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Analysis of Biodiesel Production from Waste Cooking Oil in China

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Abstract: This thesis discusses the current status of waste cooking oil (WCO) treatment in China and its application in biodiesel production. China produces a large amount of WCO every year, but its collection and treatment systems are inadequate, leading to environmental and health problems. Biodiesel is a sustainable alternative energy source capable of being produced by a variety of catalytic methods, including acid, alkali, enzyme catalysis, hydrotreating and pyrolysis. This paper presents a detailed comparison of these technologies, assessing their advantages and disadvantages in terms of yield, cost and environmental friendliness, and in particular analysing the efficiency of each method by means of the PMI (Process Mass Intensity) metric. It was shown that enzyme and base catalysis performed better in terms of yield, but suffered from higher costs and complexity; hydrotreating and pyrolysis offered higher efficiency, but had higher energy requirements. Ultimately, this paper provides a theoretical basis for optimising the utilisation of WCO, aiming to promote the green development of biodiesel industry in China.

Keywords: Biodiesel, Waste Cooking Oil, catalysis, PMI, Sustainable.

1. Introduction

Waste cooking oil (WCO) poses a significant challenge in China. China's major urban areas produce an annual total of 5 million tons of waste construction and demolition debris (WCC). People illicitly reintroduce approximately 40% to 60% of WCO into the food supply through various channels. The remaining portion of WCO is also mishandled, leading to significant environmental and health concerns. Biodiesel, a sustainable and environmentally-friendly fuel, is produced from waste vegetable oils and animal fats using chemical processes such as transesterification, pyrolysis, and hydrotreatment [1]. Its popularity is increasing due to its ability to enhance energy security and promote the circular economy by using waste materials. Therefore, the advantages of biodiesel have sparked a new wave of research worldwide. This paper addresses two research issues: first, it states the current status of biodiesel preparation in China; second, it compares the five existing preparation methods. The depletion of petroleum supplies, together with the substantial environmental contamination resulting from the incorrect disposal of WCO in China, necessitates the investigation of alternate alternatives for fuel and chemical manufacturing. Biodiesel is a promising alternative to petroleum that addresses the problems of fossil fuel depletion and WCO management. Therefore, this paper lays a theoretical foundation for the better utilization of WCO and the preparation of biodiesel.

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2. Biodiesel Processing in China at Present

China generates a substantial quantity of waste cooking oil, leading to the prevalent use of animal fat for biodiesel production. Currently, the primary catalysts employed for biodiesel synthesis in China are acidic, basic, and enzymatic catalysts utilized in transesterification processes. These technologies have gained significant popularity due to their cost-effectiveness and rapid reaction rate, particularly in treating common raw materials like waste cooking oil. This demonstrates their high level of economic viability and efficiency. Recently, there has been an emergence of novel catalytic approaches due to technology advancements. Hydrogenation catalysis and pyrolysis are alternative methods for producing biodiesel with lower PMI values. However, the use of these techniques for converting waste cooking oil into biodiesel in China is limited.China has a large amount of biodiesel raw materials, namely WCO, every year, and China's demand for biodiesel is also huge, which are the market advantages of China's catalytic biofuel. Therefore, how to better utilize WCO and better catalytic biofuel is an important issue at present.

Table 1: Common methods used in the biodiesel manufacturing process

	Reaction Type	Example	Pros	Cons
Acidic	Esterification Transesterification	H_2SO_4(high P and high T)	Easy to separate FFA	Slow Large catalyst loading Corrosion Problem
Basic(alkaline catalysis)	Transesterification Esterification	NaOH(25-40°C degrees)and KOH	Cheap Fas	Be likely to form the soap
Enzymatic (need pretreatment to deal with FFA)	Transesterification Esterifcation	Lipase	Mild reaction conditions No pollutants Lower E use	High cost Short life span stable conditions
Hydrotreatment	Hydrodeoxygenated		Lower acidity High stability Renewable	Expensive
Pyrolysis(do not need catalyst)	Cracking	SCA	Low demand of feedstock	Energy intensive

As shown in Figure 1, the five preparation methods currently widely used in China are: acidic, basic, enzymatic catalysts, hydrotreatment and Pyrolysis An extensive comparison of the species' catalytic modes is given in the following section.

3. Comparative analysis of the catalytic techniques

3.1. Acidic Catalysis

Acidic catalysis encompasses reactions like esterification and transesterification, which often employ strong acids like H_2SO_4 under conditions of elevated pressure and temperature. The main benefit of this approach is its simplicity in isolating Free Fatty Acids (FFA). Nevertheless, it is plagued by

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sluggish reaction rates, necessitates substantial quantities of catalyst, and presents notable corrosion issues.

Alkaline catalysis refers to the fundamental process of catalysis, in which a basic substance is used to accelerate a chemical reaction.

Alkaline chemicals such as NaOH and KOH are used in basic catalysis for transesterification and esterification processes, which are carried out at moderate temperatures ranging from 25 to 40°C. This procedure is efficient and expedient. However, a disadvantage of this is that it is susceptible to soap formation during the reaction, which might complicate the procedure.

3.2. Enzymatic catalysis

Enzymatic catalysis involves enzymes, such as lipase, to facilitate transesterification and esterification reactions. In many cases, pretreatment is necessary to control the presence of free fatty acids (FFA). This process runs under gentle reaction conditions and generates no contaminants, rendering it ecologically sustainable. Additionally, it requires a lower amount of energy. The disadvantages include the exorbitant expense, limited longevity of the enzymes, and the requirement for exceptionally steady conditions to sustain enzyme functionality.

3.3. Hydrotreatment

Hydrotreatment, specifically hydrodeoxygenation, is employed to generate biodiesel that has reduced acidity and enhanced stability. This strategy is also sustainable. The main drawback is its exorbitant cost, which diminishes its economic appeal despite its advantages.

3.4. Pyrolysis

Pyrolysis is a chemical process that involves breaking down substances without the need for a catalyst. It employs techniques such as SCA to facilitate the cracking reactions. One advantage of this is that it requires a small amount of feedstock, which makes it adaptable to a wide range of input materials. Nevertheless, the procedure requires a significant amount of energy, which might restrict its practicality and effectiveness.

Alkaline catalysis, employing chemicals such as NaOH and KOH, is notable for its rapidity and affordability. However, it frequently results in the creation of soap, which introduces complexity to the process. Enzymatic catalysis, employing enzymes like lipase, is ecologically sustainable and functions in gentle circumstances with reduced energy requirements. However, it is costly and necessitates consistent conditions for optimal enzyme activity. Hydrotreatment provides excellent stability and enables the manufacture of renewable fuels. However, it is an expensive process due to the requirement for hydrogen and high-pressure equipment. Pyrolysis, a process that involves breaking down substances without the need for catalysts, is very adaptable in terms of the materials it can handle. However, it requires a significant amount of energy due to the need for extremely high temperatures. Every approach has unique trade-offs, which means that the decision depends on specific requirements related to speed, cost, environmental effect, stability, and energy usage.

4. PMI values for the five catalytic modalities

PMI (Process Mass Intensity) is utilized in the biodiesel manufacturing process to assess the efficient utilization of feedstock and determine its potential for generating favorable economic outcomes. The study athered 20 literature papers pertaining to the production of biodiesel. Using the data presented in these articles, I computed the PMI (Polarizability-based Molecular Index) values for various raw

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materials and catalytic modes. Subsequently, compared the average PMI values across five distinct catalytic modes.[2]

Tablee 2: PMI values in different raw material by different catalysis

raw material	PMI	catalysis type	Yield
Soybean oil	1.47	Basic	93%
Palm oil	1.58	Enzymatic	97.90%
Corn oil	7.2	Acidic	80%
Palm oil	1.348	Acidic	91.40%
Sapindus mukorossi kernel oil	1.72	Acidic	87%
bitter almond oil	5.39	Basic	88.40%
waste oil	1.58	basic	95.78%
waste cooking oil	3.47	acid	74.30%
waste cooking oil	1.23	enzyme	98.14%
EL oil	1.324	acid	85.60%
SS kernel oil	1.308	acid	86.30%
JC oil	1.341	acid	84.20%
EL oil	1.363	basic	86.20%
SS kernel oil	1.333	basic	88.30%
JC oil	1.366	basic	86.20%
bio-oil	1.193	hydrogenation	79%
rubber oil	1.4	enzyme(TLL)	92.83%
rubber oil	5.59	enzyme(ROL)	23.22%
soybean oil	1.39	enzyme	74.80%

As is shown in Figure 2 that displays a chart that provides information on various raw materials, including their Process Mass Intensity (PMI), types of catalysts used, and the yields achieved during conversion. Acid catalysis demonstrates conversion yields that vary between 74.30% and 91.40%, with palm oil displaying a particularly high yield of 91.40%. Nevertheless, the elevated PMI values, such as the 7.2 kg_input/kg_product for corn oil, suggest a lower level of effectiveness in converting mass, along with difficulties like corrosion and the need for a significant amount of catalyst. Alkaline catalysis exhibits high conversion yields, with WCO achieving a conversion yield of 95.78% and soybean oil at 93%. Additionally, it offers modest PMI values, such as 1.47 kg_input/kg_product for soybean oil, showing an efficient process despite the possibility of soap generation concerns.[3]

Enzymatic catalysis exhibits diverse results, with WCO attaining a remarkable 98.14% yield and satisfactory PMI values, emphasizing its exceptional efficiency and ecologically sustainable characteristics. However, it should be noted that this process is expensive and necessitates steady conditions. The hydrogenation process, using soybean oil with PMI values of 1.193 kg_input/kg_product and conversion yields of 74.80% and 79%, offers a well-balanced strategy with reduced PMI and moderate yields. This highlights its effectiveness in efficiently utilizing mass and maintaining stability. [4] Pyrolysis exhibits adaptability with a modest PMI (1.21 kg_input/kg_product) and an 82.78% yield for beef fat. However, its energy-intensive characteristic is a notable disadvantage.

The PMI comparison table offers a straightforward comparison of mass efficiency among various catalytic processes. It reveals that hydrotreatment has the lowest PMI (~1.2 kg_input/kg_product), suggesting maximum efficiency in converting feedstock to product while minimizing waste. Both acid and base catalysis have similar PMI values, which are around 1.4 kg_input/kg_product.

Additionally, these catalytic processes demonstrate equal levels of process efficiency. Enzyme catalysis has a somewhat lower PMI (about 1.3 kg_input/kg_product), indicating effective use of mass under moderate circumstances, but with increased operating expenses. Pyrolysis, with a PMI (Product-to-Material Input) ratio of around 1.2 kg_input/kg_product, maintains a competitive level of mass conversion efficiency despite its high energy consumption.

To summarize, both enzyme and alkaline catalysis are efficient methods for biofuel production due to their ability to achieve high yields. However, it is important to note that enzyme catalysis is associated with greater costs and necessitates steady conditions. Hydrotreatment has remarkable mass efficiency with the lowest PMI. [5]However, it is costly owing to the need for hydrogen and catalyst. Enzyme catalysis is notable for its environmentally friendly procedure, whereas acid and base techniques provide environmental hazards owing to the chemicals employed. Pyrolysis provides a versatile method for processing different types of raw materials, effectively managing the trade-off between efficiency and energy requirements.

Other unavoidable considerations

The PMI value is a crucial aspect of biodiesel production. However, several other parameters must also be taken into account. [6]For instance, the question is whether the biodiesel generated is compatible with automotive engines and may be utilized without any necessary changes to the engine. It is important to take into account the ESG policy and assess if the index is favorable, often exceeding 70, in order to maximize investment advantages.

5. Conclusion

Overall, the study has examined several techniques for producing biodiesel and analyzed their respective benefits and drawbacks. This evaluation was conducted by doing a literature review and calculating the PMI values. China's biodiesel industry is gradually developing, but faces the challenges of insufficient supply of resources and small production scale. The raw materials mainly come from waste oil and vegetable oil, but the waste oil collection system is not perfect. The government promotes the application of biodiesel through policy support and subsidies, especially in the transportation sector, to reduce greenhouse gas emissions and promote green and low-carbon transition.[7]The PMI values for WCO pyrolysis and hydrotreatment are inferior to those for biodiesel generation by transesterification employing acid, alkaline, or enzyme catalysts. Nevertheless, the implementation of pyrolysis and hydrotreatment on an industrial scale incurs higher costs. Furthermore, the processes of pyrolysis and hydrotreatment of WCO need a higher amount of energy compared to the process of transesterification. By employing physical and medicinal techniques, we can enhance the recycling rate of WCO and simultaneously decrease its associated costs. Thus, optimizing the purification procedures to minimize material usage makes transesterification of WCO a more appealing method for biodiesel synthesis.

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