Experimental Investigation of Dissolution of Plastic Polymers into Biodiesel

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Abstract: - This study analysed the dissolution phenomena of plastic polymers into biodiesel through experimental measurement. The effects of experimental parameters, such as temperature, concentration, agitation, time and feed rate, etc, when mixing two different polymers with biodiesel wereobserved to deduce trends that can be adapted into further exploration. Suchinvestigation is reasonably new in Australia and very few are found around the world.So, any results from this study can be effectively useful in advancement of future projects. The stages taken to complete this study involved researching the most influential polymers and biodiesels used in Australia in regards to waste to be used in the testing. The possible test conditions were then investigated to produce an outline for testing. Once the methodology was completed the samples were made and tested to determine how the changes affected the reaction process. Through the research phase of the project, it was found that polyethylene (PE) and polypropylene (PP) were two of the widest used polymers and thus contributed to the largest amount of waste by weight. Thus, these polymers were investigated to determine a way of recovering the hydrocarbons and the energy still locked in the plastics that would otherwise be wasted. Similarly peanut oil biodiesel was selected to mix with these two polymers as it was made on site and was available for use for the project. The methodology employed to test these blends included measuring 60mL of the biodiesel into a chemical reactor and setting it on the heating plate to raise the temperature to various temperatures between 80 and 100°C for PE and 135-140°C for PP. A small amount of polymer, between 0.5 and 2% (m/m) was measured out and added to the biodiesel at the set temperature. The time taken for the polymer to fully dissolve was recorded along with any other observations made, before labelling and filtering the blends. The general trends that were found during the testing was, while increasing the temperature can lead to quicker, and even instantaneous reaction times, when conducted over several minutes, the reaction produces a higher yield in the final blend and thus is more desirable to maximise polymer retention in the blend.

Key-Words: Waste plastics, additives, experimental investigation, plastic dissolution in biodiesel

1 Introduction

As industrialisation occurred and the modern world emerged, the reliance on fossil fuels such as crude oils have become ever increasing. This crude oil is refined through many processes to produce a range of commercial grade fuels (about 87%) for energy production, 4% of the crude oil portion is used for production of plastics and the rest is used in various chemical applications[1, 2]. It is not only the crude oil refining processbut also the natural gas refining process provides feedstocks to produce plastics. These feedstocks are mainly known as hydrocarbon gas liquids (HGL), which comprises of natural gas plant liquids (NGL) and the olefins of the refinery processes, and are the largest portion of raw materials for plastic production in the USA [3].As the functionality and applications expanded, a larger dependence on many types of polymer strands and plastics have been developed by the course of evolution of technology.As a result, the reliance on metals and wood had branched away towards the utilisation of custom-made plastics, whichcould now design and build products for a much lower cost. It was through the World Wars that plastics became more and more useful and commercially available and, due to this, the focus was on production and not on recycling. Plastics are produced majorly with a single use application and thus left in landfills of used plastic which are continuously increasing.Due to the increase in reliance on these petrochemical products, and the dramatic reduction in crude reserves, there is now an increasing urgency to find alternatives for these products.

Along with plastic, the basic production and use of the diesel engines have not changed until recently when the world realised its path to destruction. It is predicted that between 2013 and 2030 the demand for diesel will increase by 7.5 million barrels per day to approximately 34 million barrels per day, and with that a large problem emerges [4]. The problem facing the world in recent times is to find a way to produce alternative fuels, such as biofuel, from renewable as well as recyclable sources and in recent times many new methodologieshave been discovered due to the increasing demand.

Global demand for plastic production has reached 322million tonnes in 2015, nearly a 50% increase since 2002 when it was at 200million tonnes [5]. As the world increases its demand on supply and production rates of plastics at an exponential rate not enough has been done in regards to the recycling.The global recycling rate of waste plastics was less than 5 wt% of the total new plastics produced in the year 2012 [6]. This small percentage of recycling indicates a grave loss of extracting resource value from the potential waste products. Most of the developed countries are not focusing in reprocessing the waste plastics; rather they are just focusing on clean collection of wastes to export them outside due to cost excuses. China is the prime importer of waste plastics in the world which accounted about 56 wt% of the total global imports [6]. Approximately 80% of the plastic wastes still endsup in landfill each year and some goes for incineration. In some cases, such as polyethylene terephthalate (PET), used for the production of drink and food containers, are recycled at a rate as high as 51.6%, but on average majority of plastics are dumped into landfills where it poses risks to the environment[7, 8]. Plastics that are buried in landfills leach dangerous chemicals, such as bisphenol A (BPA) and Polybrominated diphenyl ethers or PBDEs, into the ground that reach groundwater and can reappear back in commercially available products and supplies. On the other hand, incinerationemits various toxic gases (e.g. dioxin) to the ambience.

All major plastics, as identified by the plastic identification code (PIC), are based from a string of hydrocarbons for their major composition, although to attain characteristics to suit conditions and use, other elements such as chlorine, fluoride and nitrogen are added [9]. This produces plastics in 2 major categories: thermoset plastics, plastics that once made do not react to reheating or remodelling, and thermoplastics, which offer the ability to be reheated and modelled and thus recycled easier. Each type of plastics has their own merits and are categorised in 7 major groups (Table 1) identified by PIC's, each with their own abilities and uses [10].If the current trend continues the world will produce more and more plastic compounds and even though recycling is on the increase if there is not a dramatic change millions of tonnes of plastic will still end in landfills. Exploration, such as that in this article, could be a vital step in the decent way as it will lead to a potential increase in production of clean diesel in addition to assisting in the recycling as well as reduction of landfill sites.

One of the newest ideas relating to the described growing problem is to explore the chemical recycling processes that refer to the recovery or chemical conversion of waste plastics into monomer states or in some usable chemical compounds. The production of plastic-biodiesel blends by dissolving the plastic wastes into the bio-solvent (e.g. biodiesel) will potentially assist in reducing the stockpiles of plastics and at the same time increasing the current quest of alternative fuel production. Besides, the selective distillation process [11] can be applied after dissolving the mixed plastic waste into the solvent to obtain the high quality virgin polymers. For instance, the plastics are cleaned, chopped, shredded and dried after collection to avoid excessive solvent loss. Then the unsorted mixed plastics are dissolved into a common solvent (e.g. biodiesel, xylene, etc.) under a wide range of temperature so that individual plastics could be dissolved at their distinct dissolution temperatures after gaining sufficient activation energy.

Later, the liquid polymers can be separated by fractionating distillation process to be reused as raw material in the plastic manufacturing industries. The contaminants of unsorted waste plastics of all coded plastics could be drained later from the distillation column. The researchers [11] could recycle the PS, LDPE, LLDPE, HDPE, PP, and PVC polymers by using xylene at 15 ^{0}C, 75 ^{0}C, 85 ^{0}C, 105 ^{0}C, 118 ^{0}C, and 138 ^{0}C respectively at 1 atmospheric pressure by following this selective dissolution process.

The aim of this study was to experimentally investigate the dissolution characteristics of plastic polymers into biodiesel by investigating the effect of Plastic-Biodiesel mixing conditions on solubility and reaction time. Since using plastic polymers as additives to biodiesel is a reasonably new and unexplored area there were many unknowns about the conditions in which the reactions would take place and along with that the effects of changing these conditions to deduce an effective production of these blends.

The reason for conducting this research was to explore the possibility of recycling waste plastic polymers as additives to renewable biodiesel, an oxygenated biodegradable compound which is effectively used in the diesel engines as an alternative to diesel fuel. Only a few research activities have been observed based on PS dissolution into biodiesel, but the other categories of the mostly used plastics are still lacking that exploration. Hence, in this research, PE and PP have been selected to investigate the dissolution behaviour of these polymer wastes into biodiesel to proceed with further potential explorations.

Successful completion of this project will benefit the industrial world by assisting with 2 of the biggest up and coming problems, one being the increasing demand of transport fuels and the second being the need to recycle and reduce the stock pile of rubbish, especially plastics as the use is on the increase.

2 Experimental Methodology

There were several parameters which were to be analysed through testing. These were PP vs PE, effect of polymer concentration on dissolution, effect of temperature on dissolution, density and viscosity of each blend, etc. The physical experiments were undertaken to compare the type of plastic polymers, their concentrations in the solution, reaction temperatures and mixing condition to find their contribution to the overall solubility time of the distinctblends. Once the dissolution process is successfully accomplished, the samples were tested to determine their density and viscosity to compare with the legal requirements of commercially used biodiesel blends to ensure an accomplished decision can be made as to the best methodology. Figure 1 shows a chemical reactor which includes clamped beaker, heating plate and magnetic stirrerused in the experiment. To start with two tests were performed observe the dissolution parameters physically. The testing involved mixing 2% PE and 2% PP with biodiesel respectively and heated to 140°C to observe the interactions and then use the information to define the remaining test conditions[11,12]. Once these preliminary tests were performed the results were used to base the remaining tests, this included deciding the temperature ranges for the individual plastics, timing of solubility and concentrations to be considered. Finally, the following steps were used for experimental measurement.

i. 60ml of the peanut oil biodiesel (PN100) was measured out; then the biodiesel was weighted and poured into the reaction beaker (reactor).
ii. A magnetic stirrer was placed in the beaker on the heating plate and the temperature probe controlled from the heater was inserted into the reactor with the help of a clamp to control and maintain the desired temperature accurately.
iii. The temperature was set to 80°C and the stirrer speed to 600 rpm initially, noting both starting time and temperature of the biodiesel in the reactor.

Table 1: Total consumption and recycling in Australia by polymer during 2012-2013 [7]

Polymer	Plastics Identification Code	Consumption	Domestic reprocessing	Export for reprocessing	Total recycling	Recycling rate
		(tonnes)	(tonnes)	(tonnes)	(tonnes)	(%)
PET	1	119000	14900	46600	61400	51.6
HDPE	2	400100	35400	57700	93200	23.3
PVC	3	194100	4400	2500	6900	3.6
L/LLDPE	4	213200	35800	30900	66700	31.3
PP	5	218600	272	18600	45800	21.0
PS	6	20900	2400	5300	7700	36.8
EPS	6	43800	4100	200	4300	9.9
ABS/SAN	7	1900	5600	0	5600	29.5
PU	7	55100	4500	0	4500	8.2
NYLON	7	14200	800	0	800	5.6
OTHER	7	182000	10400	0	10400	5.7
TOTAL	-	1479900	145600	161800	307300	20.8

iv. Once the temperature of the biodiesel was stabilised at the preset temperature, desired amount of finely chopped plastic, e.g. 0.5% (w/w) PE or PP, was poured into the biodiesel.
v. As soon as the polymer was added to biodiesel the stop watch was started to record the dissolution period.
vi. The time, temperature and observations were noted until the polymer was fully dissolved and the timer stopped.
vii. After complete solubility was achieved for any plastic samples it was poured through a filtration system and left to filter.
viii. The plastic-biodiesel blends were labelled and set aside to finish filtering.
ix. After finishing the filtration process the blends were labelled and stored for testing.
x. This process was repeated for various blends of PE and PP plastics with PN100 respectively. The temperature was varied for each category of sample to ensure adequate analysis based on the objectives.
xi. When cooled to room temperature the blends precipitate, which was weighed to determine the overall solubility of the respective plastics into biodiesel at room temperature.
xii. A small amount of the blend was measured and weighed to calculate density of the blend.
xiii. The viscosity of each blend was measured with a Rheometer.

3 Results and Discussion

The various effects of the changes to conditions are discussed and compared back to the expected values and trends from the literature. Both preliminary testing and final testing results are discussed in this section.

3.1 Results from the Preliminary Testing

3.1.1 2% Polyethylene in 100% Peanut oil biodiesel

As mentioned earlier, the methodology was finalised after some general observation testing was undertaken to estimatethe heat required to surpass the activation energy of the solid plastics to be dissolved and thus the operational temperatures for the remaining testing to occur. The first test was performed with 2% polyethylene (average Mw~4000, Mn~1700, Sigma Aldrich) and PN100 biodiesel, with the temperature set to 140°C. The temperature curve is shown in Figure 2. The polyethylene was supplied as a fine powder. The polymer was mixed quickly and evenly with limited visible reactions at first because of the mixing of fine powder in biodiesel. This was due to the temperature being below the decompositiontemperature of the polymer. To perform this experiment, the PE fine powder was mixed with the PN100 biodiesel in the reaction beaker while the heating and stirring started on the magnetic heater. As the melting point of PE was 92°C, no reaction was expected until the blend reached near that temperature. When the temperature reached around 80°C visual changes started occurring, the blend started turning murky, showing signs that a reaction was taking place and that solubility was indeed possible between peanut based biodiesel and polyethylene, starting at approximately 80°C.

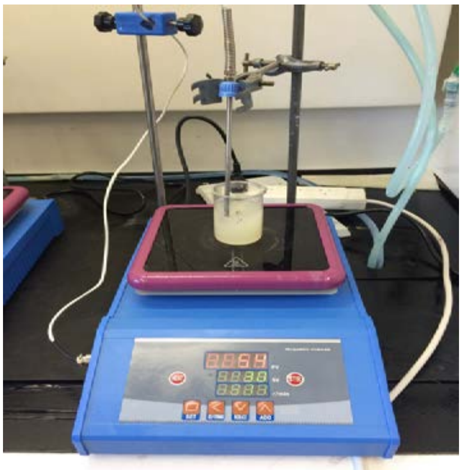

Figure 1: Chemical Reactor for mixing of blend.

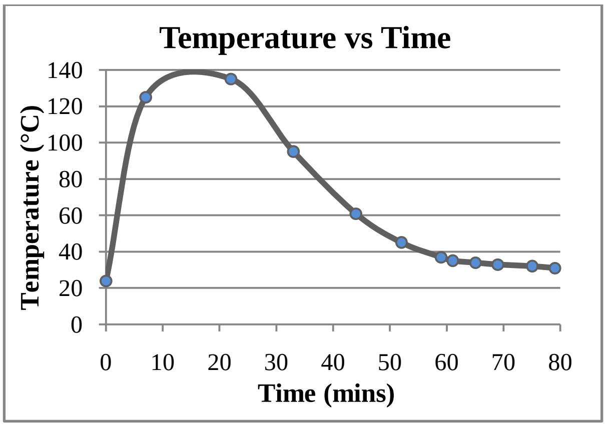

Figure 2: Temperature vs time 2% PE, PN100, T140

As the temperature keeps on increasing the polymer continued to dissolve until it was 100% dissolved (visual inspection) by the time it reaches at100°C. Even the temperature was left to continue to rise up to the maximum preset temperature of 140°C. Once the temperature was reached at the set temperature the controller was set back to 30°C to observe the dissolution characteristics of the dissolved solution during coolingand to confirm the solubility transition point. As the temperature dropped down around the 80°C mark the blend transformed from a clear, fully dissolved blend, to a murky mixture with a precipitate starting to form. At this point it was noted that the blend was becoming more viscous and was quickly realised that the mix would not remain soluble at room temperature. The mixture, now that the excess heat had been removed, was reversing back to the original compounds, although instead of precipitating a solid, the substance transformed into a thick suspended mix (Figure 3). The blend was further cooled to room temperature and poured through a funnel and filter system and left to complete filtering for several hours (almost 40 hours).

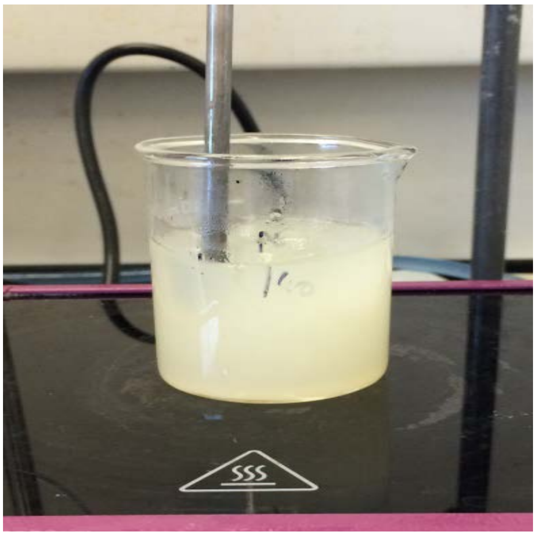

Figure 3: PE precipitation during cooling after dissolution

After the blend had completed most of the filtering it was found that a large amount of precipitated paste was accumulatedin the filter paper. The filtered biodiesel was a slightly murky colour that showed that some solubility at room temperature remained with polyethylene in peanut oil biodiesel. The colour change was anticipated due to the small carbon chains that remained making their way through the openings in the filter paper and when left to settle, continued to reform some form of the polymer suspended in the fuel. The paste that remained in the funnel also showed that some solubility persistedas the longer hydrocarbon chains remained, displaying properties of the polymer, colour, semi solid state, and the biodiesel, thickened paste consistency (Figure 4). The filtered biodiesel was the main focus of the testing as it demonstrates the consistency and flow properties required as a fuel, although it is expected that under further testing, the paste could be refined to provide power or heat in the future due to the hydrocarbons remaining within. This preliminary test was able to prove that PE was indeed soluble in Peanut oil biodiesel and reacted in a range of 80-100°C, providing the operational temperature for the remaining testing of biodiesel.

Figure 4: Filtered 2% PE, PN100, T140 blend

3.1.2 2% Polypropylene in 100% Peanut oil biodiesel

To define the reaction conditions of polypropylene a similar test was conducted, testing 2% polypropylene and biodiesel, again the temperature set to 140°C and the temperature observations were noted (Figure 5).The polypropylene was supplied in large particles approximately 5mm x 3mm. Both the melting point and the degradation temperature of PP is higher than those of PE due to their chemical composition. And due to this, it was expected that the dissolution would occur at higher temperature than that of polyethylene.

Unlike PE, the polypropylene, due to its size just moved around the beaker as it was heated and would settle quickly if the agitation was stopped. As the melting point of PP was 157°C it was sceptical that the polymer would react effectively in the biodiesel but observations were made regardless towards the higher end of the temperature range. As the temperature reached over 135°C visible changes of polymer solubility occurred and by 140°C, the maximum temperature allowed for testing, the polymers had dissolved leaving a clean and clear liquid of PP-PN100 solution. Theexperiment was left for several minutes at 140°C before setting the temperature back to 30°C to observe the cooling conditions and solubility transition point.

It was found that as the temperature reached 100°C the precipitate started to form and the blend changed in to a murky colour from clear. Again the change in colour and increasing viscosity indicated that the blend would not remain soluble at room temperature. The polypropylene solution exhibitedsimilar behaviour like PE in that the mixture thickened as the heat reduced, leaving the polymer in full suspension. Once the mix reached room temperature, it was poured into the funnel for filtering, Figure 6 shows some of the testing processes.

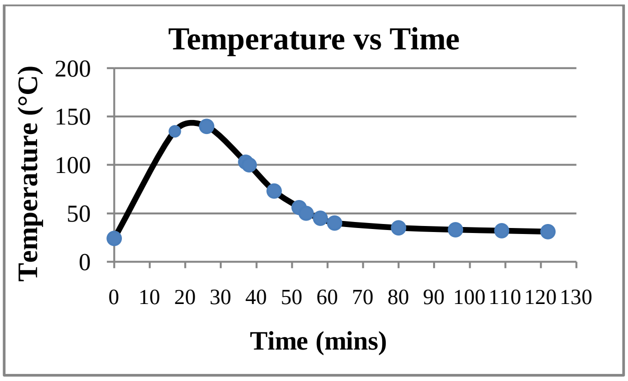

Figure 5: Temperature vs. time 2% PP, PN100, T140

When allowing the blend to filter for a few days it was found that most of the solution had filtered through the paper with very little precipitate. The filtered biodiesel remained quite clear, but since there was very little precipitate, it was assumed that some of the polymer had dissolved during the process. Similar to PE, since PP is a hydrocarbon reacting with other hydrocarbons in the diesel, it is expected that the chains broke down and when heated, allowing the smaller, more volatile chains through the filter and restricting the longer chains in the filter paper. This preliminary test was able to prove that PP was indeed soluble in Peanut oil biodiesel and reacted at temperature of 135°C+, providing the operational temperature for the remaining testing of biodiesel.

Figure 6: Filtering process

From these preliminary tests, some important information can be extracted, the first being that biodiesel dissolves polypropylene and polyethylene at temperatures below their melting points. Since PE and PP are often foundtogether in the waste stream, requiring manual labour from workers or to perform the pyrolysis reaction process, requiring 200-300°C temperatures, to separate the various polymer strands. This testing has shown that this solubility could be used to separate and extract the various polymers at temperatures well below that of pyrolysis systems, providing vast power savings. With further testing and investigation to the effects on the engine, and analysis of the precipitated paste, it is possible that using this method could boost the properties of the biodiesel, as well as extracting pure polymers for further recycling.

3.2 Results from Major Testing

In this section, a brief description of the results obtained from the tests of dissolution process of various amount of PE and PP respectively with PN100 biodiesel are presented. Also temperature of the tests were varied to observe the effect on dissolution rate of these plastics into biodiesel. Table 2 shows the data collected from the various tests performed for various blends of biodiesel with0.5 wt%, 1wt%, 1.5wt% and 2wt% of the selected plastics respectively. The biodiesel (solvent) was preheated first at the set temperature, then the selected plastic samples were fed into the solvent and total time required for complete dissolution of the respective plastic sample into the solvent was noted. The key information obtained from the table are as follows.

A sample of PE (0.5 wt%) was considered for dissolution process at 80^{O}C and abandoned after several hours of heating as no sign of dissolution was observed. Hence no recorded time of solubility has been shown in the corresponding column. Another similar observation with PP has been presented in the section 4. Two samples of PE (1.5 wt% and 2 wt%) were heated at 85°C, which demonstrated the complete dissolution in less than 20 minutes. When the PE samples of 0.5 wt%, 1.0 wt%, 1.5 wt% and 2.0 wt% were tested at 90°C, time required for complete dissolution dropped below 10 minutes with exception of 18.5 minutes for the last sample. Though larger density variation would indicate more dissolved plastic content into the biodiesel, 1.5 wt% at 85°C and 1 wt% at 90°C demonstrated better results after the filtration. Since the same quantity of samples were tested at 100°C with the observation of less than 30 sec of dissolution time period each, only 2 wt% of PE was considered for the test at 140°C to facilitate the accelerated dissolution period (0.133 minute for this case). The increase in kinematic viscosity was observed to within the range of acceptable biodiesel standard and it was one of the key factors to limit addition of more amount of PE in this experimental investigation.

All the four samples of PP (i.e. 0.5 wt%, 1 wt%, 1.5 wt% and 2 wt%) were tested for solubility with PN100 biodiesel at 135°C and 140°C respectively. In case of 135°C temperature, the complete dissolution occurred between 100 and 160 minutes, where the 1.5 wt% sample took more time to be dissolved within standard biodiesel's kinematic viscosity range. But the quantity of PP as dissolved within the solvent after filtration was observed for both 1 wt% and 2 wt%. On the other hand, the dissolution time sharply reduced for these stated quantity of PP samples when the test occurred at 140°C. Though the required time for complete dissolution was higher for 1 wt% of PP the reason for this could be the variation of amount of sample taken for each test. In fact, the variation of mass quantity of the sample should have been consistent to analyse the trend of linearity of required time. But due to consistency of wt% of the samples, there is no influence of total amount of sample to the variation of density and viscosity. These two parameters varied according to the thermo-chemical effect between the structure of the plastics and the biodiesel (solvent) at a given temperature. It has been observed from this test that 2 wt% of PP has a good solubility at 140°C than the other samples as per the change of density and kinematic viscosity, being within the standard level.

However, it was anticipated that the polymer might react and fully dissolve in the biodiesel in whichthetime taken to complete this task would greatly exceed the energy required to set the temperature a few degrees higher. To avoid loss of more thermal energy, the tests with PP was not encouraged to conduct beyond 140°C and that with PE at over 100°C.

3.3 Analysis of Polypropylene vs. Polyethylene

It was observed that the polyethylene reacted much quicker than polypropylene and required significantly less temperature to produce effective results compared to the results of polymers. PE required much less energy to activate the reaction when compared to PP due to the lower relative energy difference. This could be due to these polymers are made up of long strands and mostly used in light and general applications. PP on the other hand is a polymer which is more robust in nature due to mainly being bottles and containers, this requires a higher resistance to reactions or modifications to its structure and thus harder to recycle.Throughout the testing it was found that the rate of the reaction of PE in the biodiesel is more to the point nearing instantaneous which could be due to lower density of PE.

The quicker reactions are not always more efficient. From this it was found that similar reaction time should be compared, rather than temperature, to more accurately analyse the difference between polymers. When taking these analyses into account it was found that polypropylene tends to react more efficiently than polyethylene. This was thought to be due to a longer reaction duration closer to its transition point. Since PP has a much higher transition point it was understandable that once the activation energy was reached, the overall higher temperature led to a more effective reaction and conversion rate.

Overall, when PP and PE is compared for reaction ratesit was possible to increase the reaction rate to near instantaneous, but if efficient conversion was required to compare, it was observed that PP reacted better than PE. After filtering the blends it was found that PE had produced more precipitate which indicates that it is more efficient to a higher conversion rate and less wastage from the filtration.

3.4 Effect of Mixture Concentration on Solubility Time

The relationship between the polymer concentration and its solubility time is relatable through a power regression. While this could not be seen clearly in the Figure 8, the relationship tends to increase reaction alongside the increasing concentration, which was expected as more polymer to react would require more time to complete the reaction. One of the observations that were made were the impact of the reverse reaction and formation of precipitate, which occurred throughout the testing range.

Table 2: Results of polymer dissolution into peanut oil biodiesel

Polymer in the Solution	Mix Temperature (°C)	Test no.	Polymer Concentration (%)	Biodiesel Mass (g)	Polymer mass (g)	Solubility Time (mins)	Precipitate mass (g)	Density (g/cm^3)	Kinematic Viscosity av. (ν)(mm^2/s)	Dynamic Viscosity av. (μ)(Poise)	Increase of density (%)
Nil (biodiesel only)		1	0	48.50	-	-	-	0.8617	4.7524	0.041	-
Polyethylene (PE)	80	2	0.5	49.62	0.2481					0.0427	
	85	3	1.5	51.31	0.7695	15+	15.127	0.8758	4.921215	0.0431	1.636
	85	4	2	48.175	0.98	17+	23.27	0.8678	5.012676	0.0435	0.708
	90	5	0.5	49.72	0.29	7.5	4.472	0.8625	5.2664	0.0454	0.093
		6	1	51.47	0.51	9.5	9.854	0.871	5.322	0.0464	1.079
		7	1.5	49.45	0.742	7	13.737	0.8695	5.508913	0.0479	0.905
		8	2	49.63	0.993	18.5	13.293	0.8678	5.646462	0.049	0.708
	100	9	0.5	50.43	0.252	0.167	3.497	0.8645	5.894	0.051	0.325
		11	1	46.24	0.402	0.33	7.007	0.865	5.3187	0.046	0.383
		12	1.5	51.7	0.775	0.67	9.307	0.8635	6.4695	0.0559	0.209
		13	2	50.81	1.016	0.4167	19.604	0.8653	6.9151	0.0598	0.418
	140	14	2	47.919	0.9582	0.133		0.8641	5.022567	0.0434	0.279
Polypropylene (PP)	135	15	0.5	50.04	0.24	100+	2.9	0.8708	6.0917	0.053	1.056
		16	1	49.95	0.4995	117+	4.41	0.8748	8.2149	0.0719	1.520
		17	1.5	50.61	0.759	155+	6.69	0.8695	5.4549	0.0474	0.905
		18	2	50.39	1.012	141+	7.63	0.8758	7.2068	0.0631	1.636
	140	19	0.5	49.46	0.251	10	2.63	0.865	5.2286	0.0452	0.383
		20	1	55.7	0.57	21	4.14	0.8663	4.6996	0.0407	0.534
		21	1.5	50.7	0.74	16	4.54	0.867	4.648212	0.0403	0.615
		22	2	49.32	0.9864	17	4.92	0.8795	5.025583	0.0442	2.066

This precipitate contained a high volume of the polymer which would lead to the concentration in the fuel being less than expected in the graph (Figure 8). When looking at the possible concentrations in the blend, the characteristics and parameters must meet regulation requirement to ensure that vehicles can satisfactorily perform with this fuel. Another consideration for the maximum concentration occurs at the saturation point of the solute; this is not anticipated to be met due to the extremely low levels polymers to be tested. From this analysis no major conclusion could be made.

3.5 Effect of Agitation on Solubility Time

During testing the agitation rate of the blend was kept constant due to the small scale test size it was not anticipated to make much difference. The magnetic stirrer was set to 600 rpm, only changing the speed when the blend started to spill or broke from uniform.The agitation was not a major consideration for this testing but will need to be considered on a large scale testing. This will be necessary due to the large mass of polymer being more inclined to settle in a mixing tank. It is anticipated that the speed of agitation would be squarely proportional to the blend time, to a point when excessive slip occurs on the blade and its effectiveness declines. The constantly changing viscosity of the fluid would make keeping a constant stir rate difficult and will be left to further investigation.

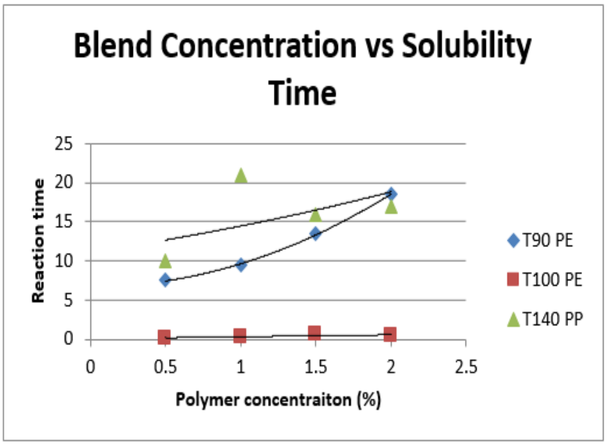

Figure8: Polymer Concentration vs Solubility Time

3.6 Effect of Feed Rate on Solubility Time

Similar to the blend agitation, the feed rate was kept constant due to the small scale test size.Due to the small amount of polymer required it was all mixedinto the heated biodiesel at once. On a large scale application of this model the feed rate would play a larger role than what was testing during the experimental phase of this study. By altering the feed rate, the time and accuracy of the blend can be more accurately managed.For example, slowly adding the polymer to the biodiesel blend allows for the reaction to complete gradually, and with the correct monitoring system, the blend can be strictly suited to the client requirements. Further investigation will be required further detail and prove this theory.

4 Conclusions and Recommendations

In conclusion, this study investigated the dissolution of waste plastic polymers into biodiesel to assist in reducing waste and boosting clean fuelproduction. The completion of this investigation provides the basic understanding of producing the waste plastic biodiesel blends as the various mixing conditions like temperature, concentration, feed rate and mixing speed, etc. have been analysed to find out both starting and finishing of dissolution process of a particular plastic polymer into biodiesel used as solvent.It was found that, PE reacted easier than that of PPand would become fully soluble between 85 and 90°C, instantaneously dissolving at 100°C. Polypropylene, a much harder polymer, required heating up to 135°C before any major phase changeoccurred, however when filtered produced significantly less precipitate and thus deemed a more efficient reaction in comparison to PE.

The effect of the mixing temperature on the dissolution processes was found to be the most significant variable affecting the blend characteristics. Each polymer has a range of temperature to overcome the activation energy that regulates the speed of the reaction; for PE, this is approximately 85-90°C and for PP, this is around the 140°C mark. So if a the temperature is below that level for respective plastic, the dissolution process will take much longer time to show any hint of transition of phase from solid to liquid, or the reaction may not progress anymore rather wasting energy. A sample of PP was taken to observe the solubility at 60°C and no progress was observed after heating continuously for more than 2 days and further wastage of energy was abandoned for that test.That is why the preliminary reaction temperature was set that high of 140°C rather than starting from a lower range. Outside of these ranges, the dissolution process was greatly affected by the reaction times, below these temperatures, the reaction time exponentially increases, and above this heat, the energy is wasted as it does not significantly affect the reaction time.

The concentrations of the blends were selected through research and are governed by the legislation to suit implementation into regular vehicles with minor testing. Due to the precipitation, not 100% of the polymer would be in the fuel when tested, some not making through the filter paper, and because of that the final concentrations could not be confirmed without a suitable mass spectrometer.

Due to small scale experimental investigation, the feed rate of the plastics into the reaction chamber was not considered, rather poured at a time. In any up scaling or further research the feed rate of the plasticswill become more important as the larger mass of solids would become more likely to settle to the bottom of the tank without agitation. The feed rate, when looking at large scale implementation would become a way of regulating the characteristics while providing an even spread of the polymer surface area to the solvent to maximise the reaction efficiency. Similarly, the stirring speed or the agitating speed was mostly maintained fixed at 600 rpm. But when the addition of more plastics into a certain amount of biodiesel would require to be dissolved, then the increase of the dissolution rate will be influenced by the stirring speed, which would help to overcome the viscous force of the denser solution.When looking at suiting the blends to current legislative norms, all tests fell within the acceptable density range according to the updated biodiesel standard, polyethylene’s most efficient blend occurred at 85°C blend with 1.5% concentration, producing a maximum density of 0.8758g/ml. The most efficient blend of polypropylene resulted in a density of 0.8758g/ml, at 2% PP at 135°C.

The main characteristic that was used to compare to the legislation requirements is the kinematic viscosity of the blends. These were found using the rheometer and the results were compared to the national requirements of 3.5-5mm^2/s, the preferred blend conditions would be either the 1.5 to 2 wt% polyethylene-biodiesel blend mixed at 85°C, or 1-2 wt% polypropylene-biodiesel blend mixed at 140°C. The general trends that were found during the testing was at while increasing the temperature can lead to quicker, and even instantaneous reaction times, when conducted over several minutes, the reaction produces a higher yield in the final blend and thus is more desirable to maximise polymer retention in the blend. This project can be further investigated by replicating these tests to confirm the results are repeatable and then go on to further testing around the key temperatures to confirm the transition temperatures. Once this can be confirmed, the testing can then incorporate a mass spectrometer for overall mass composition analysis and engine testing to assessthe performance of the tests forreal world applications. In spite of less retention of solubility of the polymers used with the biodiesel in this investigation, it provides another prospect of chemical recycling of plastic wastes with a much lower energy consumption and investment. The methodology used in this research is the simplest of its kind to recover the plastics with higher efficiency and purity.

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