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Adaption for the Wind Energy by using the Solar Nozzle

التكيّف لطاقةِ الرياح بإستعمال الخرطومِ الشمسيِ

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Nomenclature

A Area (m^2)
C_p Specific Heat Capacity, for Air (1005 J/Kg.K)
K Thermal Conductivity (W/m.K)
$\dot{m}$ Mass Flow Rate (Kg/sec)
P Pressure (Pa)
Pr Prandtl No., for Air (0.7)
q Heat Added (J/Kg)
R Gas Constant, for Air (287.1 J/Kg.K)
T Temperature (K^o)
V Velocity (m/sec)
ρ Density (Kg/m^3)
μ Dynamic Viscosity (Kg/m.sec)

Keywords

Renewable Energy, Power Plants, Wind Energy, Solar Nozzle, Compressible Fluids

Abstract

A new method has been proposed for conversion the wind energy into a kinetic energy using the hybrid effect of nozzle and solar energy. As the air flows through the horizontal nozzle it accelerates because of the narrowing constriction. Heat energy acquired from the wall is converted into the kinetic energy of flow. Critical dimensions are calculated for the convergent nozzle that made of steel. This study focuses up on the benefits of using solar nozzle on the wind energy. The study is an attempt to raise the local wind velocity (3 m/sec) to a high velocity gives good energy allowed the wind plant to generate power, on other words in order to increase the efficiency of the plant. From the obtained results, it is observed that the velocity of wind increased by the increment of heat gain and decrement of the area. The velocity value in the case of heat added is reached to (50 m/sec), while in the case of no heat transferred is about (48 m/sec). Calculation indicates that maximum heat gained could give (57 KW) output power.

الخلاصة

تم في هذا البحث تطبيق طريقة جديدة في تحويل طاقة الرياح الى طاقة حركية مستفاد منها بأستخدام خرطوم شمسي معدني موضوع بشكل افقي. حيث يتم زيادة سرعة الرياح الموقعية الى السرعة اللازمة لانتاج طاقة كهربائية اي زيادة كفاءة محطة الرياح. تزداد الكفاءة اعتمادة على شكل الخرطوم وعلى تجميع الطاقة الشمسية المسلطه عليه، ولحالة فرض سرعة دخول الهواء (3 m/sec) تكون سرعة خروج الهواء (48 m/sec) في حال عدم وجود الخرطوم بينما تكون سرعة خروج الهواء (50 m/sec) في حال وجود الخرطوم للنموذج الافتراضي المطبق. في حالة تطبيقه عملياً بالامكان الحصول على طاقة حركية مقدارها (57 KW).

1. Introduction

The improvement of any power plant needs to know what the components that depending on it. In the case of wind plant, it is necessary to know the behavior of the wind. There are several factors affect on the wind state such as velocity, temperature and flow direction. Power of the wind can be extracted by allowing it to blow past moving wings that exert torque or rotor. The wind profiles show that the wind energy conversion device with a certain amount of confidence to extrapolate better wind speed taken at a height more than (10 m) [1].

Solar power is the technology of obtaining usable energy from sun light. The advantages of used renewable energies (solar and wind) are; no pollution, no fuel needed and low costs [2]. It is clear that use of the solar energy at latitudes with higher levels of radiation will improve the performance of wind system and make it possible to cover loads with smaller and less expensive systems. Attempts to parameterize the solar radiation received at the ground are made for the global radiation (direct plus scattered, and for tilted planes also radiation reflected onto the surface), rather than separately for normal incidence and scattered radiation [3].

2. Background

Padki and Sherif 1999 [4] suggested a small model solar chimney of radically different geometry. In this case the chimney is conical with the turbine placed at the narrowing of the cone. The paper is mainly theoretical but they argue that there is no upper bound on the efficiency. The efficiency is rise up to 20% by the heat gained. Unfortunately the practical results reported are much less impressive.

An international study of power system impacts of wind power [5] has been formed in 2006 under the IEA implementing agreement on wind energy; the task will analyze case studies from different power systems. The results are not easy to compare, for example the incremental regulation due to wind was found to be 36 MW in a location in USA while in another location in Netherlands it is about 6000 MW.

Williams 2007 [6] proposes theoretically a prototype convergent nozzle made of glass and arranged vertically. A solar absorber abundantly perforated and several layers thick or of metallic honeycomb structure is arranged in the lower levels but above the base of the nozzle. The convergent solar nozzle has base diameter of (10 m), throat diameter of (1 m), and height of (10 m). Calculation indicates that the maximum output power in the summer of UK is about (59 KW) and the temperature difference through the nozzle is (1.2 ^{o}C).

Sakonidou and et al. (2008) [7] determine the tilt that maximizes natural air flow inside a solar chimney. The model starts by calculating the solar irradiation components absorbed by the solar chimney. The calculations have been obtained by a simulation program solves the relevant conservation of mass, momentum and energy equations (CFD) for solar chimney using finite difference methods. The model predicts the temperature and velocity of the air inside the chimney as well as the temperatures of the glazing and the black painted absorber. The experimental chimney duct has the shape of a narrow parallelepiped with dimensions: 1 m height, 0.74 m width and 0.11 m gap. Black painted aluminum sheet is used for the construction of walls of the chimney. The walls have absorptance of (0.95). Comparisons of the experimental model predictions with CFD calculations delineate that there is a good agreement between them at different tilt positions.

The objective of the present work is to present a theoretical analysis for the using of solar nozzle. The solution is merged between analysis of wind energy and solar energy to increase the wind energy to a rate allowed the wind plant to generate power, also the efficiency of the plant can be increased by using a convergent nozzle arranged horizontally and exposed to solar radiation. A wind turbine placed in the throat of the nozzle converts flow kinetic energy into electricity, see figure (1).

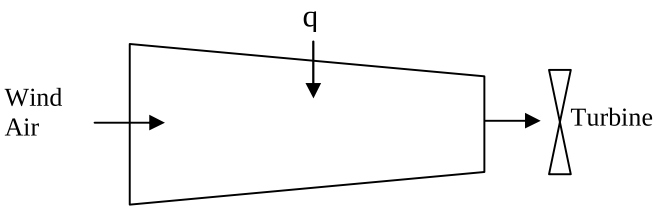

Figure (1) Supposed Wind Plant

3. Solar Radiation Modeling

The fact that the amount of solar radiation received at a given location at the Earth surface varies with time due the Earth's rotation (Diurnal Cycle) and also depending on the latitude [3]. The average rate of the solar radiation incidence on a horizontal plate in Iraq for July is about (450 W/m^2) [1].

Suppose that the nozzle we had is the solar collector, so the input radiation power is [8]:

$$q_R = I_N \, \alpha\tau \qquad \text{------ (1)}$$

$$I_N = I_S \, \text{Cos}\,\theta \qquad \text{------ (2)}$$

$$\text{Cos}\,\theta = \text{Cos}\,\phi\,\text{Cos}\,\delta + \text{Sin}\,\phi\,\text{Sin}\,\delta \qquad \text{------ (3)}$$

Where:

$\alpha\tau$ = Product of absorptive and transitivity (0.95 [7])

I_S = Solar Radiation (450 W/m^2) [1]

For Baghdad ($\phi = 33^o$) at noon time in July ($\delta = 23.4^o$) [3]

The incident angle is nearly vertical so (cos θ = 0.97).

There is heat loss across the wall denoted as [8]:

$q_L = U\left(T_b - T_a\right)$ ------ (4)

Where T_a = Air temperature (35 ^oC)

T_b = Average bulk temperature inside the nozzle (about 36 ^oC)

Principally, the overall heat transfer coefficient (U) can be calculated from [9]:

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} \quad \text{------ (5)}$$

Where, i:- refers to the internal part of the nozzle

o:- refers to the external part of the nozzle

The convection heat transfer coefficient (h) can be determined from [9]:

$$h = \frac{Nu\ K}{d} \quad \text{------ (6)}$$

Nusselt No. and Reynolds No. can be determined from [9]:

$$Nu = 0.023\, Re^{0.8}\ Pr^{0.3} \quad \text{------ (7)}$$

$$Re = \frac{\rho\ V\ d}{\mu} \quad \text{------ (8)}$$

Consequently, the useful heat gained to the flow will be:

$$q = A_N\ F_R\ \left(q_R - q_L\right) \quad \text{------ (9)}$$

The heat removed factor (F_R) has value of (0.8) [8].

A_N is the surface area of the nozzle which represents a semi-cone shape so it is calculated from:

$$A_N = \pi \frac{D_i + D_e}{2} L \quad \text{------ (10)}$$

Where, L is the nozzle length.

4. Modeling of Nozzle Flow Fields

The analysis considered the effects of both changing flow area and heat exchanged. The effects of wall friction assumed to be negligible. The quasi one-dimensional assumption will be used. Consider the steady flow through the control volume as shown in figure (2).

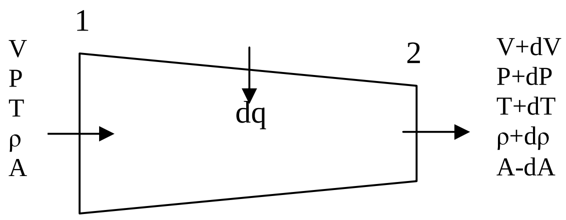

Figure (2) One-Dimensional Control Volume

Hence the continuity equation gives [10]:

$$\frac{d\rho}{\rho}+\frac{dA}{A}+\frac{dV}{V}=0 \qquad \text{------ (11)}$$

While, the conservation of momentum gives [11]:

$$PA+\left(P+\frac{dP}{2}\right)dA-(P+dP)(A+dA)=\rho\,A\,V\,dV \qquad \text{------ (12)}$$

The second term on the left hand side represents the force due to the pressure on the wall. By neglecting the second order terms gives [10]:

$$dP+\rho\,V\,dV=0 \qquad \text{------ (13)}$$

Also, the equation of state gives [10]:

$$\frac{dP}{P}=\frac{d\rho}{\rho}+\frac{dT}{T} \qquad \text{------ (14)}$$

And the conservation of energy gives [11]:

$$dq=C_P\,dT \qquad \text{------ (15)}$$

From equations (11) and (13) yields:

$$dP-\rho V^2\left(\frac{d\rho}{\rho}+\frac{dA}{A}\right)=0 \qquad \text{------ (16)}$$

From equations (14) and (15) yields:

$$\frac{d\rho}{\rho}=\frac{dP}{P}-\frac{dq}{C_P T} \qquad \text{------ (17)}$$

Substitute equation (17) into (16) and rearrange, leads to:

$$dP=\rho V^2\,\frac{\left(\frac{dA}{A}-\frac{dq}{C_P T}\right)}{1-\frac{\rho V^2}{P}} \qquad \text{------ (18)}$$

This equation gives the variation of pressure across the control volume, it mean that:

$$P_2=P_1+dP \qquad \text{------ (19)}$$

Where, 1:- refers to the inlet of the control volume

2:- refers to the outlet of the control volume

From equation (15) get:

$$T_2=T_1+\frac{dq}{C_P} \qquad \text{------ (20)}$$

Use simple equation of state for perfect gas to determination the density value, hence:

$$\rho_2=\frac{P_2}{R\,T_2} \qquad \text{------ (21)}$$

The velocity value then can be found from the continuity equation, so:

$$V_2=\frac{\overset{o}{m}}{\rho_2\,A_2} \qquad \text{------ (22)}$$

Where, $A_2 = A_1 + dA$ -------- (23)

$\dot{m} = \rho_1 V_1 A_1$ -------- (24)

The value of heat added that calculated in equation (9) is in (Watt) so it must be divide on the mass flow rate ($\dot{m}$) to satisfy the requirements of the nozzle modeling which is in (J/Kg). The output power then can be calculated at the exit of the nozzle by:

$$P_{out} = 0.5 \rho A V^3 \qquad \text{-------- (25)}$$

Demonstrating the critical length of the nozzle need to achieve the conversion of full solar energy absorbed into the kinetic energy of flow at the throat of the nozzle, it means:

$$I_S A_N = 0.5 \rho A_t V_t^3 \qquad \text{-------- (26)}$$

Then the critical length can be determined as:

$$L_{Crt} = \frac{\rho A_t V_t^3}{\pi I_S (D_i + D_e)} \qquad \text{-------- (27)}$$

For air at operation design, the critical length is calculated to be (8 m); therefore the design length (10 m) is acceptable.

5. The Mathematical Procedure

In order to calculate the flow properties inside the nozzle, an program of FORTRAN-90 is adopted and explained in flow chart as shown in figure (3). The nozzle is divided into 40 control volumes, the boundary conditions (dq) is provided in each control volume and the inlet properties are taken as shown in table (1). The nozzle is made from steel, the inlet diameter is (10 m), the exit diameter is (1 m) and its length is (10 m), and locates in horizontal level (7 m) up of the ground. Equations (18 – 24) are used to calculate the properties in the exit of the control volume then take the next control volume and repeat this procedure until reaching to the end of nozzle.

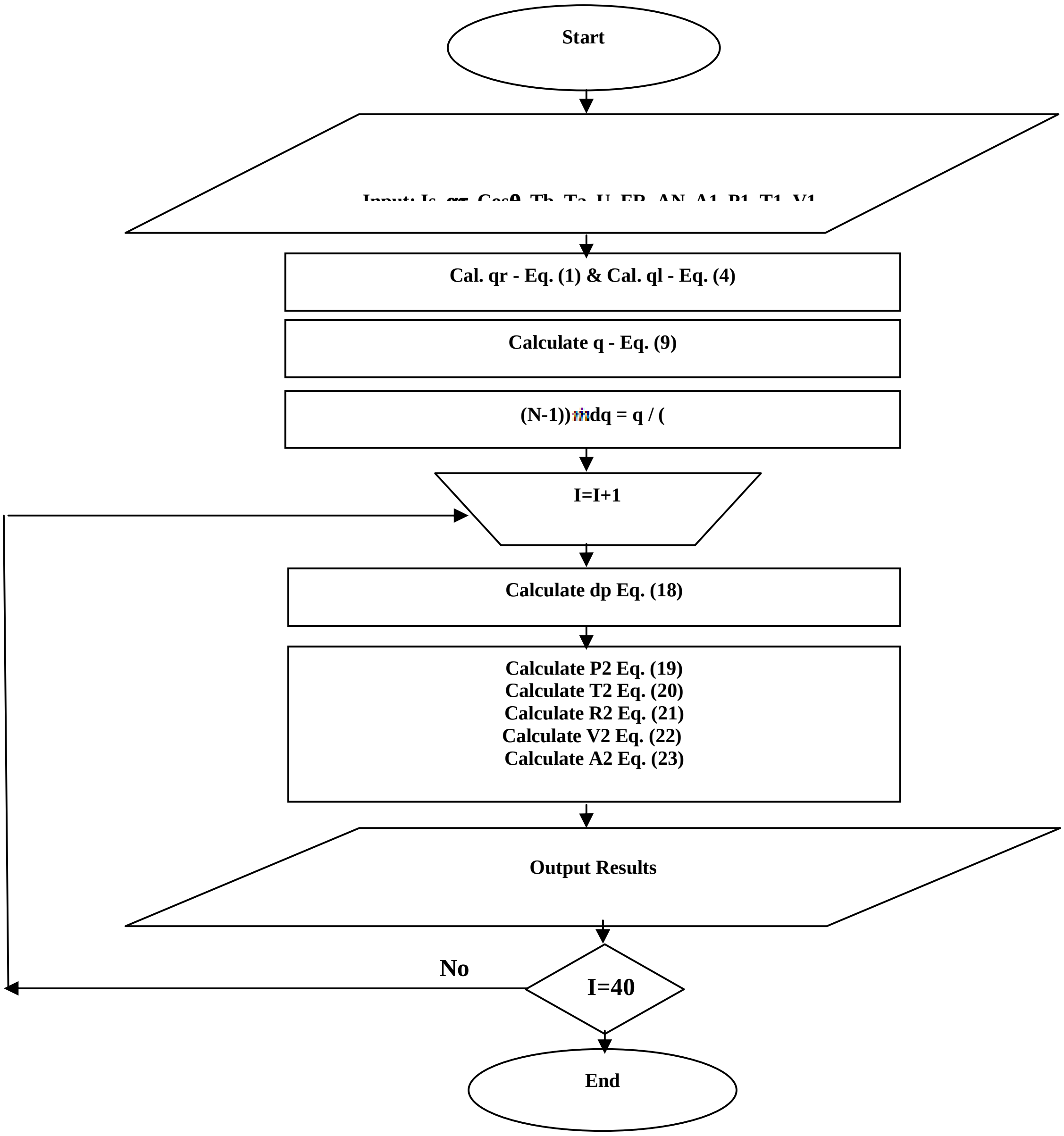
Start
Cal. qr - Eq. (1) & Cal. ql - Eq. (4)
Calculate q - Eq. (9)
(N-1))dq = q / (
I=I+1
Calculate dp Eq. (18)
Calculate P2 Eq. (19)
Calculate T2 Eq. (20)
Calculate R2 Eq. (21)
Calculate V2 Eq. (22)
Calculate A2 Eq. (23)
Output Results
No
I=40
End

Table (1) Local Air Properties

Velocity	3 m/sec	C_p	1005 J/Kg. K
Pressure	100 KPa	μ	2 x 10^{-5} Kg/m. sec
Temperature	35 ^oC	K	0.0268 W/m. K
Density	1.17 Kg/ m^3	Pr	0.7

6. Results and Discussion

Analysis of the design conditions and the interference effects of the free stream velocity and the heat load have been done. The flow velocity and temperature are the dominated parameters for comparison at different conditions. For confidence of understanding, figure (4) shows the variation of flow velocity along the nozzle, while figure (5) shows the variation of flow temperature along the nozzle.

From figure (4), it is observed that the velocity of the air increase by the decrement of the area. The raise in the value of velocity in the case of heat added is reached to (50 m/sec) and in the case of no heat it is about (48 m/sec), while Williams [6] determined that it is about (52 m/sec) for case of vertical nozzle. This mean that at heat gained the power reached to (57 KW), while in the case of no heat it is (54 KW).

From figure (5), it is observed that the temperature of the air increased rapidly in the case of heat added, while it may be less in that of no heat. The temperature difference in this study is about (0.9 ^0C), while Williams [6] determined that it is about (1.3 ^{0}C) for case of vertical nozzle and solar absorber arranged in the base of the nozzle.

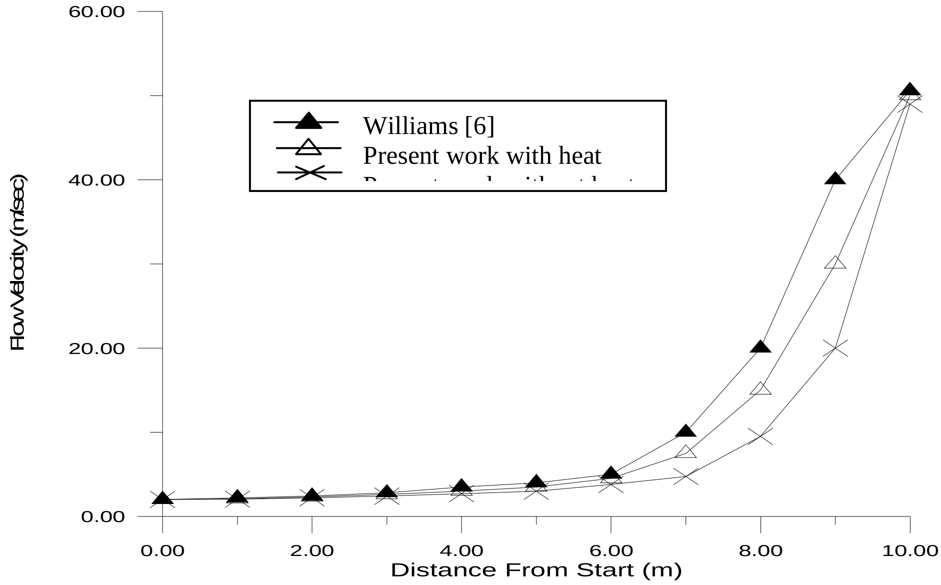

Figure (4) Variation of Flow Velocity along the Nozzle

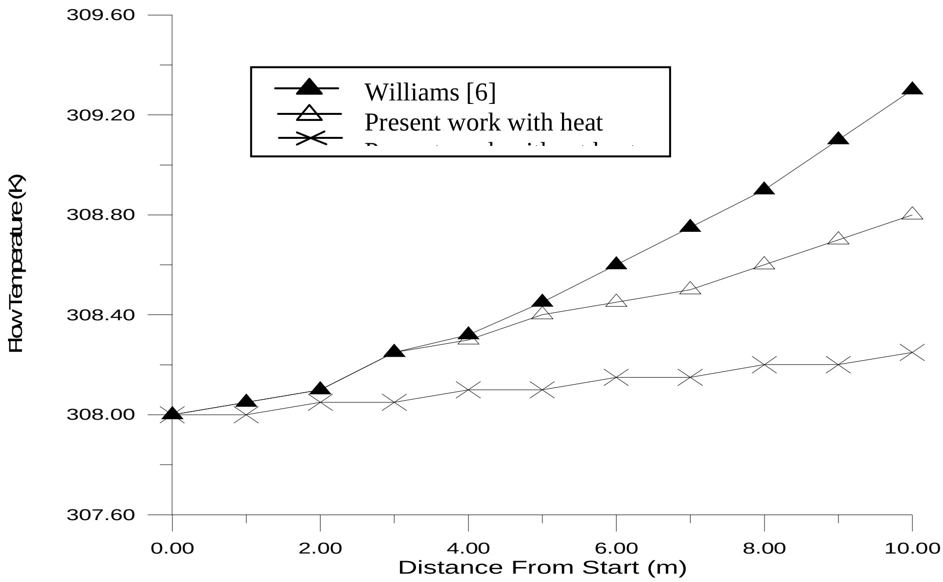

Figure (5) Variation of Flow Temperature along the Nozzle

Figure (6) show another comparison, it is observed that the percentage error of flow temperature between the experimental work of reference [7] and this study is about (-2 %) when (x < 7 m) and about (+4 %) when (x > 7 m).

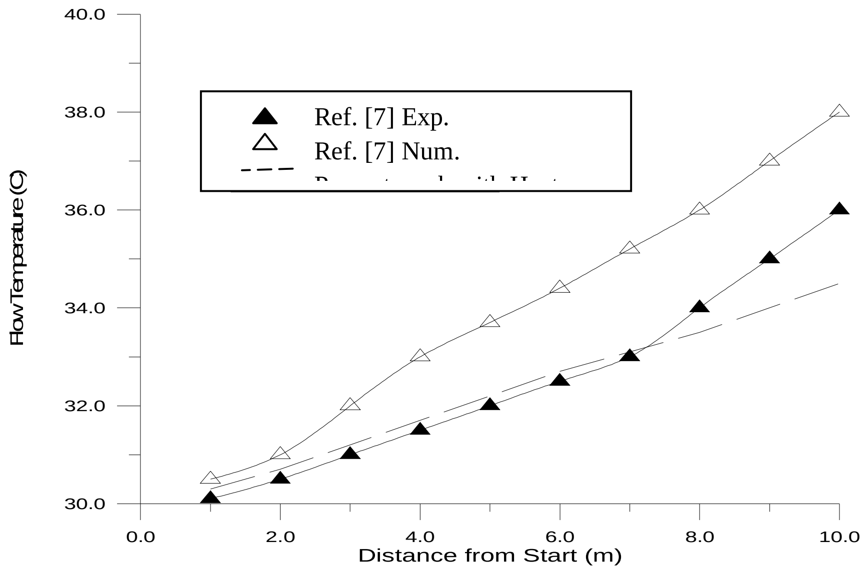

Figure (6) Comparison of Flow Temperature with Ref. [7]

Although that the heat gained is a small, but it can be increase by advantages of concentrating the solar radiation [2]. The concentrating of radiation can be rise the solar power to about (4500 W/m^2), that's mean that the exit velocity in the design operation conditions reaches to an increment of (20%) than that of no concentrating (450 W/m^2).

7. Conclusions

Generally, there are several results to be noticed from the whole research according to the fluid energy which can be listed below as:

1- It is an open cycle.

2- A prototype solar nozzle is described of 10 m height, 10 m base diameter and 1 m throat diameter.

3- The value of velocity in the case of heat added is reached to (50 m/sec), while in the case of no heat transferred it is about (48 m/sec).
4- Maximum heat gained could give an output power reached to (57 KW).
5- The temperature difference through the nozzle is (0.9 ^oC).

Furthermore analysis can be made by using of solar absorber in several layers thick arranged around the nozzle. Also put an attention to make a closed cycle with relatively by-passing, due to the difficulty of heating the air and an economic procedure.

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