Induced Mechanical Motion by Thermal Solar Energy

Abdul Al-Azzawi, Ph.D., SMIEEE, Mohammed Mostefa, Ph.D., IEEE

and Dmitry Klishch IEEE

Algonquin College, Ottawa, Ontario, Canada

Abstract — **Increasing energy demand and cost are the main motivators for this research project. Solar thermal energy is used to create mechanical motion. In turn, the mechanical motion drives a generator to generate electricity. The objective of this project is to use solar radiation to heat a black fined metal tank filed with air. The air is heated by the solar radiation and expands leaving the tank through a nozzle, which is mounted on the top outlet valve. A turbine wheel is driven by the force of the hot air flow when the air is leaving the nozzle causing a mechanical rotation. An electric generator is coupled to the turbine wheel generating electricity. The generated electricity can be used for direct and indirect applications.**

To put the concept in practical research work, a prototype is designed, constructed, and tested under lab conditions. When the black fined metal tank is heated by simulated heat source, the air expands by natural heat convection from the heat that is conducted from the walls of the metal tank. When air temperature increases the density decreases and causing the hot air flows to rise by the power of the natural bouncy effect. The black metal tank is used as air storage. Control valves are mounted on the air inlet and outlet on the black metal tank to control the air flow in and out. Consequently, the valves control the inside tank air temperature. Preliminarily tests showed that the prototype works satisfactorily under artificial heat source and lab conditions. The prototype will be tested under real environment conditions to verify the results.

Index Terms — **Convection Heat Transfer, Data Collection, Electric Generator, Fined black Metal Tank, Inlet/outlet Valves, Metal Tank, Power Meter, Solar Radiation Meter, Solar Energy, Tachometer, Thermocouples, Valves**

I. INTRODUCTION

The Sun supplies an inexhaustible amount of solar thermal energy to the universe. At any given moment, the sun radiates towards the earth solar radiation amounting to about 174 x 10^{15} W of power. The harnessing of a small portion of this radiation, though with a system that is only marginally efficient, is a good starting point to a better environment and sustainable use of clean energy [1]-[7].This availability of solar energy has initiated our research in finding ways to utilize the solar energy to supply the energy that is required to drive an electric generator available for many applications.

Solar radiation energy reaches the Earth's surface in two forms: (i) direct radiation (the solar parallel rays in a clear sky); and (ii) diffuse radiation (the non-parallel rays of sky radiation, scattered in the atmosphere by a cloudy sky, gases, and atmospheric dust). The average intensity of solar radiation normal to the Sun's rays at the outer edge of the Earth's atmosphere is 1353 W/m^2. This energy is received at the surface of the Earth from the Sun and is subject to variations due to [8] - [9]:

1. Variations in tilt of the Earth relative to the Sun. The Earth rotates around its own axis, one complete rotation in 24 hours. The axis of this rotation is tilted at an angle of 23.5^o to the plane of the Earth's orbit and the direction of this axis is constant.
2. Variations in atmospheric scattering by air molecules of water vapour, gases, and dust particles.
3. Variations in atmospheric absorption by O_2, O_3, H_2O, and CO_2.

Solar radiation measurements often include total (beam and diffuse) radiation, in energy per unit time per unit area, on a horizontal surface. The measurements are made by a pyrheliometer using a collimated detector for measuring solar radiation for a small portion of the sky including the Sun (i.e. beam radiation) at normal incidence. Also the radiation measurements made by a pyranometer measure the total hemispherical solar (beam + diffuse) radiation, usually on a horizontal surface. If shaded from the beam radiation by a shade ring, it measures only the diffuse radiation [10] - [11].

Solar energy can be collected in two ways either by thermal collectors (Liquid-heating solar collectors and Air-heating solar collectors) or electrical collectors (Photovoltaic Panels).

There are many air solar collectors which are being under research work and mass production for industrial applications especially in heating and cooling in buildings and agricultural applications, as shown in Figure 1 [12].

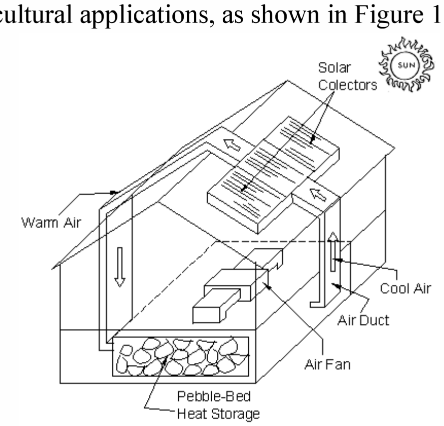

Figure 1: Air-hearing solar collectors supply hot air to a building.

2014 IEEE Canada International Humanitarian Technology Conference - (IHTC)
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There is the biggest electricity generation station in the world, which is located in Spain, as shown in Figure 2 [13] - [14].

Figure 2: Generating electricity by solar energy concentrators.

The current project is meant to generate electricity for small applications such as lighting, charging batteries, etc.

II. Analysis of Current Design

In this project, solar radiation is used as a driving force. Solar radiation incidents on the black metal tank will be absorbed and therefore, increases the surface temperature. The mode of the heat transfer in this process is accomplished through conduction by the wall and the fins and by convection through the air inside the tank. This will cause the inside air temperature to increase and its density to decrease. Hence, air will rise up by natural bouncy effect [15] - [19]. The hot air passes through a nozzle which is directed towards the turbine wheel of the generator, as shown in Figure 3. The wheel rotation with the shaft of the generator will generate electricity. The design of the system is shown in Figures 4 and 6.

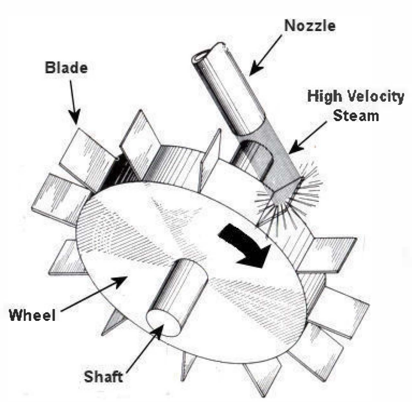

Figure 3: Nozzle and turbine wheel arrangement.

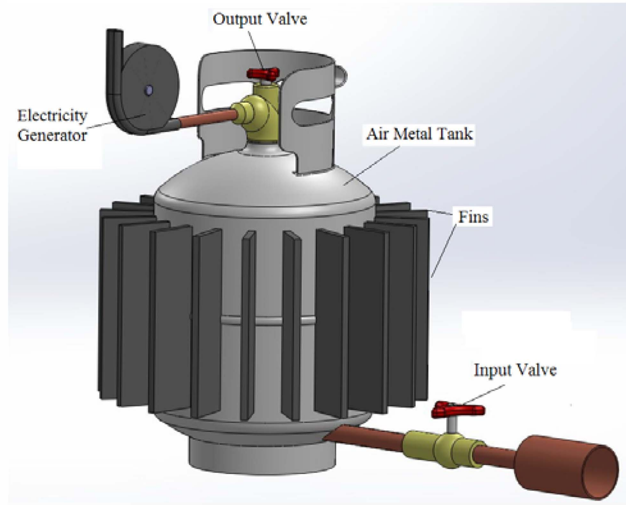

Figure 4: The design of the system.

The design of the system components are:

A. Air Storage Tank

The black metal tank is used to keep the air as working fluid. The tank is made of a metal and has a volume of 15520.2 cm^3 of air. There are 12 fins soldered on the outside surface of the metal tank in a symmetrical arrangement, as shown in Figures 4, 5 and 6. The fins absorb solar radiation and transmit the absorbed heat into the tank to heat the air inside. The fins increase heat transfer from outside surface of the wall tank and hence increase surface temperature inside the tank.

Another fin arrangement also welded inside the metal tank to increase the heat transfer between the airflow and inside surfaces of the metal tank, as shown in Figure 5.

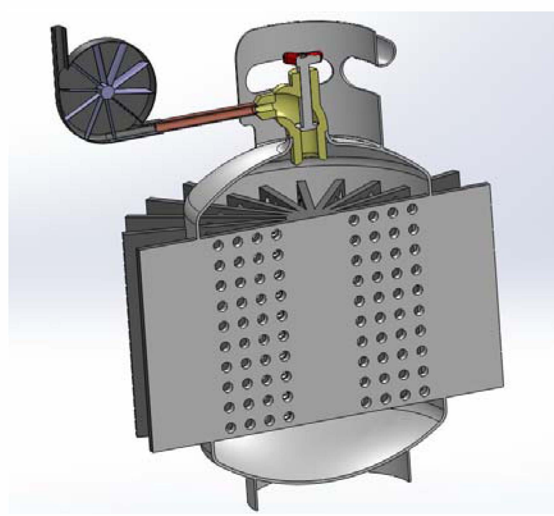

Figure 5: *Fins inside the metal tank.*

B. Air Inlet and Outlet Valves

There are two mechanical valves located on the metal tank. The valves are connected to the tank via a metal pipes to air inlet and outlet of 1.91 cm in diameter. The 1.91 cm valves are used to control the air flow into and out of the tank and consequently control the air temperature inside the tank, as shown in Figures 4 and 6.

C. Black Selective Coating

A black selective coating is applied on the outside surfaces of the tank and fins. The coating will help with maximum absorption of the solar radiation and minimize back reflection. Another advantage of the black coating is to increase the collection efficiency of the tank and increase the air temperature inside it.

D. Nozzle

A nozzle is mounted on the air output pipe. The nozzle works as an air jet directed on the wheel of the electricity generator, as shown in Figure 3.

E. Electricity Generator

A small electricity generator is mounted on the nozzle of the air outlet pipe. The generator is driven by the turbine wheel which is mounted on the shaft of the generator. When air leaves the nozzle with high velocity and hitting the wheel blades, the wheel rotates and generates electricity as a result.

F. High Temperature Tungsten Lamp

A high temperature Tungsten lamp is used as a solar energy simulator. The lamp gives a constant heat source, as shown in Figure 6.

G. Measurements and Instruments

The following measurement insturments are used in this project: thermocouples for temperatures, hot wire anemometer for air flow rates, pyrheliometer for solar radiation level intensities, Wattmeter for electrical power output, and taco meter for shaft rotation speeds [17].

III. Design and Experiment

A prototype was successfully constructed for the system design and ready for testing. Measurements were taken under the condition using a simulated solar energy source. The heat is generated by a high temperature Tungsten lamp, as shown in Figure 6. Four tests were carried out at three different temperatures 60, 80 and 100 C^o and four different valves set-ups. The results were recorded for analysis. The four different set-ups are explained in the following sections:

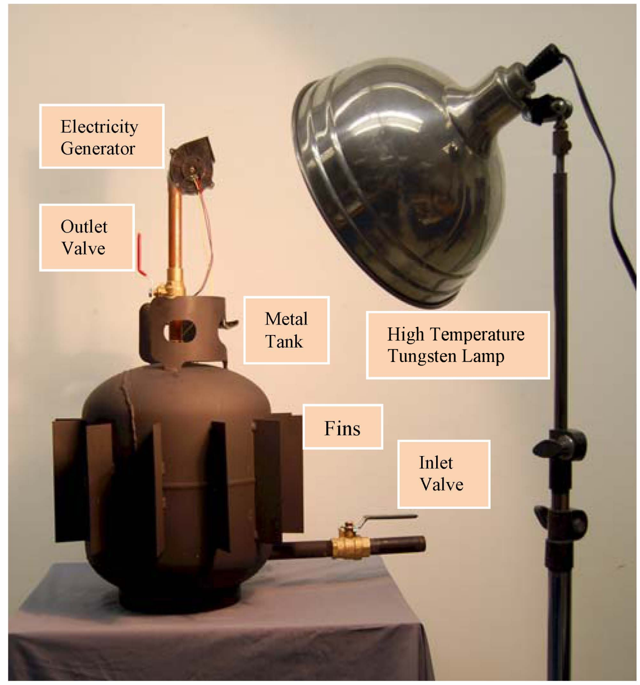

Figure 6: The system under tests.

A. Air Flow and Inside Air Tank Temperature (IAT) Measurements with Inlet and Outlet Valves Fully Opened

The system is exposed to a high temperature light source. The light source is kept at steady state temperatures of 60, 80 and 100 C^o. The air flow rates and inside air temperatures are recorded using a hot wire anemometer and thermocouple, respectively. The inlet and outlet valves are fully opened during these tests. The average value of three data collections were recorded every half an hour.

B. Similarly to Step A above, data are collected for Half Inlet and Full Outlet Valves Opened

C. Similarly to Step A above, data are collected for Half Inlet and Half Outlet Valves Opened

D. Similarly to Step A above, data are collected for Full Inlet and Half Outlet Valves Opened

E. Electricity Generation Tests

As explained in Section E of Analysis of Current Design.

IV. Results

Experiment results were recorded to evaluate the performance of the prototype design and deduce some lessons. The results for tests are obtained and presented in Figure 7. The ratios of air flow rate to inside air flow temperature (IAT) are plotted for the four valves settings at temperatures of 60, 80, and 100 C^o.

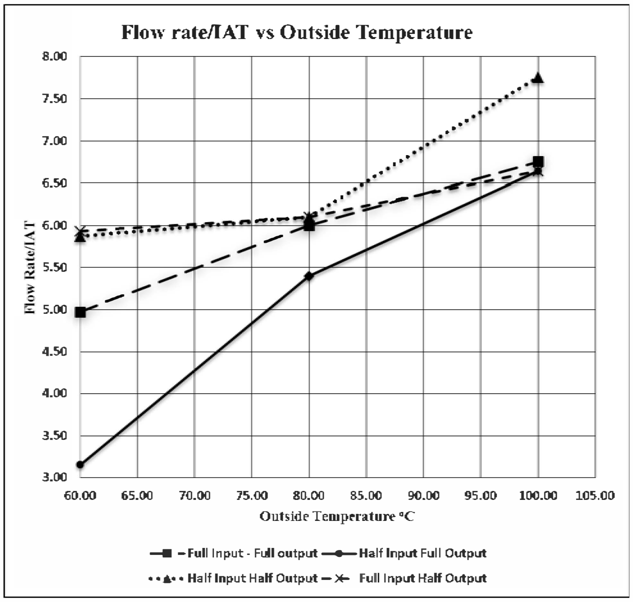

Figure 7: Air flow rate to inside air temperature ratio.

From the graphs in Figure 7, it can be seen that the flow rate/IAT is directly proportional to the outside temperature. The increase is very apparent for the case where the inlet and the outlet valves are both half full opened (see dotted line). This conclusion complies with the equation of continuity that is the smaller the cross section area the greater the velocity of the fluid.

E. Electricity Generation Tests

Due to the small size of the tank, it cannot generate the required air flow at temperature of 60 to 100 C^o. Therefore, the air flow was not high enough to drive the generator wheel. Thus, a recommendation is given on this case in the further research work needed.

It takes a long time to get the system in steady state conditions. The results show that:

- At all temperatures the inside air tank temperatures are increased when inlet valve are in half open position.
- At all temperatures, the air flow rate decreases when inlet valve are in half open position.
- At all temperatures, the air flow rate increases further when the inlet and outlet valves alternate between half and fully open positions.
- The air cannot carry high temperature as any liquid like water or oil.
- The air cannot absorb heat more than its thermal capacity. Therefore, it is not recommended to use this system for high source temperature.

V. FURTHER RESEARCH WORK NEEDED

Taken in consideration the limitation of resources, facilities, and lack of fund to run a large scale prototype. Therefore, the following suggestions and recommendations are listed to develop this project further:

1) The valves installation is very important to control the inlet and outlet air flow. The pipe diameter at air inlet can be chosen bigger than the pipe diameter at the air outlet to let more airflow in and to increase outlet air flow velocities with temperatures.

2) Make air inlet as a conical shape allowing increasing cold air flow intake into the metal tank by reducing inlet air friction.

3) A simple electronic control system can be used to control the air flow rates with temperatures.

4) Add solar concentrators to the prototype and test the system under real environmental conditions.

5) Add a metal ring cover around the tank on the top of the fins section. This will help increase the heat transfer from the outside throw the fins to the inside air tank.

6) Run tests on the inlet and outlet valves in full, half and different open positions with different temperature set-ups. To study the effects of the set-ups on the efficiency of the system.

7) Use a data requisition system connected to a computer to measure instantaneous system performance.

8) The usage of an automated system and devices in data collection, as possible, will avoid human error. It also needs to keep the standard calibration of thermocouple, air flow meter, and energy source. An energy stabilizer can be installed on the electric power supply line to the light source. It is important to keep the doors are closed and reduces the effect of the air flow measurements in the system.

9) Study the efficiency of the system under different set-up conditions.

10) A large metal tank can be used for this kind of tests. The large tank collects more heat and generates high air flow that could be even at low temperature ranges.

11) Perform experiments under real environmental conditions. Measuring solar radiation energy as input to the tank and calculate the output energy that is collected by air and predict the efficiency of the system.

12) Tests can be carried out when the tank is buried at the geothermal level, when using the geothermal energy as driving energy source to the system. Run tests to predict the efficiency of the system.

While implementing the above modifications, more tests are needed under realistic weather conditions of high temperature and dry environment to comprehensively evaluate the performance of the system.

VI. Conclusion

This project is conducted to confirm the concept of using solar energy as a driving force to generate electricity. The size of system is small to generate enough power to drive the turbine wheel. A large metal tank can be used instead. An optimal size of the tank can be estimated so that the collected solar energy does not exceed the thermal capacity of the air.

When the recommendations are taken into consideration and tests will be conducted, the results will be verified.

Further research can be done on the system while it is buried at the geothermal level as an alternative source of energy.

VII. Acknowledgment

The authors wish to acknowledge the assistance of Mr. C.S. Bilkhow from Surteck Precision Machining, Ottawa, ON for building the prototype, providing the resources and facilities necessary to work on this project. Thanks are also due to Mietek Slocinski for help with various aspects of the project.

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