Impact of Corner Modification and Cylinder Spacing on Aerothermal Behavior of Heated Square Cylinders

Srikanthshekar K C[1]
Shekarsrikanthkc@gmail.com,
Department of Mechanical Engineering,
P.E.S College of Engineering Mandya

Poorna Chandra[2]
poornachandravtu@gmail.com
Mechanical Engineering Department,
Global Academy of Technology,
Bangalore (Affilated to VTU, Belagavi)

Venuprasad K G[3]
venukrpet@gmail.com
Department of mechanical engineering,
Government polytechnic, Mirle,
Mysuru district.

Vikram C.K[4]
vikramck@pesce.ac.in
Department of Mechanical Engineering,
P.E.S College of Engineering, Mandya

Avinash M[5]
avinashm@pesce.ac.in
Department of Mechanical Engineering
P.E.S College of Engineering, Mandya

Narendra babu B R[6]
narenbabu8@gmail.com
Department of Mechanical Engineering,
VVIET,Mysuru.

This study investigates the flow and thermal characteristics around two heated square cylinders with different corner shapes such as sharp, chamfered and rounded arranged in tandem at spacing ratios (SR) of 2, 4, and 6. Simulations are conducted at Reynolds numbers (Re) of 100 and 200, focusing on pressure distribution, transverse velocity, aerodynamic forces (lift and drag), and convective heat transfer (Nusselt number). Pressure distribution results reveal that sharp-edged cylinders exhibit high fluctuations, while chamfered and rounded edges reduce pressure drag by up to 18%. Transverse velocity profiles show a 25–30% reduction in turbulence intensity for modified corners at SR = 6. Analysis of lift and drag coefficients indicates that increasing spacing and corner smoothing significantly stabilizes aerodynamic forces, with drag coefficient reductions of up to 20% observed for rounded cylinders. Heat transfer evaluation using local Nusselt numbers reveals that closely spaced sharp-edged cylinders enhance peak convective heat transfer by up to 35%, while rounded edges at higher spacing improve thermal uniformity and reduce fluctuation levels by approximately 22%. These findings demonstrate the aerodynamic and thermal benefits of corner modifications and optimal spacing in tandem cylinder arrangements.

1. INTRODUCTION

The thermal performance of heated square cylinders is a crucial aspect in various engineering applications, such as heat exchangers, cooling systems, and electronic devices. The efficiency of these systems often depends on factors like heat transfer rate, thermal resistance, and the ability to dissipate heat. In the context of square cylinders, geometric modifications, such as corner rounding and the distance between cylinders, can significantly impact the thermal behavior. The sharp edges of a square cylinder typically cause flow separation and vortex formation, leading to inefficient heat transfer. Rounding the corners of these cylinders can smoothen the flow around the surface, reducing the adverse effects of flow separation. This alteration can enhance the heat transfer by reducing thermal boundary layer thickness and increasing convective heat transfer. The degree of corner rounding influences the extent of these improvements. The arrangement of multiple cylinders plays an important role in the interaction between the flow and the thermal field. When cylinders are placed closer together, there is a potential for increased interference effects, such as vortex shedding and flow recirculation, which can either enhance or impede heat transfer depending on the specific configuration. On the other hand, increasing the inter-cylinder distance allows for more independent flow patterns and may influence the effectiveness of the heat dissipation process. This study focuses on understanding how both corner rounding and the inter-cylinder distance impact the thermal performance of heated square cylinders. By investigating these factors, it is possible to optimize the geometry and placement of these cylinders for enhanced heat transfer efficiency, which can be applied in various fields such as renewable energy, electronics cooling, and industrial heat management systems.

2. GEOMETRY AND BOUNDARY CONDITIONS

Fig.2: Two square cylinders, corners chamfered and rounded of same size with SR of 2, 4 and 6. In all cases, the upstream cylinder is fixed, and spacing ratios of 2, 4 and 6 are used. The size of the computational domain extends 6.5D from the inlet, top and bottom boundaries and 30D from the downstream cylinder. The boundary conditions for the simulation are as follows: The inlet boundary is defined with a uniform velocity of U=1 and V=0, along with a uniform temperature of 300 K. At the outlet boundary, the gauge pressure is set to zero. Both cylinder surfaces are subjected to a no-slip boundary condition with a temperature of 400 K to represent heated cylinders. Finally, the lateral boundaries (upper and lower) are treated with symmetry boundary conditions, ensuring symmetric flow behavior along these boundaries.

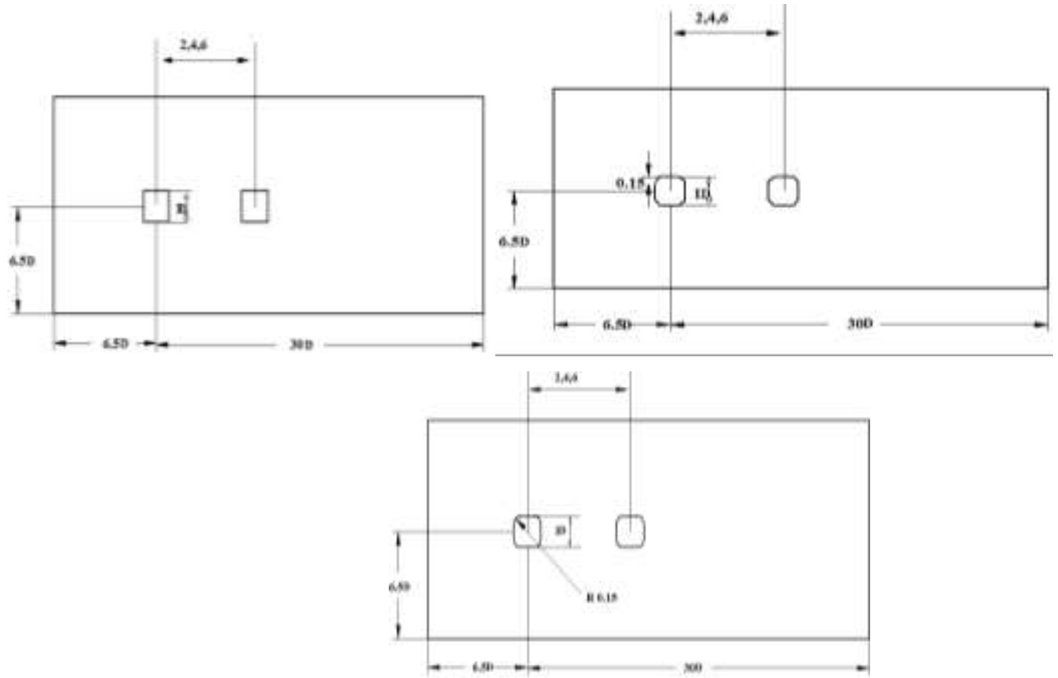


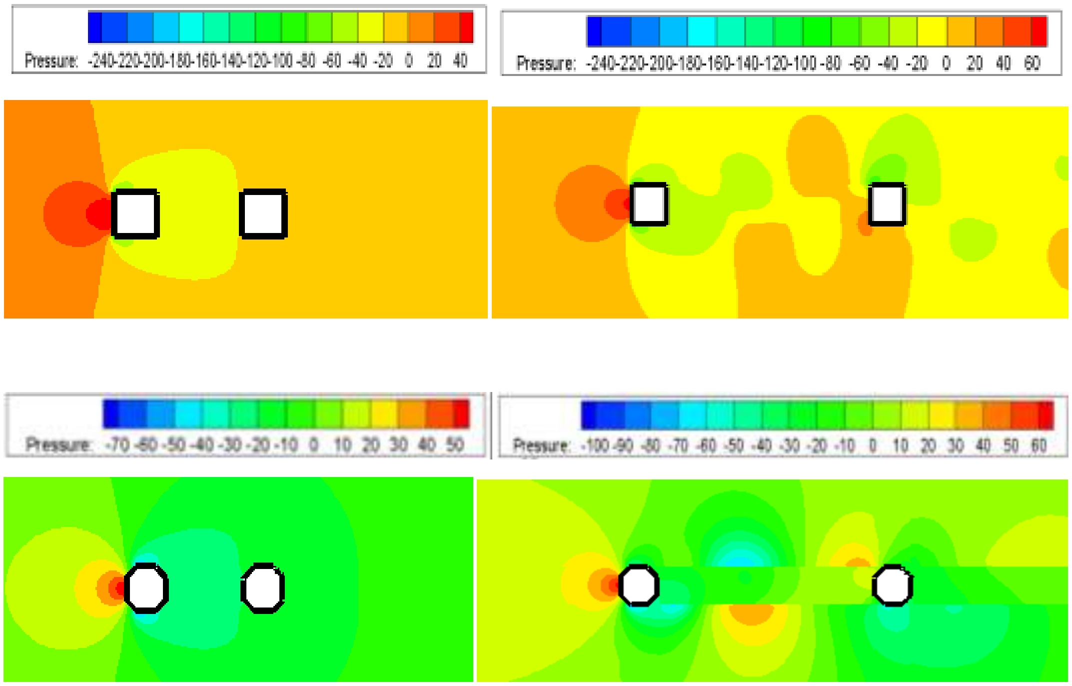
Fig.2: Two square cylinders, corners chamfered and rounded of same size with SR=2,4&6.

3.RESULTS AND DISCUSSIONS

3.1 Pressure Distribution Around Two Heated Square Cylinders with Various Corner Modifications and Spacing Ratios

Fig. 3.1 illustrates the contour plots of pressure distribution around two heated square cylinders with and without corner modifications at spacing ratios (SR) of 2 and 6 for Reynolds number (Re) = 100. The pressure values shown in the contour plots are in Pascals (Pa), as indicated by the corresponding color bars. The inflow temperature is maintained at 300°C, while the cylinders are heated to 400°C, creating a thermal boundary layer that influences the pressure field and flow separation. For square cylinders at SR = 2, a high-pressure zone up to 40 Pa is observed at the front stagnation point of the upstream cylinder, followed by a significant pressure drop as low as –240 Pa at the sides due to boundary layer separation. The downstream cylinder experiences wake impingement, leading to asymmetric pressure distribution and fluctuating low-pressure regions in the wake. These wake interactions result in strong pressure fluctuations, causing unsteady vortex shedding. At SR = 6, the pressure distribution becomes more uniform as wake interactions are reduced. The downstream cylinder experiences less wake disturbance, leading to improved pressure recovery. The pressure drop due to separation occurs slightly later than in the

SR = 2 case, indicating smoother detachment. For chamfered cylinders at SR = 2, the chamfered edges reduce the intensity of flow separation, leading to a more gradual pressure drop ranging from about 30 Pa to –70 Pa at the corners compared to the sharp-edged square cylinders. The downstream cylinder still experiences wake interference, but the pressure fluctuations are lower than in the unmodified square cylinder case. At SR = 6, flow attachment on the chamfered surfaces is improved, leading to a more stable wake. The pressure distribution shows a less steep pressure gradient in the separation region, reducing aerodynamic drag and wake turbulence. For rounded cylinders at SR = 2, the rounded corners promote better flow attachment, delaying flow separation and reducing the sudden pressure drop with minimum values near –60 Pa seen in square and chamfered cylinders. The pressure contours indicate smoother transitions between high- and low-pressure zones, leading to reduced wake turbulence. However, wake interactions between the two cylinders still persist. At SR = 6, wake interference is significantly minimized. The downstream cylinder is almost free from wake effects, resulting in a more uniform pressure distribution. The overall aerodynamic performance is improved due to lower turbulence and pressure fluctuations in the wake region. For all cases under investigation, it can be said that increasing SR to 4 reduces wake interference when compared with SR = 2 and 6. At Re = 200, vortex shedding intensifies, leading to greater wake turbulence and pressure fluctuations.



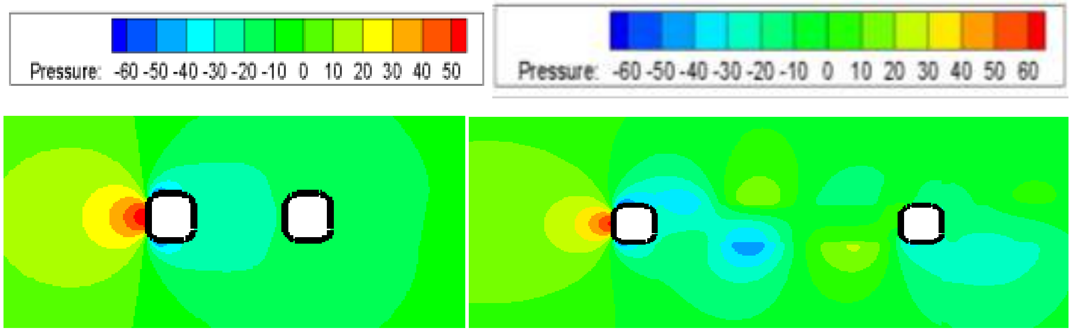
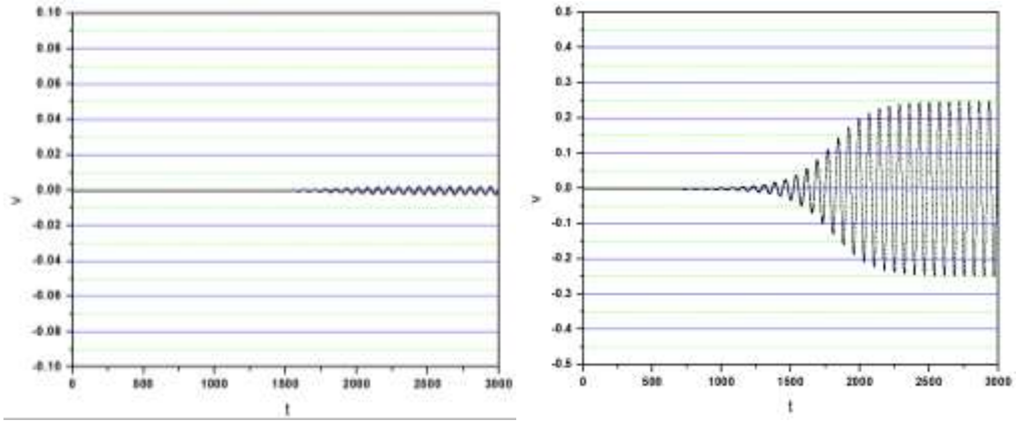


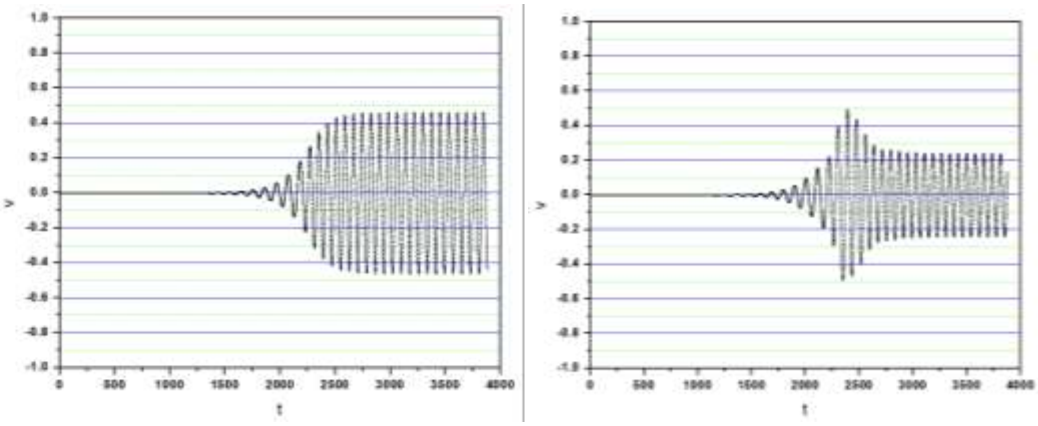
Fig. 3.1: Pressure contour plots around two heated square cylinders with different corner modifications (sharp, chamfered and rounded) at spacing ratios SR = 2 and SR = 6, for Reynolds number Re = 100.

3.2.Effect of Cylinder Geometry and Spacing on Transverse Velocity Fluctuations and Wake Dynamics in Heated Cylinder Arrays at Low Reynolds Numbers

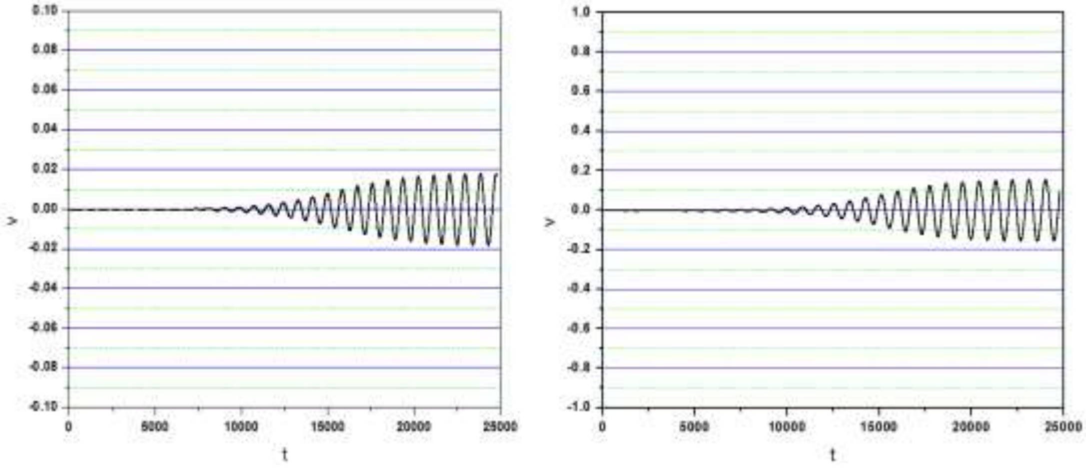
Fig. 3.2(a)–(f) shows the transverse velocity (v_y) plots (in meters per second, m/s) illustrating the variation in velocity fluctuations between and downstream of two heated square cylinders, chamfered cylinders, and rounded cylinders for spacing ratios (SR) of 2 and 6 at Reynolds number (Re) = 100. The inflow temperature is maintained at 300°C, while the cylinder surface temperature is 400°C, generating buoyancy-driven flow effects due to thermal gradients. The results highlight the influence of cylinder shape and spacing on wake turbulence, vortex shedding, and flow stabilization. For square cylinders at SR = 2, the transverse velocity plots show strong oscillations in the wake region with peak fluctuations reaching several m/s, indicating intense vortex shedding and turbulent interactions between the two cylinders. The downstream cylinder is significantly influenced by the wake of the upstream cylinder, leading to asymmetrical and amplified fluctuations. When SR is increased to 6, wake interactions are reduced, and the transverse velocity oscillations become more periodic and structured. The downstream cylinder experiences less interference, resulting in a more stabilized wake with reduced turbulence and more uniform v_y values under ±1 m/s. For chamfered cylinders at SR = 2, chamfering the edges smoothens the flow separation, reducing the intensity of vortex shedding. The transverse velocity fluctuations are less chaotic compared to square cylinders, though wake interference still affects the downstream cylinder. At SR = 6, a larger spacing ratio further minimizes wake disturbances, leading to more uniform oscillations and improved aerodynamic stability. Flow reattachment occurs more smoothly, contributing to a more predictable wake structure. For rounded cylinders at SR = 2, the rounded edges delay flow separation, reducing abrupt changes in transverse velocity. The transverse velocity oscillations are more stable compared to square and chamfered cylinders, with a lower magnitude of turbulence below ±0.5 m/s. When SR is increased to 6, flow stability is further enhanced, and the downstream cylinder is almost unaffected by wake interference, leading to periodic and well-structured velocity variations with minimal turbulence levels. When the spacing ratio is increased to 4, wake interference between the cylinders is further reduced when compared with SR = 2 and 6. When Re is increased to 200, vortex shedding intensifies, leading to stronger wake turbulence and greater pressure and velocity fluctuations for all cases under investigation.



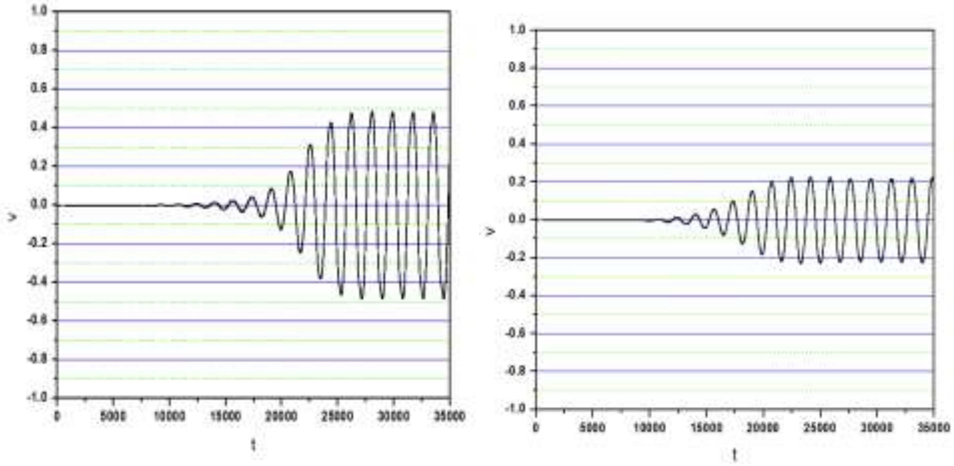
(a) **Square cylinders at SR = 2**



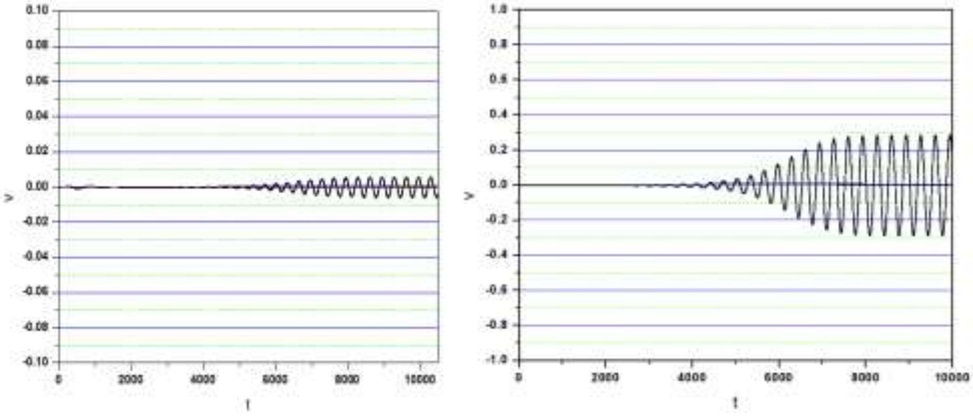
(b) **Square cylinders at SR = 6**



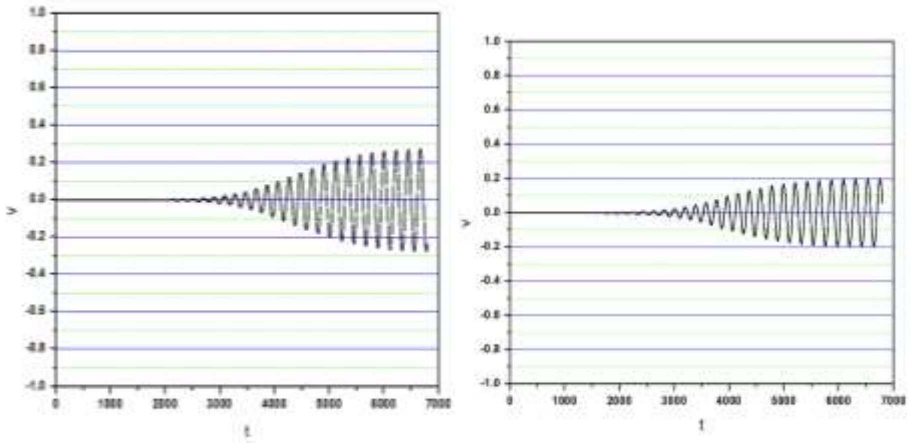
(c) **Chamfered square cylinders at SR = 2**



(d) **Chamfered square cylinders at SR = 6**



(e) **Rounded square cylinders at SR = 2**

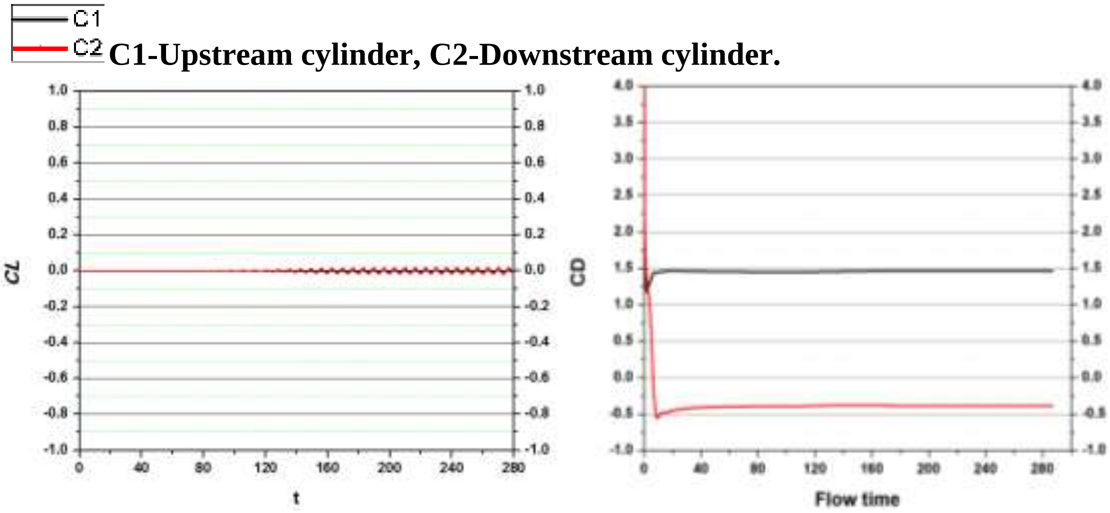


(f) Rounded square cylinders at SR = 6

Fig.3.2(a)-(f): Transverse velocity profiles between and downstream of two heated cylinders with corner modifications (sharp, chamfered and rounded) at Reynolds number Re = 100 and spacing ratios SR = 2 and 6.

3.3 Lift and Drag Coefficients for Two Heated Square Cylinders with Corner Modifications at Spacing Ratios of 2, 4 and 6 for Re = 100 and 200.

Fig. 3.3(a–c) shows the lift and drag coefficient plots illustrating the aerodynamic behavior of two heated square cylinders, chamfered cylinders, and rounded cylinders at spacing ratios (SR) of 2 and 6 for Reynolds number (Re) = 100. The inflow temperature is maintained at 300°C, while the cylinders are heated to 400°C, influencing buoyancy-driven flow effects. The results highlight the impact of shape modification and spacing on wake interference, vortex shedding, and aerodynamic forces. In all subplots, the lift coefficient (Cl) and drag coefficient (Cd) are presented as dimensionless quantities plotted against time (t) in seconds (s), with axis labels clearly marked to ensure consistent interpretation. For square cylinders at SR = 2, the lift coefficient (Cl) of the upstream cylinder remains relatively stable, whereas the downstream cylinder exhibits significant oscillations due to strong wake interference. The drag coefficient (Cd) for the upstream cylinder stabilizes at a higher value, while the downstream cylinder experiences fluctuating drag due to unsteady wake dynamics. The wake-induced vortex shedding causes periodic fluctuations, making the flow more chaotic. However, increasing the spacing ratio to SR = 6 reduces wake interactions, leading to more periodic and structured variations in Cl and Cd. The downstream cylinder experiences a more stabilized flow, with reduced fluctuations in drag and lift compared to SR = 2. For chamfered cylinders at SR = 2, chamfering reduces flow separation effects, leading to lower amplitude oscillations in the lift coefficient. The drag coefficient remains relatively stable compared to square cylinders, indicating reduced aerodynamic resistance. While wake interactions are still present, they are less intense than in sharp-edged square cylinders. At SR = 6, increasing the spacing further reduces wake interference, leading to smoother variations in both lift and drag coefficients. The downstream cylinder experiences more stable aerodynamic forces, contributing to improved flow stability. In the case of rounded cylinders at SR = 2, the rounded edges delay flow separation, leading to lower Cl fluctuations and a more stable Cd. Wake-induced disturbances are minimized compared to square and chamfered cylinders. When the spacing is increased to SR = 6, wake interference is significantly reduced, and the flow around both cylinders remains well-structured, leading to nearly uniform drag and lift variations. When the spacing ratio (SR) is increased to 4, wake interference is further reduced compared with SR = 2 and 6. Similarly, increasing the Reynolds number (Re) to 200 intensifies vortex shedding, leading to stronger turbulence and greater pressure fluctuations. This behavior applies to all cases under investigation, including square, chamfered, and rounded cylinders.



C1-Upstream cylinder, C2-Downstream cylinder.

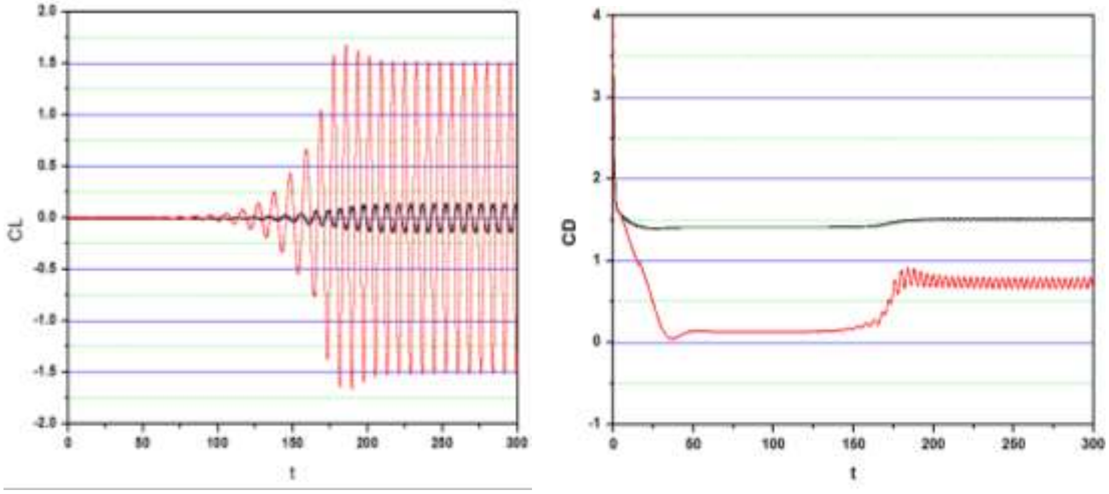


Fig.3.3 (a): Lift & drag coefficients for upstream & downstream square cylinders for Re=100, SR=2 and 6.

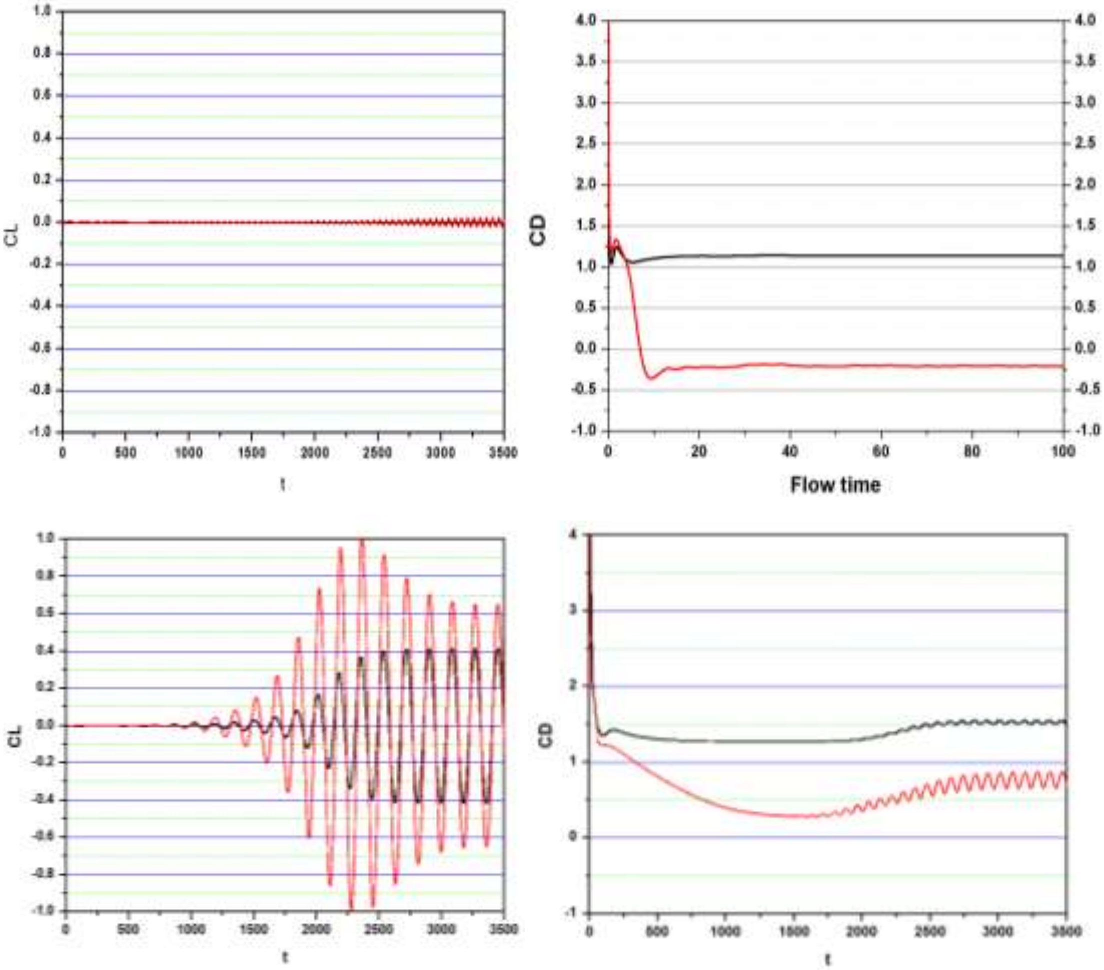


Fig.3.3 (b): Lift and drag coefficient for upstream and downstream of square cylinders with corners chamfered for Re=100, SR=2 and 6.

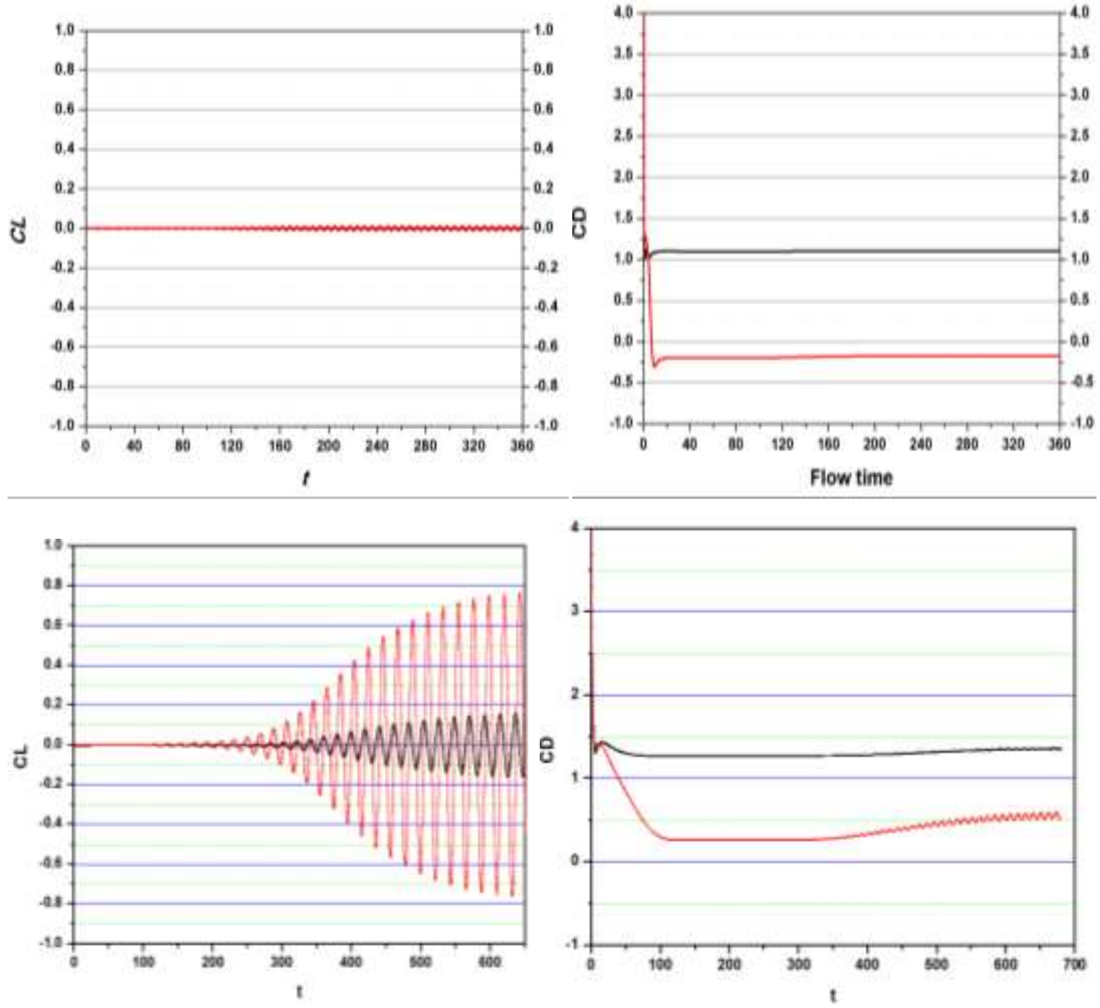


Fig. 3.3(c): Lift and drag coefficient for upstream and downstream cylinder for square cylinders with corners rounded for Re=100, SR=2 and 6.

3.4. Pressure coefficient distribution around two heated square cylinders with corner modifications at spacing ratios of 2, 4 and 6 for Re = 100 and 200

The pressure coefficient distribution (Cp) around the cylinders is presented as a function of the distance along the cylinder surface (x/L) i.e., curve length, where x represents the distance from the stagnation point, and L is the side length of the square cylinder in meters. For square cylinders at SR = 2 (Spacing Ratio 2), the pressure coefficient distribution shows a sharp peak at the front stagnation point (x/L=0), where the flow initially impacts the cylinder. This is followed by a significant drop in pressure along the sides due to boundary layer separation, causing a steep decrease in Cp in the wake region, which indicates vortex shedding and pressure fluctuations. The downstream cylinder experiences wake impingement, leading to an asymmetric pressure coefficient distribution. The wake interaction is stronger at SR = 2, where the cylinders are closer together. At SR = 6 (Spacing Ratio 6), with increased spacing between the cylinders, the wake interaction is reduced, leading to a more symmetric pressure coefficient distribution. The pressure drop occurs later compared to SR = 2, and the downstream cylinder experiences less wake interference, resulting in improved pressure recovery. For chamfered cylinders at SR = 2, the corner modifications lead to a smoother pressure coefficient distribution compared to the sharp-edged square cylinders. The chamfered edges reduce the intensity of boundary layer separation, causing a more gradual drop in Cp along the sides. Although wake interactions are still noticeable, they are less intense than in square cylinders. At SR = 6, with increased spacing, the chamfered cylinders show improved flow attachment, leading to a more stable wake and a smoother pressure drop in the separation region. The pressure coefficient exhibits a more gradual drop compared to square cylinders, indicating smoother detachment of the flow. For rounded cylinders at SR = 2, the rounded edges promote better flow attachment, reducing the sharp drop in pressure coefficient at the separation points. This shifts the separation points further downstream, minimizing wake turbulence. As a result, the pressure coefficient distribution is smoother, and the wake is less turbulent. Despite persistent wake interactions between the two cylinders, the pressure recovery is higher compared to the square and chamfered cylinders. At SR = 6, for rounded cylinders, the wake interactions are minimized, leading to a more uniform pressure coefficient distribution. The flow over the cylinders becomes smoother, reducing pressure fluctuations and vortex shedding intensity. The downstream cylinder is much less affected by the wake of the upstream cylinder. Increasing the Reynolds number to 200 (Re = 200) enhances vortex shedding, making the wake more unstable. This behavior is observed across all cylinder types (square, chamfered and rounded). While the general trend of reduced wake interaction with increased SR still holds, the wake becomes more turbulent at higher Reynolds numbers, leading to stronger vortex shedding and more fluctuations in the wake. This analysis highlights the influence of cylinder shape and spacing on the aerodynamic behavior, with the pressure coefficient distribution and wake interaction being key factors in determining the overall flow characteristics.

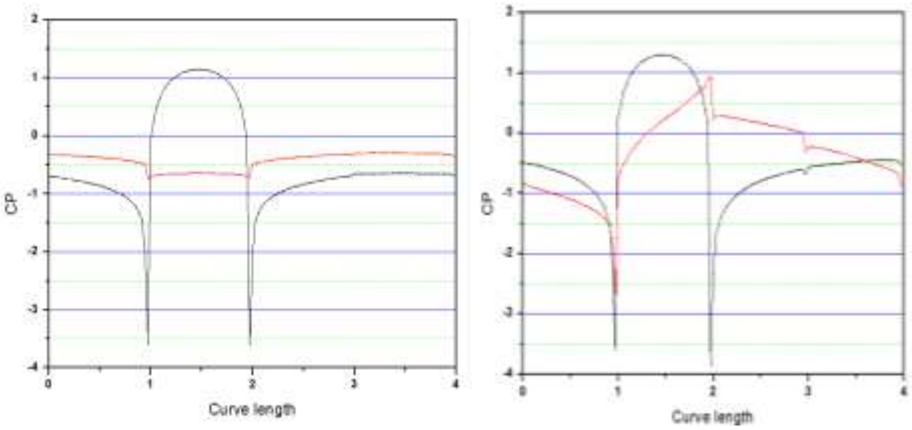


Fig. 3.4(a) shows the pressure coefficient distribution plots around two heated square cylinders without corner modifications for SR = 2 and 6 at Re = 100.

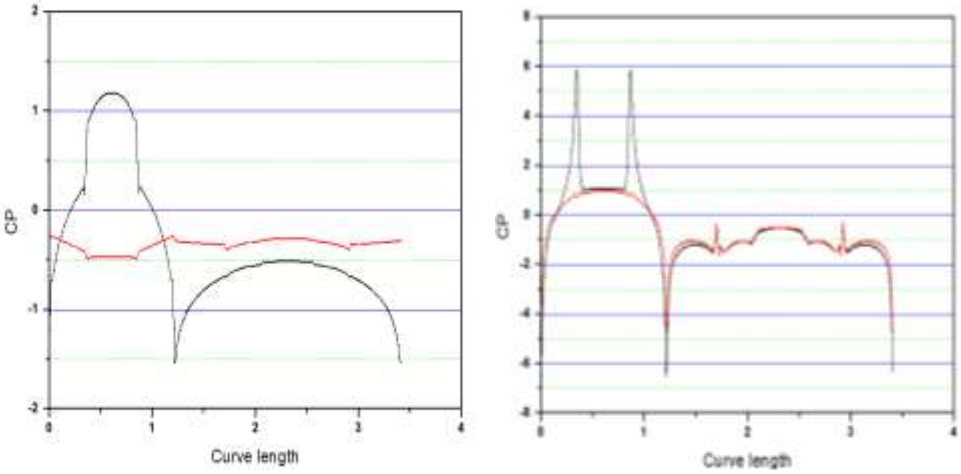


Fig. 3.4(b) presents the pressure coefficient distribution for two heated square cylinders with chamfered corners at SR = 2 and 6 for Re = 100.

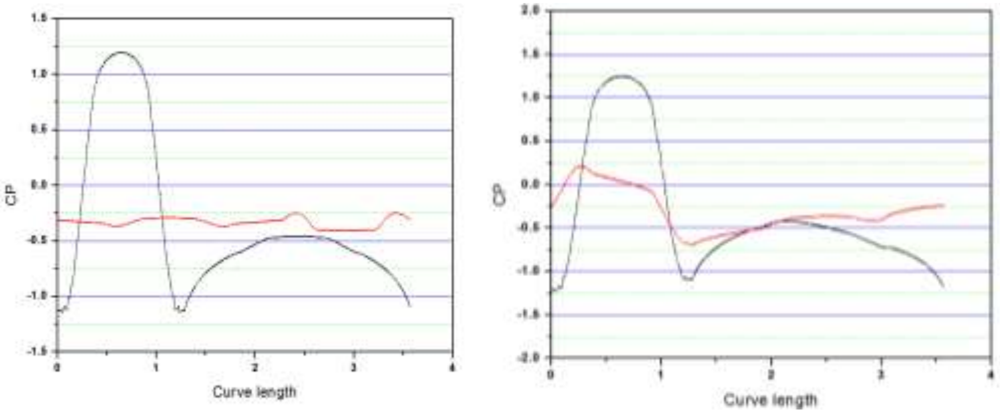
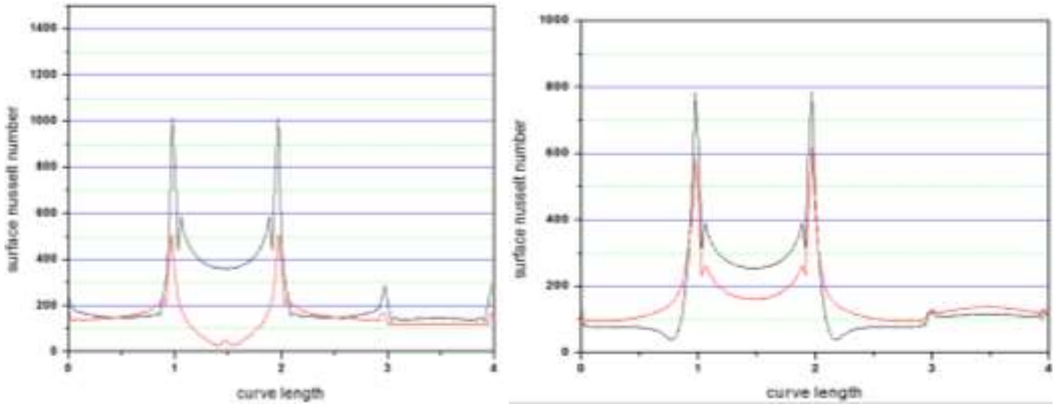


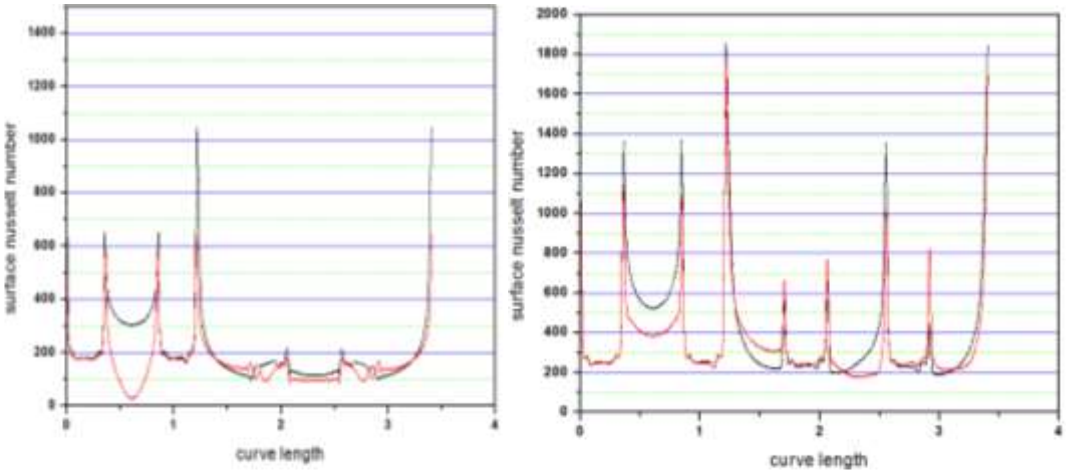
Fig. 3.4(c) illustrates the pressure coefficient distribution for two heated square cylinders with rounded corners at SR = 2 and 6 for Re = 100.

3.5 Variation of local nusselt number on a two heated cylinder surfaces with and without corner modifications for Spacing ratios 2,4 and 6 at Re=100 and 200

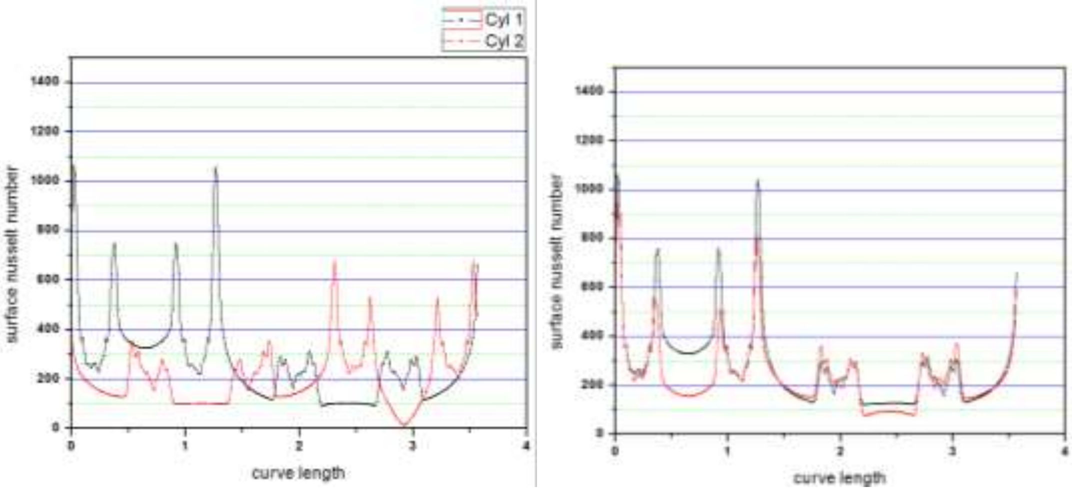
Figures 3.5 (a)-(c) show the distribution of the local Nusselt number (Nu) along the surfaces of both the upstream and downstream cylinders for square, chamfered and rounded cylinders at Re=100. The variation of the local Nusselt number along the surfaces of the two heated cylinders, with and without corner modifications, at spacing ratios (SR) of 2 and 6, shows distinct heat transfer characteristics influenced by wake interactions and vortex shedding. The surface Nusselt number is plotted against the curve length (x/L), where x represents the distance along the cylinder surface from the stagnation point, and L is the side length of the square cylinder in meters. At a lower spacing ratio of SR=2, the cylinders experience strong aerodynamic interference, resulting in intensified flow interactions between the wake and the downstream cylinder. This leads to highly fluctuating Nusselt number distributions, particularly in regions of flow separation and reattachment. The square cylinders show the highest localized Nusselt number peaks due to sharp-edge-induced turbulent mixing, while chamfered and rounded cylinders display relatively smoother variations, suggesting a reduction in sudden vortex detachment and heat transfer fluctuations. When the spacing ratio is increased to SR = 6, the aerodynamic interference between the two cylinders is significantly reduced. The wake of the upstream cylinder has more room to dissipate before reaching the downstream cylinder, leading to a more stable and periodic heat transfer distribution. The Nusselt number peaks become more uniform, and the overall heat transfer is less affected by wake turbulence. The rounded cylinders continue to show the most consistent and steady heat transfer characteristics, while the square and chamfered cylinders still exhibit higher peaks but with reduced intensity compared to the closely spaced configuration. At an increased Reynolds number of Re=200 and a spacing ratio (SR) of 4, the flow becomes more turbulent, leading to enhanced convective heat transfer. This results in higher Nusselt number values across all cylinder geometries. Additionally, at SR = 4, the heat transfer behavior and flow interactions between the two heated cylinders exhibit an intermediate pattern between SR = 2 and SR = 6. While wake interference is still present, it is less severe than at SR = 2, allowing for more stable heat transfer. However, compared to SR = 6, where the cylinders behave almost independently, SR = 4 still experiences some aerodynamic interactions, leading to moderate wake effects and periodic fluctuations in the Nusselt number distribution.



Figs.3.5 (a): Distribution of local nusselt number on the cylinder surface for upstream and downstream square cylinders at Re=100.



Figs.3.5 (b): Distribution of local nusselt number on the cylinder surface for upstream and downstream chamfered cylinders at Re=100.



Figs.3.5 (c): Distribution of local nusselt number on the cylinder surface for upstream and downstream corners rounded cylinders at Re=100.

3.6 Comparison of Strouhal number and Nusselt number for heated square cylinder with experimental and numerical investigations.

Reynolds number	Contributors	St	Nu
Re=200	Ahmad Sohankar ,C. Norberg and L. Davidson[1999]	0.160	-
Re=100 Re=200	Kavya H.P, Banjara Kotresha, Kishan Naik[2014]	0.147 0.119	-
Re=200	A. Sohankar, A. Norberg and L. Davidson[1998]	0.158	-
Re=200	A. K. Saha, K. Muralidhar, and G. Biswas[2000]	0.163	-
Re=100 Re=200	Sushanta Dutta, P K Panigrahi & K Muralidhar [2004]	0.126 0.154	-
Re=100	A. Lankadasu, S. Vengadesan[2008]	0.143	-
Re=100	Sen et al. (2011)	0.149	-
Re=100 Re=200	Cao et al. (2012)	0.140 0.156	-
Re=100 Re=200	Ambreen and Kim (2018)	0.141 0.159	4.03 5.37
Re=100 Re=200	Sharma and Eswaran (2004)	-	4.02 5.32
Re=100 Re=200	Present	0.145 0.156	4.02 5.20

Strouhal number and Nusselt number which is obtained in the present investigation is contrasted with numerical and experimental results of other investigators in Tab.4.2, good agreement is observed.

4.CONCLUSIONS

The following conclusions and specific design guidelines, along with practical applications, are drawn from the results obtained:

1. **Aerodynamic Performance**: Sharp-edged cylinders lead to significant pressure fluctuations, whereas chamfered and rounded cylinders provide smoother pressure gradients, resulting in lower aerodynamic drag.
2. **Flow Stability**: Corner modifications, especially chamfered and rounded corners, reduce turbulence intensity and promote more stable flow, particularly at higher spacing ratios.
3. **Wake-Induced Fluctuations**: Larger spacing ratios and corner modifications effectively

minimize wake-induced fluctuations, leading to more stable aerodynamic forces and improved overall performance.

4. **Heat Transfer**: Closely spaced sharp-edged cylinders enhance convective heat transfer due to increased turbulence, but larger spacing and rounded corners improve thermal stability by reducing heat transfer fluctuations.
5. **Optimal Design**: A combination of larger spacing ratios and rounded corners optimizes both aerodynamic and thermal performance, ensuring stable forces and efficient heat dissipation. This configuration is ideal for applications requiring consistent and efficient performance across varying flow conditions.

5. REFERENCES

1. Rosales J.L, A.Ortega and J.A.C Humphrey. “A Numerical Simulation of the Convective Heat Transfer in Confined Channel flow Past Square Cylinders: Comparison of Inline and Offset Tandem Pairs.” Int. J. Heat Mass Transfer, 2001.
2. Said Turki Hassen Abbassi, and Sassi Ben Nasrallah. “Two-Dimensional Laminar Fluid Flow and Heat Transfer in a Channel with a Built-in Heated Square Cylinder.” International Journal of Thermal Sciences 42, no. 12 (December 2003): 1105–13. https://doi.org/10.1016/S1290-0729(03)00091-7.
3. Atul Sharma and V. Eswaran. “Heat and fluid flow across a square cylinder in the two-dimensional laminar flow regime.” Numerical Heat Transfer, Part A: Applications 45, no. 3 (February 2004): 247–69.https://doi.org/10.1080/10407780490278562.
4. Bhattacharyya, S. and S. Mahapatra. “Vortex Shedding around a Heated Square Cylinder under the Influence of Buoyancy.” Heat and Mass Transfer 41, no. 9 (July 2005): 824–33. https://doi.org/10.1007/s00231-005-0626-9.
5. Dhiman, A. K., R. P. Chhabra, and V. Eswaran. “Heat Transfer to Power-Law Fluids from a Heated Square Cylinder.” Numerical Heat Transfer, Part A: Applications 52, no. 2 (July 5, 2007): 185–201. https://doi.org/10.1080/10407780601149870.
6. Akhilesh Sahu, K., R.P. Chhabra and V. Eswaran. “Effects of Reynolds and Prandtl Numbers on Heat Transfer from a Square Cylinder in the Unsteady Flow Regime.” International Journal of Heat and Mass Transfer 52, no. 3–4 (January 2009): 839– 50.

https://doi.org/10.1016/j.ijheatmasstransfer.2008.07.032.

7. Dipankar Chatterjee, , Gautam Biswas, and Sakir Amiroudine. “Numerical Investigation of Forced Convection Heat Transfer in Unsteady Flow past a Row of Square Cylinders.” International Journal of Heat and Fluid Flow 30, no. 6 (December 2009): 1114–28. https://doi.org/10.1016/j.ijheatfluidflow.2009.09.004.
8. Biswas, G., H. Laschefski, N. K. Mitra, and M. Fiebig. “Numerical investigation of mixed convection heat transfer in a horizontal channel with a built-in square cylinder.” Numerical Heat Transfer, Part A: Applications 18, no. 2 (September 1990): 173–88. https://doi.org/10.1080/10407789008944789.
9. Mohamed Bouaziz, Sameh Kessentini, and Said Turki. “Numerical Prediction of Flow and Heat Transfer of Power-Law Fluids in a Plane Channel with a Built-in Heated Square Cylinder.” International Journal of Heat and Mass Transfer 53, no. 23–24 (November 2010): 5420–29. https://doi.org/10.1016/j.ijheatmasstransfer.2010.07.014.
10. Sajida Jassim, Lafta Ghashim. “Numerical Study of the Mixed Convection Flow over a Square Cylinder,” Iraqi Journal of Chemical and Petroleum Engineering Vol.11 No.1 (March 2010) 29-45, 2010.
11. Mohammad Rahnama and Hakimeh Hadi-Moghaddam. “Numerical Investigation of Convective Heat Transfer in Unsteady Laminar Flow over a Square Cylinder in a Channel.” Heat Transfer Engineering 26, no. 10 (December 2005): 21–29. https://doi.org/10.1080/01457630500248521.
12. J. L. Rosales, A. Ortega, J. A. C. Humphrey “A Numerical Investigation of the convective heat transfer in unsteady laminar flow past a single and tandem pair of square cylinders in a channel.” Numerical Heat Transfer, Part A: Applications 38, no. 5 (October 2000): 443– 65. https://doi.org/10.1080/104077800750020388.
13. Amit Agrawal, S M Khot, Girish, Mahish Mohan, Dhananjay Deo, Prashant Gorhekar, and Arti Golekar. “Numerical Investigation of Flow around Side By Side Square Cylinders,” 2012.
14. Ravi Kumar Singh, K B Sahu, and Thakur Debasis Mishra. “Analysis of Heat Transfer and Flow Due to Natural Convection in Air around Heated Square Cylinders of Different Sizes inside an Enclosure.” International Journal of Engineering 3, no. 3 (2013).
15. Sohankar, A., M. Khodadadi, and E. Rangraz. “Control of Fluid Flow and Heat Transfer

around a Square Cylinder by Uniform Suction and Blowing at Low Reynolds Numbers." Computers & Fluids 109 (March2015):155–67.

16. Pritanshu Ranjan and Anupam Dewan. "Partially Averaged Navier Stokes Simulation of Turbulent Heat Transfer from a Square Cylinder." International Journal of Heat and Mass Transfer 89 (October 2015): 251–66.
17. Islam, S. Ul., R. Manzoor and C. Y. Zhou. "Effect of Reynolds Numbers on Flow Past a Square Cylinder in Presence of Multiple Control Cylinders at Various Gap Spacings." Arabian Journal for Science and Engineering 42, no. 3 (March 2017): 1049–64.
18. Syed Aley Haider and Rashid Ali. "Mixed Convective Flow Past A Square Cylinder with Variable Prandtl Number," National Conference on Mechanical Engineering – Ideas, Innovations & Initiatives AMU Aligarh, April 2-3, 2016.
19. Xiaowang Sun, C. K. Chan, Bowen Mei, and Zuojin Zhu. "LES of Convective Heat Transfer and Incompressible Fluid Flow past a Square Cylinder." Numerical Heat Transfer, Part A: Applications 69, no. 10 (May 18, 2016): 1106–24.
20. Aniruddha Sanyal and Amit Dhiman. "Wake Interactions in a Fluid Flow Past a Pair of Side-by-Side Square Cylinders in Presence of Mixed Convection." Physics of Fluids 29, no. 10 (October 2017): 103602. https://doi.org/10.1063/1.5005118.
21. Rastan, M. R., A. Sohankar, and Md. Mahbub Alam. "Low-Reynolds-Number Flow around a Wall-Mounted Square Cylinder: Flow Structures and Onset of Vortex Shedding."Physics of Fluids 29, no. 10 (October 2017):103601.
22. Renan Yuan Mengxuan Wu, and Zhu Huang. "Steady Mixed Convective Flow and Heat Transfer from Tandem Square Cylinders in a Horizontal Channel." Numerical Heat Transfer, Part A: Applications 71, no. 10 (May 19, 2017): 1023–33. https://doi.org/10.1080/10407782.2017.1330921.
23. Samy M Elsherbiny, Mohamed A. Teamah, and Atef R. Moussa. "Natural Convection Heat Transfer from an Isothermal Horizontal Square Cylinder." Alexandria Engineering Journal 56, no. 1 (March 2017): 181–87. https://doi.org/10.1016/j.aej.2016.09.020.
24. Tehmina Ambreen and Man-Hoe Kim. "Flow and Heat Transfer Characteristics over a Square Cylinder with Corner Modifications." International Journal of Heat and Mass Transfer 117 (February 2018): 50–57.
25. Necati Mahir "Three Dimensional Heat Transfer from a Square Cylinder at Low

Reynolds Numbers.” International Journal of Thermal Sciences 119 (September 2017): 37–50. https://doi.org/10.1016/j.ijthermalsci.2017.04.031.

26. S. K. Singh. “Influence of rounding corners on unsteady flow and heat transfer around a square cylinder”, International Journal on Mechanical Engineering and Robotics, Vol.3, 2015, pp 1-7.
27. Alvaro Valencia and Ronald Paredes., “Laminar flow and heat transfer in confined channel flow past square bars arranged side by side”, Heat and Mass Transfer, Vol.39, 2003, pp 721–728.
28. B. S varaprasad patnaik, Y. T. K Gowda, M. S Ravisankar, P. A Aswatha Narayana and K.N Seetharamu., “Finite element simulation of internal flows with heat transfer using a velocity correction approach”, Sadhana, Vol. 26, 2001, pp 251–283.
29. M. Sajjad and C.H. Sohn.,“ Numerical Study of Flow Past a Square Cylinder with Corner Curvature at Incidence”, 11th International Bhurban Conference on Applied Sciences & Technology Islamabad, Pakistan, 14th – 18th January, 2014, pp 294-297.
30. A.Lankadasu and S.Vengadesan., “Interference effect of two equal-sized square cylinders in tandem arrangement with planar shear flow”, International Journal for Numerical Methods in Fluids, 2007, pp 1-17.
31. Ahmed Sohanker, Lars Davidson and Christoffer Norberg., “Numerical simulation of unsteady flow around a square two dimensional cylinder”, 12th Australin fluid mechanics conference the university of Sydney, Australia, 1995, pp 517-520.
32. Andrea Mola, Giancarlo Bordonaro, and Muhammad Hajj., “Low-frequency variations of force coefficients on square cylinders with sharp and rounded corners”, VI International Colloquium on Bluff Bodies Aerodynamics & Applications Milano, Italy, July 2008, pp 20–24.
33. Pratish P. Patil and Shaligram Tiwari., “Effect of blockage ratio on wake transition for flow past square cylinder”, Fluid Dynamics Research, Vol.40, 2008, pp 753–778.
    2011,pp1160–1174.