The Multichannel Solar Chimney – commercial scale

Abstract

A radically modified solar chimney is described with a rectangular chimney and rectangular solar collector drawing ambient air through a nozzle and turbine. The chimney is of low height and partitioned into many discrete, parallel flow channels of good slenderness ratio to provide smooth flow. By careful choice of dimensions, configurations have been devised of height 5 to 100 m with a target efficiency of 50% for conversion of solar into kinetic energy. The author suggests experimental work on models of height 5m and 20m. If successful, the rectangular framework allows multiple units to be built in parallel in large assemblies with a generating potential of up to 160 MW/km^2.

Introduction

This paper should be considered in conjunction with an earlier paper, "Multichannel Solar Chimney – dimensions for a demonstration model" [1]. The essential principles are outlined in Figure 1. A rectangular solar collector generates warm air which flows by natural convection through a partitioned rectangular chimney. The buoyancy of the warm air column in the chimney draws ambient air through a convergent nozzle and turbine. The configuration is a radical modification of the solar chimney described by Schlaich et al. [2] allowing multiplication of chimney air flow velocity by using a small diameter turbine. The chimney is divided into many equivalent, parallel flow channels in the expectation that a chimney of low height could thus have a good slenderness ratio [3]. The partitions form a squared grid, are thin and light and required simply to ensure smooth, vertical air flow.

The earlier paper [1] included full theoretical development and calculations for a demonstration model of flow channel height (FCH) 5 m. The present paper considers FCH 10, 20, 30, 50 and 100 m with detailed calculations for FCH 20 m and consideration of its possible commercial application.

Theoretical Development

Consider that in Figure 1

h	height from solar absorber to top of chimney
A_1	area cross-section of chimney
A_2	area cross-section of turbine
A_3	area solar absorber
v_1	velocity of air flow through chimney
v_2	velocity of air flow through turbine
T	ambient temperature
ΔT	excess temperature (above ambient) of exit air
$\Delta T'$	fall in temperature as air flows through turbine
g	gravitational constant
ρ	density of air at atmospheric pressure and temperature T
C_p	heat capacity of air at constant pressure and temperature T
I	insolation

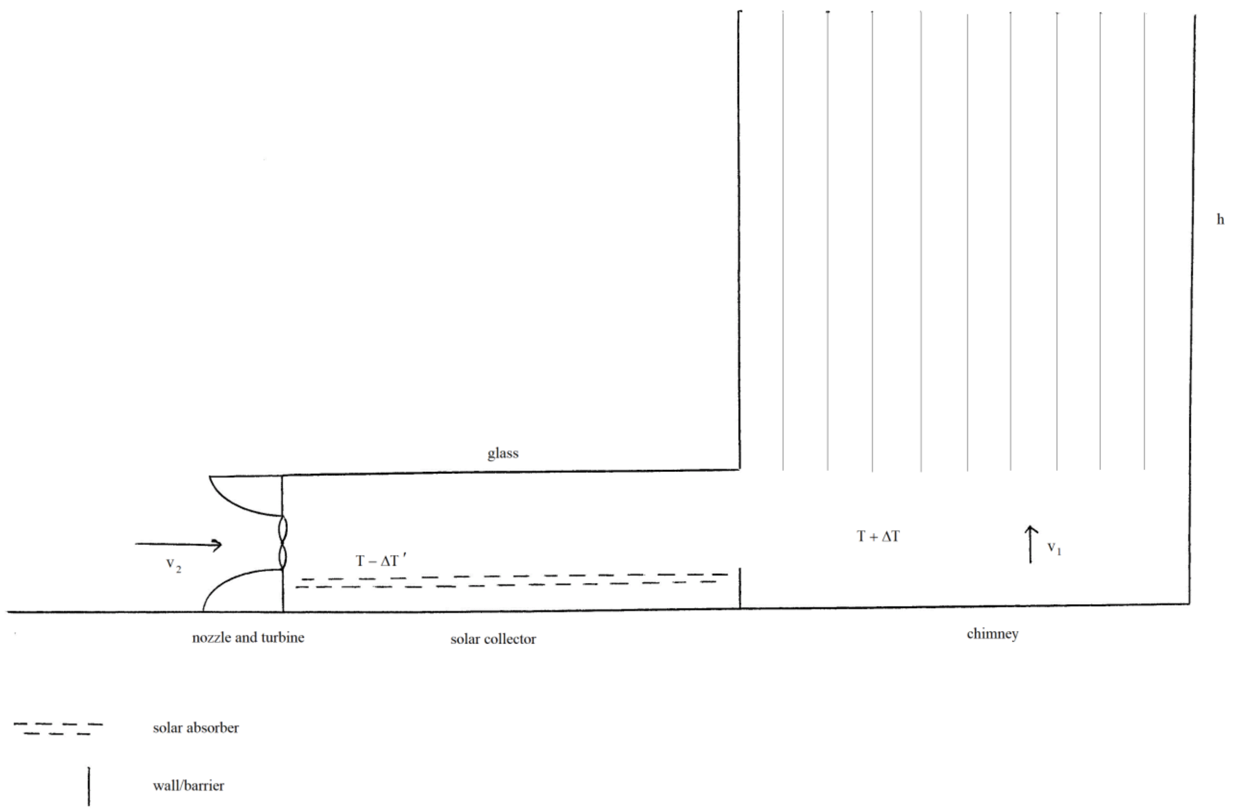

Figure 1

Energy flow through the modified solar chimney in Figure 1 is governed by the following equations:

(1)	$v_1^{\,2}$	=	$2 \frac{\Delta T}{T} gh$
(2)	$v_1 A_1$	=	$v_2 A_2$
(3)	$v_2^{\,2}$	=	$2 C_p \Delta T'$
(4)	$I A_3$	=	$\rho A_1 v_1 C_p (\Delta T + \Delta T')$

<u>Experimental Model with Flow Channel Height 20 m</u>

Consider that in Figure 1

flow channel height	20 m
turbine diameter	2 m
collector height	6 m
overall height	26 m
flow channel area	2 x 2 m
slenderness ratio	10
chimney cross-section	20 x 6 m
flow channel number	30
solar absorber area	20 x 6 m

For this configuration h = 24 A_1 = 120 A_2 = 3.14

$$\frac{A_1}{A_2} = 38.22 \quad \text{and} \quad h\left(\frac{A_1}{A_2}\right)^2 = 35{,}050$$

This indicates an efficiency of just over 50% [1].

h	=	24	m	T	=	300	ºK
A_1	=	120	m^2	g	=	9.81	ms^{-2}
A_2	=	3.14	m^2	ρ	=	1.18	$kg\ m^{-3}$
A_3	=	120	m^2	C_p	=	1005	$j\ kg^{-1}\ K^{-1}$
				I	=	750	$w\ m^{-2}$

From equation (1)

$$v_1^{\,2} = \frac{2\ \Delta T}{300} \ x\ 9.81\ x\ 24$$

$$v_1^{\,2} = 1.570\ \Delta T \qquad (1)$$

From equation (2)

$$120\ v_1 = 3.14\ v_2$$

$$v_2 = 38.22\ v_1 \qquad (2)$$

From equation (3) $$v_2^{\,2} = 2010\ \Delta T' \qquad (3)$$

From equation (4) $$750\ x\ 120 = 1.18\ x\ 120\ x\ 1005\ v_1\ (\Delta T + \Delta T')$$

From (1) (2) and (3) above

$$v_1\left(\frac{v_1^{\,2}}{1.570} + \frac{1461}{2010}\ v_1^{\,2}\right) = \frac{90{,}000}{142{,}300}$$

$$v_1^{\,3}\ (2010 + 2292) = 0.6324\ x\ 1.570\ x\ 2010$$

$$v_1^{\,3} = 0.4638$$

$$v_1 = 0.7740\ ms^{-1}$$

From (2) $$v_2 = 29.58\ ms^{-1}$$

From (1) $$\Delta T = 0.3817\ °K$$

From (3) $$\Delta T' = 0.4353\ °K$$

Maximum insolation $$I\ A_3 = 90\ kw$$

maximum kinetic energy = $\frac{1}{2} \rho A_2 v_2{}^3$

$= \frac{1.18}{2} (3.14) (29.58)^3$

$= 47.95$ kw

Efficiency = 53.28 %

The calculation shows that at insolation 750 wm^{-2} (maximum UK summer) the velocity of air flow through the turbine is 29.58 ms^{-1}. This is within the range of conventional wind turbines. The convergent nozzle allows smooth acceleration of ambient air to this velocity. Note also that as insolation changes only gradually, fluctuations in velocity through the turbine should be smooth and gradual. **The maximum output is 47.95 kw with an efficiency of conversion of solar into kinetic energy of 53.28%.**

A rectangular configuration is suggested for the solar chimney and collector for ease of construction and to allow multiple units to be built in parallel. The above model has length 50 m and width 6 m. If 10 units were built in parallel, the assembly would have area 50 x 60 m^2 and maximum output 479.5 kw. If such assemblies were built in repeat patterns, the generation capacity is

$$\frac{1000}{50} \times \frac{1000}{60} \times 479.5 \text{ kw} = 160 \text{ MW/km}^2$$

Such a construction would involve over 3,000 turbines/km^2 and would lend itself to offsite manufacture of components and economies of scale.

Results for Flow Channel Heights 5 to 100 m

The calculation for FCH 5 m is presented in the earlier paper [1]. Similar calculations have been carried out for FCH 10 m, 20 m (above), 30, 50 and 100 m and are summarised in Table 1.

Dimensions have been devised to give a target efficiency of about 50% for each model. The area of solar absorber considered is equal to the cross-sectional area of the chimney ($A_3 = A_1$). This is a minimum or low-power specification. **The area of the solar absorber could be 1-5 times the area of the chimney multiplying output by the same factor without affecting efficiency but it would also mean higher v_1 v_2 ΔT and $\Delta T'$.**

The model with FCH 5 m is suggested as a demonstration model [1]. The models with FCH 10, 20 and 30 m lend themselves easily to multiple units and each could be commercially viable if built in large assemblies as suggested above. The models with FCH 50 and 100 m require solar collector height 30 and 60 m respectively. These are included for theoretical interest but are impractically large. The main contenders for development should be flow channel height 10, 20 and 30 m.

flow channel height	m	5	10	20	30	50	100
turbine diameter	m	0.3	1	2	4	10	20
collector height	m	1	3	6	12	30	60
overall height	m	6	13	26	42	80	160
flow channel area	m^2	0.5 x 0.5	1 x 1	2 x 2	3 x 3	5 x 5	10 x 10
slenderness ratio		10	10	10	10	10	10
chimney area	m^2	5 x 1	13 x 3	20 x 6	30 x 12	50 x 30	60 x 60
flow channel number		20	39	30	40	60	36
h	m	5	12	24	38	70	140
A_1	m^2	5	39	120	360	1500	3600
A_2	m^2	0.07065	0.785	3.14	12.56	78.5	314
A_3	m^2	5	39	120	360	1500	3600
A_1/A_2		70.77	49.68	38.22	28.66	19.11	11.47
$h (A_1/A_2)^2$		25,040	29,620	35,050	31,220	25,560	18,400
v_1	ms^{-1}	0.4848	0.6323	0.7740	0.9204	1.165	1.536
v_2	ms^{-1}	34.31	31.41	29.58	26.38	22.26	17.61
ΔT	°K	0.7188	0.4909	0.3817	0.3409	0.2964	0.2576
$\Delta T'$	°K	0.5857	0.5094	0.4353	0.3462	0.2465	0.1542
maximum kinetic energy	kw	1.684	14.35	47.95	136.1	510.8	1011
efficiency	%	44.90	49.08	53.28	50.39	45.40	37.45

Table 1 Multichannel Solar Chimney Results

Further Comments

- No allowance has been made in the calculations for energy losses. The values of ΔT and $\Delta T'$ are both well below 1°C so heat losses from the solar collector should be minimal. Energy losses in the turbine and generator will be taken up by the air flow and will raise the temperature of the air flow in the chimney and contribute to buoyancy – they are in effect recycled. The major and very large energy loss is the excess heat content of exit air flow – but this is unavoidable – it is what creates the buoyancy that drives the convection flow.

- Energy storage can be added easily to the configuration. Schlaich et al [2] suggest that water bags to a height of about 0.2 m could be placed on the ground beneath the absorber to take up daytime heat to be released for evening/night generation.

- The chimney flow channel structure is presented as a squared grid cross-section. It could alternatively be made of parallel cylindrical pipes tightly packed in a rectangular framework.

Conclusion

The author asks readers to consider construction and testing of the demonstration model with flow channel height 5 m. If this is successful, the next stage should be construction of FCH 20, first as a single model for assessment and improvement and then as an assembly of 10 units in parallel to test its economic viability. If the latter gives good results then large area assemblies of multiple units could be economic with a generation capacity of up to 160 MW/km^2.

References

[1] www.globalwarmingsolutions.co.uk Multichannel Solar Chimney – dimensions for a demonstration model. July 2020.

[2] Schlaich, J., Bergermann, R., Schiel, W. and Weinrebe, G. Design of Commercial Solar Updraft Power Systems – Utilization of Solar Induced Convective Flows for Power Generation. J. Sol. Energy Eng. 2005, 127, 117-124.

[3] P. Guo, T. Li, B. Xu, X. Xu and J. Li. Questions and current understanding about solar chimney power plant : A review. Energy Conversion and Management 2019, 182, 21-33.