Journal of Multi Disciplinary Engineering Technologies
Volume 19, Issue 01
DOI: https://doi.org/10.64992/jmdet.vol.19.issue.1.5

Experimental investigation of heat transfer between two parallel disks

Rakesh Kumar Yadu[1*], Dinesh Kumar Singh[1] and Achhaibar Singh[1]

[1]Netaji Subhas University of Technology, Delhi, India.

*Corresponding author(s). E-mail(s): rakesh.yadu93@gmail.com;
Contributing authors: drasingh@hotmail.com;

Abstract

In the present study, a hundred experiments were performed and analyzed to investigate the effect of heat flux, space between two disks, and flow rate, on heat transfer between two parallel disks. An experimental setup and a spiral coil heater were specially designed to analyze the mentioned parameter's effect on the heat transfer between the two parallel disks. This study analyzed the Nusselt number and discloses its behavior with respect to the change in mentioned parameters. This study shows that the Nusselt number increases with the increase of the flow rate and the space between two disks at a certain level. When heat flux increases, the local Nusselt number's hyperbolic curve goes towards a straight line. This study shows that just after the entrance, there is a point that differentiates the disk into two zones in the first zone local Nusselt number decrease with the increase of heat flux, and in the second zone local Nusselt number increase with the increase of heat flux. After analysis of all cases, according to this study the optimum conditions for heat transfer, $\boldsymbol{g = 17.36, s = 25mm, q = q3 = 605.78W/m^2}$ and $\boldsymbol{Re = Re_5 = 100}$.

Keywords: Heat transfer, parallel disks, Nusselt number, spiral coil heater, rotor-stator system, flow rate

1 Introduction

The behavior of fluid flow and the associated temperature distribution in radially inward, converging flows between two parallel disks remains a significant area of interest in engineering and applied physics. This interest stems from its practical relevance in improving the accuracy of stress predictions, thermal loading, and component durability in rotating machinery such as turbine disks. Effective cooling of such systems necessitates a deep understanding of internal fluid motion and the resulting heat transfer characteristics. Despite advancements in computational modeling, these flow scenarios are highly complex—being influenced by factors such as geometric confinement, rotational effects, turbulent interactions, and heat exchange mechanisms. As a result, experimental investigations often provide more reliable insights than purely numerical simulations in current practice.

Published on: Dec, 2025 ISSN(P) 0974-1771 ISSN(O) 2581-9372

A considerable body of research has addressed thermal transport between disk surfaces. Mochizuki et al. [1], for instance, explored heat transfer behavior in radially flowing air between heated disk pairs. Their findings identified various flow regimes, including steady and periodic laminar as well as turbulent flow, and revealed that the Nusselt number scaled with Reynolds number raised to exponents near 0.5 and 0.8, depending on the regime. Meanwhile, Jones and Launder [2] formulated a general model capable of predicting energy dissipation and swirling flow characteristics induced by rotating disks. This model supports analysis of both thermal and mass transport in such configurations.

Suryanarayana and collaborators [3] studied the dynamics of incompressible, radially outward flow between fixed, coaxial disks under turbulent conditions. They utilized a split-film anemometer to record axial and radial velocity components and derived important turbulence characteristics, such as Reynolds stresses and energy spectra. In another study, Prakash et al. [4] numerically modeled heat transfer and fluid behavior between rotating and stationary disks using full Navier–Stokes equations, observing the development of complex recirculatory patterns at both inlet and outlet regions under rotational influence.

Garcia [5] employed a hot-wire anemometer to examine unsteady airflow in both inward and outward radial directions. His work, which incorporated a cylindrical wave equation solution, highlighted that seemingly stable flow fields could become unstable when boundary inputs changed rapidly. Sim and Yang [6] performed theoretical evaluations on laminar heat transfer between co-rotating disks, emphasizing the influence of system geometry, Prandtl number, and rotational Reynolds number on overall thermal performance.

Moretti and Kays [7] contributed by experimentally investigating how non-uniform external flow speeds affect turbulent boundary layers, developing empirical correlations using a superposition method to estimate heat transfer under variable surface temperatures. Singh [8] derived mathematical formulations for pressure and velocity profiles in systems containing both co-rotating and counter-rotating disks. His results suggested that the velocity field becomes parabolic when both disks rotate at the same speed and attributed energy losses to a combination of friction and inertial effects within the flow.

Other researchers have directed attention toward turbulence-dominated regimes. Tabatabai and Pollard [9] examined radial flow behavior under both high and low Reynolds numbers. They discovered that turbulence became more two-dimensional at high Reynolds values, while the flow began transitioning toward laminar conditions as Reynolds numbers decreased. In a separate experimental investigation, Cheah et al. [10] used three different diagnostic methods to measure mean and fluctuating velocities at various radial points. For a disk cavity with an aspect ratio of 0.127, and across a wide Reynolds number range (3.0310^6 to 1.610^6), they found that lower rotation speeds promoted a laminar flow regime.

At reduced rotational speeds and low Reynolds numbers, the airflow within the disk cavity tends to transition into a laminar state. Computational investigations focused on such low Reynolds number flows have been conducted by Hector Lacovides and his team [11], aiming to analyze turbulence transport under various conditions. Their simulations covered scenarios including rotor-stator systems both with and without throughflow, as well as cases involving radial outflow and both co-rotating and counter-rotating disks.

Ong C.L. and Owen J.M.[12] developed numerical solutions for the governing differential equations in turbulent flow using both the Cebeci–Smith method and the Keller box scheme. Their analysis computed parameters such as Nusselt number, rotational velocity, and temperature distribution across different flow rates in thermally loaded rotating cavities. In a separate study, Morse A.P. and Ong C.L.[13] employed the finite difference method to estimate both average and local Nusselt numbers using a turbulence model. They applied an elliptical computational approach tailored for radial outward flows with low Reynolds number turbulence modeled via the $k - \epsilon$ framework. Their predicted Nusselt values were found to be within 10% of the experimental observations.

Djaoui M. and Debuchy R. [14] studied turbulent flow behavior while neglecting compressibility effects. They introduced a methodology that allows simultaneous measurement of velocity and temperature, presenting both qualitative and quantitative datasets. Bayley F.J. and Owen J.M. [15] explored how additional radial flow influences rotor–stator systems. Their numerical model integrated boundary layer equations with overall fluid motion, and comparisons were made between computed and experimental data at high rotational speeds, specifically $4000rpm$, to assess radial pressure and drag forces.

Further computational analysis was carried out by Sorour M.M. and Fayed M. et al. [16], who focused on the heat transfer and fluid dynamics in systems with two stationary parallel disks having ribbed surfaces. Their simulations highlighted the role of induced swirling flows on both heat transfer efficiency and thermo-hydraulic behavior. Additionally, Owen J.M., Pincombe J.R., and collaborators [17] examined axisymmetric flow behavior in rotating cavities with both radial inward and outward components. These investigations were grounded in momentum theories originally developed by Von Kármán and further extended using models proposed by Hidein Pater L.L. and Crowther E. [18]. Their experimental work included studies of incompressible Newtonian fluids moving between co-rotating disks under both inflow and outflow conditions. The resulting data covered both laminar and turbulent regimes across a wide flow range, offering insights valuable for designing rotating thermal systems such as pumps and turbines.

Despite numerous investigations into rotating flow systems, earlier research largely neglected comprehensive analysis of heat transfer between two disks. Many critical parameters influencing thermal performance were either simplified or excluded entirely. The present study addresses this gap by identifying and experimentally analyzing three primary variables that significantly impact heat transfer behavior between disk pairs:

- Heat flux
- Flow rate
- Gap (spacing) between the two disks

To evaluate these factors, the author conducted and examined data from 100 experimental runs, aiming to determine optimal conditions for maximizing thermal efficiency between parallel disks.

2 Experimental Apparatus and Procedure

In the Mochizuki [1] experiment, an electrically conductive plastic film was utilized to measure heat transfer. However, the experiment did not account for the various materials used in the different parts of industrial devices and machines, which have their own properties. Therefore, the findings of the Mochizuki experiment are not entirely applicable to industrial machines. Consequently, this current study focuses on the use of aluminum surfaces as heat transfer surfaces. Aluminum is widely employed in the industrial sector, thus rendering the results of this study more applicable and pragmatic for industrial machines. The symbols and parameters used in the present study are summarized in Table 1.

For the experiment, the two aluminum disks were arranged in a coaxial and vertical orientation facing each other. One of the disks was designed with a 160 mm center hole, while both disks had an outer diameter of 434 mm as determined in Mochizuki's [1] experimental work. In previous studies of heat transfer between two disks, only one disk was heated, and no author considered the scenario where both disks had a heating effect. However, in practical devices such as disk heat exchangers, it is not fully applicable to consider only one disk as the heating. Therefore, the present study aimed to investigate the heat generation conditions for both disks.

Producing a steady and evenly distributed heat source in a setup involving two heated disks is a technically demanding task. To address this issue, a custom-built dual-spiral coil heater was developed, capable of delivering uniform and regulated heat flux to the disk surfaces.

Two-spiral coil heater: The spiral-shaped heater constructed for this experiment was intended to maintain consistent surface temperature across the disk. It features an outer diameter of $434mm$, an inner diameter of $160mm$, and a thickness of $8.5mm$. The heater consists of a Nichrome wire coil as the heating element, a cellulose fiber cement board (CFCB) for structural support, and a mica sheet to help ensure even heat dispersion over the disk.

To ensure uniformity, spiral grooves with dimensions of $7mm7mm$ (width and depth) were machined into the CFCB, and two spiral channels were curved into its surface. The wire coils are connected to electrodes positioned at the outer and inner radii. Heat is generated by directing an electric current from the outer edge toward the center of the coil, with the input voltage being modulated through a variac (auto variable transformer).

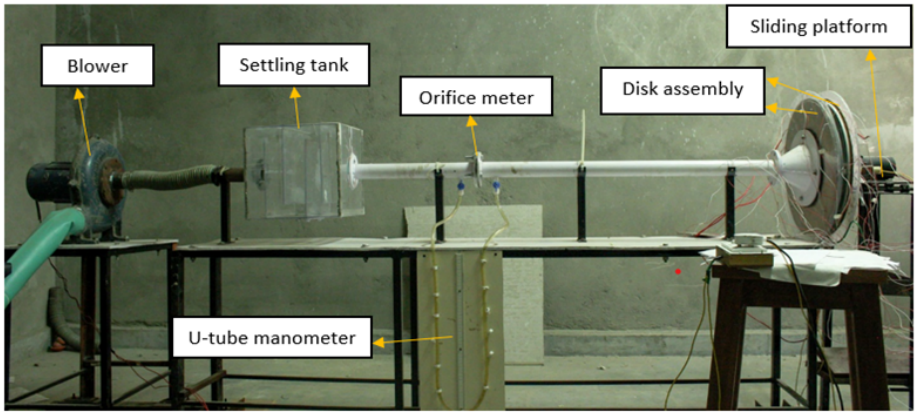


Fig. 1: Experimental set-up

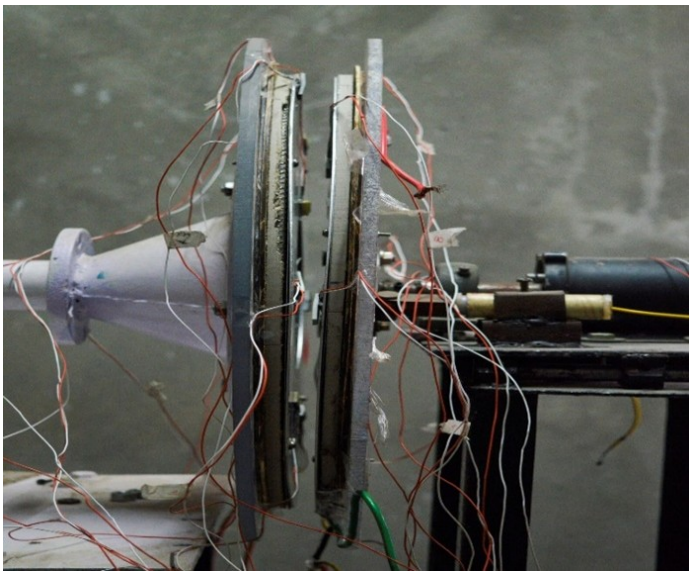
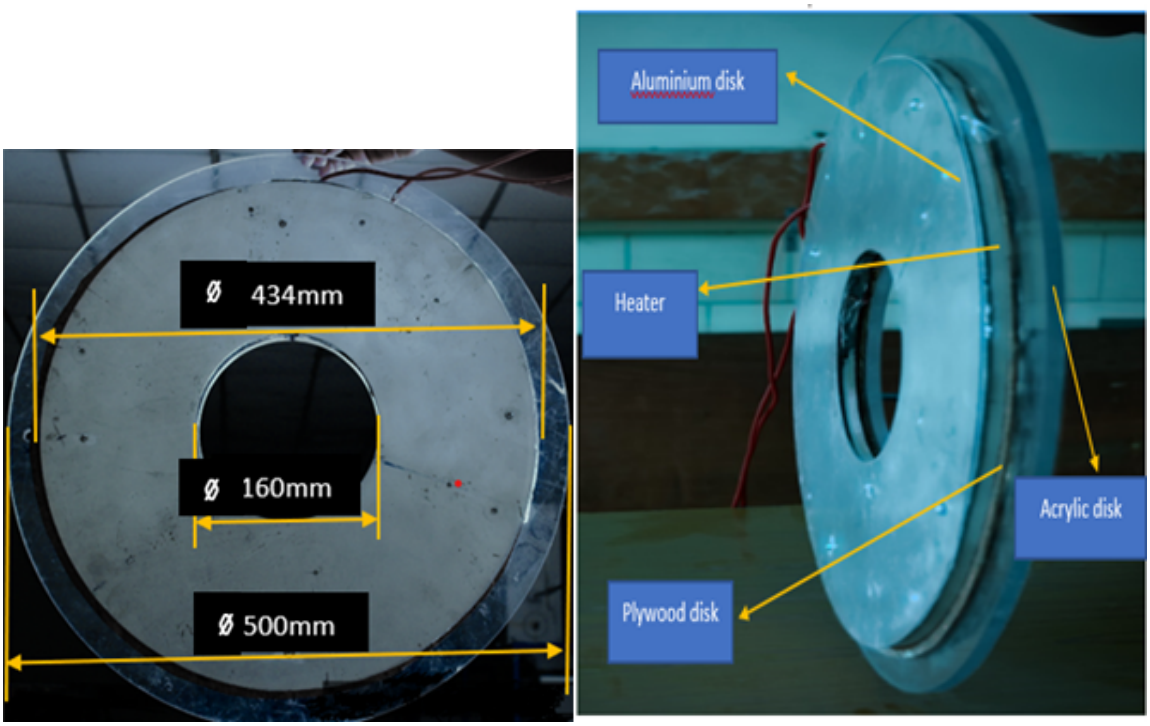


Fig. 2: Position of Disk Assembly1 and Disk Assembly2

The disk assembly is an assembly of acrylic disk, plywood disk, aluminium disk, and spiral coiled heater.



(a) (b)

Fig. 3: Disk Assembly1

$$q = \frac{I^2 R}{\pi \left(r_1^2 - r_2^2\right)} \tag{1}$$

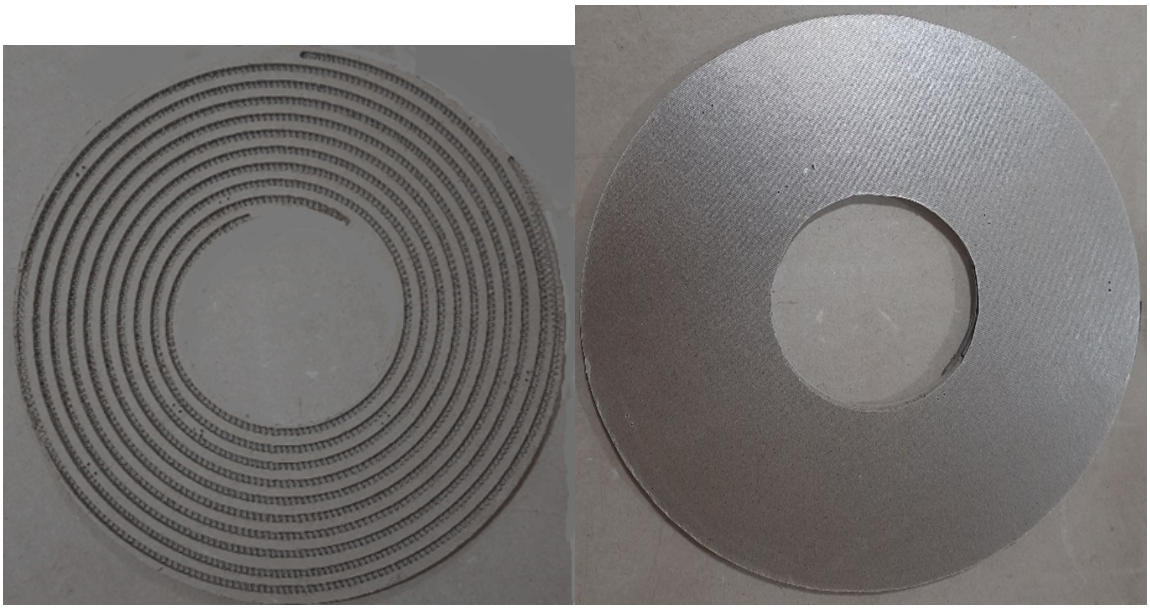
Eq. (1) is for calculation of the heat flux in W/m^2.

Fig. 2 also illustrates the experimental setup, which includes two disk assemblies. Each disk features a spiral coil heater mounted on the heating surface of an aluminum plate. The opposite face is insulated from thermal losses using a combination of plywood and acrylic disk layers. While the plywood and aluminum disks share identical diameters, the acrylic disks have a diameter of $500mm$ and a thickness of $8.9mm$. The aluminum disks, being 1.8 mm thick and having a high thermal conductivity of $247W/mK$, help minimize heat loss along the disk edges. Thus, it can be reasonably concluded that thermal losses at the back and edges are negligible.

The heater operates on alternating current (AC) and is regulated by a variable autotransformer capable of delivering up to $270V$. This setup allows precise adjustment of the heat output or flux. With this heater, a maximum temperature of up to $120C$ above ambient conditions can be achieved.

One of the disk assemblies is linked to a $50mm$ diameter pipe through a conically shaped funnel, designed to guide airflow smoothly and avoid sudden directional shifts. An orifice meter is mounted $950mm$ downstream on the pipe, with a U-tube manometer used to gauge pressure differentials. To stabilize airflow and reduce fluctuations caused by blower irregularities, a settling chamber measuring $300mm \times 300mm \times 300mm$ is placed $1350mm$ upstream of the disk. This chamber is connected to the blower through a flexible pipe, which helps absorb any vibrations generated during operation.

Another disk assembly is mounted on an independently movable sliding platform, allowing for controlled forward and backward adjustment. The experiment took place under stable laboratory conditions, with minimal disturbance in ambient air movement and temperature. Air was directed from the outer edge inward toward the center of the disk pair, transferring heat during its passage



(a) (b)

Fig. 4: Spiral coiled heater

and exiting through the central outlet. Special attention was given to the inlet and outlet layout to prevent any recirculation or mixing of incoming and outgoing air. The volumetric flow rate Q was determined with a calibrated orifice meter.

Table 1: Nomenclature

Symbol	Description	Symbol	Description
s	Gap between two disks assembly	Re	Reynolds number
a	Half gap	Nu	Local Nusselt number
g	Gap ratio	Nu_m	Average Nusselt number
d_1	Outer diameter	u	Velocity of air
d_2	Inner diameter	u_m	Average air velocity
r_1	Outer radius	D_h	Hydraulic diameter
r_2	Inner radius	v	Kinematic viscosity
T_a	Air temperature	h	Local convection coefficient
k	Coefficient of conduction	h_m	Average convection coefficient
r	Radial distance	q	Heat flux
r_m	Mean radial distance	T_s	Surface temperature
R_1	Dimensionless radius	CFBC	Cellulose fiber cement board
R_2	Dimensionless radius	Avg.	Average
R	Dimensionless radius		

3 Result and discussion

In this experimental study, the objective was to examine the effect of critical parameters – flow rate, heat flux, and gap ratio – on heat transfer between two parallel disks at very low Reynolds numbers. The selection of these factors was based on their substantial impact on the heat transfer process between parallel disks. The findings of this research can facilitate the optimization of the design and operation of systems that involve heat transfer between parallel disks, particularly in gas turbines, heat exchangers, and many industries.

To evaluate the influence of the aforementioned parameters, a total of 100 experimental trials were carried out. The test section used in these trials consisted of a disk assembly with an inner diameter of $d_2 = 160mm$ and an outer diameter of $d_1 = 434mm$. The gap ratio $g = d_1/s$ was varied across the following values: 86.8, 43.4, 28.93, 21.7, and 17.36. Additionally, the Reynolds number (Re) was adjusted across five distinct values: 60, 70, 80, 90, and 100. The Reynolds number was computed using the relation:

$$Re = \frac{u_m \times D_h}{\nu} \tag{2}$$

In Eq. (2), u_m denotes the mean fluid velocity, D_h is the hydraulic diameter, and ν refers to the kinematic viscosity of the working fluid.

Fig. 6 illustrates the uniform thermal distribution achieved by the spiral coil heater during the experiments. In this setup, RTD sensors were positioned along the radial direction to measure the surface temperature T_w , as shown in Fig. 5. The results confirmed that the heater maintained a consistent temperature profile at any given radial location, under a constant heat flux condition.

The local convective heat transfer coefficient was determined using the following equation:

$$h = q/(T_w – T_a) \tag{3}$$

where q is the heat flux, T_w is the surface temperature of the disk, and T_a is the ambient air temperature. Subsequently, the local Nusselt number was calculated by:

$$Nu = h \times D_h/k \tag{4}$$

where k is the thermal conductivity of the fluid.

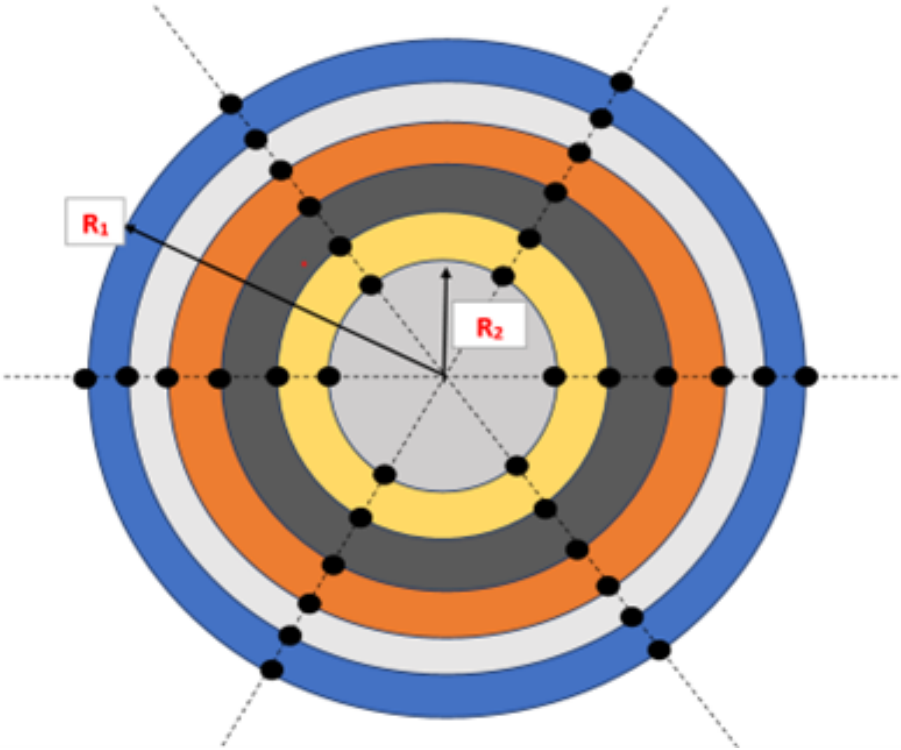


Fig. 5: Position of RTD sensors

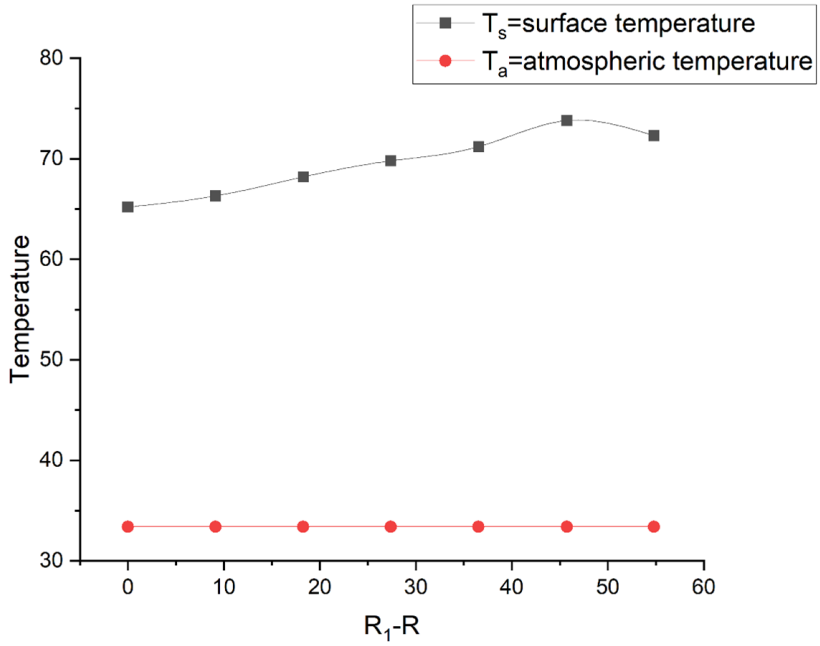


Fig. 6: Temperature distribution profile of heater surface in the radial direction for heat flux of $605.78W/m^2$

In the present study, the local Nusselt number was found to exhibit a consistent trend with respect to the Reynolds number. The graphical representation of this trend, as a function of the Reynolds number, is shown in Fig. 7. The experimental conditions for this graph were a constant heat flux $q = 605.78W/m^2$ and a gap ratio $g = 86$.

The data shows that the Nusselt number reaches its peak at the outer edge (inlet) of the disk and then progressively decreases as the radial coordinate RRR decreases. This behavior can be attributed to the fact that, as air moves toward the center of the disk, it absorbs heat, raising its temperature, and thus reducing the temperature gradient between the surface and the airflow. This results in lower local heat transfer rates. Such a trend aligns with Mochizuki's findings for low Reynolds number conditions.

At the central outlet, the Nusselt number experiences a slight increase. This is likely due to the interaction of the exiting air with ambient atmospheric conditions, causing a slight drop in air temperature, which increases the temperature gradient and enhances heat transfer in that region.

Additionally, the analysis shows that the local Nusselt number rises with increasing Reynolds number. A similar pattern is seen for varying mass flow rates—higher flow rates lead to higher local Nusselt numbers, confirming the direct relationship between convective heat transfer and flow intensity.

The figure illustrates the variation of the Nusselt number along the radial direction as a function of heat flux. The experiment was carried out at a gap ratio$d1/s = g = 43.4$ and a Reynolds number of 70. From the graph, four distinct curves can be identified, each corresponding to a different heat flux level: $q_1 = 194.24W/m^2, q_2 = 387.54W/m^2, q_3 = 605.78W/m^2$, and $q_4 = 824.54W/m^2$.

At the lowest heat flux $q1$, the curve exhibits a sharply declining trend that resembles a hyperbola, indicating that the Nusselt number drops significantly as the measurement point moves from the outer edge toward the center of the disk. As the heat flux increases to $q2, q3$, and $q4$, the curves gradually transition into a more linear form. This suggests that at higher heat flux levels, the distribution of the Nusselt number across the disk becomes more uniform.

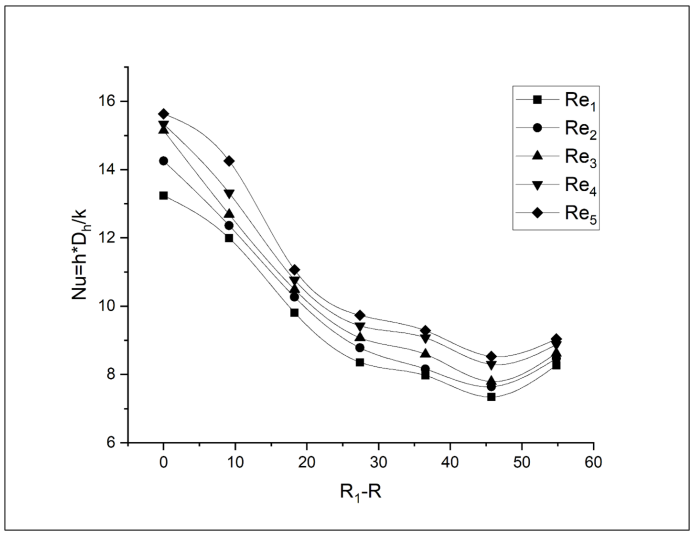


Fig. 7: Variation of Local Nusselt number (Nu–$(R_1 - R)$) as a function of Reynold number

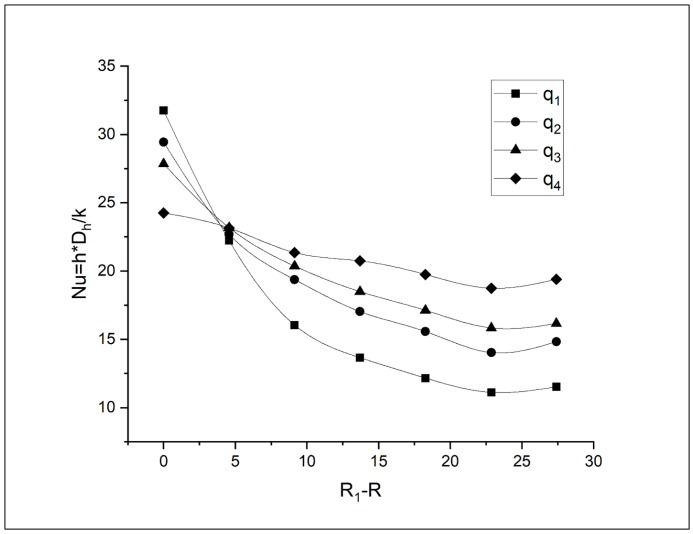


Fig. 8: Variation of local Nusselt number as a function of heat flux

Each curve features a specific intersection point, commonly referred to as the "characteristic point." At this point, the Nusselt number remains unchanged regardless of the heat flux value, indicating thermal stability at that radius. This point effectively divides the disk into two thermal zones: the outer and inner regions.

In the outer region—closer to the disk's boundary—increasing the heat flux has an inverse impact on the Nusselt number. That is, higher heat flux results in a lower local Nusselt number in this zone.

The graph presented in Fig. 9 illustrates the influence of the gap ratio on the local Nusselt number. For a smaller gap ratio ($g = 17.36$), the Nusselt number declines sharply along the radial direction—from the disk's outer edge toward the center. As the gap ratio increases, this rate of decline becomes more gradual. Around a gap ratio of $g = 28.93$, the curve flattens out, indicating that the local Nusselt number distribution has become nearly uniform across the disk.

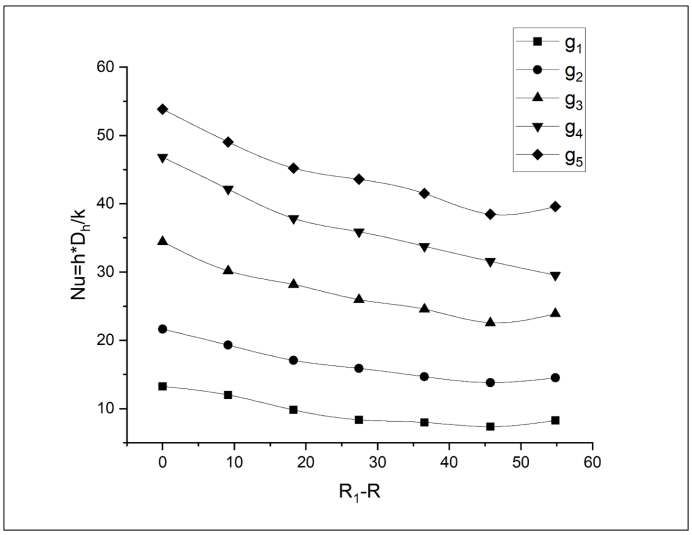


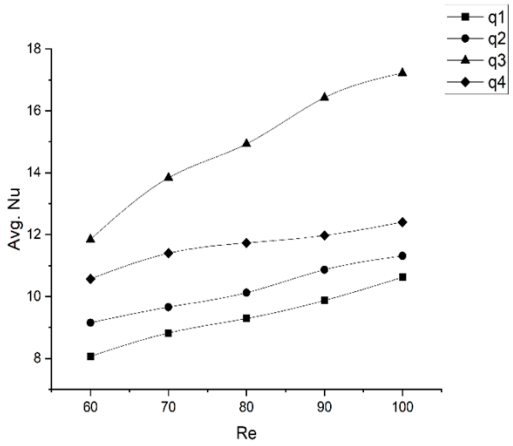
Fig. 9: Local Nusselt number as a function of $g = s/d_1$ gap ratio

The trend further indicates that increasing the separation between the two disks leads to an overall reduction in the local Nusselt number. This reduction is attributed to the separation and weakening of the thermal boundary layer, which reduces the effectiveness of heat transfer by the air moving between the disks. This experiment was performed at constant heat flux $q = 824.54W/m^2$ and $Re = 60$.

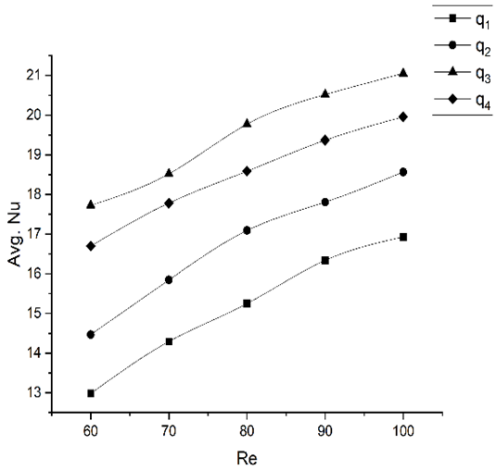
The average Nusselt number for the complete test section,

$$h_m = \frac{2h}{r_1^2 - r_2^2} \int_{r_2}^{r_1} r \, dr \tag{5}$$

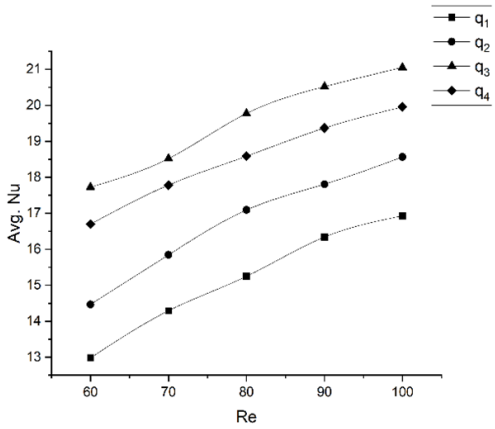
This study examined the impact of flow rate, heat flux, and gap ratio on the transmission of heat between two discs. To determine the local and average Nusselt number for each case, 100 cases were examined. The average Nusselt number for all 100 cases is shown in Fig. 10.


q1
q2
q3
q4
Avg. Nu
Re
18
16
14
12
10
8
60
70
80
90
100

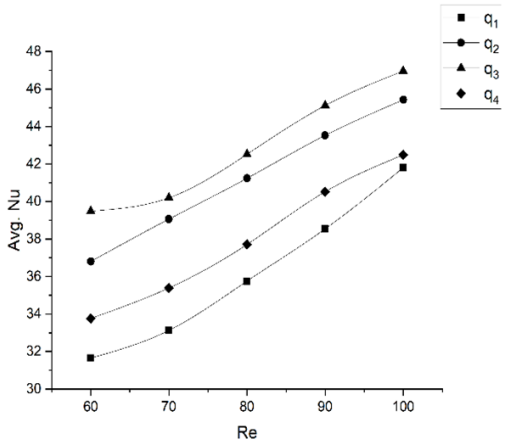
(a)


q1
q2
q3
q4
Avg. Nu
Re
21
20
19
18
17
16
15
14
13
60
70
80
90
100

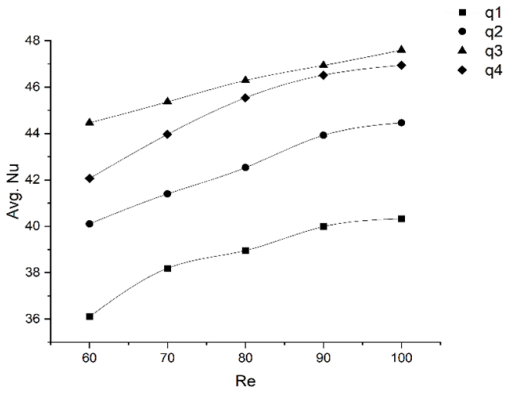
(b)


q1
q2
q3
q4
Avg. Nu
Re
21
20
19
18
17
16
15
14
13
60
70
80
90
100

(c)


q1
q2
q3
q4
Avg. Nu
Re
48
46
44
42
40
38
36
34
32
30
60
70
80
90
100

(d)



(e)

Fig. 10: Average Nusselt number as a function of Reynolds number

The graph in Fig. 10 illustrates the average Nusselt number plotted for five different gap ratios (g). Each curve demonstrates how the average Nusselt number varies with Reynolds number for a given combination of heat flux and gap spacing. The results reveal that, for all gap ratios except $g = 43.4$, increasing the heat flux from q_3 to q_4 results in a reduction in the average Nusselt number.

Fig. 10 also shows that the average Nusselt number consistently increases as the Reynolds number rises. This trend indicates that while increasing flow intensity improves convective heat transfer, raising the heat flux beyond a certain threshold may lead to a decline in average thermal performance.

Among all the cases analyzed, the combination of $g = 17.36, q = q_3 = 605.78 W/m^2$, and $Re = Re_5 = 100$ shows the highest value of the Nusselt number. This indicates that for this particular combination of parameters, the heat transfer between the two disks is most efficient.

4 Conclusion

To investigate the influence of heat flux, flow rate, and gap ratio on heat transfer between two parallel and stationary disks—and to determine the optimal conditions for thermal performance—experiments were conducted and a total of one hundred cases were evaluated. Based on the observations and analyses discussed in the preceding sections, the following conclusions are drawn:

a The Nusselt number increases with Reynolds number, implying that an increase in flow rate enhances the cooling effect.

b A decrease in the gap ratio results in a higher Nusselt number. This indicates that reducing the spacing between the disks improves convective heat transfer efficiency.

c At lower heat flux values, the variation of the local Nusselt number along the radial direction forms a curved profile. However, as the heat flux increases, the distribution becomes more linear, suggesting that at higher heat flux levels, the Nusselt number remains nearly constant across the disk surface.

d The study identifies a specific radial position near the entrance where the Nusselt number becomes insensitive to further increases in heat flux. This location effectively divides the disk into two thermal regions. In Zone 1 (near the periphery), an increase in heat flux leads to a reduction in the local Nusselt number, whereas in Zone 2 (closer to the center), the Nusselt number increases with heat flux. In other words, higher heat flux reduces convective heat transfer in the outer zone while enhancing it in the inner zone.

Declarations

- The authors received no specific funding for this study.
- The authors declare that they have no conflicts of interest to report regarding the present study.
- No Human subject or animals are involved in the research.
- All authors have mutually consented to participate.
- All the authors have consented the Journal to publish this paper.
- Authors declare that all the data being used in the design and production cum layout of the manuscript is declared in the manuscript.

References

[1] Mochizuki, S., Yang, W.-J.: Local heat-transfer performance and mechanisms in radial flow between parallel disks. Journal of Thermophysics and Heat Transfer **1**(2), 112–116 (1987)

[2] Jones, W.P., Launder, B.E.: Prediction of relaminarization with a two-equation model of turbulence. International Journal of Heat and Mass Transfer **15**, 301–314 (1972)

[3] Ervin, J.S., Suryanarayana, N.V., Ng, H.C.: Radial turbulent flow of a fluid between two coaxial disks. ASME Journal of Fluids Engineering **111**, 378–383 (1989)

[4] Prakash, C., Powle, U.S., Suryanarayana, N.V.: Analysis of laminar flow and heat transfer between a stationary and a rotating disk. AIAA Journal **23**(11), 1666–1667 (1985)

[5] Garcia, C.E.: Unsteady air flow between two disks at low velocity. Proceedings of the Institution of Mechanical Engineers **184**, 913–923 (1969)

[6] Sim, Y.S., Yang, W.J.: Numerical study on heat transfer in laminar flow through co-rotating parallel disks. International Journal of Heat and Mass Transfer **27**(11), 1963–1970 (1984)

[7] Moretti, P.M., Kays, W.M.: Heat transfer to a turbulent boundary layer with varying free stream velocity and varying surface temperature: An experimental study. International Journal of Heat and Mass Transfer **8**, 1187–1202 (1965)

[8] Singh, A.: Theoretical investigation on inflow between two rotating disks. Journal of Fluids Engineering **139**(11), 111202–11112027 (2017)

[9] Tabatabai, M., Pollard, A.: Turbulence in radial flow between parallel disks at medium and low reynolds number. Journal of Fluid Mechanics **185**, 483–502 (1987)

[10] Cheah, S.C., Iacovides, H., Jackson, D.C., Ji, H., Launder, B.E.: Experimental investigation of enclosed rotor-stator disc flow. Experimental Thermal and Fluid Science **9**, 445–468 (1996)

[11] Iacovides, H., Nikas, K.S., Te Braak, M.A.F.: Turbulent flow computations in rotating cavities using low-reynolds-number models. In: International Gas Turbine and Aeroengine Congress (1996)

[12] Ong, C.L., Owen, J.M.: Prediction of heat transfer in a rotating cavity with a radial outflow. ASME Journal of Turbomachinery **113**, 115–122 (1991)

[13] Morse, A.P., Ong, C.L.: Computation of heat transfer in rotating cavities using a two-equation model of turbulence. ASME Journal of Turbomachinery **114**(1), 247–255 (1992)

[14] Djaoui, M., Malesys, A., Debuchy, R.: On the experimental evidence of the sensitiveness

of rotor–stator flows with regard to peripheral boundary conditions. Comptes Rendus de l'Académie des Sciences, Series IIB **327**(1), 49–54 (1999)

[15] Bayley, F.J., Owen, J.M.: The flow between a rotating and a stationary disk. Aeronautical Quarterly **20**(4), 333–354 (1969)

[16] Sorour, M.M., Fayed, M., El-Din, N.A.: Heat transfer enhancement in a radial turbulent sink flow cooling system. Journal of Thermal Science and Engineering Applications **11**(3), 031003–031013 (2019)

[17] Owen, J.M., Pincombe, J.R., Rogers, R.H.: Source–sink flow inside a rotating cylindrical cavity. Journal of Fluid Mechanics **155**, 233–265 (1985)

[18] Pater, L.L., Crowther, E., Rice, W.: Flow regime definition for flow between corotating disks. ASME Journal of Fluids Engineering **96**(1), 29–34 (1974)