A review of the vortex engine

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Abstract

Convective vortices are common features of atmosphere that absorb lower-entropy-energy at higher temperatures than they reject higher-entropy-energy to space. Via the thermodynamic efficiency, it has been predicted that the intensity of convective vortices depends on the depth of the convective layer. The atmospheric vortex engine is proposed as a device for producing mechanical energy by means of artificially generated vortex. The operation of the engine is based on the facts that the atmosphere is heated from the bottom and cooled from the top. By generation of the artificial vortex, it is aimed to eliminate the physical solar updraft tower and reduce the capital of the solar chimney power plants. The paper presents the fundamentals of the atmospheric vortex engine, and reviews the state of the art in topic. Furthermore, the paper discusses an idea on utilizing the solar energy as heat source to operate the system. In conclusion, the system is feasible and promising for electrical power generation.

Keywords: convection vortex, tornado, atmosphere, vortex engine, power generation, global warming, solar energy, solar collector.

1 Introduction

To overcome the high investment costs of installing the solar updraft tower power plants SUTPPs which are mostly due to the tower height and labor costs, a development occur to decrease the tower height, where the physical chimney is replaced by the centripetal force produced by swirly upward airflow which is called vortex engine. Solar updraft tower are defined as low temperature solar thermal power plants, which use the atmospheric air as a working fluid, where only one part of the thermodynamic cycle within the plant is utilized [1]. The main features of the solar updraft tower power plants are sketched in fig. 1. Air is heated as a result of the greenhouse effect under a transparent roof (solar

WIT Transactions on Ecology and The Environment, Vol 179, © 2013 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SC130772

collector). Because the roof is open around its periphery, the buoyancy of the heated air draws a continuous flow from the roof perimeter into the chimney (updraft tower). A turbine is set in the path of the air current to convert the kinetic energy of the flowing air into electricity [2–6]. Performance enhancements of solar chimney power plants have been carried out by many investigators, by many techniques. Chikere *et al.* [7] reviewed the enhancing technologies and also suggested an alternative approach to enhance the performance of solar chimney power plants by hybriding the solar operation mode and waste heat energy from flue gas.

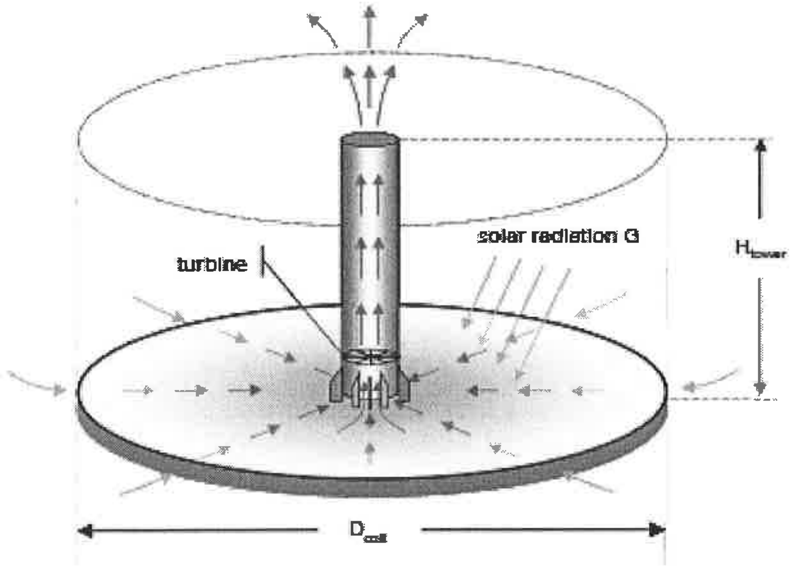

Figure 1: The main features of a solar chimney power plant; solar collector, updraft tower and turbine [5].

In this paper, the reason of use vortex engine and background of vortices genesis were presented, then convective vortices generation and an atmospheric vortex engine were reported. The purpose of this work is to review the present state of the convective vortex engine, and the development of operating the solar vortex engine with air temperature rise by using solar collector with PCM thermal energy storage.

1.1 Background of vortices

The tornado is a highly effective mechanism through which Nature acts to convey humid boundary layer air to the top of the Troposphere where precipitation is initiated. The "anvil" is formed when it reaches the tropopause, the interface with the stratosphere (fig. 2) [8].

Generally atmospheric temperature declines with altitude except where (fig. 3):

- Incoming solar radiation is absorbed in the stratosphere (in which the ozone layer lies).
- Solar wind particles are intercepted in the thermosphere which includes the ionosphere.

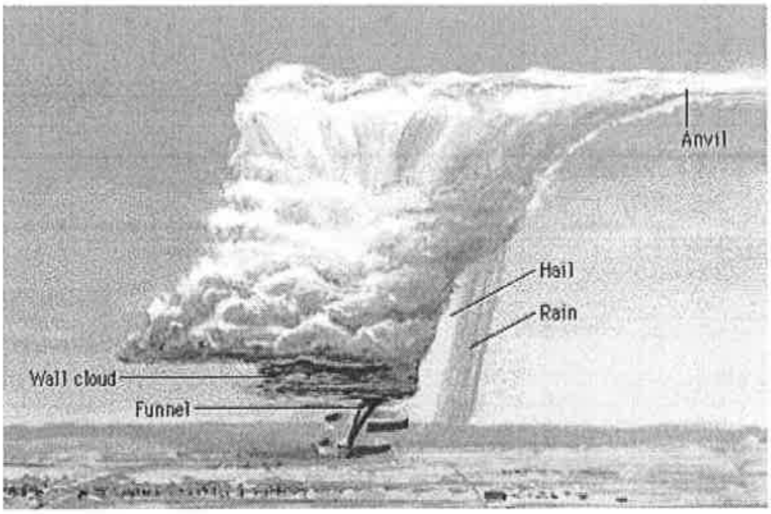

Figure 2: Vortices in nature [8].

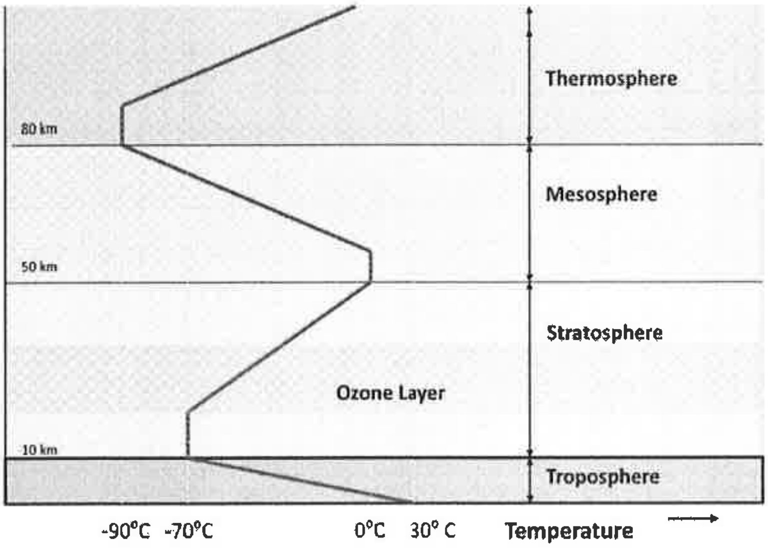

Figure 3: Simplified graph of atmospheric temperature profile [8].

The troposphere is the lowest region of the Earth's atmosphere, where masses of air are very well mixed together and the temperature decreases with altitude. The air is heated from the ground up because the surface of the Earth absorbs energy and heats up faster than the air. The heat is mixed through the troposphere because on average the atmosphere in this layer is slightly unstable. The vortex engine is basically a system to enhance the transmission of energy through the troposphere [8].

2 Convective vortices generation

Convective vortices are common features of atmospheres that absorb lower-entropy-energy at higher temperatures than they reject higher-entropy-energy to space. These vortices range from small to large-scale and play an important role in the vertical transport of heat, momentum, and tracer species. The heat engine framework is a useful tool for studying convective vortices. However, current theories assume that convective vortices are reversible heat engines. Since there are questions about how reversible real atmospheric heat engines are, their usefulness for studying real atmospheric vortices is somewhat controversial. In order to reduce this problem, a theory for convective vortices that includes irreversible processes is proposed. The main result is that the proposed theory provides an expression for the pressure drop along streamlines that includes the effects of irreversible processes. It is shown that a simplified version of this expression is a generalization of Bernoulli's equation to convective circulations. It is speculated that the proposed theory not only explains the intensity, but also sheds light on other basic features of convective vortices such as their physical appearance. In particular, it predicts that the intensity of convective vortices depends on the depth of the convective layer via the thermodynamic efficiency, the enthalpy perturbation across them, and the existence of sources of vorticity. It also predicts that non-hydrostatic pressure perturbations increase with the kinetic energy of air parcels spiraling towards the vortex [9].

Park and Kim [10] present a method for visual simulation of gaseous phenomena based on the vortex method. This method uses a localized vortex flow as a basic building block and combines those blocks to describe a whole flow field. As a result, computational efficiency is achieved by concentrating only on a localized vorticity region while generating dynamic swirling fluid flows. Vorticity equation can describe as eqn. (1):

$$\Omega(x,t) = \frac{1}{2}\nabla \times u(x,t) = \frac{1}{2}\begin{vmatrix} i & j & k \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ u & v & w \end{vmatrix} \tag{1}$$

Based on the Lagrangian framework, various boundary conditions are resolved. By exploiting the panel method, the no-through boundary condition in a Lagrangian way is satisfied. A simple and effective way of handling the no-slip boundary condition is also presented [10].

The technical useful part of heated moist air availability in the atmosphere, stratified in a gravitational field. In particular, the study focuses on the possibility that this availability can be concentrated at the ground level without using a solid ‘‘chimney”. The results reveal that this concentration can be achieved via the formation of an updraft ‘‘gravitational vortex column” (GVC) situated over turbines. A numerical solution is given for a characteristic case, with a GVC process as a part of the cycle, similar to the Brayton cycle obtained in a gravitational field. Typical integration results are shown by one characteristic numerical example of a GVC (as a part of a cycle) in the form of a Mollier h–s diagram (fig. 4) [11].

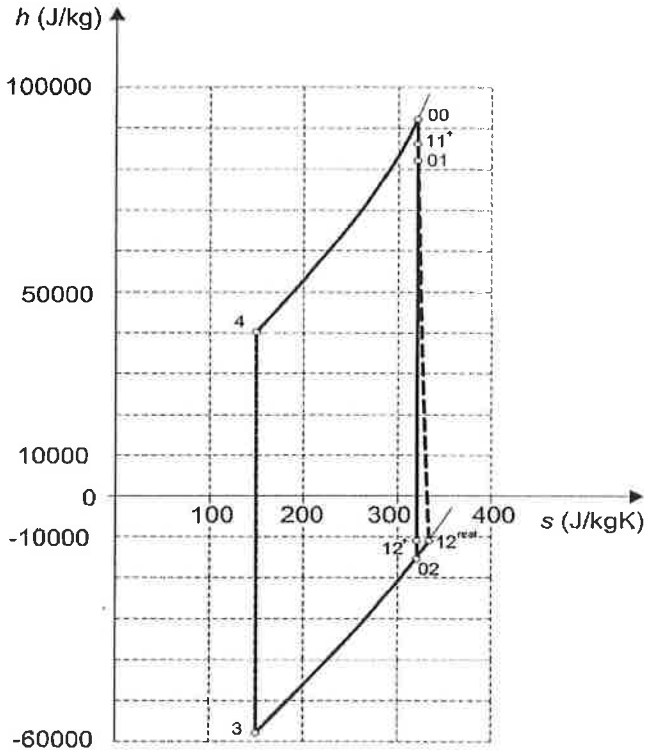

Figure 4: Mollier h–s diagram of the process in GVC and the Brayton cycle [11].

Numerical simulations of cyclones with various geometries and operating conditions were performed to study the natural vortex length. The numerical solutions were carried out using commercial CFD code Fluent 6.1. A prediction model of the natural vortex length was obtained based on response surface methodology by means of the statistical software program (Minitab V14). The results show that inlet velocity, cyclone length and vortex finder insertion deepness also play an important role in influencing the natural vortex length other than the factors mentioned in publications. Compared with some experimental conclusions, the results indicate that present prediction model can estimate the effects of different geometries and operation conditions on the cyclone's performance more acutely than other models [12].

The heating rates of underlying surface and air temporal and spatial temperature shear which lead to the stable genesis of wall-free non-stationary vortices were aimed. These vortices were generated over underlying surface of aluminum sheet due to its controlled heating from below as a result of development of unstable stratification of air. The resultant data enable one to estimate the rate of heating the air and the values of horizontal and vertical gradient of temperatures at which the unstable stratification of air leads to the generation of wall-free non-stationary vortices. The Rayleigh number was used for generalization of measuring air temperature distributions on the subject of finding of the thermal modes of wall-free vortices stable generation. Rayleigh number defines the correlation between the buoyancy and viscous forces, for different thermal modes. This criterion was determined as eqn. (2) [13]:

$$Ra = \frac{gh^3\beta\Delta T}{va} \tag{2}$$

A convective instability as the mechanism for generating vertical vortices in a cylindrical annulus non-homogeneously heated from below was presented. Assuming axisymmetry, thermal and geometrical conditions under which stable vortical structures are found. The structure of these vortices appears to be qualitatively similar to that of dust devils [14].

Closed ideal thermodynamic cycles are used to analyze the atmospheric upward heat convection process which is compared to the Brayton gas-turbine cycle. The heat to work conversion efficiency of the atmosphere is shown to be close to the Carnot efficiency calculated using the average temperatures at which heat is received and given up for hot and cold source temperatures, respectively. The efficiency is independent of whether the lifting process is discontinuous or continuous, and nearly independent of whether the heat is transported as sensible or as latent heat [15]. Most updraft properties were predicted and explain how work of buoyancy is dissipated by use of the model of one-dimensional thermodynamic entrainment-detrainment [16]. Mechanical energy is produced when heat is carried upward by convection in the atmosphere. Processes for controlling and concentrating where the mechanical energy is produced could be a method of harnessing solar energy. A process for producing and controlling a tornado-like vortex and thereby concentrating the mechanical energy where it can be captured is proposed. The work produced when air rises from the bottom to the top of the troposphere is typically 1500 J/kg, about the same as the work produced when a kilogram of water is lowered 150 m [17].

2.1 Atmospheric vortex engine

An atmospheric vortex engine (AVE) is a device for producing mechanical energy by means of a controlled tornado-like vortex. The vortex is produced by admitting air tangentially at the base of a circular wall which produces a convective vortex that acts as a dynamic chimney. The vortex is started by temporarily heating the air near the center of the station with fuel or steam. The operation of AVE is based on the facts that the atmosphere is heated from the bottom and cooled from the top and that more mechanical energy is produced by the expansion of a heated gas. An embodiment of the vortex engine is shown in figures 5 and 6 [18]. Atmospheric vortex engine has the same thermodynamic basis as the natural draft cooling tower, the total energy equation is used to calculate the energy received and produced in each process, eqn. (3):

$$w = q - \Delta h - \Delta gz - \frac{\Delta v^2}{2} \tag{3}$$

Where w is the work given up, q is the heat received, h is the enthalpy of the air including the enthalpy of its water content, g is the acceleration of gravity, z is the height, and v is the velocity [18]. Louis M. Michaud gets the United States Patent for the design of atmospheric vortex engine with Patent No: US 7,086,823 B2 in August 2006 [19].

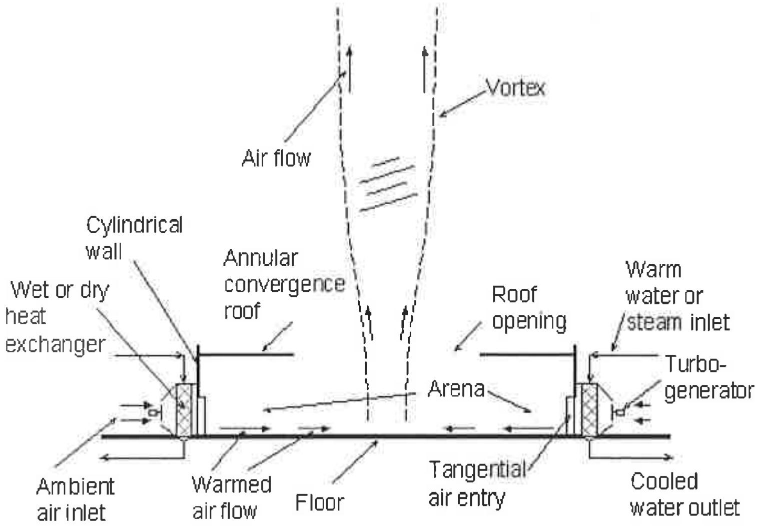

Figure 5: Atmospheric Vortex Engine – side view [18].

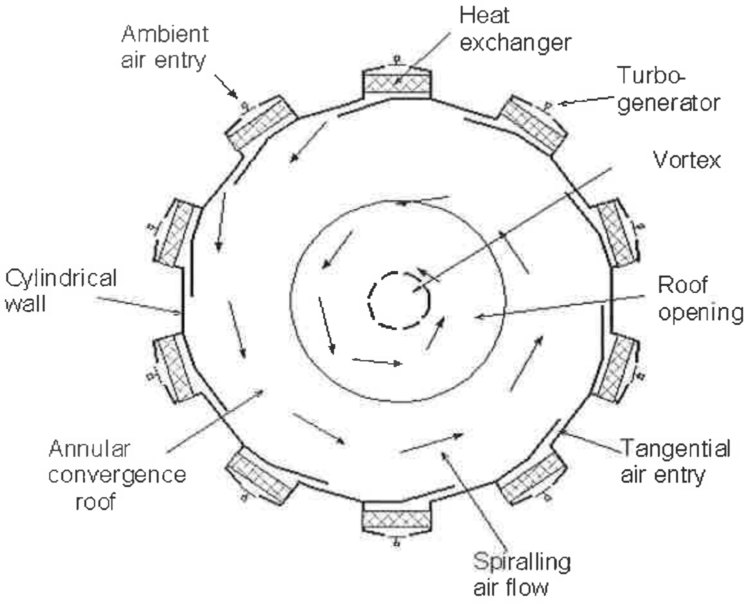

Figure 6: Atmospheric Vortex Engine – plan view [18].

Numerical simulation of atmospheric vortex engine was performed by the CFD analysis of a model-scale Atmospheric Vortex Engine (AVE). The results show that the AVE can generate a vortex flow in the atmosphere much above the AVE and the vortex acts as a physical chimney limiting the mixing of surrounding air into the raising plume of hot air. A parametric study was conducted and provides a good starting point for future designs. For a given geometry, the physical parameter ΔT (temperature difference between the inlet air to AVE and ambient air) is the main parameter that controls the strength of the vortex and in turn the power output. The full scale simulations subjected to cross wind show that the power generation capacity is not affected by the cross winds. The current full scale simulations do not consider actual temperature gradient present in the atmosphere. Figure 7 show the contour plot of the tangential velocity in the YZ plane and the vector plot of velocity magnitude at Z =0.4m plane (at the exit of AVE). It can be seen from these plots that a tornado like vortex flow was generated inside the AVE and the flow extended into the atmosphere till the top of the domain [20].

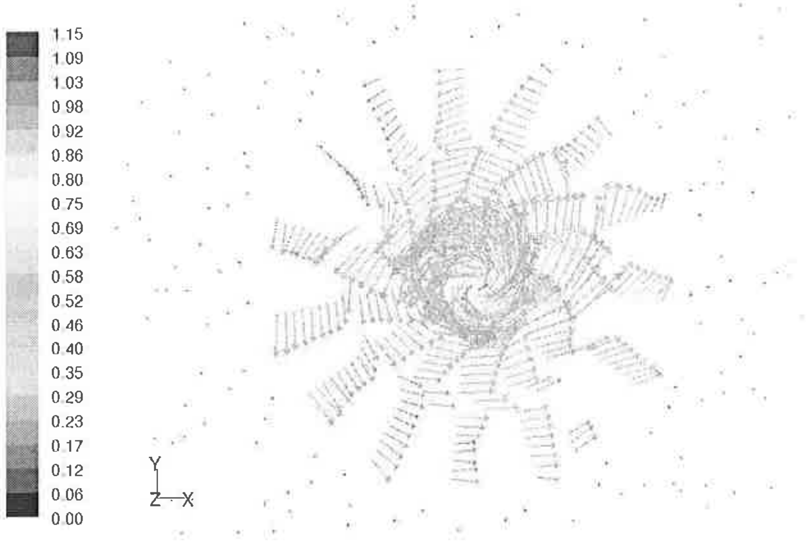

Figure 7: The vector plot of velocity magnitude (m/s) in the Z =0.4m plane for model-scale AVE (Laminar Simulations) [20].

3 The proposed model of solar vortex engine

The solar vortex engine SVE is a vortex engine capable of using the natural heat content of water and air, with using the proposed solar heat collector to capture the solar energy. A solar vortex engine replaces the physical chimney wall of SUTPP by the centripetal force produced by spiraling upward airflow. Once the vortex is established, the pressure difference between the surrounding ambient air and the reduced pressure at the base of the vortex becomes the driving force to spin the turbines. Axial flow turbines consist of stationary nozzles located immediately upstream of a bladed rotor, the kinetic energy of the gas leaving the nozzles is captured by the rotating blades. The airflow is controlled with dampers located within the tangential entry ducts to vortex engine. This development conducts the vortex engine with the solar collector in ground level heat source. The solar collector using to heat surrounding ambient air before entering the turbine then the solar vortex engine. With using of phase-change material (PCM) as thermal energy storage instead of earth soil under the solar collector, the possibility of working period could extension. The process of power generation by solar vortex engine with solar air heat collector could become a major source of clean energy. The efficiency of a solar vortex engine could be as high as 30% because a vortex can extend to a much greater height than a physical chimney while maximum efficiency of the conventional solar chimney power plant is 1.5% because of chimney height limitations.

4 Conclusions

Mechanical energy is produced when heat is carried upward by convection in the atmosphere. A convective vortex engine uses a created tornado like vortex to capture the mechanical energy produced during upward heat convection.

The purpose of reduction the high investment costs of installing the solar updraft tower is presented, where the physical chimney is replaced by the centripetal force produced by swirly upward airflow in the vortex engine, furthermore review the present state of the convective vortex engine is reported.

The heat engine framework is a useful tool for studying convective vortices. However, current theories assume that convective vortices are reversible heat engines. In particular, it predicts that the intensity of convective vortices depends on the depth of the convective layer via the thermodynamic efficiency, the enthalpy perturbation across them, and the existence of sources of vorticity.

An atmospheric vortex engine (AVE) is a device for producing mechanical energy by means of a controlled tornado-like vortex. For a given geometry, the physical parameter ΔT (temperature difference between the inlet air to AVE and ambient air) is the main parameter that controls the strength of the vortex and in turn the power output.

The development of the solar vortex engine SVE with high efficiency could become a major source of clean energy.

Acknowledgement

The authors acknowledge Universiti Teknologi PETRONAS for providing the fund to this research project.

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