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Research Article

PROVIDING ELECTRICAL POWER INCREASE BY STIMULATING TEMPERATURE DIFFERENCE AT LOW TEMPERATURES IN STIRLING MOTORS

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ABSTRACT

In this research, the variation of electrical power according to the temperature in Stirling motors was analyzed. The performance characteristics of a low power Beta type Stirling motor were determined in the situation of working gas becoming air gas in this research, Results were compared and are presented graphically. Performance tests of a Stirling motor heated by thermal specifications of the sun were made at heater temperatures of 673 K, 773 K and 873 K. Also, an electrical power increase was provided by raising the temperature difference between the hot edge of the displacer and cooler temperatures.
Keywords: Solar thermal, solar energy, stirling motor, renewable energy system.

1. INTRODUCTION

Nowadays, fossil based energy sources are diminishing rapidly and continue to cause a global energy crisis. The necessity for an increase in energy has directed scientists to conduct research into renewable energy sources and more efficient machines that can transform these sources into energy [1].

The sunlight energy applications of Stirling motors are thought to be practical for the climatization of homes and synchronized power generation. Mills (2004), through his research revealed that the most productive transformation unit is the system that consists of a Stirling motor, dish, and a mirror [2]. In spite of the productivity of these systems being higher, they have not come into common usage due to a variety of problems. In order to be used easily in rural areas, their design should be small, strong, and suitable for individual usage [3-7]. The idea of using Stirling motors in housing was suggested 20 years ago, but it was not put into practice at that time. Thus, it is important to develop a Stirling motor that is capable of operating at various temperatures at the present time [8-12].

Nowadays, power is generated by traditional sources such as coal etc., natural gas, and fuel oil. This use of traditional sources causes global warming by releasing sera gas into the atmosphere, which in turn gives rise to climate changes. A 2ºC temperature increase has occurred

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related to global warming as of 2015. The a verage global temperature increased from 15ºC to 17ºC [13-17]. Global warming temperature increases were expected to happen between the years 2040-2050. However, an increase in population and the rapid release of sera gases moved the predicted date forward to 2015. For this reason, the number of studies on how to generate power from sunlight and the machines related to this work should be increased in order to protect the world from warming further [18-21].

2. STIRLING MOTORS

In Stirling motors energy is produced by formation of temperature difference between edges as a result of heating one end of displacer pipe. In consequence of pushing and pulling movement of power piston in displacer pipe, energy is produced. The speed of pushing and pulling movement is however associated with temperature difference between hot edge and cooler edge. As one edge of displacer pipe is heated, the temperature of other edge is at ambient temperature value initially. In other words as one edge is heated the other edge is unheated so produced electric energy is at maximum level due to high temperature difference. However as heat transfer from heated edge to cooler edge occurs shortly afterwards, temperature difference between edges reduces and produced electric energy regresses to minimum level. In this research in order to avoid productivity loss in energy production, displacer pipe was divided into two equal parts and heated edge was made of Iron whereas cooler edge was made of Zirconium. Thus it was provided to increase electrical productivity by avoiding heating of coolers. The raw material state of Zirconium was shown in Figure 1.

Figure 1. Raw material view of Zirconium

3. STIRLING MOTOR HEAT TRANSFER SIMULATION

For 673 K, 773 K and 873 K temperature values a simulation was made in ANSYS Products 13.5 programme. Simulation results were compared for 50 cm iron displacer pipe and 25 cm zirconium displacer pipe connected to easily heating 25 cm iron. It was obtained that displacement piston occured by combination of iron and zirconium provides heating of cooler edge approximately 29% less. In order to obtain electrical productivity increase for less heating displacer, by using Ideal Adiabatic v.1.x simulation programme there obtained increase in produced electric quantities at the rate of 288.83%-319.28% [22].

Stirling motor that works for externally heating principle, is consisted of a movement mechanism, a heater, a regenerator, a cooler, a power piston, a piston and a motor block. Whatever its type all Stirling motors are consisted of heater, regenerator and cooler parts. The function of movement mechanism is to perform thermodynamic cycle by moving piston and displacer scheduling to eachother. In this study it was tried to prove how electrical productivity is increased at low temperatures in cas e of increasing temperature difference on displacer pipe by making stimulation studies for Stirling motor working at low temperatures (673 K, 773 K ve 873 K). The movement stages of Beta type Stirling motor based for the study during working, are seen in Figure 2.

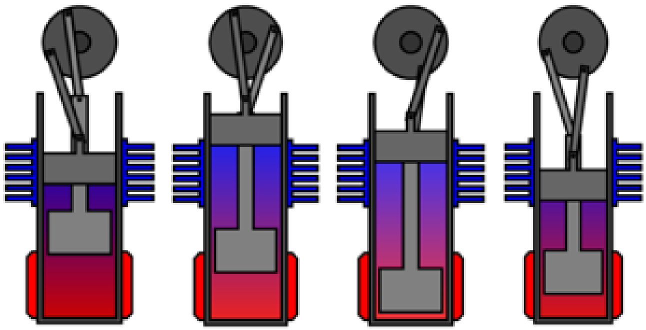


Figure 2. Beta type stirling motor movement stages [7]

As Table 1 showing the properties of Iron and Zirconium comparatively is examined, it is understood that in case of using Zirconium in cooler edge provides additional advantages. These advantages [16] can be ordered as follows;

- As density of iron is 7.86 g/cm³, the density of zirconium is 6.52 g/cm³. According to this zirconium having less density and porous structure can make more cooling than iron.
- As melting point of iron is 1811 K, the melting point of zirconium is 2128 K. That means as iron is exposed to physical deformation at high temperatures such as 1200-1300 K, zirconium is not exposed to physical change at this temperature. Zirconium is exposed to deformation at 1700-1800 K.
- As thermal conductance of iron is 80.4 W/(m.K), thermal conductance of zirconium is 22.6 W/(m.K). That means thermal conductance of zirconium is 4 times less than the iron's. This property makes zirconium more advantageous in formation of temperature difference in displacer pipe.
- As thermal expansion value of iron is 11.8 µm/(m.K) (at 25°C), thermal expansion value of zirconium is 5.7 µm/(m.K) (at 25°C). That means zirconium is exposed to physical change under temperature by expanding late approximately two times more than iron.
- As sound transmission property of iron is at 5120 m/s values, zirconium is at 3800 m/s values. That means zirconium can work with less noise than iron.

Due to all its properties manufacturing cooler edge from zirconium in Stirling motors is more advantageous in terms of electrical productivity increase. Zirconium is also used in many fields in our daily life. Zirconium is used;

- directly in combustors of nuclear reactors as well as building material of nuclear reactors due to its corrosion resistance and having less neutron absorption property,
- in parts of space vehicles since materials made of ZrO_2 compound in Space and Aviation industry are resistant to heat,
- in combusters due to its high resistance to heat, jet motor wings and gas turbine wings that are exposed to high temperatures,
- as being a refractory material Zirconiumdioxide (ZrO_2) is used in pattern processes requiring high heat, in metallurgical ovens, in manufacturing of refractory materials due to its high melting point, in glass and ceramic industry, in manufacturing of many equipments due to its corrosion resistance.

Table 1. Comparative properties of Iron and Zirconium [23, 24]

Properties	**Iron**	**Zirconium**
Phase	solid	solid
Density	7.86 g/cm³	6.52 g/cm³
Melting point	1811ºK	2128ºK
	1538ºC	1855ºC
Boiling point	3134ºK	4682ºK
	2861ºC	4409ºC
Heat of fusion	13.81 kJ/mol	14 kJ/mol
Molar heat capacity	25.10 J/(mol·K)	25.36 J/(mol·K)
Electrical resistivity	96.1 nΩ·m (20ºC'de)	421 n nΩ·m (20ºC'de)
Thermal conductivity	80.4 W/(m·K)	22.6 W/(m·K)
Thermal expansion	11.8 µm/(m·K) (25ºC'de)	5.7 µm/(m·K) (25ºC'de)
Speed of sound	5120 m/s	3800 m/s

Today displacer pipe of Stirling motors are manufactured from monotype material. In Figure 3 a boundary diagram of displacer pipe of Stirling motor is viewed.

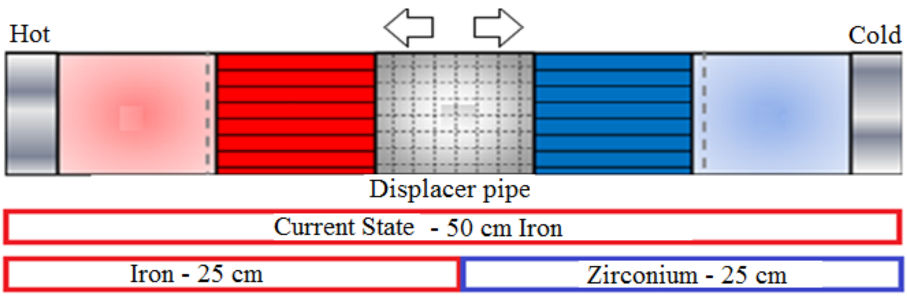


Figure 3. Boundary diagram of a displacer pipe

In Figure 4 Beta type Stirling motor having 50 cm length of iron displacer pipe, is seen. Although an iron or a steel displacer pipe is advantageous in terms of heat admission capacity, since it transmits the heat well the heat can reach to cooler edge which is the other side of displacer pipe in a short time. Accordingly fast transmission of heat affects produced energy quantity negatively by reducing temperature difference.

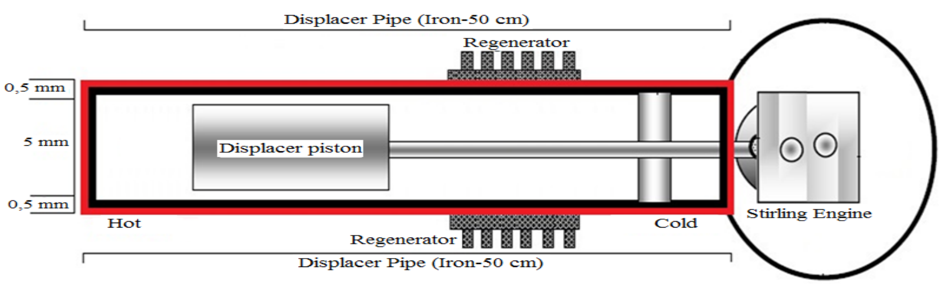


Figure 4. Beta type Stirling motor having 50 cm length of iron displacer pipe

In simulation created for this aim in ANSYS Product 13.5 programme. 50 cm iron displacer pipe and 25 cm zirconium displacer pipe connected to 25 cm iron were compared in terms of transmitting heat [25].

For example in simulation created in ANSYS Product 13.5 programme as welding heat of 50 cm iron displacer pipe was at 673 K, the heat of cooler edge reached to 535 K. Again in another example as welding heat was 773 K, cooler heat increased to 600 K and as at 873 K welding heat, cooler heat increased to 660 K. As it is understood from here in case of less temperature difference, there occured a reduction in produced electrical power as it can be seen in Table 2. It is observed as temperature difference increases between edges of displacer pipe, there reach a maximum efficiency in produced elecrical power. In other words high welding heat causes technical problems such as;

- physical deformation,
- friction coefficient increase
- sealing problems

That is why high efficiency electric production is done at low temperatures in Stirling motors. For high efficiency it is necessary to avoid transmission of welding heat to cooler edge. For this aim it was thought to manufacture displacer pipe from two different materials, using easily heating iron for heating edge and for cooler edge using zirconium that distracts heat urgently and has lower heat transmission coefficient.

In Figure 5 Beta type Stirling motor sample of 50 cm displacer pipe manufactured from 25 cm zirconium connecting to 25 cm iron, is viewed.

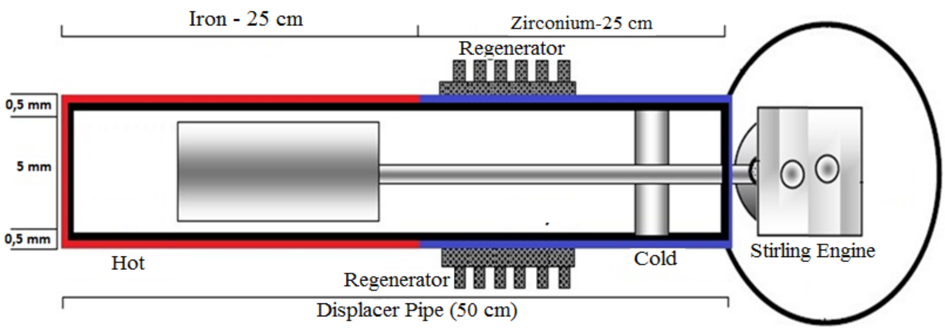
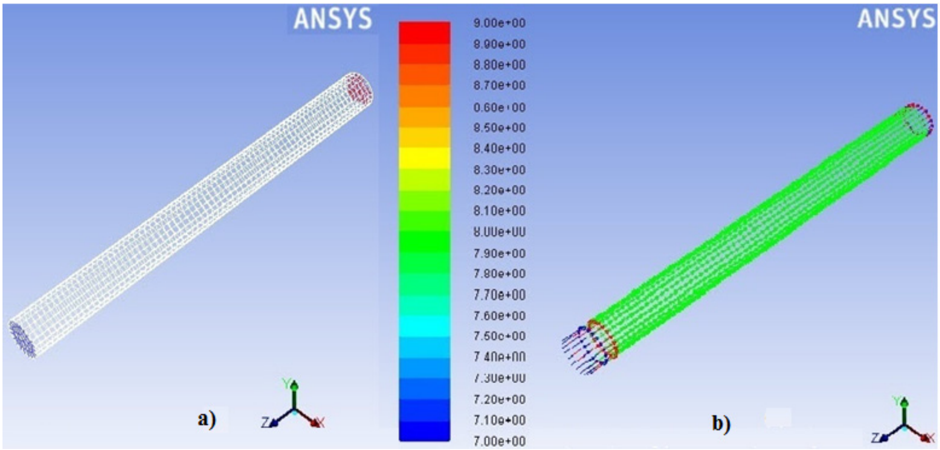


Figure 5. Beta type Stirling motor having 25 cm iron heating edge and 25 cm zirconium cooler edge

In Figure 6.a’da in simulation prepared by using ANSYS programme, mesh process of 50 cm iron displacer pipe was done. In order to make heat analysis of displacer, the displacer was approximately divided into 300.000 perts in simulation setting. Thus temperature value of each desired point can be measured in detail. As it is also seen in Figure 6.b heating process of displacer pipe was done.

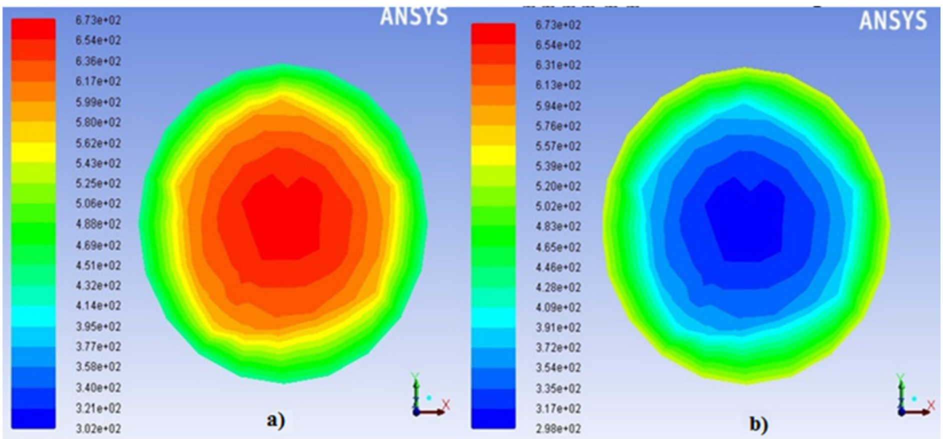


(a) Displacer mesh process (b) Diplacer heating process

Figure 6. Mesh and heating processes for displacer

In a simulation done for 673 K, 773 K and 873 K temperature values 50 cm iron displacer pipe and 25 cm zirconium displacer pipe connected to 25 cm iron, were compared. As hot edge inlet heat of 50 cm iron displacer pipe was at 673 K, the heat of cooler edge was measured as 535 K.

The hot edge inlet heat of 50 cm iron displacer pipe is seen in Figure 7.a and cooler edge heat is seen in Figure 6.b.



a) Hot edge inlet heat of displacer pipe b) Cooler edge heat of displacer pipe

Figure 7. Hot edge inlet heat and cooler edge heat of iron displacer at 673 K

Temperature change graphics of analysis done in ANSYS programme for 50 cm iron displacer pipe at 673 K, is shown in Figure 8. As the change in Figure 8 is examined, it was seen that cooler heat of iron displacer pipe as 535 K. In other words it is seen that inlet heat still steers at a currently high temperature although it decreases until 138 K. As there is 138 K temperature difference in other words as cooler heat is 535 K, produced electrical power was measured as 10.69 W.

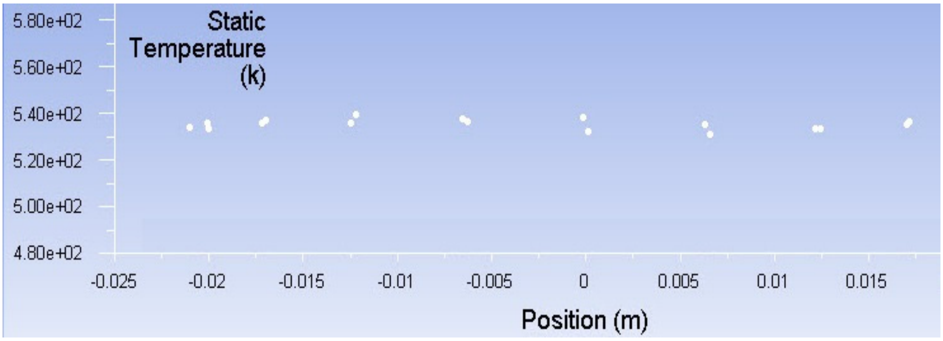
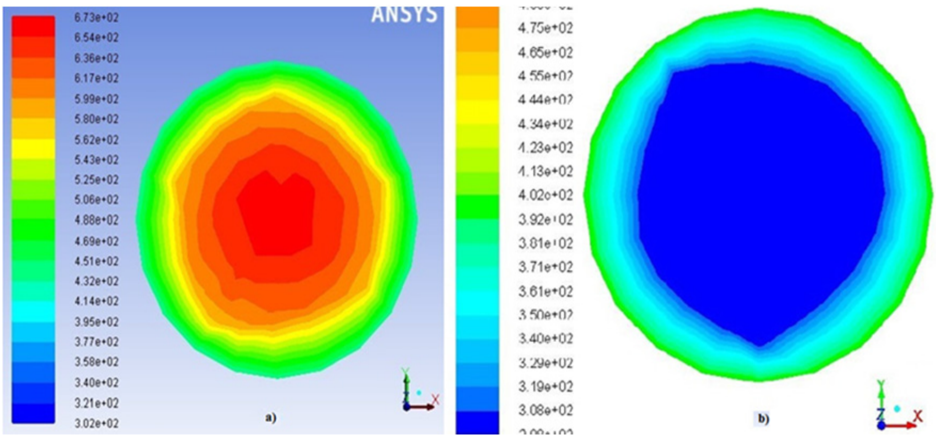


Figure 8. Heat change of 50 cm iron displacer pipe

As hot edge inlet heat of displacer pipe consisted of 25 cm iron (hot edge) and 25 cm zirconium (cooler edge) was at 673 K, the heat of cooler edge was measured as 535 K. At 673 K the hot edge inlet heat of iron displacer pipe is seen in Figure 9.a and cooler edge heat is seen in Figure 9.b.



a) Hot edge inlet heat of displacer pipe b) Cooler edge heat of displacer pipe

Figure 9. At 673 K hot edge inlet heat and cooler heat of displacer consisted of 25 cm iron and 25 cm zirconium

Temperature change graphics of analysis done in ANSYS programme for displacer pipe consisted of 25 cm iron (hot edge) and 25 cm zirconium (cold edge) at 673 K, is shown in Figure 10. As the change in Figure 9 is examined, it was seen that cooler heat of displacer pipe made of iron and zirconium pipe is 383 K. In other words it was seen that inlet heat decreased as 290 K and it even decreased to lower heat value. As there is 290 K temperature difference, electrical power was measured as 43.57 W. According to this, displacer pipe manufactured from 25 cm iron and 25 cm zirconium can produce 307.58% more electricity than a single 50 cm iron displacer pipe.

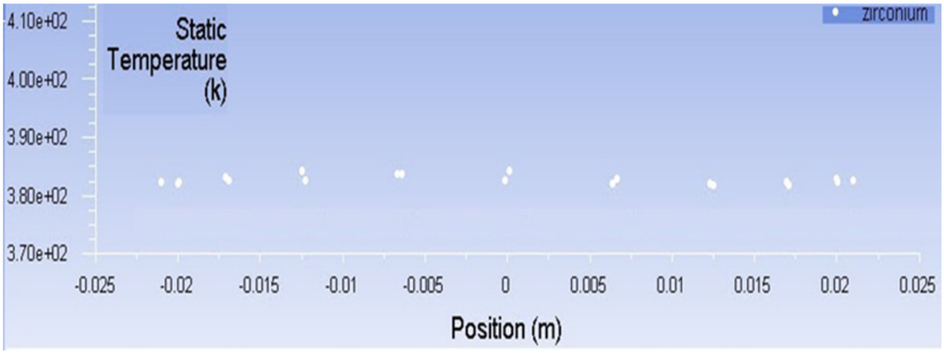


Figure 10. Temperature difference at displacer pipe manufactured as 25 cm iron ve 25 cm zirconium

In ANSYS simulation programme the outlook of unheated 50 cm iron displacer pipe is viewed in Figure 11.a whereas the outlook of heated displacer pipe at 673 K is viewed in Figure 11.b. In Figure 11.c only heat change of 25 cm zirconium part of displacer pipe manufactured from 25 cm iron and 25 cm zirconium is viewed.

As Figure 11 is examined it is observed in Figure 11.b that after heating process outer side of 50 cm iron displacer pipe turns to colour red which is a sign of high heat values. However as it is seen from Figure 11.c that 5 cm of cooler edge made of zirconium turns to colour red which is a sign of high heat values since only this part touches to hot edge made of iron. As the rest (20 cm) of cooler edge is colour orange, the farthest point is observed as yellow-green which is accepted as low heat value. Heat changes for displacer pipe is seen in Figure 11.

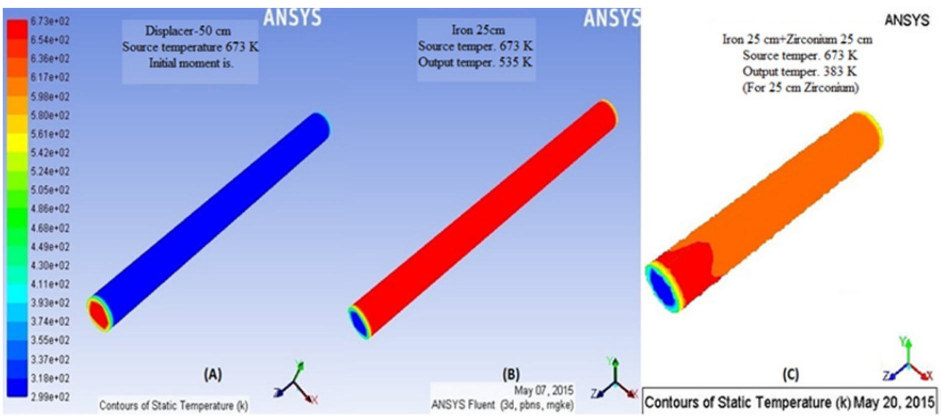
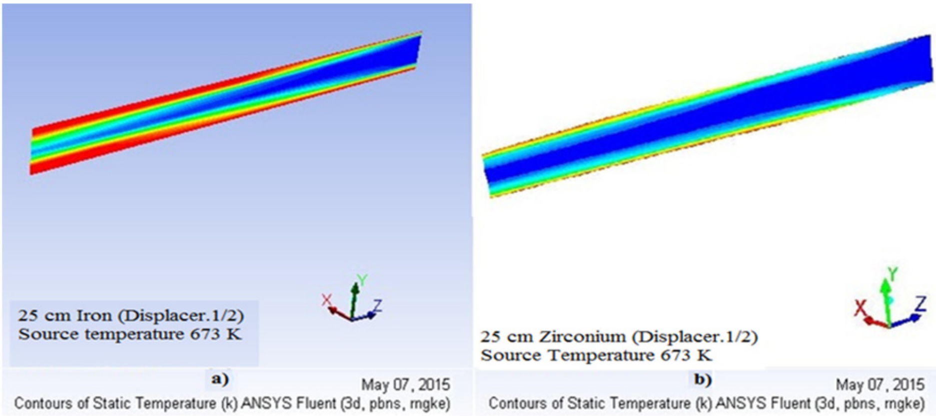


Figure 11. Heat changes for displacer pipe

This heat change is also seen in heat change in lateral section of displacer pipe in Figure 12. In Figure 12.a in lateral section of 25 cm cooler edge of iron displacer pipe it is seen that colour red which is a sigh of high heat value continues to the end of displacer pipe. High heat values can also be seen from Figure 12.b. Meanwhile cooler temperature measured from 50 cm iron displacer pipe in simulation setting is 535 K. However as it can be seen from 12.b, it is also seen from lateral section of 25 cm cooler edge of zirconium displacer pipe that 25 cm cooler temperature does not continue to the discharge end. It is observed that colour blue that symbolizes low heat continues to the end of displacer pipe, in outer side yellow-green colour is dominant and red colour is never encountered. Low heat values can be seen from Figure 12.b. Meanwhile cool end temperature from displacer pipe made of 25 cm iron and 25 cm zirconium in simulation setting is 383 K.



a) Cooler manufactured from Iron   b) Cooler manufactured from Zirconium

Figure 12. Cooler lateral section view for iron and zirconium

In Ideal Adiabatic v.1.x Stirling motor simulation programme at 673 K, as temperature difference between hot edge and cooler on iron displacer pipe is 138 K, 10.69 W electrical power is produced. For 673 K when 50 cm displacer pipe that 25 cm of it was manufactured from iron whereas the rest 25 cm cooler part is made of zirconium, temperature difference between hot end and cooler on displacer pipe was measured as 310 K and 43.57 W electrical power is produced.
For 773 K and 873 K it can be seen from Table 3 that electrical power values obtained from simulation showing electric produced due to temperature difference rise, increases a few times more.

Table 2. Powers produced at different temperatures for displacer pipe manufactured from different mines

Hot edge manufacturing material (25 cm)	Cooler manufac turing material (25 cm)	Hot edge (K)	Cooler (K)	Tempera ture difference (K)	Gener ated power (W)	Power increase% (W)
Iron	Iron	673	535	138	10.69	307.58%
Iron	Zirconium	673	383	290	43.57	
Iron	Iron	773	600	173	13.07	288.83%
Iron	Zirconium	773	408	365	50.82	
Iron	Iron	873	660	213	13.69	319.28%
Iron	Zirconium	873	430	443	57.4	

- With this method more electrical energy can be produced without requiring higher heat values. In other words if heating process is done with solar energy, bigger reflector capsule or expensive and more quality fresnel lens should be used to reach required high heat values. If heating process is done with an energy produced from a diffrent source, it is necessary to use resistances providing heating process by making more consumption or if LPG or similar gas source is used heating process will be done by consuming more gas. With this method higher electric production can be provided at lower temperatures without requiring to reach higher heat values.

- Again at high heat values some metals expose physical deformation since they reach to fusing point. For example iron melts approximately at 1811 K so it exposes to deformation at 1200 K. As deformation on displacer pipe limits the movement of displacement piston due to friction, it affects energy production negatively or stops completely. The datas regarding fusing point of iron is seen in Table 2.

Discussion

As a result, all these analysis processes were repeated for 50 cm iron displacer pipe and 25 cm zirconium displacer pipe connected to 25 cm iron at 673 K, 773 K and 873 K in ANSYS 13.5 simulation programme. Obtained heat values are used in Stirling motor Ideal Adiabatic v.1.x simulation programme and electrical power quantities that will be produced, were calculated. As it is seen in Table 2;

- 307.58 % electrical power increase at 673 K when temperature difference is increased from 138 K to 290 K,
- 288.83 % electrical power increase at 773 K when temperature difference is increased from 173 K to 365 K,
- 319.28 % electrical power increase at 873 K when temperature difference is increased from 213 K to 443 K

is obtained. Accordingly in Stirling motors trying to increase electric production by rising heat on displacer pipe causes physical deformation on some type of displacer pipes, imputed cost or occupational accidents due to uncontrollable heat values. Instead of increasing heat, the method of increasing temepature difference between edges in displacer pipe rises margin by increasing electrical power production.

Acknowledgment

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