<u>The Simple Solar Engine</u> – use of an electrical fan and nozzle to transfer energy from a solar collector to a turbine – the efficient conversion of solar energy into electricity?

<u>Summary</u>

A new method is proposed for the conversion of solar energy into electricity drawing on the principles of the solar air collector, the heat pump, the convergent nozzle and the turbine. An electrical fan provides continuous air flow through a solar absorber; the warmed air then flows through a convergent nozzle where the excess heat is converted into flow kinetic energy and then through a turbine generating electricity. The amount of solar energy converted into electricity can be many times the electrical demand of the fan. Readers are asked to design experimental configurations to test and develop the proposal. If successful it could provide a method for conversion of solar energy, or more generally all heat into electricity with high efficiency.

<u>Introduction</u>

Consider the configuration shown in Figure 1

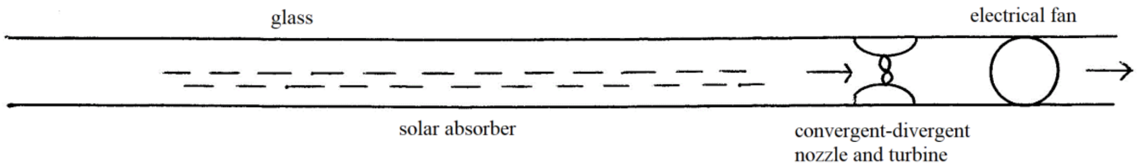

Figure 1

The outer structure is a long wide-diameter pipe of circular cross-section made of glass or transparent plastic. An electrical fan draws ambient air through the pipe at modest velocity. As air enters the pipe it flows through a solar absorber. This is essentially a metal coated with absorber paint that takes up solar energy with high efficiency. As ambient air flows through the solar collector it takes up all the solar energy absorbed.

The warmed air then flows through a convergent-divergent nozzle where it is accelerated to a considerably higher velocity. The extra flow kinetic energy comes from the internal energy of the air whose temperature falls. An air turbine sited at the throat of the nozzle takes up the flow kinetic energy generating electricity.

The velocity of the air flow through the turbine is a multiple of the velocity of air flow through the pipe in the ratio of cross-sectional area of the pipe to cross-sectional area of the turbine. The kinetic energy available to the turbine is a multiple of the kinetic energy imparted by the electrical fan. This multiple is the square of the velocity ratio.

Thus one unit of electrical energy input for the fan can produce many units of electrical output for the turbine. Solar energy taken up by the absorber is transferred by the air flow to the convergent nozzle where it is converted into kinetic energy which is then taken up by the turbine. The fan provides the air flow carrier for the efficient conversion of solar energy into electricity.

Key to Symbols

A_1	area cross-section of pipe
A_2	area cross-section of turbine
A_3	area of solar absorber
v_1	velocity of air flow through pipe
v_2	velocity of air flow through turbine
$\dot{m}$	mass flow
T	ambient temperature
ΔT	increase in temperature of air flow through solar absorber
ρ	density of air at atmospheric pressure and temperature T
C_p	heat capacity of air at constant pressure and temperature T
I	insolation
η	efficiency

Theoretical Development

(1) Operation of electrical fan

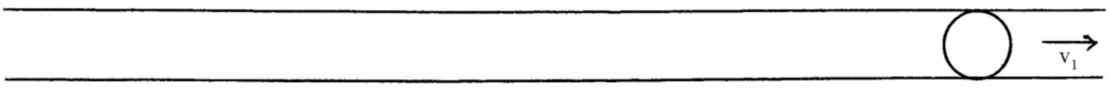

Figure 2

Consider an electrical fan sited near the exit of a long wide-diameter pipe of cross-sectional area A_1 as shown in Figure 2. Consider that the fan provides exit air velocity v_1 and that the mass flow rate is $\dot{m}$. The energy consumed by the fan is

$$\tfrac{1}{2}\,\dot{m}\,v_1^{\,2} \cdot \frac{1}{\eta}$$

where η represents the efficiency of the fan. Pump efficiencies can range from 50% to 90% [1].

Note also that

$$\dot{m} \quad = \quad \rho\, A_1\, v_1$$

(2) Addition of solar absorber

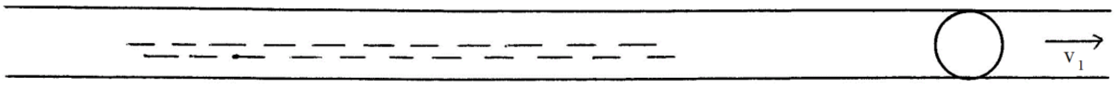

Figure 3

Consider the addition of two layers of solar absorber around mid-height of the pipe for most of its length of width equivalent to the diameter of the pipe and structured so that there is easy flow above, below and between the layers of absorber (Figure 3). As air flows through the solar absorber consider the increase in temperature to be ΔT.

Solar energy absorbed = mass flow x heat capacity x temperature rise

$$I A_3 = \rho A_1 v_1 C_p \Delta T$$

(3) Addition of convergent-divergent nozzle

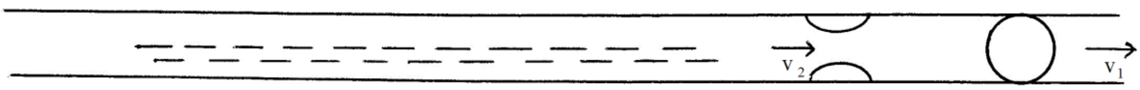

Figure 4

Consider the installation of a convergent-divergent nozzle between the solar absorber and the fan (Figure 4) where the throat of the nozzle has cross-sectional area A_2. The air flow is accelerated to a higher velocity v_2 as it flows through the throat of the nozzle where

$$A_1 v_1 = A_2 v_2$$

No energy is added or removed during flow through the nozzle and no shaft work is done.

The additional kinetic energy of the air flow through the throat of the nozzle comes from the ΔT acquired in the solar absorber. As air flows through the divergent section of the nozzle it slows to its earlier velocity v_1 with turbulence restoring its earlier temperature of $T + \Delta T$.

(4) Addition of turbine

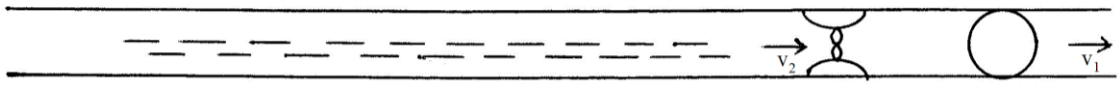

Figure 5

Consider the further installation of a turbine of cross-sectional area A_2 sited at the throat of the nozzle as shown in Figure 5. The turbine is designed to extract the kinetic energy of the air flow at its velocity v_2. The total kinetic energy available to the turbine is

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

This is several times the electrical energy consumed by the fan.

$$\frac{\text{Kinetic energy available to turbine}}{\text{Electrical energy consumed by fan}} = \eta \left(\frac{v_2}{v_1}\right)^2 = \eta \left(\frac{A_1}{A_2}\right)^2$$

Thus if the diameter of the turbine is one half the diameter of the pipe $A_1 = 4 A_2$ and $v_2 = 4 v_1$. The kinetic energy available to the turbine is 16η times the electrical demand of the fan. The extra energy comes from the solar energy taken up by the absorber which is converted into kinetic energy in the convergent nozzle.

Air flow leaves the configuration with velocity v_1 and at ambient temperature T.

Origin of Proposal

The proposal outlined in this paper is original. It is based on configurations developed in earlier work on the solar chimney [2] which led to a repeat unit for a multiturbine solar collector. Drawing on the principles of the heat pump, it occurred to the author that the air flow provided by the chimney in that configuration could alternatively be provided by an electric fan. It would require a certain electrical input but if the carrier air flow took up all the solar energy absorbed, this could be converted into kinetic energy in the convergent nozzle and harnessed by a turbine. The heat (convertible into kinetic energy) carrying capacity of the air flow is many times the electrical energy used to produce the air flow. The output could be many times the electrical input.

Value of air flow velocity v_1

The optimum value of v_1 would have the total solar energy taken up by the absorber converted into kinetic energy available to the turbine

$$I A_3 = \tfrac{1}{2} \rho A_2 v_2^{3}$$

$$A_1 v_1 = A_2 v_2$$

But insolation varies and the value of v_1 must be linked continuously to the level of insolation. It may be that the best determinant of v_1 is the temperature of the exit air flow. Ideally the air flow leaving the fan should be at the ambient temperature T. If exit air is above ambient temperature the power of the fan should be increased to raise v_1. This in turn raises v_2, the turbine extracts more energy from the air flow and exit air temperature falls to T.

Overall efficiency

There will be energy losses during the various conversion processes. As noted earlier, pump efficiencies can range from 50% to 90%. Solar absorbers have efficiencies of over 90%. Nozzles have 90 - 99% efficiency. The turbine is well-sheltered and has smoothly changing ducted flow and should have efficiency 80%. In total an overall efficiency of conversion of solar energy into electricity of 50% should be achievable.

If the proposal is successful it could have wide application for the conversion of heat into electricity e.g. from solar hot water, industrial waste heat, power station hot water.

Conclusion

A new method is outlined in this paper for the conversion of solar energy into electricity. The author has no laboratory and has conducted no experimental work. Readers are asked to consider carefully the arguments presented, to challenge the physics and to design experiments to test and develop the proposal. The author has designed several possible outline configurations which will be the subject of a future paper.

References

[1] Fluid Mechanics with Applications, Anthony Esposito,
Published by Prentice-Hall, New Jersey, USA, 1998, p281.

[2] www.globalwarmingsolutions.co.uk Multichannel solar chimney with multiturbine solar collector. April 2022. Figure 3.