Closed Cycle Convergent Solar Chimney

Abstract

A new configuration is described for conversion of solar energy into electricity using natural convection in a closed cycle. It is based on the solar chimney but with a venturi multiplication of up to 100 times the vertical flow velocity. The air flow is accelerated inside a conical glass vessel with a turbine fitted near the top of the cone. Exit air then falls under gravity via an outer channel to complete the cycle. The key feature is that the work done in lifting air to the level of the turbine is simultaneously exactly compensated by the potential energy gained by air falling in the outer return channel. There is no nett loss to gravity. The closed cycle has a theoretical efficiency of up to 100%. Calculations are presented for an experimental model of height 3 m, absorber diameter 4 m and turbine diameter of 0.4 m. At insolation 750 wm^{-2} this could generate up to 9.42 kwh and could be the basis of solar home electricity systems. A Table is presented of calculations for larger models of height 3, 5, 10, 20, 50 and 100 m and ever larger output. The author asks readers to build an experimental model to verify and develop the proposal.

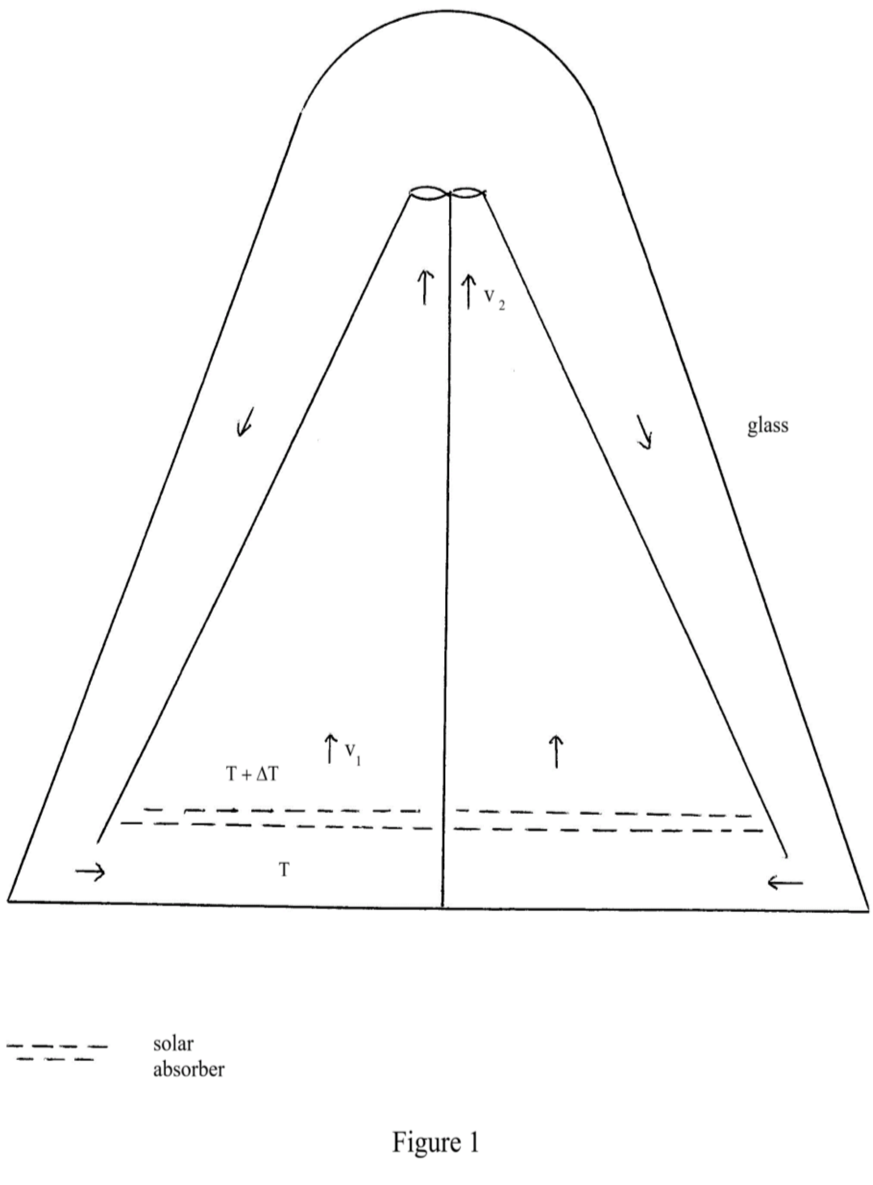

Figure 1

The Proposal

Consider the configuration outlined in Figure 1. The double-walled structure is made of glass or transparent plastic. The shape is conical with a central axis fixed at ground level and supporting a turbine fitted near the top of the cone. At a short distance above the open base of the cone there are two layers of solar absorber. This is a metal painted black or with a specialist coating that takes up over 90% of incident solar energy. The two layers have a large area of holes/spaces to allow easy vertical flow. The outer vessel is sealed and contains air at atmospheric pressure and ambient temperature.

Solar energy is transmitted by the glass and is taken up by the solar absorber. This warms air in its neighbourhood which rises because it is lighter drawing air from beneath to replace. A convection current is established with warm air rising inside the conical vessel, striking the blades of the turbine and falling through the outer channel to the base to be drawn into the conical vessel in a continuous flow closed cycle.

As the warm air rises inside the central vessel it must gain vertical velocity to pass through the ever-narrowing cross-section. The flow kinetic energy is drawn from the internal energy of the air which falls in temperature. As the air flow strikes the turbine it loses its flow kinetic energy generating electricity. Beyond the turbine the air is at ambient temperature and falls under gravity as it descends to complete the convection cycle.

The key feature of the closed cycle is that work done against gravity as air rises from the absorber to the turbine is simultaneously exactly compensated by the potential energy gained in the fall of an equal mass of air in the outer channel. There is no nett loss of energy. <u>With suitable dimensions, all of the energy taken up by the solar absorber can be converted into flow kinetic energy available to the turbine. The closed cycle has a theoretical efficiency of up to 100%</u>.

There will be some loss of energy by conduction through the outer wall of the configuration. There will also be some energy loss in the turbine. Shrouded or ducted turbines are claimed to have an efficiency of up to 80% [1].

The closed cycle convergent solar chimney should allow conversion of solar energy into electricity with an efficiency of up to 80%.

Experimental Model

Consider that in Figure 1

h	height from solar absorber to turbine
A_1	area of solar absorber
A_2	area intercepted by turbine blades
v_1	velocity of air flow just above solar absorber
v_2	velocity of air flow through turbine
T	ambient temperature
ΔT	gain in temperature as air flows through solar absorber
ρ	density of air at atmospheric pressure and temperature T
C_p	heat capacity of air at atmospheric pressure and temperature T
I	insolation

Consider that the experimental model has

height	3 m
absorber diameter	4 m
turbine diameter	0.4 m

The values selected conform to ‘a formula for good efficiency’ [2] which requires that

$$h \left(\frac{A_1}{A_2}\right)^2 \sim 30{,}000$$

In the model

h	=	3 m	T	=	300 °K
A_1	=	12.56 m^2	ρ	=	1.18 kg m^{-3}
A_2	=	0.1256 m^2	C_p	=	1005 j kg^{-1} m^{-3}
			I	=	750 w m^{-2}

The value quoted for insolation is for UK summer maximum. The argument developed above predicts that

solar energy absorbed = kinetic energy air flow through turbine

$$I\ A_1 = \tfrac{1}{2} \rho\, A_2\, v_2^{\ 3}$$

$$v_2^{\ 3} = \frac{2 \times 750 \times 12.56}{1.18 \times 0.1256}$$

$$= 127{,}100$$

$$v_2 = 50.28\ ms^{-1}$$

The velocity of air flow just above the solar absorber is given by

$$v_1 A_1 = v_2 A_2$$

$$v_1 = 0.5028\ ms^{-1}$$

The value of ΔT can be calculated from

solar energy absorbed = mass flow x heat capacity x temperature gain

$$I\ A_1 = \rho\, A_1\, v_1\, C_p\, \Delta T$$

$$\Delta T = \frac{750}{1.18 \times 0.5028 \times 1005}$$

$$\Delta T = 1.258\ °K$$

In the above model

maximum insolation = $I\ A_1$

= 750×12.56

= 9.42 kw

$$\text{maximum kinetic energy} = \tfrac{1}{2}\,\rho\, A_2\, v_2^{\,3}$$

$$= 0.59 \times 0.1256 \times (50.28)^3$$

$$= 9.42 \text{ kw}$$

The author has no laboratory and has carried out no experimental work on this proposal. He asks readers to consider building the model described and developing the proposal if results are promising.

As calculated above it could deliver up to 9.42 kw electricity at insolation 750 w m^{-2}. If built in a warm climate with average annualised insolation of 6 kwh/m^2/day it would produce up to 75 kwh/day. The experimental model outlined could be the basis for solar home electricity systems.

Larger Models

If the model above gives good results it should be possible to design larger models with higher output. The results presented in Table 1 have been calculated in exactly the same way as above. The suggested dimensions for h A_1 A_2 are in line with the 'formula for good efficiency' quoted earlier [2].

h	m	3	5	10	20	50	100
absorber diameter	m	4	5	10	20	50	100
A_1	m^2	12.56	19.63	78.5	314	1963	7850
turbine diameter	m	0.4	0.6	1.4	3.2	10	24
A_2	m^2	0.1256	0.2826	1.539	8.038	78.5	452.2
v_2	ms^{-1}	50.28	44.53	40.18	36.76	31.68	28.05
v_1	ms^{-1}	0.5028	0.6412	0.7875	0.9409	1.267	1.616
ΔT	°K	1.258	0.9864	0.8031	0.6721	0.4992	0.3914
KE max	kw	9.42	14.72	58.88	235.5	1472	5888

Table 1 Calculations for Larger Models

The results show that as we move to greater height, larger solar absorber area and larger turbines, the velocity of air flow through the turbine (v_2) falls from 50.28 ms^{-1} at height 3 m to 28.05 ms^{-1} at height 100 m.

As we consider heights of 20 – 50 – 100 m there will be increasing concern about the height of the turbine and its safety. There would be challenges but of the same order as with construction of turbines for onshore wind. These can be built safely with a height of 100 m or more and with power of up to 20 MW.

The author suggests that early work should concentrate on heights of up to 10 m and if successful, then proceed stepwise to taller, larger configurations which would give higher output and economies of scale.

Alternative Configurations

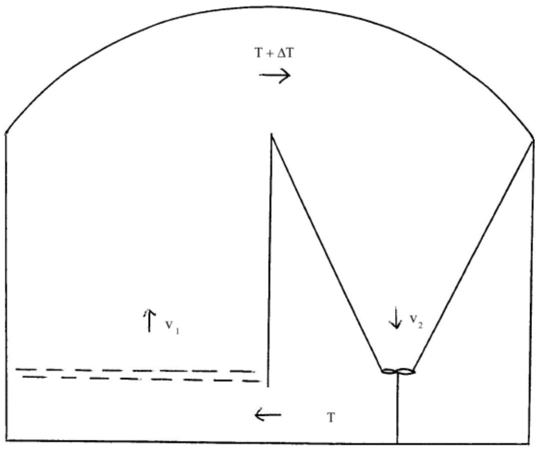

Figure 2

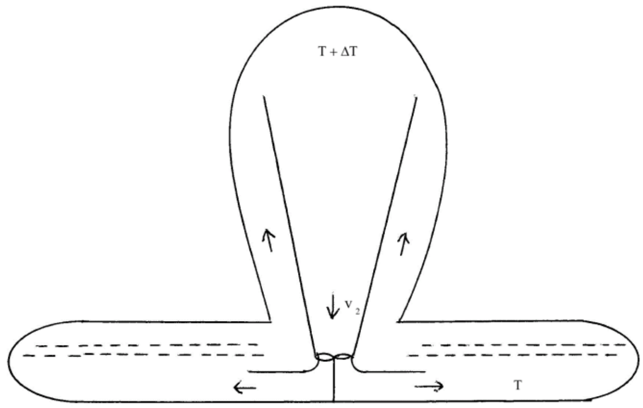

Figure 3

When we consider larger heights there will be greater challenges in designing support for higher output and larger turbines operating at the higher level. Alternative configurations are possible as shown in Figures 2 and 3 using an inverted conical framework to house a turbine at near ground level.

In Figure 2 warm air rises from the solar absorber drawing air from beneath to replace. This in turn draws air in a downflow through the inverted conical vessel and the turbine. Air in the upper levels is at a temperature T + ΔT. As it is drawn down through the inverted conical vessel, it has to gain velocity because of the narrowing cross-section. The excess heat represented by ΔT is converted into flow kinetic energy with velocity v_2 which is harnessed by the turbine. This configuration has the additional advantage that all the ancillary electrical equipment is at near ground level.

In Figure 3 the solar collector is circular with the inverted conical accelerator at its centre and the turbine again at near ground level.

Further Comments

- The physics of the convergent solar chimney is described in an earlier paper [2] with suggestions for an experimental model. This described an open configuration which drew in ambient air at its base and released a continuous flow of exit air at an upper level at slightly elevated temperature. In this new proposal exit air is effectively recycled eliminating energy loss in the closed cycle.

- The configuration proposed in the closed cycle has similarities to Crookes' radiometer (1873) where delicately suspended light metal surfaces, alternately black or polished rotate at high velocity in bright sunshine. There are three other instruments in 19^{th} century physics – Crookes' otheoscope, Joule's thermoscope and Bennett's Convection Mill – that show an anomalously high efficiency for conversion of solar energy into mechanical energy [3]. All involve closed cycles. All have similarities to the Closed Cycle Convergent Solar Chimney.

Conclusion

A new configuration is described for harnessing solar energy using natural convection in a closed cycle. The key feature is that work done against gravity in lifting air from the solar absorber level to a turbine at an upper level is simultaneously exactly compensated by the potential energy gained as an exactly equal amount of air falls under gravity in the outer return channel. There is no nett work done against gravity and the closed cycle has a theoretical efficiency of up to 100%. A small experimental model is described of height 3m, absorber diameter 4 m and turbine diameter 0.4 m. Calculations show that it could generate up to 9.42 kwh at insolation 750 wm^{-2}. It could be the basis of solar home electricity systems. Calculations are presented for larger models of height up to 100 m. The larger is the height of the configuration the lower is maximum air flow velocity declining from 50.28 ms^{-1} for height 3 m to 28.05 ms^{-1} for 100 m. The author asks readers to consider building an experimental model to verify and develop the proposal.

References

[1] J. Schlaich, The Solar Chimney – Electricity from the Sun, Edition Axel Menges, Stuttgart, Germany, 1995.

[2] www.globalwarmingsolutions.co.uk Convergent Solar Chimney – an outline for an Experimental Model. April 2025.

[3] www.globalwarmingsolutions.co.uk Convective Energy Conversion Cycle. July 2005.

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