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PARAMETERS FOR DESIGN DEVELOPMENT AND PERFORMANCE ASSESSMENT OF SOLAR UPDRAFT TOWER PLANTS ON A SMALL SCALE

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Abstract - Energy consumption has been increasing day by day because of population growth throughout the world. Present energy resources such as petroleum products may not sustain for long to meet human needs. The rapid utilization of limited fossil fuel reserves and other conventional energy sources are the main reasons for fuel scarcity in the globe. Use of fossil fuel and natural gas creates pollution, environmental problems etc. Also, their rising prices, diminishing availability in the future, force the society to find an alternate solution for fossil fuel. This has created awareness about alternative sources and therefore, much research is needed on non conventional energy sources. Solar energy is one source which is freely and abundantly available and a huge amount of energy can be harnessed. One of the solar energy based plants is called solar updraft tower (SUT) power plant which has attracted attention of researchers because of its simple construction and novel technique.

Various kinds of solar power generating technologies such as thermo electric power generation, thermionic power generation, solar central power tower technology, parabolic trough solar thermal technology and dish solar thermal technology have been developed since so many years. However, this power generating technologies have some specific demerits such as high investment cost, low installed capacity and poor ability to resist wind force. To solve the problems of above said, SUT is one of the choices among the various solar technologies for producing power because of its simple design, easy fabrication, low operational and maintenance cost. Estimation of solar input parameters such as radiation falls on collector, energy losses, radiation absorbed by absorber plate and consequently its heat losses is a very important thing in the design of a SUT system

1.2 Energy

The definition of energy in physics terminology is ”The property of matter and radiation which is manifest as a capacity to perform work (such as causing motion or the interaction of molecules)”.In other words, ”Energy is the capacity for doing work. It may exist in various forms such as potential, kinetic, thermal, electrical, chemical, nuclear, or other forms. In the energy process heat transfer from one body to another. After it has been transferred, energy is always designated according to its nature. Hence, heat transferred may become thermal energy, while work done may manifest itself in the form of mechanical energy”.The Laws of thermodynamics defines the basic behaviour of energy, temperature and entropy. The four laws of thermodynamics clearly describe the characterization of the energy quantities with respect to various circumstances.

The Zeroth Law of Thermodynamics states that ”If two thermodynamic systems are each in thermal equilibrium with a third, then they are in thermal equilibrium with each other”. This law defines the concept of temperature.

The First Law of Thermodynamics is also known as Law of conservation of energy and it states that ”Energy can neither be created nor destroyed; energy can only be transferred or changed from one form to another”. i.e.,When energy passes as work, as heat, or with matter,in or out from a system, the system’s internal energy changes in accord with the law of conservation of energy.

Second law of thermodynamics indicated the irreversibility of natural processes and states that ”The entropy of an isolated system not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium”. In simple words, the entropy of the universe (the ultimate isolated system) only increases and never decreases. Third law of thermodynamics states that ”As temperature approaches absolute zero, the entropy of a system approaches a constant minimum”. This law defines the concept of entropy. The above mentioned four laws convey the concept of energy behaviour and the nature of temperature process. These laws help in the performance analysis with respect to solar energy studies.

efficiency of the system is measured at the STC conditions are taken into account and the thermal efficiency varies with respect to the time. The overall efficiency is the sum of electrical and thermal efficiencies per annum and it is expressed in (%). The energy yield in PV/T is the sum of electrical and thermal system. The electrical yield calculated as per the data sheet and its annual degradation. The thermal energy is measured in Btu/hr and it is converted into respective units of kW. The total energy yield of PV/T system is the sum of electrical and thermal energy yields and it is measured in kWh/kW .

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2. Literature review

A A small experimental model was established by Ayadi et al. [5] to bring out the influence of Hch on air flow characteristics inside SUT. Also, CFD simulations were carried out and validated with experimental findings. Finally they came to an agreement that Hch was a crucial parameter to influence the heat transfer characteristics of air inside SUT. Similar study was executed by Ayadi et al. [6]'s another work to examine the impact of collector roof angle on SUT system performance. The various process parameters such as air velocity, temperature, pressure and solar radiation were measured and discussed for different collector roof slope angles.

Tingzhen et al. [7] developed a sophisticated mathematical model which described the complete physical process and estimated the performance of SUT plant. Various performance parameters such as relative static pressure, temperature distribution, power generation and efficiency of the system have been investigated. They concluded that the driving force, maximum power output and efficiency were not only depends on Hch but also depends on solar radiation and other geometric dimensions.

The effect of water vapour film condensate (presents on top and bottom surfaces of collector canopy) on the SUT system performance was assessed by Al-Kayiem et al [32]. It is observed that the presence of condensate film on surface of canopy can reduce the hydrothermal performance of SUT by two ways: by reducing the transmittance of solar heat flux and by absorbing heat from water vapour particles to evaporate.

Asnaghi et al. [33] developed a numerical model for SUT and estimated the velocity and temperature distribution of air. ANSYS FLUENT was used to solve this numerica

3. Literature gaps

Overall, this setup has been enormously reviewed, though there is a dearth of design parameters, as this setup involves a number of process and design parameters, such as turbine blade parameters, solar radiation parameters, quantity and selection of storage materials, materials for solar collector (cover and absorber plate).

No performance and design details of SUT have been found for the main components such as solar collector, chimney, turbine etc.

The solar input parameters have not been estimated for this specific application and subsequent energy losses also not found.

Similarly, the materials needed for the above components have not been discussed.

There is no solar energy storage facility found as the system has a huge area of solar collector.

There is always a dearth of information about which position of collector and absorber plates give better flow and performance characteristics. The present numerical investigation analyses this fact by developing three different cases and predicting the parameters, so that better case can be identified.

of the SUT and its components (collector, chimney and turbine) is explained. For the numerical work, the selection of the software for simulation, different operating and geometrical parameters considered are discussed. The domain selection, mesh generation, boundary condition, solution method are discussed. Also material and method for small scale SUT experimental set-up are discussed. After that, the design and development of the experimental setup are explained in this section. Various instruments used for measuring different parameters are explained followed by the experimental procedure.

4. Analytical methodology

The objective of this work is to investigate the performance of SUT and to tabulate all the inputs and estimated parameters with the materials of a SUT power plant. All the three main components' (turbine, solar collector and a chimney) process parameters are estimated and discussed. Appropriate materials are discussed and selected for solar collector, chimney, turbine and heat storage materials. Solar beam, diffuse and global radiation are estimated to analyze the performance of collector cover. Energy losses in solar collector cover and transmissivity estimations are performed to calculate theoretical energy collected in solar collector. Pressure drop inside the chimney is estimated and from that the actual power output of the turbine is calculated. The quantity of heat storage materials needed is evaluated in terms of both mass and volume.

Before going in to design, certain assumptions have to be made for this analysis,

Axisymmetric air flow in the collector inlet, that is, non uniform heating of the collector surface in terms of the sun's altitude angle is neglected.

Constant environment conditions including ambient temperature and inlet air temperature.

Heat losses through the wall of the chimney are neglected.

The air follows the ideal gas law.

Only the buoyancy force is considered in the chimney.

An absorber plate made up of copper was placed on top of TES system to absorb maximum amount of solar radiation. A number of rectangular copper plates (length of 1220 mm, width of 356 mm, and thickness of 1.5 mm) were purchased from Hyderabad, India and cut and riveted into a circular piece of 3.5 m diameter. Black paint was applied on it to increase its absorption capacity. Temperature sensors are fixed on the surface of absorber plate in all four directions (East, West, North and South) at a distance of 300 mm, 800 mm and 1300 mm from the entrance of collector.

5. Results and discussion based on theoretical analysis

In this section, the obtained theoretical results are discussed. The results obtained for design, development and materials selection of laboratory scale SUT are discussed. The solar radiation calculations, energy gain and loss, collector efficiency, overall efficiency and power output of SUT system are also explained. Optimisation of the geometrical dimensions of SUT is explained. Optimisation of the design and performance parameters for various wind turbine blades of a SUT plant using blade element momentum (BEM) theory is discussed.

6. Solar radiation calculation

radiations were calculated on 21st of every month of the year 2016, at NIT Warangal. Figs. 3.1 and 3.2 show that the comparison between the availability of solar radiation on 21st of every month of the year 2016. From both Figs. 3.1 and 3.2 the maximum solar global radiation was observed in summer

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(April/May). In the primary time frame; both daylight hour and temperature are high. The second peak happens in August (harvest time) which is not so noticeable, because of a high temperature but rather short sun shining period (Fig. 3.2). In the winter (November/December), again sufficient sun shining periods are available but the temperature is low (Fig. 3.2). Subsequently, it brings about low global sun radiation. These theoretically estimated global radiation values were compared with India's Meteorological department values, 2016 [75]. The most extreme estimation of global radiation is 1059.38 W/m2 at the time of April when the bright sunshine hour and normal temperature are 9.17 hours and 31.5˚C respectively [75]. The base estimation of global radiation is 851.22 W/m2 at the time of December when the bright sunshine hour and normal temperature are 8.39 hours and 21.6˚C [75] respectively

7. Future scope

Numerical investigation of the performance parameters estimation of a solar updraft tower (SUT) plant coupled with various wind turbines using ANSYS FLUENT package (with dynamic mesh model (DMM) approach).
NACA 4412 wind turbine
NACA 23012 wind turbine
NACA 0012 wind turbine
Experimental analysis of a small scale solar updraft tower (SUT) plant coupled with a real turbine (turbine will be manufactured by 3-D Printer with optimised dimensions).
Numerical analysis on estimation of flow and heat transfer characteristics of a solar updraft tower (SUT) plant coupled with guide vanes and wooden base cone at chimney base using ANSYS FLUENT package.
Numerical investigation of the performance parameters estimation of a SUT plant coupled with thermal energy storage system (rocks and lime stones) using ANSYS FLUENT package

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