenance\ Cost}$$

Equation 1 (Obhuo, 2018)

As shown in equation 1, the annual operations and maintenance cost is gotten by adding up the fixed operations and maintenance cost, the variable operations and maintenance cost and the major maintenance cost. Fixed operations and maintenance costs are costs incurred in the running of the engine that do not vary significantly with the quantity of energy generated, examples are routine predictive and preventive maintenance. On the other hand, variable operations and maintenance costs are incurred costs that are directly influenced by the quantity of energy generation, examples are purchase of chemicals, consumables, lubricants, spare parts, etc (Allision, 2014; Obhuo,2 018)

Major maintenance costs are costs incurred due to extended outages, an example is scheduled major overhaul (Allision, 2014; Obhuo, 2018). Figure 14 shows the total operations and maintenance costs of the project from the various fleets. The results from the figure show that the clean, optimistic, medium, and pessimistic degraded fleets have total operations and maintenance costs to be 1.224, 1.242, 1.265, and 1.297 billion US dollars respectively.

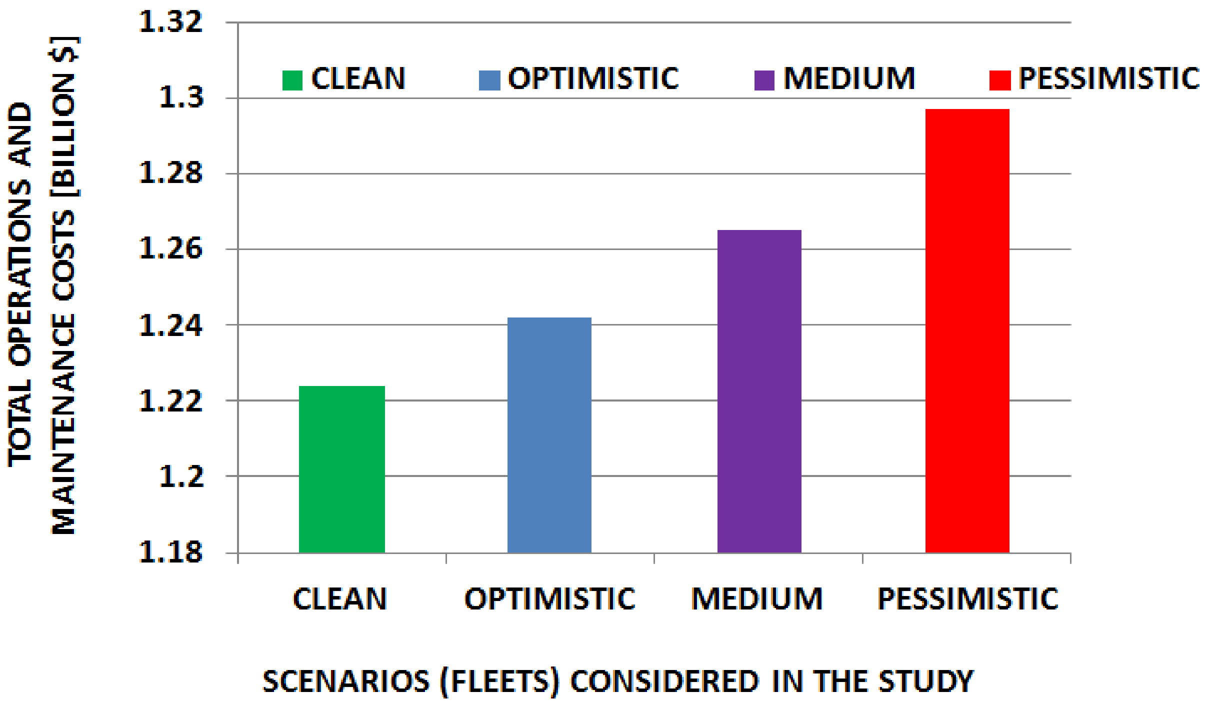


Fig. 14. Total operations and maintenance costs in the economic utilization of associated gas

5.2 The impact of engine degradation on the operations and maintenance costs of the various fleets

Gas turbine degradation has a significant effect on the operations and maintenance costs in this business of the economic utilization of associated gas. This effect is demonstrated in Figure 15, it can be seen that engine degradation resulted to 1.4%, 3.3%, and 5.9% increase in the operations and maintenance costs of the optimistic, medium, and pessimistic degraded fleets respectively. The trend shown in Figure 15 follows the pattern expected both in theory and practice.

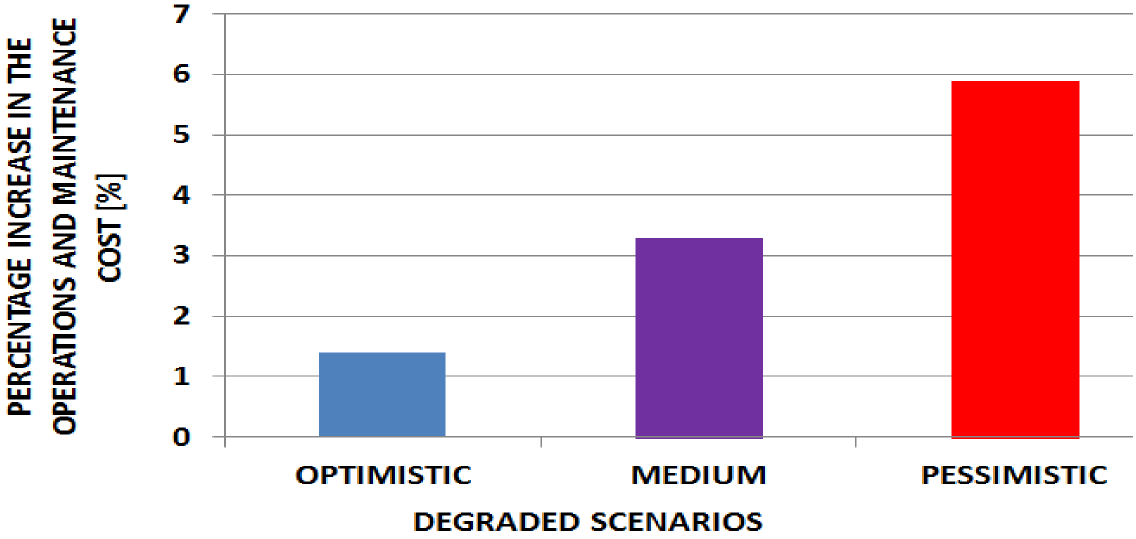


Fig. 15. Percentage increase in the operations and maintenance costs due to degradation

6. Conclusion

Associated gas is a viable source of fuel for industrial gas turbines, and this is due to its high methane content. This study presents a useful model and methodology to be employed for the optimization of gas turbine fleet composition, thermal efficiency and for the assessment of the impact of compressor degradation on the aforementioned. This methodology serves as a guide to investors and governments for the economic use of this fuel. The Cranfield University gas turbine performance simulation software, Turbomatch, was used in modeling a hypothetical but realistic 296 mega watt reheat gas turbine engine. The study was done using clean engines and degraded engines of three variations – the optimistic, medium, and pessimistic. Genetic algorithm tool in Matlab was used in optimizing the fleet compositions and thermal efficiencies. The effect of compressor degradation on the optimized fleet composition and thermal efficiencies were also ascertained. Results show that the clean, optimistic, medium, and pessimistic degraded fleets have total operations and maintenance costs to be 1.224, 1.242, 1.265, and 1.297 billion US dollars respectively. Engine degradation resulted to 1.4%, 3.3%, and 5.9% increase in the operations and maintenance costs of the optimistic, medium, and pessimistic degraded fleets respectively.

The results, approach and methodology presented in this paper would be a very useful decision-making tool for investors and governments who would want to invest in the economic utilization of associated gas using a similar reheat gas turbine. It is, therefore, encouraging that instead of allowing associated gas to be flared thereby causing environmental pollution and wasting energy resource, the methodology and results presented in this study should be employed as a guide in the business of the economic utilization of associated gas when a similar reheat gas turbine is to be used. This study was done using the Alstom GT-26 engine, as such the results gotten would be different when other engines of different configurations are used. It is therefore recommended that the methodology be adopted for several gas turbines of various cycle configurations. Also, only compressor degradation was considered, it is highly recommended that degradation of other engine components be considered.

Acknowledgment

The authors are grateful to the Petroleum Technology Development Fund of Nigeria (PTDF/E/OSS/PHD/OM/693/14), for funding the PhD research that has led to the publication of this paper.

Declaration of conflicting interests

The authors would like to acknowledge that there is no conflict of interest.

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