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Streamlined Method to Design a Mini Solar Updraft Tower for Educational Purposes

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Abstract - *As the name suggests, the paper is all about the method to make mini solar updraft tower for project related purposes. The reason behind paper's confinedness to use it for such purposes is primarily that other complex factors that plays role at macro-level is neglected here. Starting right from the requirement of the power output that needs to be procured to achieving the same, each and every point is discussed here in this paper.*

Key Words: Design, Solar, Updraft, Tower, Project, educational, method, material, source, power, green, energy, efficient, low, maintenance.

1.INTRODUCTION

In this era, one of the most significant restrictions on the universal adoption of solar power and renewable energy: accessibility. There must be a revolutionary way to make solar power into something that is available to everyone and anyone throughout the world.

The [1]Solar Updraft Tower (SUT) technology generates renewable energy by sun-wind energy harvesting. In SUT the solar radiation, which is an inexhaustible input, is converted into electrical power through the natural updraft of heated air in a very high chimney.

The main problem in traditional SUTs is that they require substantial region of greenhouses and a large updraft of air in the chimney to obtain the desired outputs, which is nearly impossible to achieve with domestic models used for educational purposes this could be tackled by the proposed invention.

1.1 BASIC PARTS OF SOLAR UPDRAFT TOWER

The solar updraft tower's three essential elements – solar air collector, chimney/tower, and wind turbines.

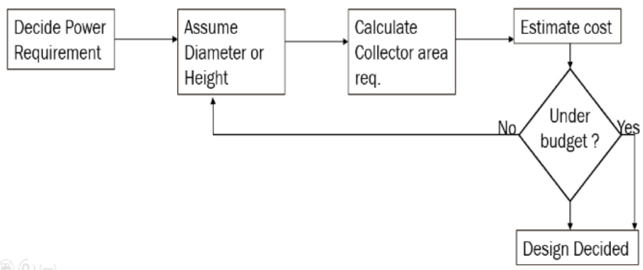
Solar Collector- Hot air for the solar tower is produced by the greenhouse effect in a simple air collector consisting of a glass or plastic glazing stretched horizontally several meters above the ground. The height of the glazing increases adjacent to the tower base, so that the air is diverted to vertical movement with minimum friction loss. This glazing admits the solar radiation component and retains long-wave re-radiation from the heated ground[2].

Solar/Chimney Tower- The tower itself is the plant's actual thermal engine. It is a pressure tube with low friction loss (like a hydro power station pressure tube or pen stock) because of its favorable surface-volume ratio. The updraft velocity of the air is approximately proportional to the air temperature rise (ΔT) in the collector and to the tower height.

Turbines- Using turbines, mechanical output in the form of rotational energy can be derived from the air current in the tower. Turbines in a solar tower do not work with staged velocity like free-running wind energy converters, but as shrouded pressure-staged wind turbo generators, in which, similarly to a hydroelectric power station, static pressure is converted to rotational energy using cased turbines[3].

The SUT is a design concept for a renewable-energy power plant for generating electricity from low temperature solar heat. Sunshine heats the air beneath a very wide greenhouse-like roofed collector structure surrounding the central base of a very tall chimney tower. The resulting convection causes a hot air updraft in the tower by the chimney effect[4]. This airflow drives wind turbines, placed in the chimney updraft or around the chimney base, to produce electricity.

1.2 DESIGN PARAMETERS FOR ANALYSIS



The given flow chart shows us the complete selection procedure of a SUT for educational purposes,

To begin with the primary process is selecting the power output for tower, which is as per the need of one. After that it requires to presume any one of the following parameters, either it be radius of the solar collector or the height of the chimney tower.

The following step is to calculate the estimated area required for the erection of SUT. The final step includes the financial evaluation for the fabrication of SUT, if the overall expenditure on the building of SUT is under the estimated cost then the design should be selected or else the whole procedure has to be repeated to get the optimal dimensional parameters of the SUT.

2. MATHEMATICAL SIMULATION OF PHYSICS IN SOLAR UPDRAFT TOWER

The Power output P of the SUT can be calculated as:

$$P = Q_{solar} \cdot \eta_{coil} \cdot \eta_{turbine} \cdot \eta_{tower} = Q_{solar} \cdot \eta_{plant}$$

The solar energy input Qsolar :

$$Q_{solar} = G_h \cdot A_{coll}$$

The pressure difference Δp_{tot} produced between tower base and the ambient:

$$\Delta p_{tot} = g \cdot \int \rho_{amb} - \rho_{heated} \cdot dH$$

The pressure difference Δp_{tot} can be subdivided into a static and a dynamic component, neglecting friction losses:

$$\Delta p_{tot} = \Delta p_s + \Delta p_d$$

With the total pressure difference and the volume flow of the air at $\Delta p_s = 0$ the power P_{tot} contained in the flow is now:

$$P_{tot} = \Delta p_{tot} \cdot v_{tower\ max} \cdot \Delta A_{coll}$$

from which the efficiency of the tower can be established:

$$\eta = P_{tot} / Q$$

Actual subdivision of the pressure difference into a static and a dynamic component depends on the energy taken up by the turbine. Without turbine, a maximum flow speed of $v_{tower,max}$ is achieved and the whole pressure difference is used to accelerate the air and is thus converted into kinetic energy:

$$P_{tot} = \frac{1}{2} m v_{tower,max}^2$$

Using the Boussinesq approximation (Unger, 1988), the speed reached by free convection currents can be expressed as:

$$v_{tower,max} = \sqrt{2 \cdot g \cdot H_{tower} \cdot \frac{\Delta T}{T_0}}$$

Tower efficiency is given as:

$$\eta = \frac{g \cdot H}{c_p \cdot T_0}$$

This simplified representation explains one of the basic characteristics of the solar tower, which is that the tower efficiency is fundamentally dependent only on its height. For heights of 1000m the deviation from the exact solution, caused by the Boussinesq approximation, is negligible[5].

The physical constants and logical quantifiers used in the relations are as follows:

SYMBOL	MEANING
η	Efficiency of the respected processes and machines
G_h	Average daily solar irradiation (W/m^2)
A	Area of collector (m^2)
g	Gravitational constant (m/s^2)
ρ	Density of Air in particular conditions (kg/m^3)
h	Height of tower (m)
dH	Difference in height
$v_{ambient}$	Ambient velocity of air (m/s)
dT	Temperature Difference (K)
To	Ambient Temperature (K)
C	Discharge coefficient
P_{air}	Air Pressure (Pa)
$V_{towermax}$	Maximum velocity of air inside the chimney tower (m/s)

3. PROTOTYPE OF SUT

The Building Materials are illustrated as follows in the table. The grey PVC pipes were used to construct the chimney [6]. The white PVC tubes were used to construct probes to uphold the prototype. Polyethylene plastic was used as a greenhouse material to cover the solar collector and trap solar energy to heat the air. The metallic plate was centred in the middle of the prototype welded along with the to hold the chimney as will be further illustrated in the next sections.

For, the prototype of SUT the base power output is selected to be 10W, based on that we get the following parameters for the construction of the prototype.

Model of SUT

NAME	DIMENSIONS
Grey PVC Pipes	75mm Diameter
White PVC Tubes	20mm Diameter
Polyethylene sheets	$25m^2$
Metallic Plate	5kg
Stainless Steel Struts	1.2 kg
Galvanized Steel Wire	7m

Materials used in Construction

4. PROPERTIES OF MATERIALS USED IN ERECTION OF SUT

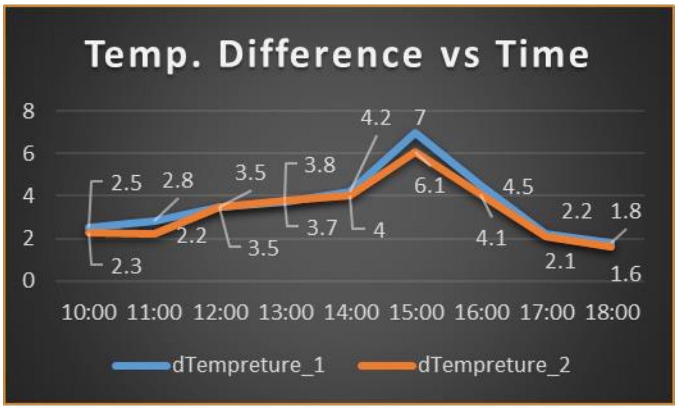
The given table shows the physical properties of the materials which are used for the construction of SUT

Physical Properties	Collector sheet	Absorber sheet	Chimney
Density (Kg/m^3)	2500	2160	2719
Th. Conductivity (W/mk)	1.15	202.4	1.83
Sp. Heat (J/KgK)	750	871	710
Absorbtion Co-eff	0.03	0.9	0
Transmissivity	0.9	Opaque	Opaque
Emissivity	0.1	0.9	1
Reflective index	1.526	1	1
Thickness (m)	0.004	0.004	0.00125

5. OBSERVED TEMPERATURE DIFFERENCE FOR PROTOTYPE

After the erection of the solar updraft tower the temperature difference (ΔT) is taken on hourly basis for two days:

Time	dT_1	dT_2
10:00	2.5	2.3
11:00	2.8	2.2
12:00	3.5	3.5
13:00	3.7	3.8
14:00	4.2	4
15:00	7	6.1
16:00	4.5	4.1
17:00	2.2	2.1
18:00	1.8	1.6



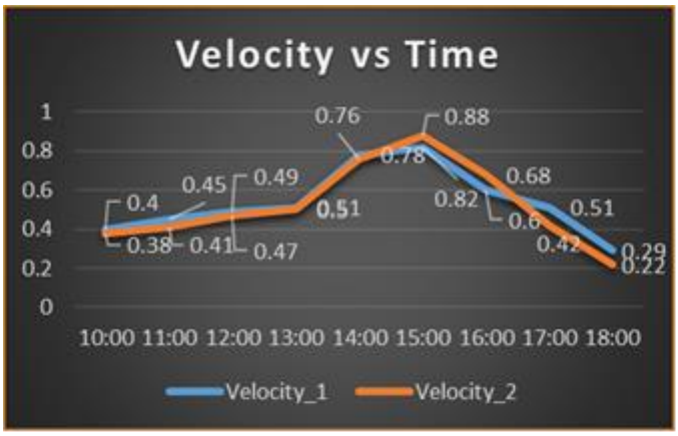
6. MAXIMUM VELOCITY OF AIR OBTAINED IN THE TOWER FOR PROTOTYPE

To obtain the $v_{tower,max}$ the following mathematical relation is used

$$v_{tower,max} = \sqrt{2 \cdot g \cdot H_{tower} \cdot \frac{\Delta T}{T_0}}$$

By, putting the values of (ΔT) temperature difference obtained from the physical model, we can acquire the theoretical values of maximum velocity [7]. The values of velocities obtained in such manner is tabulated in the below table:

Time	Velocity_1	Velocity_2
10:00	0.4	0.38
11:00	0.45	0.41
12:00	0.49	0.47
13:00	0.51	0.5
14:00	0.78	0.76
15:00	0.82	0.88
16:00	0.6	0.68
17:00	0.51	0.42
18:00	0.29	0.22



7. DETERMINING THE OVERALL EFFICIENCY OF SUT PROTOTYPE

From the table itself it is pretty clear that the maximum temperature difference and velocity obtained is in mid-afternoon at 15:00PM.

To obtain the power generated in the SUT prototype we will use the following physical relation [8]:

$P_{tot} = \Delta p_{tot} \cdot v_{tower\ max} \cdot A_{coll}$

Applying this formula along with the maximum temperature and velocity achieved in the SUT prototype we can get the maximum power output as P_{tot} 4W.

Now for finding out the overall efficiency of the SUT the following mathematical relation should be applied:

$\eta_{prototype} = P_{tot} / P_{est}$

where P_{est} is the estimated power output for which the SUT is designed and $\eta_{prototype}$ is the efficiency of the updraft tower.

In the following case that we have considered the overall efficiency of the SUT is found out to be 0.4 which is about to be 40%.

8. CONCLUSION

The purpose of the research is to identify a suitable manner for construction of Solar Updraft Tower (SUT) for educational purposes on a much smaller scale than the original design. Based on the analysis it is concluded that the design parameter flow chart can be successfully implemented for determining the basic parameters of a SUT. The amount of power output depends on the maximum temperature difference attained in the chimney of the tower.

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