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Performance Characteristic prediction of Allison and GPU-3 Stirling Engine Using Mathematical Model

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Abstract : *A low temperature ratio Stirling engine analysis required for cost effective, less environment harmfulness and more efficient power generation for this temperature ratio. A new and complete model for a Stirling engine has been established. This computerized model predicts the behavior of existing engines reasonably accurately for cases where a quantitative comparison is available. In order to obtain a closed solution suitable for design optimization a model for a Stirling engine has been derived considering different types of losses in this engine. This new model has sufficient accuracy for prediction of the behavior a real engine and its results are quit close to the complete model predictions.*
A general method of Stirling engine design optimization is presented. This method, which is based on the computerized model, separately optimizes each components of the engine. Different correlations are used to determine optimum geometry for each of the heat-exchangers, based on Mach number, Reynolds numbers, operating temperature ratio, and heat exchanger dead volume. This optimization method utilizes derived results for optimum swept volume ratio, phase angle difference between the cylinder displacements, bore-stroke ratio, and engine speed.

***Keywords**-Stirling engine, Performance prediction, Schmidt analysis, Phase angle, Engine speed, Heater temperature*

I. INTRODUCTION

Analysis of the Stirling cycle is complicated by the fact that not all elements of the working fluid pursue the same thermodynamic cycle. Since the ideal cycle analysis has been presented in closed form solutions, and then they are useful for preliminary design and first order calculations. In this section the first order analysis (Schmidt equations) are presented with considering different types of losses in Stirling engine.

II. IDEAL STIRLING CYCLE, SCHMIDT EQUATIONS

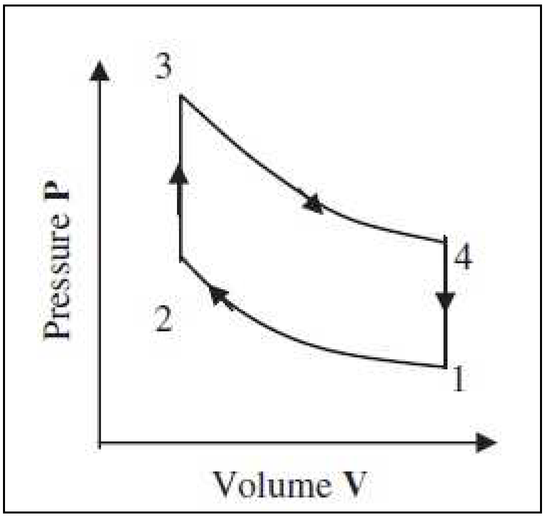

Figure-1: Ideal Stirling Cycle P-V Diagram

As shown in Figure-1, the ideal Stirling cycle consists of two isotherms connected by two isochors. These processes may be produced by interconnecting two suitably varying volumes through a regenerator. The cycle starts with isothermal compression in the cold space at cold temperature TC, process 1-2. Then the gas flows through the regenerator and gains enough heat to reach the hot temperature TH. This heating is such that the same volume of gas which enters to the regenerator from cold space should discharge from regenerator to hot space, i.e. the volume variations of hot and cold spaces must be appropriately related. This constraint is necessary to satisfy the isochoric heating process 2-3. Then gas expands isothermally in hot space (hot cylinder) at TH, requiring heat to be added to gas to maintain it at TH, process 3-4. Then the gas returns through the regenerator where heat is removed from the working fluid and stored for its subsequent return, process 4-1. So, defined engine is very idealized and impractical engine. A more realistic cycle and corresponding analysis was devised by Gustav Schmidt in 1871. This analysis which has a sinusoidal volume variation has now become the classical analysis of the cycle and is generally believed to give a more reasonable approximation of actual engine performance. Nevertheless, the analysis still remains very highly idealized, so that in practice the indicated performance of an engine will likely be no better than 60% of the predicted Schmidt cycle performance.

Principal assumptions of the Schmidt cycle are [1]:

1. The regenerative process is perfect.
2. The instantaneous pressure is the same throughout the system.
3. The working fluid obeys the characteristic gas equations, PV=RT.
4. There is no leakage and the mass of working fluid remains constant.
5. The volume variations in the working space occur sinusoidal.
6. There are no temperature gradients in the heat exchangers.
7. The cylinder wall and piston temperatures are constant.
8. There is perfect mixing of the cylinder constants.
9. The temperature of the working fluid in the dead volumes is constant.
10. The speed of the machine is constant.
11. Steady state flow conditions are established.

III. Suggestion for Performance Characteristics

3.1 Allison engine

The investigation conducted by the Allison division of General Motors Corporations [21] has been the only test reported in which all conditions were described in sufficient detail to give a reliable verifications of the overall model. The development of this engine was part of a space-power program and several engine designs were built and tested as part of the project.

(1) Phase angle

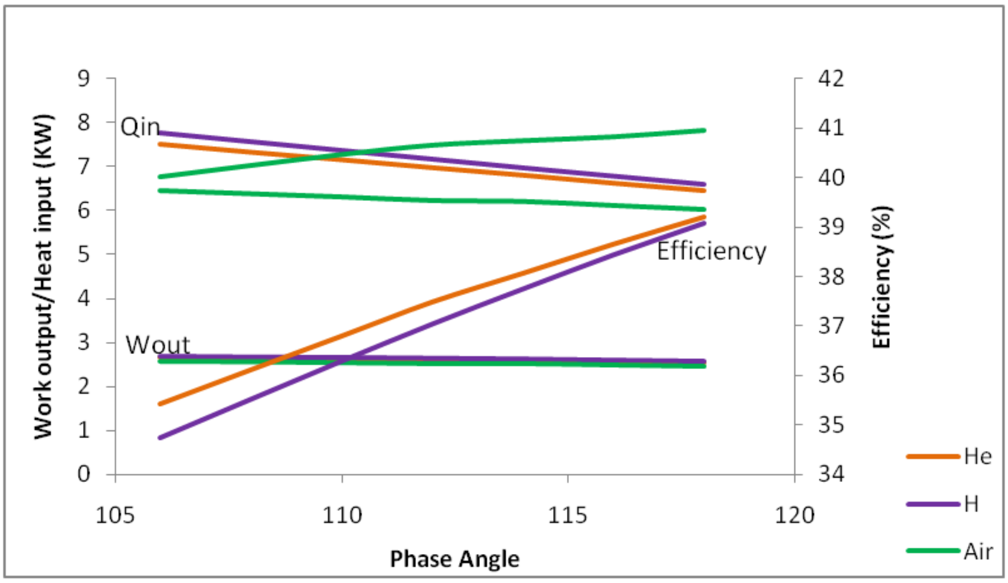

Figure-2: Predicted performance of Allison engine with Phase angle

Figure-2 shows that as phase angle increase work output will remain almost steady but heat input requirement will decrease as a result of it as phase angle increase engine efficiency will increase.

Also air has almost straight and higher efficiency compare to other two working medium. And in Hydrogen work output is higher than Helium and Air but also heat input requirement is higher so overall efficiency is lower than other.

(2) Mean pressure

Figure-3 shows the performance characteristics of engine with mean pressure. As pressure increase work output and heat supply will increase and as a result of it, finally efficiency increases.

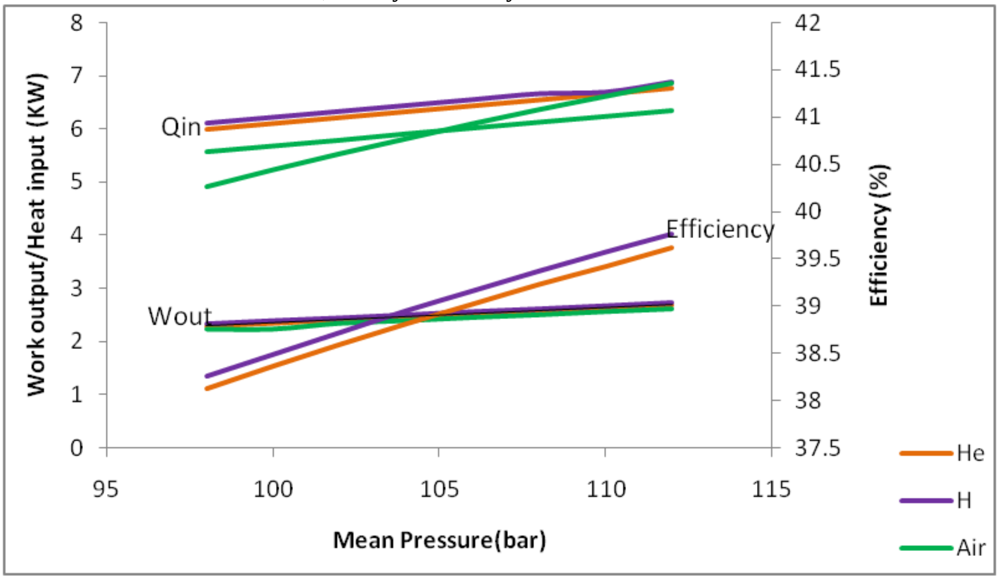

Figure-3: Predicted performance of Allison engine with Mean pressure

In this case also Air has higher efficiency than other two due to lower requirement of heat supply compare to other and work output of engine will remain almost straight in all cases.

(3) Engine Speed

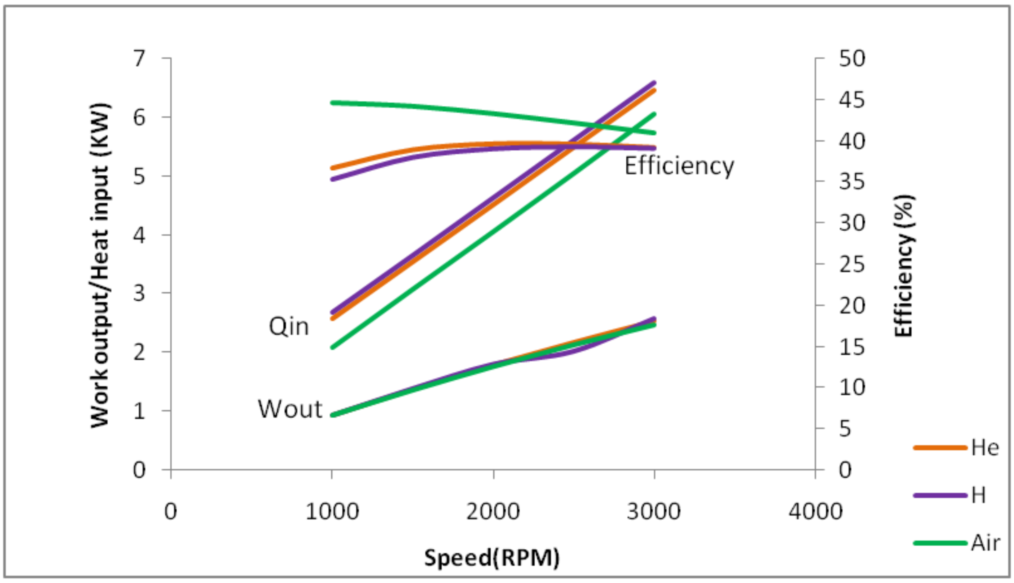

Figure-4: Predicted performance of Allison engine with Engine speed

Figure-4 shows performance characteristics of engine with changing engine speed. As shown here, engine speed increase work output and heat supply in engine will increase. But efficiency in case of Hydrogen and Helium will increase up to 1800 RPM and it will decrease gradually so 1800 RPM is optimum speed for better efficiency. So it’s advisable to run this engine at this optimum speed.

In case of Air efficiency will always decrease with increase in speed but its required less supply of heat compared to Hydrogen and Helium so its maintain more efficiency then Hydrogen and Helium.

(4) Heater Temperature

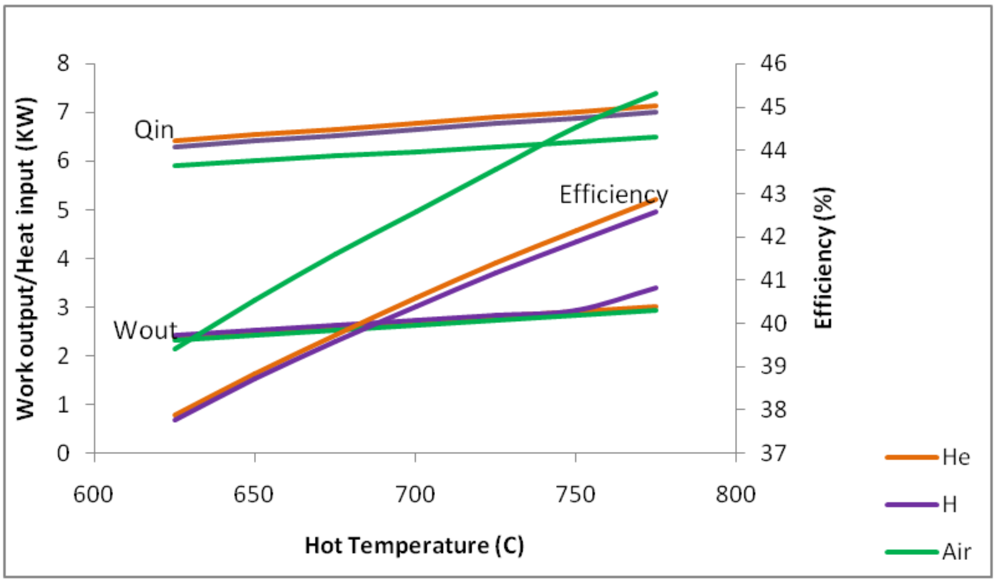

Figure-5: Predicted performance of Allison engine with Heater Temperature

Figure-5 shows the performance characteristics of engine with increase in Heater temperature. As its increase work output and heat supply both increase gradually and finally as a result of it efficiency also increases. So it's advisable to keep heater temperature as high as possible up to metallurgical limit of parts.

(5) Cooler Temperature

As shown in Figure-6 if engine cooler temperature will increase than work output and heat supply decreases with it.
In this case also due to low heat input requirement there will be higher efficiency than other two working medium. So it's advisable to keep cooler temperature as low as possible.

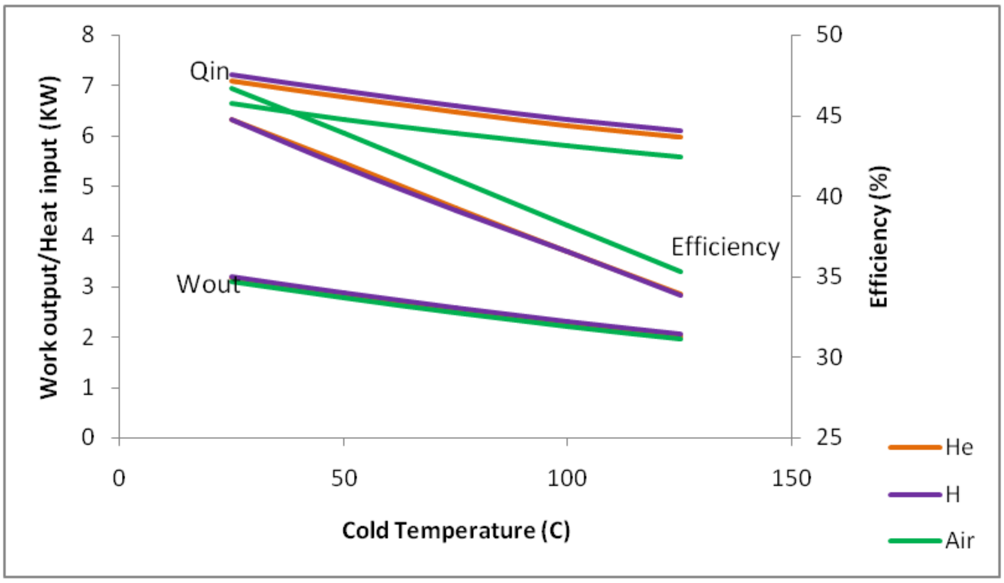

Figure-6: Predicted performance of Allison engine with Cooler temperature

1.3.2 GPU-3 engine

General Motors Research conducted a program for the U.S. Army to produce a silent electric power source in 1960s. This Ground power unit (GPU) development went through three different models.

(1) Phase angle

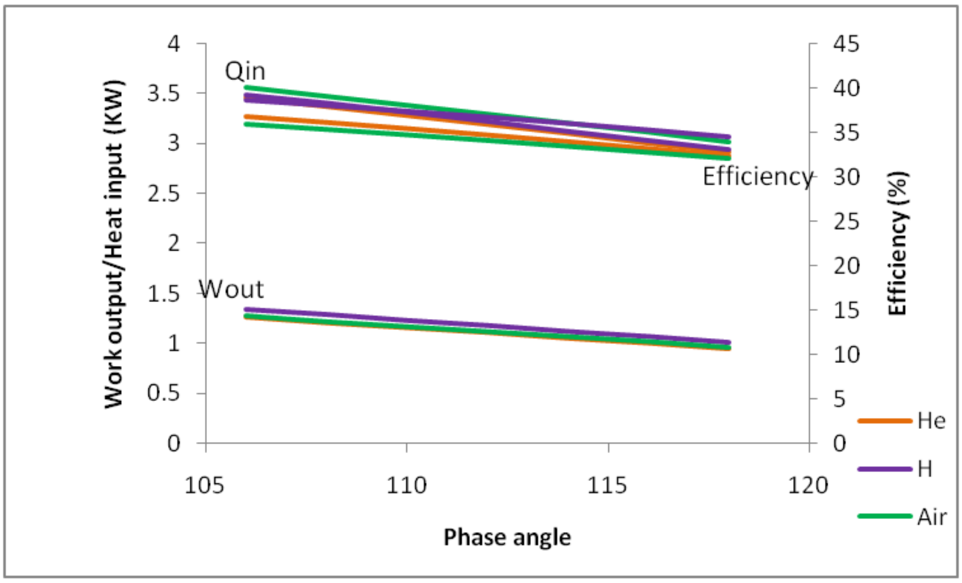

Figure-7: Predicted performance of GPU-3 engine with Phase angle

Figure-7 shows the performance characteristics of GPU-3 engine with changing its phase angle. In this case as phase angle increase, work output and heat supply both will decreases gradually and as a result of its finally efficiency will decreases.
Also in this case at lower phase angle Air has more heat requirement compare to other and less heat requirement at higher phase angle. Also in this engine Helium perform more efficient than other at lower phase angle and its entire have almost same performance characteristics at higher phase angle.

(2) Mean pressure

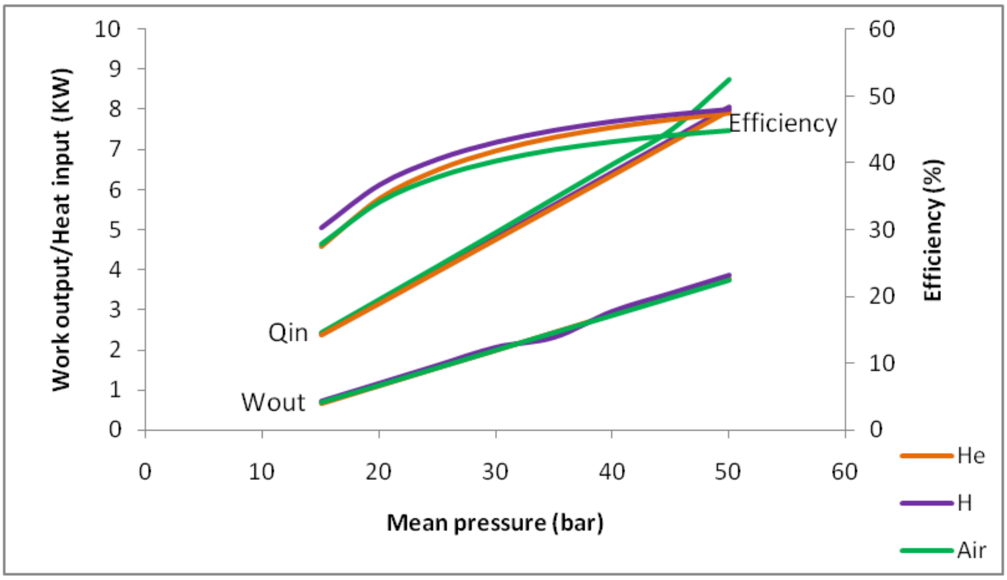

Figure-8: Predicted performance of GPU-3 engine with Mean pressure

Figure-8 shows performance of engine with changing mean performance. As pressure increases work output and heat supply both increases. But efficiency sharply increases up to 24 bars and then its try to be flatter.
In this case higher mean pressure required more heat supply and decreases it's decreases efficiency.

(3) Engine speed

Figure-9: Predicted performance of GPU-3 engine with Engine speed

Figure-9 shows that as engine speed increases work output and heat requirement both increases, but efficiency will decreases. In this case at lower engine speed Air perform better and at higher speed Helium perform better.
So it's advisable to use Air as a working medium at lower engine speed and Hydrogen as a working at higher engine speed for this engine.

(4) Heater temperature

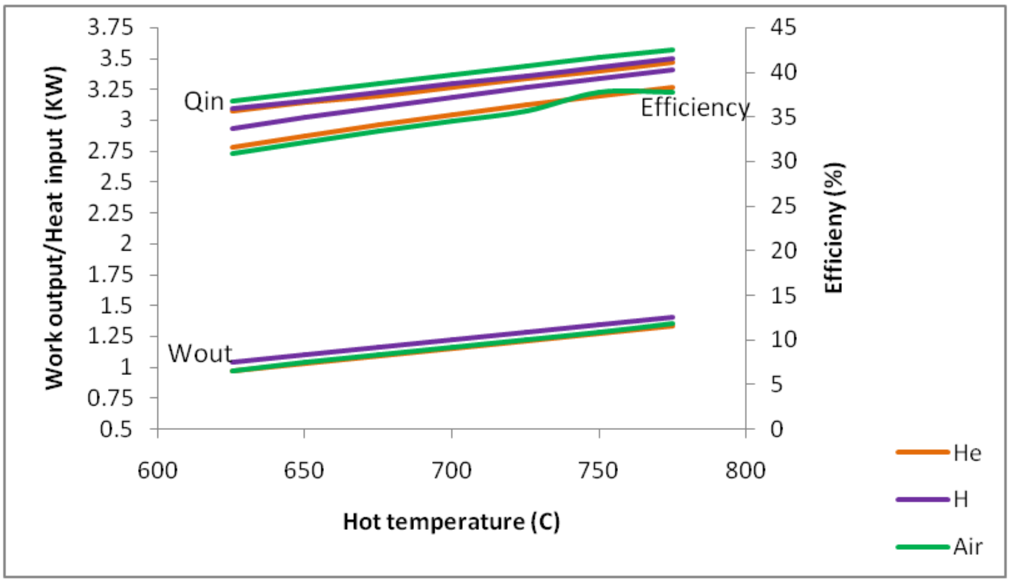

Figure-10: Predicted performance of GPU-3 engine with Heater temperature

As shown in Figure-10 as heater temperature increases, work output, heat supply and finally efficiency also increases. In this case Hydrogen has better performance and it's not advisable to use air as a working medium for this engine.

(5) Cooler temperature

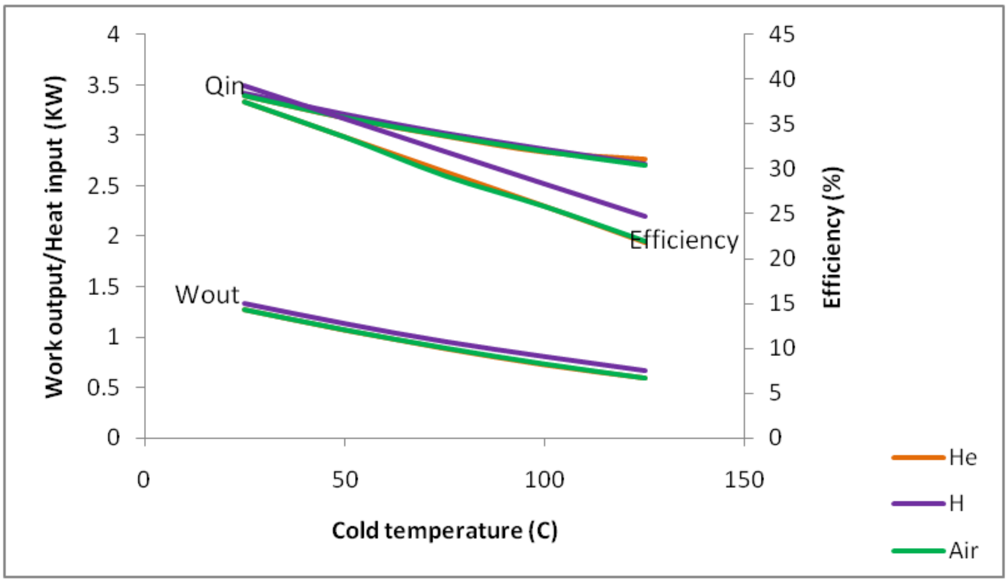

Figure-11: Predicted performance of GPU-3 engine with Cooler temperature

As shown in Figure-11, if we increase cooler temperature than work output, heat supply and finally engine efficiency will decreases. Also in this Hydrogen perform better than other working fluid.

CONCLUSION

Computational model of Stirling engine expresses the Stirling engine performances in closed form solution predicts the behavior of real engines accurately and it is well suited for optimization in closed form solution predicts the behaviors of real engine accurately and it is well suited for optimization studies and for studies of engine performance under extreme conditions. This model allows deriving a general optimization method.

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