iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** X **Month of publication:** October 2016

DOI:

www.ijraset.com Volume 4 Issue X, October 2016
IC Value: 13.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

An encompassing Review on Solar Air Heater

Jasjeevan Singh[1]
[1]*Assistant Professor, Department of Mechanical Engineering, Khalsa College of Engineering & Technology, Amritsar, India*

Abstract: It has been observed that the heat transfer coefficient between absorber surface of collector and flowing fluid i.e. air can be improved by providing artificial roughness on the absorber surface, .In this way the Thermal efficiency is increased. Due to roughness geometry pumping power of solar collector is increased due to friction losses in the duct. So, it is necessary to take into account size, shape and flow pattern of various roughness elements to increase maximum efficiency with minimum frictional losses. Various artificial roughness geometries have been reported in the literature by investigators, for determining the effect of various roughness geometries on heat transfer enhancement and friction characteristics in roughened duct of solar air heater. Reviews of various studies are presented in this paper.
Keywords: Solar air heater, Artificial roughness; Nusselt number; Reynolds number, Friction factor

I. INTRODUCTION

Due to advancement in technology and fast growing population in each and every field such as Agriculture & Research, Industrial, energy is the main requirement and same trend will be increasing day by day. Conventional energy resources are depleting very fast. They are not sufficient to meet the energy demands very long. Hence the desire of mankind is to find alternate energy resources. Alternate energy resources can be divided into renewable and non-renewable energy resources. Although there are many forms of renewable energy resources available to us, solar energy is most promising source, due to clean energy, available freely, free of cost, pollution free, presence everywhere, non exhaustive nature. The easiest methodology for making proper use of solar energy is its conversion to thermal energy using solar collector. These solar collectors are part of solar water heater and solar air heater which are used for heating water and heating air respectively. Solar air heater has been used to deliver heated air at low to moderate temperatures which can be used for crop drying and industrial applications. The thermal efficiency of solar air heater having smooth plate collector is very low due to low convective heat transfer coefficient between absorber plate and the air flowing in the duct. In a smooth plate solar air heater a thin viscous sub layer develops next to the wall in turbulent boundary layers where the velocity is relatively low. In this region heat transfer is predominated by conduction and beyond this heat transfer process is dominated by convection. The objective is to increase heat transfer coefficient between the absorber plate and the air flowing over the plate. By providing roughness element on the absorber surface of plate can improve heat transfer coefficient, but it would result in increased frictional losses. Therefore greater power is required by blower. In order to keep the frictional losses at minimum level, the turbulence must be created only in the region very close to the duct surface i.e. in laminar sub-layer.

II. PERFORMANCE ANALYSIS OF CONVENTIONAL SOLAR AIR HEATER

Following Hottel-Whillier-Bliss equation reported by Duffie and Beckman (1980) commonly used for predicting useful energy gain by the air flowing through the duct.

$$Q_u = A_c\left[I\left(\tau\alpha\right)_e - U_l(T_{pm} - T_{am})\right] \qquad (1)$$

Thermal efficiency of solar collector is

$$\eta_{th} = \frac{Q_u}{A_c I} \qquad (2)$$

Where

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ISSN: 2321-9653
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Q_u	useful energy gain in the collector (W)
A_c	collector area (m^2)
I	insolation on tilted surface (W/m^2)
$(\tau\alpha)_e$	effective transmittance-absorptance product
T_{pm}	mean temperature of absorber plate (K)
T_{am}	ambient temperature (K)
U_l	overall heat loss coefficient (W/m^{2}K)

Actual useful energy gain Q_u' by the air flowing through the collector may be obtained by using the following equations;

$$Q_u = \dot{m}\, C_p (T_o - T_i) \quad (3)$$

$$Q_u = h\, A_c (T_{pm} - T_{am}) \quad (4)$$

Eq. (4) shows that useful energy gain in a solar air heater can be increased by increasing heat transfer coefficient between absorber plate and flowing air.

$$h = \frac{\dot{m} C_p (T_o - T_i)}{A_c \left(T_{pm} - T_{am}\right)} \quad (5)$$

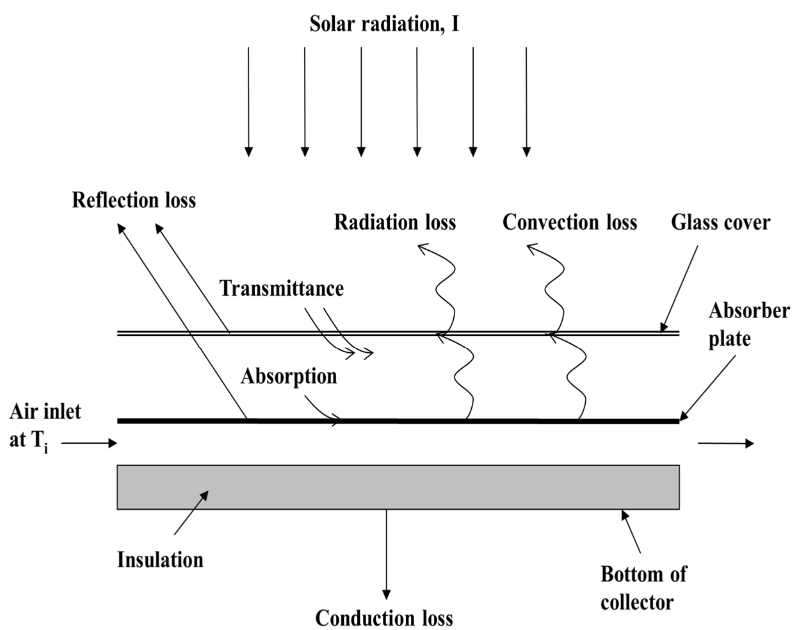

Fig.1: Thermal network of a conventional solar air heater

III. EFFECT OF ROUGHNESS PARAMETERS

The effect of various roughness parameters and geometry on heat transfer coefficient and friction factor is given below.

A. *Effect of relative roughness pitch (p/e)*

Due to flow separation downstream of a rib, reattachment of free shear layer does not occur for relative roughness pitch (p/e) of less

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ISSN: 2321-9653
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than about eight. It results in decrease of heat transfer enhancement. However, an increase in relative roughness pitch (p/e) beyond 10 also result in decrease of heat transfer enhancement.

B. Effect of Reynolds Number

With the increase of Reynolds number, the friction factor decreases due to the restriction of sub layer where as Nusselt number increases with increase in Reynolds numbers because it is nothing but ratio of conductive resistance to convective resistance of heat flow as Reynolds number decreases the thickness of boundary layer decreases and hence convective resistance decreases which in turn increases the Nusselt number.

C. Effect of Rib

It generates two separate regions of the flow, one on each side of the rib. The turbulence occurs due to formation of vortices and hence enhancement in heat transfer as well as in the friction losses takes place.

D. Angle of attack (α)

Various researchers have investigated experimentally the effect of angle of attack on the flow pattern beside the relative roughness pitch (P/e) and relative roughness height (e/D). In addition breaking sub layer and creating wall turbulence the transverse rib gives high heat transfer rate than inclined rib due to secondary flow induced by rib.

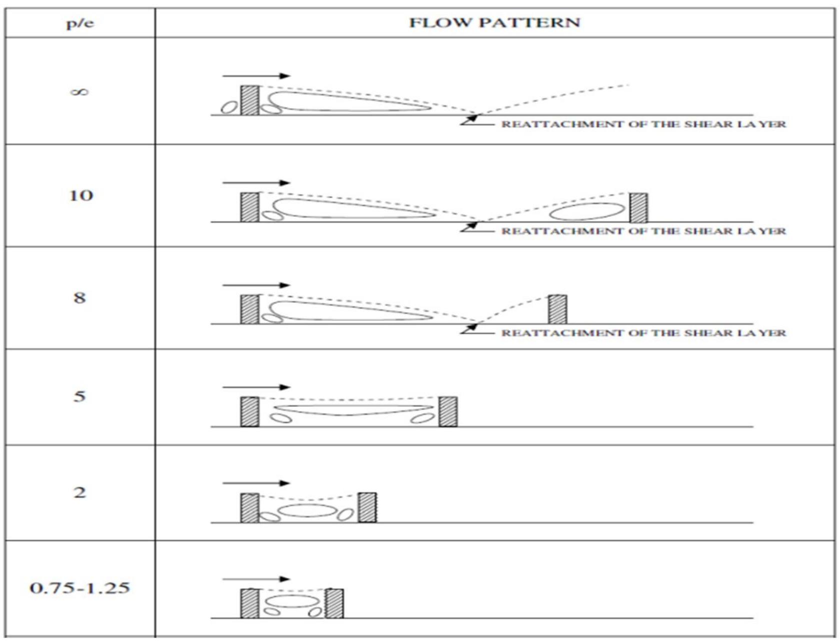
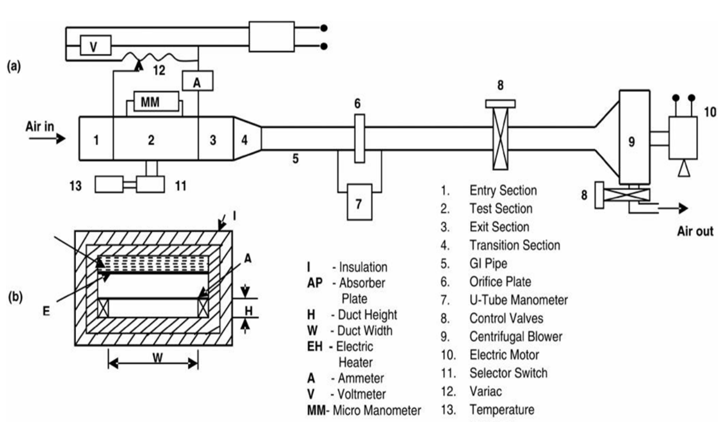


Fig.2: Effect of (p/e) on flow pattern.

IV. EXPERIMENTAL APPROACH



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The following parameters were measured during the experiments.

A. Temperature of Plate.

B. Inlet temperature of collectors using Thermocouples.

C. Outlet air temperature of collectors and Pressure drop across orifice plate.

V. A REVIEW OF INVESTIGATIONS

The concept of artificial roughness was first applied by Joule[1] to enhance heat transfer coefficients for in tube condensation of steam and hence then many experiments were carried out on the application of artificial roughness in the areas of compact heat exchangers, electronic experiments, nuclear reactors. Gupta et al. [2] carried out investigation on heat and fluid flow in rectangular solar air heater ducts having transverse rib roughness on absorber plate as shown in Fig. 4.

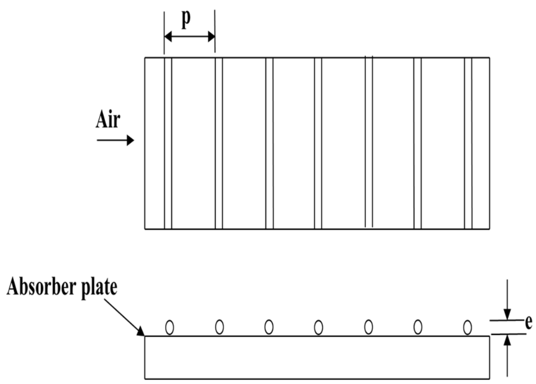

Fig. 4: Type of roughness geometry investigatedbyGupta et. al (1993).

Saini and Saini [3] carried out experimental investigation with expanded metal mesh as roughness element as shown in Fig. 5.

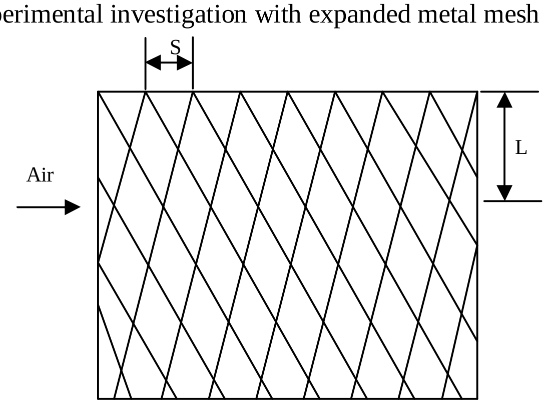

Fig. 5: Roughness geometry investigated by Saini and Saini (1997).

Muluwork et al. [4] compared thermal performance of staggered discrete V-apex up and down with corresponding transverse staggered discrete ribs as shown in Fig. 6.

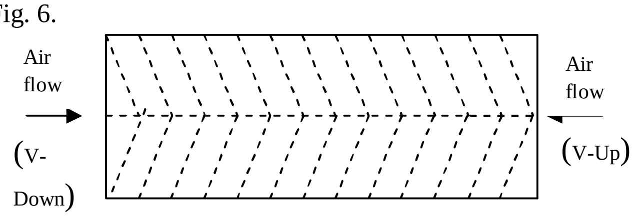

Fig. 6: Roughness geometry investigated by Muluwork et al. (1998).

Karwa et al. [5] (1999) experimentally studied the effect of relative roughness height, relative roughness pitch, rib head chamfer

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angle and duct aspect ratio on the friction factor and heat transfer coefficient with roughness geometry as shown in Fig. 2.7. Authors reported that presence of chamfered ribs on wall of duct increases Stanton number as well as friction factor.

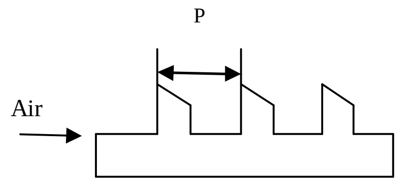

Fig. 7: Roughness geometry investigated by Karwa et al. (1999).

Momin et al. [6] (2002) investigated effect of geometrical parameters of V-shaped ribs on heat transfer and fluid flow characteristics of rectangular duct of solar air heater having V-shaped ribs on absorber plate as shown in Fig. 8.

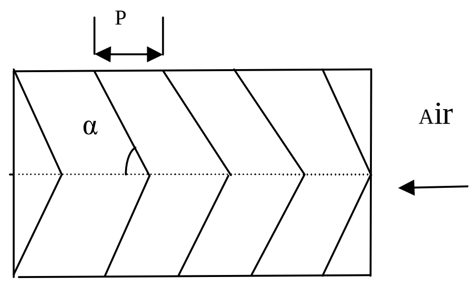

Fig. 8: Roughness geometry investigated by Momin et al. (2002).

Sahu and Bhagoria [7] (2005) carried out experimental investigation in order to study heat transfer coefficient by having 90^o broken transverse ribs on absorber plate as shown in Fig. 2.10.

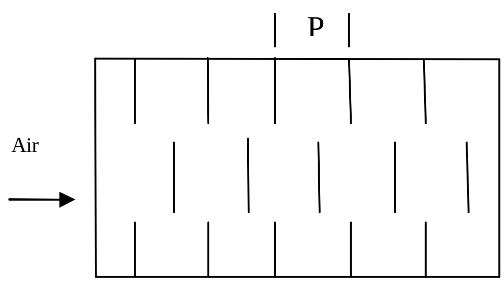

Fig. 9: Roughness geometry investigated by Sahu and Bhagoria (2005).

Mahajan et al. [8] performed an experimental investigation on heat transfer and friction for artificially roughened solar air heater duct roughened with plain woven square wire mesh as shown in Fig. 10.

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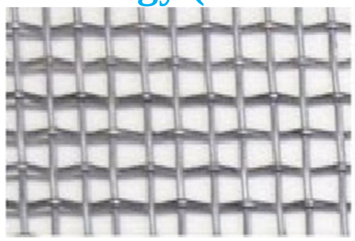

Fig. 10: Roughness geometry investigated by Mahajan et al. (2010)

Sharma et al. [7] reported CFD based investigation of solar air heater duct provided with artificial roughness in the form of square type protrusion shape geometry. Shape and orientation of roughness geometry investigated by author is shown in Fig. 11.

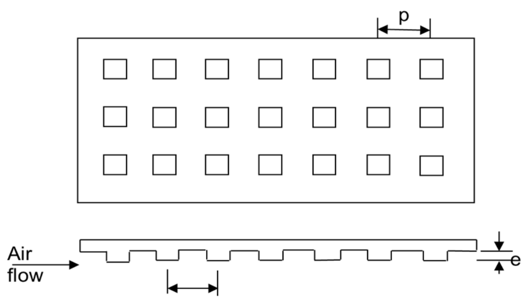

Fig. 11: Type of roughness geometry investigated by Sharma et. al (2011).

Bhushan and Singh [8] investigated solar air heater duct roughened with protrusions for the range of system and operating parameters. The shape and orientation of the roughness geometry is shown in Fig. 12.

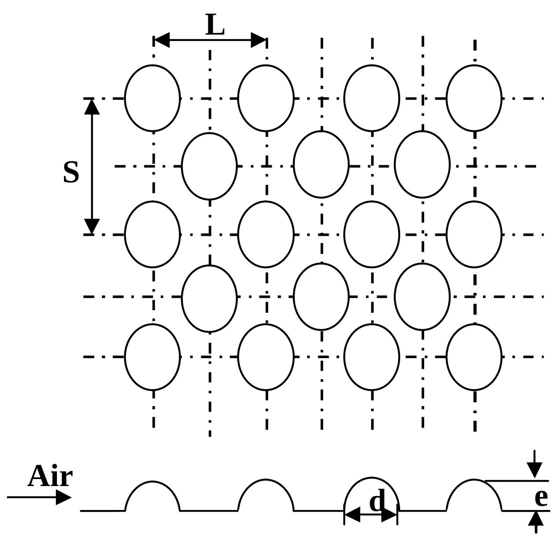

Fig. 12. Type of roughness geometry investigated by Bhushan & Singh (2011).

Kumar et al. [9] investigated and developed correlations for Nusselt number and friction factor for solar air heater with roughened duct having multi v-shaped with gap rib as artificial roughness geometry as shown in Fig. 13.

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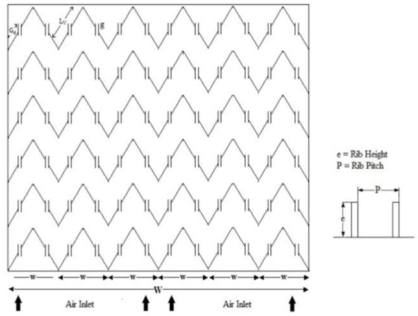

Fig. 13: Roughness geometry investigated by Kumar et al. (2013).

Singh, J. et al. [10] carried out thermo hydraulic performance on solar air heater duct using triangular protrusion as roughness geometry as shown in Fig. 14

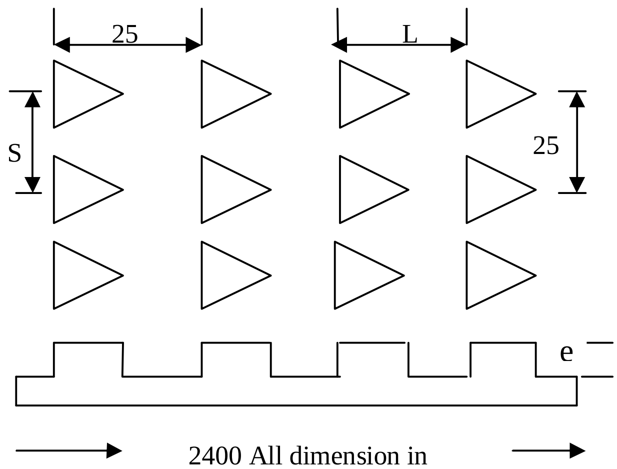

Fig. 14: Type of roughness geometry investigated by Singh, J.et al. (2014).

Soi, et al. [11] CFD based performance investigation of solar air heater having roughness elements as a combination of transverse and v-up ribs on the absorber plate as shown in Fig. 15.

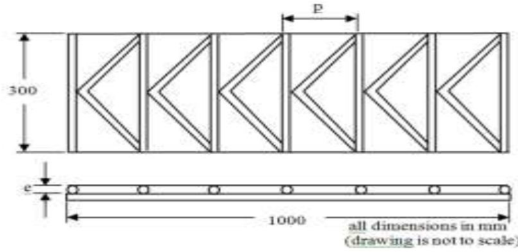

Fig. 15: Type of roughness geometry investigated by Soi, et al. (2016).

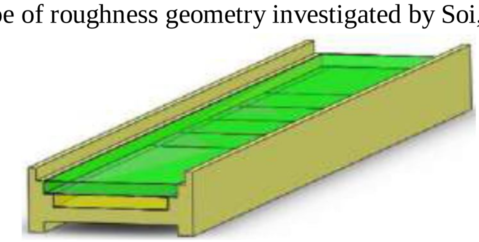

Fig. 16: CFD Model of Solar aAir Heater Duct.

Table 1: Values of Roughness Parameters of above Investigators.

Sr. No.	Investigator	Rib Geometries	Range of Parameters
1	Gupta et al. [2]	Transverse Rib	Re=3000-18000 P/e=10 e/D=0.033
2	Saini and Saini [3]	metal mesh	Re=1900-13000 e/D=0.012-0.034 (L/e) of 25-71.87 (S/e) of 15.62-46.87
3	Muluwork et al. [4]	V-shaped staggered discrete wire ribs	Re=5000-30000 e/D=0.020 α=60°
4	Karwa et al. [5]	Inclined discrete and continuous wire ribs	e/D=0.0467-0.05 p/e=10 α =60-90°
5	Momin et al. [6]	V-shaped continuous wire ribs	Re=2500-18,000 e/D=0.020-0.035 p/e=10 α =30-90°
6	Sahu and Bhagoria [7]	Wedge shaped transverse integral rib	Re=3000-18,000 p/e=60.17 W/H=4.8,6.1,7.8,9.66,12 e/D=0.015-0.033 ϕ= 8,10,12,15
7	Mahajan et al. [8]	Square wire mesh	Re=4000-8000 p/e=1.75-5.65 e/D=0.022
8	Sharma et al. [9]	Square type Protrusion	Re=4000-20000 P/e=38.8-61.1 e/D=0.016
9	Bhushan and Singh [10]	Dimple type protrusion	Re=4000-20000 L/e=25-37.50 S/e=18.75-37.50 e/D=0.03
10	Kumar et al. [11]	Multi v-shaped with gap rib	P/e=10 e/D=0.43 α =60°
11	Singh, J. et al. [12]	Triangular type protrusion	Re=4000-20000 L/e=25-37.5 S/e=18.75-37.5
12	Soi, et al [13]	Transverse and v-up ribs	Re=4000 – 16000 P/e= 7.5- 10.7 e/D= 0.025-0.036

VI. CONCLUSION

In this paper, the effort has been made to review the work carried out by researchers on the artificial roughness on the absorber plate in solar air heater. It is observed that, better performance is obtained for turbulence formation on roughened surfaces. In a nut shell, it is found that with artificial roughness, thermal performance of absorber plate increases with minimum friction factor.

A. Use of artificially roughened surfaces with different types of roughness geometries is found to be most effective technique to enhance heat transfer rate from heated surface to flowing fluid at cost of moderate rise in fluid friction.
B. Use of protrusions on absorber plate is an effective technique to increase heat transfer rate, less expensive and cost no extra weight on absorber plate.
C. The artificial roughness elements includes various types of geometries such as ribs, machining on metal, dimpled surfaces, but research is going on to find best geometry which can enhance heat transfer coefficient with moderate friction duct losses.

NOMENCLATURE

A cross-sectional area of duct, m^2
A_c collector area, m^2
A_t area of orifice plate at the throat, m^2
C_d coefficient of discharge (dimensionless)
C_p specific heat of air, J/kgK
D hydraulic diameter of duct, m
E height of roughness element, m
e/D relative roughness height (dimensionless)
f friction factor (dimensionless)
f_s friction factor for smooth plate (dimensionless)
g acceleration due to gravity, m^2/s
H height of duct, m
I insolation, W/m^2
Δh_1 difference of manometric fluid in U-tube manometer, m
Δh_2 difference of manometric fluid levels in micro- manometer, m
h heat transfer coefficient, W/m^2 K
k thermal conductivity of air, W/m K
L length of test section, m

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