Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
2326-9865

Analysis of Helical Coil Heat Exchanger Using CFD

Vikaskumar K. Mehtre[1], Aditya R. Wankhade[1], Mahesh P. Kumbhare[1], Ganesh. E. Kondhalkar[1]
[1]Department of Mechanical Engineering, AnantraoPawar College of Engineering & Research, Parvati, Pune (MH)

Article Info
Page Number:460-469
Publication Issue:
Vol 71 No. 1 (2022)

Article History
Article Received*: 02 February 2022*
Revised*: 10 March 2022*
Accepted*: 25 March 2022*
Publication*: 15 April 2022*

Abstract
Helical coil has better heat transfer rate as compared to shell and tube heat exchanger, Because of development of secondary flow. There are so many applications where the helical coil is used such as heating ventilation and air conditioning applications, steam generators used in steam power plants, in condenser's, the reason behind using helical tube is it provides large surface area per unit volume. In the presented work the heat transfer coefficient (h_i) for inside and heat transfer coefficient (h_o) for outside from the different research paper were studied and compared. For the calculation of heat transfer coefficient MATLAB code is developed for the same. The values of heat transfer coefficient for inner side has agreement between each other, however outside heat transfer coefficient has no agreement is found. Computational fluid dynamics is used for the simulation and results were compared with experimental and they found in close agreement.

Keywords- Helical Coil, CFD, Matlab , Heat Transfer Coefficient

---

.

NOMENCLATURE

d_i	Tube inner diameter (=2*r) in m
d_o	Tube outerdiameter in m
$D_{c,b}$	Coil bottom diameter(=2*$R_{c,b}$)in m
$D_{c,t}$	Coil top diameter(=2*$R_{c,t}$) in m
D	Diameter of straight helical coil(=2* R) in m
D_{ave}	Average diameter (=$D_{c,b}$ +$D_{c,b}$/2) in m
$D_{s,o}$	Outer shell diameter in m
$D_{s,i}$	Inner shell diameter in m
L	Length of coil in m
H	Height in m
P	Pitch of coil in m
N	Number of turns
B	Clearance in m
k_t	Thermal conductivity of tube material in W/m °K
k_c	Thermal conductivity of tube fluid in W/m °K
k_s	Thermal conductivity of shell fluid in

	W/m °K
β_c	Coefficient of volumetric thermal expansion of tube fluid in 1/°K
β_s	Coefficient of volumetric thermal expansion of shell fluid in 1/°K
ρ_c	Mass density of tube fluid in (kg/m^3)
ρ_s	Mass density of shell fluid in (kg/m^3)
μ_c	Dynamic viscosity of tube fluid in m/kgS
μ_s	Dynamic viscosity of shell fluid in m/kgS
$T_{c,i}$	Inlet temperature of tube fluid in °K
$T_{c,o}$	Outlet temperature of tube fluid in °K
$T_{s,i}$	Inlet temperature of shell fluid in °K
$T_{s,o}$	Outlet temperature of tube fluid in °K
$C_{p,c}$	Specific heat of tube fluid in J/Kg°K
$C_{p,s}$	Specific heat of shell fluid in J/Kg°K
$C_{p,mn}$	Minimum specific heat in J/Kg°K
PF	Parallel flow arrangement
CF	Counter flow arrangement
m_c	Mass flow rate of tube fluid in Kg/ S
m_s	Mass flow rate of shell fluid in Kg/ S
$(mC_p)_{min}$	Minimum value of product of m and C_p
De	Dean Number
D_{eq}	Equivalent Diameter
D_{hx}	Hydraulic Diameter
DR	Diameter Ratio
PR	Pitch Ratio
HCCHE	Helical cone coil heat exchanger
HCCSS	Helical cone coil straight shell
HCCCS	Helical cone coil cone shell
θ	Cone angle of conical coil
N	Velocity exponential
R_{th}	Thermal Resistance
Z	drag coefficients
	SUBSCRIPTS
C	Cold water
H	Hot water

I	Inner, tube side
S	Shell
T	Tube
C	Coil
O	Outer, outside
Ov	Overall
Ave	Average
W	Wall

1.0 INTRODUCTION

Straight helical coil heat exchanger

“Heat exchanger is a device which is use to transfer the heat from one fluid to another fluid through the same device”. In helical coil heat exchanger the helical coils are used for the heat transfer. There are so many applications where the helical coil is used such as heating ventilation and air conditioning applications, steam generators used in steam power plants, in condenser’s, the reason behind using helical tube is it provides large surface area per unit volume. Although such heat exchanger provides high heat transfer rates, we are finding very less research in this area. We are not able to find information about heat transfer coefficient for natural convection for helical coils. But we all are well known about the heat transfer coefficient are available for natural convection for vertical plate and horizontal plate. This lacuna provide motivation for doing research in this area to fill the present need. [1]

From the research paper it is confirmed that heat transfer from the helical coil is high as compared to straight tube heat exchanger because of the generation of secondary flow of fluid in plane normal to the main flow in the helical tubes which show great performance in heat transfer enhancement while the uniform curvature of spiral conical structure inconvenient in pipe installation in heat exchanger.[2]

In this type of heat exchanger, because of the centrifugal action the secondary flow is generated which acts in plane normal to the main flow in the helical tubes. as the maximum velocity is at the centre, hence the centrifugal force is maximum at centre and the fluid at the centre is subjected to this maximum centrifugal action, and that’s why fluid pushes towards the outer wall. The fluid present near the outer wall replaces the fluid ejected outwards while moving in-words along the tube wall, which in-turns forms the two symmetrical vortices about a horizontal plane through the tube center.

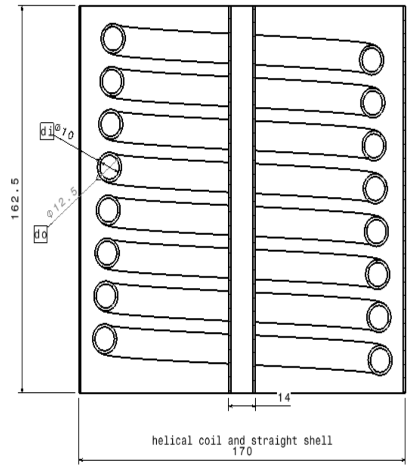


Fig 1.1 Straight Helical Coil Heat Exchanger

Inside heat transfer coefficient for helical coil and curved tube are greater than inside heat transfer coefficient of straight tube because of secondary flow (Dean Vortex) in curved tube and it is characterized by Dean Number which is equal to

$De = Re \times ((d_i/D)^{0.5})$ (1.1)

In this type the curvature ratio is constant. Secondary flow become intensive, which in turn increases (hi).

For calculation of outside heat transfer coefficient (h_0) correlations are found only for typical applications and specified ranges of Re, Ra study by researchers.

Generally correlations for h_0, covering entire range of Re, di/D is not found due to this we have used the available correlations of straight tube.

It is observed that the flow is in viscous regime for inside coiled tube up to much higher Reynolds number than that for straight tubes. Helical coils are having high heat and mass transfer when it compared to straight tube because of the generation of secondary flow in the primary flow. [3]

2.0 LITERATURE SURVEY

The Mohamed Ali**[1]** was performed the experimental investigation of Natural convection made to study, steady type Natural Convection was obtained from turbulent natural convection to water. The experiment have been carried for four coil diameter to tube diameter ratio for five and ten coil tubes and for five pitch outer diameter ratio.

He correlated Rayleigh Number for two different coil sets and the heat transfer coefficient decreases with coil length for tube diameter do =0.012m but increases with coil length for do=0.008m. For tube diameter of 0.012 m with either five or ten coil turns, critical D/d_0 is obtained for a maximum heat transfer coefficient.

Yan ke **[2]** investigated numerical simulation of conical tube bundles. He observed the effect of structural parameters on heat transfer characteristics. fluid flow characteristics inside tube of different cross section also investigated result shows that cone angle cross section have been significant effect inside heat transfer. Also helical pitch has little influence on heat transfer enhancement. He also includes that the secondary fluid become intensive along the tube due to increase of tube curvature. Secondary fluid flow contains four contours and flow direction of each contour are different due to this heat transfer rate increases.

J.S Jaykumar**[3]** after validating the methodology of CFD analysis of a heat exchanger, the effect of considering the actual fluid properties instead of a constant value is established. Various boundary conditions are compared to calculate heat transfer characteristics inside a helical coil. It is found that the specification of a constant temperature or constant heat flux boundary condition for an actual heat exchanger does not give satisfactory result through modelling. For this problem the heat exchanger is analysed with considering conjugate heat transfer and properties of heat transport fluid which are temperature dependent. An experimentation was carried out for the calculation of the heat transfer characteristics. Experimental results and CFD calculation results using the CFD package FLUENT 6.2 are compared. Finally the correlation is developed by using the experimental result obtained. The inner heat transfer coefficient of the helical coil is thus obtained. CFD code FLUENT is used for finding Heat transfer characteristics of the heat exchanger with helical coil. The CFD predictions are in good agreement with the experimental results within experimental error limits.

N. Ghorbani**[4]** conducted experimental study of thermal performance shell and coil heat exchanger in the purpose of this article is to access the influence of tube diameter , coil pitch , shell side and tube side mass flow rate on the modified effectiveness and performance coefficient of vertical helical coiled tube heat exchanger. The calculation has been performed for the steady state and the experiment was conducted for both laminar and turbulent flow inside coil. It was found that the mass flow rate of tube side to shell ratio was effective on the axial temperature profiles of heat exchanger. He concluded that with increasing mass flow rate ratio the logarithmic mean temperature difference was decreased and the modified effective's decreases with increasing mass flow rate.

R. Patil [5] suggested design methodology for helical coil heat exchanger. heat transfer coefficient based on the inside coil diameter hi, is obtained using method for a straight tube either one of Sieder –Tate relationships or plot of the Colburn factor ,JH vs Re. outside heat transfer coefficient is calculated using correlation for different range of Reynolds number. Helical coil heat exchanger is the better choice where space is limited and under the conditions of low flow rates or laminar flow.

3.0 SIMULATION

3.1 Geometry and Meshing

Geometry is created in the CATIA V5 for both the parallel and counter flow. After that the meshing of geometry is completed. Both volume and surface mesh is done for the geometry.

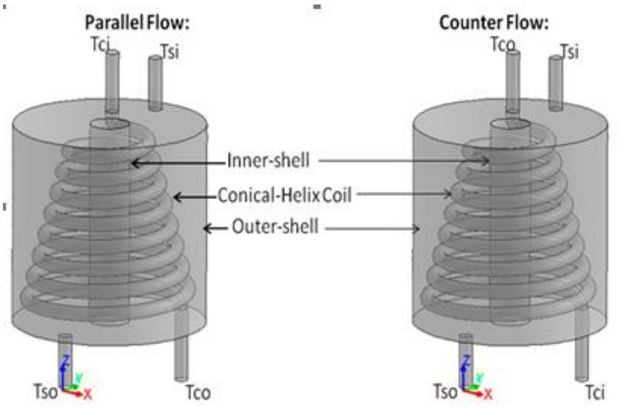


Fig.3.1 Geometry

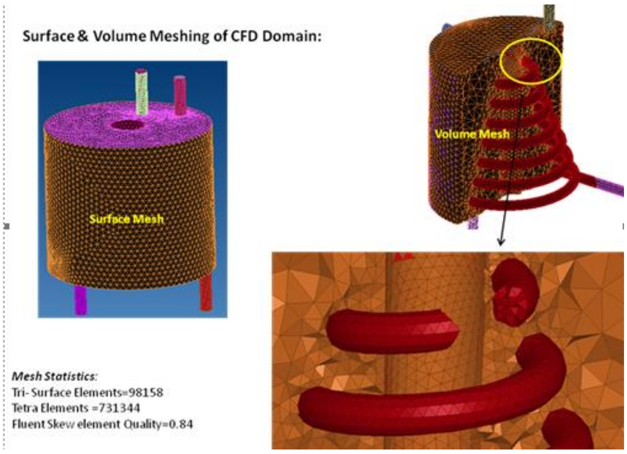


Fig.3.2 Meshing

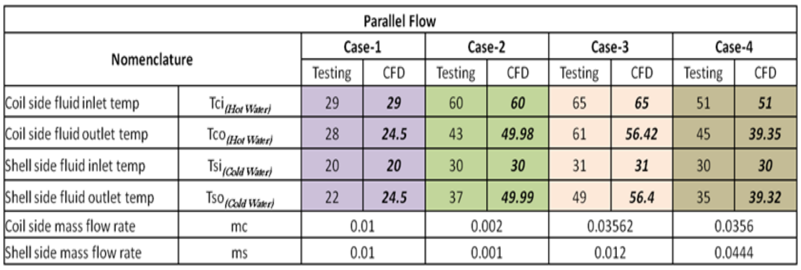
3.2 Boundary Conditions & Assumptions:

- **Solver :** Pressure based Steady State
- **Model*:*** K-epsilon Realizable Standard Wall Function
- **Boundary Conditions:**

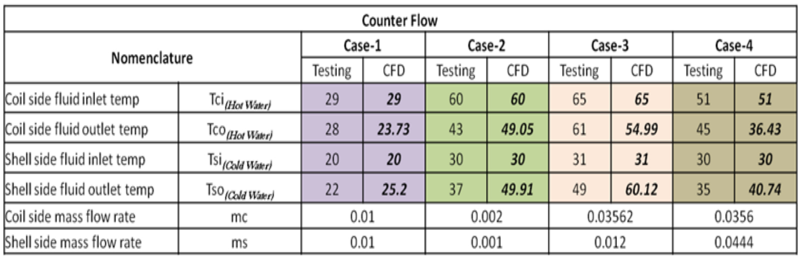
  - Fluid: water-liquid
  - Coil inlet=mass flow inlet type with Temp Tci
  - Shell inlet=mass flow inlet type with Tsi
  - Coil outlet= static pressure outlet
  - Shell outlet= static pressure outlet
  - Wall-coil= copper, 0.12 mm thick, coupled wall
  - All other walls= stationary no slip

4.0 RESULTS

4.1 Temperature Results Of CFD Compared With Experimental

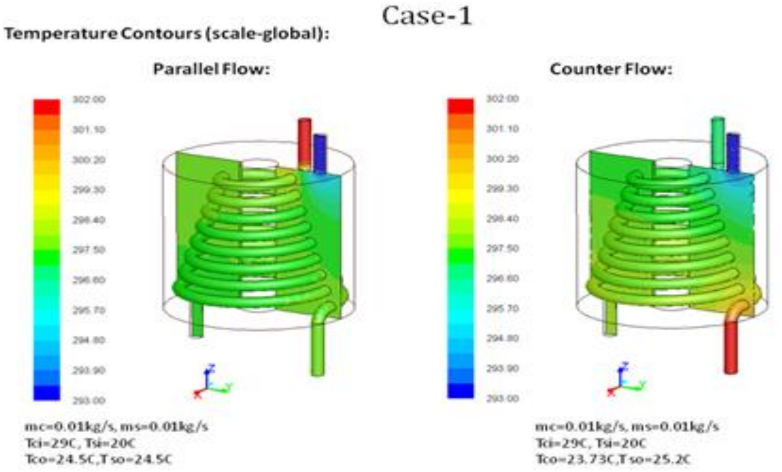


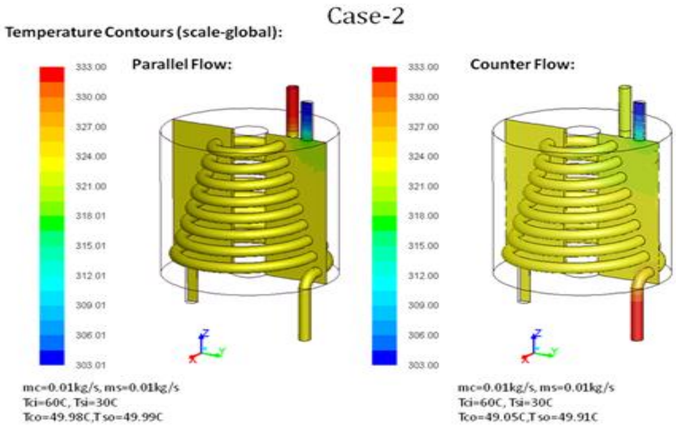
Parallel Flow									
Nomenclature		Case-1		Case-2		Case-3		Case-4	
		Testing	CFD	Testing	CFD	Testing	CFD	Testing	CFD
Coil side fluid inlet temp	$\mathrm{Tci}_{(Hot\ Water)}$	29	***29***	60	***60***	65	***65***	51	***51***
Coil side fluid outlet temp	$\mathrm{Tco}_{(Hot\ Water)}$	28	***24.5***	43	***49.98***	61	***56.42***	45	***39.35***
Shell side fluid inlet temp	$\mathrm{Tsi}_{(Cold\ Water)}$	20	***20***	30	***30***	31	***31***	30	***30***
Shell side fluid outlet temp	$\mathrm{Tso}_{(Cold\ Water)}$	22	***24.5***	37	***49.99***	49	***56.4***	35	***39.32***
Coil side mass flow rate	mc	0.01		0.002		0.03562		0.0356	
Shell side mass flow rate	ms	0.01		0.001		0.012		0.0444	

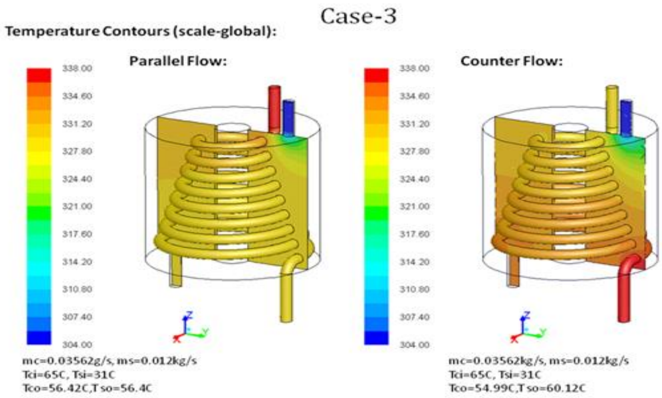


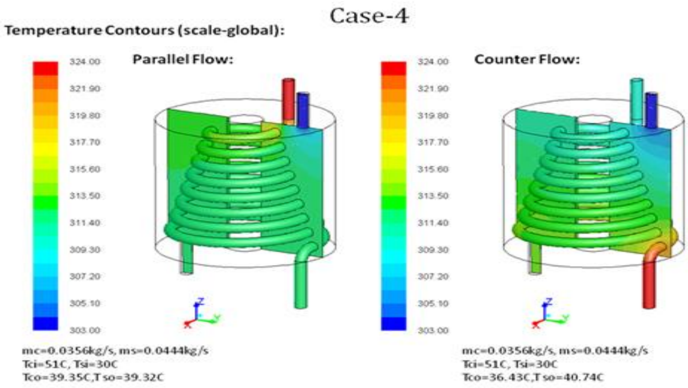
Counter Flow									
Nomenclature		Case-1		Case-2		Case-3		Case-4	
		Testing	CFD	Testing	CFD	Testing	CFD	Testing	CFD
Coil side fluid inlet temp	$\mathrm{Tci}_{(Hot\ Water)}$	29	***29***	60	***60***	65	***65***	51	***51***
Coil side fluid outlet temp	$\mathrm{Tco}_{(Hot\ Water)}$	28	***23.73***	43	***49.05***	61	***54.99***	45	***36.43***
Shell side fluid inlet temp	$\mathrm{Tsi}_{(Cold\ Water)}$	20	***20***	30	***30***	31	***31***	30	***30***
Shell side fluid outlet temp	$\mathrm{Tso}_{(Cold\ Water)}$	22	***25.2***	37	***49.91***	49	***60.12***	35	***40.74***
Coil side mass flow rate	mc	0.01		0.002		0.03562		0.0356	
Shell side mass flow rate	ms	0.01		0.001		0.012		0.0444	

Temperature contours for all the cases for parallel and counter flow:









5.0 CONCLUSION

A good agreement is found for temperatures obtained by simulation and measured by experimentation. Temperature variation of fluid through coil and shell is observed from contour the counter flow heat exchanger heat transfer is more. As the computational analysis is having more advantages such as cheaper, parametric study, less time than the experimental analysis. Present study provides the methodology for the helical coil heat exchanger by computationally which can be used for the analysis of helical coil heat exchanger using computational method. Heat transfer coefficients correlation for the helical coil can be developed which gives satisfactory result over large range.

6.0 ACKNOWLEDGEMENT

We would like to express our sincere gratitude to Dr. Pradeep J. Awasare (Adjunct Professor), Er. Ashok Saraf (Innovation Club Member) for their invaluable guidance and support throughout the research process. We also wish to thank Dr. Sunil B. Thakare (Principal, APCOER, Pune) for their support. Finally, we are grateful to all of the research participants who generously gave their time and effort to this project.

REFERENCES

[1] M. Ali, “Experimental investigation of natural convection from vertical helical coiled tubes,” International Journal of Heat and mass transfer, volume 37, pages 665-671, 1994.
[2] Yan Ke,Ge Pei-qi, Su Yan-cai and MengHai-tao, “Numerical simulation on heat transfer characteristics of conical spiral tube bundle,” Applied thermal Engineering, volume 31, pages 284-292, 2011.
[3] Jaykumar J. S. “Helically coiled heat exchangers,” Heat Exchangers- Developments in heat transfer, In Tech Publishers, pages 311-342, 2011.
[4] Dhablia, D., & Timande, S. (n.d.). Ensuring Data Integrity and Security in Cloud Storage.
[5] Dhabalia, D. (2019). A Brief Study of Windopower Renewable Energy Sources its Importance, Reviews, Benefits and Drwabacks. Journal of Innovative Research and Practice, 1(1), 01–05.
[6] Mr. Dharmesh Dhabliya, M. A. P. (2019). Threats, Solution and Benefits of Secure Shell. International Journal of Control and Automation, 12(6s), 30–35.
[7] N. Ghorbani, H. Taherian and M. Gorji, “Designing Shell-and-Coil Mixed Convection Heat Exchangers,” Proceedings of 2008 ASME Summer Heat Transfer Conference, HT2008, pages 1-7, 2008.
[8] R.K. Patil, R.W. Shende and P.K. Ghosh, “Designing a helical- coil heat exchanger,” Chemical Engineering, pages 85-88, 1982.
[9] Cengel Y. A. “Heat and mass transfer,” Tata McGraw –Hill Publishing Company Limited, Special Indian Edition, pages 408-421, 2007.
[10] Abo Elazm M.M., Ragheb A.M.,Elsafty A.F. and Teamah M.A., “ Computational analysis for the effect of the taper angle and helical pitch on the heat transfer characteristics of the helical cone coils,” The Achieves of Mechanical Engineering, vol. LIX No.3, pages 361-374, 2012.
[11] Abo Elazm M.M., Ragheb A.M.,Elsafty and A.F.,Teamah M.A., “ Experimental and numerical comparison between the performance of helical cone coil and ordinary helical coils used as dehumidifier for humidification dehumidification in desalination units,” International journal of applied engineering research, Dindigul, volume 2, No.1, pages 104-114, 2011.
[12] M. Salimpour , “Heat transfer coefficients of shell and coiled tube heat exchangers”, Experimental Thermal and Fluid Science, volume 33, pages 203–207, 2009.
[13] N. Ghorbani, H. Taherian, M. Gorji and H. Mirgolbabaei , “Experimental study of mixed convection heat transfer in vertical helically coiled tube heat exchangers,” Experimental Thermal and Fluid Science, volume 34, issue 7, Pages 900-905, oct 2010
[14] Ashish R. Pawar, “Roof Crash Simulation of Passenger Car for Improving Occupant Safety in Cabin” in Elsevier Journal
[15] Ashish R. Pawar, “Design and Development: A Simulation Approach of Multi-Link Front Suspension for an All-Terrain Vehicle”, SAE Technical Paper, SIAT 2021
[16] Aditya Pawar, AniketWanjale, HarshalWanjale, YashSathe, Ashish R. Pawar, “Static Structural Analysis & Optimization Of Driver Cabin Mounting Bracket Of Heavy Commercial Vehicle”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue VI, June 2021 ISSN: 0973-2861, pp. 111-124
[17] Siddharth P. Patil, Saurabh R. Birwatkar, Pranil D. Phadke, Karan R. Pawar, Ashish R. Pawar, “Static Structural Analysis & Topology Optimization Of Automotive Track Control Arm For Light Passenger Vehicle”, Journal of Analysis & Computation (IJAC, UGC),

Volume XV Issue VI, June 2021 ISSN: 0973-2861, pp. 91-100

[18] Sandhya R. More, Ganesh E. Kondalkar, Ashish R. Pawar, “Crash Analysis Of A Conformable CNG Tank Using FEA Tool”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue VI, June 2021 ISSN: 0973-2861, pp. 71-78

[19] SumitEkbote, SidhheshGade, SanketMhetre, Raj Dhawade, Ashish R. Pawar, “Experimental Analysis Of Automatically Manufactured Chain Link Fencing Wire”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue VI, June 2021 ISSN: 0973- 2861, pp. 57-67

[20] Tushar S. Kalaskar, Kashinath H. Munde, Ashish R. Pawar, “Design And Analysis Of Hybrid Aluminium-Composite Driveshaft With Crack Using Experimental Modal Analysis And FEA”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue VI, June 2021 ISSN: 0973-2861, pp. 27-40

[21] Sandhya R. More, Ganesh E. Kondalkar, Ashish R. Pawar, “Review Of Conformable Cng Tank Storage In Light Goods Vehicle”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue VI, June 2021 ISSN: 0973-2861, pp. 21-26

[22] Deepak N. Patil, Ganesh E. Kondhalkar, Ashish R. Pawar, “Improvement In Productivity And Quality Of Bumper Punching Machine”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue V, May 2021 ISSN: 0973-2861, pp. 1-6

[23] Shubham A. Andore, Ashish R. Pawar, P. N. Abhyankar, “Study Of Effects Of Different Profiles Of Dental Implant Using FEA”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue V, May 2021 ISSN: 0973-2861, pp. 1-13

[24] Abhilash D. Bhosale, Ashish R. Pawar, “Experimental & Numerical Investigation Of Pretention Effect On Fatigue Life Of Double Lap Bolted Joint Under Dynamic Shear Loading”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue V, May 2021 ISSN: 0973-2861, pp. 1-19

[25] Deepak N. Patil, Ganesh E. Kondhalkar, Ashish R. Pawar, “Structural Optimization Of Bumperfog Lamp Punching Machine”, Journal of Analysis & Computation (IJAC, UGC), Volume XV Issue V, May 2021 ISSN: 0973-2861, pp. 71-84

[26] Ashish Pawar, SurajJadhav, “Investigate Optimum Shape of Crash Box Analysis Experimentally & Numerically on Geometry Aspect” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[27] Ashish Pawar, YogeshVyavahare, Ganesh Kondhalkar, “Roof Crash Simulation of Passenger Car for Improving Occupant Safety in Cabin” in IUP Journal of Mechanical Engineering, Volume 13 Issue 2/3.

[28] Ashish Pawar, SurajJadhav, “Experimental & Non-Linear Analysis to Investigate Optimum Shape Crash Box” in Journal of Interdisciplinary Cycle Research (JICR, UGC), Volume XII Issue VII, July 2020 ISSN: 0022-1945, pp. 966-973

[29] Ashish Pawar, Swastik Kumar Pati, Ganesh Kondhalkar, “Comparative Analysis of Kenaf& Jute E Glass Epoxy Specimen Along with B Pillar Natural & Synthetic Combination Replica Test Under UTM” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[30] Ashish Pawar, HarshalDharmale, Ganesh Kondhalkar, “Experimental FEA Investigation of Bolt Loosening in a Bolted Joint Structure ” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861, pp. 1-12

[31] Ashish Pawar, HarshalDharmale, Ganesh Kondhalkar, “Numerical Investigation Of Bolt Loosening In A Bolted Joint Structure” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861, pp. 1-12

[32] Ashish Pawar, AbhijeetSalunkhe, KashinathMunde, “Optimization of Power Lift Gate Spindle & Socket Assembly” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[33] Ashish Pawar, AbhijeetSalunkhe, KashinathMunde, “Investigate Numerical Analysis of

Power Lift Gate Spindle & Socket Assembly with Modifications” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[34] Ashish Pawar, BalasahebTakale, “ ” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[35] Ashish Pawar, SampadaAhirrao, Ganesh Kondhalkar, “Fatigue Analysis of Leaf Spring Bracket for Light Duty Vehicles on Topology Optimization Approach” in Journalof Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861, pp. 1-11

[36] Ashish Pawar, Rahul Nimbalkar, “Investigation of Carbon Fiber& E Glass Epoxy Composite with Multi-Bolt Joints using Tensile Loading ” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[37] Ashish Pawar, Rahul Nimbalkar, “Numerical Analysis of Carbon Fiber& E Glass Epoxy Composite Plates in Tensile Loading with Multi-Bolt Joints” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[38] Ashish Pawar, MakarandPatil, Ganesh Kondhalkar, “Predication of Effect of Welding Process Parameter of MIG Process on Weld Bead Geometry” in Journal of Analysis & Computation (IJAC, UGC), Volume XIV Issue VII, July 2020 ISSN: 0973-2861

[39] Ashish Pawar, “Topology Optimization Of Leaf Spring Bracket For Light Duty Vehicle” in Journal of Emerging Technologies and Innovative Research (JETIR, UGC), Volume 6 Issue 5, May 2019 ISSN: 2349-5162

[40] Ashish R. Pawar, Dr. K. H. Munde, VidyaWagh, “Stress Analysis of Crane Hook with Different Cross Section Using Finite Element Method” in Journal of Emerging Technologies and Innovative Research (JETIR, UGC), Volume 6 Issue 1, Jan 2019 ISSN: 2349-5162, pp. 79-83

[41] Ashish R. Pawar, Dr. K. H. Munde, Mahesh Mestry, “Pre-Stressed Modal Analysis of Composite Bolted Structure” in Journal of Emerging Technologies and Innovative Research (JETIR, UGC), Volume 5 Issue 7, July 2018 ISSN: 2349-5162

[42] Ashish R. Pawar, KashinathMunde, Vijay Kalantre, “Topology Optimization of Driver Cabin Mounting Bracket of Heavy Commercial Vehicle” in International Journal of Science & Engineering Development Research (IJSDR), Volume 3, Issue 7, July 2018 ISSN: 2455-2631

[43] Ashish R. Pawar, KashinathMunde, Vijay Kalantre, “Topology Optimization of Front Leaf Spring Mounting Bracket” in International Journal of Science & Engineering Development Research (IJSDR), Volume 3, Issue 7, July 2018 ISSN: 24