Performance Enhancement of Double Pipe Heat Exchanger with Helical Fin and Vortex Generator using CFD

Yedukondalu Talakonda, B. Jayachandraiah, B. Chandra Mohana Reddy

Abstract: Transferring heat from one fluid to another fluid without losing of major energy is a challenging task in the food processing and other industries. Double Pipe Heat Exchanger (DPHE) are light capacity Heat Exchangers (HE) used for air and other gas applications. In the present work an attempt is made to enhance the heat transfer of DPHE with helical fins and vortex generator. The working fluids are air and steam (water vapour) along outer and inner pipes. The parameters considered are helix angles, i.e. 35^0, 40^0, & 45^0 and pitch size i.e. 80 mm, 75 mm and 70 mm, and a vertex generator. CATIA V5 and Autodesk CFD are used for modelling and analysis. It is found that 40^0 angle helix fin 70 mm pitch along Delta Wing type (Triangular) vortex generator (VG) gives best performance.

Keywords : DPHE, Vortex generator, Autodesk CFD, Catia.

I. INTRODUCTION

The double-pipe heat exchanger is one of the simplest types of heat exchangers. This is a concentric tube construction. Flow in a double-pipe heat exchanger can be co-current or counter-current. DPHEs are capable of working with variety of fluids and conditions. The change in the geometry of the inner tube, adding shapes at the outside of the tube can increase the efficiency of DPHE. The present research finds better turbulence in flow of DPHE achieves best heat transfer rates.

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* Correspondence Author
Yedukondalu Talakonda*, Ph.D Scholar, Mechanical Engineering, JNT University, Ananthapuramu, India. Email:yedukondalu357@gmail.com.
Dr. B. Jayachandraiah, Prof. of Mechanical Engineering, Srikalahastheeswara Institute of Technology, Srikalahasti, India.
Email:bjcskit2011@gmail.com.
Dr. B. Chandra Mohana Reddy, Head of Mechanical Engineering, College of Engineering, JNT University, Ananthapuramu, India.
Email:cmr_b@yahoo.com.

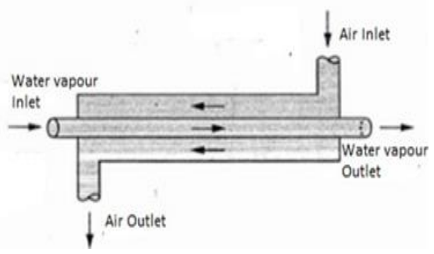

Fig. 1.Double Tube Heat Exchanger

Fig. 2. Helical Fin on Inner Tube

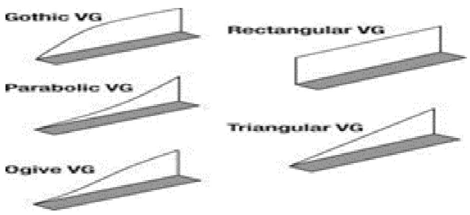

Fig. 3.Vortex Generators

II. LITERATURE SURVEY

A lot of work has been carried out by the researchers towards CFD and DPHE. New techniques and shapes of fins along the inner tube of DPHE are introduced. Some of the work carried is presented here. Shiva Kumar et. al [1], Mohan et. al [2], Qingang et.al [3] worked on performance of DPHE with hot fluid has made to flow through inner tubes and cold fluid is flow through the outer tubes. The simulations are carried out by using CATIA V5, Solid Works and leading CAD commercial software. Most of the researchers worked on ANSYS FLUENT for CFD analysis. Hae et.al [4], Mohan et.al [5], Seyed et.al [6], Mohamad Omidi et.al [7] worked on short helical fins, different pitches, nano fluids along with experimental, numerical, cfd simulations and empirical studies.

The vast literature leads to the present investigation for the performance enhancement of DPHE with Autodesk Commercial CFD software with theoretical analysis.

III. DATA COLLECTION

From the vast literature survey and Tubular Exchanger Manufacturers Association (TEMA) standards the HE Model is designed. Most of the dimensions are taken from the standard cases. The following are the geometrical dimensions used for the design of DPHE.

Table- I: Geometrical Dimensions for DPHE

S.No	Description	Unit	Value
1	Heat Exchanger Length, L	mm	920
2	Outer Pipe Inner Diameter, D_i	mm	48
3	Outer Pipe Outer Diameter,D_o	mm	50
4	Tube Length, l	mm	920
5	Inner Pipe Outer Diameter, d_o	mm	22
6	Inner Pipe Inner Diameter, d_i	mm	21
7	Helix Pitch, P_t	mm	70, 75, 80
8	Helix Length	mm	920
9	Helix Angle	Deg	35, 40, 45
10	Side Plate Diameter D_{sp}	mm	50
11	Side Plate Thickness, T_{sp}	mm	2
12	Helix Height	mm	13
13	Triangular Vortex Generator Dimensions	mm	3x3

IV. MODELING

Commercial CATIA V5 is used in the modelling of DPHE. All the individual parts are modelled separately and assembled. The helix angles and pitches are changed according to the requirement. Each and every model is designed and saved separately.

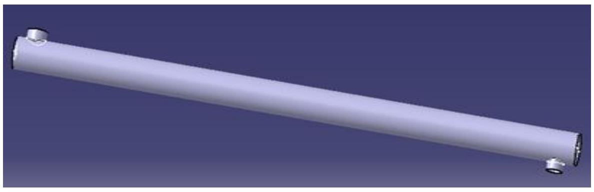

Fig. 4.Desing of Outer Pipe

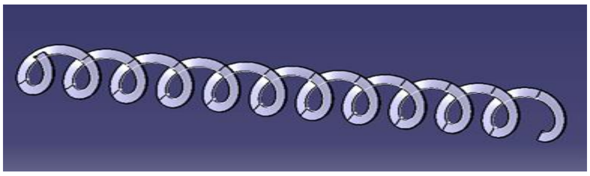

Fig. 5.Desing of Helix with an angle of 350

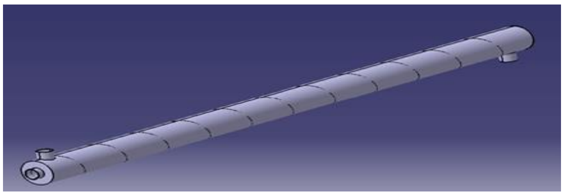

Fig. 6.Assembly Model of Inner Tube, Helix and Outer Tube on Heat Exchanger

V. MESHING AND ANALYSIS

Before going for the actual analysis the model is meshed using Autodesk CFD Simulation.

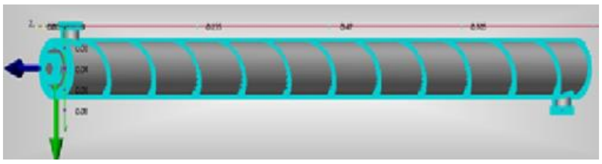

Fig. 7.Meshed Double Pipe Heat Exchanger

A. CFD Governing Equations

For CFD analysis the Governing Equations used

Continuity equation: $\frac{\partial \rho}{\partial t} + \text{div}(\rho u) = 0$ (1)

Momentum Equation:

Stress components in x – direction (2)

$$\frac{\partial Du}{Dt} = \frac{\partial(-p+\tau_{xx})}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_{Mx}$$

Y – Component of the momentum equation (3)

$$\frac{\rho Dv}{Dt} = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial(-p+\tau_{yy})}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + S_{My}$$

Z – Component of the momentum equation (4)

$$\frac{\rho Dw}{Dt} = \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial(-p+\tau_{zz})}{\partial z} + S_{Mz}$$

Energy Equation

Rate of increase of energy = Net rate of heat added to fluid particle + Net rate of work done on fluid particle (5)

B. Materials

Table- II: Material Properties

S.No	Materials	Density (Kg/m^3)	Specific Heat (kJ/kgK)	Thermal Conductivity (W/m^2K)
1	Hot Liquid (Water Vapour)	958.4	1.8882	0.02556
2	Cold Fluid (Air)	997.4	0.1004	0.02563
3	Pipe (Red Coper)	8940	0.39	385
4	Helical Fin (Red Copper)	8940	0.39	385
5	Vortex Generator (Red Copper)	8940	0.39	385

C. Boundary Conditions

The input conditions considered for this work are inlet_temp and inlet velocities for the fluids. The inlet velocities for water vapour & cold air are 19462.15 mm/sec & 13269.61 mm/sec. The inlet temperatures are 100 ^{0}C & 25 ^{0}C for water vapour and air. The outlet pressure is considered to be zero gauge pressure, because outlet pressure is considered to be atmospheric pressure.

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D. Model Calculations

Hot fluid heat transfer rate (Q_h):

$$Q_h = m_h C_{ph}(T_{hi} - T_{ho}) \quad W \qquad (6)$$

Cold fluid heat transfer rate (Q_c):

$$Q_c = m_c C_{pc}(T_{co} - T_{ci}) \quad W \qquad (7)$$

Average value of heat transfer rate (Q_{avg})

$$Q_{avg} = (Q_h + Q_c)/2 \quad W \qquad (8)$$

Logarithmic mean temperature difference (LMTD):

$$LMTD\ (\Delta T_{lm}) = \left(\frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln\left(\frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}}\right)} \right) \qquad (9)$$

Surface Area(As):

$$A_s = \pi D_o L \quad m^2 \qquad (10)$$

Overall Heat Transfer Coefficient (U_o)

$$Q_{avg} = U_o A_s \Delta T_{lm}$$

$$U_o = \frac{Q_{avg}}{A_s \Delta T_{lm}} \qquad (11)$$

VI. RESULTS

The results of DPHE along Helical fins with and without VG are presented below. The CFD results provides better values of heat transfer rate, X, Y & Z- velocity, continuity, k-ε, energy are the part of scaled residual which have to converge in the control volume.

A. Double Pipe Heat Exchanger without Fin

a. Temperature Contour

The DPHE without Helical Fins shown as follows. The inlet Temperature of Water Vapour in Inner Pipe of Heat Exchanger is 100 °c and in outlet it decreased to 83.0767 °c. In the case of cold Air inlet Temperature was 25 °c and the outlet Temperature is increased to 59.3591 °c.

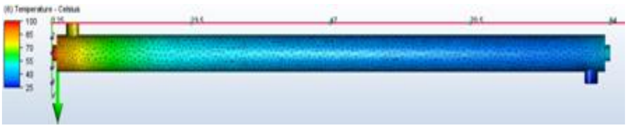

Fig. 8.Temperature Distribution Without Fin in DPHE

b. Velocity Contour

The Velocity profile of inner pipe at inlet is 19462.15 mm/s and in outlet it is 10699.9097 mm/s. In the case of outer pipe at inlet is 10269.61 mm/s and in outlet it is 12312.8298 mm/s.

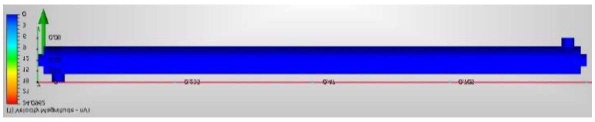

Fig. 9.Velocity contour of DPHE without Fin

B. DPHE with 35⁰ Helix angle and 80 mm Pitch Size

a. Temperature Contour

The outlet temp. of Water Vapour in Inner Pipe of Heat Exchanger is decreased to 78.362°c. In case of cold air outlet Temperature is increased to 75.5893°c.

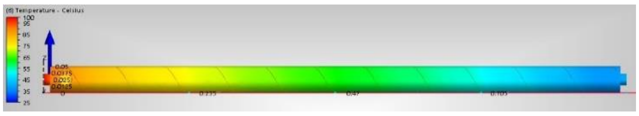

Fig. 10. Temperature Distribution across 35^0 helical fin

b. Velocity Contour

The Velocity of Inner pipe at inlet is 11923.7424 mm/s. In the case of outer pipe the outlet at velocity is 11119.4333 mm/s.

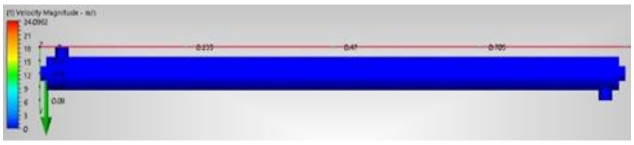

Fig. 11. Velocity Contour for 35^0 helical fin

C. DPHE with 40^0 Helix angle and 80 mm Pitch Size

a. Temperature Contour

Temperature of the Water Vapour in DPHE at outlet is decreased to 75.6807 °c. At the outlet the temperature of cold air is increased to 78.4347 °c.

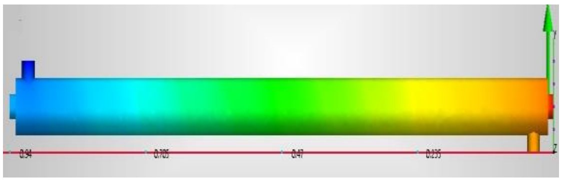

Fig. 12. Temperature Distribution for 40^0 helical fin

b. Velocity Contour

The profile of Inner pipe, at outlet is 10709.4388 mm/s and at outer pipe outlet is 12377.278 mm/s.

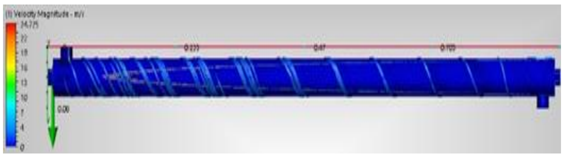

Fig. 13. Velocity Contour for for 40^0 helical fin

D. DPHE with 45^0 Helix angle and 80 mm Pitch Size

a. Temperature Contour

Temperature of the Water Vapour at outlet is decreased to 78.2782 °c. For air, the outlet Temperature is increased to 75.5044 °c.

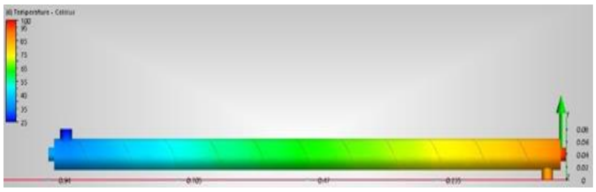

Fig. 14. Temperature Distribution for 45^0 helical fin

b. Velocity Contour

The Velocity at inner pipe is 11901.0231 mm/s. For outer pipe, at outlet the velocity is 1237.7278 mm/s.

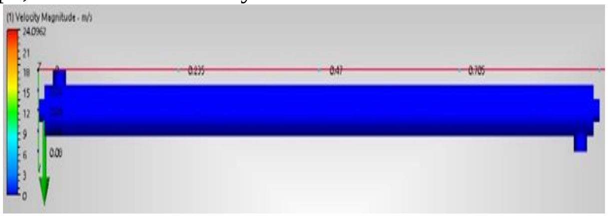

Fig. 15. Velocity Contour for 45⁰ helical fin

After considering these cases, the following results are obtained.

Table- III: Temperature & Velocity Results

S.No	Helix Angle (θ)	Pitch Sizes (mm)	Air Temperature (°C)		Water Vapour Temperature (°C)		Velocity (mm/sec)	
			In let	Out let	In let	Out let	Air	Water Vapour
1.	35	80	25	75.5893	100	78.362	13269.61	19462.15
2.	40	80	25	78.4347	100	75.6807	13269.61	19462.15
3.	45	80	25	75.5044	100	78.2782	13269.61	19462.15

From the above table it is clear that 40^0 helix angle gives the best heat transfer rate and selected for the analysis with different pitch sizes.

E. DPHE with 40^0 Helix angle and 75 mm Pitch Size

a. Temperature Contour

Temperature of the Water vapour at outlet is decreased to 75.6324 °c. For cold air the outlet the Temperature increased to 78.8363°c

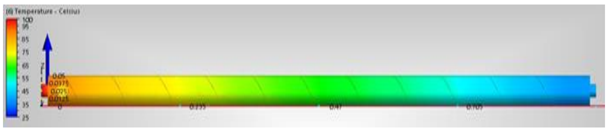

Fig. 16. Temperature Distribution for 75 mm pitch at 40^0 helical fin

b. Velocity Contour

The Velocity at the inner pipe outlet is 10724.563 mm/s. In the case of outer pipe, velocity at outlet is 12357.458 mm/s.

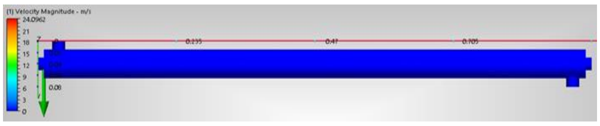

Fig. 17. Velocity Contour for 75 mm pitch at 40^0 helical fin

F. DPHE with 40^0 Helix angle and 70 mm Pitch Size

a. Temperature Contour

Temperature of the water vapour at outlet it decreased to 75.5841 °c. and cold air outlet the temperature increased to 79.2379 °c.

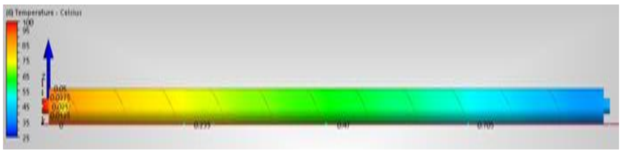

Fig. 18. Temperature Distribution for 70 mm pitch at 40^0 helical fin

b. Velocity Contour

The Velocity of inner pipe at outlet is 10742.2639 mm/s and for outer pipe it is 12330.2743 mm/s.

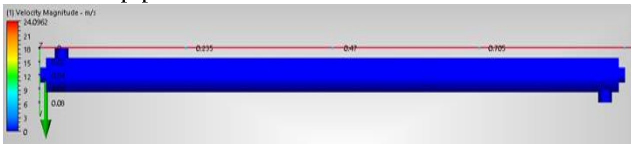

Fig. 19. Velocity Contour for 70 mm pitch at 40^0 helical fin

The results are tabulated as follows.

Table- IV: Temperature & Velocity Results

S.No	Helix Angle (θ)	Pitch Sizes	Air Temperature (°C)		Water Vapour Temperature (°C)		velocity (mm/sec)	
			In let	Out let	In let	Out let	Air	Water Vapour
1.	40	80	25	75.5893	100	78.362	13269.61	19462.15
2.	40	75	25	78.4347	100	75.6807	13269.61	19462.15
3.	40	70	25	75.5044	100	78.2782	13269.61	19462.15

From the above results it is clear that 40^0 helix angle gives better heat transfer with 70 mm pitch. So, 40^0 helix angle and 70 mm pitch size is considered for further investigation with Vortex Generators.

G. DPHE with 40^0 Helix angle and 70 mm Pitch Size with VG

a. Temperature Contour

Temperature of the water vapour at outlet is decreased to 76.0362 °c and cold air outlet the temperature increased to 77.6729 °c.

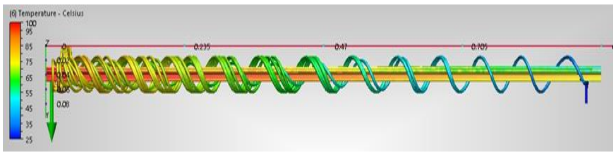

Fig. 20. Temperature Distribution for 40^0 fin with VG

b. Velocity Contour

The velocity of inner pipe outlet is 11887.4818 mm/s. and outer pipe outlet velocity is 11112.8558 mm/s.

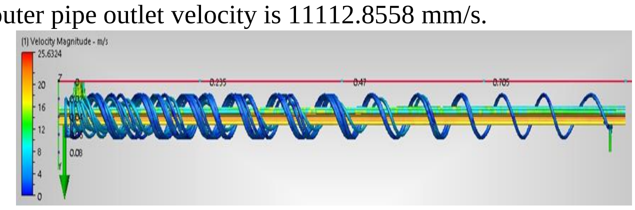

Fig. 21. Velocity Contour for 40^0 fin with VG

VII. DISCUSSION

All the results are tabulated as below for the better understanding of the performance of the DPHE.

Table- V: Temperature & Velocity Results

S.No	Types of Converged Design	Helix Angle (degrees)	Pitch Sizes (mm)	Q_{avg} (W)	LMTD	Surface Area (m^2)	Overall Heat Transfer Coefficient ($W/m^2\ ^0C$)
1	Tube in tube	-	80	150.2561	48.841	0.14452	21.2883
2	Helical Fins	35^0	80	207.3503	34.088	0.26282	23.1444
3		40^0	80	224.8986	36.986	0.26472	25.1365
4		45^0	80	213.8842	35.172	0.27293	24.1686
5		40^0	70	227.2023	37.365	0.27732	25.9138
6		40^0	75	226.0483	37.176	0.28432	25.3367
7	Delta Wing Type Vortex Generator	40^0	70	231.13805	38.023	0.29283	27.1305

A. Graphs

a. Overall Heat Transfer Coefficient vs Helix Angle

The following graph plotted between Helix Angle and overall heat transfer coefficient. This shows an increase in overall heat transfer in 40^0 helix angle than the tube in tube heat exchanger.

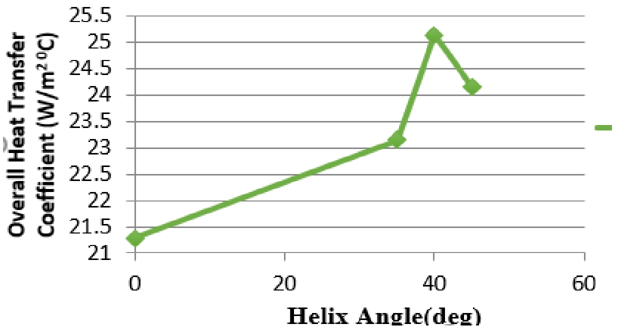

Fig. 22. Helix angle vs overall heat transfer coefficient

b. Overall Heat Transfer Coefficient vs Helix Angle

This shown an increase in overall heat transfer in 40^0 helix angle and 70 mm pitch size and vortex generator than the tube in tube heat exchanger.

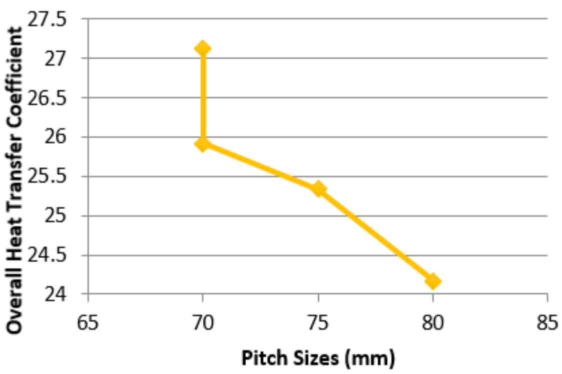

Fig. 23. Helix angle vs overall heat transfer coefficient

VIII. CONCLUSION

A DPHE is modelled and simulated using Catia V5 and Auto desk Simulation Software. Mass flow rate and inlet temperatures of the fluids are the boundary conditions. Analysis carried-out for different operating conditions.

Simple DPHE is taken to the reference for the evaluation of enhancement of the heat exchanger. Helical fin is placed on the outer surface of the inner pipe with constant pitch of 80 mm with different helical angles i.e. 35^0, 40^0, 45^0. From the analysis it is found 40^0 with 80 mm gives better performance.

Form the results, it is considered 40^0 helical angle with different pitches i.e. 70 mm, 75 mm and 80 mm and found 40^0 with 70 mm gives the best performance. Finally a triangular vortex generator is provided for the 40^0 helix angle with 70 mm pitch size of heat exchanger. Better results are observed in the final case with vortex generators.

It is found that the heat transfer enhanced by the heat exchanger with 70 mm pitch with 40^0 helical angle is about 142-145% than the simple DPHE without fin.

The heat transferred in DPHE enhanced with vortex generator is 148-153% more than that transferred by the DPHE without fin.

Th present work concludes that heat transfer at the shell side increased by helical fins and vortex generators. This shown the importance of VGs in heat transfer enhancement.

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AUTHORS PROFILE

Yedukondalu Talakonda is pursuing his full time Ph. D in mechanical engineering at JNT University, Ananthapuramu. His research areas are Heat Exchangers, CFD, FEM and Machine Design.

Dr. B. Jayachandraiah is Professor in the department of mechanical engineering, Srikalahastheeswara Institute of Technology, Srikalahasti. He received his Ph.D from the Jawaharlal Nehru Technological University, Hyderabad. He has an enormous 27 years' experience in the field of teaching and 18 years in research. He awarded 10 Master Degrees in Mechanical Engineering. He published more than 85 research papers in reputed international, national journals and conferences. Presently he is supervising 3 Ph. D Scholars. His areas of interest are CFD, FEM and Heat Transfer.

Dr. B. Chandra Mohana Reddy is Head and Associate professor of mechanical engineering in CEA, JNT University, Ananthapuramu. He received his Ph. D in mechanical engineering. He has a vast experience of 27 years in teaching and research with 7 years industry. Presently he is supervising UG, PG and Ph.D Scholars in various advanced research problems. He published more than 80 research articles in reputed international, national journals and conferences. His areas of interest are Production, Industrial Engineering and Design.