

**SYNTHESIS, CHARACTERIZATION AND EVALUATION OF WASTE COOKING
OIL TRANSESTERS BLENDED WITH AVIATION FUEL**

Submitted in partial fulfillment of the requirements for the award of Bachelor of

Technology degree in Chemical Engineering

by

MUHAMED FADHL.M(40190013)

MADHAN.P (40190011)



DEPARTMENT OF CHEMICAL ENGINEERING

SCHOOL OF BIO AND CHEMICAL ENGINEERING

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A++" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

APRIL-2024



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE

www.sathyabama.ac.in

DEPARTMENT OF CHEMICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **MUHAEMED FADHL.M(40190013), MADHAN.P (40190011)**. With the title **"SYNTHESIS, CHARACTERIZATION AND EVALUATION OF WASTE COOKING OIL TRANSESTERS BLENDED WITH AVIATION FUEL"** who carried out the project entitled under my supervision from **NOVEMBER 2023-APRIL 2024**


Internal Guide

Dr. DAWN S S

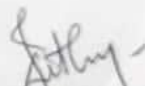

Head of the Department

Dr. S SATHISH M.E., Ph.D.,



Submitted for Viva Voce Examination held on **6/4/24**

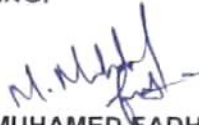

Internal Examiner


External Examiner

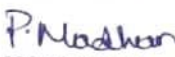
DECLARATION

We **MUHAMED FADHL (40190013)** and **MADHAN (40190011)** hereby declare that the Project Report entitled "**SYNTHESIS, CHARACTERIZATION AND EVALUATION OF WASTE COOKING OIL TRANSESTERS BLENDED WITH AVIATION FUEL**" is done by us under the guidance of **Dr. DAWN S S**, center for waste management in Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of **BACHELOR OF TECHNOLOGY IN CHEMICAL ENGINEERING**.

DATE 06/04/2024


MUHAMED FADHL.M

PLACE: CHENNAI


MADHAN.P

ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to Board of Management of **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr.S.SATHISH M.E.,Ph.D.**, Head of the Department, Department of Chemical Engineering for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Dr.DAWN S S** , for his valuable guidance, suggestions and constant encouragement paved way for the successful completion for our project work.

We wish to express our thanks to all Teaching and Non-Teaching Staff members of the Department of Chemical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

The global pursuit of sustainable energy sources has led to increasing interest in biodiesel as an alternative to conventional fossil fuels. Waste cooking oil biodiesel, a by-product of the food industry, holds promise as a renewable fuel source. However, its direct use in aviation applications, particularly in jet engines, presents technical challenges due to differences in combustion characteristics compared to traditional jet fuel. This project aims to address this issue by the transesterification of waste cooking oil biodiesel blended with jet fuel and analysing its combustion behaviour. The research methodology involves a comprehensive experimental approach, encompassing the transesterification process to convert waste cooking oil into biodiesel and subsequent blending with jet fuel at varying ratios. Detailed characterization studies, including physicochemical properties analysis and performance evaluation, will be conducted to assess the suitability of the blended fuels for aviation applications. Furthermore, combustion behaviour will be studied through advanced techniques such as calorimetry, spectroscopy, and engine testing to understand the impact on combustion are expected to contribute significantly to the understanding of waste cooking oil biodiesel-jet fuel blends' combustion characteristics, providing valuable insights for their application in aviation. The findings could potentially offer a sustainable solution to mitigate environmental impacts associated with conventional jet fuels while addressing waste management challenges in the food industry. The combustion rate in the initial stage is influenced by both the level of air turbulence and its composition, whereas in the subsequent stage, it follows a consistent pattern relative to fuel composition across varying turbulent intensities. Lastly, an experimental correlation is introduced for the normalized combustion rate.

TABLE OF CONTENTS

CHAPTER NUMBER	TITLE	PAGE NO
	ABSTRACT	i
	TABLE OF CONTENT	ii
	LIST OF ABBREVIATION	iv
	LIST OF FIGURES	v
	LIST OF TABLES	vi
1	INTRODUCTION	1
	1.1 Production of trans ester	1
	1.2 Transesterification	2
	1.3 Aviation fuel	2
	1.4 Ultrasonic blending	3
	1.5 Shadowgraph	4
	1.6 Grey scale image analysis	4
2	LITREATURE SURVEY	6
3	AIM AND SCOPE	11
4	MATERIALS AND METHODOLOGY	12
	4.1 Materials	12
	4.2 Trans ester production	12
	4.3 Trans ester analysis	14
	4.4 Gas chromatography	14
	4.5 Preparation of bio-jet fuel blend	14
	4.6 Bio-jet fuel characterization	15
	4.7 Droplet combustion study	16

	4.8 Image processing	17
	4.8.1 Droplet Shape	18
	4.8.2 Flame Heat Release (HR)	18
5	RESULTS AND DISCUSSIONS	19
	5.1 Trans ester characterizations	19
	5.2 GC-FID (gas chromatography) analysis of WCO Trans ester.	21
	5.3 Quantitative analysis of bio-jet fuel blends	25
	5.3.1 Density	25
	5.3.2 Viscosity	26
	5.3.3 Pour point and cloud point	27
	5.3.4 Calorific value	28
	5.3.5 Acid value	29
	5.3.6 Moisture content	30
	5.4 Single droplet combustion	31
	5.5 Quantitative analysis of droplet combustion	33
	5.5.1 Combustion analysis of 100% biodiesel	34
	5.5.2 Combustion analysis of 100% jet fuel	35
	5.5.3 Combustion analysis of 10% bio-jet fuel	36
	5.5.4 Combustion analysis of 20% bio-jet fuel	38
	5.5.5 Combustion analysis of 30% bio-jet fuel	39
	5.6 Comparative analysis of all bio-jet fuel sample and blends	40
6	SUMMARY AND CONCLUSION	44

	6.1 Scope of future work	45
7	REFERENCES	46

LIST OF ABBREVIATIONⁱⁱⁱ

WCO	Waste cooking oil
GC	Gas chromatography
HR	Heat Release
FID	FLAME IONIZATION DETECTOR
FAME	Fatty acid methyl esters (FAME)
HEFA	Hydro processed Esters and Fatty Acids
ATJ	Alcohol-to-jet (ATJ)
PROMETHEE	Preference ranking organization method for enrichment evaluation
GAIA	Graphical Analysis for Interactive Assistance (GAIA)
PIV	Particle Image Velocimetry
ASTM	American Society for Testing and Materials

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1.1	(a)single droplet combustion setup	4
	(b)burning of the droplet fuel	
4.1	(a)transesterification	12
	(b)biodiesel separation	
4.2	Flowchart for the preparation of biodiesel and jet fuel blends	13
4.3	(a)blended bio-jet fuel	15
	(b)ultra sonicator	
5.1	GC-FID graph for biodiesel	21
5.2	Viscosity bath	26
5.3	Bomb calorimeter	29
5.4	Weight of oil sample after 110°C at hot furnace	30
5.5	Suspension of droplet on cross section wire	31
5.6	Combustion of droplet in various time rate	32
5.7	Single droplet combustion graph for WCO biodiesel	35
5.8	Single droplet combustion graph for 100% jet A1 fuel	36
5.9	Single droplet combustion graph for 10% blended jetfuel	37
5.10	Single droplet combustion graph for 20% blended jetfuel	39
5.11	Single droplet combustion graph for 30% blended jetfuel	40

v
LIST OF TABLES

TABLE NO	TITLE	PAGE NO
5.1	Properties of WCO biodiesel	20
5.2	Composition analysis of GC-FID	24
5.3	Density of WCO biodiesel blended jet A1 fuel	25
5.4	Viscosity of WCO biodiesel blended jet A1 fuel	26
5.5	Pour point / cloud point of WCO biodiesel blended jet A1 fuel	28
5.6	Calorific value of WCO biodiesel blended jet A1 fuel	29
5.7	Acid value of WCO biodiesel blended jet A1 fuel	30
5.8	Moisture content of WCO biodiesel blended jet A1 fuel	31
5.9	D ² vs time plot for 100% WCO biodiesel	34
5.10	D ² vs time plot for pure jet A1 fuel	36
5.11	D ² vs time plot for 10% biodiesel blended jet fuel	37
5.12	D ² vs time plot for 20% biodiesel blended jet fuel	38
5.13	D ² vs time plot for 30% biodiesel blended jet fuel	40
5.14	Compared analysis plots for all the biodiesel blended jet fuel sample	41

CHAPTER-1

INTRODUCTION

The aviation industry, a vital component of global transportation networks, faces increasing pressure to mitigate its environmental footprint amid growing concerns over climate change and sustainability. Conventional jet fuels, primarily derived from fossil sources, contribute significantly to greenhouse gas emissions and environmental degradation. As a result, there is a pressing need to explore alternative, renewable fuel sources that can reduce aviation's carbon footprint while maintaining operational efficiency and safety standards.

1.1 PRODUCTION OF TRANS ESTER

One promising avenue in this quest for sustainable aviation fuels is biodiesel derived from waste cooking oil a renewable resource abundantly available as a byproduct of the food industry. Waste cooking oil biodiesel offers the potential to significantly reduce lifecycle greenhouse gas emissions compared to conventional jet fuels, making it an attractive candidate for blending with aviation fuel. However, the successful integration of waste cooking oil biodiesel into jet fuel blends requires a thorough understanding of its chemical composition, combustion characteristics, and compatibility with existing aviation infrastructure.

This project seeks to address these critical knowledge gaps by investigating the transesterification process of waste cooking oil into biodiesel and its subsequent blending with jet fuel. By combining experimental analyses with advanced combustion studies, we aim to elucidate the impact of waste cooking oil biodiesel-jet fuel blends on combustion efficiency, emissions performance, and engine operability. Ultimately, this research endeavors to provide valuable insights into the feasibility and viability of utilizing waste cooking oil biodiesel as a sustainable component of aviation fuel, thereby contributing to the advancement of greener and more environmentally friendly aviation technologies.

1.2 TRANESTERIFICATION

Transesterification is a chemical reaction that involves the exchange of ester groups between different molecules. In the context of biodiesel production, transesterification refers specifically to the process of converting triglycerides, commonly found in vegetable oils or animal fats, into fatty acid methyl esters (FAME) and glycerol. This reaction typically occurs in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide, and involves the reaction of triglycerides with an alcohol, usually methanol or ethanol. During transesterification, the ester groups of the triglycerides are replaced by the alcohol groups from the methanol or ethanol, resulting in the formation of FAME molecules and glycerol as a byproduct. Transesterification is a key step in the production of biodiesel, as it converts raw feedstocks into a form that is suitable for use as a renewable fuel source. Transesterification is employed in biodiesel production to convert triglycerides found in vegetable oils and animal fats into fatty acid methyl esters (FAME), primarily for its ability to broaden the range of renewable feedstocks, enhance fuel properties such as viscosity and cold flow characteristics, ensure compatibility with existing diesel engines and infrastructure, mitigate environmental impacts through reduced emissions, and contribute to energy security by utilizing domestic resources, all within a sustainable framework promoting a cleaner energy future.

1.3 PRODUCTION OF AVIATION BIOFUEL

Commercially available Jet A1 fuel is a specialized aviation-grade kerosene primarily used to power jet engines in aircraft. Formulated to stringent specifications, Jet A1 boasts high purity and stability, ensuring optimal performance and safety in flight. Its carefully controlled composition minimizes the risk of engine fouling and corrosion while maximizing combustion efficiency. With a low freezing point and excellent lubricating properties, Jet A1 remains fluid even at high altitudes, making it suitable for a wide range of operating conditions encountered during flight. Its consistent quality and reliability make Jet A1 the fuel of choice for airlines, military aircraft, and general aviation worldwide. Additionally, the properties of esters in biodiesel are influenced by the characteristics of the raw materials, potentially resulting in the carryover of contaminants, such as metals, into the FAME. This contamination can adversely affect the engine's hot-end materials. To meet the required

specifications, biodiesels are often blended with fossil jet fuel to enhance their HV and freezing point properties, and sometimes anti-icing additives are incorporated.

1.4 ULTRASONIC BLENDING

Ultrasonic blending is a cutting-edge technique utilized across various industries for achieving thorough and efficient mixing of materials. This method harnesses high-frequency sound waves, typically above the range of human hearing, to agitate and disperse substances within a liquid medium. The process involves the application of ultrasonic vibrations to the liquid, inducing cavitation - the formation and collapse of microscopic bubbles. This phenomenon generates intense local heating and high-pressure zones, leading to the breakup of particles and the dispersion of materials throughout the solution. Ultrasonic blending offers several advantages, including enhanced mixing efficiency, reduced processing times, and improved product quality. It finds applications in diverse fields such as chemistry, food processing, pharmaceuticals, and nanotechnology, where it is used for tasks ranging from emulsification and homogenization to nanoparticle synthesis and drug formulation. With its versatility and effectiveness, ultrasonic blending continues to revolutionize mixing processes and contribute to advancements in manufacturing technologies.

Ultrasonic blending of biodiesel and jet fuel at various ratios, including 10%, 20%, 30%, and 100%, offers a promising avenue for achieving homogeneous mixtures with enhanced properties. This innovative technique utilizes high-frequency sound waves to agitate and disperse the components, facilitating efficient blending and ensuring uniform distribution of biodiesel within the jet fuel matrix. The process of ultrasonic blending promotes intimate mixing at the molecular level, leading to improved combustion characteristics, reduced emissions, and enhanced fuel stability. By precisely controlling the blending ratios and optimizing the ultrasonic parameters, such as frequency and amplitude, it becomes possible to tailor the properties of the blended fuel to meet specific performance requirements. Ultrasonic blending of biodiesel and jet fuel presents a sustainable approach towards reducing reliance on fossil fuels while enhancing the overall efficiency and environmental sustainability of aviation fuel systems.

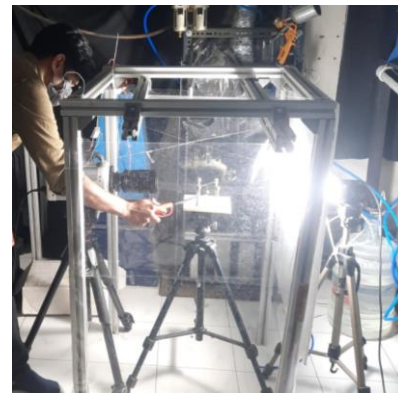
1.5 SHADOWGRAPHY

Shadow imaging, also known as shadow-graphy or shadow casting, is a technique used to visualize objects or phenomena by observing the shadows they cast. This method is particularly useful for examining transparent or translucent objects or detecting changes in density or refractive index within a medium. In shadow imaging, a light source is positioned on one side of the object or medium being examined, and a screen or detector is placed on the opposite side. When light passes through or around the object, it creates a shadow on the screen. The shadow's characteristics, such as its size, shape, and intensity, can provide information about the object's properties or the medium through which the light travels.

Shadow imaging has various applications across different fields, including fluid dynamics, aerodynamics, material science, biology, and medicine. It can be used to study phenomena such as flow patterns in fluids, shock waves, combustion processes, and the behavior of biological tissues. Advancements in imaging technologies, such as digital shadow-graphy and laser-based techniques, have improved the resolution and sensitivity of shadow imaging methods, allowing for more precise and detailed observations of objects and phenomena.



Fig1.1- (A)



(B)

(A) Single droplet combustion setup

(B) Burning of the droplet fuel

1.6 GREY SCALE IMAGE ANALYSIS

A grayscale image, also known as a black-and-white image, is an image in which each pixel is represented by a single sample value, typically ranging from 0 (black) to 255 (white) in an 8-bit image. Unlike color images, grayscale images contain

only shades of gray, with variations in brightness corresponding to different intensity levels. Each pixel in a grayscale image represents the intensity of light at that particular point, with higher values indicating brighter areas and lower values indicating darker areas. Grayscale images are commonly used in various applications, including photography, medical imaging, and digital graphics, due to their simplicity and ease of interpretation.

In addition to its general definition, a grayscale image is widely utilized in MATLAB image processing for diverse applications, including the calculation of droplet diameters in cross-sectional wire for droplet combustion tests. In this context, grayscale images serve as crucial inputs for image processing algorithms that analyze droplet shapes and sizes. By converting color images into grayscale, MATLAB can extract intensity data from each pixel, allowing for precise measurements of droplet dimensions. This process involves various image processing techniques such as edge detection, thresholding, and morphological operations to identify and characterize droplet boundaries accurately. Grayscale images provide essential visual representations of droplet cross-sections, enabling researchers to quantify droplet diameters and analyze combustion behavior effectively. This application underscores the versatility and utility of grayscale images in scientific research, particularly in fields like combustion science and fluid dynamics.

CHAPTER-2 LITERATURE SURVEY

2.1 Rehab M. El-Maghraby et.al. (2019) has published on journal Material science and engineering titled as **A Study on Bio-Diesel and Jet Fuel Blending for the Production of Renewable Aviation Fuel investments**. In this study, bio-jet fuel production by blending bio-diesel with traditional jet fuel at different concentrations of bio-diesel (5, 10, 15, 20 vol. %) was investigated. This blending technique will reduce bio-jet production cost compared to other bio-jet techniques. Bio-diesel was originally produced by the transesterification of non-edible vegetable oil (renewable sources), so, its blend with jet fuel will has a reduced carbon foot print. The blend was tested to ensure that the end product will meet the ASTM D1655 international specifications for Jet A-1 and Jet A and can be used in aircrafts.

2.2 Sinem Gurkan Aydin et al. (2022) has published on journal **Bio-Based Jet Fuel Production by Transesterification of Nettle Seeds costs**. Due to this increase, fuel manufacturers and airline companies have started to search for alternative fuels. Since aviation has an important place in the transportation sector, biomass has the greatest potential in the search for renewable energy sources. Biological substances of plant and animal origin and containing carbon compounds are energy sources, and the fuels produced from them are called biofuels. Biofuels are an important source of sustainable energy, which greatly reduces the greenhouse gas effect, improves weather conditions, reduces dependence on oil produced from fossil fuels, and is important for new markets. The nettle seed oil used in the current study was purchased from the local market and was obtained using the cold-pressing method at low temperatures.

2.3 Marian Elmoraghy, Ihab H. Farag et Al. (2014) has published on journal **In-situ Transesterification of Chlorella vulgaris towards Bio-Jet Fuel Production**. This study investigated the integrated one-step extraction/transesterification of freeze dried Chlorella vulgaris to produce biodiesel for blending with jet fuel. The one step or “in-situ” transesterification reaction was run in methanol assisted by ultrasonication, and was completed in 30 minutes. The FAMES produced were identified using a gas

chromatograph. Yields upto 56.82 mg FAME/g dry algae were obtained. Predicted physical properties of in-situ FAME satisfied European and American standards confirming its quality.

2.4 Trevor J. Morgan et Al. (2019) has published on journal Material science forum titled as in this article presents **Review of Biomass Resources and Conversion Technologies for Alternative Jet Fuel Production in Hawai'i and Tropical Regions pathways**. The objectives of this study were to review alternative jet fuel feedstock candidates and relevant conversion data to provide a baseline of information to be accessed and built upon in developing production scenarios in Hawai'i and other tropical regions bounded by the Tropic of Cancer in the northern hemisphere and the Tropic of Capricorn in the southern hemisphere. Seventeen plants that produce oil, fiber, and sugar feedstocks were identified, and information on cultural practices, yield ranges, invasiveness, and mechanization status was assembled. Available data on pretreatment requirements and conversion processes for the 17 feedstocks, including mass and energy balances, product and by-product yield and quality, and scale requirements/unit sizes, were reviewed. This effort seeks to inform the development and design of alternative jet fuel production along regional supply chains in Hawai'i and other locations in the tropics.

2.5 Alisson Aparecido Vitoriano Julio1et Al. (2022) has published on journal Material today titled as in this article **Exergoeconomic and Environmental Analysis of a Palm Oil Biorefinery for the Production of Bio-Jet Fuel** This work aims to explore the production of bio-jet fuel via different routes in the context of a biorefinery in which the pro-duction of the bio-jet fuel is integrated with a palm oil mill and a transesterification plant for the production of biodiesel. In addition to handling the extraction and transesterification phases, the system has also a second-generation ethanol plant and facilities for the production of bio-jet fuel via HEFA and ATJ. The biorefinery has a cogeneration plant that is responsible for supplying all the processes with thermal and electric energy. The system is evaluated using the first and second laws of thermodynamics, and is shown to have efficiencies of 37% and 55%, respectively. An exergoeconomic and economic analysis is also carried out in this study.

2.6 Saeid Baroutian et Al. (2013) has published on journal The study focused on the development of blended aviation biofuel derived from esterified *Jatropha Curcas* and waste vegetable oils. This involved blending methyl esters obtained from waste vegetable oil and jatropha oil with Jet A-1 aviation fuel. Through a two-step transesterification process, waste vegetable oil and non-edible jatropha underwent conversion into methyl esters. Various blends of waste vegetable oil with Jet A-1 were meticulously prepared and assessed to identify the optimal ratio for suitability.

2.7 Thong D. Hong et Al. (2013) In present study, the production process of aviation bio-jet paraffins was proposed consistent with the socioeconomic conditions, production technology and feedstock sources of the Tropics. The route of blending bio-jet paraffins with fossil kerosene (commercial Jet A-1), which formed bio-kerosene using as alternative fuel for aircraft, was also provided. Two prototypes of bio-paraffins, which were manufactured in Indonesia, were used to make the samples of bio-kerosenes for current work. The experimental and theoretical investigations of these bio-kerosenes were performed to ensure their common properties satisfying the ASTM D1655 requirements and to verify the feasibility of developing and applying renewable fuel for the Tropics' aviation industry.

2.8 M. Mofijur et Al (2022) in this investigation, an MCDA tool known as the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)-Graphical Analysis for Interactive Assistance (GAIA) was used to evaluate 38 non-edible sources to determine whether or not they are suitable for use in the production of SAF via the oil to jet fuel route. Each feedstock is evaluated as to whether or not it satisfies the selected criteria connected to the quality of fuel, as well as whether or not it satisfies international alternative fuel requirements and aviation fuel standards.

2.9 Mayur J. Sathe , Iqbal H. Thaker et Al (2009) In present study shadow image is cast by bending of the parallel light rays coming from the back side of the bubbles. The refraction by strong curvature of the bubbles projects the dark part around the backlight and hence casts a shadow on CCD of the camera against the bright background. The shadow has got a sharp boundary and can be easily tracked between two successive images to get the individual bubble velocity. The intensity gradient at the bubble edge can be used to discern whether it is in focal plane. The choice of the backlight intensity and positioning of two cameras is crucial for the

success of the experiment. [Tokuhiro et al. \(1998\)](#) used two cameras facing each other for combined PIV and shadowgraphy measurements on a single bubble. [Lindken and Merzkirch \(1999b\)](#) used two cameras under a 301 angle, one for PIV measurements and the other for shadowgraphy measurements. The technique employed in the current work uses a dichroic mirror to split the shadow and PIV image. This ensures that the recorded PIV and shadow images are not skewed. A digital mask generated from shadow image is applied to particle image in order to achieve reliable liquid velocity measurement. In addition, the liquid velocity data is subjected to wavelet transform to quantify the flow structures. Each of these aspects has been elaborated in the corresponding subsections.

2.10 Ahmad Muneerel-Deen Faik et Al (2017) The liquid-phase processes occurring during fuel droplet combustion are important in deciding the behaviour of the overall combustion process, especially, for the multicomponent fuel droplets. Hence, understanding these processes is essential for explaining the combustion of the multicomponent fuel droplet. However, the very fast combustion of the too small fuel droplet makes experimental investigation of these processes uneasily affordable. In the present work, a high speed backlighting and shadowgraph imaging of the multicomponent fuel droplet combustion including liquid-phase dynamics are performed. Two categories of multicomponent fuels – in which diesel is the base fuel – are prepared and utilized. The first category is biodiesel/diesel and bioethanol/diesel blends, while the second category is the water-in-diesel and diesel-in-water emulsions. Specific optical setups are developed and used for tracking droplet combustion.

2.11 Kushboo pandey et Al (2020) Investigations pertaining to nanofuel droplet combustion can be carried out in; **(a)** Pendant mode, where droplet is suspended on a fibre or cross-wire arrangement. This mode of experiment offers the easiness of droplet shape and flame imaging. However, the suspended droplet sizes are limited to order of millimetres can be suspended with shape distortion due to the wire. Furthermore, previous studies have established that the wire effects (heat transfer) can be neglected if the wire dimension is $< 100\mu m$ **(B)** Free-falling/contactless mode; here the burning characteristics can be studied for smaller droplets in free-fall without wire effects although experimental imaging is arduous due to droplet motion as compared to the pendant mode.

2.12 Patel ujas et Al (2019) A detail investigation of the complex spray combustion process is challenging due to interplay of various sub-processes including primary and secondary breakup of liquid jet/sheet, interaction of droplets among themselves and also surrounding turbulent flow, droplet evaporation, chemical reaction, heat release etc. Each of these processes refer to distinct lines of research on their own right. Hence, it is important to investigate them separately under simplified configurations such that suitable models can be developed which can contribute towards deeper understanding on the spray combustion phenomena. In the present work the focus is on experimental study of evaporation and combustion characteristics of an isolated fuel droplet. In spite of availability of significant body of literature on this subject knowledge on practical droplet evaporation and combustion processes is still insufficient due to interplay of several influencing factors. Most of earlier studies considered single component droplets under stagnant and mean convective flows. However, in practical cases mostly the fuels are multi-component, and, in addition, they are always subjected to air turbulence in the combustion chamber. Also, recently nanofuels have gained interest in aerospace applications where high volumetric energy density of fuels is desired. The current research work intends to investigate the above mentioned aspects on droplet evaporation/combustion. Accordingly, the objectives are multi-fold: first, to study combined influence of turbulence and composition on droplet evaporation and also combustion, and, second, to examine the effect of addition of nanoparticles on droplet combustion under stagnant and turbulent environment. The following sections present an overview on the earlier studies on each of these topics followed by the specific aim of the present research.

CHAPTER-3

AIM AND SCOPE

OBJECTIVE:

- To synthesize trans-esters from different oil sources and evaluate its properties and performance in blends with jet A1 fuel as per ASTM standards.
- To identify the role of identified additives in upgrading the properties of the blends of the trans-esters and make it equivalent to jet A1 fuels.
- To compare and contrast the bio jet fuel blends with and without additives prioritizing performance and emission when tested in jet fuel engines.
- To pursue socio-economic feasibility for the conversion of second and third generation oil sources to bio aviation fuel.

5 SCOPE:

- Several processes including hydro-processing of oils and fats, fisher-tropsch process (gasification of biomass), hydrolysis of biomass have been reported in literature for the production of synthesized paraffinic fuel (Jet fuel).
- Less study has been done on investigating transester as blend with jet fuels
- Hence an attempt will be made to transesterify non-edible oil sources and evaluate its performance with the blending of commercially available jet fuel with and without additives that would reduce carbon foot print and enhance energy security.

CHAPTER-4

MATERIALS AND METHODOLOGY

4.1 MATERIALS

Waste vegetable oil sourced from sathyabama institute of science and technology, chennai, tamilnadu, India. The characteristics of the waste cooking oil outlined in Table (5.1). Jet A-1 aviation fuel was acquired from sathyabama institute of science and technology, chennai, tamilnadu, India. Pure potassium hydroxide and sulfuric acid, utilized as catalysts, were sourced from international research center, Sathyabama university, Chennai.

4.2 WASTE COOKING BIODIESEL PRODUCTION

For this study, restaurant waste cooking oil chosen as the biofuel sources. The processed waste vegetable oil underwent transesterification employing a homogeneous potassium hydroxide catalyst. Methanol at a concentration of 25% (v/v) and potassium hydroxide at 0.7% (w/v) were combined with the treated oils at 60°C for 2 hours. This mixture served to neutralize the sulfuric acid remnants from the initial step and catalyze the subsequent reaction.

The resulting transesters were then separated from the glycerol by-product, subjected to hot water washing, and dried via atmospheric evaporation. Fig.1 Outlines the procedure for producing jet biofuel from waste vegetable oil.

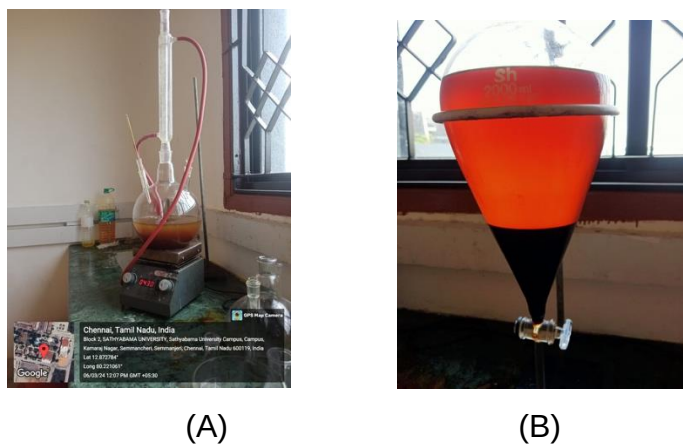


Fig 4.1: (A)Transesterification process (B)Biodiesel separation

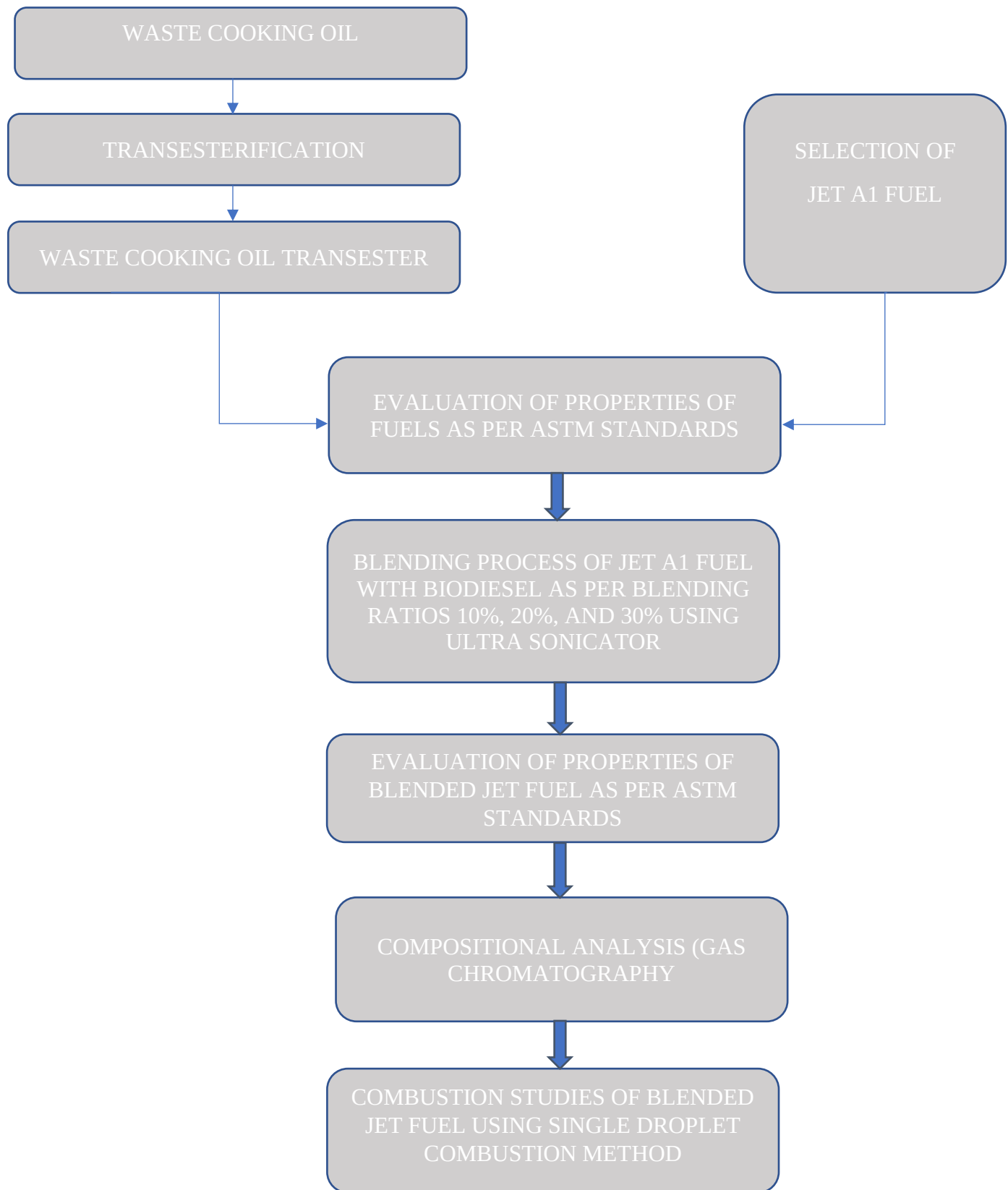


Fig 4.2: Flowchart for the process of biodiesel and jet-fuel blends

4.3 TRANSESTER ANALYSIS

The quality of the biodiesel derived from waste cooking oil underwent various tests. Density was measured using the hydrometer method, viscosity at 40°C was determined using equipment from Universal Lab Product Co., India, while flash point and fire point were assessed using instrumentation from Deep Vision Instrument Pvt. Ltd., India. Cloud point and pour point were determined using equipment from Hindustan Apparatus Mfg. Co., India, and calorific value was measured using equipment from M.K. Scientific Instruments, India. Additionally, copper strip corrosion was evaluated using instrumentation from Kochler, India. These tests were conducted following ASTM methods including ASTM D664, ASTM D445, ASTM D130, ASTM D2500, ASTM D 1298, ASTM D93, ASTM D1500, and ASTM D240.

4.4 GAS CHROMATOGRAPHY - FLAME IONIZATION DETECTOR (FID)

The YL Clarity 6500 Gas Chromatography system was configured for sample analysis. Initially, the oven, equipped with a 0.53 mm TR-WAX capillary column, was programmed to increase from 140°C to 260°C at a rate of 10°C/min. Helium, serving as the carrier gas, was set to flow at a rate of 5 mL/min before sample injection. The capillary column (TR-WAX) underwent standardization using a Supelo FAME mix comprising 37 components. The Flame Ionization Detector (FID) was adjusted to ignition and maximum temperatures of 471 K and 513 K, respectively, to generate chromatographic signals. This facilitated the determination of the fatty acid trans ester composition for both biodiesel and biodiesel blended jet fuel, achieved by injecting one mL of the sample into the split mode injection port. Subsequently, the GC-FID was cooled to reach a temperature of 323 K. Thus, the saturated and unsaturated fatty acid compositions of the biodiesel sample were ascertained.

4.5 PREPARATION OF BIO-JETFUEL BLEND

The trans ester obtained from waste vegetable oil were blended with Jet A-1 aviation fuel at different volume ratios, ranging from 100%, 10%, 20%, and 30%. These trans esters exhibit full miscibility with kerosene-type Jet A-1 fuel. The blending process took place at 40°C utilizing an ultrasonic bath. Subsequently, the blends of jet biofuel were stored in glass containers.



(a)



(b)

Fig 4.3: (a)blended bio-jet fuel and (B)ultra sonicator

4.6 BIO-JETFUEL CHARACTERIZATION

The bio-jetfuel blends formulated with different proportions of trans esters and aviation fuel, underwent analysis to assess their chemical and physical properties. This characterization encompassed evaluating density, viscosity, pour point, cloud point, water content, heating value, and acid number. The densities of the blends were measured at a temperature of 158°C, with an uncertainty in density measurements of $\pm 0.00001 \text{ g/cm}^3$. The heating values were assessed employing a C2000 Oxygen Bomb Calorimeter from centre for waste management, IRC, sathyabama institute of science and technology, Chennai. The bomb, pressurized with an excess of pure oxygen at 30 atm and holding a predetermined sample mass, was immersed beneath a specified volume of water before the electrical charge was ignited. The resulting temperature change, induced by the energy liberated during combustion, was meticulously recorded. This temperature increase, combined with a bomb factor, was utilized to determine the energy released during the sample combustion. The pour points and cloud points of the bio-jetfuel blends were established using a manual Pour Point Bath from centre for waste management, IRC, sathyabama institute of science and technology, Chennai. Flash points of the samples were determined utilizing an HFP380 Flash Point Tester from Pensky-Martens, Germany. The kinematic viscosities of the produced jet biofuel were determined via capillary viscometry following the standard procedure outlined in ASTM D445-06. The total acid numbers of the bio-jetfuel blend samples were determined employing an auto-titrator furnished with a dosing system, stirrer, and controller from Metrohm, UK. A predetermined quantity of

sample was dissolved in titration solvent and then titrated with alcoholic potassium hydroxide until reaching a colorimetric endpoint.

4.7 DROPLET COMBUSTION TEST

The droplet evaporation experiments, detailed in the preceding chapter, were conducted by positioning the droplet at the junction of two cross-sectional wires to minimize the impact of supports on evaporation characteristics compared to conventional suspension methods. However, when studying combustion, careful consideration must be given to how droplets are suspended, as the presence of a flame leads to elevated temperatures. The choice of wire material for suspending droplets should meet two criteria: first, it must withstand high temperatures, and second, it should not create any hot spots within the droplet to prevent internal boiling. Given that the current investigation also examines the combustion behaviour of bio-jetfuel droplets, which are susceptible to micro-explosions (as will be discussed later), the nucleation sites provided by the wires to the suspended droplets could significantly influence the combustion process.

The study of droplet combustion outlined above is poised to yield several significant outcomes. Firstly, it can provide valuable insights into the optimal suspension methods for droplets during combustion experiments, taking into account factors such as temperature resistance and the prevention of hot spots within the droplet. Secondly, by observing the combustion behaviour of droplets, researchers can deepen their understanding of various combustion characteristics, including ignition, burning rate, and flame structure, thus informing the development of more efficient combustion systems. Additionally, the investigation may uncover how different parameters such as droplet size, fuel composition, and suspension method influence the combustion process, facilitating further optimization of combustion technologies. Moreover, by studying the behaviour of bio-jetfuel droplets prone to micro-explosions, the research can lead to strategies for mitigating associated hazards and improving safety measures in relevant applications. Finally, the data obtained from these experiments can enhance the accuracy of mathematical models and simulations of droplet combustion, enabling better predictions and optimizations for practical implementation. In conjunction with the aforementioned experiments, a high-speed image-capturing camera is employed to meticulously record the droplet combustion

process. Subsequently, the data obtained from these recordings is meticulously processed using MATLAB software to extract crucial parameters, including the diameter of the droplet, enabling a comprehensive analysis of the combustion dynamics and behaviour.

For assessing the burning rate of the droplet, a series of images depicting the droplet in combustion were captured using a high-speed camera (Photron FASTCAM Mini UX100) employing the shadowgraph technique detailed in the preceding chapter. These images underwent analysis via a custom image processing code implemented in MATLAB. For each instantaneous image, the projected droplet area allowed for the calculation of an equivalent diameter (denoted as "d") of the droplet. Ignition of the droplet occurred via a butane flame produced by a lighter. Simultaneously, flame and droplet images were recorded using the same camera without backlight, employing high exposure settings. In experiments conducted within a turbulent box, the droplet was suspended at the box's centre, where the flow field had been previously characterized. It's noteworthy that during the combustion of large droplets, such as those in the present study, significant buoyant flow occurs around the droplet flame, potentially impacting local turbulence characteristics. Each set of droplet burning experiments, conducted under both stagnant and turbulent ambient conditions, was repeated six times to ensure experiment repeatability. The uncertainty associated with the burning rate constant under stagnant and turbulent atmospheres ranged from $\pm 3\%$ to $\pm 5\%$ and $\pm 9\%$ to $\pm 15\%$, respectively, with higher uncertainty observed in turbulent conditions.

4.8 IMAGE PROCESSING

In coordination with the experiments, a high-speed camera captures the droplet combustion process with precision. Following this, the data from these recordings undergoes meticulous processing using MATLAB software to extract vital parameters, such as the droplet diameter. These processed image values are then employed within MATLAB code to analyze the behaviour and dynamics of combustion, offering a graphical depiction that enhances our understanding of the process comprehensively.

4.8.1 Droplet Shape:

The obtained grayscale images of droplets undergo conversion to binary format using Otsu Thresholding. This binary representation is then employed to extract instantaneous droplet area along with shape descriptors such as aspect ratio and centroid. The diameter of the droplet (denoted as d) is determined by equating the instantaneous droplet area to that of a circle, expressed as $Ad = \pi d^2$.

4.8.2 Flame Heat Release (HR):

Utilizing high-speed OH^* chemiluminescence flame imaging, quantitative assessment of flame location and heat release (HR) is enabled. The intensity thresholding technique is applied for evaluating flame heat release (Q). The flame boundary is delineated based on a predefined intensity cutoff (I). Pixels (i,j) with intensities $\geq I$ are assigned a binary value of 1, while those with intensities $< I$ are assigned 0. The resulting binary area facilitates the calculation of instantaneous line-of-sight flame area (A_f). This area is then overlaid onto the corresponding raw image to determine I , the average intensity of the flame.

CHAPTER-5

RESULTS AND DISCUSSION

5.1 TRANS ESTER CHARACTERIZATIONS

The properties of biodiesel derived from waste cooking oil were evaluated and found to be comparable, as indicated in Table 5.1. In this study, the density and viscosity of the waste cooking oil biodiesel were determined to be 0.881 g/cc at 15°C and 4.27 cSt at 40°C, respectively, meeting biodiesel standards.

Biodiesel viscosity and oxidation stability exhibit an indirect relationship with the unsaturated FAME composition within the biodiesel. Higher levels of double bonds in FAME increase the likelihood of oxidative product formation and shorter hydroperoxide, consequently leading to poorer oxidation stability. Elevated biodiesel viscosity and density may result in fuel pump failure, ring sticking, poor atomization, and carbon deposits. The biodiesel exhibited an acid value of 0.48 mg KOH/g, complying with ASTM D664 standards. Cloud (ASTM D2500) and pour points (ASTM D97) are pivotal in determining fuel viability during colder seasons. At lower temperatures, saturated fatty acids in the biodiesel can precipitate, settling and potentially clogging filters. The biodiesel demonstrated considerably low cloud and pour points of 5°C and -4°C, respectively, suggesting improved operability when used in engines operating at reduced temperatures. These values meet ASTM D6751 standards (-3 to 12°C and -15°C to 10°C) as reported by Baldev et al. [22]. The calorific value of waste cooking oil biodiesel was determined to be 9346 cal/g. A copper strip corrosion test conducted at 60°C for 3 hours resulted in a slightly tarnished appearance. The flashpoint and fire point, according to ASTM D93, were measured at 157°C and 172°C, respectively, as shown in the table 5.1

TABLE 5.1 Properties of waste cooking oil biodiesel

PROPERTIES	AS PER ASTM STANDARD	UNITS
DENSITY	0.881	g/cc
VISCOSITY	4.27	cSt
CALORIFIC VALUE	9346	Cal /g
ACID VALUE	0.48	mg KOH/g
CLOUD POINT	5	°C
POUR POINT	-4	°C
MOISTURE CONTENT	0.05	g
FLASH POINT	157	°C
FIRE POINT	172	°C

5.2 GC-FID (GAS CHROMATOGRAPHY-FLAME IONIZATION DETECTOR) ANALYSIS OF WCO TRANSESTER

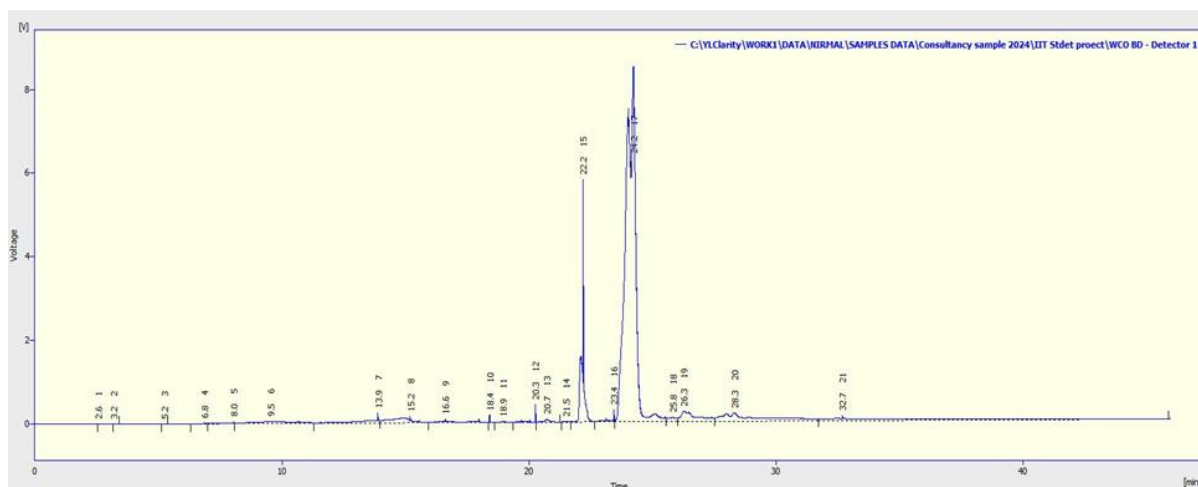


Fig 5.1: GC-FID graph for biodiesel

GC-FID technology is highly effective for analyzing biodiesel samples because it enables the extraction and quantification of specific components within complex mixtures. Through GC-FID, various elements present in biodiesel samples are separated and measured. Notably, the presence of methyl esters, the primary constituents of biodiesel, can be identified using this method. By quantifying methyl esters, GC-FID facilitates the assessment of biodiesel production and purity, crucial for evaluating its suitability as a fuel. Moreover, GC-FID analysis aids in identifying any contaminants or undesirable molecules that may have formed during the transesterification process, ensuring compliance with quality standards.

In this examination, the findings are delineated based on retention time, area, and peak height for various compounds, accompanied by their respective percentages. Below is an elucidation of the observed outcomes:

- Methyl heptaecanoic acid, methy ester (compound 1): this compound is detected at a retention time of 2.553 minutes with the area of 23.989 mV.s. it makes a small fraction of the total, with the percentage of 11.2101%.
- methyl stearic acid and elaidic acid, methy ester (compound 2): this compound is detected at a retention time of 3.183 minutes with the area of 44.35.67 mV.s. it makes a small fraction of the total, with the percentage of 2.0701%.

- methyl arachidic acid, methy ester (compound 3): this compound is detected at a retention time of 5.233 minutes with the area of 13.272 mV.s. it makes a small fraction of the total, with the percentage of 6.2149%.
- methyl hexanoate, methy ester (compound 4): this compound is detected at a retention time of 6.847 minutes with the area of 16.9389 mV.s. it makes a small fraction of the total, with the percentage of 7.9301%.
- methyl myristate, methy ester (compound 5): this compound is detected at a retention time of 8.043 minutes with the area of 71.879 mV.s. it makes a small fraction of the total, with the percentage of 3.3654%.
- methyl palmitate acid, methy ester (compound 6): this compound is detected at a retention time of 9.533 minutes with the area of 40.87 mV.s. it makes a small fraction of the total, with the percentage of 1.911036%.
- Methyl palmitoleate acid, methy ester (compound 7): this compound is detected at a retention time of 13.887 minutes with the area of 12.4389 mV.s. it makes a small fraction of the total, with the percentage of 0.582101%.
- methyl oleate (9), methy ester (compound 8): this compound is detected at a retention time of 15.197 minutes with the area of 5.230 mV.s. it makes a small fraction of the total, with the percentage of 0.02446%.
- methyl oleate (11), methy ester (compound 9): this compound is detected at a retention time of 16.590 minutes with the area of 2.752 mV.s. it makes a small fraction of the total, with the percentage of 0.01254%.
- methyl linoleate, methy ester (compound 10): this compound is detected at a retention time of 18.393 minutes with the area of 36.121 mV.s. it makes a small fraction of the total, with the percentage of 0.16943%.
- methyl linolenate, methy ester (compound 11): this compound is detected at a retention time of 18.943 minutes with the area of 5.123 mV.s. it makes a small fraction of the total, with the percentage of 0.00263%.
- methyl arachidate, methy ester (compound 12): this compound is detected at a retention time of 20.253 minutes with the area of 134.538 mV.s. it makes a small fraction of the total, with the percentage of 0.6308%.
- methyl eicosonate, methy ester (compound 13): this compound is detected at a retention time of 21.497 minutes with the area of 15.913 mV.s. it makes a small fraction of the total, with the percentage of 0.0745%.

- methyl eicosadienoate methy ester (compound 14): this compound is detected at a retention time of 22.180 minutes with the area of 600.11 mV.s. it makes a small fraction of the total, with the percentage of 2.8101%.
- methyl arachidonate, methy ester (compound 15): this compound is detected at a retention time of 23.430 minutes with the area of 1051.6617 mV.s. it makes a small fraction of the total, with the percentage of 0.18723%.
- methyl eicosatrienoate, methy ester (compound 16): this compound is detected at a retention time of 24.240 minutes with the area of 40.37 mV.s. it makes a small fraction of the total, with the percentage of 0.1888%.
- methyl arachidonate, methy ester (compound 17): this compound is detected at a retention time of 25.827 minutes with the area of 1051.6617 mV.s. it makes a small fraction of the total, with the percentage of 4.123%.
- methyl behenate and methyl eicosapentaenoate, methy ester (compound 18): this compound is detected at a retention time of 26.263 minutes with the area of 40.061 mV.s. it makes a small fraction of the total, with the percentage of 0.18733%.
- methyl erucate, methy ester (compound 19): this compound is detected at a retention time of 26.289 minutes with the area of 203.145 mV.s. it makes a small fraction of the total, with the percentage of 0.18723%.
- methyl lignocerate, methy ester (compound 10): this compound is detected at a retention time of 28.310 minutes with the area of 96.66 mV.s. it makes a small fraction of the total, with the percentage of 0.4526%.
- methyl nervonate, methy ester (compound 21): this compound is detected at a retention time of 32.690 minutes with the area of 72.463 mV.s. it makes a small fraction of the total, with the percentage of 0.3396%.
- methyl docosahexaenoate, methy ester (compound 22): this compound is detected at a retention time of minutes with the area of 72.631 mV.s. it makes a small fraction of the total, with the percentage of 0.3076%.

The cumulative area for all compounds amounts to 331564.728 mV.s, while the total peak height reaches 16462.959 mV. These findings offer a comprehensive breakdown of the compounds identified within the sample under scrutiny, with certain compounds showcasing particularly elevated percentages.

TABLE 5.2 Composition analysis of GC-FID

Sl.NO	Area [mV.s]	Compound composition	Compound name
1	23939.148	11.210105967696	methyl heptadecanoic acid
2	4435.673	2.07711504052057	methyl stearic acid and elaidic acid
3	13272.107	6.21499670266458	methyl linolenic acid
4	5298.212	2.48102054255725	methyl arachidic acid
5	16936.176	7.93078883373582	methyl hexanoate
6	7187.232	3.36560149652842	methyl myristate
7	4087.053	1.91386498907938	methyl palmitate
8	1243.398	0.582252273139429	Methyl palmitoleate
9	523.083	0.24494672324597	methyl oleate (9)
10	27.522	0.0128878662032136	methyl oleate (11)
11	361.219	0.169149848922993	methyl linoleate
12	51.23	0.0239897313273248	methyl linolenate
13	1347.095	0.630810992043384	methyl arachidate
14	159.174	0.0745372144113916	methyl eicosonate
15	6001.1	2.81016546297889	methyl eicosadienoate
16	10516.167	4.92445873361856	methyl arachidonate
17	403.225	0.188820211096243	methyl eicosatrienoate
18	400.044	0.187330628130164	methyl behenate and methyl eicosapentaenoate
19	2031.453	0.95127877560195	methyl erucate
20	966.623	0.452645443388886	methyl lignocerate
21	724.673	0.33934629260524	methyl nervonate

5.3 QUANTITATIVE ANALYSIS OF BIO-JETFUEL BLENDS

Typically, aircraft fuel tanks lack insulation, leaving only a thin tank wall between the fuel and the air, where temperatures decrease with altitude. Jet fuel specifications mandate the fuel to withstand the formation of solid crystals even at temperatures as frigid as -47°C . According to standard atmospheric tables utilized for aircraft engineering calculations, this requirement corresponds to an altitude of 9500 meters. Trans esters obtained from waste cooking oil underwent successful pre-treatment and were blended with Jet A-1 aviation fuel at different ratios (10%, 20%, 30% and 100%). The binary blends of jet biofuel underwent chemical and physical characterization to determine the most appropriate blending ratio for testing combustion characteristics. The temperature aligns with the maximum standard atmospheric altitude of 7000 meters. Unless the cold flow characteristics of biodiesel experience substantial enhancement, Bio-Jetfuel blends might restrict aircraft operations to lower altitudes where ambient temperatures surpass the cold point.

5.3.1 Density

The densities of the produced jet biofuel and its blends were determined and presented in Table 5.3. Density is crucial for calculating flight fuel requirements, modeling combustion processes, and various other applications. The density of jet fuel is influenced by its composition and temperature, illustrating the variation in density of jet biofuel with the fraction of trans esters in the binary blends. trans esters exhibit higher densities compared to Jet A-1. According to the specification and standard limits of Jet A-1, its density must fall within the range of $0.7750\text{--}0.8400\text{ g/cm}^3$. Consequently, only the blends of waste vegetable oil biodiesel containing less than 50% ester content fall within the acceptable range for aviation purposes

Table 5.3: density of waste cooking oil bio-jetfuel and blends

JET A-1 FUEL %	0	90	80	70	100
WCO BIODIESEL %	100	10	20	30	0
Blends	0.881	0.762	0.777	0.788	0.775

5.3.2 Viscosity

Viscosity, a measure of a liquid's resistance to flow under pressure, is affected by gravity or mechanical force. In turbine engines, high-pressure jet fuel is injected into the combustion section through nozzles, forming a fine spray of quickly evaporating fuel droplets as they mix with air [6]. Fuel viscosity influences the spray pattern and droplet size, impacting fuel atomization [6]. Higher viscosity can lead to slow engine starting [7], affecting pressure drop in fuel system lines. Elevated viscosities require the fuel pump to exert more effort to maintain consistent flow rates, also affecting the performance of the fuel system control unit. In this study, viscosities of binary blends of Jet A-1 with trans esters were measured at -20°C. The reported viscosity data represent the mean of triplicate determinations, as shown in Table.5.4. Concentration-dependent behavior was observed in the binary blends; viscosity increased linearly with higher volume fractions of esters. Results suggest that binary blends containing waste vegetable oil trans esters with ester contents of 20% or less meet aviation fuel standards in terms of viscosity.



Fig 5.2 Viscosity bath

Table 5.4 Viscosity of waste cooking oil bio-jetfuel and blends

JET A-1 FUEL %	0	90	80	70	100
WCO BIODIESEL %	100	10	20	30	0
BLENDS	4.27	1.134	1.414	1.498	1.186

5.3.3 Pour point and cloud point

The pour point denotes the lowest temperature at which a fuel sample maintains its flow under specified standard conditions. It's crucial for jet fuel to seamlessly flow from the fuel tanks through an aircraft's system to the engines [6]. While fluidity generally refers to a substance's flowability, it lacks a precise physical definition. Pour point serves as a quantitative measure for characterizing jet fuel fluidity at low temperatures. Given the extreme cold encountered both in-flight and on the ground in harsh weather conditions, jet fuel must maintain its fluidity to ensure continuous engine operation. In this study, pour points of Jet A-1, waste vegetable oil trans esters, and their blends at various ratios were determined, as depicted in table. [5.5]. Results reveal that the pour points of trans esters notably exceed those of Jet A-1, which stands $<35^{\circ}\text{C}$. However, blends containing less than 30% waste oil trans esters exhibit favorable fluidity characteristics at low temperatures. Another property that defines the fluidity of jet fuel is the cloud point. The cloud point represents the temperature at which wax crystal formation initiates in a fuel sample under specific standard conditions. Formation of crystal networks below the cloud point can impede flow and lead to blockages in pipes and fuel filters. Cloud point testing was conducted on trans esters, Jet A-1, and their blends to assess fluidity. The cloud point of Jet A-1 and waste vegetable oil trans esters was found to be -18°C and 7°C , respectively, indicating significant disparity from Jet A-1. Similar to pour point assessments, blends containing 30% or less waste oil esters exhibited acceptable performance at low temperatures. The results of the cloud point analysis are depicted in table.5.5.

Table 5.5:(a)pour point and (b)cloud point of waste cooking oil bio-jetfuel and blends

(a) pour point

JET A-1 FUEL %	0	90	80	70	100
WCO BIODIESEL %	100	10	20	30	0
BLENDS	-4	<-35	<-35	<-35	<-35

(b)cloud point of waste cooking oil bio-jetfuel and blend

JET A-1 FUEL %	0	90	80	70	100
WCO BIODIESEL %	100	10	20	30	0
BLENDS	5	<-35	<-35	<-35	<-35

5.3.4 Calorific value

The heating value stands as another crucial attribute of jet biofuel. In an aircraft turbine engine, power generation hinges on converting the chemical energy stored in the fuel into a blend of mechanical energy and heat [7]. Given the constrained space aboard most aircraft, the energy content per unit of fuel becomes paramount. Measuring the heating value of jet fuel entails burning a known quantity under specified conditions. In this study, the heating values of the binary blends were determined via oxygen bomb calorimetry. As depicted in table. [5.5], it's evident that the heating value exhibits a linear decline with increasing volume fraction of esters in the mixture. However, the results indicate that all binary blends meet the minimum requirement of 42.8 MJ/kg, attributed to the high calorific values of the trans esters. The results of the waste cooking oil trans ester blended jet fuel can be seen in table (5.6)



Fig 5.3 Bomb calorimeter

Table 5.6: Calorific value of waste cooking oil bio-jetfuel and blends

JET A-1 FUEL %	0	90	80	70	100
WCO BIODIESEL %	100	10	20	30	0
BLENDS	9346	8817.15	7914.26	7688.44	9941.26

5.3.5 Acid value

The acid number serves as a comprehensive indicator encompassing all acidic components, while also reflecting the long-term stability and corrosive potential of the biofuel. Given that jet fuel comes into contact with various materials during distribution and utilization, it's imperative that the fuel does not induce corrosion in any of these materials [7]. Typically, fuel tanks are constructed of aluminum, but fuel systems may also incorporate steel and other metals. Hence, a lower acid value signifies higher quality. In this study, the acidities of biofuels were assessed in terms of total acid number, with the results detailed in Table 6. The findings reveal that the acidity of waste vegetable trans esters is relatively high, and an increase in esters content correlates with heightened acidity of the jet-bio fuel. As shown in the table 5.7, Only blends containing 20% or less esters content aligns with Jet A-1 specifications.

Table 5.7 Acid value of waste cooking oil bio-jetfuel and blends

JET A-1 FUEL %	0	90	80	70	100
WCO BIODIESEL %	100	10	20	30	0
BLENDS	0.48	0.1	0.2	0.2	0.1

5.3.6 Moisture content

In this investigation, the water content of the prepared jet biofuels was assessed, revealing that efficient separation and dewatering processes resulted in all samples containing less than 0.2wt% water. It is imperative to minimize the presence of free water in both fuel storage and aircraft tanks. Jet fuel is susceptible to rapid contamination by microorganisms ubiquitous in air and water. These microorganisms pose a significant risk by clogging fuel filters and accelerating metal corrosion. Based on the characterization outcomes, it was observed that jet biofuel blended with 10%, 20% and 30% trans esters from waste vegetable oils exhibits properties similar to Jet A-1 aviation fuel as shown in the table.5.8



Fig 5.4 Oil sample after 110 C in hot furnace

This assertion holds true concerning the mentioned physical and chemical attributes. These resemblances validate the quality of the produced jet biofuels and endorse the viability of partially substituting petroleum-based aviation fuel with trans esters derived from non-edible oils like waste vegetable oil.

Table 5.8 moisture content waste cooking oil bio-jetfuel and blends

JET A-1 FUEL %	0	90	80	70	100
WCO BIODIESEL %	100	10	20	30	0
BLENDS	0.05	0.01	0.01	0.02	0.01

5.4 SINGLE DROPLET COMBUSTION

In this segment, findings regarding the combustion of fuel droplets with varying volatility in both stagnant and turbulent atmospheres are presented. Initially, the discussion focuses on observations derived from experiments involving droplet and flame visualization. Subsequently, the results pertaining to the measurement of the mass burning rate constant are elaborated upon (K_B).

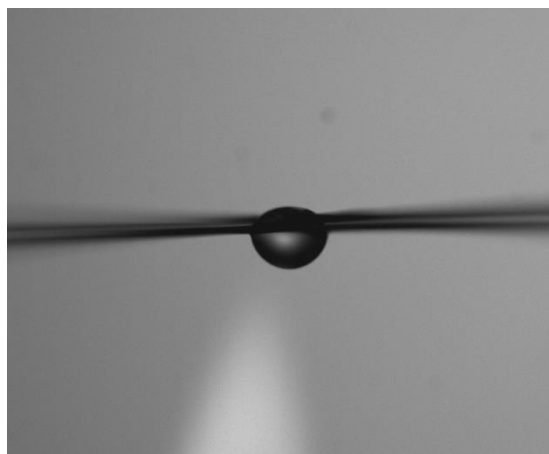
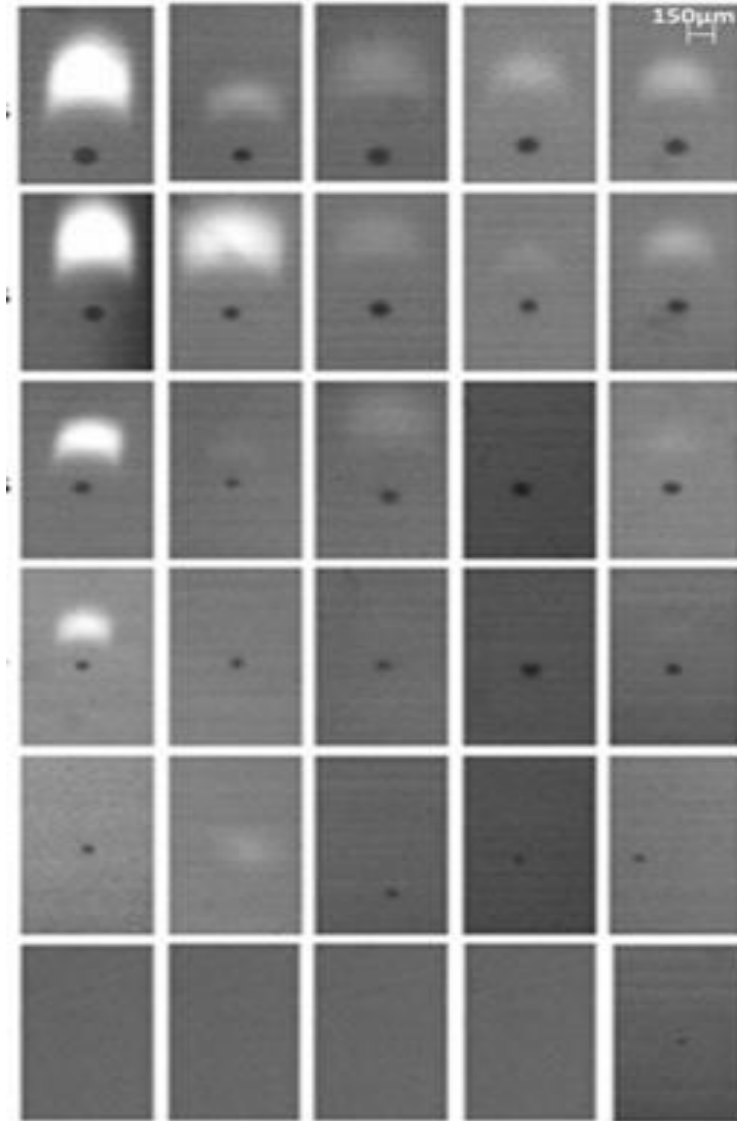


Fig 5.5: Suspension of droplets utilizing the cross-sectional wire technique.

Figures 5.5 and 5.6 depict instantaneous flame images illustrating the burning of droplets in stagnant atmospheres, respectively. In both scenarios, the images reveal a characteristic diffusion flame surrounding the droplet, with the brighter area attributed to emissions from soot particles. However, while Figure 4.2a demonstrates flame shape and orientation primarily influenced by natural convection induced by buoyancy, Figure 4.2b presents a different scenario, with flame shape and orientation changing randomly between images. This randomness stems from the interplay

between air turbulence and natural convection affecting the flame. Notably, transitions from the envelope to wake (at $t = 0.408$ sec) and from wake back to envelope flame (at $t = 0.468$ sec) are observed in Figure 5.6



Fig; 5.6 combustion rate to the period of time of the blended samples

5.5. QUANTITATIVE ANALYSIS OF SINGLE DROPLET COMBUSTION

Figure (5.6) illustrates the temporal progression of the normalized surface area for waste cooking oil (WCO) biodiesel, as well as all bio-jetfuels and blends, under stagnant atmospheric conditions. The burning process of both fuels unfolds in two distinct stages. The initial stage, termed the droplet heat-up period, entails the gradual increase in droplet temperature until it reaches the boiling point. Subsequently, the second stage encompasses the quiescent droplet combustion process, characterized by the dominance of equilibrium vaporization from the droplet surface. Notably, it is observed that for both fuels, the reduction in droplet surface area follows an almost linear trend over time, indicating similarity with the d^2 – law of droplet burning. In the above figure, time is normalized by square of initial droplet size (d_0) such that the slope in d^2/d_0^2 vs t/d_0^2 plot represents the mass burning rate constant, as per classical d^2 – law,

$$d^2/d_0^2 = -K_B(t/d_0^2) + 1.$$

For a single jet-fuel droplet, the increase in the droplet diameter in the first stage due to thermal expansion which is followed by the linear regression of the droplet surface area in the second stage is observed. Yet, in the case of jet fuel droplets, the initial enlargement of droplet diameter is notably absent. This discrepancy could be attributed to the fact that the boiling point of jet fuel exceeds that of biodiesel by 20%, while their thermal expansion coefficients are nearly identical. Consequently, biodiesel allows for greater potential thermal expansion.

As discussed in the preceding chapter regarding droplet evaporation, there exists a significant contrast in the volatility between jet fuel and biodiesel, resulting in a jet fuel evaporation rate nearly ten times higher than that of biodiesel,(ref). Nonetheless, as depicted in Fig. 5.6, it is evident that the burning rate constants (represented by slopes in the plots) for both jet fuel and biodiesel are approximately equal. This observation can be rationalized by the d^2 -law, which stipulates that the burning rate constant is expressed as

$$K_B = \frac{8\lambda_g}{C_{pg} \rho_l \ln(1+BT)}$$

Here, λ_g and C_{pg} denote the thermal conductivity and specific heat of the gas, respectively, while ρ_l represents the liquid density. BT , referred to as the transfer number, signifies the ratio between the potential for vaporization stemming from the heat of combustion coupled with the sensible enthalpy difference between the ambient surroundings and the droplet, relative to the enthalpy of vaporization.

5.5.1 combustion analysis of biodiesel

Figure;(5.7) compares the time evolution of the normalized surface area of jet-A1 fuel, WCO biodiesel, and binary mixtures of bio-jet fuel/WCO biodiesel for various volume fractions of WCO biodiesel (Φ) under stagnant and turbulent conditions, respectively. Since the gasification rate during droplet combustion is significantly higher compared to droplet evaporation under ambient conditions, the droplet burning timescale becomes comparable to the timescale of diffusion of the liquid components within the bio-jet fuel droplet. This stands in contrast to the pure evaporation case, where the liquid diffusion timescale is much smaller than the droplet evaporation rate (as discussed in the previous chapter). This elucidates the single-sequence burning observed in the d^2 vs t plot after the initial heat-up period. It is evident from Figure 5.7 that for higher concentrations of WCO biodiesel, the d^2 vs t plot approaches that of WCO biodiesel as shown in table, (5.8)

Table 5.9: D^2 vs time plot for 100% WCO biodiesel

time(s)	Biodiesel
0	1
0.2	1.003263
0.4	1.001438
0.6	1.000801
0.8	0.964801
1	0.954311
1.2	0.951291
1.4	0.679517

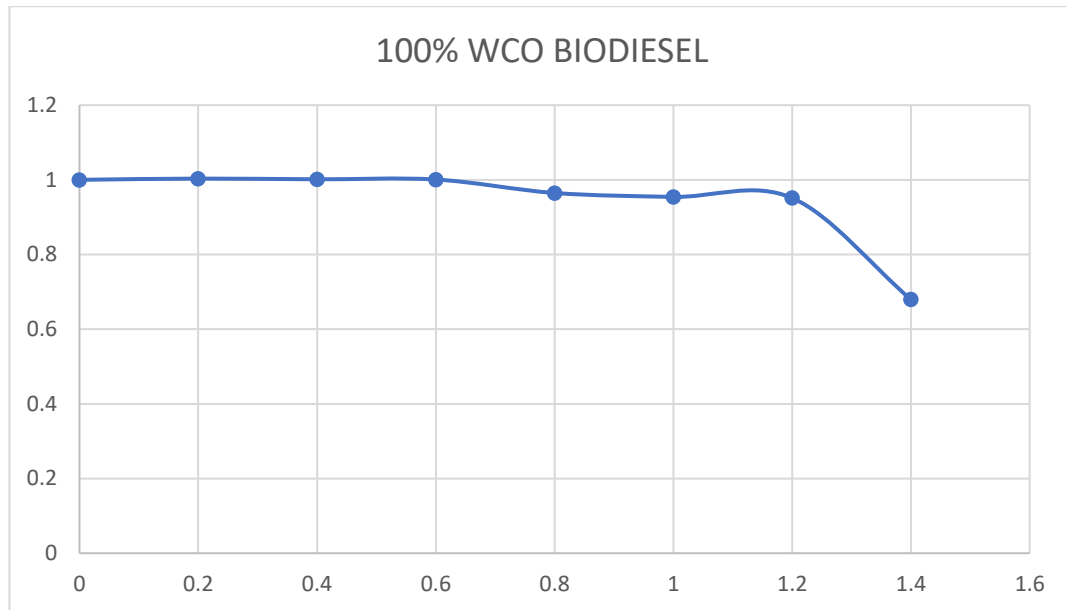


Fig 5.7 Single droplet combustion graph for 100% biodiesel

5.5.2 COMBUSTION ANALYSIS OF 100% JETFUEL

Figure (5.8) compares the time evolution of the normalized surface area of jet-A1 fuel, under stagnant and turbulent conditions, respectively. Since the gasification rate during droplet combustion is significantly higher compared to droplet evaporation under ambient conditions, the droplet burning timescale becomes comparable to the timescale of diffusion of the liquid components within the bio-jet fuel droplet. This stands in contrast to the pure evaporation case, where the liquid diffusion timescale is much smaller than the droplet combustion rate (as discussed in the previous chapter). This elucidates the single-sequence burning observed in the d^2 vs t plot after the initial heat-up period. It is evident from Figure [], the d^2 vs t plot approaches that of 100%jet-A1 fuel., as shown in table(5.9)

Table 5.10 D^2 vs time plot for 100% WCO biodiesel

time	JET A1
0	1
0.2	0.895945
0.4	0.657039
0.6	0.151875

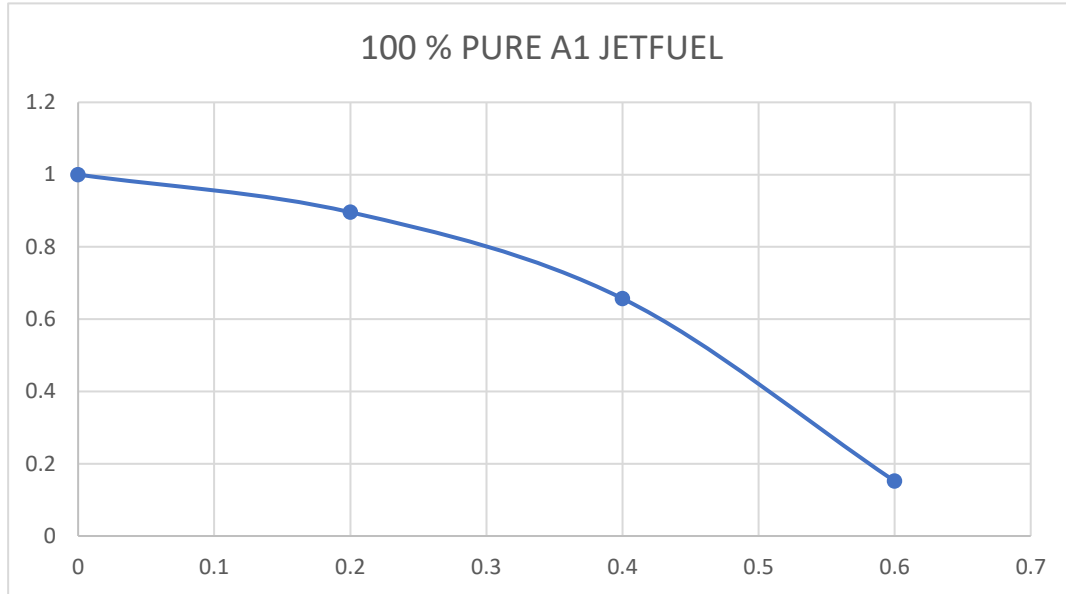


Fig 5.8 Single droplet combustion graph for 100% jet A1 fuel

5.5.3 COMBUSTION ANALYSIS OF 10% BIO-JETFUEL

Figure (5.9) compares the time evolution of the normalized surface area of binary mixtures of bio-jet fuel/10%WCO biodiesel for various volume fractions of WCO biodiesel (Φ) under stagnant and turbulent conditions, respectively. Since the gasification rate during droplet combustion is significantly higher compared to droplet evaporation under ambient conditions, the droplet burning timescale becomes comparable to the timescale of diffusion of the liquid components within the bio-jet fuel droplet. This stands in contrast to the pure combustion case, where the liquid diffusion timescale is much smaller than the droplet evaporation rate (as discussed in the previous chapter). This elucidates the single-sequence burning observed in the d^2 vs t plot after the initial heat-up period. It is evident from Figure 5.10 that for higher

concentrations of 10% WCO biodiesel, the d^2 vs t plot approaches that of WCO biodiesel.

Table 5.11 Single droplet combustion graph for 100% jet A1 fuel

Time(s)	10% Blend
0	1
0.2	0.907039
0.4	0.714033
0.6	0.492475
0.8	0.230854
1	0.175741

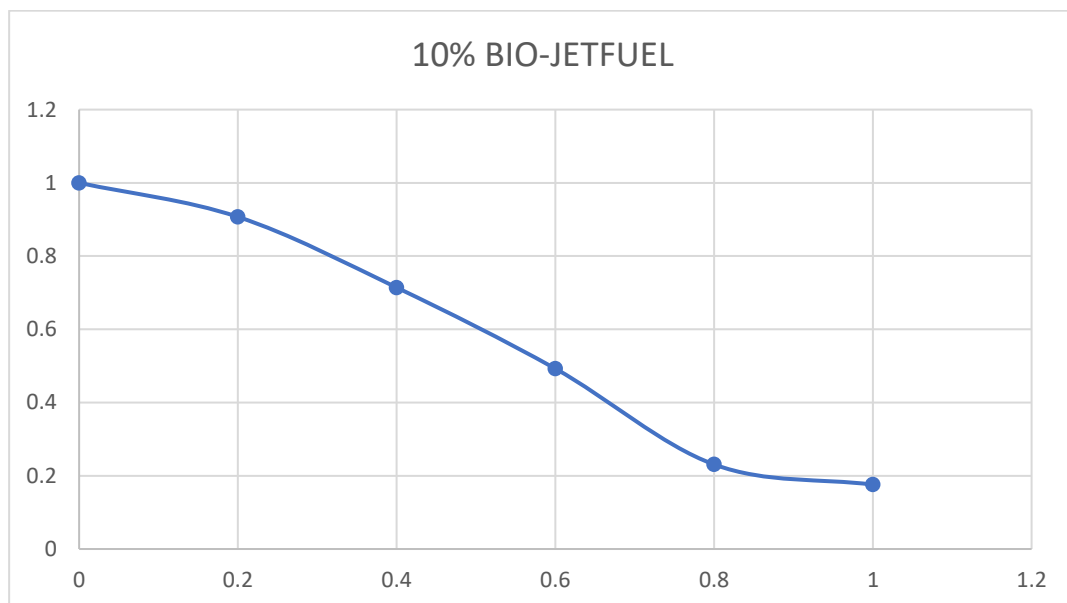


Fig 5.9 Single droplet combustion graph for 10% blended jet A1 fuel

5.5.4 COMBUSTION ANALYSIS OF 20% BIO-JETFUEL

Figure (5.10) compares the time evolution of the normalized surface area binary mixtures of bio-jet fuel 20%WCO biodiesel for various volume fractions of WCO biodiesel (Φ) under stagnant and turbulent conditions, respectively. Since the gasification rate during droplet combustion is significantly higher compared to droplet evaporation under ambient conditions, the droplet burning timescale becomes comparable to the timescale of diffusion of the liquid components within the bio-jet fuel droplet. This stands in contrast to the pure evaporation case, where the liquid diffusion timescale is much smaller than the droplet evaporation rate (as discussed in the previous chapter). This elucidates the single-sequence burning observed in the d^2 vs t plot after the initial heat-up period. It is evident from Figure 5.10 that for higher concentrations of 20% WCO biodiesel, the d^2 vs t plot approaches that of WCO biodiesel., as shown the table [5.12]

Table 5.12 Single droplet combustion graph for 100% jet A1 fuel

Time(s)	20% Blend
0	1
0.2	0.972361
0.4	0.852666
0.6	0.63852
0.8	0.30185
1	0.206931

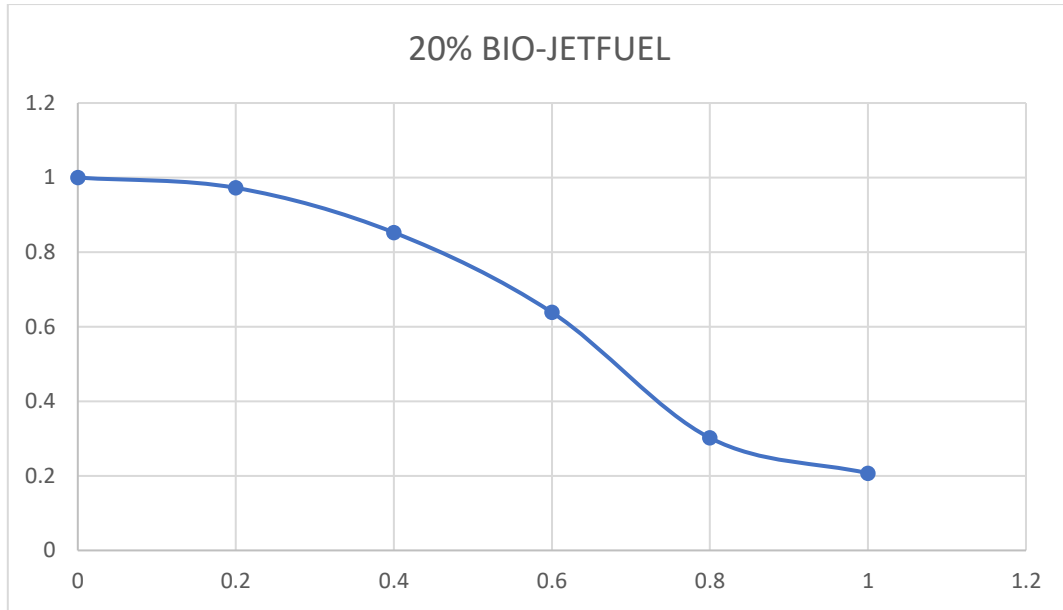


Fig 5.10:Single droplet combustion graph for 20%blended jet A1 fuel

5.5.5 Combustion analysis of 30% bio-jetfuel

Figure (5.11) compares the time evolution of the normalized surface area of bio-jet fuel 30% WCO biodiesel mixture for various volume fractions of WCO biodiesel (Φ) under stagnant and turbulent conditions, respectively. Since the gasification rate during droplet combustion is significantly higher compared to droplet evaporation under ambient conditions, the droplet burning timescale becomes comparable to the timescale of diffusion of the liquid components within the bio-jet fuel droplet. This stands in contrast to the pure evaporation case, where the liquid diffusion timescale is much smaller than the droplet evaporation rate (as discussed in the previous chapter). This elucidates the single-sequence burning observed in the d^2 vs t plot after the initial heat-up period. It is evident from Figure [5.11] that for higher concentrations of 30% WCO biodiesel, the d^2 vs t plot approaches that of WCO biodiesel., as shown the table [5.13]

Table 5.13 Single droplet combustion graph for 100% jet A1 fuel

Time(s)	30% Blend
0	1
0.2	1.001789
0.4	0.961145
0.6	0.867331
0.8	0.828988
1	0.729806
1.2	0.636247
1.4	0.345603
1.6	0.13727

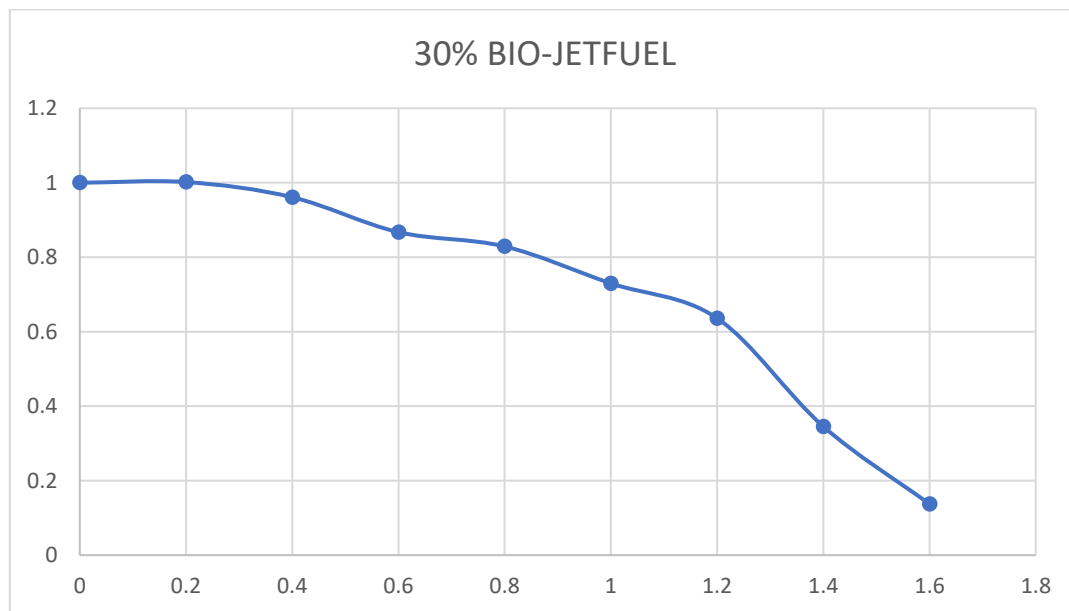


Fig 5.11 Single droplet combustion graph for 30% blended jet A1 fuel

5.5.6 Comparative analysis of all bio jet-fuel sample and blends

Through the graphical analysis as shown in the figure (5.12)., The droplet diameter evolution over time, this study provides insights into the combustion rate of jet fuel and its biodiesel blends. The results offer valuable information for fuel formulation and engine optimization in the aviation industry, aiming for improved efficiency and reduced environmental impact.

Table 5.14 Compared analysis plots for all the biodiesel blended jet fuel sample

time	JET A1	10%	20%	30%	BIODIESEL
0	1	1	1	1	1
0.2	0.895945	0.907039	0.972361	1.001789	1.003263
0.4	0.657039	0.714033	0.852666	0.961145	1.001438
0.6	0.151875	0.492475	0.63852	0.867331	1.000801
0.8		0.230854	0.30185	0.828988	0.964801
1		0.175741	0.206931	0.729806	0.954311
1.2				0.636247	0.951291
1.4				0.345603	0.679517
1.6				0.13727	

It can be observed that in a turbulent environment, the initial heating period is prolonged for biodiesel in comparison to Jet A1 fuel, possibly due to the higher boiling point of biodiesel. Remarkably, contrary to droplet evaporation, the burning rate constant is reduced under turbulent conditions compared to stagnant conditions. This decrease in burning rate can be ascribed to: (i) the fluctuating and random orientation of the flame over time, leading to transitions to wake flames which may alter droplet surface temperature distribution, and (ii) heat dissipation from the flame caused by external air turbulence. According to the d^2 -law, once more, in contrast to the pure evaporation of droplets under turbulent conditions

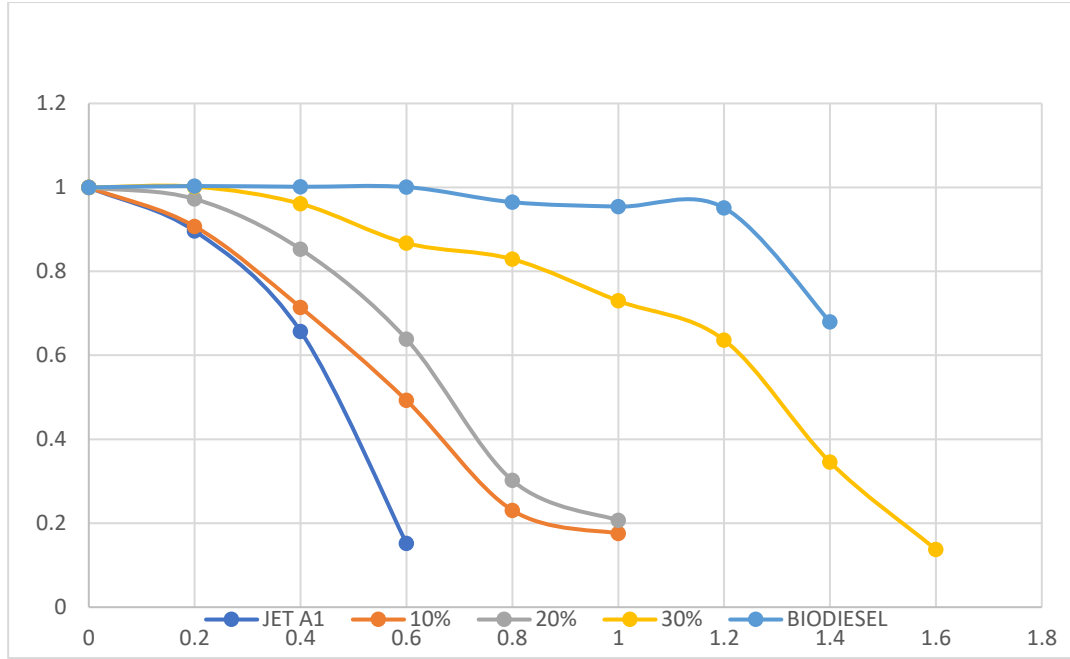


Fig 5.12 Comparative analysis graph for the biodiesel-jet A1 blends

The blends of bio-jet fuel, comprising mixtures of Jet A1 fuel and biodiesel, were prepared with varying volume fractions of biodiesel (Φ). Three distinct cases are documented: $\Phi = 10\%$, 20% , and 30% . Figure (5.14) displays instantaneous flame images depicting the binary mixture of Jet A1 fuel and biodiesel, specifically with a 30% volume fraction of biodiesel ($\Phi = 30\%$), under stagnant and turbulent atmospheric conditions, respectively. The depicted flame images exhibit analogous characteristics (flame shape, orientation, stand-off distance, etc.) to the single-component fuel droplets discussed in previous Section. Additionally, consistent flame behavior was observed across all binary mixture experiments. Therefore, for brevity, the flame behavior is illustrated here only for $\Phi = 30\%$. Because of the variance in volatility between the two components, one might anticipate micro-explosions, yet none have been observed in any of the studied mixtures. Nevertheless, this variance is not significant enough to induce micro-explosions.

Also, Figure (5.12) compares the time evolution of the normalized surface area of jet-A1 fuel, WCO biodiesel, and binary mixtures of bio-jet fuel/WCO biodiesel for various volume fractions of WCO biodiesel (Φ) under stagnant and turbulent conditions, respectively. Since the gasification rate during droplet combustion is

significantly higher compared to droplet evaporation under ambient conditions, the droplet burning timescale becomes comparable to the timescale of diffusion of the liquid components within the bio-jet fuel droplet. This stands in contrast to the pure evaporation case, where the liquid diffusion timescale is much smaller than the droplet evaporation rate (as discussed in the previous chapter). This elucidates the single-sequence burning observed in the d^2 vs t plot after the initial heat-up period. It is evident from Figure (5.12) that for higher concentrations of WCO biodiesel, the d^2 vs t plot approaches that of WCO biodiesel.

The rationale for this observation has been previously elucidated in Section Figure (5.12) illustrates the change in the burning rate constant normalized by the burning rate constant of Jet A1 fuel under stagnant conditions (denoted as $K_B/K_{B,HS}$) for various volume fractions of biodiesel in the mixture. It is noted that as the volume fraction of biodiesel increases, the burning rate constant slightly decreases under stagnant conditions. Conversely, a contrary trend is observed for droplet burning under turbulent conditions, where $K_B/K_{B,HS}$ is consistently smaller than 'one'.

CHAPTER-6

SUMMARY AND CONCLUSION

The configuration and alignment of the n-heptane droplet flame were observed to undergo random variations during droplet combustion in turbulent conditions. This occurred due to the fluctuating, diminished, and non-uniform dispersion of flame temperature around the droplet, stemming from unpredictable flame orientation, transitions to wake flames, and additional dissipation of heat from the flame due to air turbulence. Consequently, the burning rate decreased under turbulent conditions across all analyzed fuel compositions. Comparable outcomes were also noted for WCO diesel droplets.

Under stagnant environmental conditions, despite notable differences in the evaporation rates of n-heptane and WCO biodiesel droplets due to their varying volatilities, the burning rate constants for both fuels, as well as their binary mixtures, exhibited similar values during droplet combustion. This uniformity in burning characteristics persisted under turbulent conditions for both base fuels and their binary blends.

Regarding the combustion of bio-jet fuel (comprising Jet A1 and WCO biodiesel), the introduction of surfactants alone could induce sporadic low-intensity micro-explosions toward the end of the droplet's lifespan, albeit infrequently. The intensity and frequency of secondary droplet ejections resulting from micro-explosions increased accordingly. The combustion duration of bio-jet fuel and its blends can be delineated into three phases: i) classical droplet combustion, ii) puffing and micro-explosions, and iii) flame emergence due to the pyrolysis products of surfactants and residues from nanoparticle combustion. The influence of air turbulence on reducing the burning rate of bio-jet fuel droplets outweighed the reduction in droplet lifespan caused by micro-explosions.

6.1 SCOPE OF FUTURE WORK

Studying the combustion processes of single isolated droplets holds allure due to its simplistic setup, yet its capacity to offer insights into the intricacies of complex spray combustion phenomena. The discoveries from the present investigation evoke curiosity to expand research into more intricate scenarios. Some potential avenues for future exploration include:

- i. Investigating multi-component droplet evaporation under high-pressure and high-temperature conditions, both individually and in combination. Additionally, exploring similar studies using bio-jet fuel and its blends holds significance and interest.
- ii. Delving into the effects of turbulence on droplet combustion necessitates the compilation of a broader experimental database. This would involve employing different fuels and exploring various experimental conditions to ascertain whether the observed turbulence effect on droplet burning is universal. Hence, experiments can be conducted using a wider range of turbulent conditions and diverse fuels.
- iii. To bridge the gap between bio-jet fuel and its blend droplet and spray combustion, experiments could employ a droplet generator capable of periodically generating regularly spaced and mono-sized droplets arranged in a stream.

•

REFERENCE

1. Ajay Arora. K, et al. "Production of biodiesel using heterogeneous catalyst", *Bioresource Technology*,102, (2011),2151–2162.
2. Appenroth, Klaus-J. "Biomass and bioenergy production potential of duckweed (Lemnaceae family) species." *Journal of Applied Phycology*,232, (2011),215-222.
3. Cheng, Jay J., and Don Mau. "The potential of duckweed as a high-yield biofuel feedstock." *Biofuels, Bioproducts and Biorefining*,1.4, (2007),394-401.
4. Chen, Pengpeng, et al. "Duckweed (Lemnaceae family) as a model plant for ecotoxicological studies." *Plant Ecology*,219.6, (2018), 671-693.
5. Cui, W., et al. "Duckweed Biomass as a Renewable Raw Material for Bioethanol Production by Simultaneous Saccharification and Fermentation (SSF) Process." *Energy & Fuels*,28.12, (2014), 7666-7671.
6. Gui-Li Yang, Meng-Meng Zheng, Hai-Min Liao, Juan Tan, Dan Feng, Shi-Ming, "Influence of cadmium and microplastics on physiological responses, ultrastructure and rhizosphere microbial community of duckweed", *Ecotoxicology and Environmental Safety*,243, (2022),114011.
7. Grigore Cican, Marius Deaconu, Radu Mirea, Laurentiu Consatantin Ceatra, Mihaiella Cretu, "An experimental investigation to use the biodiesel resulting from recycled sunflower oil, and sunflower oil with palm oil as fuels for aviation turbo-engines", *International Journal of Enviromental Research and Public Health*,18, (2021),5189.

8. Goncalo Pacheco, Andre Silva, Mario Costa, “ Single-droplet combustion of jet A-1, hydroprocessed vegetable oil, and their blends in drop-tube furnace”, *Energy Fuels*, 35, (2021), 7232-7241.
9. Harahap, Leduc, Mesfun.S, Khatiwada.D, Kraxner.F,” Oppurtunities to optimize the palm oil supply chain”, *Energies*,12, (2019),420.
- 10.Heinrich.G,”Jatropha curcas L.- An Alternative oil crop”, *Biokerosene*,237, (2018),257.
- 11.Huzir.N.M, Aziz.M, M.A.Ismail,” Agro-industrial waste to biobutanol production: eco-friendly biofuels for next generation”, *Renewable Sustainable Energy*,94, (2018), 476.
- 12.IATA. World Buisness Summit on climate change. Copenhagen (2009).
- 13.Jayaram.K and Gokalp.I,” Pyrolysis, combustion and gasification characteristics of miscanthus and sewage sludge”. *Energy convers*, 89, (2015),83-91.
- 14.Kalnes, T. M. T., Shonnard, D. R., and Koers, K. P.” Green diesel production by hydro refining renewable feedstockds”. *Biofuels Technology*, 4, (2011),7-11.
- 15.Kandaramath Hari, T., Yaakob, Z., and Binitha, N. N. “Aviation biofuel from renewable resources: routes opportunities and challenges”. *Renewable Sustainable Energy*, 42, (2015), 1234-1244.
- 16.Mandolesi de Araujo, c. D., de Andrade, C. C., de Souza e Silva, E., and Dupas, F.A.”
- 17.Biodiesel diesel production from waste cooking oil”. *Renewable Sustainable Energy*, 27, (2013), 445-452.

18. Newes, E. K., Bush, B. W., Peck, C.T., Peterson, S.” Potential leverage points for developments of the cellulosic ethanol industry supply chain”. *Biofuels*, 6, (2015), 21-29.
19. Nguyen, D. D., Dharmaraja, J., Shobana, S., Sundaram, A., Chang, S. W., Kumar, G., et al.” Transesterification and fuel characterization of rice bran oil: a biorefinery path”. *Fuel*, 253, (2019), 975-987.
20. Oladosu, G., and Msangi, S.” Biofuel-food market interactions: a review of modelling approaches and findings”. *Agriculture*, 3, (2013), 53-71.
21. Ujas Patel, Srikrishna Sahu.” Effect of air turbulence and fuel composition on bi-component droplet evaporation”. *International Journal of Heat and Mass Transfer*, 141, (2019), 757-768.

muhamed fadhl

ORIGINALITY REPORT

17%	10%	14%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	repository.um.edu.my Internet Source	2%
2	www.researchgate.net Internet Source	2%
3	N. Nirmala, S.S. Dawn. "Optimization of Chlorella variabilis. MK039712.1 lipid transesterification using Response Surface Methodology and analytical characterization of biodiesel", Renewable Energy, 2021 Publication	<1%
4	Sathe, M.J.. "Advanced PIV/LIF and shadowgraphy system to visualize flow structure in two-phase bubbly flows", Chemical Engineering Science, 20100415 Publication	<1%
5	vdoc.pub Internet Source	<1%
6	rosap.ntl.bts.gov Internet Source	<1%
7	etd.iisc.ac.in	

	Internet Source	<1 %
8	doaj.org Internet Source	<1 %
9	Alisson Aparecido Vitoriano Julio, Eric Alberto Ocampo Batlle, Christian Jeremi Coronado Rodriguez, José Carlos Escobar Palacio et al. "Exergoeconomic and Environmental Analysis of a Palm Oil Biorefinery for the Production of Bio-Jet Fuel", Waste and Biomass Valorization, 2021 Publication	<1 %
10	Hong, Thong D., Tatang H. Soerawidjaja, Iman K. Reksowardojo, Osamu Fujita, Zarrah Duniani, and Mai X. Pham. "A study on developing aviation biofuel for the Tropics: Production process—Experimental and theoretical evaluation of their blends with fossil kerosene", Chemical Engineering and Processing Process Intensification, 2013. Publication	<1 %
11	www.scientific.net Internet Source	<1 %
12	Saeid Baroutian, Mohamed K. Aroua, Abdul Aziz Abdul Raman, Azzahra Shafie, Raja Adeliza Ismail, Hartini Hamdan. "Blended aviation biofuel from esterified Jatropha	<1 %

curcas and waste vegetable oils", Journal of the Taiwan Institute of Chemical Engineers, 2013

Publication

-
- 13 Ujas Patel, Srikrishna Sahu. "Effect of air turbulence and fuel composition on bi-component droplet evaporation", International Journal of Heat and Mass Transfer, 2019 $<1\%$
- Publication

-
- 14 M. Mofijur, Shams Forruque Ahmed, Zahidul Islam Rony, Kuan Shiong Khoo et al. "Screening of non-edible (second-generation) feedstocks for the production of sustainable aviation fuel", Fuel, 2023 $<1\%$
- Publication

-
- 15 "Biojet Fuel: Current Technology and Future Prospect", Springer Science and Business Media LLC, 2024 $<1\%$
- Publication

-
- 16 Submitted to Taylor's Education Group $<1\%$
- Student Paper

-
- 17 Khushboo Pandey, Saptarshi Basu, Gautham V, Aditya Potnis, Kamanio Chattopadhyay. "Self-tuning and topological transitions in a free-falling nanofuel droplet flame", Combustion and Flame, 2020 $<1\%$
- Publication
-

18	coek.info Internet Source	<1 %
19	R. O. Dunn, . "ALTERNATIVE JET FUELS FROM VEGETABLE OILS", Transactions of the ASAE, 2001. Publication	<1 %
20	ijred.cbiorid.id Internet Source	<1 %
21	Submitted to University of South Florida Student Paper	<1 %
22	Ch Durga Prasad. "Dielectric properties of the system $\text{Ca}_{1-x}\text{La}_x\text{Ti}_{1-x}\text{Co}_x\text{O}_3$ ", Bulletin of Materials Science, 12/1988 Publication	<1 %
23	www.knowafest.com Internet Source	<1 %
24	etheses.whiterose.ac.uk Internet Source	<1 %
25	Submitted to Sheffield Hallam University Student Paper	<1 %
26	Alok Ranjan, Dawn S.S., Nirmala N., Santhosh A., Arun J.. "Application of deep eutectic solvent in biodiesel reaction: RSM optimization, CI engine test, cost analysis and research dynamics", Fuel, 2022 Publication	<1 %

27	Valentin Soloiu, April Covington, Jeff Lewis, Marvin Duggan, James LoBue, Marcis Jansons. "Performance of JP-8 Unified Fuel in a Small Bore Indirect Injection Diesel Engine for APU Applications", SAE International, 2012 Publication	<1 %
28	Submitted to Xiamen University Student Paper	<1 %
29	Gautham Vadlamudi, Akhil Aravind, Saptarshi Basu. "Insights into the flame transitions and flame stabilization mechanisms in a freely falling burning droplet encountering a co-flow", Journal of Fluid Mechanics, 2023 Publication	<1 %
30	S. Ishak, A. Kamari. "A review of optimum conditions of transesterification process for biodiesel production from various feedstocks", International Journal of Environmental Science and Technology, 2019 Publication	<1 %
31	Submitted to Chulalongkorn University Student Paper	<1 %
32	Submitted to Federal University of Technology Student Paper	<1 %
33	Submitted to University of Minnesota System Student Paper	<1 %

34	G. E. Fodor, K. B. Kohl. "Analysis of middle distillate fuels by midband infrared spectroscopy", Energy & Fuels, 1993 Publication	<1 %
35	Submitted to University of Malaya Student Paper	<1 %
36	metapress.com Internet Source	<1 %
37	www.waljatcollege.edu.om Internet Source	<1 %
38	Gautham Vadlamudi, S. K. Thirumalaikumaran, Saptarshi Basu. "Insights into the dynamics of wake flame in a freely falling droplet", Physics of Fluids, 2021 Publication	<1 %
39	Rakesh Sarin, Meeta Sharma, Arif Ali Khan. "Terminalia belerica Roxb. seed oil: A potential biodiesel resource", Bioresource Technology, 2010 Publication	<1 %
40	Sena Isik, Gunes Unal. "Open-source software for automated rodent behavioral analysis", Frontiers in Neuroscience, 2023 Publication	<1 %
41	docplayer.net Internet Source	<1 %

42	Submitted to UCSI University Student Paper	<1 %
43	Submitted to University of Dundee Student Paper	<1 %
44	www.engineering108.com Internet Source	<1 %
45	www.science.gov Internet Source	<1 %
46	Alessandro Ruvio, Onur Bayrak. "A preliminary design of a hybrid train's on-board batteries for a 25kV-50Hz high speed railway line", Journal of Energy Storage, 2024 Publication	<1 %
47	Elissavet Emmanouilidou, Sophia Mitkidou, Agapios Agapiou, Nikolaos C. Kokkinos. "Solid waste biomass as a potential feedstock for producing sustainable aviation fuel: A systematic review", Renewable Energy, 2023 Publication	<1 %
48	Ramin Nabizadeh, Samira Yousefzadeh, Kamyar Yaghmaeian, Mahmood Alimohammadi, Zahra Mokhtari. "Bottled water quality ranking via the multiple-criteria decision-making process: a case study of two-stage fuzzy AHP and TOPSIS", Environmental Science and Pollution Research, 2021 Publication	<1 %

49	Yun Wang, Qiongyin Zhang, Jingwen Hao, Zhicheng Luo, Jun Xiao. "Global warming potential of bio-jet fuel produced by biomass aqueous-phase conversion", Sustainable Production and Consumption, 2023 Publication	<1 %
50	digitalworks.union.edu Internet Source	<1 %
51	hdl.handle.net Internet Source	<1 %
52	www.imarcgroup.com Internet Source	<1 %
53	N. Nirmala, S.S. Dawn, C. Harindra. "Analysis of performance and emission characteristics of Waste cooking oil and Chlorella variabilis MK039712.1 biodiesel blends in a single cylinder, four strokes diesel engine", Renewable Energy, 2020 Publication	<1 %

Exclude quotes Off
Exclude bibliography On

Exclude matches Off