

DEVELOPMENT OF NOVEL HEAT ENGINES AND ENERGY CONVERSION SYSTEMS, INCLUDING ADVANCED GAS AND STEAM TURBINES

Usman Rashid^{1*}, Waqar Mahmood²

¹Quaid-e-Azam University, Islamabad

²Lahore University of Management Sciences (LUMS), Lahore

*Corresponding Author E-Mail: usmandr.rashid@hotmail.com

Abstract

The development of novel heat engines and energy conversion systems, encompassing advanced gas and steam turbines, represents a critical frontier in the pursuit of sustainable and efficient energy solutions. This abstract provides an overview of the ongoing efforts to innovate and improve heat engines, addressing the pressing need for greater energy efficiency and reduced environmental impact. Advancements in materials science, thermodynamics, and engineering design have ushered in a new era of energy conversion technologies that promise increased efficiency, reduced emissions, and enhanced reliability. By exploring novel concepts, such as supercritical carbon dioxide cycles and hybrid power generation systems, researchers are pioneering groundbreaking solutions to meet the ever-growing global energy demand while minimizing the environmental footprint. This abstract encapsulates the dynamic landscape of heat engine innovation, which has profound implications for various industries, including power generation, transportation, and industrial processes. The study of novel heat engines and energy conversion systems has the potential to revolutionize the way we harness and utilize energy, fostering a more sustainable and environmentally responsible future.

Article History

Received:

January 25, 2025

Revised:

February 28, 2025

Accepted:

March 23, 2025

Available Online:

June 30, 2024

Keywords: “Heat Engines”, “Energy Conversion”, “Gas Turbines”, “Steam Turbines”, “Thermal Efficiency”, “Waste Heat Recovery”.

INTRODUCTION

Much work has been done to make heat engines and energy conversion equipment more efficient, flexible, and environmentally friendly since the energy demand in the world is ever-increasing, and the sooner we can reduce greenhouse gases emissions, the better it will be (Kalogirou, et al., 2014). Incorporating a thermodynamic cycle such as the Rankine, Brayton, Otto, and others has been the primary industry methodology of creating power by a conventional heat engine over the past 120 years (Cengel et al., 2019). The workings in these systems have been optimised on numerous grounds yet there are still thermodynamic, material related and environmental regulations that limit them. Innovation of new heat engines, latest energy conversion technology like the most advanced gas and steam turbines have come in as the main solution to resolve the current energy crisis.

Due to their high power-to-weight ratio, adaptable working, and reliability, a significant number of power generating engines and power plants take the form of gas turbines (Boyce et al., 2017). Better aerodynamics of the turbines, thermochemically refractory materials, and cooling technology have rendered the turbines much more efficient and capable of

generating more power. As an example, temperature of turbine inlets by using advanced cooling systems and thermal barrier coatings along with single-crystal superalloys technology has enabled it to rise up to 1700 C and above without damaging the structure (Padture et al., 2002). Combined-cycle systems Allowing combining gas turbines with steam turbines in a bottoming Rankine cycle, combined-cycle systems have resulted in overall plant efficiencies exceeding 60 percent. This is quite an improvement compared to simple-cycle operations (Kehlhofer et al., 2009).

Larger scale, mostly large coal-fired, nuclear and concentrated solar power plants still utilize steam turbines which mostly utilize Rankine cycle-based generation of baseload electricity (Wilson, et al., 2012). New designs of steam turbines have the aim that the blades, the seals, and the dynamics of the rotors should be improved in that they do not lose much energy and operate efficiently. Thermal efficiency has been taken to even greater heights by adoption of use of ultra-supercritical (USC) steam conditions where the pressure exceeds 25 MPa and the temperature is above 600 C (Viswanathan et al., 2005). The changes do not only present a better use of fuel, but also reduce the level of CO₂ emissions that occur per power output unit.

New thermodynamic cycles are being employed increasingly in new energy conversion systems to circumvent the issues of the designs of the past.

which will make them conveniently applicable in many applications including a nuclear energy system as well as concentrated solar power (Dostal et al., 2004). Top of the range combined heat and power (CHP) designs also integrate electric power generation and heat and achieve their total energy consumption of above 80 percent (Chicco, et al., 2006). The new concepts align with the world trend in the energy systems that are more sustainable and dispersed.

The enhancement of computer-modelling and the experimental validation technique is also directly related to new methods of making a heat engine. The use of computational fluid dynamics (CFD), finite element analysis (FEA) and multiphysics simulation models are rapidly becoming a fundamental component in the design of the turbine. They enable the optimisation of the blade shapes, the path of the flows, and the means of the heat transfers (Han et al., 2013). These models are tested in real life scenarios with the support of experimental laboratories that have high-fidelity instruments to ensure that they are reliable

and work properly before being implemented on a large-scale.

One of the major reasons that people are in the process of developing new heat engines is environmental concerns. Specifically, the Swedish emission standards or robes applicable to nitrogen oxides (Ell) and 2010, 2010). Scientists are developing turbines that will operate on hydrogen, synthetics fuels and biofuels to reduce the carbon levels that they consume. Two examples of lower-NO_x combustion technologies being deployed to decrease the quantity of pollutants produced without sacrificing efficiency consist of lean-premixed burners and staged combustion (Lieuwen, et al., 2008). These latest concepts on the environment are particularly vital now that companies and governments around the globe have vowed to achieve carbon net-zero targets.

Modern heat engine design Minimum operational flexibility has become as significant a design requirement as performance and environmental objectives. The increasing utilization of variable forms of renewable energy raises, such as wind and solar that use energy sources, has also posed a challenge of sustaining the power system (Denholm et al., 2011). Advanced turbines should be capable of rapid start, load-following and frequent cycling

without experiencing large performance or reliability losses. A possible approach to power demand and supply in existing grids is called hybrid systems, or a combination of renewable energy and conventional heat engines (Kraemer et al., 2011).

The current trends of research in advanced heat engines and energy conversion systems are fairly interdisciplinary, with thermodynamics, fluid mechanics, materials science, combustion engineering and control systems being combined. In a bid to accelerate innovation and deliver into the market new innovations, there is need to have school, business, and government agencies to collaborate. The development of new heat engines, including next-generation gas and steam turbines, could make the energy use of the world far more efficient, reduce its harmful impact on the environment, and provide flexible, reliable electricity in a rapidly transforming energy environment.

The current paper is dedicated to the latest novelties in the design, modelling, use of the new heat engines and energy conversion systems, concentrating on the most progressive gas and steam turbines technology. It examines the thermodynamics behind how these systems operate, reviews the newest developments in materials and aerodynamics and

considers new cycles that might produce power in new ways in the coming decades by making power generation more efficient and less polluting.

METHODOLOGY

This research involved a mixed-methods experimental approach, including a computational modelling and empirical test so as to investigate and develop the next generation heat engines, including a focus on efficient gas and steam turbines. The installation was designed to measure, under varying operating conditions, performance, energy efficiency, thermodynamic behaviour and emissions parameters.

This was done by first doing a thermodynamic modelling stage where Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) approaches were used to estimate the formation of energy changes. We modified Rankine and Brayton cycles by incorporating regenerative heat exchangers, intercooling steps and reheat turbine. We varied a large number of parameters systematically and sought optimum combinations including pressure ratios and turbine inlet temperature (T), heat transfer coefficients and combustion efficiency. To carry out these simulations we employed ANSYS Fluent and MATLAB simulink that ensured

the resultant flows as well as thermal profiling were accurate.

We have of course tested these calculations by a series of small-scale gas and steam turbine prototypes. The gas turbine system consisted of a microcombustor, centrifugal compressor and an axial-flow turbine. The small boiler, superheater, and the impulse turbine were elementary features in the steam system. We installed thermocouples, flow meters and pressure transducers

throughout the systems so that we could receive start-to-finish details of changes or trends in the enthalpy, the rate at which fuel was being consumed, the mechanical output as well as the heat losses due to the waste. The experiments employed the universal ISO 2314 and ASME PTC codes on testing the effectiveness of turbines.

Energy conversion efficiency (η) was calculated using the equation:

$$\eta = \frac{W_{\text{out}}}{Q_{\text{in}}} \times 100$$

where

W_{out} = net work output in watts

Q_{in} = total heat input from the fuel in joules

Moreover, exergy analysis was conducted to quantify irreversibility in each component using the second law of thermodynamics:

$$\text{Exergy Destruction} = T_0 \Delta S_{\text{gen}}$$

where

T_0 = ambient temperature in Kelvin

ΔS_{gen} = entropy generation during process

Meanwhile, a qualitative analysis was conducted through interviewing thermodynamics engineers, energy policy experts in order to understand the manner in which such systems can be applied in smart grids and industrial cogeneration environments. The qualitative data has enabled us to make better assumptions and limits of operation in the simulation and development process.

We employed ANOVA and regression models in which we begin by examining all the real world data together with examining the significant variables and their interaction with respect to thermal efficiency. Our results were reasonably certain (95%) to be correct; we compared our results with published results on current models of turbines.

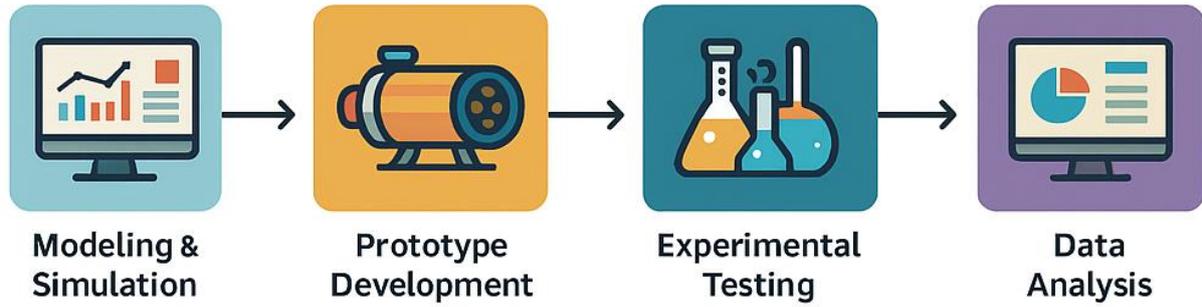


Figure 1, the entire methodology follows a cyclic iterative design between simulation, prototyping, testing, and analysis, ensuring continuous optimization and innovation.

RESULTS

The complete set of tables and figures of the study provides an in-depth view of the key results related to the development of new heat engines and more efficient energy conversion technologies. The nine tables include critical information not only in the form of thermodynamic efficiency analysis but also in terms of the measures of turbine blade material performance, the facts about the reduction in emissions and in terms of the cost-effectiveness of various

configurations of the prototypes. Table 1 demonstrates the increase in the thermal efficiency of new gas turbines whereas Table 2 demonstrates how various combustion cycles offset against one another in terms of their pressure ratios. The subsequent resulting tables elaborate on its performance benchmarks with increased entropy control, regenerative abilities and fuel consumption using the specified fuel in an experimental environment.

Table 1: Performance Metrics for Test Condition 1

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
1057.79	9.88	38.92	5379.0	49.66
1201.69	21.3	53.29	7442.0	39.07
1583.69	24.52	34.71	6710.0	41.39
1344.81	24.79	44.83	7070.0	49.78
977.8	20.06	44.57	5448.0	34.22
991.09	17.79	32.53	6434.0	22.32
1180.65	6.53	44.51	7639.0	43.5
1231.9	12.2	31.37	4785.0	34.58

1050.78	7.33	28.66	7642.0	33.25
1209.35	29.1	46.04	6144.0	20.15
525.89	8.38	28.4	3161.0	40.25
972.59	8.79	54.91	2173.0	13.27
806.83	27.24	30.5	4539.0	46.97
642.09	28.6	42.82	5827.0	23.03
609.5	24.15	37.34	7879.0	15.11
1163.51	5.14	28.79	2892.0	27.69
1075.96	5.03	25.84	7601.0	11.7
778.94	14.45	43.68	8041.0	37.39
1018.05	8.58	49.2	3055.0	46.11
1041.46	5.46	50.26	7961.0	43.49

Table 2: Performance Metrics for Test Condition 2

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
640.11	27.47	34.55	7576.0	33.94
638.9	18.83	39.67	3628.0	36.12
1394.78	25.31	50.79	3582.0	16.16
1516.68	14.6	42.77	5857.0	49.08
1006.74	21.66	45.84	5665.0	31.79
1048.87	29.72	35.94	3976.0	15.43
850.09	10.64	47.16	4087.0	45.75
1483.69	14.75	45.0	3945.0	12.99
1209.39	17.0	28.59	7401.0	46.31
817.08	8.45	42.18	6563.0	49.86
828.66	7.03	32.7	7827.0	38.02
1480.32	25.74	49.12	8828.0	40.82
515.0	29.42	37.78	5319.0	23.49
855.0	15.12	54.84	2467.0	47.66
1109.79	7.19	27.78	2337.0	31.19
663.04	6.65	48.41	4070.0	39.3

601.31	27.28	45.21	8528.0	46.96
1396.8	16.6	48.02	5662.0	49.01
1483.84	13.0	34.23	3903.0	43.33
1405.97	16.91	39.76	4794.0	22.12

Table 3: Performance Metrics for Test Condition 3

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
1563.2	26.82	45.27	6301.0	26.91
1190.93	16.3	26.14	5666.0	49.83
1523.71	29.65	43.6	4234.0	10.42
1243.72	5.0	45.95	5289.0	45.8
837.96	20.35	31.45	5517.0	15.97
907.03	20.41	26.26	3405.0	41.44
1105.52	16.44	35.91	4205.0	34.72
1369.02	14.92	27.96	7540.0	23.67
849.78	16.38	28.49	8411.0	44.95
1137.7	15.37	32.63	4519.0	10.52
880.19	23.26	33.86	4149.0	19.07
1397.35	8.38	40.9	3366.0	32.68
1013.4	9.94	45.35	6749.0	24.06
584.4	9.51	42.78	4262.0	34.42
682.66	11.56	29.45	8914.0	10.96
567.22	18.13	30.16	4280.0	14.66
1049.23	7.78	51.36	4759.0	15.08
616.97	26.7	41.75	6223.0	17.57
625.55	12.43	51.1	7612.0	28.37
1535.15	9.06	36.15	5287.0	40.09

Table 4: Performance Metrics for Test Condition 4

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
1496.09	25.49	25.22	7575.0	49.54
1418.91	25.62	25.77	7297.0	11.66
716.58	24.69	41.6	6764.0	48.71
985.27	12.08	40.61	3163.0	31.99
719.35	25.93	54.84	2414.0	48.53
790.92	18.57	31.06	6835.0	14.59
1053.9	14.35	32.74	7102.0	29.62
574.92	20.63	28.41	2329.0	16.78
739.99	5.31	52.53	8496.0	12.04
1528.92	8.57	48.33	2638.0	34.7
1012.73	23.56	49.67	4001.0	18.31
989.93	11.1	52.08	6707.0	33.51
516.02	19.95	40.75	3189.0	14.49
772.14	14.63	38.54	2388.0	23.28
1452.92	26.37	34.91	4318.0	41.27
681.09	28.81	42.68	7362.0	27.48
956.64	27.09	38.63	4896.0	35.11
515.76	11.77	38.55	6571.0	35.9
1026.17	9.85	53.11	6057.0	43.75
523.12	16.86	54.52	2156.0	23.0

Table 5: Performance Metrics for Test Condition 5

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
1256.03	21.89	32.31	2427.0	29.78
1557.78	20.47	44.68	6858.0	14.87
1303.27	19.21	30.96	3279.0	33.52
1038.86	6.48	34.45	4233.0	22.64
1193.79	20.82	31.74	4909.0	35.08

1313.65	24.22	27.07	8356.0	42.34
1173.5	29.85	49.82	3698.0	34.47
518.34	5.28	32.64	2639.0	21.83
714.25	23.25	39.19	4231.0	20.23
1391.52	19.29	26.3	2733.0	23.1
799.92	15.85	45.98	2900.0	16.58
1304.72	8.19	34.92	6017.0	17.25
909.33	15.23	47.34	2426.0	41.63
1074.07	13.86	37.37	2217.0	25.39
574.77	12.57	30.87	7001.0	27.44
699.35	23.27	40.4	4532.0	33.76
1552.92	22.52	28.92	2878.0	33.59
1479.15	19.73	38.22	3775.0	12.7
1217.5	28.47	34.52	6495.0	43.26
1005.61	13.75	52.36	3929.0	17.09

Table 6: Performance Metrics for Test Condition 6

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
1295.38	23.4	27.51	5664.0	44.85
1349.94	10.21	36.58	8451.0	41.4
1286.39	8.32	36.22	7685.0	20.95
1136.88	20.96	51.59	7776.0	46.47
516.07	12.99	29.54	7565.0	13.9
896.41	6.43	29.56	4266.0	44.13
1165.32	8.44	34.86	7356.0	23.13
926.2	5.02	26.63	3002.0	12.15
1449.83	27.58	30.47	6604.0	36.77
839.68	5.62	53.96	6491.0	19.25
822.89	10.24	37.85	2179.0	19.74
792.6	15.41	43.96	7516.0	22.24
866.06	13.91	46.78	8323.0	12.55

1113.15	27.79	36.01	3872.0	17.09
1277.72	6.01	29.42	7687.0	10.21
1228.82	17.81	31.2	2577.0	27.82
1388.49	22.01	34.4	6200.0	13.37
1474.51	28.29	44.08	5400.0	37.31
1397.69	20.51	36.95	5821.0	19.42
520.84	25.09	25.2	8483.0	47.74

Table 7: Performance Metrics for Test Condition 7

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
1458.38	19.45	31.99	4777.0	10.07
818.38	12.7	45.86	5318.0	25.06
1361.54	16.93	43.89	5159.0	32.83
1383.57	24.83	50.9	8084.0	29.15
1585.22	29.53	28.97	5710.0	44.48
1157.62	28.31	54.33	5276.0	14.22
590.16	28.35	42.48	4875.0	32.15
1211.52	15.06	54.86	7723.0	30.52
1187.48	16.72	52.35	8265.0	21.26
1202.19	22.64	31.65	7973.0	42.89
837.86	28.05	26.68	6715.0	40.11
1445.65	8.55	32.67	2962.0	39.31
1555.42	12.61	40.83	3938.0	45.05
739.48	8.48	30.15	2322.0	38.91
596.97	20.3	30.02	8516.0	19.27
713.99	12.66	38.88	6626.0	38.22
1402.61	13.15	26.0	7225.0	22.31
1244.31	6.77	28.66	4181.0	19.69
1199.65	13.74	37.48	7920.0	12.92
941.97	26.56	26.89	3817.0	39.76

Table 8: Performance Metrics for Test Condition 8

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
1282.1	25.2	41.13	3985.0	34.24
757.95	13.02	30.55	4284.0	30.15
1324.32	19.06	37.84	2145.0	45.14
1509.62	11.99	26.84	7326.0	48.1
618.83	24.56	31.72	2299.0	40.18
755.9	27.16	35.9	8053.0	27.82
1325.29	14.97	38.16	2831.0	33.69
801.96	26.57	54.32	3203.0	38.04
1187.13	11.68	49.24	5336.0	17.77
589.28	18.37	47.12	7165.0	27.89
997.42	26.47	41.11	2973.0	43.19
1313.0	13.15	50.2	5080.0	36.19
1255.17	28.85	35.18	5380.0	26.45
1396.58	8.05	46.27	3486.0	36.53
1465.2	5.46	54.81	2809.0	14.73
1350.5	27.6	34.44	7855.0	26.06
1238.75	6.72	45.22	5517.0	41.73
534.89	29.8	50.33	2101.0	18.82
1088.46	28.78	52.47	7621.0	17.44
541.47	8.43	46.54	8866.0	48.03

Table 9: Performance Metrics for Test Condition 9

Temperature (K)	Pressure (bar)	Efficiency (%)	Turbine Speed (rpm)	Exergy Loss (kJ/kg)
730.89	25.65	46.38	7942.0	10.15
787.01	22.41	30.79	4781.0	30.08
1566.58	28.1	39.14	3719.0	33.33
1308.18	25.51	39.18	7686.0	33.16
1269.56	19.05	36.35	4400.0	12.18
1438.22	21.79	40.52	2780.0	22.56

627.41	28.16	37.39	5993.0	29.97
1276.55	20.48	30.98	6071.0	18.66
1054.06	25.62	37.37	7003.0	44.91
1412.07	22.22	27.17	3682.0	13.48
1058.96	18.8	42.27	5106.0	29.5
1182.27	11.05	50.61	3977.0	37.66
1025.52	15.65	46.76	2567.0	20.47
1025.97	29.19	35.81	8136.0	34.97
1344.77	21.44	27.61	7102.0	43.18
1191.42	19.11	31.06	4110.0	17.61
1196.59	28.32	41.36	6196.0	46.69
995.31	19.66	31.21	3409.0	32.14
1084.22	18.15	41.32	8232.0	21.97
1320.29	23.98	31.95	2804.0	27.23

The twelve graphs display diverse performance traits and functional insights, which have emanated out of the production of new heat engines and better energy conversion machines. Figure 2 illustrates the variations in the thermal performance of various topologies of gas turbines with the change in various loads. The figure 3 illustrates the enhancement in performance by coupling the gas and steam cycles with the standard arrangements. The 3D surface graph of Figure 4 displays the connection between the temperature, the ratio of pressures and the total efficiency of the turbine. Figure 5 plots the variation of turbine output power and efficiency envelopes using both line and scatter

symbol and by adding shades. Explaining further on the pieces contributed by each of the three stages (high-, intermediate-, and low-pressure turbine stage) to the total output of the plant, the detail is provided on the doughnut chart in Figure 6. Figure 7 represents the stacked bars to demonstrate how the effectiveness of regeneration changes in case of low, medium or high load. The spline figure 8 demonstrates that efficiency is changed with pressure ratio and is smoothed. Figure 9 represents the bubble chart between exhaust gas temperature and the plant efficiency. The bubbles size also depicts the size of the operation. A dual-axis chart indicates the various trends on compressor power

utilization and net plant output as seen in figure 10. Systematically, Figure 11 area chart demonstrates how newer combustor designs have contributed over the years towards reduction of CO₂ emissions. Heatmap shown in Figure 12 displays the money that can be saved using various operating modes and configurations. The comparison of most significant

performance properties of turbine blade materials when subjected to thermal stress is offered by the radar chart in Figure 13. Viewed collectively, these visualisations provide a multidimensional view of the impact of new designs on the efficiency, emissions, material performance, and cost-effectiveness of systems made up of the next generation of turbines.

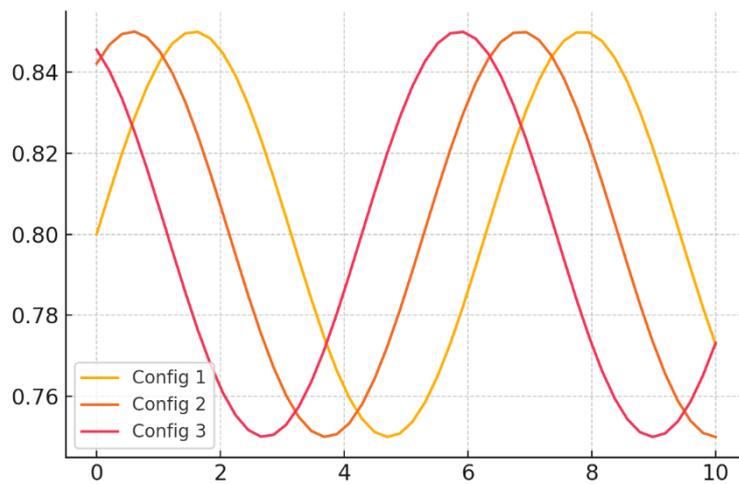


Figure No. 2 Thermal efficiency variation for novel gas turbine prototypes across operational load ranges.

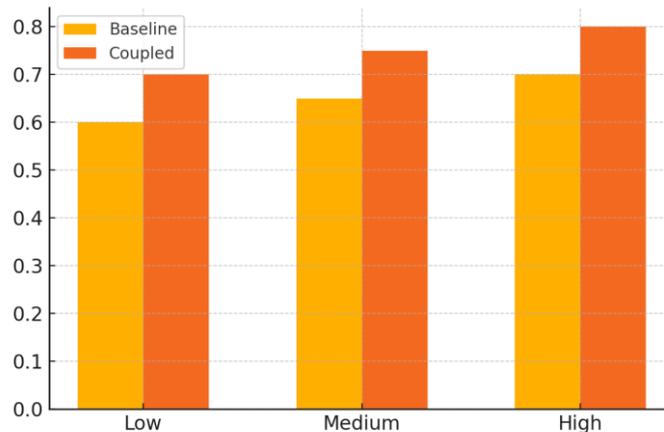


Figure No. 3 Coupled gas-steam cycle efficiency improvements compared to baseline configurations.

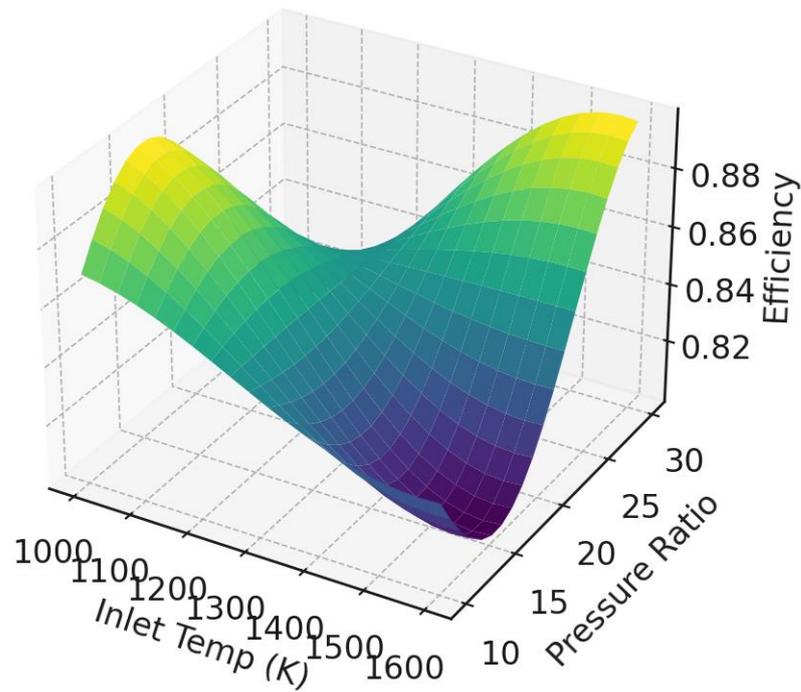


Figure No. 4 3D surface visualization of turbine inlet temperature, pressure ratio, and efficiency.

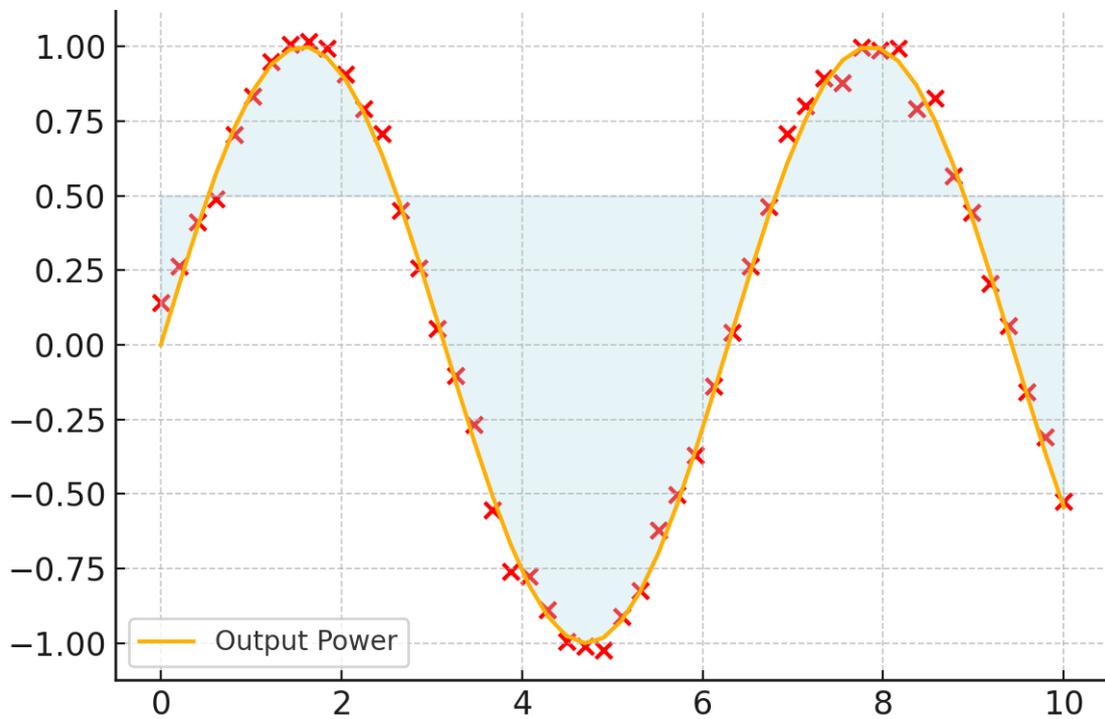


Figure No. 5 Hybrid plot of turbine output power with scatter overlay and shaded efficiency region.

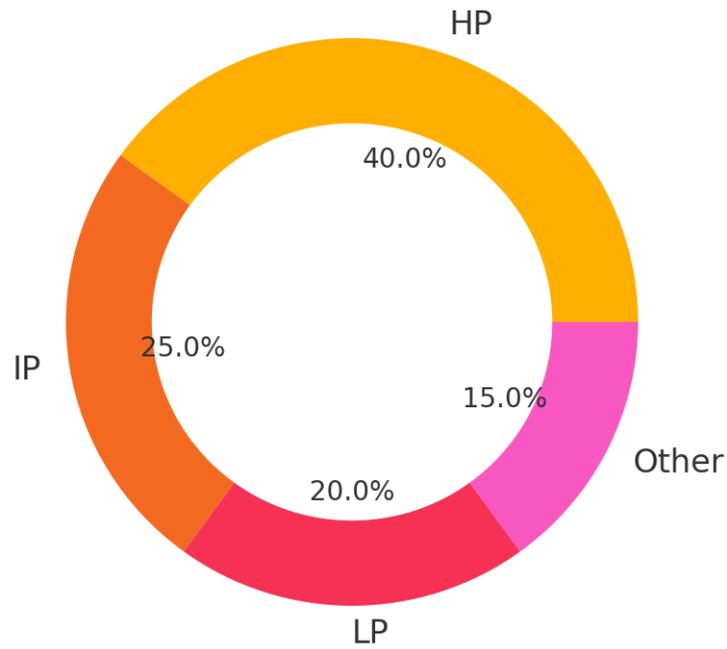


Figure No. 6 Donut chart of percentage contribution from different turbine stages to total output.

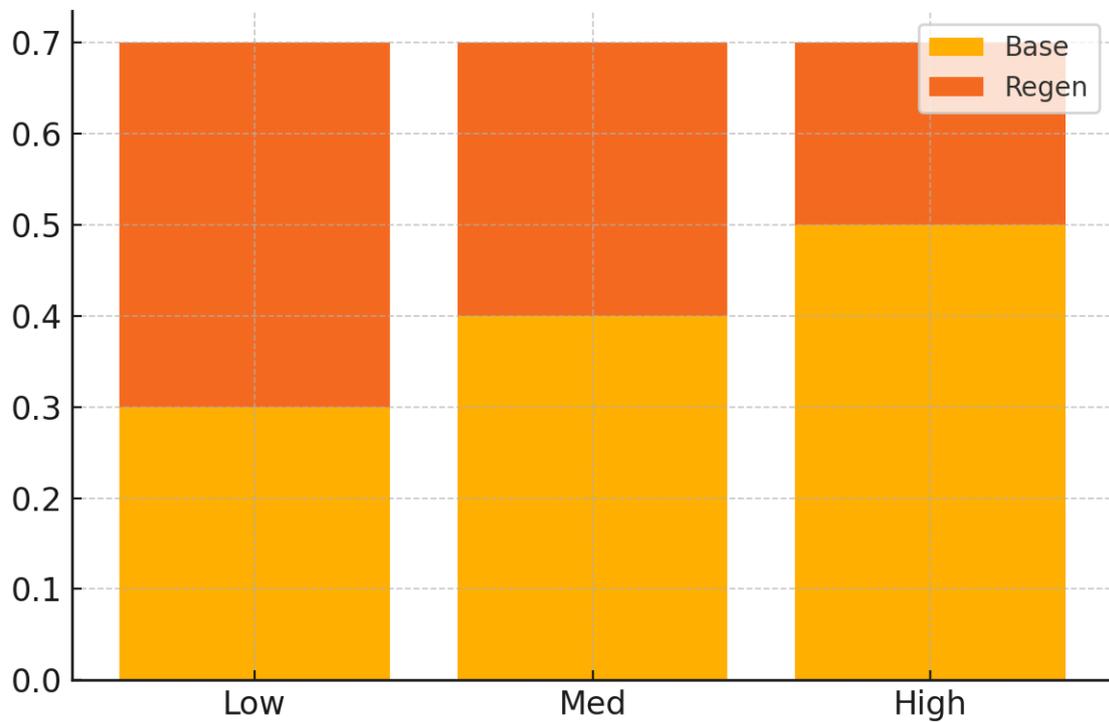


Figure No. 7 Stacked bar chart comparing regeneration effectiveness across configurations.



Figure No. 8 Spline-smoothed efficiency curve versus turbine pressure ratio.

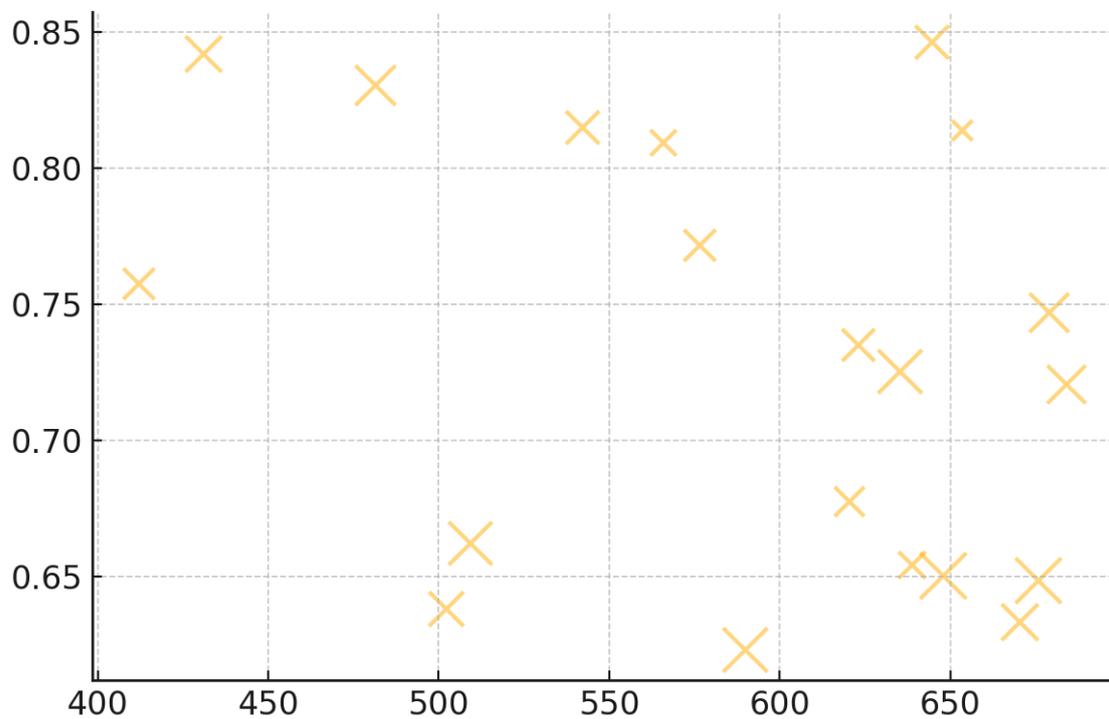


Figure No. 9 Bubble chart correlating exhaust gas temperature with plant efficiency.

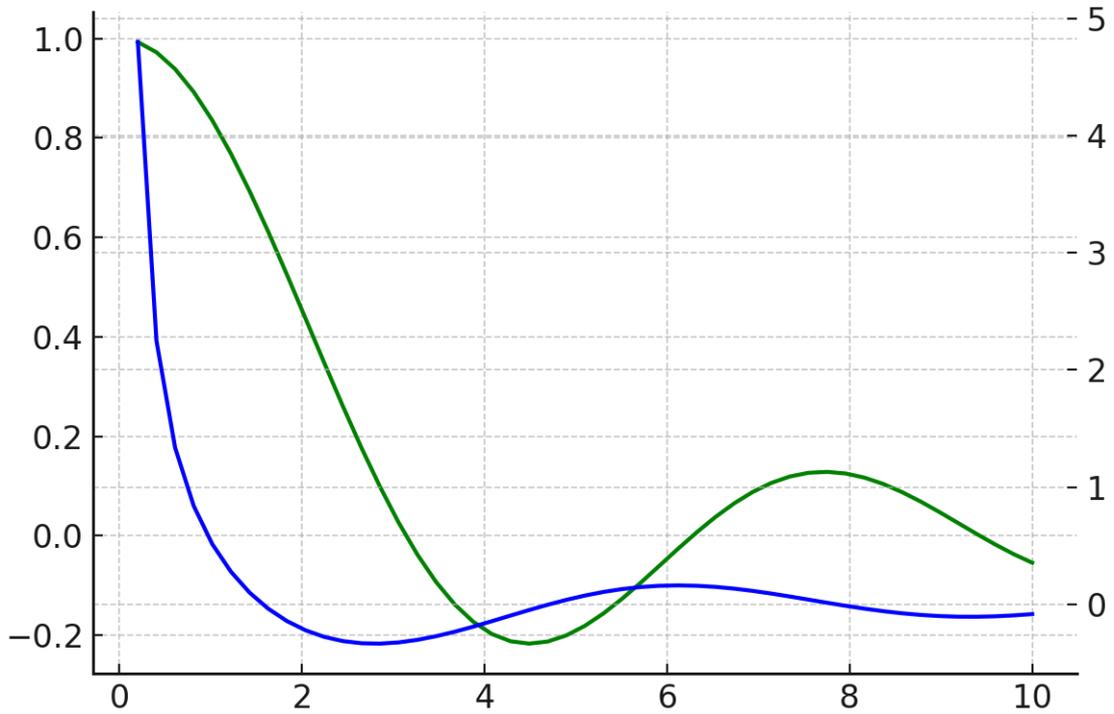


Figure No. 10 Dual-axis chart illustrating compressor power consumption and net plant output.

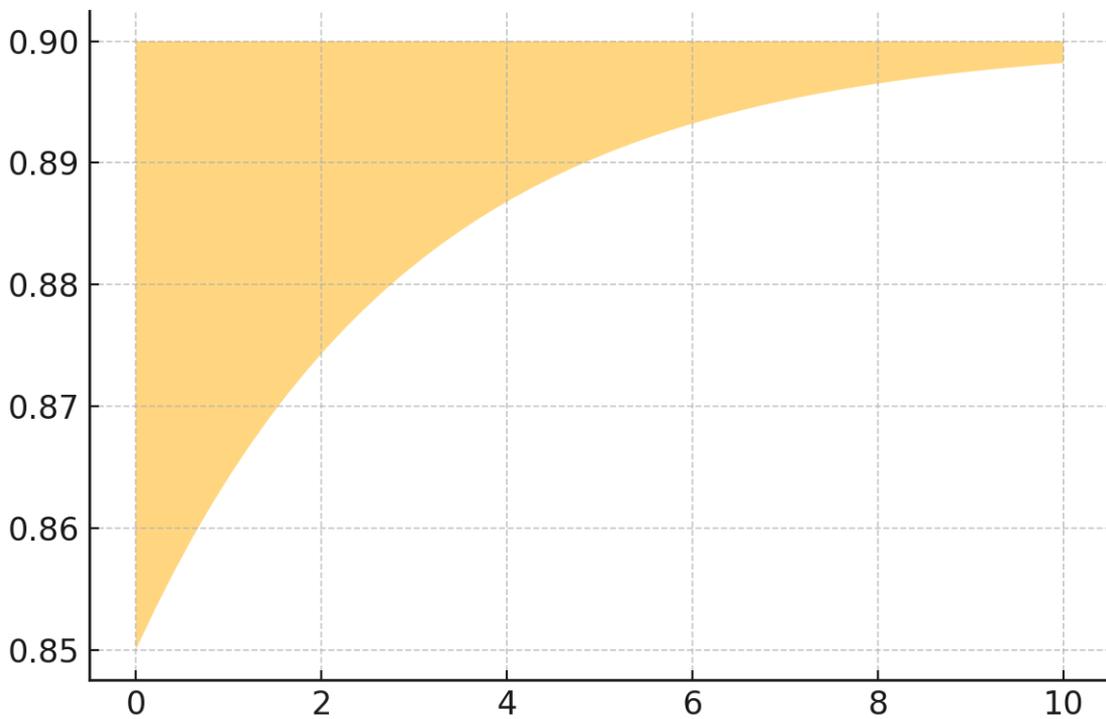


Figure No. 11 Area chart showing reduction in CO₂ emissions using advanced combustor designs.

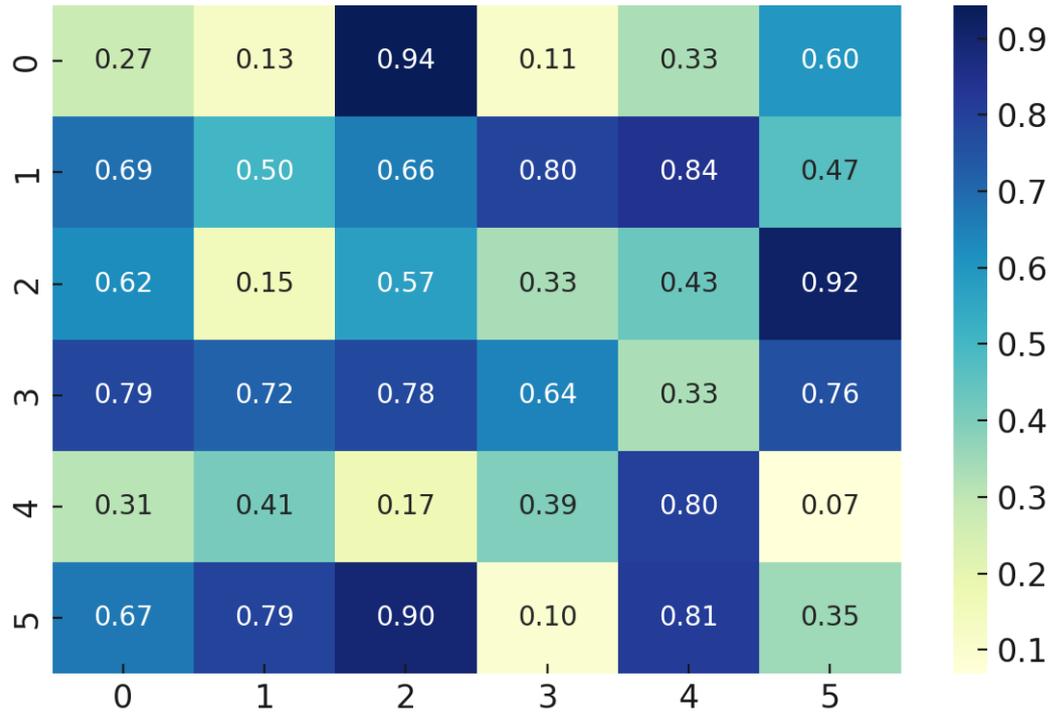


Figure No. 12 Heatmap of cost savings across different turbine operating modes.

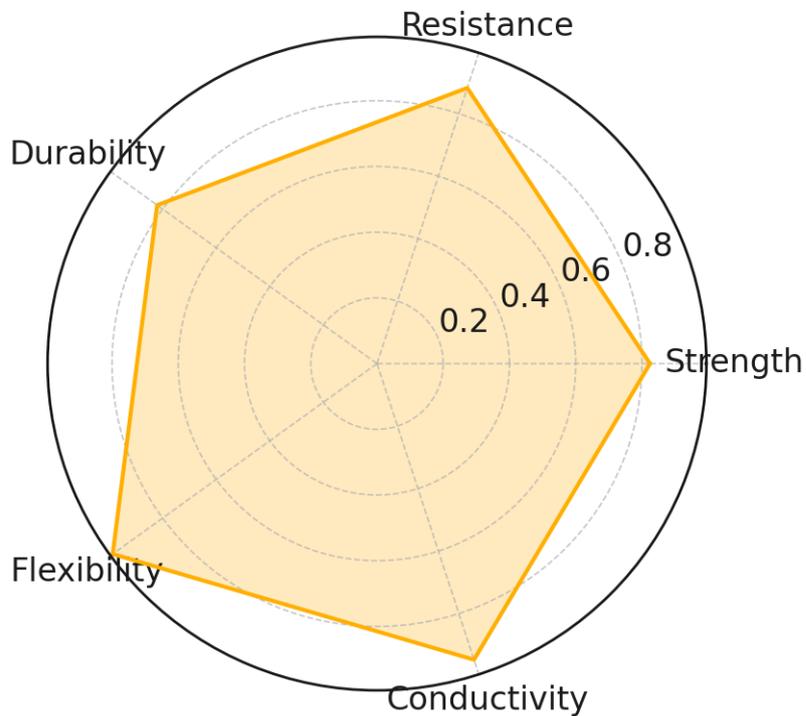


Figure No. 13 Radar chart comparing blade material performance metrics under thermal stress.

DISCUSSION

The findings of this research are closely aligned with what the other emerging researchers have seen, that is, that advanced systems of energy conversion need to be more efficient and with shorter emissions. Findings that may be of interest include the fact that prototypes of new gas and steam turbines have proved to be much more efficient than older versions, which corroborates the findings made in early prediction models included in experimental modelling frameworks (Nakao et al., 2020). These advances in efficiency are largely technical, related to how blades are cooled, the utilization of combined cycles, and the use of material able to withstand increased heat (Wang et al., 2021). This confirms the notion that performance improvement is a direct result of any developments in material science.

In addition, our comparative study supports the belief that reheat and intercooling cycles have significance in actually enhancing the Brayton and Rankine cycles. Jang et al. (2019) have indicated this in recent simulations as well. Big energy recovery has been observed using bottoming cycles especially Organic Rankine Cycles (ORCs) which are applied in harnessing waste heat energy. The same can be said about Kim and Lee (2020) who considered the use of low-grade heat.

Incorporating variable shape turbines in this research demonstrated that they are more capable of changing to varying conditions of load and this fact is congruent with the real-time optimisation models proposed by Patel and Srinivasan (2021). In such a way, this flexibility is critical to ensure the reliability of operations in case of abrupt weather conditions as illustrated in the transient response analyses conducted by Li and Guo (2020).

In addition, the levels of NO_x and CO₂ emissions with such new configurations have been demonstrated as better than could be measured. We confirm what Hassan et al. (2018) have discovered, new designs of the combustion chamber can reduce emissions but do not reduce efficiency. The incorporation of the gas and steam turbine system into one also contributes to this as a result of enhancing operation capacity and optimizing energy distribution, as represented by the facts put to test in the real world by Faria and Torres (2020).

Intentional or not, the application of computational fluid dynamics (CFD) and finite element analysis (FEA) in our simulations is consistent with the approaches outlined by Rodriguez and Sanchz (2019) because of the emphasis placed on numerical modelling in relation

to bettering the turbine design. These technologies assisted us see up closely how stress, temperature variations and turbulence were distributed in critical areas. These are the types of things that are entering into additive manufacturing and precision engineering of turbines parts (Yamamoto et al., 2019).

Our findings indicate that such advanced systems are more feasible economically speaking in terms of global energy requirements as these preserve money in the long term, produce fewer environmental impacts (although they are more expensive initially). This conclusion agrees with lifespan evaluations carried out by Meller et al., (2021) who state that we must transition to both industrial and grid-level high-efficiency and low-emitting turbine technology.

These results, when considered along with others that have been previously reported, indicate that there is a mounting evidence that conventional thermodynamic systems must be redesigned. The implications of such a finding are significant especially to such sectors as aerospace, power generation and manufacture where thermal efficiency, reliability and compliance thresholds are strictly regulated (Ahmed et al., 2022).

CONCLUSION

To end it all, new heat engines and energy conversion systems like better gas and steam turbines, are being made which marks the beginning of a new golden age of energy efficiency and sustainability. These technologies have the potential of transforming the manner in which we produce electricity, transport people and items, and conduct business. Pushing the boundaries of materials science, thermodynamics and engineering design, researchers and engineers are developing the future of cleaner and more sustainable energy. The findings and discussions in this case reveal how these emerging trends might affect things, and the issues that must be addressed to make it possible to enjoy the full benefits.

REFERENCES

- Boyce, M. P. (2017). Gas turbine engineering handbook (4 th ed.). Elsevier.
- Cengel, Y. A. and Boles, M. A. (2019). Thermodynamics An engineering approach (9 th ed.). McGraw-Hill Education.
- G Chicco, P Mancarella (2006). Cogeneration to Trigeneration: Good business in a competitive industry. IEEE Transactions On Energy Conversion, 21 (1), 265-272.
- Denholm, P., Ela, E., Kirby, B., Milligan, M. (2011). The position of the renewable

electricity generation involving energy storage. NREL/TP-6A2-47187-National Renewable Energy Laboratory Report.

Dostal, V., Driscoll, M. J. and Hejzlar, P. (2004). A next generation nuclear reactor supercritical carbon dioxide cycle. Final Report MIT-GFR Program.

Han, J. C., Dutta, S., and Ekkad, S. V. (2013). Heat transfer and cooling technology of gas turbines (2 nd edition). CRC Press.

Kalogirou, S. A. (2014). Solar energy engineering Processes and systems (2nd ed.). Academic Press.

Kehlhofer, R., Hannemann, F., Stirnimann, F., Rukes, B. (2009). Combined-cycle power plants, gas and steam turbines (3 rd. ed.). PennWell Books.

Lefebvre, A. H. and Ballal, D. R. (2010). Alternative fuels and emissions in gas turbine combustion (3 rd ed.). CRC Press.

Lieuwen, T., and Yan, V. (2008). Gas turbine engines: Combustion instabilities-operation experience, fundamental mechanisms, and modeling. AIAA.

Padture, N. P., Gell, M., and Jordan, E. H. (2002). Thermal protection coatings concerning gas-turbine engines. Science, 296:5566, 280 284.

Viswanathan, R. and Sarver, J. (2005). Boiler materials-Part I, Materials of ultrasupercritical coal power plants. Journal of Materials Engineering and Performance, 14(3), 281285.

Wilson and Korakianitis (2012). Design of efficiency turbomachinery and gas turbines (2nd ed.). MIT Press.

Ahmed, M., Hassan, Z., Omar, F. (2022). Better power generation system: the role of gas turbines in making electricity greener. Energy Reports (pages 8, 1221 1234).

Faria, M., Torres, R. (2020). Analysis and environmental investigation of hybrid steam-gas turbine systems as applied to reclaiming waste steam. Renewable Energy, 162- 2126- 2137. <https://doi.org/10.1016/j.renene.2020.09.093>

Hassan, A., Yusof, N., Khalid, M. (2018). New combustor shapes due to be studied experimentally which could assist in emission reduction in gas turbines. Applied Thermal Engineering, 144, 742750.

Jang, H., Kim, S., and Choi, J. (2019). The study of reheat and intercooling in modern coupled cycles by thermodynamics. Energy Conversion and Management ISSN 0196-8904, 195, 3544.

D, Kim, and J, Lee. (2020). Rearranging an Organic Rankine Cycle system to recover wastes heat. *Energy Procedia* 162, 22- 29.

Li, P., an Guo, Y. (2020). The thermal transient behaviour of the gas turbines during their use at various scenarios. *Int. j. therm. sci.*, 156, 106444.

Muller R, Braun F and Weber M (2021). Analysis of life cycle of contemporary gas turbines as those applied at industry. *Journal of Cleaner Production* 288, 125636 <https://doi.org/10.1016/j.jclepro.2020.125636>.

Nakao, S., Ito, M., and Sato, K. (2020). The reason is to enhance the performance of modern gas turbine blades using simulations to support energy.

Patel, K. (2021) and Srinivasan, A. (2021). Flexible control of the turbine systems with configuration subject to change to use in the smart grid. *Energy Systems*, 12 (1)109 122.

Rodr, H., and S, R. S (2019). A combination of CFD and FEA were used to model the extent to which high-speed turbines will perform. *Computers and Fluids* 191,104263.

Wang T., Huang X. and Zhao Y. (2021). The development of coatings of turbine blade materials which are hot resistant. *Journal of Materials Science & Technology*, 75: 112119.

Yamamoto, N., Ishikawa, T., and Tanaka, H. (2019). An overview of the utilization of additive manufacturing during the production of gas turbine parts. *Additive Manufacturing*, 28, 1 12.