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Experimental Study of Forced Convection Heat Transfer from Horizontal Cylinder

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ABSTRACT

Forced convection heat transfer from a heated cylinder at different air flow conditions was experimentally studied. The present experimental assembly was developed to investigate the impact of air velocity on the thermal performance of the heated surface. The heat transfer characteristics between the cylinder wall and surrounding air were described by important dimensionless numbers such as the Reynolds number, Nusselt number, heat transfer coefficient, and temperature difference between the cylinder surface and surrounding air. Results obtained from plotted data show a considerable promotion in heat transfer at higher air velocity. The Reynolds number was varied in the range of approximately 1.5×10^3 to 6.5×10^3 , and the corresponding Nusselt number increased from 90 to 180, indicating a strong influence of flow on the augmentation of convective heat transfer. It was also found that the heat transfer coefficient increased with the increase in air velocities and total heat transfer rate, which verified the leading effect of forced convection.

ملخص

درست تجريبياً عملية انتقال الحرارة بالحمل القسري من أسطوانة مُسخَّنة في ظل ظروف تدفق هواء مختلفة. طُوِّر الجهاز التجريبي الحالي لدراسة تأثير سرعة الهواء على الأداء الحراري للسطح المُسخَّن. وُصفت خصائص انتقال الحرارة بين جدار الأسطوانة والهواء المحيط بأرقام لا بُعديّة مهمة، مثل عدد رينولدز، وعدد نوسلت، ومعامل انتقال الحرارة، وفرق درجة الحرارة بين سطح الأسطوانة والهواء المحيط. تُظهر النتائج المُستخلصة من البيانات المُرسمة تحسناً ملحوظاً في انتقال الحرارة عند سرعات هواء أعلى. تراوح عدد رينولدز بين 1.5×10^3 و 6.5×10^3 تقريباً، وزاد عدد نوسلت المقابل من 90 إلى 180، مما يُشير إلى تأثير قوي للتدفق على زيادة انتقال الحرارة بالحمل. كما تبين أن معامل انتقال الحرارة

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يزداد مع زيادة سرعات الهواء ومعدل انتقال الحرارة الكلي، مما يؤكد التأثير الرئيسي للحمل الحراري القسري.

1. Introduction

The aim of this research is to experimentally study forced convection heat transfer from a horizontal cylinder and to analyze the influence of air velocity on surface temperature, temperature difference, and heat transfer coefficient. Forced convection heat transfer over cylindrical surfaces is a classical problem in thermal engineering with numerous industrial applications, including heat exchangers, cooling of pipelines, and thermal management systems. When air is forced to flow across a heated horizontal cylinder, the heat transfer rate depends strongly on the flow velocity and the resulting fluid surface interaction.

Increasing the heat transfer rate between an item and the fluid around it is a common use of forced convection. One use case involves increasing heat transfer by inducing forced convection at the outside condensing unit with the use of a fan. When making heat exchangers, circular tubes are almost the only option. Modern research on heat transfer enhancement has focused on the fundamental but critical issue of predicting forced convective heat transfer from a spherical tube carrying a hot nanofluid. Engineers and researchers face this challenge in many different fields, including transportation, heating, ventilation, and air conditioning, heat exchangers, and textiles. There is a pressing need to enhance fluid characteristics and develop a more efficient form of fluid since effective heat transmission is a constraint in all of these businesses.

2. Review of Literature

Forced convective heat transfer from a cylinder has been widely investigated and applied in engineering as the coolability of pipes, heat exchangers, and thermal management equipment [1]. The heat transfer of fluid past a horizontal cylinder is essentially a function of the Reynolds number, the properties of the fluid, and the condition of the heating surface. With an increased flow velocity, we have higher turbulence intensity and a thinner thermal boundary layer to promote convection heat transfer. In a few experimental studies, forced convection over horizontal cylinders in cross-flow has been examined [2]. also reported that Nu is an increasing function of Re, and empirical correlations determined based on his experimental results have been used

extensively in the practical situation of engineering. These correlations compared well with extensive experimental data over a broad range of flow types and particularly included turbulent flows [3]. Introduced a general correlation for forced convection heat transfer from circular cylinders in the range of laminar to turbulent flow. It considers the Reynolds and Brandt's numbers and has been found to offer a reasonable prediction of the average Nusselt's number for gases and liquids flowing across horizontal cylinders. This correlation is one of the most widely used in forced convection heat transfer theory. Textbooks and classical handbooks also have emphasized the significance of controlled experimental conditions (except uniform heat flux or surface temperature) for which reliable heat transfer coefficients are discharged [4]. Experiments with internal heaters and surface-mounted thermocouples have been demonstrated to be powerful tools for the study of the fundamentals of forced convection heat transfer. Even though there are widely accepted theoretical connections known to date [5], these studies still have an experimental character. Experiments are useful not only to validate models but also to gain a better understanding of convective heat transfer [6]. SIRIUS A's forced convection heat transfer is strongly affected by the flow rate and boundary conditions, in agreement with most literature. Experimental studies, are vital sources of information for validation of theoretical models and also for thermal system design/optimization support data [7]. Forced convection heat transfer to incompressible power-law fluids from a heated circular cylindrical flow regime under stable cross-flow conditions has been studied. Extensive research has been conducted on the relationship between the average Nusselt's number and the Reynolds number ($5 \leq Re \leq 40$), power-law index ($0.6 \leq n \leq 2$), and Brandt's number ($1 \leq Pr \leq 1000$). Based on the numerical results, simple correlations are developed as functions of the relevant dimensionless variables [8,9]. Further physical insights have been obtained by studying not only the average Nusselt's number but also the influence of Re, Pr and n on the distribution of local Nusselt's numbers. Also discussed are the two forms of thermal boundary conditions: a constant temperature and a uniform heat flow over the cylinder's surface [10,11]. Numerous theoretical, experimental, and computational investigations on pipelines focused on mixed convection. Combined analytical and numerical methods to study mixed convection in a long heated horizontal cylinder duct. Infrared thermography was used to experimentally

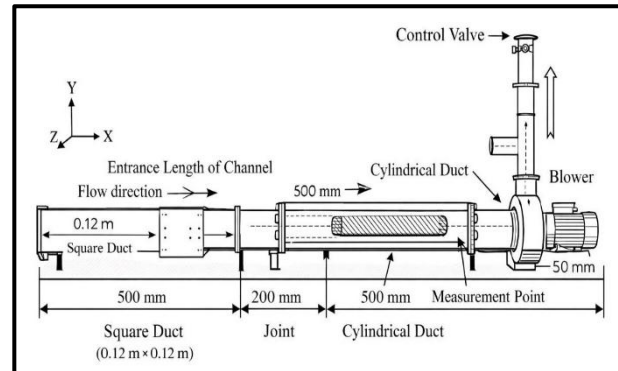
estimate the wall temperature. The results demonstrate that a secondary flow has been hydrodynamically established, with two transverse rollers that rotate counter-clockwise. Additionally, a rise in the average temperature of the cylinder wall is indicative of the thermal establishment [12,13].

discovered that when mixed convection is established inside a horizontal tube that is not uniformly heated around its circumference, heat exchange increases and spontaneous convection rolls occur. tested for a variety of inclination angles, heat fluxes, and Reynolds numbers in an experimental setting including mixed convection and laminar heat transfer in a slanted cylindrical duct. A local Nusselt's number distribution according to dimensionless axial distance ($Re.Pr$) was inferred from the surface temperature along the duct. Additionally, they discovered that for a given Re , an increase in heat flow results in an increase in surface temperature [14,15]. We found three different orientations' worth of correlations that yield Nu from Ra . Free convection decreases heat transmission for a lower Reynolds number ($Re = 400$) and boosts heat transfer for ($Re = 1600$) according to experimental study on mixed convection in a horizontally oriented cylinder [16]. I have conducted experiments on the heat transport in horizontal cylinders, both naturally and artificially. Pipe mixed convection has been the subject of several theoretical, experimental, and computational investigations [17–19].

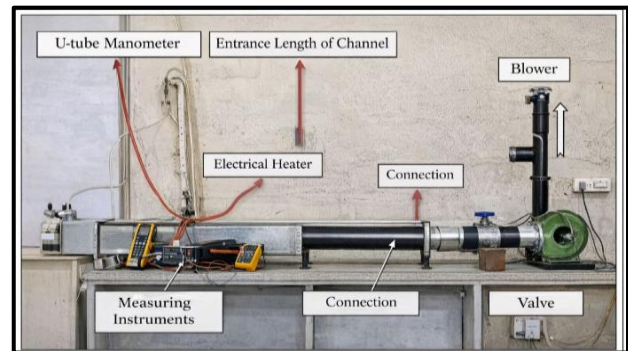
Used analytical and numerical methods to study mixed convection in a heated horizontal cylindrical duct. Infrared thermography was used to experimentally estimate the wall temperature. The results demonstrate that a secondary flow has been hydrodynamically established, with two transverse rollers that rotate counter-clockwise. In addition, a rise in the average temperature of is indicative of the thermal establishment. the cylinder wall. have shown the increase in heat exchange and the appearance of natural convection rolls, related to the establishment of mixed convection inside a non-uniformly heated horizontal tube on its circumference [20].

3. Experimental System and Procedure

The experimental facility in Figs. 1,2, in used in the present work was developed and built. All parts of the system were designed and assembled with attention to secure fastening between mated parts and for reduced to air leak during working. The section is a square air duct with an internal height of 0.12 m, width of 0.12 m, and total length of 0.5 m made of galvanized iron having a wall thickness of 0.5 mm. The channel has a square cross-section and hydraulic diameter of 0.12 m. Airflow in the system is provided by an electric blower by a 150 W single-phase motor with a speed of 3600 rpm. The test section is connected to the blower via a pipe with a diameter of 50 mm. A regulator and control valve are



employed to adjust the airflow entering the square channel to four different flow rates. To measure air



velocity, a digital anemometer is installed at the test section exit. For each operating condition, several reading are taken, and the average value is used to representative air velocity.

Figure 1. an apparatus schematic for the experimental setup

Figure 2. A photograph of the channel with measuring.

3.1 Experimental Procedure

- The electric heater is installed horizontally in the test section.
- The blower and power supply are turned on, and the system is stabilized.
- The chamber aperture is four-plexed in the desired position.
- For each chamber opening, five voltage (V) and current (I) readings are measured.

- The air temperature (T_a) and the temperature difference (ΔT) are measured step by step every short time for each electrical input.
- The pressure drop (ΔP) is controlled by a Pitot tube at various levels.
- The chamber is opened and closed five times, and all measurements are repeated.

3.2 Equipment Used

The experiments were performed on a measuring and control system that was developed to obtain reliable, accurate data. The essential apparatus employed in the experiment can be briefly described as follows:

1. Horizontal Cylinder

The metallic test specimen was a horizontal cylinder. Forced convection heat transfer in cross-flow air was studied against this controlled surface.

2. Electrical Resistance Heater

An electric inside cylindrical heater was installed inside the cylinder to supply a uniform and constant heat flux during the test. Cold chamber heating was employed to keep the temperature constant, as required for accurate heat transfer analysis.

3. Blower (Air Fan)

Forced air flow over the horizontal cylinder was created using a centrifugal blower. The velocity of air was regulated by the speed of the blower, so that the various type of forced convection can be studied.

4. Air Duct (Test Section)

The air flow was directed smoothly over the cylinder by means of a horizontal tunnel. The duct guaranteed a clear direction of the air flow and reduced the flow disturbances.

5. Thermocouples

Thermocouples were placed at and along the surface of the cylinder to monitor surface temperature. Approximately 4 to 6 Thermocouples are used. More thermocouples in the air flow were used to measure the temperature of the ambient air.

6. Anemometer

Air velocity upstream of the test section was measured by an anemometer, which ensured the free-stream velocity values to be accurate.

7. Power Supply and Wattmeter

The heater was connected to a regulated power source. Voltage, current, and electrical power input were recorded during the experiment using a wattmeter.

8. Temperature measurement

The temperature measured by using the thermocouple channels was recorded on digitized temperature monitor or data acquisition system.

4. Result and Discussion

4.1 Calculation procedure

The same approach was applied to the current experimental implementation we present. Based on the measured electrical and thermal profiles of each experiment, the convective heat transfer coefficient and dimensionless parameters were calculated. The electrical power of the interior heater for the horizontal cylinder is estimated from :

$$Q = I * V = hA (T_w - T_{\infty}) \quad (1)$$

The Reynolds number (based on the diameter of the cylinder) was calculated as follows:

$$Re = \rho v d / (\mu) \quad (2)$$

The Nusselt number was evaluated from:

$$Nu = h d / k \quad (3)$$

For the forced convection about a horizontal cylinder, the experimental data were correlated in empirical form as follows:

$$Nu = C Re^m \quad (4)$$

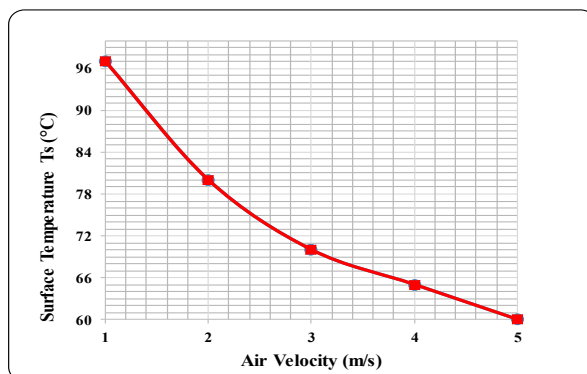
The thermophysical properties of air, such as density, dynamic viscosity, thermal conductivity, and Prandtl's number, were estimated at the mean film temperature and taken from standard sources [21,22]. The film temperature was estimated as

$$T_f = (T_w + T_{\infty}) / 2 \quad (5)$$

This calculation procedure was repeated for all 12 test cases corresponding to different air flow rates and chamber opening conditions.

4.2 Discussing

The Experimental data are presented in fig. 3 showing the variation of surface temperature of a heated horizontal cylinder with air velocity under forced convection conditions. The air velocity was varied in a controlled manner from 1 to 5 m/s to investigate the influence of thermal behaviour of the surface of the cylinder. Air velocity is regarded as the manipulated variable in the test, and it was controlled by controlling the flow rate of the blower. Every selected velocity step was let stabilized so that the measured surface temperature corresponded with the thermal equilibrium between the heat supplied and the heat taken away by convection. The surface temperature of the cylinder was recorded by calibrated thermocouples held closely to the outer side of the cylinder. Data were taken only when the temperature readings reached a stable value with time, signifying that thermal equilibrium had been established. This procedure helps to eliminate the transient effect and then ensures more reliable experimental results. It is clear that the surface temperature reduces with increasing air velocity. At low air velocities, the flow around the cylinder is weak, and this leads to an increased thickness of the thermal boundary layer on its surface. This constrains the heat transfer rate due to convection and allows higher surface temperatures. The flow of the air increases its superseding velocity, and the stronger the intensity of the. Airflow should be more turbulent near to the



cylinder. This leads to the improvement in convective heat transfer by reducing the thickness of the thermal boundary layer and increasing the convection heat transfer coefficient. As a result, more heat is from the cylinder surface and the surface temperature decreases. The drop in surface temperature is greater at the lower air velocity, and for the higher air velocities, a smaller fall in temperature occurs. Such behavior can be

explained by decreasing efficiency of convective cooling at higher flow velocities, as known from the forced convection heat transfer theory.

Figure 3. the effect of air velocity on the surface temperature of heated cylinder

The influence of air velocity on the temperature difference between the surface of a heated cylinder and surrounding air in forced convection conditions is presented in fig. 4. The temperature difference is the difference between the cylinder surface temperature and the free stream air temperature. In the figure above, the temperature difference decreases consistently as air velocity increases. For a low air velocity of about 1 m/s, the maximum value of temperature difference was achieved, showing a high thermal gradient between the cylinder surface and the surrounding air. This is equivalent to the weakened convective cooling, which means heat removal from the surface is scarce around low air intensity. As the air speed increases, the flow around the cylinder becomes stronger and more turbulent. This serves to improve the forced convection heat transfer by minimizing the thickness of the thermal boundary layer that grows over the surface of the cylinder. Consequently, the convective heat transfer coefficient is increased, and the cylinder surface exchanges heat with THE air better. This results in the reduced ΔT at a higher air velocity. It can also be seen from the figure that at lower air velocities, the decrease in temperature difference is more obvious. An almost sharp reduction of the temperature difference caused by an initial increment in air velocity, but this reduction tends to occur more gradually with further increase of air velocity. Indeed, such a tendency indicates that the enhancement for convective heat transfer is exhausted at high flows, as is known from classical forced convection theories. In general, this figure verifies that the velocity of air has a significant effect on governing the heat temperature distribution in the heated cylinder. Forced convection condition: The higher air velocity creates more convective heat transfer, resulting in a lower temperature difference between the surface and the ambient air with an improved overall heat removal efficiency.

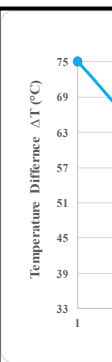


Figure 4. effect of air velocity on the temperature difference of forced convection conditions.

Fig. 5 demonstrates the variation of convection heat transfer coefficient with the air velocity for the forced convection along a horizontal cylinder. The controlled operating parameter is the air speed, and here, the heat transfer coefficient provides an indication of the thermal response. It can be seen in the figure that the heat transfer coefficient first increased with air speed in incremental linear response. At low air speed, approximately 1 m/s, it can be seen that a lack of flow momentum and a narrow range turbulent at the surface of the cylinder brings about weak convective heat transfer due to a minimum value in the convection heat transfer coefficient. The flow over the cylinder is more violent and turbulent at a higher air velocity. This further reduces the thickness of the thermal boundary layer on the cylinder wall. Hence, the heat transfer resistance decreases as the convective heat transfer coefficient increases. The observed non-linearity in the graph suggests this tendency, that there is an abrupt raise for heat transfer coefficient when air velocity increases from 1 to 3 m/s. The heat transfer coefficient increases with the air speed, and at higher speeds, it will still increase, but at a slower rate. This variation can be attributed to a decrease in the level of augmentation observed with higher flow rates. While turbulence and mixing are increased, the thermal boundary layer is already thin, which means that an increase in air velocity yields less of a return for heat transfer. The graph as a whole illustrates very well that for forced convection heat transfer to a horizontal cylinder, air velocity is a dominating parameter. Turbulent air flow, that is the case of high air velocities promote convection heat transfer by increasing turbulence intensity and decreasing thermal resistance at the surface, which will increase the value of the heat transfer coefficient. This trend agrees well with the classical forced convection heat transfer theory and experimental correlations for external flow over cylinders.

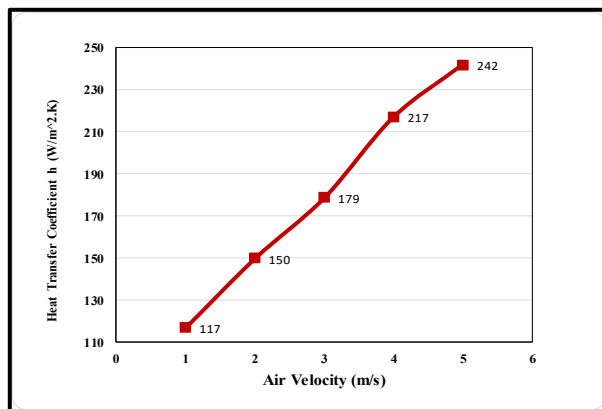


Figure 5. variation of the convective heat transfer coefficient with air velocity for forced convection.

Forced convection over a horizontal cylinder: Fig. 6 indicates that the Nusselt's number increases with an increase in Reynold's number, as seen for flow over a horizontal cylinder. Larger Reynold's numbers correspond to more intense flow, leading to a thinner thermal boundary layer and a decrease in fluid mixing near the surface. This causes enhancement of convective heat transfer and an increment in Nusselt's number values. The pattern, which is the result of the strong influence of flow rate on heat transfer in forced convection, is consistent with classical heat transfer theory and equation sets for external flow over cylinders.

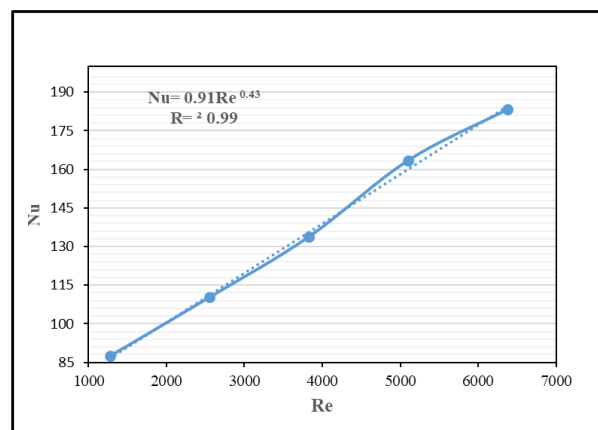


Figure 6. Nusselt Number & Reynolds Number for Forced Convection.

Fig. 7 shows the correlation between (h) and (Q_{total}) for forced convection over a horizontal heated cylinder. The outcomes indicate an evident tendency: the heat transfer performance is enhanced with an increase in the total heat transfer rate. At small (Q_{total}) , less heat is carried away by the airflow from the cylinder surface; therefore, smaller heat transfer coefficient values are obtained. The convection strength increases with increasing (Q_{total}) because there is more wind to carry heat, and the temperature difference between the surface and air is larger. This enhancement decreases thermal resistance near the air/water interface, and it is clear that higher dimensionless temperature varies with high values of (h) . The almost linear trend in the figure demonstrates a very close relationship between the convective heat transfer coefficient and cooling rate. This indicates that the convective heat transfer performance increases with the growth in the total heat transfer rate, which is in accordance with forced-convection heat transfer theory and experimental results.

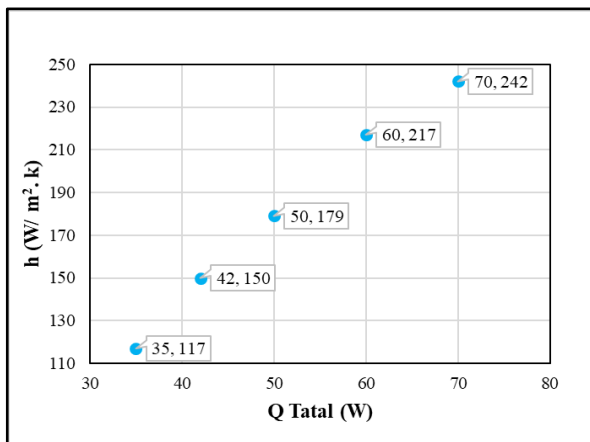


Figure (7): effect of total heat transfer rate on heat transfer coefficient.

Conclusions

From the experimental results shown in figures, the heat transfer characteristics of the horizontal heated cylinder under a is forced convection may be concluded as follows:

1. The surface temperature and ΔT decrease with an increase in air velocity, which represents more removal of heat (due to higher forced convection).
2. The heat transfer coefficient (h) rises with the growth of the total heat transmission quantity (Q_{total}), indicating that a larger heat input leads to higher performance convective heat transmission.
3. The Nusselt's number (Nu) increases monotonically with Re , indicating the importance of air flow strength for the convective heat transfer enhancement. Higher Reynold's numbers at higher air velocities lead to a thinner thermal boundary layer and enhanced heat transfer from the cylinder surface.
4. The ($Nu-Re$) and ($h-Q_{total}$) correlations are smooth and well-behaved, showing that we have reliable experimental conditions and good measurements of the average Nusselt's number. As air was a working fluid and temperature differences were not high, Prandtl's numbers can be assumed to be constant across the test.
5. In general, the present experimental results indicate that a is forced convection heat transfer over the heated horizontal cylinder is greatly influenced by increasing air velocity and heat input.

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