Fuel supplement Studies (Tallow)

The limited quantity of fossil fuels has been the primary driving force for research into alternative sources of fuel. Natural materials have always provided Man with combustible material . Among these materials has been tallow, traditionally used in the making of candles. Tallow is obtained from the fat in cattle, sheep and goats. Its chemical composition is based on glycerol esters of various fatty acids. The fatty acids, for the most part, resemble long chain hydrocarbons. An early suggestion for the use of tallow relied on the idea that the long hydrocarbon chain portion of the fatty acid portion of tallow could be catalytically cracked to produce the shorter chain fuel oils. An alternative strategy would be to extend current fuel stocks by addition of fuel supplements.

The aim of the project has been the exploration of the use of tallow as a fuel supplement. Samples of various grades of tallow were obtained from the Agricultural and Food Authority, Moorepark Research Centre, Fermoy, Eire. The tallow obtained was graded 1, 2 and 6 (Table 1.1).

Of the three grades, grade 1 tallow was chosen as the starting material as it appears the most homogenous and the lightest in colour.

Our first objective was to determine whether tallow and diesel were miscible/soluble. Tallow at room temperature is a solid material with a low melting point. The tallow was added to diesel in the liquid form to ease the mixing and speed up the process at which a tallow-diesel solution was obtained. Preliminary results indicate that tallow, even in small amounts, does not remain as a stable solution in diesel.

Consequently, research has been undertaken which involves the mixing of tallow with diesel to produce a stable solution by the addition of a blending additive. Initial results have proved encouraging and further work in this direction has been undertaken. Work is also proceeding in improving the quality of the tallow given that there exists a variable quality in the tallow depending on the choice of fatty material used in preparing the tallow.

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1 Introduction

1.1 Grading of tallow

Tallow is the name given to the fat obtained from cattle, sheep and goats. The quality of tallow depends largely on the parts of the animal the fat - bearing matter is selected from. Despite the variation in quality, tallow can be graded.

Samples of various grades of tallow were obtained from the Agricultural and Food Authority, Moorepark Research Centre, Fermoy, Eire. The tallow obtained was graded 1, 2 and 6 (Table 1.1).

Tallow 1, also known as “Top white tallow” was selected for testing as visually, it appears the most homogenous and the lightest in colour. This consideration was prompted by cosmetic considerations of mixing the tallow with diesel.

	Titre Min	% FFA	Specific FAC	%MIU
Tallow 1	41.0	2	5	1
Tallow 2	42.0	2	5	1
Tallow 3	40.5	6	13 - 11	1

(Titre Min - is the solidification temperature)
(%FFA - percentage of free fatty acids)
(Specific FAC - this is a measure of colour)
(%MIU - percentage of moisture + insoluble impurities and unsaponifiable material)

Table 1.1 Grades of Tallow

Pure fatty acids and their glycerides are colourless. The colour of natural fats is due to presence of fat-soluble pigments such as carotenoids or to the products of auto-oxidation. Much of their odour is derived from the presence of nonfatty material such as ketones or to the smaller chain fatty acids, sterols and vitamins.

In the grading of tallows the FAC test is often used. In this test, the sample is melted, filtered into glass tubes and matched against a set of standards 1.2 Chemical composition The major components of Beef tallow were identified as the fatty acids (Table 1.2).

	% content	C-Chain
Major constituents		
Oleic acid,	~40	C-18
palmitic acid	~25	C-16
stearic acid	~25	C-18
Minor constituents		
2-Myristoleic		C-14
Palmitoleic		C-16
linoleic acid		

Table 1.2 Components of beef Tallow [1]

The fatty acids identified in natural fats are derived from glycerides containing these acids. A glyceride is simply the ester formed by the dehydration of the fatty acid with glycerol. A typical figure of 10-14% of glycerol can be extracted from fat by alkaline hydrolysis [2].

The unsaponifiable material in fats/tallow are usually long chain monohydric alcohols. The component glycerides were initially carried out by fractional recrystallization from various solvents.

2 Results and discussion

2.1 Tallow and neat diesel

Our first objective was to determine whether tallow and diesel were miscible/soluble and if so, to what extent. A series of experiments were initiated in which a varying amount of heated tallow was added to a fixed quantity of diesel. The tallow was added in liquid form in order to ease the mixing and speed up the process at which a tallow-diesel solution was obtained.

The results showed that tallow was not readily retained by diesel. The unprocessed grade 1 tallow would only remain in solution for any considerable length of time when the percentage of tallow was 5% v/v.

2.2 Tallow and additive

Having determined that tallow was not particularly soluble in diesel, a search for another solvent/additive which would readily take up tallow was sought. The criteria for the solvent was that it be readily combustible and that it should be miscible with diesel, ideally, the amount

of the solvent should be a minimum. A simple test was devised in which tallow in its liquid form was added to prospective solvents at 20%v/v. The rationale being that if the tallow were poorly soluble or insoluble in the neat additive, then that- solvent would be of little value in tallow-diesel mixing studies.

The most promising results obtained were with THF, diethyl ether and kerosene. With the exception of THF and ether, all the solvents selected precipitated out granules of either tallow or one of its components when the tallow content was higher than 10%.

Tallow or one of its components was found to precipitate out at concentrations of 20%v/v with ether as the additive.

2.3 Refining the tallow

The refining of tallow was based on the additive studies. It can be seen that a suitable concentration at which the putative less lipohilic component(s) of tallow will precipitate out has been observed to be around 20%. It was assumed that the precipitate was different from the tallow from its colourless appearance. This assumption is supported in the different melting points for the granular precipitate and for the ether-soluble residue. It war reasoned that, if the less lipophilic components were being precipitated out, then prior removal of these components from the tallow should produce a material more suited for mixing with diesel.

The choice of ether as the refining component stems from two considerations; the first reason being the ease at which ether may he removed to leave behind the more lipophilic component(s) and secondly, the relatively cheaper cost of diethyl ether. Its disadvantages lie only in the fire risk when handling such a volatile and flammable material. The choice of ether in an ether/ ethanol mixture had also been previously used in fractionation of tallow [3]

2.4 Refined tallow, additive and diesel

Having refined the tallow, a series of experiments were carried out with respect to the solubility of the refined tallow in diesel and in diesel—additive mixtures. The diesel-additive mixture used as their additive some of the more promising additives. Having found that diethyl ether was a suitable additive, given the high hydrocarbon chain length of the remaining glycerides, it was suggested that longer chain ethers or esters might prove a suitable choice. The best result for the refined tallow-diesel experiments has been the addition of THF, which has managed to keep the tallow in solution. Both n—butyl ether and isopropyl ether will help tallow into diesel provided the percentage of tallow in the diesel remains around 15% and that the additive is present in quantity higher than 10%.

2.5 Suggestions for further work.

The role of THF although exceedingly good for helping the refined tallow into solution with diesel, is likely to present problems with regards to static corrosion tests. Further, THF is extremely volatile and its evaporation from the diesel solution would lead to situation whereby the tal low might come out of solution. It is therefore suggested that perhaps a mixture of THF with one of the higher boiling point ethers might prove more suitable.

Obviously, one aspect of the introduction of tallow into diesel that will require exploring is the engine performance testing. In addition to monitoring the engine's performance, careful monitoring of the exhaust and ~deposits from using tallow-diesel fuel will have to be made.

Ideally, the variable quality of the tallow could possibly present problems in formulation of an additive. It is suggested that the investigation of fuel supplementation with animal fats could be extended and applied to fats from vegetable sources.

2.6 References

[1] T. P. Hilditch, H. E. Longnecker, *Biochem. J.* 1937, 31, 1805.

[2] H. G. Kirschenbauer, "Fats and Oils" Reinhold Publishing Corporation 1960

[3] A. Seidenberg, US patent 1 340 186, 18/5/1919 (C.A. P14: 2099[9])

3.0 Experimental

3.1 Tallow and diesel mixing studies

General procedure:

Tallow grade 1 (From the agricultural institute Eire) was heated in a hot water bath at 50°C until the tallow had melted to a clear yellow liquid. A measured quantity of tallow was then mixed with a fixed quantity of diesel. Each mixture was gently warmed and stirred to give a clear solution. The various solutions were then left to stand.

3.1.1 5% solution

Diesel (20ml) and hot tallow (1ml) were mixed together. The clear solution by 28 days had precipitated out granules of tallow.

3.1.2 10% solution

Diesel (20ml) and hot tallow (2ml) were mixed together. The clear solution by *3* days had precipitated out granules of tallow.

3.1.3 15% solution

Diesel (20ml) and hot tallow (3ml) were mixed together. The clear solution by 3 days had precipitated out granules of tallow.

3.1.4 20% solution

Diesel (20ml) and hot tallow (4ml) were mixed together. The clear solution by 24 hours had precipitated out granules of tallow.

3.1.5 25% solution

Diesel (20ml) and hot tallow (5ml) were mixed together. The clear solution by 24 hours had precipitated out granules of tallow.

3.1.6 30% solution

Diesel (20ml) and hot tallow (6ml) were mixed together. The clear solution by 24 hours had precipitated out granules of tallow.

3.1.7 35% solution

Diesel (20ml) and hot tallow (7ml) were mixed together. The clear solution by 24 hours had precipitated out granules of tallow.

3.1.8 40% solution

Diesel (20ml) and hot tallow (8ml) were mixed together. The clear solution by 24 hours had precipitated out granules of tallow.

3.1.9 45% solution

Diesel (20ml) and hot tallow (9ml) were mixed together. The clear solution by 24 hours had precipitated out granules of tallow.

3.1.10 50% solution

Diesel (20ml) and hot tallow (10ml) were mixed together. The clear solution by 24 hours had precipitated out granules of tallow.

3.2 Tallow and additive Studies

General procedure

A measured quantity of grade 1 tallow was mixed with a fixed quantity of a potential additive.

3.2.1 Texafor

3.2.1.1 25% solution

Hot tallow (5ml) was mixed with Texafor M6 (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). On standing the solution was observed to become hazy as it cooled to a temperature 31°C and by the time it reached ambient temperature it had become opaque with a consistency like vaseline.

3.2.1.2 20% solution

Hot tallow (4ml) was mixed with Texafor M6 (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). On standing the solution was observed to become hazy as it cooled and at ambient temperature it had become opaque with a consistency like vaseline but with a greater mobility than 3.2.1.1.

3.2.1.3 10% solution

Hot tallow (2ml) was mixed with Texafor M6 (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). On standing overnight the solution was observed to had become opaque with a consistency like vaseline but with a greater mobility than 3.2. 1. 1.

3.2.2 Dobanol

3.2.2.1 20% solution

Hot tallow (4ml) was mixed with Dobanol 91-2.5 (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had become a very fluid gel.

3.2.2.2 10% solution

Hot tallow (2ml) was mixed with Dobanol 91-2.5 (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had become a very fluid gel.

3.2.3 Caflon - standard CD

3.2.3.1 20% solution

Hot tallow (4ml) was mixed with Caflon CD (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had set into a very viscous gel.

3.2.3.2 10% solution

Hot tallow (2ml) was mixed with Caflon CD (2Oml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had set into a very viscous gel but less viscous than 3.2.3.1.

3.2.4 ADD2/131088

3.2.4.1 20% solution

Hot tallow (4ml) was mixed with a formulated additive ADD2 (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had set into a thick gel.

3.2.4.2 10% solution

Hot tallow (2ml) was mixed with Caflon CD (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, this solution had also set into a very viscous gel.

3.2.5 Ethanol

Despite vigorous heating the two solutions showed poor mixing although the ethanol layer did become hazy and remained so at ambient temperatures overnight.

3.2.6 Empilan K3

3.2.6.1 20% solution

Hot tallow (4ml) was mixed with empilan K3 (20ml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had set into a very fluid gel.

3.2.6.2 10% solution

Hot tallow (2ml) was mixed with empilan K3 (2Oml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had set into a very fluid gel.

3.2.7 Diethyl ether

3.2.7.1 20% solution

Hot tallow (4ml) was mixed with ether (20ml) The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Within 24 hrs, the solution had precipitated white granules.

3.2.7.2 20% solution - unheated

Hot tallow (4ml) was allowed to set and ether (2Oml) added. The mixture was left to stand at ambient temperature (20°C) with periodic shaking. Within 24 hrs, the yellow solution with a yellow/white solid was obtained.

3.2.7.3 10% solution

Hot tallow (2ml) was mixed with ether (2Oml). The mixture was heated to give a clear yellow solution. The solution was left to stand at ambient temperature (20°C). Even after 18 days, the solution remained clear.

3.2.8 Acetone

3.2.8.1 20% solution

Hot tallow (4ml) was mixed with acetone (2Oml). The mixture was heated to give a clear pale yellow solution which rapidly becomes hazy on standing and rapidly precipitates out white granules.

3.2.9 Ethyl acetate

3.2.9.1 20% solution

Hot tallow (4ml) was mixed with ethyl acetate (20ml). The mixture was heated to give a clear pale yellow solution. Within 24 hrs, sets to a yellow gel rather like butter.

3.2.10 Kamco waxbreaker

3.2.10.1 20% solution

Hot tallow (4ml) was mixed with the commercial waxbreaker (20ml). The mixture was heated to give a clear pale yellow solution. Within 24 hrs, the solution has precipitated white granules through out the yellow liquid.

3.2.11 Kerosene

3.2.11.1 20% solution

Hot tallow (4ml) was mixed with kerosene (2Oml). The mixture was heated to give a clear pale yellow solution. Within 48 hrs, the solution had precipitated white granules covering the base of the sample jar.

3.2.12 2-Butoxyethanol

3.2.12.1 20% solution

Hot tallow (4ml) was mixed with 2 - butoxyethanol (20ml). The mixture was heated to give a clear yellow solution. Within 24 Hrs, a fine white precipitate had formed.

3.2.12.2 10% solution

Hot tallow (2ml) was mixed with 2—butoxyethanol (2Oml). The mixture was heated to give a clear yellow solution. Within 24 Hrs, a fine white precipitate had formed.

3.2.12.3 5% solution

Hot tallow (1ml) was mixed with 2 - butoxyethanol (20ml). The mixture was heated to give a clear yellow solution. Within 24 Hrs, a fine white precipitate had formed.

3.2.13 1- Hexanol

3.2.13.1 20% solution

Hot tallow (4ml) was mixed with 1-hexanol (20ml). The mixture was heated to give a clear yellow solution. Within 24 Hrs, a yellow/white precipitate had formed.

3.2.13.2 10% solution

Hot tallow (2ml) was mixed with 1-hexanol (2Oml). The mixture was heated to give a clear yellow solution. Within 24 Hrs, a yellow/white precipitate had formed.

3.2.13.3 5% solution

Hot tallow (1ml) was mixed with 1-hexanol (20ml). The mixture was heated to give a clear yellow solution. Within 24 Hrs, a yellow/white precipitate had formed.

3.2.14 Butyl acetate

3.2.14.1 20% solution

Hot tallow (4ml) was mixed with butyl acetate (20ml). The mixture was heated to give a clear yellow solution. After 16 hrs, a white solid in the yellow liquid was observed.

3.2.14.2 10% solution

Hot tallow (2ml) was mixed with butyl acetate (20ml). The mixture was heated to give a clear yellow solution. After 16 hrs, a white solid in the yellow liquid was observed.

3.2.14.3 5% solution

Hot tallow (1ml) was mixed with butyl acetate (20ml). The mixture was heated to give a clear yellow solution. After 16 hrs, the solution still remained clear. Within 4 days, a white solid in a yellow liquid was observed.

3.2.15 Dimethyl sulphoxide

3.2.15.1 20% solution

Hot tallow (4ml) was mixed with dimethyl sulphoxide (20ml). The mixture was heated to give a bilayer of a yellow oil floating in a clear liquid. The yellow oil on standing overnight solidified.

3.2.15.2 10% solution

Hot tallow (2ml) was mixed with dimethyl sulphoxide (2Oml). The mixture was heated to give a bilayer of a yellow oil floating in a clear liquid. The yellow oil on standing overnight solidified.

3.2.15.3 5% solution

Hot tallow (1ml) was mixed with dimethyl sulphoxide (20ml). The mixture was heated to give a bilayer of a yellow oil floating in a clear liquid. The yellow oil on standing overnight solidified.

3.2.16 Isopropyl ether

3.2.16.1 20% solution

Hot tallow (4ml) was mixed with isopropyl ether (20ml). The mixture was heated to give a clear yellow solution. After 3 days, a white solid was observed to have precipitated.

3.2.16.2 10% solution

Hot tallow (2ml) was mixed with isopropyl ether (20ml). The mixture was heated to give a clear yellow solution. After 3 days, a white solid was observed to have precipitated.

3.2.16.3 5% solution

Hot tallow (1ml) was mixed with isopropyl ether (20ml). The mixture was heated to give a clear yellow solution. After 3 days, 3 granules was observed.

3.2.17 N-Butyl ether

3.2.17.1 20% solution

Hot tallow (4ml) was mixed with n-butyl ether (20ml). The mixture was heated to give a clear yellow solution. After 3 days, a white solid was observed to have precipitated

3.2.17.2 10% solution

Hot tallow (2ml) was mixed with n-butyl ether (20ml). The mixture was heated to give a clear yellow solution. After 3 days, a white solid was observed to have precipitated

3.2.17.3 5% solution

Hot tallow (1ml) was mixed with n—butyl ether (2Oml). The mixture was heated to give a clear yellow solution. After 3 days, the solution was still clear.

3.2.18 Tetrahydrofuran

3.2.18.1 20% solution

Hot tallow (4ml) was mixedwith tetrahydrofuran (2Oml). The mixture was heated to give a clear yellow solution. After 3 days, the solution was still clear.

3.2.18.2 10% solution

Hot tallow (2ml) was mixed with tetrahydrofuran (2Oml). The mixture was heated to give a clear yellow solution. After 3 days, the solution was still clear.

3.2.18.3 5% solution

Hot tallow (1ml) was mixed with tetrahydrofuran (20ml). The mixture was heated to give a clear yellow solution. After 3 days, the solution was still clear.

3.2.19 Acetonitrile

3.2.19.1 20% solution

Hot tallow (4ml) was mixed with acetonitrile (2Oml). The mixture was heated to give a bilayer; a yellow oil in a clear colourless liquid.

3.3 Tallow, diesel and additive studies.

3.3.1 Texafor M-6

Hot tallow (3ml) was mixed with diesel (20ml). and texafor (3ml) added. The mixture was warmed with gentle shaking until a clear orange solution was obtained.

3.3.2 Dobanol 91-2.5

Hot tallow (3ml) was mixed with diesel (20ml). and dobanol (3ml) added. The mixture was warmed with gentle shaking until a clear orange solution was obtained. After 4 hrs, the solution became hazy. On standing overnight, circular clusters of fine needles of tallow were observed.

3.3.3 Caflon - standard CD

Hot tallow (3ml) was mixed with diesel (2Oml) and Caflon (3ml) added. The mixture was warmed with gentle shaking until a clear orange solution was obtained. After 4 hrs, 2 liquid layers were observed a dark orange lower layer and a lighter coloured upper one. On standing overnight, needle clusters were observed at the boundary of the layers.

3.3.4 Empilan K3

Hot tallow (3ml) was mixed with diesel (20ml) and empilan K3 (3ml) added. The mixture was warmed with gentle shaking until a clear orange solution was obtained. The solution was still clear after four hours but on standing overnight, a waxy scum was observed on the upper layer and granules of tallow had precipitated out.

3.3.5 ADD-3/131088

Hot tallow (3ml) was mixed with diesel (20ml) and additive (3ml) added. The mixture was warmed with gentle shaking until a clear orange solution was obtained. After four hours, a fine precipitate was observed. On standing overnight there was an increase in the amount of precipitated tallow.

3.3.6 Diethyl ether

Hot tallow (3ml) was mixed with diesel (20ml) and ether (3ml) added. The mixture was warmed with gentle shaking until a clear orange solution was obtained. After 4 hrs, the solution still remained clear and after standing overnight, a clear solution with a very small quantity of granules was observed.

.3.3.6 Kamco Waxbreaker

Hot tallow (3ml) was mixed with diesel (2Oml) and the commercial waxbreaker (3ml) added. The mixture was warmed with gentle shaking until clear orange solution was obtained. After 4 hrs, the solution still remained clear and after standing overnight, granules of tallow were observed.

3.4 Refining of Tallow Grade 1

3.4.1 Procedure 1

Hot tallow (2Oml) was dissolved in ether (100ml) and left to stand. After 2 hrs, an oft-white solid had precipitated out of solution. The solid was filtered from the solution and found to have a m.p of 49 - 54°C and a volume of 0.5ml when liquified.

The ether filtrate was left to stand overnight whereupon a second white precipitate was filtered from the solution. This second residue was washed with cold ether and the washings combined with the filtrate. The solid (3.4.1b) had a melting point of 55 - 58°C in a yield of 4.1g.

The resulting clear yellow solution was concentrated by standing in hot water (50°C). On standing at ambient temperatures the resultant yellow oil had solidified to afford a substance rather like margarine. Yield 10.5g or 12.0ml when liquified.

3.4.2 Procedure 2

Hot tallow (40ml) was dissolved in ether (100ml) and left to stand. After 2 hrs, an off-white solid had precipitated out of solution. The clear ether solution was decanted and filtered. This afforded an off-white solid 5.4g with a melting point of 46 - 53°C and a volume of 7.2ml when liquid.

The ether filtrate was concentrated by standing in hot water (50°C) to give a clear yellow liquid (32.5ml). On standing at ambient temperatures the resultant yellow oil had solidified to afford a substance rather like butter (3.4.2b, 31.0g) with a melting point of 43 - 45°C.

3.4.3 Procedure 3

Hot tallow (3x80ml) was dissolved in ether (3x200ml) and left to stand overnight. A yellow/ white solid was obtained and this was filtered from the solution. The each solid was dissolved once again in ether (3x50ml) and left to stand. On standing overnight an white solid in a pale yellow liquid was obtained. The solid was filtered from the solution to afford 35.1g (31.5ml when liquid).

The filtrates were combined and condensed by standing in a water bath at 60 - 70°C. On standing overnight at ambient temperature, globules of a yellow solid suspended in a small quantity of a yellow liquid were obtained. The liquid was allowed to drain from the solid and then decanted. The yellow oil (4.5ml/12.5g) solidified on standing.

The main residue (3.4.3c) was obtained in a yield of 144.5g or 167ml when liquid. It was found to melt at a temperature of 37 - 41°C.

3.5 Studies on processed tallow.

3.5.1.1 20% tallow 3.4.1c

Hot processed tal low (3.4.1c, 4ml) was mixed with diesel (20ml) and the mixture warmed until a clear orange solution was obtained. The solution remained clear even after 13 days

3.5.1.2 15% tallow 3.4.1c

Hot processed tallow (3.4.1c, 3ml) was mixed with diesel (2Oml) and ether (3ml). The mixture warmed until a clear orange solution was obtained, the solution remained clear even after 13 days.

3.5.2.1 20% tallow 3.4.2b

Hot processed tallow (3.4.2b, 4ml) was mixed with diesel (20ml) and the mixture warmed until a clear orange solution was obtained. On standing overnight, a few small granules of tallow were observed.

3.5.2.2 15% tallow 3.4.2b

Hot processed tal low (3.4.2b, 3ml) was mixed with diesel (20ml) and the mixture warmed until a clear orange solution was obtained. The mixture warmed until a clear orange solution was obtained. On standing for 8 days, a small quantity of granular tallow was observed to have precipitated out of solution.

3.5.2.3 15% tallow 3.4.2b

Hot processed tallow (3.4.2b, 3ml) was mixed with diesel (2Oml) and ether (3ml). The mixture was warmed until a clear orange solution was obtained. On standing for 8 days, a small quantity of granular tallow was observed to have precipitated out of solution.

3.5.3 Procedure 3 refined tallow

3.5.3.1 15% tallow in diesel

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) was mixed with diesel (20ml) to give a clear orange solution. Even after 12 days a clear solution was obtained.

3.5.3.2 Butyl acetate

3.5.3.2.1 5% additive

Hot refined tallow (3.4.3c, 1ml) was mixed with diesel (20ml) and butyl acetate (1ml) were mixed and warmed to give a clear orange solution. By the 2nd day, fine granules were observed to have precipitated out.

3.5.3.2.2 10% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and butyl acetate (2ml) were mixed and warmed to give a clear orange solution.

3.5.3.2.3 15% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and butyl acetate (3ml) were mixed and warmed to give a clear orange solution.

3.5.3.2.4 10% additive - 20% tallow

Hot refined tallow (3.4.3c, 4ml) was mixed with diesel (20ml) and butyl acetate (2ml) were mixed and warmed to give a clear orange solution. After standing overnight fine granules were observed in a clear orange liquid.

3.5.3.3 Isopropyl ether

3.5.3.3.1 5% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and isopropyl ether (1ml) were mixed and warmed to give a clear orange solution. On the 7th day only two granules were observed to have come out of solution.

3.5.3.3.2 10% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and isopropyl ether (2ml) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.

3.5.3.3.3 15% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and isopropyl ether (3ml) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.

3.5.3.3.4 10% additive - 20% tallow

Hot refined tallow (3.4.3c, 4ml) was mixed with diesel (20ml) and isopropyl ether (2ml) were mixed and warmed to give a clear orange solution. After the 2nd day fine granules in a clear orange solution were observed.

3.5.3.4 N—Butyl ether

3.5.3.4.1 5% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and n-butyl ether (1ml) were mixed arid warmed to give a clear' orange solution. By the 3rd day, granules were observed to have come out of solution.

3.5.3.4.2 10% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and n-butyl ether (2ml) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.

3.5.3.4.3 15% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and n-butyl ether (3ml) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.

3.5.3.4.4 10% additive - 20% tallow

Hot refined tallow (3.4.3c, 4ml) was mixed with diesel (20ml) and n-butyl ether (2ml) were mixed and warmed to give a clear orange solution. After the 2nd day fine granules in a clear orange solution was observed.

3.5.3.5 Tetrahydrofuran (THF)

3.5.3.5.1 5% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and tetrahydrofuran (1m) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.

3.5.3.5.2 10% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (20ml) and tetrahydrofuran (2ml) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.

3.5.3.5.3 15% additive

Hot refined tallow (3.4.3c, 3ml) was mixed with diesel (2Oml) and tetrahydrofuran (3ml) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.

3.5.3.5.4 10% additive - 20% tallow

Hot refined tallow (3.4.3c, 4ml) was mixed with diesel (20ml) and tetrahydrofuran (2ml) were mixed and warmed to give a clear orange solution. The solution still has remained clear after 7 days.