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Nikhil Sharma · Avinash Kumar Agarwal
Peter Eastwood · Tarun Gupta
Akhilendra P. Singh *Editors*

Air Pollution and Control

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Preface

Energy demand has been rising remarkably due to increasing population and urbanization. Global economy and society are significantly dependent on the energy availability because it touches every facet of human life and activities. Transportation and power generation are major examples of the energy. Without the transportation by millions of personalized and mass transport vehicles and availability of 24×7 power, human civilization would not have reached contemporary living standards.

First international conference on 'Sustainable Energy and Environmental Challenges' (SEEC-2017) was organized under the auspices of 'International Society for Energy and Environmental Sustainability' (ISEES) by the 'Center of Innovative and Applied Bioprocessing' (CIAB), Mohali, from 26–28 February 2017. The ISEES was founded at IIT Kanpur in January 2014 with an aim to spread knowledge in the fields of energy, environment, sustainability and combustion. The Society's goal is to contribute to the development of clean, affordable and secure energy resources and a sustainable environment for the society and to spread knowledge in the above-mentioned areas and spread awareness about the environmental challenges, which the world is facing today. The ISEES is involved in various activities such as conducting workshops, seminars, conferences, etc., in the domains of its interests. The Society also recognizes the outstanding works done by the young scientists and engineers for their contributions in these fields by conferring them awards under various categories.

This conference provided a platform for discussions between eminent scientists and engineers from various countries including India, USA, South Korea, Norway, Malaysia and Australia. In this conference, eminent speakers from all over the world presented their views related to different aspects of energy, combustion, emissions and alternative energy resource for sustainable development and cleaner environment. The conference started with four mini-symposiums on very topical themes, which included (i) new fuels and advanced engine combustion, (ii) sustainable energy, (iii) experimental and numerical combustion and (iv) environmental remediation and rail road transport. The conference had 14 technical sessions of topics related to energy and environmental sustainability and a panel

discussion on 'Challenges, Opportunities and Directions of Technical Education & Research in the Area of Energy, Environment and Sustainability' to wrap up the three days technical extravaganza. The conference included two plenary talks, 12 keynote talks, 42 invited talks from prominent scientists, 49 contributed talks and 120 posters. Total 234 participants and speakers attended this three days conference, which hosted Dr. V. K. Saraswat, Member NITI Ayog, India, as a chief guest for the award ceremony of the ISEES. This conference laid out the roadmap for technology development, opportunities and challenges in this technology domain. The technical sessions in the conference included advances in IC engines and fuels; conversion of biomass to biofuels; combustion processes; renewable energy: prospects and technologies; waste to wealth—chemicals and fuels; energy conversion systems; numerical simulation of combustion processes; alternate fuels for IC engines; sprays and heterogeneous combustion of coal/biomass; biomass conversion to fuels and chemicals—thermochemical processes; utilization of biofuels; and environmental protection and health. All these topics are very relevant for the country and the world in present context. The society is grateful to Prof. Ashok Pandey for organizing and hosting this conference, which led to germination of this series of monographs, which included 16 books related to different aspects of energy, environment and sustainability. This is the first time that such voluminous and high quality outcome has been achieved by any society in India from one conference.

The editors would like to express their sincere gratitude to the authors for submitting their work in a timely manner and revising it appropriately at a short notice. We would like to express our special thanks to Dr. Varun Goel, Dr. R. Anand, Dr. M. Udaya Kumar, Prof. R. S. Bharj, Dr. Shijo Thomas, Dr. Niraj Kumar, Mishra, Dr. T. N. Verma, Dr. Pravesh Chandra Shukla, Dr. Chetankumar Patel, Dr. S. K. Verma, Dr. Akhilendra Pratap Singh, Dr. Joonsik Hwang, Dr. Rohit Singla, Paramvir Singh and Nikhil Sharma who reviewed various chapters of this monograph and provided their valuable suggestions to improve the manuscripts. We acknowledge the support received from various funding agencies and organizations for the successful conduct of the first ISEES conference (SEEC-2017), where these monographs germinated. These include Department of Science and Technology, Government of India (Special thanks to Dr. Sanjay Bajpai); TSI, India (Special thanks to Dr. Deepak Sharma); Tesscorn, India (Special thanks to Sh. Satyanarayana); AVL, India; Horiba, India; Springer (Special thanks to Swati Mehershi); CIAB (Special thanks to Dr. Sangwan).

This volume covers the practices and technologies that are applied to the prevention of air pollution and control. Greenhouse gas emissions, urban air quality and growing petroleum consumptions are the three challenges faced by the society anywhere in the world. This book covers all aspects related to air pollution including major sources of air pollution, measurement techniques, modelling studies and solution approach to control air pollution. This book also emphasizes on vehicles as major source of air pollution and shows the quantitative analysis of engine exhaust emissions. Focus on particulate matter as major pollutant from engines and coal-fired power plants is another important aspect of this book. Few

chapters are also based on emission control techniques using different aftertreatment devices. This monograph aims to strengthen the knowledge base dealing with air pollution. This monograph is intended for air pollution practitioners, and we hope that the book would be of great interest to the professionals, postgraduate students involved in environmental studies.

Kanpur, India — Nikhil Sharma
Kanpur, India — Avinash Kumar Agarwal
Basildon, UK — Peter Eastwood
Kanpur, India — Tarun Gupta
Kanpur, India — Akhilendra P. Singh

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Part I
General

Introduction to Air Pollution and Its Control

Nikhil Sharma, Avinash Kumar Agarwal, Peter Eastwood, Tarun Gupta and Akhilendra Pratap Singh

Abstract Air pollution prevention is an economic burden to a person and to a nation on a global scale. Air pollution is a threat to human and environment; therefore, it is extremely important to understand fundamental sources, causes, health effects associated with air pollution. This monograph gives an overview about air pollution and suggests the suitable preventive measures to reduce air pollution. This monograph includes air pollution from IC engines, primary organic aerosols (POAs), effect of volatile organic compounds (VOCs) on health and some advanced topics such as numerical simulation of airflow in hospital. This monograph also includes various engine technologies such as multipoint port fuel injection (MPFI), common rail direct injection (CRDI), indirect injection engine (IDI) and gasoline direct injection (GDI) techniques to reduce air pollution from road transport sector. Nuclear pollution, which is another threat for human life and environment is discussed towards end of this monograph.

Keywords Air pollution · IC engine · Particulate and aerosols Numerical simulations

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1 Introduction

Air pollution may be defined as the presence of undesirable material such as motor vehicle exhaust, exhaust from factories, construction in the atmosphere, which is large enough in quantity to produce adverse health effect to all living organisms and environmental. In last few decades, air pollution became a global concern due to adverse health effects and other environmental issues such as global warming, poor visibility, etc. There are primarily two sources of air pollution in the atmosphere; (1) Natural emissions; and (2) Anthropogenic emissions. Anthropogenic emissions are produced by internal combustion (IC) engines and furnaces via combustion. IC engine has made our life more convenient; however, in return for this convenience, automobiles have caused air pollution which has lead to adverse health effect. Expanding area of cities, rising traffic jams, higher energy consumption, rapid economic development are directly associated to air pollution.

Air pollution is divided into two categories—primary and secondary air pollution. Primary pollutants are those which are emitted directly from a source like exhaust of automobile, industries, burning of fossil fuels. Some of them include hydrocarbons, carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxide, particulate matter. A secondary pollutant is a product of reaction among the primary pollutants or with water vapour and sunlight; examples are sulphuric acid, ozone, peroxy-acyl-nitrate (PAN), etc.

The **second part** of monograph is concerning air pollution from IC engines. Various technologies such as MPFI, CRDI, GDI, diesel engine and IDI have been discussed in this section. Among these technologies diesel engines are widely utilized as a power source in various applications, such as construction equipment, passenger and commercial vehicles, marine transportation and electricity generation from gensets. In spite of several advantages in diesel engines, they have high NO*x* and soot emissions, which lead to global warming, acid rain and photochemical smog. First two sections of this book deal with two techniques namely; (a) Active control and (b) Passive control techniques. Active control techniques are those which restrict the formation of the pollutants in the combustion chamber and passive control techniques refer to use of after-treatment devices for emission reduction. Active control techniques include improved combustion chamber design, use of engine control unit (ECU), exhaust gas recirculation (EGR), optimized fuel injection strategy, use of advanced combustion techniques such as homogeneous charge compression ignition (HCCI), premixed charge compression ignition (PCCI). Use of high pressure common rail direct injection (CRDI) system is another active control technique, which offers significant improvement in engine performance and emission characteristics compared to the conventional mechanical fuel injection system. Application of EGR is another important method for controlling the NOx emissions in IC engines. However, to meet the current stringent emission norms, passive control techniques are also required in addition to active control techniques. In passive control techniques, various after-treatment devices such as diesel oxidation catalyst (DOC), diesel particulate filter (DPF), NO_x absorbers,

selective catalytic reduction (SCR) are employed to reduce different harmful species from engine tail pipe.

Alternatives fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG), hydrogen and renewable liquid fuels namely biodiesel, ethanol can also be used in IC engines to reduce the engine out emissions. Among these alternative fuels, biodiesel has been adopted to replace mineral diesel, which suppresses the formation of soot precursors in diffusion flames. One chapter of this monograph discussed the effect of biodiesel on soot particles in diesel engines. This chapter included the morphological characteristics of soot particles along with its chemical composition determined by the elemental analysis (EA) and thermo-gravimetric analysis (TGA).

Age of the vehicles is another issue related to air pollution because in rural areas as well as in cities of India old vehicles are still used. In one of the chapters, authors have attempted to study the emission characteristics of BS-III commercial diesel auto rickshaws operating in the city of Imphal, Manipur, India. Advanced technologies such as GDI also contribute to air pollution. Particulates from GDI engines are of different sizes such as coarse, fine and ultra-fine and they also vary in composition and origin. Particulate of different sizes is known to cause adverse health effects. In one of the chapters, fundamental aspects of both homogeneous and stratified modes of combustion of GDI engines have been discussed, in addition to wall, spray and air-guided GDI engine concepts. A section of chapter covers detailed comparison of particulate emitted by GDI and MPFI engines. Various size and concentration-based PM measurement technique and instruments available commercially are included in this section. A discussion on influence of engine load, fuel type and spray characteristics on particulate emissions are elaborated towards the end of this chapter in addition to GDI soot morphological studies.

The **third part** of the book is about particulate and POA. Atmospheric aerosols are microscopic solid particles in atmosphere and organic aerosol (OA) is a dominant component of atmospheric aerosol. OA is carbon-containing compounds and plays a critical role in affecting air quality of a region and change climate to a greater extent. OA is of two type's primary and secondary organic aerosols (SOAs). POA is freshly emitted organic mass in the atmosphere in particulate form and is an important subject of ongoing research for both air quality and climate. POA constitutes the emissions from both natural and anthropogenic aerosol particles ranging in size from a few nanometres to several tens of microns. Another class of primarily emitted volatile species, i.e. intermediate volatile organic compounds (IVOCs), present around 0.28–2.5 times of POA, potential SOA precursors, also goes unnoticed. This suggests that the policymakers and environmental regulating authorities need to take into account the secondary volatile organic compounds (SVOCs) and IVOCs causing positive and negative sampling artefacts in order to correctly account for POA source contributions. VOCs are one of them which are carcinogenic and lead to photochemical reactions. Emissions of VOCs are directly associated with large number of industrial processes, emission through transportation and various indoor and outdoor sources. A section of book focuses on the major sources of carbonyl and aromatic compounds in indoor and outdoor. Some

remedial processes like photo-catalytic oxidation, plasma decomposition, chemisorption and catalytic oxidation have been described in this study through which decomposition of these contaminants can be achieved. This part of monograph contains a deep study on health effects from the carbonyl and aromatic compound.

The forth part of the book is about numerical simulation related to air pollution. Two important concepts have been touched in this section of monograph (a) modelling of soot formation in diesel engine (b) airflow in a room of the ICU. In this part of monograph, the various theories associated with the soot formation like soot inception, coagulation, agglomeration, oxidation are discussed. Also, the results of the numerical studies carried out by the authors on diesel-air flames at laboratory conditions are briefly presented. IAQ helps to maintain healthy and productive indoor environments. In this context, one chapter deals with air pollution in Healthcare place, the importance of ventilation in a hospital environment, indoor air pollutants and transmission of contaminants and airborne particle inside the infirmary. In this work, simulation of airflow in a room of the ICU has carried away to examine airflow pattern using FLUENT 15 CFD software. The study predicts room airflow information in terms of velocities, temperatures and contaminant distributions which are beneficial for infection control, building layout investigation.

In the last section of this monograph, two important aspects related to porous media and environmental issues related to nuclear power are discussed. First chapter describes the significant development to attain lower emissions and higher thermal performances. This chapter shows that changing the operating parameters and design configurations of the porous radiant burners, good emission characteristics and higher thermal efficiency can be achieved. This book chapter also summarizes the development of various porous radiant burners used in both industrial and cooking applications. The other chapter is related to environmental issues associated with nuclear power. This chapter emphasizes on radioactive wastes, which are produced from nuclear power plants. Discharges from nuclear power plant can cause substantial climatic contamination, which results in harmful health effects. In last chapter, different techniques for modelling and control of hazardous material have been presented. The modelling is in view of recreation and perception of spreading of air pollutants, estimation of the source term for atomic and compound fiascos and the hazard appraisal of unsafe substances. This chapter includes the principle of modelling the nuclear and chemical disasters, optimal control of theoretical frame with example, various modelling techniques, challenges associated with measurement of pollutants.

This monograph presents both fundamental science and applied emerging technologies for emission reduction from various sources. Particulate emitted from engines directly affect human health and environment therefore major part of this monograph is on particulate characteristics and its control techniques. Specific topics covered in the manuscript include:

- Simultaneous Control of Oxides of Nitrogen and Soot in CRDI Diesel Engine using Split Injection and Cool EGR Fuelled with Waste Frying oil Biodiesel and its Blend,
- Biodiesel Soot Characteristics,
- Techniques to Control Emissions from a Diesel Engine,
- BS-III Diesel Vehicles in Imphal, India: An emission Perspective,
- Gasoline Direct Injection Engines Technology and Particulate Emission,
- Primary Organic Aerosols,
- Effects of VOCs on Human Health,
- Thermodynamics of Carbon Nanotubes and Soot Formation,
- A Study on Evolution and Modelling of Soot Formation in Diesel Jet Fames,
- Numerical Simulation of Air Pollution Control in Hospital,
- A Review on Clean Combustion Within Porous Media,
- An Overview of Current Knowledge Concerning the Environmental Consequences of the Nuclear Pollution: Sources, Effects and Control.

The topics are organized in five different sections: (i) General, (ii) IC Engine, (iii) Particulate and Aerosols, (iv) Numerical Simulation and (v) Miscellaneous.

Part II
Internal Combustion Engine

Simultaneous Control of Oxides of Nitrogen and Soot in CRDI Diesel Engine Using Split Injection and Cool EGR Fueled with Waste Frying Oil Biodiesel and Its Blends

R. Anand

Abstract Air pollution is one of the major threats to human health and living organisms, and its control is a greater challenge due to rapid growth in population and industrialization. Diesel vehicle exhaust emissions soot and nitrogen oxides (NO_x) are the major causes of global warming, acid rain, and photochemical smog. Fuel quality improvement, low-temperature homogeneous combustions, and high turbulent combustions are the most important diesel engine emission control strategies to restrict the air pollution. Use of different gaseous fuels, CNG, LPG, hydrogen and renewable liquid fuel biodiesel, ethanol, etc., in diesel engine reduces the engine out emissions to a great extent. Common rail direct injection (CRDI) has several advantages compared to the conventional mechanical fuel injection system. The high-pressure injection enhances the air-fuel mixture to obtain the better thermal efficiency as well as lower emissions. Exhaust gas recirculation (EGR) is one of the predominant methods for controlling the NO_x emission in internal combustion engines. EGR with split injection strategy is one of the effective methods to decrease soot and NO_x emissions simultaneously without much drop in engine efficiency.

Nomenclature

ASTM	American Society for Testing and Materials
B20	20% biodiesel
B40	40% biodiesel
B60	60% biodiesel
B80	80% biodiesel
B100	Biodiesel
BMEP	Brake mean effective pressure (bar)
BSEC	Brake specific energy consumption (MJ/kWh)

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BSFC	Brake specific fuel consumption (kg/kWh)
aTDC	After top dead center
bTDC	Before top dead center
BTE	Brake thermal efficiency (%)
CD	Combustion duration (°CA)
CH_3OH	Methanol
CH_3ONa	Sodium methoxide
CO	Carbon monoxide (% vol.)
CO_2	Carbon dioxide (% vol.)
CRDI	Common rail direct injection
DP	Dwell period
EGR	Exhaust gas recirculation
FSN	Filter smoke number
HRR	Heat release rate (J/°CA)
ME	Methyl ester
NO	Nitric oxide (ppm)
ID	Ignition delay (°CA)
SI	Split injection
SOI	Start of injection
SOC	Start of combustion
UBHC	Unburned hydrocarbon (ppm)
WFO	Waste frying oil

1 Introduction

Unaccounted extraction and utilization of fossil fuels increase the level of carbon dioxide, and it is the main contributor for global warming. The world energy consumption had been multiplied in the middle of the years 1971–2001. It was predicted that the world energy requirement would be escalated by 53% and consumption of petroleum will ascend from 84.4 to 116 million barrels in the USA by the end of 2030 [1]. The reduction of fossil fuel resources with the constant increment in the energy consumption has spurred research interest in the search of alternative sources of energy. The major substitute energy sources of renewable are wind energy, solar energy, tidal energy, and biodiesel. Many researchers are working on biodiesel because it is renewable, nontoxic, and environmental friendly. Biodiesel, a methyl ester of fatty acid, is obtained from vegetable oils and animal fats. Biodiesel feedstock such as edible and nonedible oils is sunflower oil, palm oil; soybean oil, jatropha oil, and pongamia oil [2].

The high cost of biodiesel is the main difficulty for commercialization; however, the use of waste frying oil (WFO) rather than virgin oil to produce biodiesel is one of the cost-effective approaches. In Middle East European countries, about 0.7 – 10

million tons of rapeseed and sunflower oil based WFO have been produced per year [3, 4]. As per the Environmental Prevention Act, WFO has to be properly treated before disposing into the environment to prevent environmental pollution. But, the cost of pre-treatment processes is high. The cost of biodiesel can be reduced by using the WFO as a feedstock [5].

The various methods of transesterification reaction proposed by researchers are base-catalyzed transesterification, acid-catalyzed transesterification, enzyme-catalyzed transesterification, pyrolysis transesterification, and super critical alcohol transesterification [6]. Transesterification is the process of converting triglycerides into the ester. Freedman et al. [7] observed that the maximum yield of 93% was achievable with a reaction temperature of 60 °C, molar ratio of 6:1, and catalyst concentration of 0.5 wt%. Vicente [8] employed the response surface methodology tool for the optimization of biodiesel production from sunflower oil. The maximum yield was obtained at following condition of molar ratio of 1:6, reaction temperature of 50 °C, catalyst concentration of 1.3 wt%. Hamamre and Yamin [9] conducted the experiments on biodiesel synthesis from waste frying oil using potassium hydroxide (KOH) as a catalyst. From the results, it can be concluded that it is possible to obtain the maximum yield of 98% of biodiesel by transesterification process.

Environmental pollution and global warming are mainly due to exhaust emissions coming out from automobiles and industrialization. Diesel engine emissions can be reduced by incorporating engine modification or fuel modification. Engine modification such as injection pressure, injection timing, injection duration, fuel quantity, swirl ratio, compression ratio, piston bowl design and fuel modification such as fuels blended with alcohols or metal additives are noticed by Imtenan et al. [10], and Agarwal et al. [11] conducted the experiment on common rail direct injection (CRDI) diesel engine with different injection pressures, injection timings, and loads. It found that the particulate matter (PM) concentration increases with increase in engine load, decreased with increase in injection pressure due to smaller fuel droplet size and better evaporation. There is a drop in PM concentration while advancing of injection timing. The advanced injection timing provides more time for mixing of fuel with air. Yehliu et al. [12] investigated the experiment on CRDI diesel engine fueled with pure soybean methyl ester. The results show that the ignition characteristics of fuel could affect the start of combustion process. Soybean biodiesel was achieved the minimum PM concentration compared to other blends. This was due to the presence of oxygen in biodiesel; however, sometimes the PM concentration increased due to unburned or partially burned hydrocarbon emission.

Qi et al. [13] reported the effect of injection timing and exhaust gas recirculation (EGR) on V6 Ford Lion Engine fueled with neat biodiesel. The results unveiled that the brake specific fuel consumption (BSFC) and soot emissions were increased at higher EGR rate. However, the nitrogen oxide emission was reduced and cylinder gas peak pressure (CGPP) and heat release rate (HRR) are reduced. With retarded injection timing, the BSFC was increased and nitrogen emission was decreased. Similarly, split injection was conducted on a caterpillar scote diesel engine fueled with oxygenated fuel at no-load and full-load condition. At full load, the soot

emission was reduced with no penalty of nitric oxide (NO) emission. The soot emission of split injection was less compared to single injection. The results revealed that the reduction of soot at full-load condition was due to oxygenate fuel with rich mixture combustion associated with advanced injection timing as noticed by Choi and Reitz [14]. Park et al. [15] studied the effect of multiple injection strategies on diesel engine fueled with biodiesel. The results unveiled that in a single injection, the combustion pressure and heat release rate are significantly reduced at injection timing of 30° bTDC. The emissions of carbon monoxide (CO), hydrocarbon (HC), and soot were increased due to incomplete combustion. In multiple injection strategy, the CO, HC and Soot emission reduced whereas NO emission increased due to smaller droplet size and shorter dwell period.

Exhaust gas recirculation (EGR) has suppressed the combustion temperature which reduces the NO formation and controlled the premixed combustion phase. The reduction of NO emission can be achieved through the combined effect of thermal effect (lower peak combustion temperature by circulation high specific heat gases), dilution effect (lower O_2 concentration), and chemical effect (dissociation of water (H_2O) and carbon dioxide (CO_2) combustion). Rajesh Kumar et al. [16] reported the experiment on diesel engine with different injection timings and EGR percentage up to 30%. An isobutanol-diesel blend with injection timing of 22° bTDC without EGR has found to be optimized condition for diesel engine, which gives minimum emissions with minimum BSFC compared to other blends. Yasina et al. [17] concluded the experiment on diesel engine with EGR fueled with palm oil. Brake specific fuel consumption is increased and exhaust gas temperature (EGT) is decreased with increase in EGR percentage. Increase in brake specific fuel consumption due to insufficient oxygen in cylinder leads to incomplete combustion which results in reduction of brake thermal efficiency (BTE). Tornatore et al. [18] studied the combined effect of injection timing and EGR. The NO emission and BTE were reduced when increasing the EGR rate or retardation of injection timing. Valentino et al. [19] studied the effect of injection timing and EGR for 40% butanol-diesel blends on CRDI diesel engine. The minimum NO emission and smoke was achieved at advanced injection timing and moderate injection pressure. Ozer Can et al. [20] studied the effect of EGR on diesel engine fueled with soybean biodiesel. The EGR rate varied from 5 to 15%. The results unveiled that the more BSFC and lesser BTE were occurred at 15% EGR at full-load condition. The NO and HC emissions were improved by 55 and 15%, respectively, with 15% EGR at full-load condition. There is no significant change in CO emission with higher CO_2 emission at full-load condition.

From the previous works, it could be concluded that few works had been done in the field of a transesterification reaction of waste frying oil to biodiesel production using sodium methoxide as a catalyst. Furthermore, there were fewer contributions made to the study of the split injection strategies on common rail direct injection diesel engine fueled with biodiesel and its blends. Hence, in this paper, an initiative has been done to explore the biodiesel production by using sodium methoxide as the catalyst. Moreover, split injection strategies with exhaust gas recirculation

technique have been employed to study the performance, emission and combustion characteristics on CRDI diesel engine fueled with diesel and biodiesel blends.

2 Materials and Methodology

2.1 Purification of Raw Oil and Biodiesel Synthesis

In this investigation, sunflower-based waste frying oil has been considered as the feedstock. It was purchased from various restaurants in Tiruchirappalli, Tamilnadu, India. Sodium methoxide and methanol were bought from Eswarr Scientific & Co, Trichy, Tamilnadu, India. The methyl ester was produced through transesterification process at Thermal Engineering Laboratory, National Institute of Technology, Tiruchirappalli, Tamilnadu. The waste frying oil contains impurities and food particles; therefore, it was subjected to the purification process. About 100 g of oil was weighed and heated at 80 °C for 30 min, and it was kept in a separating funnel to remove the food items. The heated oil was washed with distilled water to remove the odor, followed by the sample subjected to a heating of 110 °C for removing the water content. The acid value of water-washed frying oil was measured to be 3.34 mg KOH/g by using titration method, followed by acid washing in which 1% of phosphoric acid was added to the oil and stirred for further 30 min. This resulted in reduction of acid value by 2.27 mg KOH/g [21]. The raw biodiesel was washed with distilled water for removing excess methanol and unreacted catalyst. The presence of excess methanol reduces the fuel properties of biodiesel like density, viscosity, flash point, and corrosion [22].

The biodiesel experimental setup is shown in Fig. 1. WFO was taken into three necked round bottom flask; catalyst and methanol were mixed with help of magnetic stirrer to attain homogeneity. The prepared solution was poured into the reactor, and the mixture was stirred at the following condition, temperature of 55 °C, time of 1.5 h, molar ratio of 1:6, catalyst concentration of 1 wt%, and stirrer speed of 600 rpm. The product was allowed to settle down in a separating funnel for 24 h and the biodiesel was collected on the top side of separating funnel while glycerol settled down on the bottom portion of the funnel. It was cleaned with distilled water and heated at 110 °C to remove moisture content. Challenges and difficulties in biodiesel production lies in the collection and storage of WFO and biodiesel derived from WFO. Waste frying oil consumes more water for purification, and it is difficult to dispose glycerol and wastewater after purification process. Methanol is toxic and it should be used in a ventilated area as inhalation or ingestion of high concentrated methanol can lead to death or blindness. This process involves more chemical exposer and demands almost safety measures. The transesterification process equations are given below.

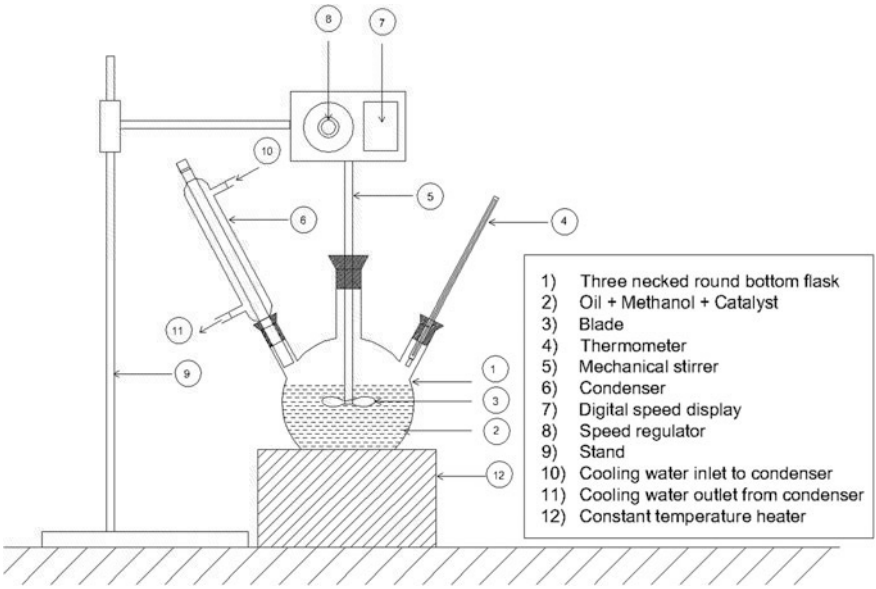

Fig. 1 Schematic view of biodiesel setup

$$\mathrm{TG} + \mathrm{ROH} \leftrightarrow \mathrm{DG} + \mathrm{RCOOR}_1 \tag{1}$$

$$\mathrm{DG} + \mathrm{ROH} \leftrightarrow \mathrm{MG} + \mathrm{RCOOR}_2 \tag{2}$$

$$\mathrm{MG} + \mathrm{ROH} \leftrightarrow \mathrm{GL} + \mathrm{RCOOR}_3 \tag{3}$$

Overall equation is given below

$$\mathrm{TG} + 3\mathrm{ROH} \leftrightarrow \mathrm{GL} + 3\mathrm{ME} \tag{4}$$

2.2 *Methyl Ester Characterizations*

Methyl ester conversion was determined by nuclear magnetic resonance (^{1}H NMR-BRUKER 400 MHz). Chloroform and tetramethylsilane were used as a solvent and internal standard, respectively, in ^{1}H NMR analysis. ^{1}H NMR spectra of biodiesel are shown in Fig. 2. The peak at 3.66 δ ppm is obtained for biodiesel, and it shows the presence of the methyl ester (CH_3COOR) group. However, the presence of methanol (CH_3OH) confirmed through the peak appeared at 2.7 δ ppm. Gas chromatography and mass spectrometer (Perkin Elmer Clarus 500) was used to find out the biodiesel composition, and fatty acid methyl ester composition is shown in Table 1. The capillary column (5% Phenyl 95% dimethyl polysiloxane)