

Carbon Dioxide Reduction in Gasoline Engine - A Comparative Study

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ABSTRACT: We have undertaken a study to artificially reduce carbon dioxide using different catalysts in a gasoline passenger car as our continued effort to control carbon dioxide in the atmosphere. Carbon dioxide absorption/adsorption efficiency from the exhaust gas stream using different catalysts such as activated charcoal, activated alumina, ZSM-5 zeolite and activated ZSM-5 zeolite shows a clear trend and dependency on the mass flow rate and surface properties of catalysts. The CO₂ absorption efficiency of these catalysts are measured at two different engine operating conditions and are compared. The CO₂ reduction on activated charcoal at 700 rpm and 2500 rpm are 0.48% and 0.38% respectively, the CO₂ reduction on activated alumina at 700 rpm and 2500 rpm are 7.35% and 6.61% respectively, the CO₂ reduction on ZSM-5 zeolite at 700 rpm and 2500 rpm are 6.46% and 45.48% respectively and the CO₂ reduction on activated ZSM-5 zeolite at 700 rpm and 2500 rpm are 52.3% and 46.12% respectively. The CO₂ absorption / adsorption performance at 700 rpm and 2500 rpm shows a consistent variation proportional to mass flow rate in all the four catalysts. High efficiency is observed at lower rpm and low efficiency is observed at higher rpm showing the mass flow rate and thus residence time control the performance. The relatively low performance of activated charcoal derived from coconut shell is also due to low surface area and porosity. The highest activity of activated ZSM-5 zeolite is due to increased Bronsted acidic site which facilitates CO₂ adsorption.

KEYWORDS: Catalytic reduction of CO₂, Gasoline passenger car, Activated alumina, ZSM-5 zeolite, Activated ZSM-5 zeolite, Activated charcoal, Coconut shell.

I. INTRODUCTION

The world is moving towards a crucial new climate agreement which could provide the long-needed global plan to slow down climate change and enable humanity to adapt to the unavoidable part of a changing climate [1,2]. While recognizing that some climate change is unavoidable, researchers and innovators are working on procedures to limit global warming to 2°C in this century, relative to the pre-industrial period. Further, they have decided to review this limit to see if it should be further lowered to 1.5°C. Given the aim to limit global temperature, the critical question has now become what level of emission would make this possible. The enhanced greenhouse effect changes the climate and pollutes the environment [3,4]. The greenhouse gases result in the global warming and uncontrollable climate change, floods, draughts and famine. Carbon dioxide is one of the major components of greenhouse gases results in enhanced greenhouse effect. CO₂ is the main contributor for greenhouse gases and enhanced greenhouse gases causing the significant impact on climate change, storm patterns and increased tide height and sea levels. Abnormal climate change and uncontrolled natural calamities and catastrophes are increasing in the recent years. Due to that the level of carbon dioxide in the atmosphere is rising significantly [5-7]. CO₂ originates from human impact on the environmental emissions as a consequence of the consumption of fossil fuels. The impact of carbon dioxide on the environment, health and societal welfare is illustrated in figure 1.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

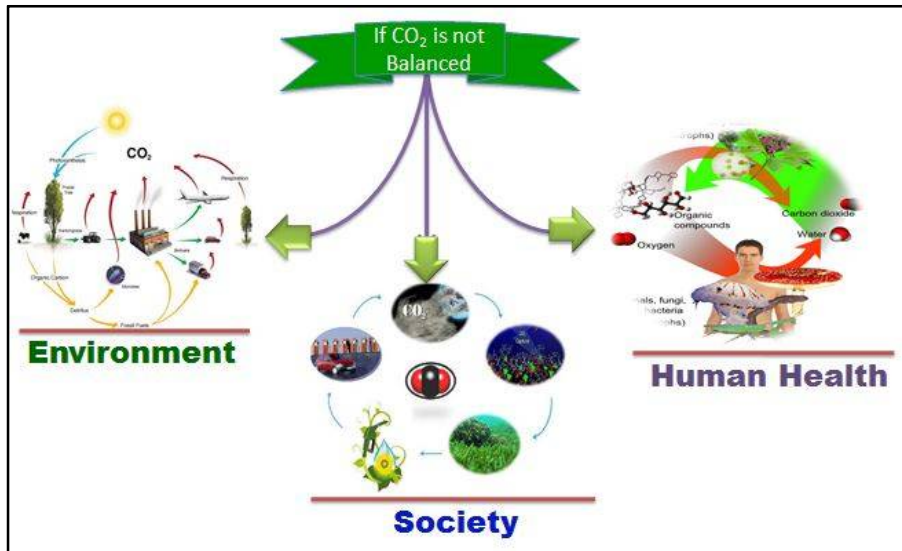


Figure 1. The Impacts of Carbon dioxide

Carbon dioxide is produced when any substance containing carbon is burnt. It is also a product of breathing and of fermentation. Plant absorbs carbon dioxide through photosynthesis, and plants and soil return CO₂ emission from various sources through respiration performed by plants and animals, decay of plants and animal matter, Burning fossil fuels such as coal, petroleum products and natural gas releases carbon. Carbon dioxide is released when limestone (calcium carbonate) is heated to produce lime. A variety of human activities lead to the emission (sources) and removal (sinks) of carbon dioxide (CO₂). The breakdown of CO₂ from various sources is shown in the figure 2.

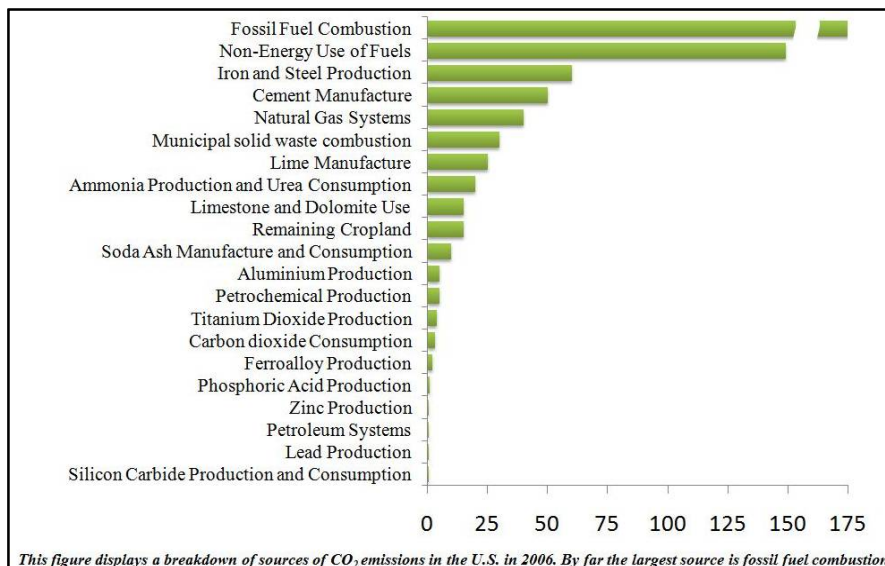


Figure 2. Production of carbon dioxide from various sources

As seen in figure 2, the largest source of CO₂ emission is the combustion of fossil fuels such as coal, oil and gas in power plants, automobiles, industrial facilities and other sources. The exponential growth of mobility sector in the current century causes the higher production of CO₂[8,9]. There are many naturally reducing sources of carbon dioxide from the atmosphere is available, Carbon sequestration is the process by which growing trees and plants absorb or remove CO₂ from the atmosphere and turn it into biomass (e.g., wood, leaves, etc.). Deforestation, conversely, can lead

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

to significant increase of CO₂ emissions in the atmosphere. Consequently, the residual growth of carbon dioxide in the atmosphere is increasing. A representative example of the CO₂ production from few passenger cars and reduction by few trees and the gap between the production and reduction is shown in Figure 3 [5].

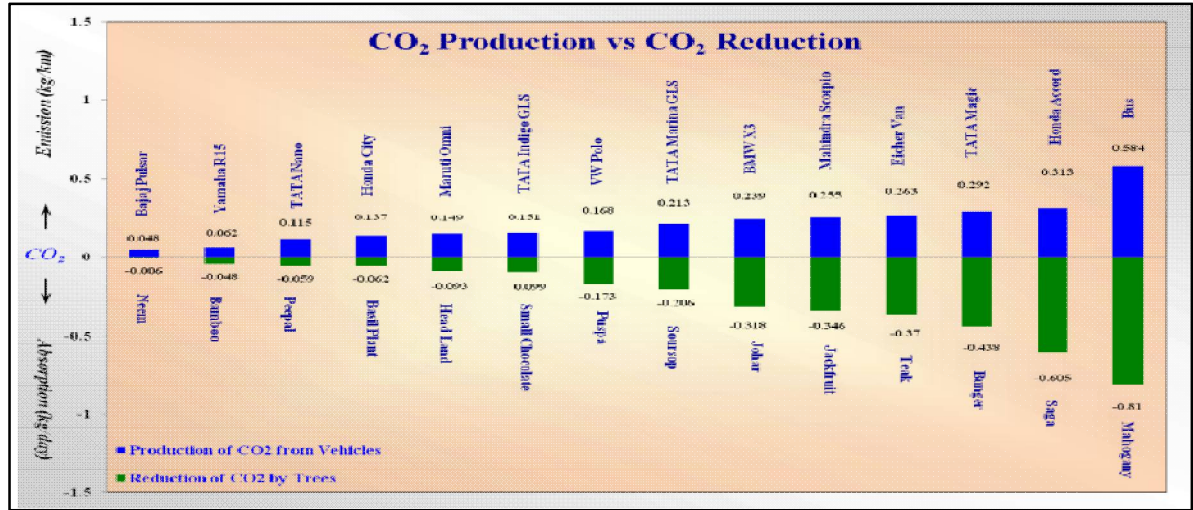


Figure 3. The gap between CO₂ production and consumption

This demands the need for fixing CO₂ concentration in the atmosphere. Though, several activities such as planting tree and green development to reduce CO₂ and also development of fuel efficiency in combustion to minimize the production of CO₂, the gap seems to be continuously growing. Hence, artificial methods to reduce CO₂ are required. The different ways of reducing CO₂ both by natural processes and also by artificial methods are illustrated in figure 4 [10].

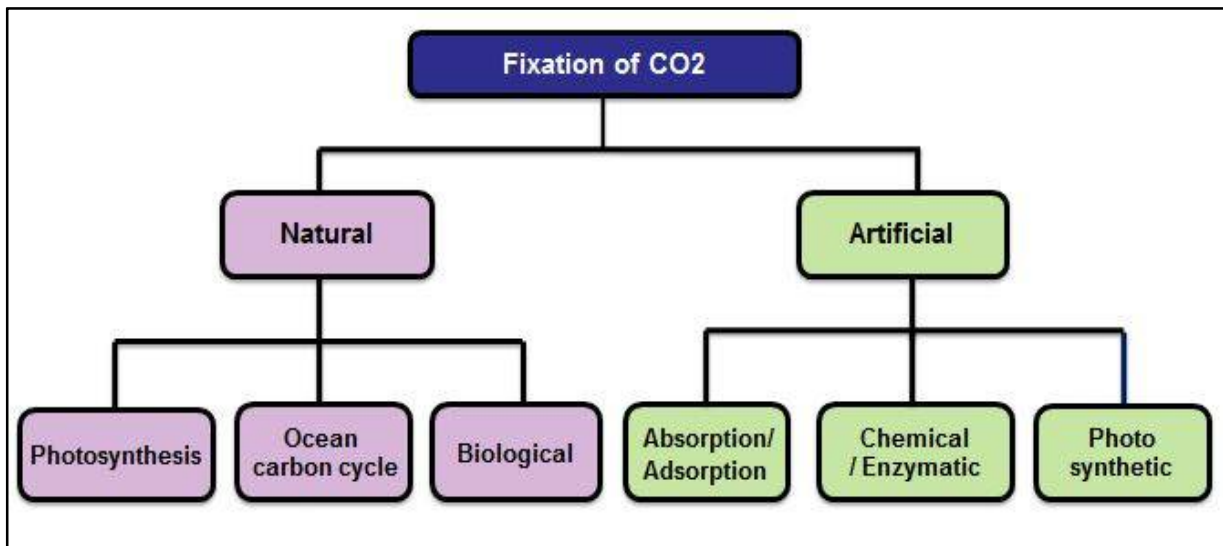
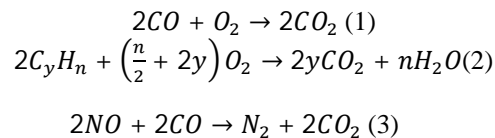


Figure 4. Methods of CO₂ fixation

Our current study is to artificially reduce CO₂ using different catalysts such as activated charcoal granule, activated alumina sphere, ZSM-5 zeolite pellet and activated ZSM-5 zeolite capsule. A comparative study of CO₂ adsorption/absorption at a given experimental condition is presented in this paper.

II. SCHEMATIC REPRESENTATION OF CO₂ REDUCTION IN GASOLINE VEHICLE

The gasoline-burnt internal combustion engines emit regulated gases such as CO, NO_x, and HC. They are converted into CO₂, H₂O, and N₂ by three-way catalytic converter (TWC) as described in the equations.



The products coming out of the three-way catalyst system contain CO₂, H₂O, N₂, O₂, etc. The slip stream of the exhaust gas coming out of the TWC, rich in CO₂, is then passed through a fixed-bed CO₂ absorption/adsorption catalyst chamber as shown in Figure 5.

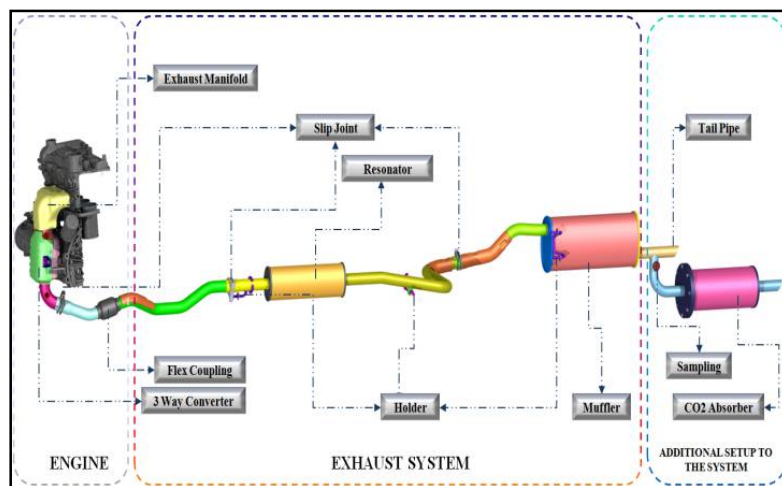


Figure 5. The Schematic of the CO₂ reduction in gasoline engine

Heterogeneous catalytic absorption/adsorption is carried out in a tubular reactor of one type or another. Fixed-bed tubular reactor and tubular honeycomb structures are used in the current study. The materials used for CO₂ reduction is chosen to have the absorption and adsorption characteristics. Catalysts are usually loaded on high surface area porous support materials. Charcoal, alumina and ZSM-5 zeolite are few materials supports used in our current study.

III. CATALYST FROM DIFFERENT SOURCE

Charcoal from coconut shell is prepared by controlled firing of the raw materials. Charcoal is porous and can absorb liquids and gases on its porous surface. A representative sample of the activated charcoal granule from coconutshell is shown in Figure 6a. Activated alumina used in our studies is in the spherical form, with a size of approximately 5-8mm diameter and surface area between 360-480 m²/g (Figure 6b). ZSM-5 zeolite is used as pellets (Figure 6c) and activated ZSM-5 zeolite is used as capsules (Figure 6d). Activation of zeolite is carried out by ion exchange process. The resultant zeolite has increased amount of Bronsted acidic site.



Figure 6. Various catalyst used for CO₂ absorption/adsorption

IV. THE REACTOR MODEL

The CO₂ absorption studies are carried out using the absorption chamber filled with the catalyst material. The absorption chamber is chosen to minimize catalyst abrasion. The diameter of the cylindrical chamber is 100 mm and the length is 300 mm. The child parts and assembly of the reactor chamber is shown in figure 7 a, b and c. The CO₂ absorption studies are carried out using the absorption chamber filled with the catalyst material. Absorption chamber is chosen to minimize catalyst abrasion. The catalyst filled reactor chamber is attached at the tail end of the exhaust system through a slip stream for performance evaluation.

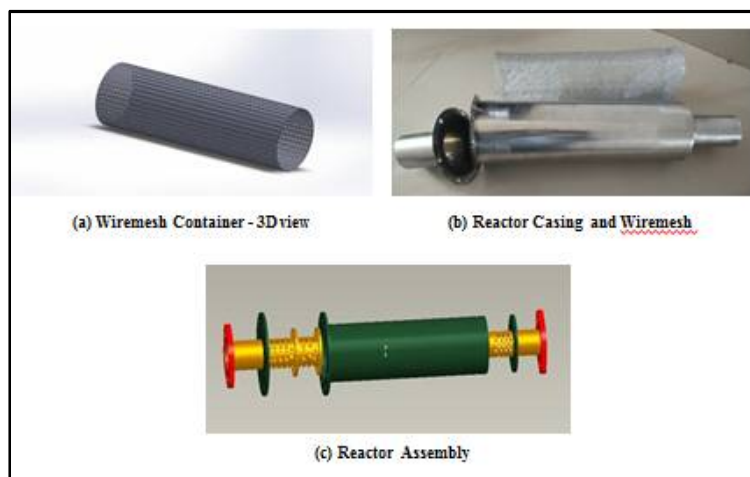


Figure 7. CO₂ Reduction reactor chamber model

The reactor design and the catalyst chamber are chosen to have the full catalyst utilization. The gas flow uniformity is studied using computational fluid dynamic simulation method. Star CCM+ software is utilized to perform CFD analysis. As seen in figure 8, the flow uniformity is the maximum at the centre of the reactor to get the best performance.

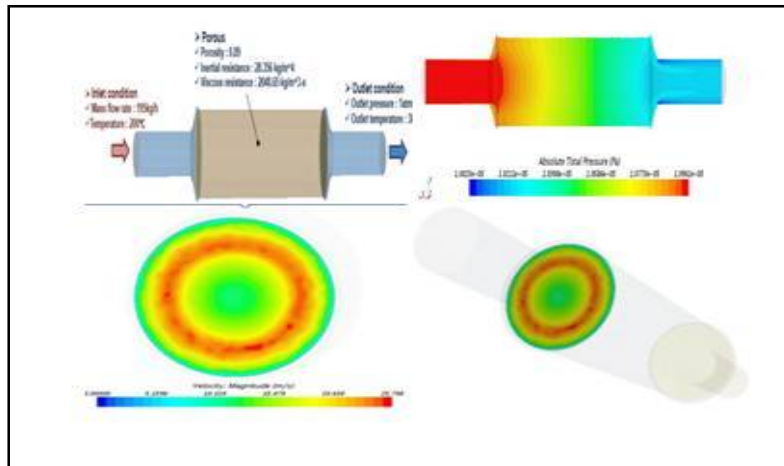


Figure 8. Computation Flow Uniformity of the reactor assembly

V. VEHICLE TEST ASSEMBLY FOR CO₂ REDUCTION STUDY

The CO₂ reduction is studied from the exhaust gas at the tail pipe of the gasoline passenger car as shown in figure 9.



Figure 9. CO₂ Reduction catalyst assembly at the tail pipe

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The exhaust gas is passed through a three-way catalyst to convert NO_x, HC, and CO. The gas coming of TWC, rich in CO₂, is passed through a CO₂ reduction catalyst chamber as shown in Figure 9. A constant volume sampling method is used to analyze the exhaust gas stream. The gas analyzer capable of analyzing CO, CO₂, HC, and NO_x is used in this application. Results are reproduced by repeated experiments under identical test conditions. Samples are taken before and after the CO₂ absorption catalytic chamber for quantitative measurement of CO₂ reduction. The physical capture of CO₂ on activated charcoal, activated alumina, ZSM-5 Zeolite and activated ZSM-5 Zeolite are studied at two different engine operating conditions (700 RPM and 2500 RPM). The quantitative reduction of CO₂ of the absorption and adsorption efficiencies is calculated and compared in Table 1.

Table 1.CO₂ Reduction Performance Comparison

| S.NO | Catalyst | RPM | % CO ₂ | CO ₂ Reduction as a function of RPM |
|------|----------------------------------|------------|-------------------|---|
| 1 | Activated Charcoal | 700 & 2500 | 0.48 | i. When RPM 700 CO ₂ reduction 0.48% ii. When RPM 2500 CO ₂ reduction 0.38% |
| 2 | Activated Alumina | 700 & 2500 | 7.35 | i. When RPM 700 CO ₂ reduction 7.35% ii. When RPM 2500 CO ₂ reduction 6.61% |
| 3 | ZSM-5 Zeolite Pellet | 700 & 2500 | 6.46 | i. When RPM 700 CO ₂ reduction 6.46% ii. When RPM 2500 CO ₂ reduction 5.48% |
| 4 | Activated ZSM-5 Zeolite Capsules | 700 & 2500 | 52.3 | i. When RPM 700 CO ₂ reduction 52.3% ii. When RPM 2500 CO ₂ reduction 46.12% |

As shown in Table 1, the CO₂ reduction on activated charcoal at 700 rpm and 2500 rpm are 0.48% and 0.38% respectively, the CO₂ reduction on activated alumina at 700 rpm and 2500 rpm are 7.35% and 6.61% respectively. , the CO₂ reduction on ZSM-5 Zeolite at 700 rpm and 2500 rpm are 6.46% and 45.48% respectively and the CO₂ reduction on activated ZSM-5 Zeolite at 700 rpm and 2500 rpm are 52.3% and 46.12% respectively. Activated charcoal derived from coconut shell shows relatively low efficiency compared to that of the activated alumina and ZSM- 5 Zeolite may be due to low surface area and porosity. Activated alumina and ZSM-5 zeolites are showing relatively similar efficiency where as activated ZSM-5 zeolite show very high absorption/adsorption characteristics. This may be due to increased Bronsted acidic site in the activated ZSM-5 zeolite which facilitates CO₂ adsorption. This shows that chemical adsorption and catalytic reduction is more efficient than physical adsorption as adsorption is limited to physical nature of the catalyst. The variation of CO₂ adsorption/adsorption at two different engine operating conditions is due to effect of mass flow rate. At low rpm, the gas flow is low and the residence time of the exhaust gas is higher, consequently CO₂ adsorption/adsorption is higher. Similarly at high rpm, the gas flow is high and the residence time of the exhaust gas is lower, consequently CO₂ adsorption/adsorption is lower.

VI. SUMMARY AND CONCLUSION

Carbon dioxide absorption / adsorption efficiency from the exhaust gas stream using different catalysts such as activated charcoal derived from coconut shell, activated alumina, ZSM-5 zeolite and activated ZSM-5 zeolite shows a clear trend and dependency on the mass flow rate and surface properties of catalysts. The CO₂ reduction on activated charcoal at 700 rpm and 2500 rpm are 0.48% and 0.38% respectively, the CO₂ reduction on activated alumina at 700 rpm and 2500 rpm are 7.35% and 6.61% respectively, the CO₂ reduction on ZSM-5 zeolite at 700 rpm and 2500 rpm are 6.46% and 45.48% respectively and the CO₂ reduction on activated ZSM-5 zeolite at 700 rpm and 2500 rpm are 52.3% and 46.12% respectively.

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46.12% respectively. The absorption / adsorption performance of CO₂ at 700 rpm and 2500 rpm shows a consistent variation proportional to mass flow rate in all the four catalysts. Higher efficiency is observed at lower rpm and lower efficiency is observed at lower rpm showing the mass flow rate direct dependency. The relative lower efficiency of activated charcoal from coconut shell is also due to low surface area and porosity and the highest activity of activated ZSM-5 zeolite is due to increased Bronsted acidic site which facilitates CO₂ adsorption along with conventional absorption.

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BIOGRAPHY



Dr. S. Rajadurai, born in Mylaudy, Kanyakumari District, Tamil Nadu, India, received his Ph.D. in Chemistry from IIT Chennai in 1979. He has devoted nearly 37 years to scientific innovation, pioneering theory and application through the 20th century, and expanding strides of advancement into the 21st century. By authoring hundreds of published papers and reports and creating several patents, his research on solid oxide solutions, free radicals, catalyst structure sensitivity, carbon dioxide reduction and emission control has revolutionized the field of chemistry and automobile industry.

As a corporate executive in the United States and India for over three decades, Dr. Rajadurai managed strategy on power train development and emission control for low, ultra low, super ultra low and partial zero-emission systems. From 1990-1996, he was the Director of Research at Cummins Engine Company. He was the Director of Advanced Development at Tenneco Automotive between 1996 and 2002 and subsequently Emission Strategist and Director of

Emissions at ArvinMeritor until 2004. From 2004-2009, he was Vice-President of ACS Industries and since 2009 as President & CEO and Head of R&D Sharda Motor Industries Ltd.

Dr. Rajadurai has held leadership positions on the Board of Directors for the U.S. Fuel Cell Council, Manufacturers of Emission Control Association (MECA), Chairman of MECA Committee on Advanced Technologies and Alternate Fuels and Walker Exhaust India. He is an active participant in Clean and Green Earth Day demonstrations since 1997 and US Clean Diesel School Bus Summit (2003). He was a panelist of the Scientists and Technologists of Indian Origin, New Delhi 2004. He is a Fellow of the Society of Automotive Engineers. He was the UNESCO representative of India on low-cost analytical studies (1983-85). He is a Life Member of the North American Catalysis Society, North American Photo Chemical Society, Catalysis Society of India, Instrumental Society of India, Bangladesh Chemical Society and Indian Chemical Society.



Ms. J. Maya, born in Piracode, Kanyakumari District, Tamil Nadu, India is a Senior Executive – Professional Management working at Research and Development, Sharda Motor Industries Ltd., a global automotive component development and manufacturing Industry. Maya graduated in Electronics and Communication Engineering from AnnaiVailankanni College of Engineering, Kanyakumari, Tamil Nadu, India (2015). She is also an M.B.A. Post Graduate from Madras University. She had undertaken a special project on "Value implementation of tube mill operations and its control system - A TPM Approach" for yield improvement at Sharda Motor Industries. She had attended National Workshop on "Role of control system on Engineering" at DMI College, Aralvaimozhi (2014) and "Competency Development" at AnnaiVailankanni College of Engineering (2015). Maya is working with Mylaudy Dr. Rajadurai, Head of R&D, on emission control projects. She is working on environmental research activities including understanding of global warming, climate change, carbon dioxide control etc.. She is working on global warming reduction and carbon dioxide control projects. She had been

co-ordinating Graduate and Post Graduate research projects at Sharda Motor with Universities and Colleges. She shows keen interest in developing engineers through professional training and support.