Solar Electricity using Wind Turbines

The Conversion of Solar Energy into Electricity in a Closed Cycle driven by Natural Convection using

(1) a solar absorber and convergent nozzle to generate wind energy in a sealed enclosure.
(2) a vertical axis horizontal rotation wind turbine to absorb the kinetic energy of the air flow in the throat of the nozzle producing electricity.

Summary

Since 2001 the author has put forward a series of proposals on this website for harnessing solar energy using natural convection in large sealed ground level solar collectors. The convective energy conversion cycle involved requires no heat rejection and may allow the conversion of solar energy into electricity with very high efficiency. Consider the configuration depicted in Figure 1:

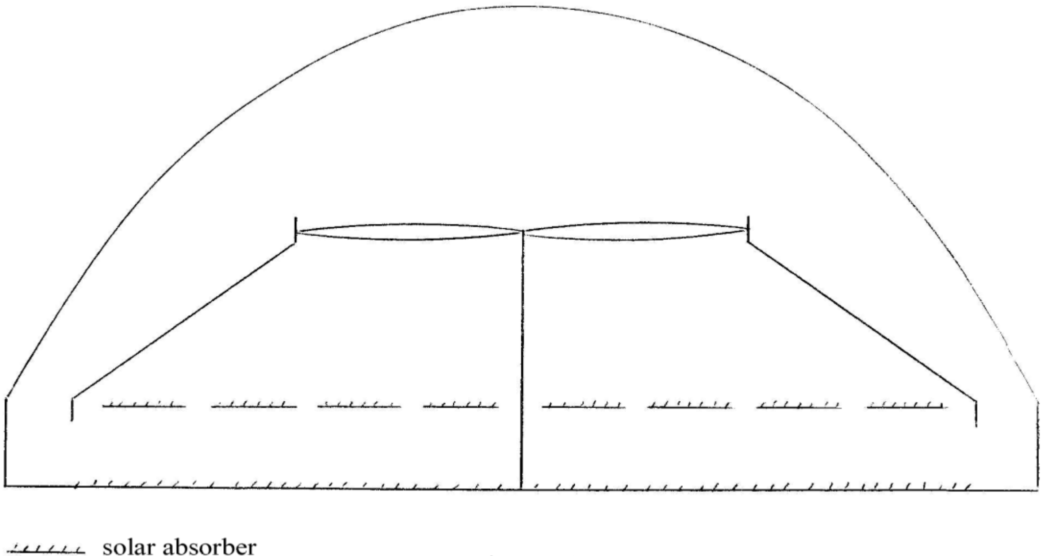

Figure 1

The outer dome and inner nozzle are made of glass or other transparent material. The dome contains air at atmospheric pressure and is sealed at ground level. The solar absorber is placed above ground level with substantial gaps to allow air flow. The ground is also covered with solar absorber material. A horizontal rotation wind turbine is placed in the centre of the dome with its vanes in the throat of the nozzle.

Solar energy is taken up with high efficiency by the absorber warming air in its vicinity which rises because of buoyancy. The raised temperature and pressure of the air drives flow through the nozzle. The constriction requires air to flow at higher velocity. The kinetic energy of the air flow is taken up by the turbine with accompanying cooling of the air. At the top of the dome the cooled air flows along the inside of the containment losing its residual excess energy through the glass of the dome. It then flows under the base of the nozzle and through the solar absorber to complete the cycle.

The author believes that this simple convection cycle allows conversion of the solar energy absorbed into electricity with high efficiency. Calculations indicate that with a nozzle mouth diameter double that of the throat and insolation 750 watts/m^2 (maximum UK summer) air flow through the throat of the nozzle is 16.68 m/s (37mph). The fall in static pressure from the mouth to the throat of the nozzle is 180 Pascals (0.0018 atmospheres) and the rise in temperature as air flows through the absorber is 0.49°C. This energy gain is lost to the turbine and through the outer containment.

The author asks that theoretical and experimental work be carried out to test and develop the above model. It is suggested that laboratory experiments be conducted on models of about one metre dimensions. Simultaneously an outdoor prototype should be built with a dome of 10 metres diameter and turbine of 5 metres diameter. If such experiments were successful it is anticipated that a commercial module would be of 100 metres diameter with a turbine of 50 metres diameter housed in a sealed shallow dome of height 20 metres. This will generate an average output of over 1MW. Such units could be built on low value scrub or desert land at a density of up to 100 modules/km^2.

The proposal outlined in this paper may allow solar energy to be converted into electricity much more efficiently and cheaply than for any other source of renewable energy using the mature technologies of the wind industry and solar collectors. Resource availability is far higher and more predictable than for wind and there would be minimal environmental impact.

Theoretical Background

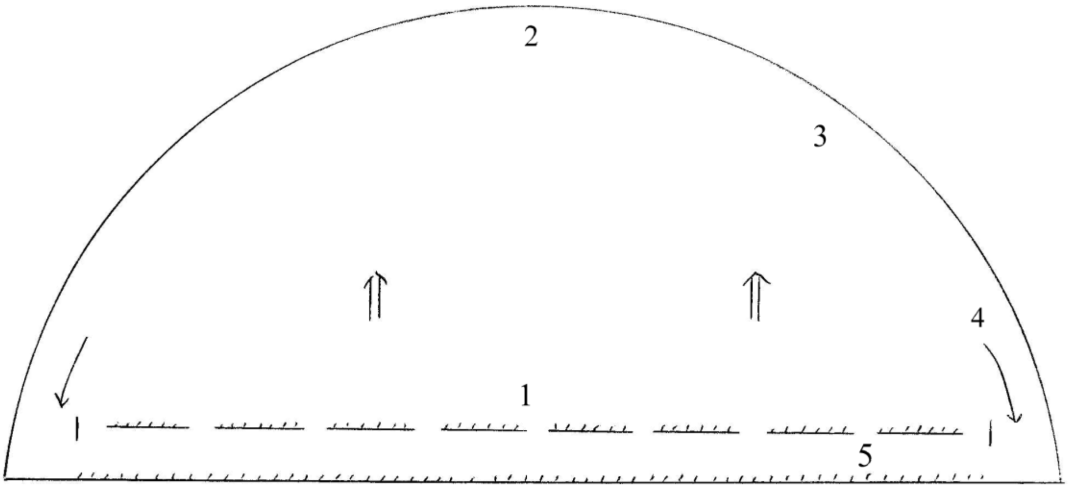

Figure 2

Consider a solar air collector as shown in Figure 2. The glass dome contains air at atmospheric pressure and is sealed at ground level. The solar absorber covers 80% of the area above ground but has generous gaps to allow air flow. The ground is also covered with solar absorber surface to make maximum use of incident solar energy. What will be the path of energy inside this enclosure?

The absorber takes up solar energy with high efficiency. The hot absorber surface warms air in its neighbourhood which rises because of its buoyancy (1). As the warm air reaches the glass of the dome, heat passes through the glass at (2) and the air cools. As the air cools it becomes denser and flows to (3) and to (4) losing heat through the glass on its passage. The flow of air reaches the ground and enters and passes through the solar absorber at (5) to repeat the cycle. This simple convection cycle will dissipate all of the solar energy absorbed through the glass of the outer containment.

Now consider adding a transparent convergent nozzle to the above configuration as depicted in Figure 3:

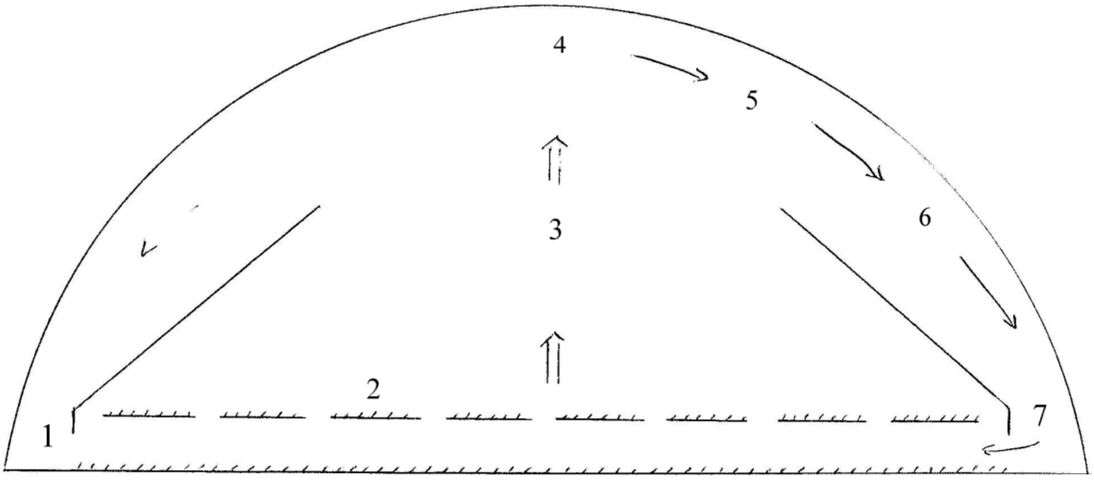

Figure 3

A convection cycle will again be established to transport the solar energy taken up by the absorber to be lost through the outer containment. Let us consider this cycle in some detail to assess the influence of the nozzle.

Consider that the lowest temperature inside the apparatus at (1) and (7) is T and that the pressure is P. These will be higher than ambient temperature and pressure because of solar heating and the energy loss that must take place through the walls of the vessel.

Consider the apparatus when it is in a steady state. The absorber is continually taking up solar energy which warms air in its neighbourhood raising its temperature by an amount ΔT. The entire configuration is at constant volume so by the gas laws the pressure of air at (2) rises by an amount ΔP. The warm air rises because of buoyancy and the extra static pressure ΔP at (2) drives the flow through the nozzle. There will be a certain base convection flow velocity at (2) but as the air flow is squeezed through the nozzle its velocity increases such that:

$$\frac{\text{velocity of flow at (3)}}{\text{velocity of flow at (2)}} = \frac{\text{cross-sectional area of nozzle at (2)}}{\text{cross-sectional area of nozzle at (3)}}$$

<u>By the law of conservation of energy the temperature remains constant at T + ΔT between (2) and (3) as does total pressure. It is the author’s assertion that the velocity at (3) will be such that the static pressure at (3) is P and the dynamic pressure is ΔP</u>.

There is no obstruction at (3) to take up energy so as the flow emerges from the throat of the nozzle into the buffer volume at the top of the dome, it is effectively throttled. Its kinetic energy is dissipated, the dynamic pressure is lost through turbulence and at (4) the static pressure reverts to P + ΔP whilst the temperature has remained at T + ΔT.

The warm air now loses heat through the outer containment. Its temperature falls and it becomes heavier and so it flows from (4) to (5) to (6) to (7). The temperature of the air flow falls to T and by the gas laws its pressure also falls to P as it completes its cycle at (7).

It the above analysis is correct then it implies that the heat energy acquired by the air flow from the solar absorber at (2) should all be available as kinetic energy at (3). If there is this strong air flow at (3) this can be intercepted by a wind turbine placed in the throat of the nozzle and exported. Now consider adding a wind turbine as in Figure 4.

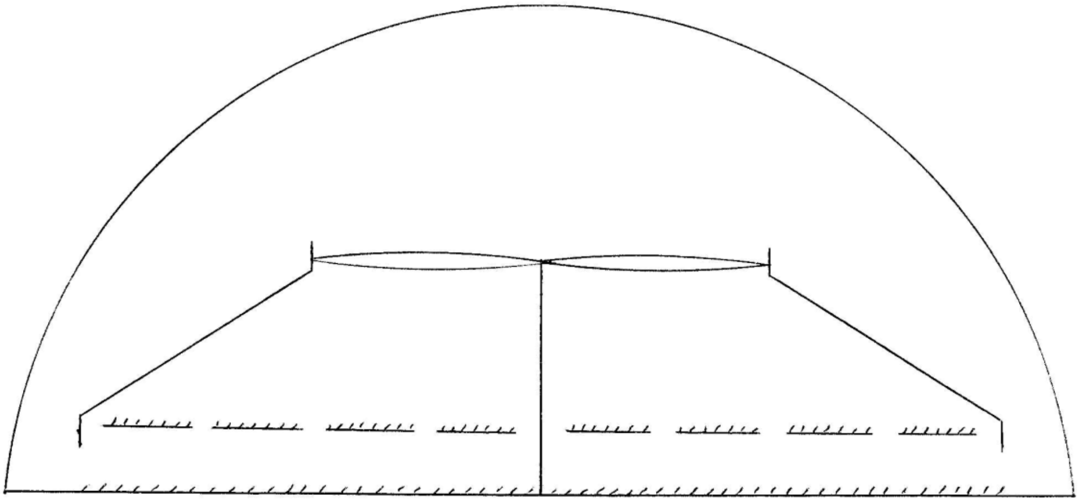

Figure 4

Consider that the diameter of the mouth of the nozzle is twice the diameter at the throat of the nozzle. Further that the cross-sectional area at the mouth of the nozzle is A_1 m^2 and the area swept by the turbine is A_2 m^2. Then $A_1 = 4A_2$. Consider that:

insolation (maximum UK summer)	750 watts/m^2
velocity of air flow at mouth of nozzle	V_1 m/s
velocity of air flow at throat of nozzle	V_2 m/s
temperature rise as air flow passes through solar absorber	ΔT
pressure increase as air flow passes through solar absorber	ΔP

The amount of energy received by the solar absorber is 750 A_1 watts. If all of this energy is converted into the kinetic energy of air flow in the throat of the nozzle then it is equivalent to the energy of wind with velocity V_2 intercepted by area A_2

energy of wind = $\frac{1}{2}\rho A_2 V_2^3$

where ρ is the density of air = 1.293 kg/m^3 at 0°C and atmospheric pressure

$$750\,A_1 = \tfrac{1}{2}\rho A_2 V_2^3$$

But $A_1 = 4A_2$ thus

$$V_2^3 = \frac{750 \times 4 \times 2}{1.293}$$

$$= 4640.3$$

$$V_2 = 16.68 \text{ m/s}$$

Thus the above configuration if working with 100% efficiency would produce a wind velocity of 16.68 m/s (37mph) in the throat of the nozzle at UK maximum summer insolation of 750 watts/m^2.

To calculate ΔP the Bernoulli equation gives the loss in static pressure as air flows through a convergent nozzle as

$$V_2^{\,2} - V_1^{\,2} = \frac{2\,\Delta P}{\rho}$$

To allow estimation, assume $V_1 = 0$

$$\Delta P = \frac{16.68 \times 16.68}{2} \times 1.293$$

$$= 180 \text{ Pascals} = 0.0018 \text{ atmospheres}$$

It is remarkable that such a modest increase in pressure produces such substantial wind velocity. This calculation has been rechecked several times using other formulations of the Bernoulli equation.

The temperature rise in passing through the solar absorber, ΔT, which is also the fall in temperature in passing through the turbine, can be obtained from the gas laws which for a gas at constant volume gives:

$$\frac{\Delta T}{T} = \frac{\Delta P}{P}$$

If we assume $T = 273K$ and $P = 1$ atmosphere $= 1.013 \times 10^5$ Pascals

$$\Delta T = \frac{180 \times 273}{1.013 \times 10^5} = 0.485°C$$

Model Experiments

The calculations above depend on the extraordinary assumption that efficiency will be 100% for absorption of solar energy, its transfer from absorber to the convection flow, its conversion into kinetic energy by the nozzle and the generation of electricity from kinetic energy by the turbine. In practice of course there will be significant energy losses particularly by the turbine but overall efficiency should nevertheless be well over 50%. Any energy losses will be manifested by a raised operating temperature within the configuration as heat is lost through the glass of the dome. The author asks that model experiments be conducted to test the assertions made above and, if successful to develop the concept.

(1) The configuration in Figure 3 could be used for measuring temperature and flow rate at various points along the flow. Of particular significance is the flow rate at (3). This will quickly give an idea as to whether there is a strong enough air flow to be intercepted by a turbine and exported as electricity. This apparatus could also be used to test different values of A_1/A_2 and assess the influence of this ratio on flow velocity at (3). The author

suggests experiments with A_1/A_2 ratios of 4, 3, 2, 1 as well as A_1/A_2 ratios of 5, 10, 20, 50 …

(2) Laboratory experiments could be conducted with Figure 4 with a dome say, of one metre diameter and other components to scale. If the apparatus is placed in bright sunshine with insolation of up to 750 watts/m^2 the output could be a large fraction of this amount. If so, then the unit developed could be of interest for solar home systems for remote dwellings in the developing world.

(3) A prototype solar electricity generator should be constructed with a dome of diameter 10 metres and height 5 metres. The nozzle must be transparent and of sufficient strength to withstand the uplift caused by flow acceleration. The turbine would be of 5 metres diameter and could be a Wells turbine or a wind turbine modified for horizontal rotation. In this model the area at the mouth of the nozzle $A_1 = \pi r^2 = 3.14 \times 5 \times 5 = 78.5$ m^2 and maximum insolation 78.5 x 750 watts = 59 kilowatts. The author asserts that the output could be up to 40 kW. If such a prototype gave successful results, it would open the possibility of solar farms where there could be up to 100 such modules per hectare.

(4) If the above experiments give promising results, the eventual commercial unit anticipated would be a shallow dome of diameter 100 metres and height 20 metres with a turbine of diameter 50 metres. Wind turbines already exist with a diameter of up to 100 metres. The configuration is depicted in Figure 5.

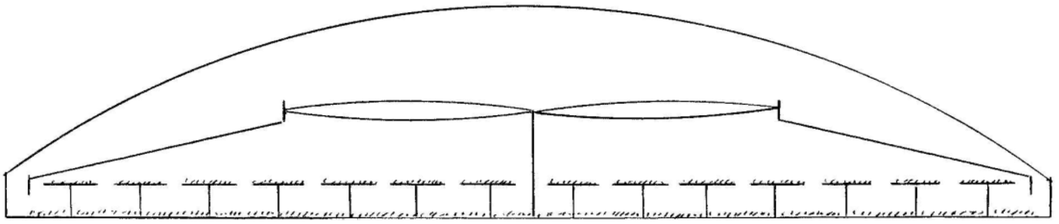

Figure 5

For a solar collector of these dimensions (100 times area of prototype above) the maximum insolation (UK summer) is 5900 kilowatts. If built in the tropics where the average annualised insolation is 6 kWh/day, then averaged over 24 hours, 365 days a year insolation would be 1962 kilowatts. An average output of over 1 Megawatt should be achievable.

Modular units as above could be built on low value scrub or desert land. They could be built in clusters in solar farms with up to 100 units/km^2. Thus an average electricity generation of 100 MW/km^2 should be achievable in tropical climates. The solar farms suggested would be relatively environmentally benign. Their outer perimeter could be screened with trees … which would also provide a dust shield. Output from solar energy would be highly predictable and reliable in hot climates.

Proof of Concept

The author has carried out no experimental work. The above ideas are purely theoretical and are published in the hope that they will be taken up by a university department, energy research institute or industrial company. During his research work the author has come across two instruments from nineteenth century physics that use the convection cycle described above:

1. Joule devised an instrument that he called the thermoscope to detect the heat energy of moonlight [1]. He estimated that the passage of a full moon caused a temperature rise of "a few ten-thousandths of a degree" in his apparatus. The estimate is correct. The author believes that heat is converted into mechanical effect with extraordinarily high efficiency in Joule's thermoscope.
2. The Convection Mill was devised by Bennett as a simple demonstration of the process of natural convection [2]. Solar energy absorbed by a hollow blackened metallic cylinder inside sealed glass containment, produces convection currents which rotate vanes. This instrument is again sensitive to the light of a full moon, indicating a high efficiency of conversion of heat energy absorbed into mechanical effect. The Convection Mill is on display in the Heat Section of the Science Museum in London.

References

[1] James P. Joule, Proceedings of the Literary and Philosophical Society of Manchester, March 11th 1863, Volume 3, p73-4

[2] A. R. Bennett, Engineering, London, 1897, Volume 63, p239-241.

Acknowledgement

The author wishes to thank E. J. Hoffman, Laramie, Wyoming, USA, author of 'Power Cycles and Energy Efficiency' (Academic Press, San Diego, 1996) for his comments, encouragement and steadfast support in 20 + 20 letters exchanged since March 2002. The broad principles above are considered in E. J. Hoffman's new website contrarianisms.com Part II A Primer on Energy and Thermodynamics, Chapter 7.3, Convective Power Cycles.

Dr Alan Williams ***March 2007***