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Study of Thermodynamic Analysis of Solar Updraft Tower and Its Design

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ABSTRACT

In this paper, we study of thermodynamical properties and design of solar tower. Solar energy is the energy that originates from the thermonuclear fusion reactions occurring in the sun. It is thus, an embodiment of the entire electromagnetic radiation (Visible light, infrared, ultraviolet, x-rays and radio waves).
Keywords: SFEE, EMW, Radio Waves, Solar Energy.

I. INTRODUCTION

The idea of using solar radiation to generate air convection that can subsequently be converted to an energy source has been around since the start of the 20th century, when a Spanish Colonel called "Isidoro Cabanyes", proposed it in a scientific magazine. Solar Updraft towers, also called solar wind or solar chimney plants, provide a very simple method for renewable electricity generation, with a constant and reliable output. Other renewable energy sources such as wind turbines and solar arrays suffer from high diurnal and seasonal fluctuations, or unpredictable patterns of output [1-5]. Sensible technology for the wide use of renewable energy must be simple and reliable, accessible to the technologically less developed countries that are sunny and often have limited raw materials resources. It should not need cooling water and should be based on environmentally friendly production from renewable or recyclable materials. Invariably, solar updraft tower meets these requirements. A typical pictorial illustration of the robust set up and technology behind the solar updraft tower is shown in figure 1 below.

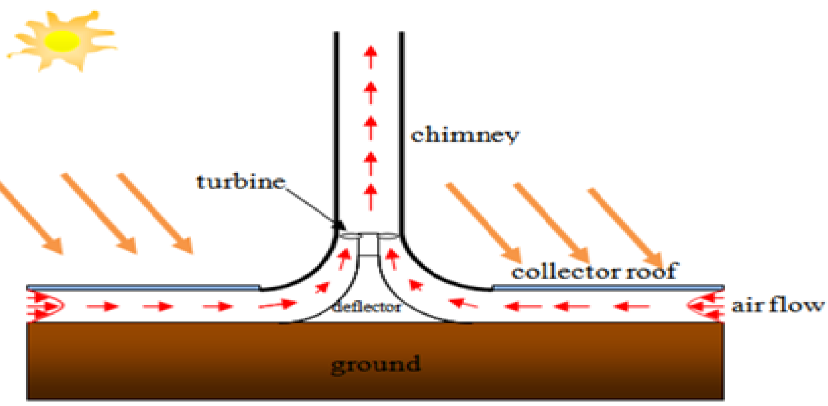

Figure 1 Schematic of solar updraft tower

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II. MATERIALS AND METHODS

The solar intensity emitting or radiating from the sun depends largely upon its peak wavelength, λ_{max} and temperature. In accordance with the "*Wien Displacement Law*", thus;

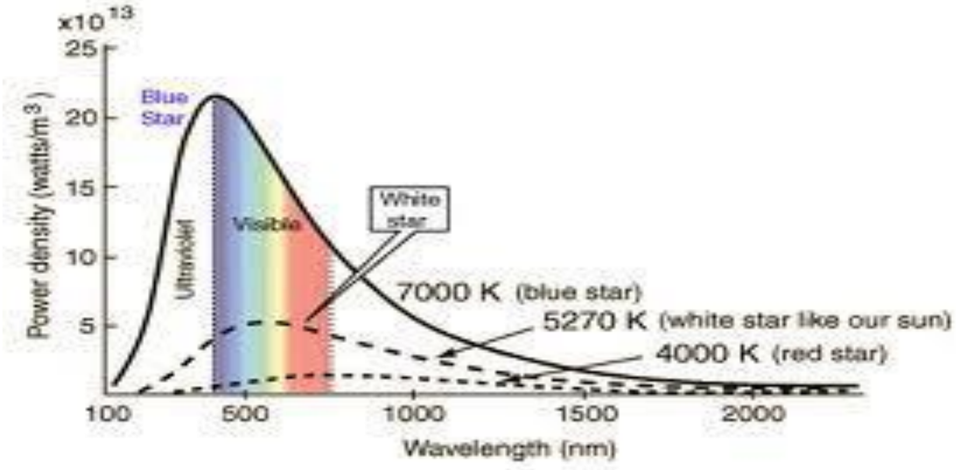

Figure 2 Wien displacement law of electromagnetic wave propagation

$\lambda_{max} = \frac{2897}{T}$ (1)

Thence, the surface irradiance or radiation output, ***E*** of the sun can be evaluated using "*Stefan-Boltzmann Law*" when the temperature has been known from equation 1 above. Thus;

$E = \epsilon\sigma T^4$ (2)

Where;

E= Surface Irradiance of the Sun

ϵ=Emissivity of the Sun

σ=Stefan-Boltzmann Constant($5.67 \times 10^{-8} Wm^{-2}K^{-4}$)

T= Temperature of sun in Kelvin

It is however pertinent, to know that both Wien Displacement and Stefan-Boltzmann laws strictly apply to black bodies. Black bodies are capable of absorbing and emitting radiation at all wavelengths. But, since the Sun and Earth are not perfect black bodies, these laws only provide an approximation, hence certain correction factors like opacity,T_r transmitivity, τ, and absorptivity, α need to be taken into consideration [6-8].

III. RESULTS AND DISCUSSION

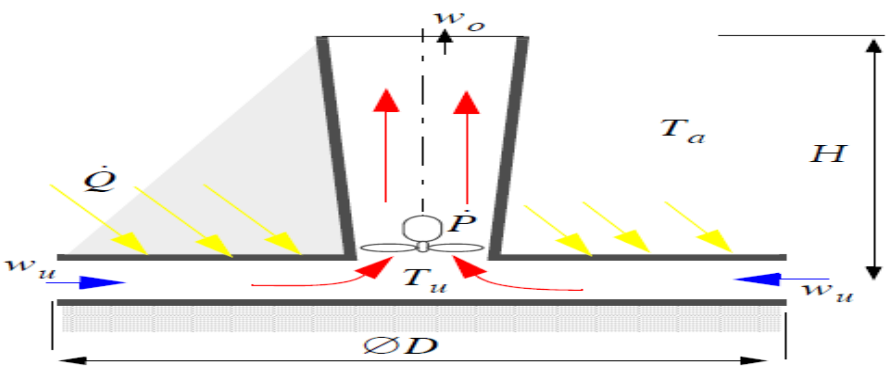

Figure 3 Thermo Fluid of Solar Updraft Tower

The above figure can be thought of as a control volume, thus obeying the first law of thermodynamics. This means, that mass or energy can neither be created or destroyed, although can be transformed from one form to the other. As the solar irradiance is converted into solar insolation, it warms up the entrapped air present in the greenhouse or air collector, which are then forced to generate convective heat flow, that are up-drafted to drive the turbine. It can be inferred that the sole purpose of the thermodynamic analysis of this tower is to evaluate the output power $\dot{P}$ as a function of the geometric parameters and the heat input $\dot{Q}$ generated from the solar irradiance.

Solar Heat

The solar heat (Heat input from solar radiation) is seen to distribute in such a symmetric form, since heat transfer with time is symmetrical as shown in figure 4. This is the quantity of heat needed to pass through the greenhouse and warm the air flow. It follows thus that the larger the heat absorbed by the collector, the larger the air mass flow, since it has been established that warm air has greater tendencies to displace cold air in space. The output curve envisaged that, the disorganized energy inherent in the heat flow will do well in converting much of the updraft into useful energy to drive the turbine, if the optical factors (such as transmittance, absorptance and emittance property of the Plexiglas) are so close to unity, in their entity [9].

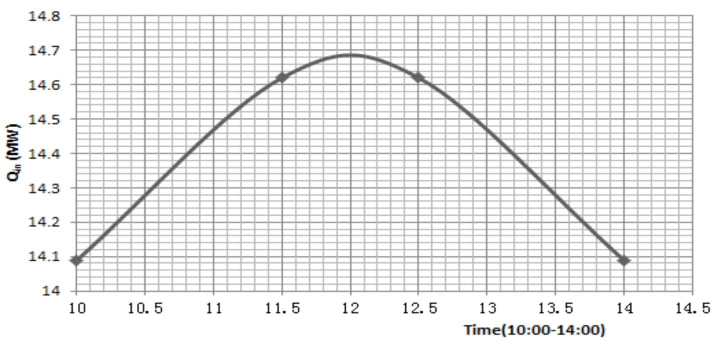

Figure 4 Solar heat distribution effects with time.

Output Power Vs Air Mass Flow

As can be seen below in figure 5, the power output of the turbine unit is null when the air mass flow null. However, it reaches a maximum at a point where the air mass flow is optimized. The characteristic curve also reveals that the relationship between the output power and mass flow is non-linear; thereby re-assuring that the former bears a third power relationship with the latter. Each curve corresponds to a given temperature difference between the heating zone temperature and that of the dead state (environment). The ideal power estimated without irreversibility is plotted against the air mass flow and compared with the same effect an actual power (which takes into account the effect of all possible irreversibility like friction loss, heat loss, pressure loss, gravitational loss etc) would produce, were presented in the below curve as shown in figure 5.The curve reveals that, irreversibility tends to reduce the performance of the turbine and therefore, the output power will be maximized at the point where the air mass flow is optimum. This is not the case for ideal power consideration, because there are no losses and the process is considered quasi-static. Thus, the ideal power which is the maximum theoretical value possible shows a continuous increase as the mass flow increases. The difference between both cases is represented by,h_f a factor called head loss due to irreversibility.

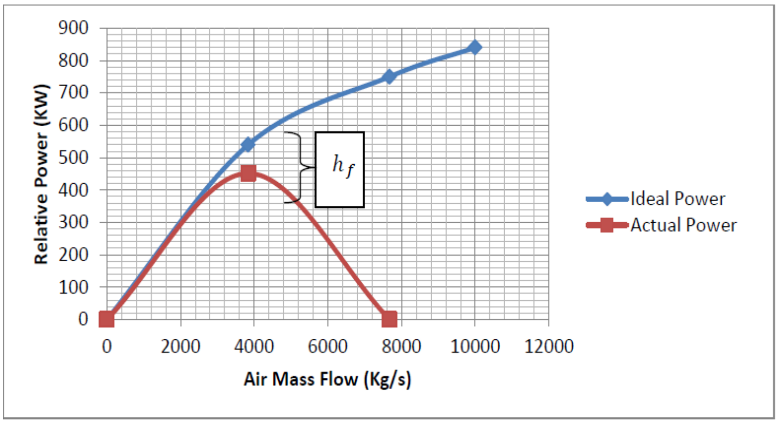

Figure 5 Power output vs. Air flow rate.

IV. CONCLUSION

It can be inferred from the results obtained and graphical output of characteristics that the robust design would function at its best if the temperature difference is as large as possible. Since, the hotter air tends to be more energetic and create a stack effect along the tower. It was also shown that at elevated temperatures, the mass flow becomes larger that it produces a thrust of higher magnitude on the turbine blades which in turn improves its performance. The performance of the turbine both for ideal and actual cases was presented. The power output was found to be dependent on the third power of the air mass flow and thus upon the tip-speed ratio. The effects of losses were considered and insight was gained into improving the design to minimise such irreversibility.

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