PERFORMANCE ANALYSIS OF A WIND TURBINE BASED ON A SOLAR NOZZLE

Jamal H. Waheb* **Tawfeeq Wesmi M.**** **Saad A. Razuqi*****

*** Engineering Dept., University of Anbar ,**

**** Al-Mustansiriyah University ,**

*****. Al-Mustansiriyah University,**

E-mail:jamal.waheb@yahoo.com* E-mail: t awfeeq1978@yahoo.com_E-mail:saada_59@yahoo.com*****

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ABSTRACT:

A modified method has been proposed for conversion of wind energy into mechanical energy 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 glass. 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 (1 m.sec^{-1}) to a high velocity that gives good energy allowed the wind plant to generate power, other words in order to increase the efficiency of the plant. From the results, it is observed that the velocity of wind increases by the increment of heat gain and decrement of the area. The exit velocity value in the case of heat added is reached to (19 m.sec^{-1}), while in the case of no heat transferred is about (18 m.sec^{-1}). Calculation indicates that maximum heat gained could give (2.5 KW) output power.

تحليل أداء محطة الريح باستخدام النافث الشمسي

جمال حميد وهيب * ، توفيق وسمي محمد ** ، سعد عبد الوهاب رزوقي***

*** جامعة الانبار- كلية الهندسة – قسم الميكانيك**

**** الجامعة المستنصرية – كلية الهندسة – قسم الميكانيك**

***** الجامعة المستنصرية- كلية الهندسة**

E-mail:jamal.waheb@yahoo.com* E-mail: t awfeeq1978@yahoo.com E-mail:saada_59@yahoo.com*****

الكلمات المفتاحية:الطاقة، محطات قدرة، النافث الشمسي، مدخنة شمسية، جريان المائع ألانضغاطي

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المستخلص:

تم اقتراح طريقة معدلة لتحويلِ طاقةِ الرياح إلى الطاقةِ الميكانيكيةِ تَستخدم التأثيرَ الهجينَ للنافث والطاقةِ الشمسيةِ .ان التيارات الهوائية المارة خلال النافثِ الأفقي تتعجّلُ بسبب تناقص المساحة وبسبب الطاقة الحراريةِ المكتسبة مِنْ الشمس خلال الجدار. ان الأبعاد الحرجة مَحْسُوبة للنافثِ المتقاربِ المصنوع من الزجاج .تُركز هذه الدراسةِ على منافع إستعمال النافث الشمسي حيث إنّ الدراسةَ محاولةُ لرَفْع سرعةِ الريحِ المحليّةِ (1 m.sec^{-1}) الى سرعة عالية تَعطي طاقةً جيدةً تسَمح لمحركِ الرّيحَ بتَوليد الطاقة الكهربائيةِ او تزيدَ كفاءةَ المحطةِ. مِنْ النَتائِجِ، يُلاحظُ زيادةِ سرعة الهواءِ بزيادةِ كميةِ الحرارةِ المكتسبة وتناقصِ المساحةِ . ان قيمة السرعةَ في حالة اضافة الحمل الحراري تصل إلى (19 m.sec^{-1}) ، بينما في حالة عدم وجود الحرارة فهي (18 m.sec^{-1}) وكذلك تشير الحسابات بأنّ في حالة الحرارةِ المضافة يُمْكِنُ أَنْ نكتسب طاقة مقدارها (2.5 KW).

Nomenclature

A *Area (m^2)*
C_p *Specific heat capacity, for air (1005 J.kg^{-1}.K^{-1})*
d *Diameter of the nozzle (m)*
h *Heat transfer coefficient (W.m^{-2}. K^{-1})*
I *Incident radiation (W.m^{-2})*
K *Thermal conductivity (W.m^{-1}.K^{-1})*
$\dot{m}$ *Mass flow rate (kg.sec^{-1})*
Pr *Prandtl No., for air (0.7)*
q Heat added (J.kg^{-1})
R *Gas constant, for air (287.1 J.kg^{-1}.K^{-1})*
V *Velocity (m.sec^{-1})*

θ Incidence angle
μ Dynamic viscosity ($kg.m^{-1}.sec^{-1}$)
ρ Density ($kg.m^{-3}$)
CFD Computational fluid dynamics

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) (Mukund, 1999). 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 (Nandkumar, 2007). It is clear that the using of 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 (Sørensen, 2004). Padki and Sherif (Padki and Sherif, 1999), 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 (Holttinen et.al. 2006), has been formed in 2006 under the IEA implementing agreement on wind energy; the task would 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 (Williams, 2007), propose 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 indicated 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, et.al.2008), 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 study is introducing an analysis and procedure of using solar nozzle. The solution was merging between analytical of wind energy and solar energy to increase the wind energy to a rate allowed the wind plant to generate power, also in order to increase the efficiency of the plant 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, (figure 1)

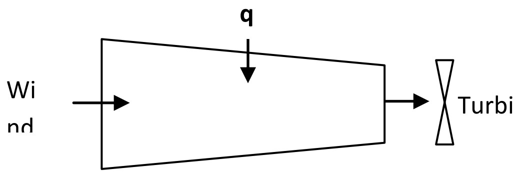


Figure (1) Supposed Wind Plant

Method and Materials

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 (Sørensen, 2004). The average rate of the solar radiation incidence on a horizontal plate in Iraq (Baghdad) for July is about (450 W/m^2) (Mukund, 1999).
SSuppose that the nozzle is solar collector, so the iinput radiation power (q_R) is (Duffie and Backman, 1992):

$$q_R = I_N \, \alpha\tau \qquad (1)$$

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

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

Where:
$\alpha\tau$ = Product of absorptive and transitivity (which is 0.95 for the nozzle material) (Sakonidou, et.al. 2008).
I_S = Solar Radiation for Baghdad at a specific conditions (450 W/m^2) (Mukund, 1999).
The solar angles that used in equation (3) are variables and depend on the location and time, hence for Baghdad at noon time in July ($\phi = 33^o$), ($\delta = 23.4^o$), and (cos θ = 0.97).
The heat loss across the wall is denoted as (Duffie and Backman, 1992):

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

Where T_a = Local air temperature (35 ^{o}C average value in Baghdad, July)
T_b = Average bulk temperature inside the nozzle (suppose as 36 ^{o}C)

Principally, the overall heat transfer coefficient (U) can be calculated from (Holman, 1986):

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} \qquad (5)$$

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 (Holman, 1986):

$$h = \frac{\mathrm{Nu}\ K}{d} \qquad (6)$$

Nusselt No. and Reynolds No. can be determined from (Holman, 1986):

$$Nu = 0.023\,\mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.4} \qquad (7)$$

$$\mathrm{Re} = \frac{\rho\ V\ d}{\mu} \qquad (8)$$

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

$$q = A_N\ F_R\left(q_R - q_L\right) \qquad (9)$$

The heat removed factor (F_R) has value of (0.8) (Duffie and Backman, 1992).
A_N is the surface area of the nozzle which represents a semi-cone shape so it is calculated from:

$$A_N = \pi\,\frac{D_i + D_e}{2}\,L \qquad (10)$$

Where, L =Nozzle length (m).
D_i = Inlet diameter (m)
D_o= Exit diameter (m)

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).

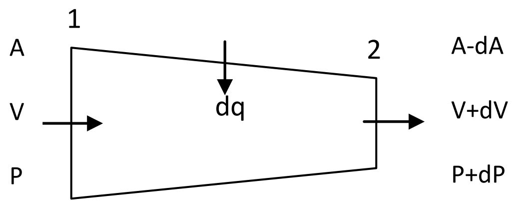


Figure (2) One-Dimensional Control Volume

Hence the continuity equation gives [10]:

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

While, the conservation of momentum ggives [11]:

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

(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 (Patrick and William, 1997):

$$dP + \rho\,V\,dV = 0 \qquad (13)$$

Also, the equation of state gives [10]:

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

And the conservation of energy gives (Koonsrisuk et.al. 2010):

$$dq = C_P\,dT \qquad (15)$$

From equations (11) and (13) yields:

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

From equations (14) and (15) yields:

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

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

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

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

$$P_2 = P_1 + dP \qquad (19)$$

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

2:- refers to the outlet of the control volume

From equation (15) get:

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

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

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

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

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

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

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 that used in equation (20) which is in (J/kg). Also the decrement in area (dA) is depending on linear formula.

The output power then can be calculated at the exit of the nozzle by:

$$P_{out} = 0.5\,\rho\,A_e\,V_e^3 \qquad (24)$$

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 exit of the nozzle, it means:

$$I_S\,A_N = 0.5\,\rho\,A_e\,V_e^3 \qquad (25)$$

Then the critical length can be determined as:

$$L_{Crt} = \frac{\rho\,D_e^{\,2}\,V_e^3}{4\,I_S\,(D_i + D_e)} \qquad (26)$$

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

The Mathematical Procedure

In order to calculate the flow properties inside the nozzle, a 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 heat gain (dq) is provided in each control volume and the inlet properties are taken as shown in table (1). The nozzle is made from glass, the inlet diameter is (4 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.

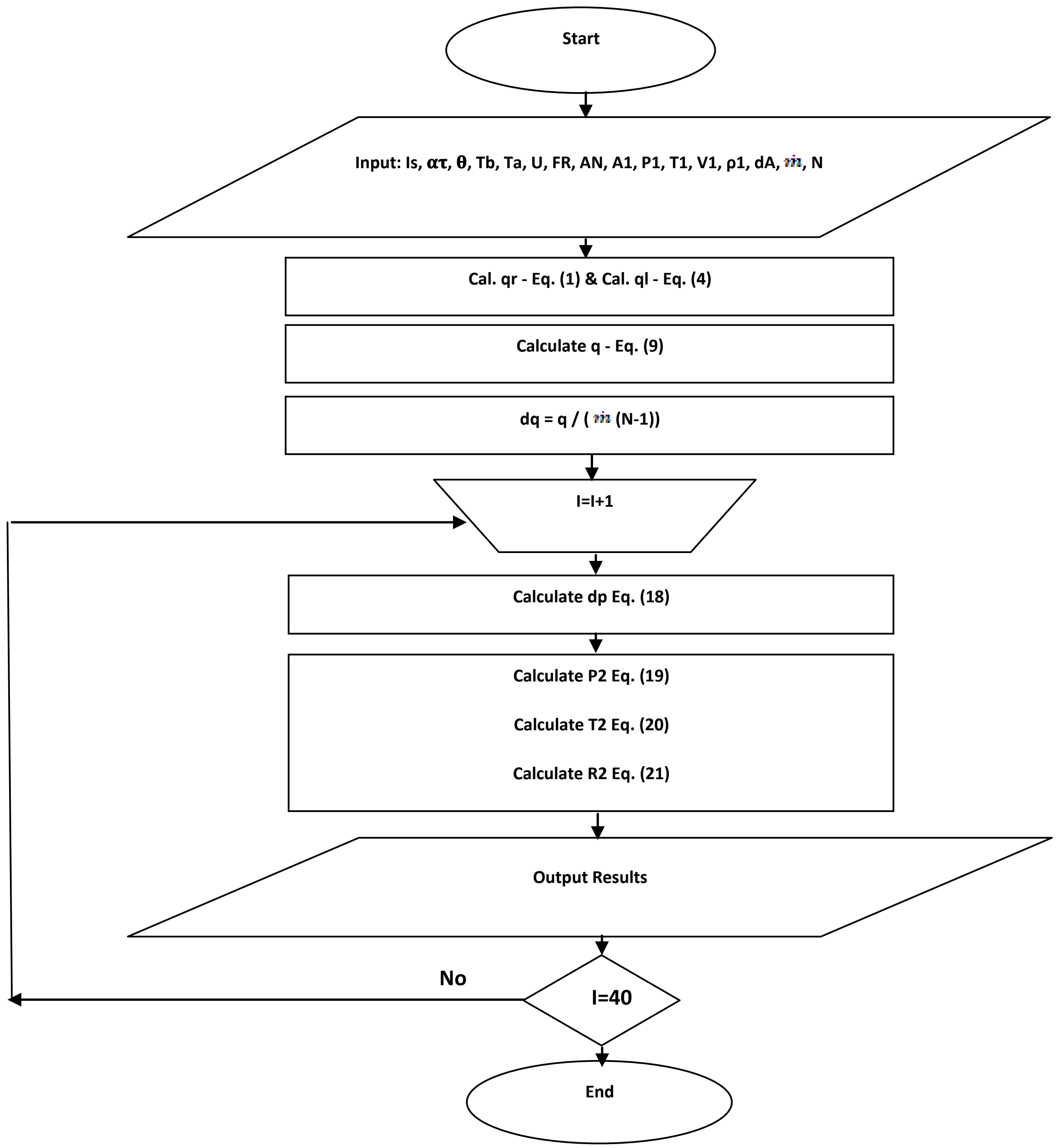
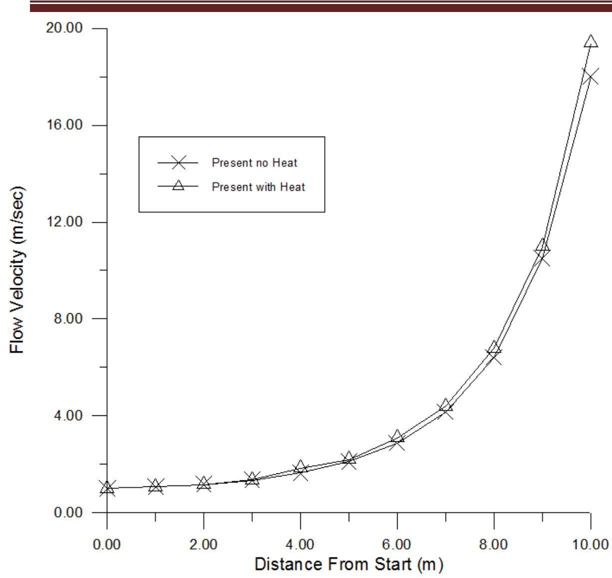


Figure (3) Program Flow Chart

Table Local Air Properties

Velocity	**1 m.sec^{-1}**	**C_p**	**1005 .J.kg^{-1}.K^{-1}**
Pressure	**100 Kpa**	**μ**	**2 x 10^{-5} kg.m^{-1}sec^{1-}**
Temperature	**35 ^{o}C**	**K**	**0.0268 W.m^{-1}.K^{-1}**
Density	**1.17 kg.m^{-3}**	**Pr**	**0.7**



Figure(4)Variation of flow velocity along the nozzle

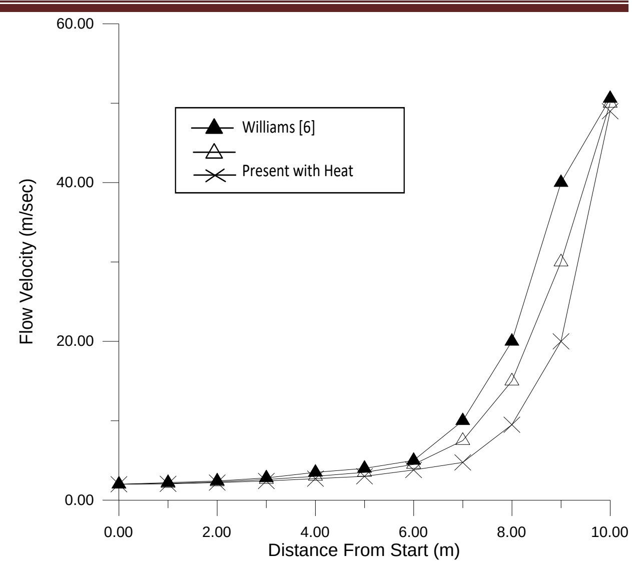


Figure (5) Comparison of flow velocity with, (Williams, 2007

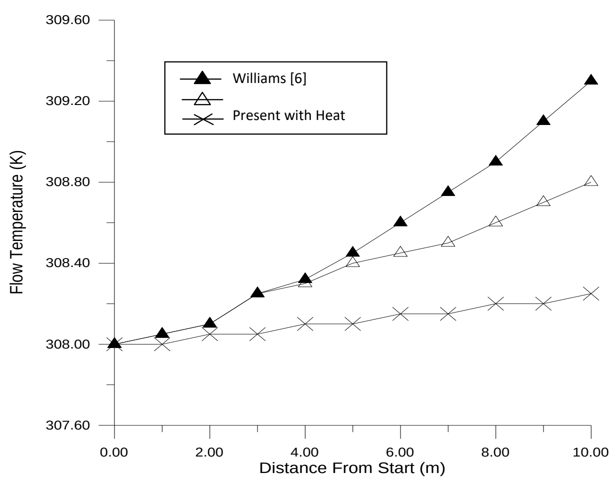


Figure (6) Variation of flow temperature along the nozzle

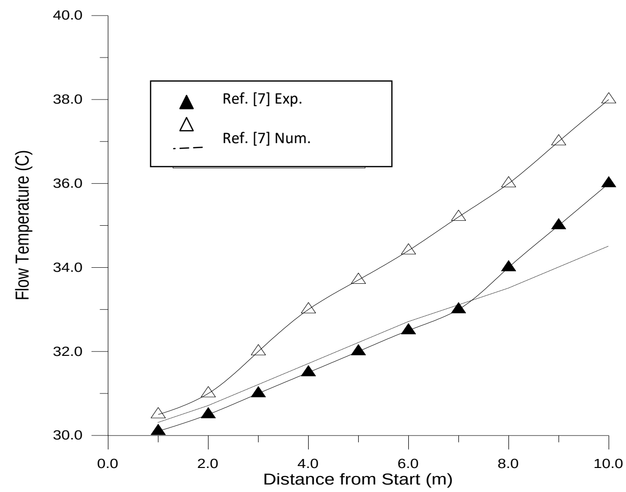


Figure (7) Comparison of flow temperature with, (Sakonidou, et.al. 2008)

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