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Determination of Coefficient of Performance of Stirling Refrigeration sm

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Abstract: ***Refrigeration is a process of reducing the temperature of the desired space under atmospheric temperature. The present system focuses on the design and fabrication of a Stirling refrigeration system with a β-type configuration. The refrigerants carbon dioxide and helium are used and the efficient among them is determined. The objective of the work is to achieve rapid heat transfer from the system and to reach a temperature of below -10 degree Celsius, which is done by reversing the cycle of a stirling engine by providing mechanical energy. This system consists of displacer and piston which is linked to a rhombic drive mechanism which is operated by the motor. Regenerator placed inside the displacer will absorb the heat to give out the cooling effect. Stirling-engine coolers are used as cryocoolers, a very efficient cooling device, in superconductivity and electronic research. They are found to be useful in many space applications due to their long working life and reliability as cryocoolers. The cooling effect obtained by the system and the work done to operate the system is determined and the COP is determined for both the working substance.***

Index Terms: ***Refrigerent [1], COP [2], Rhombic drive[3], regenerator [4]***

I. INTRODUCTION

In recent studies, there have been different types of cooling system which have been used widely in different industries. Stirling motors are characteristically cleaner contrasted with diesel motors and calm because of their utilization of outside, steady weight burning. They don't ordinarily require a diesel particulate channel as sediment molecule creation is limited. Because of their mechanical simplicity, and consolidation of gas orientation, modern free-cylinder Stirling motors are sturdy and have exhibited lifetimes in excess of 50,000 hours.

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The major challenge in this system is the amount of power used to run the system. So, this research shows how a Stirling cooler is used efficiently which works with less power and improve the coefficient of performance. Stirling engine creates little vibration contrasted with the interior ignition engine. On account of the absence of the blast, the nonappearance of the valves that open and close, the absence of gas getting away from, the Stirling engine requires simple upkeep. These engines are powerful and crumble less rapidly than inner burning engines. In contrast to the interior ignition engine, Stirling engines fit with any heat source, apart from conventional engines.

II. LITERATURE REVIEW AND RELATED STUDIES

A. Literature Review

Caughley et. al. [1] performed a CFD analysis of a free piston Stirling cryocooler which uses a combination of metal diaphragms to enclose and interrupt the displacer. The diaphragms favors the displacer to move without brushing into the surface. This design helps to reduce the demand and size of the heat exchangers. Song et. al. [2] studied the cryogenic structure and explained how to contain CO_2 catch without pressure drop condition. In this work, the novel framework was connected on CO_2 catch from post-burning vent gas and diverse procedure parameters were explored to acquire the maximum performance. Tijaniet. et al. [3] studied the cooler which uses the acoustic power created by a direct engine to siphon heat through a regenerator from a cold heat exchanger to an ambient one. This efficiency outperforms the execution of the most productive standing-wave cooler by just about a factor of two. Yin et. al. [4] studied a general irreversible quantum Stirling refrigeration cycle. He considered heat spillage considering non- ideal regeneration loss. The results of this paper are important to comprehend the quantum thermodynamics cycles with a molecule bound in various potential as working substance. Li et. al. [5] studied duplex Stirling cooler, In his research paper he used a resonance tube coupled duplex Stirling cooler, which utilizes a basic resonance cylinder to coordinate the impedance between the motor and the cooler. McFarlane et. al. [6] studied the numerical model considering alpha Stirling cooler with air as the working liquid and will be useful in upgrading the mechanical structure of these machines.

Ahmed et. al.[7] studied the numerical modeling which considerably contribute to the performance improvement and technological advancement of Stirling engines. Kaldehi et. al.[8] has presented an investigation of the structure of an Alpha-type Stirling motor which is fit for working in sensible working condition ranges. This led to finding out the working fluid used in the system like hydrogen, helium etc. Hachem et. al. [9] built a productive theoretical model that can precisely anticipate the performance of the designed engine.

The shaft power indicated power, and thermal efficiency of the engine is Studied. Moreover, a model engine has been assembled and tested to approve the model .Wang et. al. [10] has studied the development of Stirling cycle engines for recovering low and moderate temperature heat. This effort shows that a cost-effective Stirling cycle engine is useful for recovering small-scale spread out low-grade thermal energy from various sources. Açıkkalp et. al. [11] presented a research paper to show an alternative environmental friendly energy system consisting of a solar driven Stirling Engine, chemical heat pump, and absorption refrigeration system. Yang et. al. [12] has studied Stirling thermos-compressor which typically works at low frequency which is a Stirling-type external-combustion engine. It uses the temperature dissimilarity between heating and ambient temperature to produce thermos-acoustic power and pressure wave for refrigerators. Hang-Suin et. al. [13] studied and presented a theoretical model by joining altered non-ideal adiabatic model and dynamic examinations so as to anticipate the dynamic conduct of a 1-kW class beta-type Stirlingmotor. Ahmadi et. al. [14] studied the sterling refrigeration cycle and the main aim of this research article is a parametric demonstration of irreversible Stirling cryogenic refrigerator cycles that incorporates irreversibility. Jan et. al.[15] studied the numerical models which have been created by the creators, and the results of which might be utilized to structure a trial refrigeration unit working in the Stirling cycle. The benefit of demonstrating is the computation speed when contrasted with displaying dependent on full Navier-Stokes arrangement of conditions in this manner empowering the dimensioning of the gadget. Breeze et. al.[16] has studied and shown that the Stirling motors are being completed around the world, utilized for drivers' application, for example, solar multi-target improvements strategies are valuable for anticipating geometric and working parameters relating to the ideal exhibitions of the Stirlingmotor. Doğan et. al.[17] in this research the overall design and performance of the Duplex system are analyzed with different refrigerants/working fluids. It makes use of both Stirling Engine and Stirling refrigerator. Gadelkareem et. al.[18] has studied a scientific model in order to study Stirling cycle. Diverse plan parameters controlling the execution of the Stirling cycle fridge/heat pump were advanced so as to accomplish the desired cold and hot water temperatures at high efficiency. Katool et. al.[19] has studied the disadvantages of petroleum products regarding engines with the likelihood of environmentally friendly power vitality utilization. The Gamma-type Stirling cooler utilized in the current examination has better outcomes in correlation with other announced outcomes for V-type and Free-cylinder Stirling refrigerator in the weight of 3 bar. Yuanyang et. al.[20] has studied the V-type integral Stirling refrigerator comprising of an expansion cylinder, a compression cylinder and a heat exchanger in-between is made and tested in this research. The parameters, for example, the power utilization and the coefficient of power are examined under different turning speeds and charged weights. Cheng et. al.[21] developed a beta-type Stirling cooler with a rhombic drive system. Thermodynamic design and preliminary research are made and directed in correspondence. Flannery et. al.[22] the importance of technological demands for a heavy truck secondary power unit and examines a possible alternative technology for the next generation secondary power unit which could reduce essential problems linked to emissions, noise and maintenance undergone today by standard diesel engine vapor compression secondary power units. Izadiamoli et. al.[23] studied Otto Stirling method with the purpose of simultaneous generation of energy and cooling using the waste power of exhaust gases. Two situations are evaluated based on fuel economy, emission decreasing, and economic viewpoints. Langdon-Armsa et. al. [24] has designed a solar-powered refrigerator in the moderate capacity range of up to 5kW of cooling power. By the application of liquid pistons and one of the various ancient thermodynamic cycles identified the Stirling cycle, this result has the potential to better competitive to solar cooling technologies while producing cheap, safe, low, environmentally-friendly for domestic application, due to its sincere fabrication, easy design and inactive working gas. Mikalsen et. al.[25] has discussed about two other types of engines that depend on the reciprocating motion of pistons to produce power, the Stirling Engine and Free Piston Engine.

B. METHODOLOGY:

The system consists of following main components:

1) Half HP Motor
2) Cylindrical casing
3) Displacer
4) Power piston
5) Two similar gears
6) Connecting rod
7) Regenerator

The Stirling engine, as most warmth engines, cycles through four fundamental procedures: cooling, pressure, warming, and extension. This is practiced by moving the gas forward and backward among the hot and cold end of the chamber. The tube-shaped packaging is isolated into two, Upper packaging and lower packaging where the upper packaging is the place the development of the displacer is accomplished, and lower packaging is the place the snapshot of intensity piston is accomplished. As the Stirling engine is a shut cycle engine, the chamber is fixed with working liquids regularly air, hydrogen or helium. The power piston is firmly fixed and the displacer which is in all respects freely fitted with the goal that air can move openly between the hot and cold areas of the engine. A regenerator is set inside the displacer which goes about as a warmth exchanger and in this way store heat from the hot liquid in a warm capacity medium before it is moved to the chilly liquid. The displacer and power piston are set inside the chamber packaging such a way, that it is arranged on the focal point of the total packaging setup.

The inside arrangement of the barrel-shaped packaging makes it simple for the get together of piston association pole and displacer association bar. The midway adjusted displacer interfacing pole experiences the empty piston association bar where both the interfacing pole is associated with the rhombic drive joins. The rhombic molded connections are associated with the two riggings; the development of the apparatuses is accomplished by a half HP motor associated with one of the rigging shafts, as the apparatus pivots the connections move and hence the snapshot of the piston and displacer is seen.

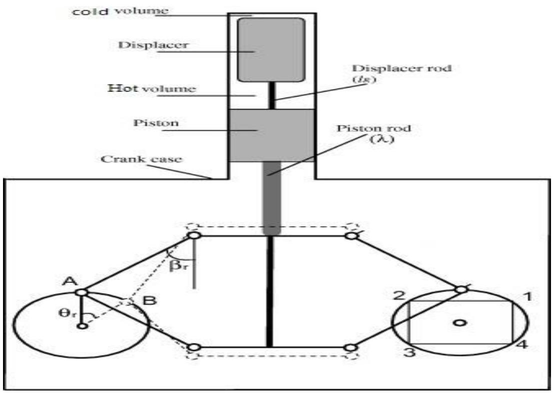

Fig. 1. Systematic diagram of Stirling engine refrigerator with rhombic drive mechanism

Stirling engine is a thermodynamic gadget works in principle at Stirling cycle and utilize compressible liquid, for example, air, hydrogen, helium, nitrogen or steam is utilized as the working liquid. The Stirling engine offers the likelihood to have a high-productivity engine with low fumes emanations contrasted with interior burning engines. Stirling engine is a warmth engine working by cyclic pressure and extension of the working liquid at various temperature levels that reason any net change of warmth vitality to mechanical work

Ansys Testing

After the whole design has been completed, the design has to be tested. Therefore In order to test the casing of the system model the use of Ansys software was introduced to find the temperature distribution, total heat flux , total deformation and equivalent elastic strain of the casing, the results gained from these where used to correct the errors and redesign the casing

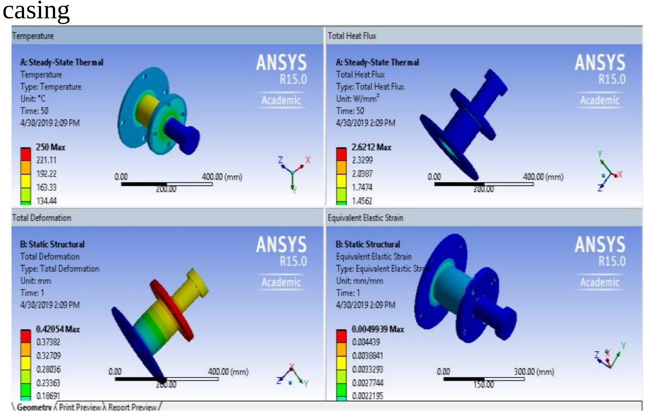

Fig.2. Ansys software test result

Study Design

The model was designed using the locally available resources and working in a team. It took several weeks to accomplish the working model within the given time and budget. Following strategic approaches are followed to achieve our goal.

2.4 Design, Installation and Manufacturing Design

The 3D design of the stirling refrigeration system was done using Solid Works, and AutoCAD was used for drawing parts for manufacturing in 2D. We also have done the analysis of the system using Ansys Workbench to identify the different properties like temperature distribution, total deformation, strain, stress, total heat flux, and limitations of the system before fabrication.

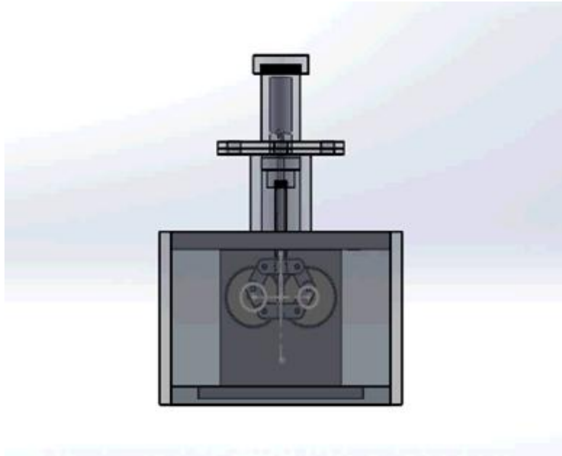

Fig. 3. Design conducted in Solid works

2.5 Fabrication

These are some of the main parts manufactured on referring to various research papers

- **Displacer**

The material used for this part is aluminum, since it is light weight, corrosion resistant and has good thermal conductivity. Aluminum is a very desirable metal because it is more malleable and elastic than steel.

Fig. 4. Displacer linked with the connecting rod

- **Piston**

The material used for this part is mild steel. It is very strong and can be made from easily available natural materials and since it is less expensive So, in this project for piston and piston link we will be using mild steel.

Fig. 5. Power piston linked with connecting rod

- **Rhombic Drive Mechanism**

Fig. 6. Rhombic drive mechanism

The rhombic drive is a particular strategy for moving mechanical vitality or work, utilized when a solitary chamber is utilized for two independently wavering pistons. In structure the connections we will utilize the mellow steel for better steadiness and will have the solidarity to withstand the speed of the motor and furthermore since the material is more affordable

- **Spur Gears**

Spur gears are the most well-known sort of gears. They have straight teeth and are mounted on parallel shafts. Now and then, many spur gears are utilized without a moment's delay to make huge rigging decreases We are utilizing a top notch steel spur gears in the scope of apparatus proportions.

Installation of Main parts

Some of the main parts of stirling engine refrigerator are piston displacer and gears. The displacer is placed inside the upper casing where as piston is placed inside the middle casing which is connected to the rhombic drive links using connecting rods, which is further connected to the two gears.

Fig.7. Complete setup of the parts

Power

The power generated for the moment of the piston and displacer in most of the research papers are through an external heat source which allows the gas to expand such a way that the moment of the piston is achieved thus displacer comes down. However, in this model the external source is replaced with a half HP motor. A half HP motor is used to rotate the gears hence moving the displacer and piston back and forth. To control the speed of the motor a regulator is introduced in to the system. The Stirling engine refrigerator can also acts as heat pump when reversing the rotation of the motor.

Fig. 8. Half HP motor

II. MATH

2.9 Calculations

- Volume of refrigerator: (1)

$$V_r = \pi \times r^2 \times h$$
$$= \pi \times 15^2 \times 85$$
$$= 60082.95\, mm^3$$

- Swept Volume Ratio: (2)

$$Dv = \frac{v_{DS}}{v_{PS}}$$

- Dead volume ratio in expansion space: (3)

$$X_E = \frac{V_{DE}}{V_{DC}}$$

- Compression ratio: (4)

$$C_r = \frac{Total\ Volume}{Clearence\ Volume}$$

- Heat added: (5)

$$Q_{added} = xC_V(T_H - T_C) + RT_H\, l_n\, {}^{V_2}/_{V_1}$$

- Heat rejected: (6)

$$Q_{rejected} = XC_V(T_C - T_H) + RT_C\, ln\, {}^{V_2}/_{V_1}$$

- Coefficient of Performance: (7)

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$$COP = \frac{Cooling\ Effect}{Work\ Input}$$

$$COP = \frac{Q_H}{Q_H - Q_C} = \frac{T_H}{T_H - T_C}$$

$$= \frac{263}{603 - 263}$$

$$COP = 0.774$$

$$COP < 1$$

1. Experimental Results:

1.1 Refrigeration with air as working fluid

- The graph given below shows the temperature and speed of the experiment done in the form of a line graph where the lowest temperature 10 degree Celsius is achieved at the speed 43.33 rps (2600rpm) and temperature drop is from 26 degree Celsius at the speed 30 rps(1800) .

Table 1. Temperature(°C) versus Speed (rps)

TEMPERATURE (K)	TEMPERATURE (°C)	SPEE D (rpm)	SPEE D (rps)
299	26	1800	30
295	22	2000	33.33
292	19	2200	36.66
285	12	2400	40
283	10	2600	43.33

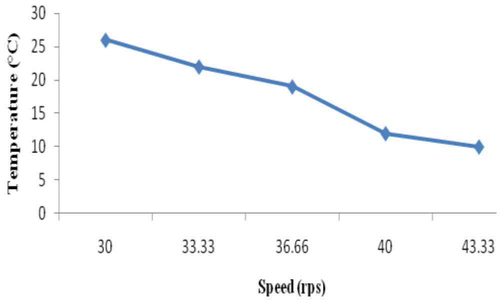

Fig. 9.Temperature (°C) versus Speed of motor (rps)

- The line graph given below illustrates the temperature and piston stoke speed in x and y axis. This graphs shows that at a piston speed of 3.16 m/s a temperature of 10 degree Celsius is achieved and the highest temperature present is 26 degree Celsius which is run at a piston speed of 2.18 m/s . This proves that the temperature of the system degreases with increase in piston stroke speed

Table 2.Temperature (°C) versus VPS(m/s)

TEMPERATURE(K)	TEMPERATURE (°C)	VPS (m/s)
299	26	2.18
295	22	2.43
292	19	2.67
285	12	2.91
283	10	3.16

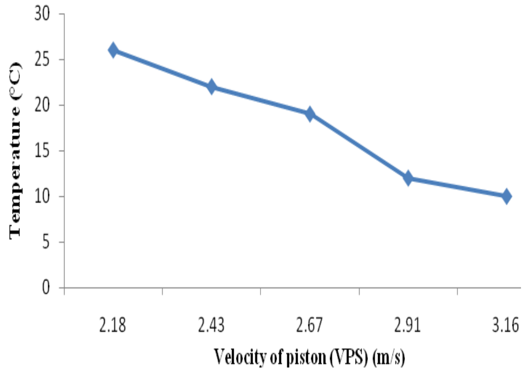

Fig.10. Temperature (°C) versus VPS(rps)

- The graph below illustrates comparison of temperature and time taken for achieving temperature. the working fluid air the low temperature 10 degree Celsius is achieved in 55 minutes that is 3300 seconds. Temperature drop is observed at the first 14 minutes (840 seconds)

Table 3. Temperature (°C) Versus Time taken (seconds)

TEMPERATURE (K)	TEMPERATURE (°C)	TIME (min)	TIME (secs)
299	26	14	840
295	22	20	1200
292	19	25	1500
285	12	36	2160
283	10	55	3300

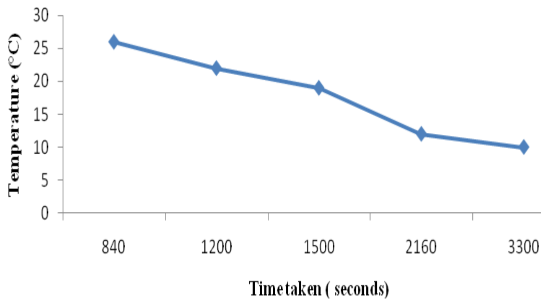

Fig.11. Temperature (°C) versus Time taken (seconds)

3.2 Refrigeration with helium as working fluid

- In the temperature versus Speed line graph given below , the working fluid used here is helium and is noticed that at the speed 43.33 rps (2600 rpm) the temperature has reduced to 16.8 degree Celsius and it is known that with increase in rpm ,decrease in temperature can be achieved.

Table 4. Temperature (°C) versus Speed (rps)

TEMPERATUR E (K)	TEMPERATU RE(°C)	SPEE D (rpm)	SPEE D (rps)
299	26	1800	30
294.9	21.9	2200	36.66
291	18	2400	40
289.8	16.8	2600	43.33

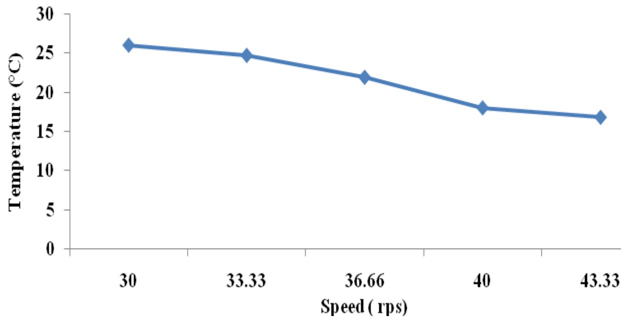

Fig. 12. Temperature (°C) versus speed(rps) with Helium as Working fluid

- The line graph below illustrates the temperature and piston stroke speed when helium is used as a working fluid where when the piston stroke speed is about 3.16 m/s , the temperature achieved at this speed is 16.8 degree Celsius

Table 5.Temperature (°C) versus VPS(m/s)

TEMPERATURE (K)	TEMPERATURE (°C)	VPS (m/s)
299	26	2.188
297.7	24.7	2.431
294.9	21.9	2.674
291	18	2.918
289.8	16.8	3.161

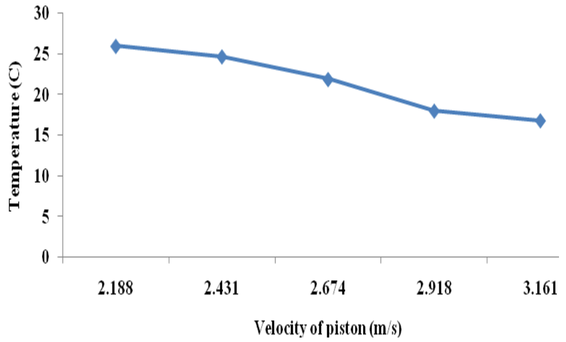

Fig.13. Temperature (°C) versus VPS (rps)

- The line graph given below describes the comparison of temperature and time taken for achieving the temperature required.

Table 6. Temperature (°C) versus Time taken (sec)

TEMPERATUR E (K)	TEMPERATURE(°C)	TIM E (sec)
299	26	120
297.7	24.7	300
294.9	21.9	600
291	18	900
289.8	16.8	1200

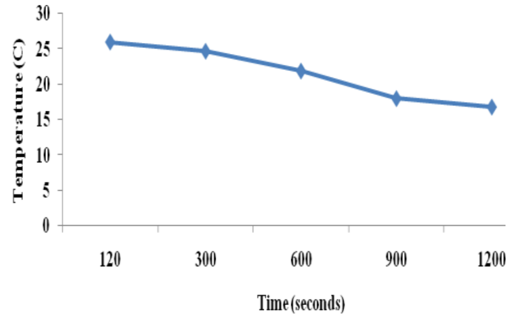

Fig.14. Temperature (°C) versus Time taken (seconds)

3.3 Heat pump with air as working fluid

- The line graph given bellow illustrates the temperature and speed when the model is used as a Heat pump. Here the highest temperature achieved is 35 degree Celsius at a speed of 43.33 rps (2600 rpm)

Table 7.Temperature (°C) versus Speed(rps)

TEMPERATUR E (K)	TEMPERATUR E (°C)	SPE ED (rpm)	SPEE D (rps)
300	27	1800	30
302	29	2000	33.33
304	31	2200	36.66
307	34	2400	40
308	35	2600	43.33

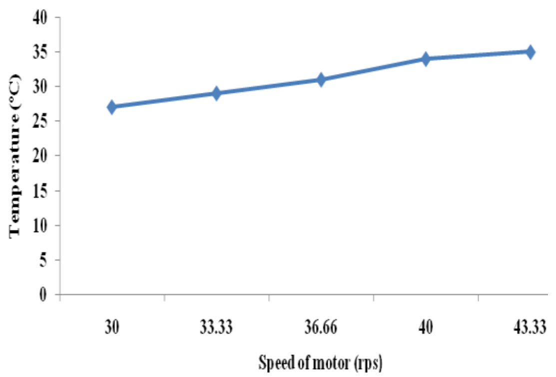

Fig.15. Temperature (°C) versus Speed (rps) when used as a heat pump

- The comparison of the temperature and piston stoke speed is given below .The highest temperature 35 degree Celsius is gained when the piston stroke speed is of 3.161 m/s which means that when the speed increases the temperature also increases in the case of Heat pump .

Table 8. Temperature(ºC) versus VPS(m/s)

TEMPERATURE (K)	TEMPERATURE (ºC)	VPS (m/s)
300	27	2.188
302	29	2.431
304	31	2.674

307	34	2.918
308	35	3.161

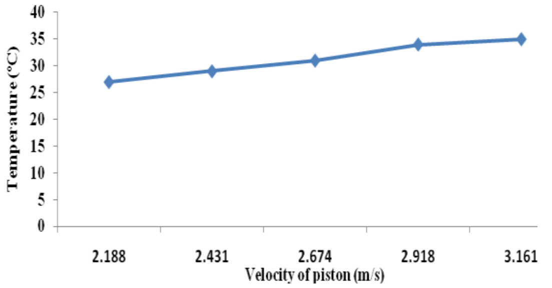

Fig.16. Temperature (ºC) versus VPS (m/s) in the case of Heat pump

- The line graph illustrated below shows the results gathered from the experiment on the temperature and the time taken for achieving the temperature in a heat pump. At 50 minutes that is 3300 seconds the temperature increased to35 degree Celsius

Table 9 .Temperature (ºC) versus Time (sec)

TEMPERATURE(K)	TEMPERATURE(º C)	TIME (secs)
300	27	840
302	29	1200
304	31	1500
307	34	2160
308	35	3300

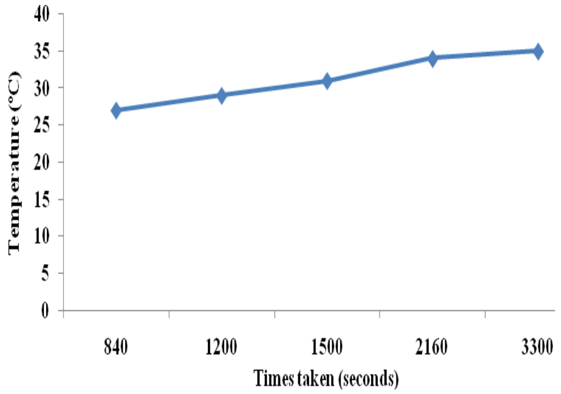

Fig.17.Temperature (ºC) versus Time taken (seconds)

CONCLUSION

- In this project work, Stirling refrigerator system has been studied and based on these the following conclusions has been drawn.
- The theoretical results obtained based on ANSYS shows that temperature distribution, total heat flux, equivalent elastic strain and thermal stress of the system were within the acceptable range and the factor of safety obtained was 3.7
- The total deformation diagram shows that there exists a thermal stress at the lower part of the cylinder. These thermal stresses have been dealt by chamfering the edge of the lower cylindrical casing in order to reduce the thermal stress produced in the system.
- In case of refrigeration, the motor rotates in the clockwise direction where the lowest temperature obtained is 10ºC which was achieved in 55 minutes (3300seconds) with respect to air as working fluid and 16.1ºC in 20 minutes (1200seconds) with respect to helium as working fluid. When the rotation of the motor is reversed i.e. anticlockwise direction , the machine acts as a heat pump, thus achieving a higher temperature of 35ºC in 50 minutes (3000seconds) with air as the working fluid.
- Coefficient of Performance of a Refrigerator system obtained using this method is 0.27 and Coefficient of Performance of a Heat Pump is 2.33. The COP in case of refrigerator obtained was less than 1 and occurs due to poor insulation and heat loss to the surroundings.

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