International Communications in Heat and Mass Transfer 86 (2017) 239–244

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

# Effect of apex angle variation on thermal and hydraulic performance of roughened triangular duct

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ARTICLE INFO

*Keywords:*
Apex angle
Dimple shaped roughness
Triangular duct
Correlation

ABSTRACT

The experiments were performed to analyze the influence of apex angle on thermal and hydraulic characteristics of triangular duct for Reynolds number range from 2000 to 16,000. Four different triangular ducts of apex angle 30°, 60°, 90° and 110° were fabricated for the experimentation. The one side of the duct is roughened with dimple shaped roughness element. The both relative shortway length (*s*/*e*) and relative longway length (*l*/*e*) of dimple shaped roughened element was kept constant (i.e., 10) but relative roughness height (e/D) is varied from 0.016 to 0.038. Result shows that apex angle plays an important role in heat transfer. The experimental results are presented in a form of correlation for Nusselt number (*Nu*) and friction factor (*f*).

## 1. Introduction

The triangular ducts are widely used in many engineering applications such as solar air heater (*SAH*), compact heat transfer, HVAC applications etc. The fluid flow behavior and heat transfer rate through triangular duct is important to understand in order to design an effective compact heat exchanger [1–8]. Even though, the rate of heat transfer through triangular duct is low as compared to circular pipe, but it requires less pumping power to flow fluid through the duct [9].

Several researchers had performed experiments and numerical studies to determine heat transfer and pressure drop through triangular duct [10–15]. It is concluded from the comprehensive review on the nature of fluid flow and heat transfer rate in triangular duct that the thermo-hydraulic performance of the duct can be improved by rounding of corners, modifying shape and using roughness etc. [16]. In triangular duct, the high temperature region is observed at the corners due to laminar flow conditions even under turbulent flow throughout the duct [17]. This decreases the heat transfer coefficient value up to zero at the corners, in the case of sharp cornered triangular duct and value of heat transfer coefficient strongly depends on the corner angles [18–19]. The fluid interaction at the corners can be improved by modifying triangular duct which results in considerable augmentation of heat transfer rate [20–22]. Under the turbulent flow conditions, formation of laminar sublayer takes place over the hot surface which also decreases heat transfer rate between fluid and hot surface. The heat transfer through the duct can be improved by using artificial roughness in the form of ribs at the inner surfaces of duct [23]. Roughness breaks laminar sublayer and improves the heat transfer coefficient [24]. Moreover, roughness also increases pressure drop through the duct and increases the effort of external device to pump fluid through the duct [16]. In order to improve heat transfer rate through the triangular duct different shaped artificial roughness is employed such as circular [25–26], semi-circular [27], rectangular [28] and square [29–30] etc.

In the literature no such study is available which deals with the effect of variation in apex angle of the roughened triangular duct. Thus, this work has been carried out to see the performance of roughened triangular duct with different values of apex angle. Four different values of apex angle of 30°, 60°, 90° and 110° were considered for the experimentation and one side of triangular duct is roughened by providing dimple shaped element. The work has been carried out to achieve following objectives;

a. Effect of varying apex angle ($\theta$) on the fluid flow and heat transfer in roughened triangular duct.
b. Effect of relative roughness height (e/D) on the heat transfer and fluid flow behavior.
c. Development of correlation for Nusselt number (*Nu*) and friction factor (*f*).

## 2. Detail of experiment set-up

The experimental work consists of design and fabrication of four different apex angle triangular ducts as shown in Fig. 1. The apex angle ($\theta$) of fabricated duct varies from 30° to 110° and one side of the duct is

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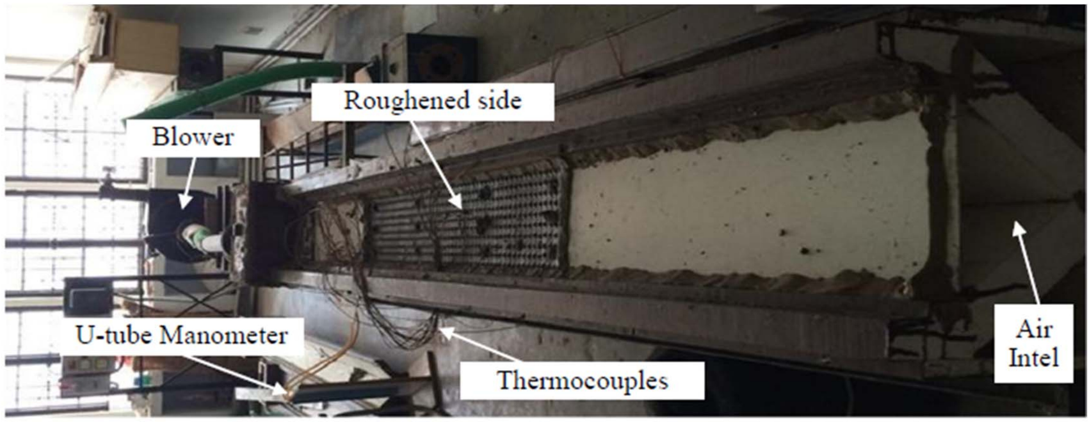
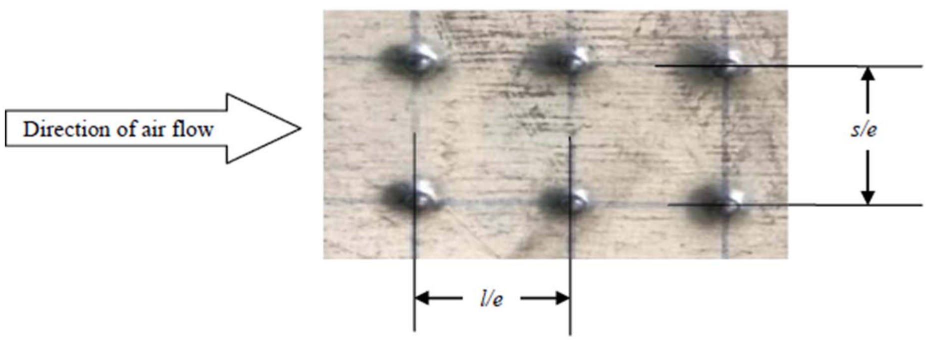
http://dx.doi.org/10.1016/j.icheatmasstransfer.2017.06.008




(a). Pictorial view of experimental setup




(b). Pictorial view of absorber plate with roughness parameters

**Fig. 1.** Pictorial view of the experimental setup and roughness elements.

**Table 1**
Detail of different ducts with range of operating and roughness parameters.

| Parameter | Duct-1 | Duct-2 | Duct-3 | Duct-4 |
|---|---|---|---|---|
| Apex angle, $\theta(^{\circ})$ | 30° | 60° | 90° | 110° |
| Total length of duct, $L$ (*mm*) | 2300 | 2600 | 2300 | 2600 |
| Length of test section, $L_t$ (*mm*) | 1000 | 1000 | 1000 | 1000 |
| Length of entrance section, $L_{ent}$ (*mm*) | 650 | 900 | 550 | 780 |
| Length of exit section, $L_{exit}$ (*mm*) | 650 | 700 | 750 | 720 |
| Length of roughened side, $a_r$ (*mm*) | 160 | 160 | 160 | 160 |
| Shape of roughened element | Dimpled | | | |
| Relative shortway length, $s/L_t$ | 10 | | | |
| Relative longway length, $l/L_t$ | 10 | | | |
| Dimple depth to print diameter, $d/D$ | 0.5 | | | |
| Heat flux, $Q''(Wm^{-2})$ | 1000 | | | |
| Insulation provided by | Glass wool | | | |
| Reynolds number, $Re$ | 2500 to 16,000 | | | |
| Inlet temperature (Air), $T_i$ (K) | 300 K | | | |

**Table 2**
Equipments used in experimentation.

| S. No. | Equipment | Specification in terms of least count |
|---|---|---|
| 1. | U-tube manometer | $\pm 1 \times 10^{-2}$ mm of water |
| 2. | Milli-voltmeter | $\pm 1 \times 10^{-2}$ m-volt |
| 3. | Micro-manometer | $\pm 1 \times 10^{-3}$ mm of water |
| 4. | T-Type thermocouples | ± 0.25 °C |

roughened with dimple shaped element. The recommendation of ASHRAE standard 93–77 is used for the designing of experimental set-up [31]. The proposed experimental setup consists of three consecutive section named as entrance, test and exit section. For achieving fully

**Table 3**
Details of an uncertainty analysis for different ducts.

| S. No. | Parameters | Value of an uncertainty analysis (%) | | | |
|---|---|---|---|---|---|
| | | Duct-1 | Duct-2 | Duct-3 | Duct-4 |
| 1. | Density | 0.75 | 0.75 | 0.76 | 0.75 |
| 2. | Mass flow rate | 1.69 | 1.69 | 1.70 | 1.69 |
| 3. | Heat transfer coefficient | 4.98 | 4.98 | 5.01 | 4.98 |
| 4. | Nusselt number | 5.01 | 5.01 | 5.21 | 5.01 |
| 5. | Friction factor | 2.63 | 2.63 | 2.64 | 2.63 |

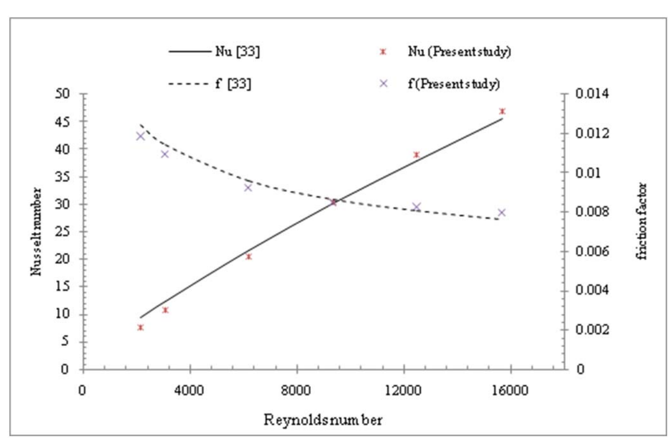



**Fig. 2.** Validation of Nusselt number and friction factor.