ISSN: 2350-0328

International Journal of AdvancedResearch in Science, Engineering and Technology

Vol. 8, Issue 1 , January 2021

Numerical solution methodology for the novel design of hybrid solid desiccant packed bed columns for drying of gases

Selvaraji Muthu , Sekarapandian N *

Research Scholar, Department of Thermal and Energy,School of Mechanical Engineering, Vellore Institute of Technology, Vellore Campus, Tiruvalam Road, Katpadi, Vellore, Tamil Nadu 632014, India
Associate Professor, Department of Thermal and Energy,
School of Mechanical Engineering, Vellore Institute of Technology,
Vellore Campus, Tiruvalam Road, Katpadi, Vellore, Tamil Nadu 632014, India

ABSTRACT: In this article numerical simulation of the performance of novel hybrid stationary packed solid desiccant bed designs for drying of gases is presented. Each of the proposed hybrid packed bed is comprised of a mixture of solid desiccants of different types having both fixed and varying particle diameter distribution along the vertical axial direction. Typically in the beds of this type, the time taken for the bed saturation is heavily related to the input condition of the gases. Also the adsorption isotherm curves of different desiccant types have a strong effect on the exit conditions of the gases dried using these beds. In order to simulate the transport phenomena associated with the packed solid desiccant bed application an in-house CFD code using finite volume method is developed. This code has the capability to model the simultaneous heat conduction and moisture diffusion taking place in the bed during the gas transport. The numerical results of the base model design are validated against the experimental data available in the literature. The predicted exit temperature and moisture content of the gas are in good agreement with the literature data. Further, the validated model is used to simulate for several other novel packed bed designs the coupled heat and mass transfer in the adsorption and desorption phases under wide operating conditions. The results of interest include the assessment of improvement in performance of drying of gases in terms of pressure dew point, relative humidity at exit and the prediction of the desorption phenomena for the regeneration of the beds for next cycle of operation. Finally, the paper summarizes the benefits of various designs and highlights the optimum design.

KEYWORDS: Hybrid solid desiccants, Packed beds, Drying of gases, Numerical simulation, Finite volume methods

I. INTRODUCTION

The stationary fixed desiccant bed is filled with solid desiccant particles as shown in Fig-1. The moist wet air is supplied to the bed and dry hot air exits at the outlet during the adsorption process. During the adsorption process the water-vapor in the process air is got transferred from the process air flow stream to the desiccant pore-surfaces due to differential partial vapor pressure between the flow stream and desiccant pores and this phenomena of moisture transfer (mass transfer), the direction is inversed during the desorption process of the regeneration phase and by which the desiccant bed gets regenerated for the next adsorption phase. As the moisture vapor pressure on the surface of the desiccant particle is heavily influenced by the actual desiccant particle temperature and the moisture content present on the desiccant, the adsorption heat energy released to desiccant particle is dependent on the mass transfer rate from process air stream to desiccant pores, which is heavily depended due to the moisture partial pressure on the desiccant particle surface.

II. RELATED WORK

This phenomena of both adsorption and desorption in the fixed solid desiccant bed have to be treated as a coupled transient sensible and latent heat and moisture (mass) transfer phenomena, which are numerically simulated [1, 2] and experimentally measured the performance of the beds [3 & 4]. This adsorption and desorption phenomena is analyzed for rotary desiccant wheel application as well [5-7].

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 8, Issue 1 , January 2021

A novel hybrid packed beds [8] are proposed to enhance the adsorption and desorption phenomena during the drying application. The hybrid desiccant beds [9 & 10] show the capability to achieve a very low dew point temperature for the drying applications.

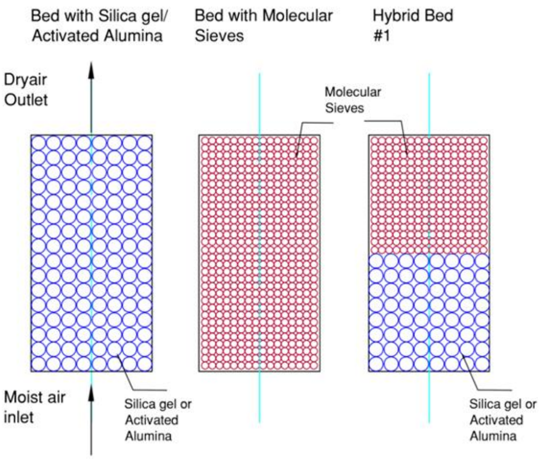

Fig. 1. Hybrid stationary packed solid desiccant beds

An innovative concept of novel hybrid solid desiccant packed bed is proposed in comparison with conventional silica gel and molecular sieves beds for performance prediction and comparative purpose as shown in Figure 1.

- Conventional silica gel (SG) desiccant bed
- Conventional molecular sieves (MS) desiccant bed
- Hybrid bed having 50% of bed at bottom filled with Silica gel and remaining 50% of bed filled with molecular sieves desiccant

III. MATHEMATICAL MODELLING OF ADSORPTION AND DESOPTION PENOMENA

The governing equations are derived [3, 4] based on the conservation of moisture and conservation of energy in the air and in the desiccant.

The moisture conservation of the process air and regeneration air in the stationary solid desiccant packed bed is given as below in equation (1)

$$\frac{\partial W}{\partial t}=\frac{k_m a}{(1-\varepsilon)\rho_s}(\omega_a-\omega_s) \tag{1}$$

Similarly, moisture conservation in desiccant for the stationary solid desiccant packed bed is given as below in equation (2)

$$\frac{\partial \omega_a}{\partial t}=-\frac{G_a}{\varepsilon\rho_a}\frac{\partial \omega_a}{\partial y}+\frac{k_m a}{\varepsilon\rho_a}(\omega_s-\omega_a) \tag{2}$$

Sensible and latest heat energy conservation in the process and regeneration air of stationary solid desiccant packed bed is given as below in equation (3)

$$\frac{\partial \theta_a}{\partial t}=\frac{G_a}{\rho_a\varepsilon}\frac{\partial \theta_a}{\partial y}+\frac{k_h a}{\rho_a C_a\varepsilon}(\theta_a-\theta_s)$$
$$+\frac{C_v k_m a}{C_a\rho_a\varepsilon}(\omega_a-\omega_s)(\theta_a-\theta_s) \tag{3}$$

Sensible and latest heat energy conservation in the desiccant for the solid desiccant packed bed is given as below in equation (4)

$$\frac{\partial \theta_s}{\partial t} = \frac{\lambda_{eff}}{(1-\varepsilon)\rho_s c_s}\frac{\partial^2 \theta_s}{\partial y^2} + \frac{\Phi}{c_s}\frac{k_m a}{(1-\varepsilon)\rho_s}(\omega_a - \omega_s) + \frac{k_h a}{(1-\varepsilon)\rho_s c_s}(\theta_a - \theta_s) \tag{4}$$

The initial and boundary conditions are referred from literature [2] to compare the numerical results [2 & 3].

IV. NUMERICAL MODELLING AND METHODOLOGY OF SOLVING GOVERNING EQUATIONS

The governing equations (partial differential equations) are discretized under implicit scheme by using finite volume method to get set of linear algebraic equations and then these set of linear algebraic equations are solved with the boundary conditions and input conditions using the CFD code developed in FORTRAN 95 using Guass-Siedel iterative method, as shown in the flow chart given in Figure 2.

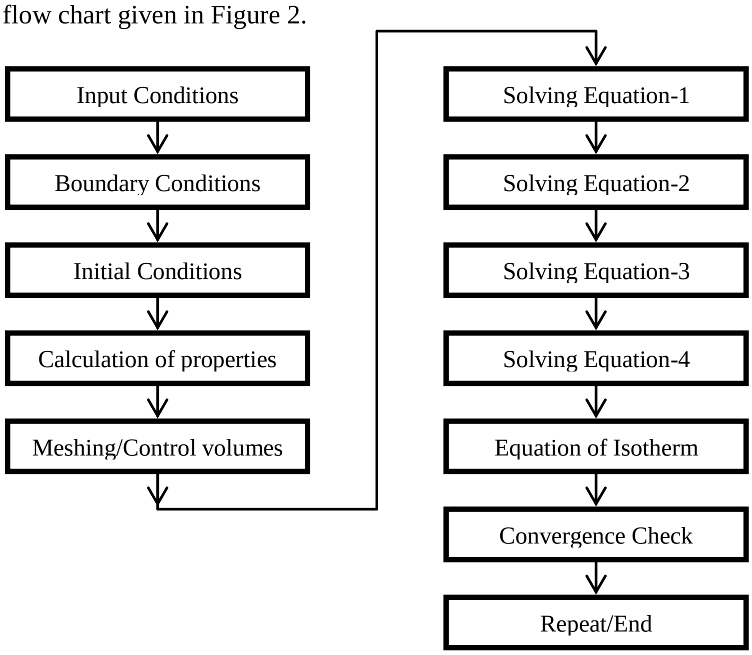

Fig. 2. Numerical modelling and methodology of solving governing equations

V. VALIDATION

The numerically simulated and predicted result of present model is compared with numerical results [1 & 2] and experimental results [3] from literature.

The numerical results of present model show a good agreement with experimental data for the moisture content and exit air temperature of process air during adsorption, as shown in Figure 3.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 8, Issue 1 , January 2021

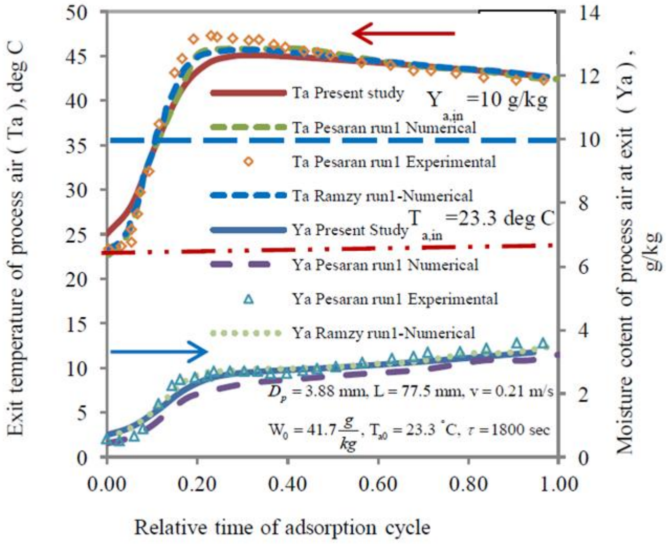

Fig. 3. Validation of numerical results with experimental results

VI. RESULTS AND DISCUSSION

The temperature of air and moisture content for the packed bed across the length for the various inlet moisture content from 5 to 20 g/kg are predicted by numerical model, as shown in Figure 4. It is evident that the temperature of process air is directly depending on the moisture content removal capacity, which is in turn related to the moisture content of process air at inlet.

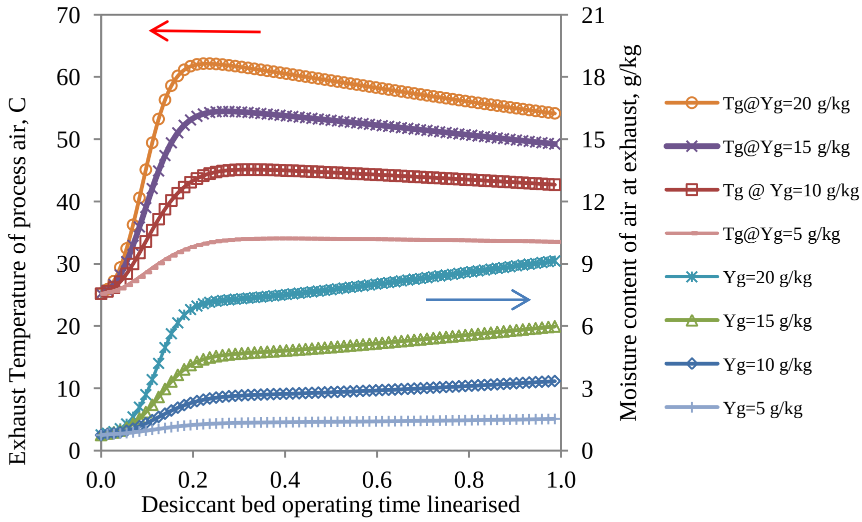

Fig. 4. Parametric simulation for calculation of temperature of process air for different inlet moisture and temperature

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 8, Issue 1 , January 2021

The corresponding moisture removal (MRC) capacity and relative moisture removal (RMRE) efficiency are plotted for the for the packed bed sections across the length for the various inlet moisture content from 5 to 20 gms/kg, as shown in Figure 4. It is seen that MRC is directly depending on the moisture content of process air at inlet, however, the RMRE is inversely proposal to inlet moisture content.

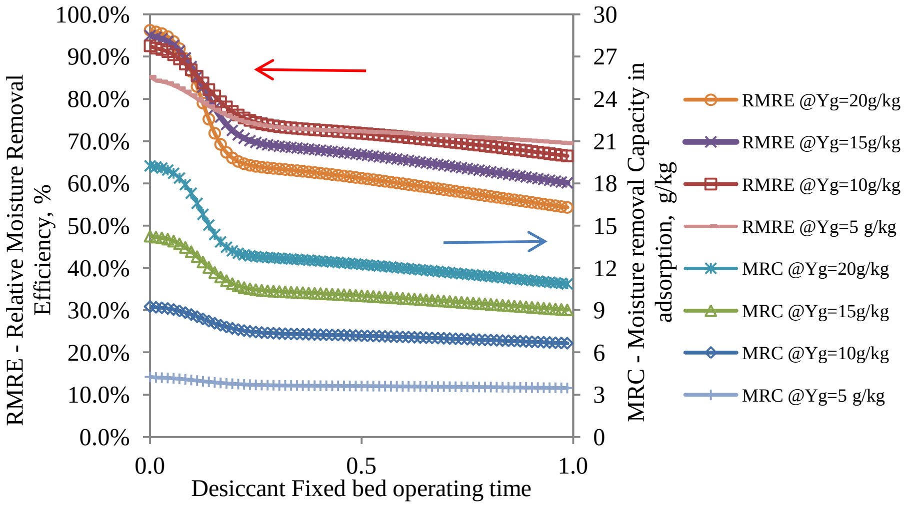

Fig. 5. Parametric simulation for calculation of RMRE and MRC for different inlet moisture and temperature

In Figure 5, is shown the relative humidity (RH) in % for the packed bed sections across the length, as the moisture removal capacity (MRC) is very aggressive and strong within the shorter length of bed at the inlet section, and hence the relative humidity (RH) drop is very significant (that is from 56% at inlet, it is dried and reduced to as low as 1% within 50% of the bed length from the inlet), hence in order to visualize the further reduction of moisture contents, a logarithmic scale is used for Y-axis in the relative humidity (RH) plots, a lowest value of 0.4% can be seen in this plot very clearly for both the MS bed and hybrid bed having 50% SG from the bottom of the bed and remaining 50% MS descants filled.

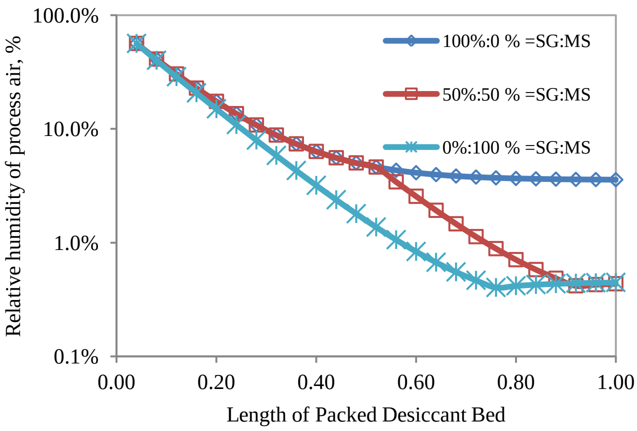

Fig. 6. Performance (RH) of hybrid stationary packed solid desiccant beds for 10 g/kg

For the plots of dew point temperature (DPT) values achieved over the packed bed length, a conventional linear scale is used. A it can be seen in Figure 7, that a lowest value of DPT of about – 39.3°C using the hybrid bed (50% : 50% of SG :MS), is shown in Figure 8 and Table-2, however,, the conventional MS bed gives a DPT of about -38.82°C.

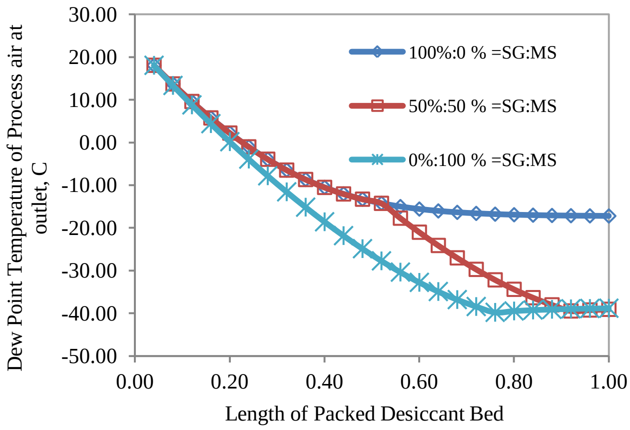

Fig. 7. Performance (DPT) of hybrid stationary packed solid desiccant beds for 10 gms/kg

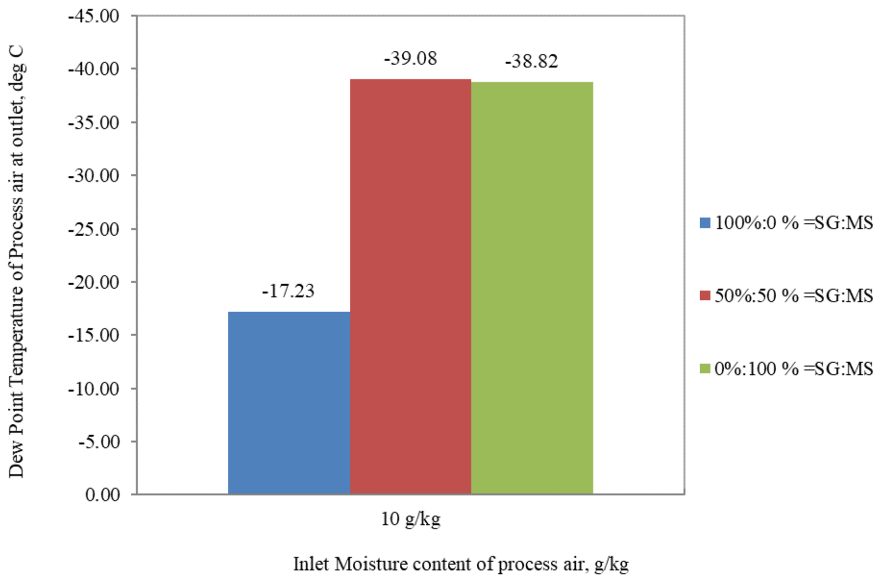

Fig 8: Performance (DPT) of hybrid packed bed

Table 2 : DPT Performance of the hybrid desiccant bed

Highest achieved Dew Point Temperature (°C)			
Inlet Moisture	100%:0 % =SG:MS	50%:50 % =SG:MS	0%:100 % =SG:MS
10 g/kg	-17.23	-39.08	-38.82

IJARSET

ISSN: 2350-0328

International Journal of AdvancedResearch in Science, Engineering and Technology

Vol. 8, Issue 1 , January 2021

VII. CONCLUSION

The numerical simulation model shows a very good agreement with experimental data from literature. The effect on moisture content and temperature of air at output are predicted under the various input moisture contents and temperatures.

The effect on moisture content and DPT of air at output are predicted under different moisture contents and temperatures of process air at input for the conventional Silica gel (SG), conventional molecular sieves (MS) beds and hybrid bed.

Hybrid bed with 50% of bed length with SG desiccant at the bottom and remaining 50% of bed length with MS desiccant is superior than the entirely MS bed, by which the cost of hybrid bed can be lower than this MS bed at the same time without compromising the performance.

As a future scope this simulation is to be used to predict the performance of hybrid desiccant beds for the drying and dhimmification applications.

REFERENCES

[1]. Ramzy Kattaya, Ahmed, Kadoli, Ravikiran, P. Ashok Babu, T. (2012). Performance studies on the desiccant packed bed with varying particle size distribution along the bed. International Journal of Refrigeration. 35. 663–675. 10.1016/j.ijrefrig.2011.11.016.

[2]. Pesaran AA, Mills AF., 1987,"Moisture transport in silica gel packed beds. I—theoretical study", International Journal of Heat Mass Transfer 30(6):1037–49.

[3]. Pesaran AA, Mills AF. Moisture transport in silica gel packed beds-II. Experimental study. Int J Heat Mass Transfer 1987; 30(6):1051–60.

[4]. P.L. Brillhart, Evaluation of Desiccant Rotor Matrices Using an Advanced Fixed- Bed Test System, Ph.D. Thesis, University of Illinois, Chicago, 1997

[5]. Muthu, S., Talukdar, P., and Jain, S. (November 11, 2015). "Effect of Regeneration Section Angle on the Performance of a Rotary Desiccant Wheel." ASME. J. Thermal Sci. Eng. Appl. March 2016; 8(1): 011013. doi: https://doi.org/10.1115/1.4030966

[6]. Muthu, S., Talukdar, P., and Jain, S., (2017) "Performance enhancement of rotary desiccant wheel by the innovative designs of multiple desiccant layers", Springer India, Fluid Mechanics and Fluid Power – Contemporary Research DOI https://doi.org/10.1007/978-81-322-2743-4_102

[7]. Muthu, S., Sekarapandian, N. (2019), Periodic transient performance prediction of the rotary desiccant wheel. Proceedings of the 46th National Conference on Fluid Mechanics and Fluid Power (FMFP) PSG College of Technology, Coimbatore, India.

[8]. Muthu, S., Sekarapandian, N. (2019), Numerical Analysis of Coupled Heat and Mass Transfer in Solid Desiccant for Stationary Hybrid Desiccants Beds. Proceedings of the 46th National Conference on Fluid Mechanics and Fluid Power (FMFP) PSG College of Technology, Coimbatore, India.

[9]. Muthu, S., Sekarapandian, N. (2019), Simulation of Hybrid Rotary Desiccant Wheels having Nonhomogeneous Mixture of Multiple Desiccants Types, Proceedings of the 25th National and 3rd International ISHMT-ASTFE Heat and Mass Transfer Conference, IIT Roorkee, Roorkee, India.

[10]. Muthu, S., Sekarapandian, N. (2020), Performance Enhancement of Rotary Desiccant Wheel using Novel Homogenous Composite Desiccant Designs, Proceedings of International Conference on Design, Automation and Control 2020, VIT Vellore, India.

DEFINITIONS/ABBREVIATIONS

Db	Diameter of the packed bed (m)	Le	Lewis number
Dp	Diameter of the solid desiccant particle (m)	Nu	Nusselt number
Cp	Specific heat capacity at constant pressure (kJ/kg K)	p	pressure (Pa)
DK	Knudsen diffusivity coefficient (m2/s)	Pa	Atmospheric pressure (Pa)
DO	Ordinary or molecular diffusivity coefficient (m2/s)	qst	heat of adsorption in J/kg desiccant
DS	Surface diffusivity coefficient (m2/s)	r	Pore radius of the desiccant particle (m)
k	Thermal conductivity (W/m K)	RH	Relative humidity (%)
Ky	Convective mass transfer coefficient (kg/m2 s)	Sh	Sherwood number
h	Convective heat transfer coefficient (kW/m2K)	q	Temperature (K)
L	Length of the packed bed (m)	t	Time

ISSN: 2350-0328

International Journal of AdvancedResearch in Science, Engineering and Technology

Vol. 8, Issue 1 , January 2021

u	Velocity (m/s)	**Subscripts**	
W	Adsorption in kg water vapour/kg desiccant	0	initial state
w	Humidity ratio, kg water vapour/kg dry air	a	air
z	axial direction	s	Solid desiccant
Greek symbols		p	process air
ρ	density (kg/m3)	r	regeneration air
ε	porosity		

AUTHOR'S BIOGRAPHY

Selvaraji Muthu, research scholar at Vellore Institute of Technology, having 22+ years of experience in-overall and mainly in to Research and Development, currently working as Senior General Manager with (1) MAHLE Engine Components India Pvt. Ltd, Chennai, heading the department to design and development of Pistons, Pin and Ring pack for Passenger gasoline and diesel vehicles, medium and heavy duty diesel Engine applications for OEMs in India. Earlier to Mahle , worked in (2) Subros Ltd, Noida on the design and development of refrigeration and air-conditioning compressors (swash plate , Vane and Scroll types) , (3) Kirloskar –Pneumatic, Pune on Screw compressors packaging, (4) Knorr-Bremse, Faridabad on Air supply unit (Air compressor and Air dryers) for Railway braking applications and (5) Elgi Equipments, Coimbatore on Design and development of Oil Free Screw compressor Airends for industrial, textile applications and had also worked in (6) Park College of Engg. And Tech. , Coimbatore in 1998-2000.
An ASME member since 2006, Member of SAE India since 2012 , Life member for ISHMT, member of design society.

Sekarapandian.N Associate professorat Vellore Institute of Technology, having 15+ years of experience in-overall encompassing Corporate Research and Development, Application engineering software development, Industrial consultancy and Academic teaching/research, currently working as Associate Professor with Vellore Institute of technology, Vellore in the Department of Thermal and Energy, School of Mechanical Engineering. Earlier to VIT worked in Analzyer CAE solutions Pvt Ltd, Pune (2017-2018), SABIC research and technology Pvt Ltd, Bangalore (2013-2017), Fluidyn Software and Consultancy Pvt Ltd., Bangalore (2010-2012), Half Time teaching Research Associate, IIT Madras (2005-2010) and had worked in Karpagam College of Engg. And Tech., Coimbatore in 2003-2005. Have a doctorate in Computational Fluid Dynamics from IIT Madras, Completed Master of Engineering in Design and production of thermal power equipment from NIT (2003), Trichy and Bachelor of Engineering in Mechanical Engineering (2001) from Park College of Engineering and Technology, Coimbatore. TRIZ Level 2 Certified Practitioner.