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Engine Test of Bio-Diesel Manufactured from Waste Cooking Oil and Reward Preferential Benefit Analyses for Its Promotion

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1. Introduction

The main problem for current biodiesel is high cost. According to the statistics, 70% of manufacturing cost of biodiesel is from feedstock. So using cheap feedstock and raise the transesterification rate to reduce cost is the key for the manufacturing biodiesel. But there are following shortcomings for adopting chemical method to synthesize biodiesel: complicated manufacturing process, excess of alcohol; the follow-up process must have corresponding alcohol retrieval device, high energy-consuming, dark colour because the quality of the unsaturated fatty acid is easy to change under high temperature; difficult to retrieve esterified products, high cost; there is waste alkali liquid emission in the manufacturing process.

To solve above-mentioned problems, some researcher have begun to use bio-enzyme to synthesize biodiesel, that is, use animal and plant fatty and low carbon alcohol to conduct transesterification reaction through fatty acid and manufacture corresponding fatty acid: methyl and ethyl. The biodiesel synthesized by enzyme method has moderate condition, that is, low transesterification rate, 40% to 60% in general. At present time, the fatty acid is effective in the esterification or transesterification of long chain fatty alcohol and low esterification rate for short chain fatty alcohol such as methanol and ethanol. Besides, short chain alcohol is poisonous to enzyme that the enzyme life is short. The difficulty to retrieve its by-products glycerol and water constrains the product. The glycerol is poisonous to immobilized enzyme that shortens the life of immobilized enzyme. So it is necessary to develop new immobilization method for fatty enzyme and esterification process to manufacture high quality and low cost biodiesel.

Developing biodiesel by biocatalyst transesterification is one of new process that is developing in the world. Using biocatalyst to conduct the esterification production of biodiesel could essentially be divided into extracellular enzyme and intracellular enzyme. There already had many researches on the extracellular reaction. Akoh et al., Who had tested many fatty acids to dissolve enzyme, found that dissolving enzyme had the best effectiveness [1]. Knothe et al (2000) also offered pre-processing method for fatty ester composition [2]. Wu, W.T. et al. also conducted researches on the enhancement of activity of enzyme in commercialized enzyme Novozyme435 [3]. The biggest shortcoming of extracellular reaction is that the enzyme has to go through the process of isolation and purification that is complicated in

process and the enzyme is usually not stable and expensive. Therefore, many researches use entire cell to catalyze [4]. The research by Ban et al pointed out that using entire cell for immobilization of biocatalyst had big potential for production of biodiesel in biomass support particles, (BSPs) [5].

In Germany, the cars manufactured by Mercedes-Benz, BMW, VW and Audi auto manufacturers are allowed to use bio-diesel without the need of the modification of engines. Because the use of bio-diesel enjoys can enjoy tax-exempt incentive measures, the retail price at present time is about 1.45 marks/litre whereas the price of diesel is 1.60 marks/litre, so bio-diesel has excellent competitiveness comparing to general diesel. The tests of engines of using bio-diesel showed that the waste gas emission indicators not only satisfy present Europe's No. 2 Standard, but also satisfy Europe's tougher No. 3 Standard that will be effective soon. Due to its excellent environment protection property, bio-diesel enjoys the tax preferential policy by government and its price is lower than general diesel. Besides using as fuel diesel, fatty acid methyl esters (bio-diesel) has value in widespread applications to chemical industries [6].

In order to enhance engine efficiency and decrease pollution emission, the relative experiments with mixed fuels were involved in this paper. For example, the bio-diesel derived from waste cooking oil was mixed with petrochemical diesel in addition to the accelerant so as to increase the viscosity of mixed fuel and decrease pollutant emission was added to mixed fuel to promote engine combustion efficiency [7].

Biodiesel, no matter what feedstock and manufacturing process are, is superior to petrochemical diesel in terms of environment protection and human health. So it has been paid more and more attention. In 2000, the world's total production of biodiesel was about 800 thousand tons. But in 2007, the production exceeded three million tons. Most of the incremental quantity was contributed by European countries, Austria, Belgium, France, Germany and Italy in particular. Those countries have been sparing no efforts to the promotions of biodiesel including enacting incentive measures and tax reduction regulations, stipulating national standards of biodiesel and conducting road test and waste gas emissions.

Until today, most of the production of biodiesel come from Europe, top of the whole world with more than 80%, and the production still continue to grow; on the application, in addition to government cars, the metropolitan public traffic vehicles, private cars, trucks, agricultural machines have been shifted to use biodiesel. The main reason of the success is that the direct and indirect incentives and subsidies by European governments and calls for environment protection from the people have contributed to the success of promotion of biodiesel and become leadership in this field [8].

2. Manufacture of biodiesel by transesterification reaction with alkali process from waste cooking oil

At present time, the fatty acid is effective in the esterification or transesterification of long chain fatty alcohol and low esterification rate for short chain fatty alcohol such as methanol and ethanol. Besides, short chain alcohol is poisonous to enzyme that the enzyme life is short. The difficulty to retrieve its by-products glycerol and water constrains the product. The glycerol is poisonous to immobilized enzyme that shortens the life of immobilized enzyme. So it is necessary to develop new immobilization method for fatty enzyme and esterification process to manufacture high quality and low cost biodiesel. The comparisons

of benefit and defect between Alkali process and enzyme process of biodiesel transesterification are discussed in Table 1.

Process Item	Alkali process	Enzyme process	Remark
Reaction temperature	60~70°C	30~40°C	Additive amount of energy depends on temperature
Free fatty acid	Saponified matter	Methyl esters	NaOH with fatty acid may produce saponified matter
Water content of material	Interference reaction	No impact	Water moisture of alkali process reaction can produce caking that has negative impact on following processing.
Methyl esters yield	Average	High	Yield means methyl esters rate per material
Glycerol yield	Difficult	Easy	Glycerol is additional product, and can increase extra income.
Methyl esters purification	Repeated water washing	None	Waste washing water drainage, and additional wastewater treatment is required.
Catalyst cost	Cheap	Very expensive	Increase ferment use time can reduce cost.

Table 1. Comparison between Alkali Process and Enzyme Process

The high acid value oil in waste cooking oil generally composes of impurities, free fatty acid, polymer, resolver, etc. that are not good to transesterification and have to be pre-processed. The methods we could consider are physical refining and methanol pre-erification. The oil feedstock we used was Uni-President soybean oil, waste cooking oil from restaurants and waste cooking oil from Yang-Yang Oil Retrieval Company.

The Iodine value is almost the same in Table 2, so the modulation of the Iodine value is not necessary. It showed in Table 2 that we could judge the degree of free fatty acid of the oil from acid value. The higher acid value is that the higher degree of free fatty acid will be. The results of the test of acid value showed that the acid value of Uni-President soybean oil was 0.04488 (mg KOH/g), the acid value of waste cooking oil from restaurants after modulation was 0.26928(mg KOH/g), waste cooking oil from Yang-Yang Oil Retrieval Company was 1.929 (mg KOH/g). It showed that the content of the free fatty acid in the waste cooking oil from Yang-Yang Oil Retrieval Company was higher. The reason is that the waste cooking oil retrieved by Yang-Yang Oil Retrieval Company was the mixed oil from restaurants that usually had higher acid value. This could be acted as referenced basis for the acid value of retrieved waste cooking oil. The iodine value of all the tested feedstock is almost the same under 8% difference. So, the modulation must be focused on the acid value for the feedstock from waste cooking oil.

If Uni-President soybean oil was used as raw material, NaOH catalyst was decreased, and methanol was increased, the saponified substances obviously decreased and can be stirred uniformly after transerification. The tap funnel produced obvious layers after 10 minutes. The methyl ester at upper layer was easy to separate from the glycerol at the lower layer. The crude methyl ester yield increased, and crude methyl ester volume yield was up to 97%. But the residue methanol was not removed from the crude methyl ester volume. After removal, the crude methyl ester volume required correction. After distillation, the methyl ester volume was 395ml, and the methyl ester volume yield was 79.0%. The loss is due to water washing.

When the waste cooking oil from restaurants after modulation was used as raw material, no saponified substance appeared after transerification. The tap funnel had obvious layers after 10 minutes. The methyl ester at upper layer was easy to separate from the glycerol at the lower layer. The crude methyl ester volume was 503 ml, and the crude methyl ester yield was up to 100.6%. After distillation, the methyl ester volume was 400ml, and the methyl ester volume yield was 80.0%. The loss is due to water washing.

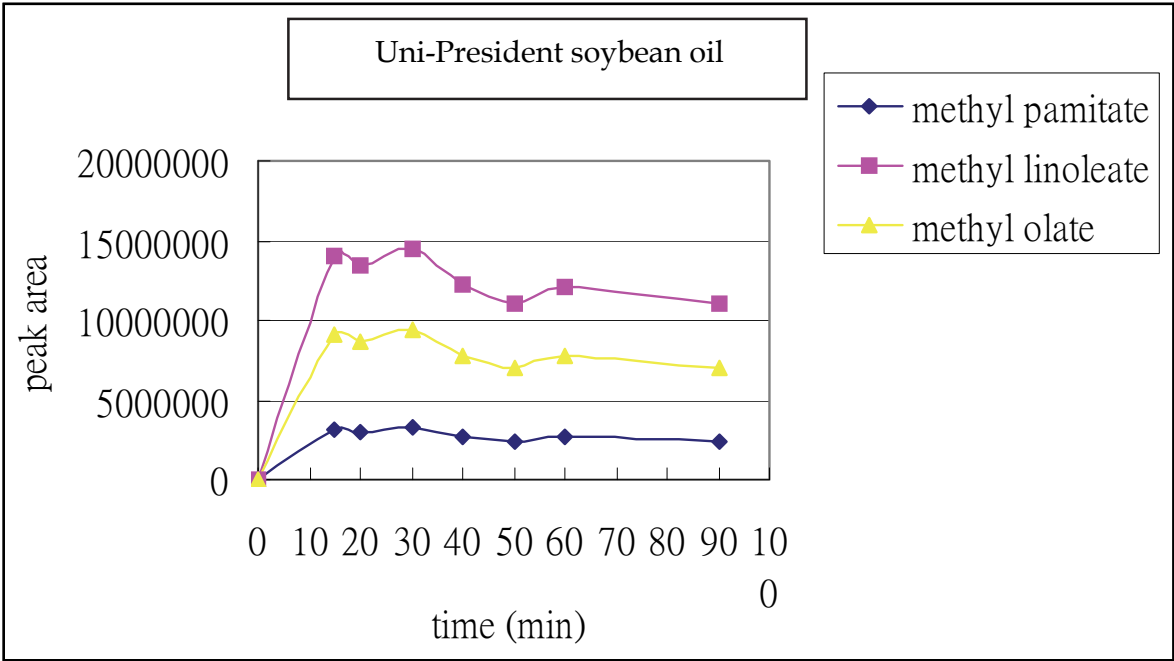


Fig. 1. Uni-President soybean oil transerification reaction curve

If using waste cooking oil retrieved by Yang-Yang Oil Retrieval Company, no saponified substance appeared after transerification. The tap funnel had obvious layers after 10 minutes. The crude methyl ester volume was 528 ml, and the crude methyl ester yield was up to 97.77%. After distillation, the methyl ester volume was 512ml, and methyl ester volume yield was 94.81%. The loss caused by water washing reduced more, and low methyl ester volume was obtained shown in Fig.1 and Fig.2.

From the above experiments, the acid value of waste cooking oil must be modulated down to 0.26928(mg KOH/g) for the self-manufacture of the biodiesel to keep the normal processes of the transerification Reaction with Alkali. The colour of waste cooking oil from Yang-Yang Oil Retrieval Company and restaurants after modulation was deeper than the Uni-President soybean oil before and after transerification. GC-MASS analysis was

conducted for products from transesterification, chromatography area and time was used to plot reaction curve. The reaction balance can be achieved after 15 minutes for all the tested feedstock in Fig. 1 and Fig. 2.

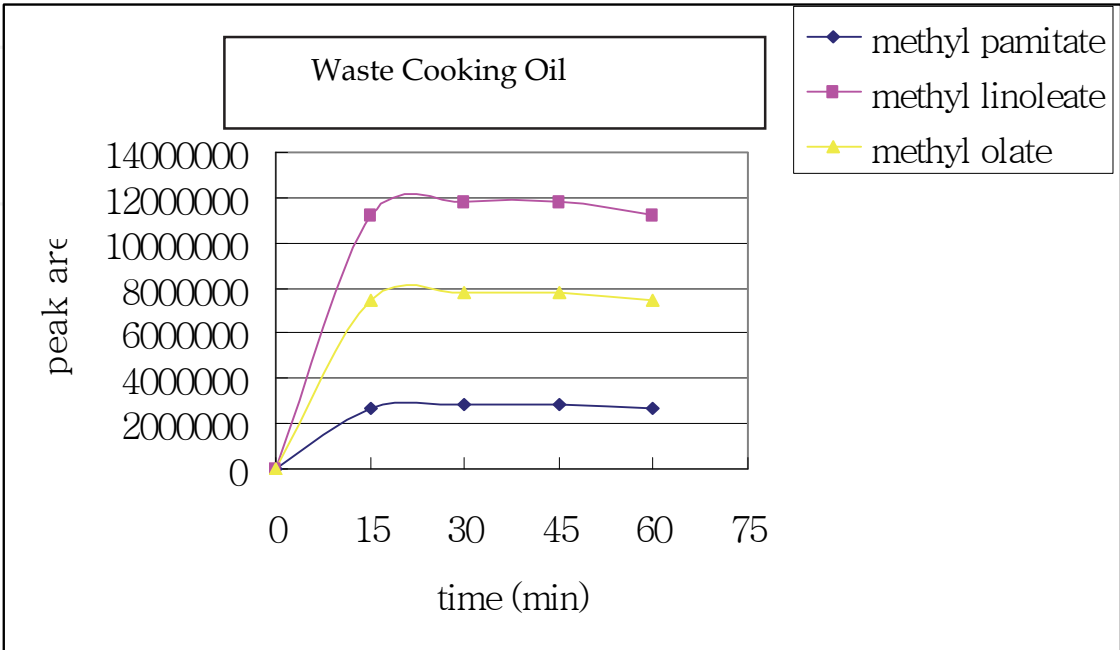


Fig. 2. Transesterification reaction curve of waste cooking oil from Yang-Yang Oil Retrieval Company

The production of the methyl linoleate was more over the one of the methyl palmitate during the processes for the manufacture of biodiesel from the waste cooking oil.

Name of Oil	Uni-President soybean oil	Waste cooking oil from Restaurants (after modulation)	Waste cooking oil Retrieved by Yang-Yang Oil Retrieval Company
Iodine Value (g I2 /100g)	135.91	142.32	145.67
Acid Value (mg KOH / g)	0.04488	0.26928	1.929
Viscosity (cP,22.5°C)	58.6	65.7	67,3
Density (g / ml,25°C)	0.918	0.918	0.908

Table 2. Analyses of the Property of Feedstock Oil for Manufacturing Biodiesel

Item	Unit	Results of Test			Test Method	ASTM Biodiesel Standard
		PD	B20	B100		
Density @15.5°C	G/ml	0.84	0.85	0.88	ASTM D4050	0.85
Flash Point	°C	87	92	150	ASTM D93	100 min.
Contents of Sulphur 1	Wt%	0.0258	0.0200	<0.001	ASTM D2622	0.05 max.
Power Viscosity@40°C	CST	3.460	3.517	4.136	ASTM D445	1.9-6.0
Water and Sediment	Vol. %	0.00	0.00	0.00	ASTM D1796	0.00
Corrosiveness	3hr (50°C)	1a	1a	1a	ASTM D130	No.3b max.
Ash	Wt%	0.003	0.002	0.003	ASTM D482	0.002
Aromatic Hydrocarbons	Wt%	24.5	*	*	ASTM D5186	none
Cetane Index2	none	53.9	53.7	47.3	ASTM D976	53.7
Rams bottom Carbon Residue3	Wt%	0.051	0.033	0.035	ASTM D524	0.033
Carbon Contents	Wt%	86.71	86.49	76.53	ASTM D5291	86.5
Hydrogen Content	Wt%	13.28	13.5	11.72	ASTM D5291	13.5
Oxygen Content	Wt%	0.01	0.01	11.75		none
Total Thermal Value	Cal/ g	10990	10625	9490	ASTM D240	10630
Net Thermal Value	Cal/ g	10317	9941	8896	ASTM D240	9940

Note: * means the tests that could not be completed by analytic instruments under SOP of Refinery Institute of China Petroleum Company. The number 1, 2, 3 were tested by Material and Chemical Research Laboratories, Industrial Research Institute for the research.

Table 3. Analyses of Fuel Properties of Petroleum Diesel, B20 and B100

The high flash point and low sulphur content exists in the manufactured biodiesel than petroleum biodiesel. The cetane index and heating value of the manufactured biodiesel is a litter low than petroleum biodiesel. And, the properties of the manufactured biodiesel meet the standard of the biodiesel almost.

3. Engine application of bio-diesel manufactured from waste cooking oil

The fuel in the test included petrochemical diesel (PD), self-manufactured pure biodiesel (B100) through transesterification reaction of soybean oil and mixed biodiesel that is mixed by above-mentioned two fuels with volume ratios of 4:1. Then we sent these fuels to Refining Institute of China Petroleum Company, Taiwan for analyses and tests.

The engine test was conducted at Alternative Inspection Centre of Ford Company, Taoyuan County, Taiwan. The facilities of this centre are listed in Table 4. We used the equipment of the centre to test the engines of garbage trucks (provided by Cleaning Department of Chungli City. Test was conducted during the maintenance of the trucks). The regulations of the engine are listed in Table 5. According to CNS11644 and CNS11645, we conducted pollution tests of non-loading instant speed up, full load fixed speed. Meanwhile, we used waste gas analysis instruments (listed in Table 6) to test the ingredients of gas emission by engines under full loading, including CO, CO2, SO2, NOX and brake horsepower. Besides,

because when the garbage truck is often in idling state, so we conducted the gas emission test under the idling state and test brake horsepower with car body power meter. Pollution degree is defined as follows:
(CO emission concentration)/ (CO2 emission concentration + CO emission concentration)

Item	Specification
Vehicle body dynamometer	SCHENCK 364/L/D/1200
Smoke meter	KOMYO ST-100
Tachometer	AVL 873

Table 4. Testing Instrument

Item	Specification
Engine brand	INTERNATIONAL
Vehicle type	4900, 4x2, Turbo 7636C.C, A5
Vehicle mileage	270743KM
Engine type	In-line six-cylinder
Starting date	1992
Max power	182.7kW@2600rpm
Vehicle weight	15,000kg

Table 5. Garbage Truck Engine Data

Equipment	Brand and Model	Analyser principle	Measurement range	Accuracy
SO2 analyser	Siemens LTRAMAT6E	NDIR	0~1000ppm	±1.0% of Range
CO2 analyser	Siemens LTRAMAT21P	NDIR	P~20%	±1.0% of Range
CO analyser	Siemens ULTRAMAT6E	NDIR	0~3000ppm	±0.5% of Range
O2 analyser	AMETEK FCA/Rack Mt.	ZrO2	0~20.9%	±1.5% of Range
NOX analyser	Siemens ULTRAMAT23	NDIR	0~1000ppm	±1.0% of Range

Table 6. Exhaust-Gas Analyzer

3.1 Test of brake horsepower

The brake horsepower tests of engine were conducted in using petrochemical diesel, B20 and B100 under the state of full loading. Under full loading, increase loading step by step, the rotational speed from 2600rpm is reduced to 2500, 2400, 2300 and finally 2200rpm. The output brake horsepower by the engine in using premium diesel, B20 and B100 were shown as Fig. 3. Calculated by average values, comparing to premium diesel, the brake horsepower output by B20 is reduced by 8%, and, B100 is reduced by 10%.

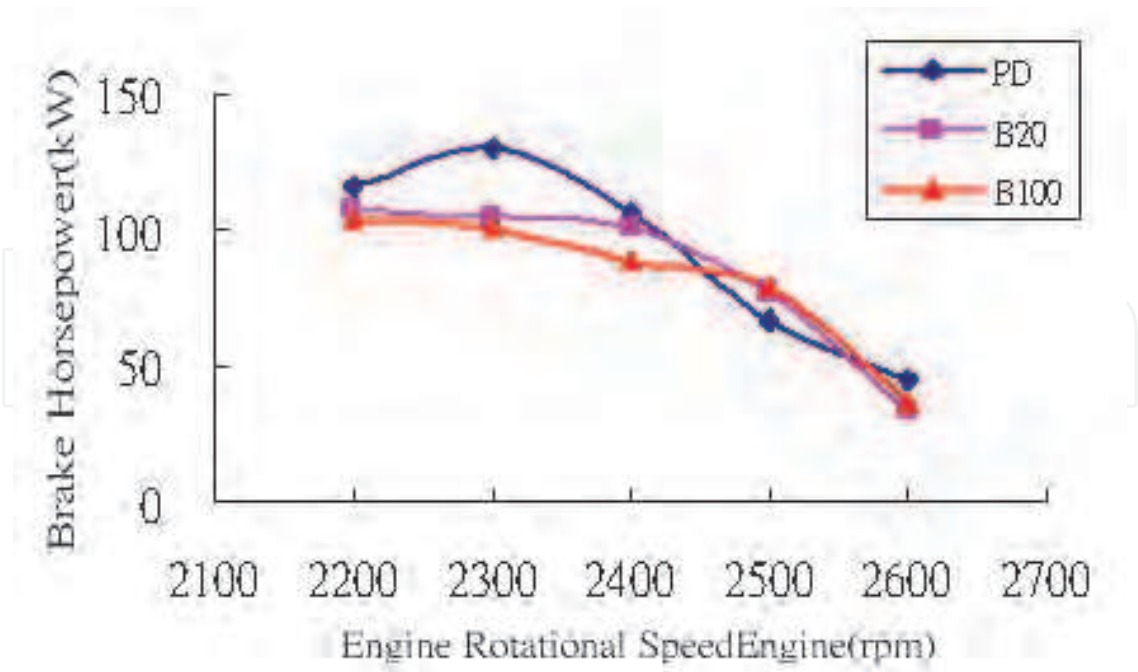


Fig. 3. Engine Horsepower Output by Three Fuels under Full Loading

3.2 Test of pollutant emissions by engine

Reorganized concentration of waste flue such as carbon monoxide, sulfur dioxide and nitrogen oxide compound emitted by engine under the state of full load and idle as Table 7. Under the test of full load, when used B20 and B100, the concentrations of carbon monoxide emitted by engine were reduced 14% and 51% respectively comparing petrochemical diesel. Under the test of idle, when used petrochemical diesel, B20 and B100, the concentrations of carbon monoxide emitted by engine were almost the same.

Under the test of full load, when used B20 and B100, the concentrations of sulphur dioxide were reduced 68% and 73% respectively comparing petrochemical diesel,. Under the test of idle, the concentration of sulphur dioxide emitted by B100 was the lowest; the concentrations of sulphur dioxide emitted by petrochemical diesel and B20 were almost the same.

Under the test of full load, when used B20 and B100, the concentration of nitrogen oxide compound increased 1% and 13% respectively comparing petrochemical diesel,. Under the test of idle, the concentration of nitrogen oxide emitted by B100 was the highest; the concentrations of nitrogen oxide emitted by petrochemical diesel and B20 were almost the same.

Under the test of full load, the load increased gradually. When the engine speed decreased from 2680rpm to 2360rpm and to 2100rpm, B100 had the lowest pollution degree, followed by B20, and the premium grade diesel had the highest pollution degree, see Fig. 4. In terms of average value, as compared to premium grade diesel, the pollution degree of B20 can be reduced by 8%; the pollution degree of B100 can be reduced by 69%.

Under the test of idle, pollution degree of premium grade diesel, B20 and B100 was 7%, 3% and 2% respectively, see Fig. 5. Under the test of free acceleration, pollution degree of the premium grade diesel was close to that of B20, and the pollution degree was 31.3% and 38.6% respectively. B100 had the lowest pollution degree, 19.3%, see Fig. 6.

RPM	CO ₂ (%)	CO(ppm)	O ₂ (%)	SO _x (ppm)	NO _x (ppm)
PD					
2600	8.1	200	10	18	256
2340	9.1	282	8	46	520
2080	9.5	316	7	57	517
Idle	1.6	98	18	17	275
B20					
2600	6.7	174	12	18	333
2340	9.3	257	8	25	453
2080	9.5	255	8	29	525
Idle	1.7	103	19	13	263
B100					
2600	6.8	124	12	10	331
2340	9.1	133	9	10	547
2080	9.6	131	8	12	582
Idle	1.8	108	18	12	334

Note> The idle is at 630 rpm

Table 7. Emission Test under the State of Full Load

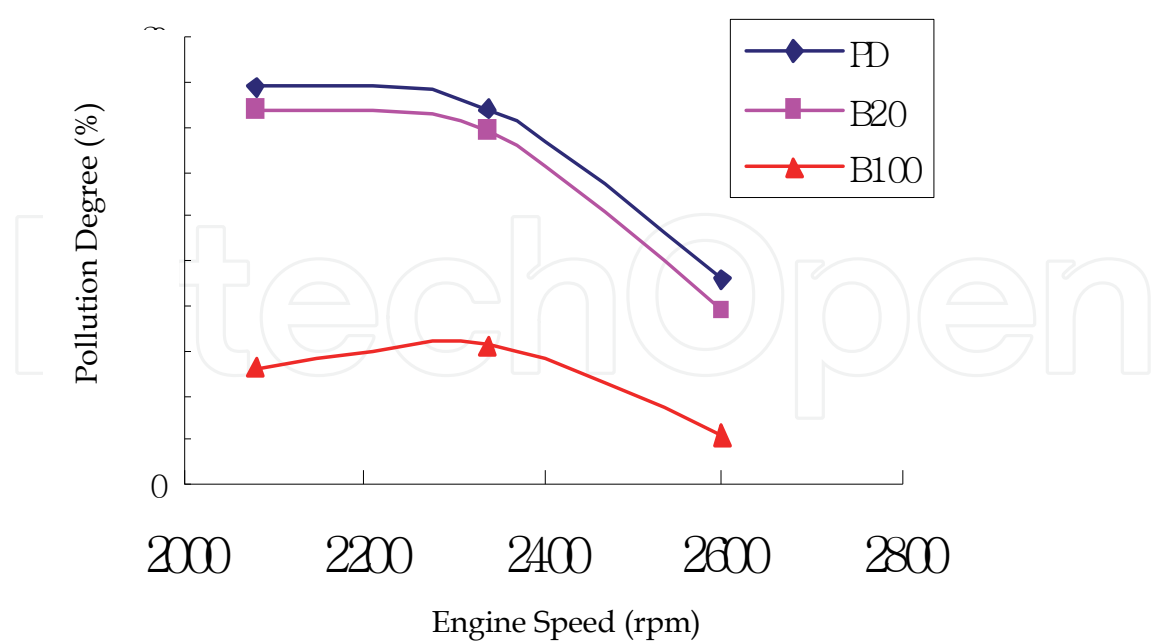


Fig. 4. Pollution Degree Test under Full Load

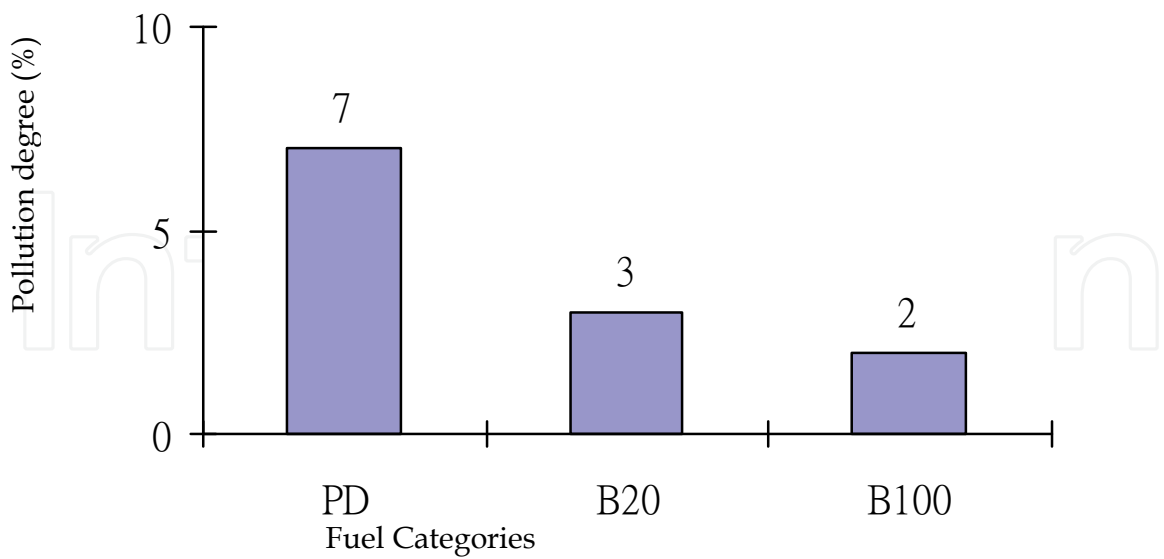


Fig. 5. Pollution Degree Test under Idle State

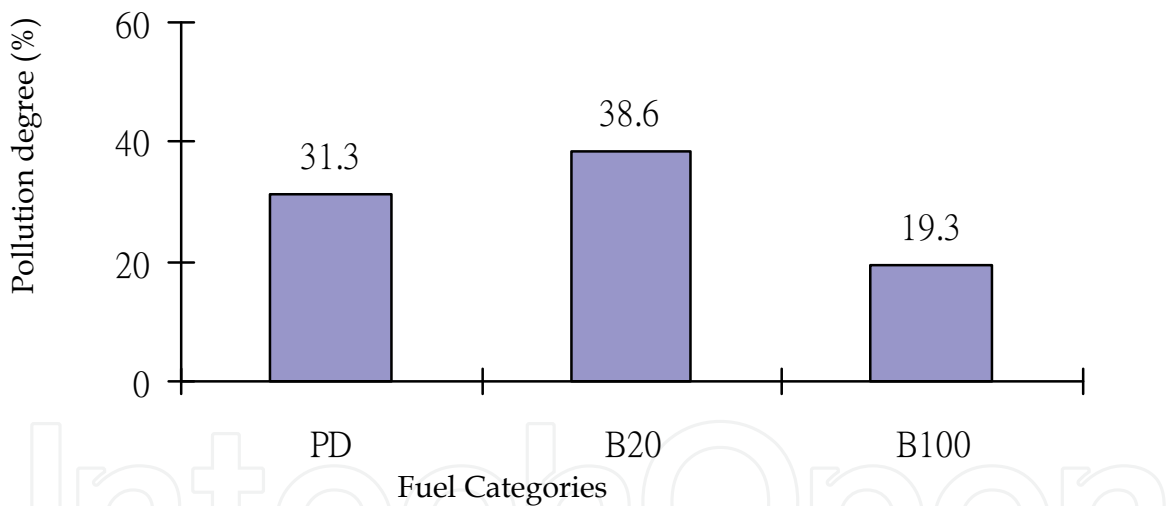


Fig. 6. Pollution Degree Test under Free Acceleration

4. The analyses of reward preferential benefit for biodiesel promotion in Taiwan by financial IRR and PB estimation

Through economic research, the study aims to understand the potential and feasibility of promotions and application of biodiesel in Taiwan. It is hoped that the results of research could provide the operators with references in investment and the government with references in working out regulations and incentives. With reference to the establishment and operation of factories abroad and conditions in Taiwan, we evaluated the feasibility of establishing biodiesel factory through economic analyses to provide operators with the base in planning and establishing factories in Taiwan.

The article collected foreign related literature and analyzed the cost and benefits in three parts:

(1) Net Present Value Method: After initial investment, the yearly flowing-in amount of net cash was converted into present value according to capital cost (minimum investment reward). After deducting the present value of initial investment, the difference is net present value (NPV). When $NPV > 0$, we could accept the investment plan; if $NPV < 0$, we should abandon the plan. Under consideration of inflation, the formula is as follows:

$$NPV = \sum_{t=1}^n \frac{[(R_t - C_t) - Tr(R_t - C_t) + D_t]}{[(1+r)^t \times (1+np)]} - CE_0 \quad (1)$$

R_t : The total income at the end of the t period, the value is the monetary value at the end of the t period.

C_t : The total cost at the end of the t period, the value is the monetary value at the end of the t period.

Tr : Tax rate of income for enterprise

D_t : Depreciation

I : Capital Cost

P : Inflation Rate

CE_0 : Initial investment cost

(2) Internal Reward Method: After investment, the discount rate of total of every year's flowing-in amount of net cash that is converted into present value equivalent to total initial investment is internal reward rate (IRR). When $IRR > 1$ (capital cost), we could accept the investment plan, but if $IRR < 1$, we should abandon the plan. Under consideration of inflation, the formula is as follows:

$$NPV - CE_0 = 0$$

$$NPV = \sum_{t=1}^n \frac{[(R_t - C_t) - Tr(R_t - C_t) + D_t]}{[(1+r)^t \times (1+np)]} \quad (2)$$

Note: The definition of symbols is the same as net present value method and in which r is the IRR.

Discount and Repayment of Principal Method: It refers the time that the initial total investment could be repaid through operation. When the net flowing amounts of cash in every period (i.e. the results of total income deducted by total expenses of the period) are equal, the time of discount and repayment of principal (PB) is results of initial investment amount being divided by the total of each period's discount net cash flowing amount. On the other hand, when and if each period's discount net cash flowing amounts are equal, then we need to use interpolation to obtain PB.

In the research, we took the example of an Ireland's 3000 tons/year biodiesel factory to conduct benefit analyses to explore the unit input cost of different feedstock. The related investment and operation cost came from Ireland's literature [2]. We inducted as follows:

Mould Factory Capacity Planning: 1) Oil-Squeezing Factories (waste eating oil does not need the equipment): with 30% oilseed transform ratio, the average oilseed investment cost is NT\$1,415/ton (or NT\$1.25/litre). If we wish to provide mixed biodiesel factories with 25% tea oil, then we will need a tea oil oil-squeezing factory with capacity of 750 tons/year, the investment cost is NT\$5.12 Millions; if we want to supply a 100% biodiesel factory, we

have to invest NT\$ 21.2 millions for a tea oil oil-squeezing factory with capacity of 3,000 tons/year; 2) biodiesel refinery: with oil transform ratio 95% for vegetable oil and 87% for waste eating oil, the total investment for a factory with the capacity of 3,000 tons is about NT\$38.4 millions, average oil-squeezing cost is NT\$2,625/ton (or NT\$2.31/litre. Operation hours: 24 hours per day and 330 days per year; Operation pattern: lot production pattern. Three different feedstock: 100% tea oil camellia, mixed (25% tea oil and 75% waste eating oil), 100% waste oil.

(3) Discount Rate (necessary reward rate): 20%, pound: NT \$ dollars = 1:45
Furthermore, the subject of the research was small mould factory with output of 1,275 kiloliter one year. We also conducted evaluation of economic benefits of hardware equipment and price incentives according to the instalment cost of hardware equipment and operation cost provided by Pacific Biodiesel, Inc. The analyses were conducted with self-developed software [9].

4.1 The Analyses of unit output cost of different feedstock

This research took an Ireland’s biodiesel mould factory with output 3,000 tons/year as an example to compare unit output cost of three different feed stocks (tea oil-camellia, mixed, waste eating oil):

From Table 8, we could learn that the feedstock was 60% to 70% of production cost. If we raise the additive ratios of the waste eating oil or all replace with waste eating oil, the unit cost could be reduced 12.5% to 17%. Therefore, the biodiesel with waste eating oil as feedstock could not only reduce production cost but also had benefit of environment protection, and would never be affected by the fluctuation of prices of agricultural products.

Unit: NT dollars/litre

Category of Feedstock \ Items of Cost	100% Tea Oil	Mixed (25% Tea Oil and 75% Waste Eating Oil)	100% Waste Eating Oil
* Feedstock Cost	12.02	9.74	8.98
Operation Cost	3.29	3.29	3.29
Investment Cost**	2.31	2.31	2.31
Unit Cost **	17.6	15.4	14.6

Note: *Feedstock Cost: Tea Oil includes agricultural products purchase cost and oil-squeezing cost; waste eating oil means charges fro cleaning, but not included purchase cost for waste eating oil.
** Investment cost: included only investment cost of biodiesel refinery. The investment cost of oil-squeezing factory had been included in feedstock cost.
***Annual production: 3000 tons (3000÷0.8827=3,400 kilolitres)

Table 8. Comparison and Analyses of Unit Cost of Different Feedstock

4.2 The analyses of benefits of incentives for biodiesel mould factory in Taiwan

For the present development of biodiesel in Europe, the size of small mould factory is annual output of 5,500 to 13,500 kilolitres. This research will target at mould factories with annual output of 1,275. According to the instalment cost of hardware equipment and operation cost calculated by Pacific Biodiesel, Inc., we conducted the evaluation of economic

benefits of the incentives for hardware equipment and price. This article will take the popularized gasoline and diesel prices as the benchmark for comparing with biodiesel (13.3 to 15.4 NT Dollars/litre of published tag prices, but here we used it as the lowest price to conduct analyses).

After analyzing unit output cost of different of different feedstock in Table 1, we could learn that the feedstock cost was 60% to 70% of production cost. There was significant difference in the effects on the production cost between oil plants and waste eating oil as feedstock. Using waste eating oil as feedstock could reduce 17% of production cost. Therefore, for the planting conditions of land in Taiwan, it seems more feasible to use low-cost waste eating oil as feedstock. The research will take waste eating oil and the oil of cooking residue as subjects to conduct related analyses.

CASE1 to 3 are interrelationship between the retrieval time limit of equipment subsidy ratio, internal reward rates and oil purchase prices of biodiesel. Reorganizing the data of CASE1 to 3, we could obtain results as Table 9 and 10. When the feedstock is waste eating oil (the purchase cost is zero) and oil of cooking residue, because of the reduction of feedstock and perhaps the income of disposal charges, the operators could have economic benefit without any subsidy. But, when the purchase cost of waste eating oil is NT\$5/kg, the operator will suffer loss and could not be able to have economic benefit with ordinary diesel sales price 13.3/litre as oil price. From Table 10, we could learn that since waste eating oil (Case 1 – purchase cost was zero), and the oil of cooking residue (Case 3) could have economic benefit without any subsidy, Table 9 only explores the price and equipment subsidy under a situation in which the purchase cost > 0 (Case 2). With 12%, 15% and 20% as reasonable reward rates for the operation of investors. Use interpolation method to calculate demand of oil purchase price and retrieval time limit of the goal of each reward rate; if we adopts price subsidy policy, then the oil purchase prices demand should deduct the sales price NT\$13.3/litre of the ordinary fossil diesel, the difference is the demand of price subsidy.

From Table 9, we could learn that when the purchase cost of waste eating oil is NT8/kg (including purchase price NT\$5/kg and cleansing and transportation charges NT\$3/kg). the oil price of break-even point (IRR=12%) is NT\$14.6/kg; Retrieval time limit is 21.8 years. If we take current ordinary fossil diesel price NT\$13.3/litre as oil purchase price, then the subsidy demand of single price is NT\$1.3/litre; if not consider price subsidy, then the equipment subsidy ratio will be as high as 90% to make up difference with ordinary fossil diesel sales price. However, if we consider equipment subsidy ratio in couple with price subsidy (mixed subsidy), then we could reduce demand of price subsidy and equipment subsidy ratio. For example, when IRR=12%, equipment subsidy 50%, demand of price subsidy is only NT\$0.5/litre, retrieval time limit could be reduced to eight years.

If we want to encourage intention of investment and raise inventory reward rate (IRR), for example 15~20%, then the demand of relative non-subsidy oil price will also be raised to NT\$16.9/kg, but the retrieval time limit will reduce to 6.4 years and the subsidy for the price difference will be increased to NT\$3.6/litre. If we only use equipment subsidy, it is impossible to make up the difference even if we use 100% subsidy. So we should have price subsidy in the same time to reach the goal of raising investment reward rate. For example, when IRR=20%, equipment subsidy 50%, then the price subsidy may only need NT\$2/litre and retrieval time limit could reduce to five years. Summarizing the results of analyses of Table 9 as follows:

1. If 12%~20% are reasonable internal reward rate for operation, the oil purchase price should be between NT\$14.6 to 16.9/litre.

- 2. If the tag price of ordinary fossil diesel is NT\$13.3/liter, the difference of purchase price is NT\$1.3 to 3.6 after deducting NT\$13.3/litre, the average difference is NT\$2.5/litre.
- 3. If we couple with using equipment subsidy ratio, for example, 59%, then the difference of oil purchase will be between NT\$0.5/litre to NT\$2.1/litre, the average is NT\$1.3/litre, reducing about half, comparing to the difference by using single price subsidy.

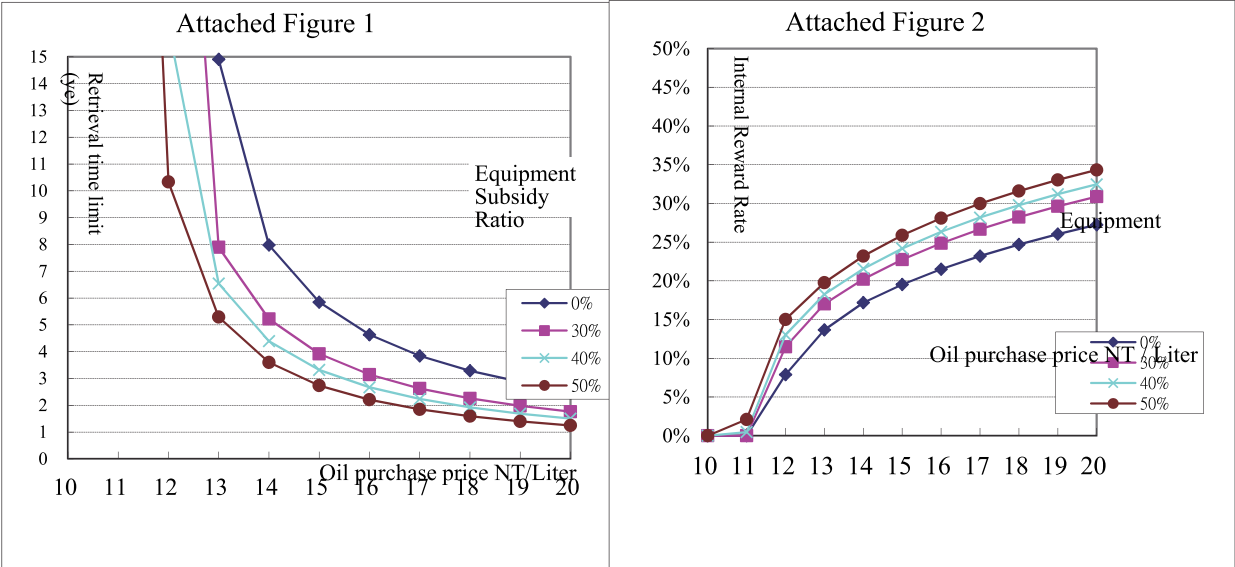
Using Case 2 cost benefit evaluation of model factory of output 1.275 kilolitres to further analyze the effects of financial subsidies such as hardware and equipment subsidy and low-interest loan on unit production cost.

Item		IRR=12%*	IRR=15%	IRR=20%
No Subsidy	Demand of Oil Price under No Subsidy (NT\$/litre)	14.61	15.34	16.92
	Retrieval Time Limit (year)	21.8	15.7	6.4
Single Subsidy	Demand of Price Subsidy** (NT\$/litre)	1.3	2.0	3.6
	Equipment Subsidy Ratio (%)	90	>100	>100
Mixed Subsidy	Equipment Subsidy Ratio (%)	30	30	30
	Demand of Price Subsidy (NT\$/litre)	1.1	1.4	2.9
	Retrieval Time Limit (year)	10.8	9.8	5.3
	Equipment Subsidy Ratio (%)	40	40	40
	Demand of Price Subsidy	0.8	1.3	2.5
	Retrieval Time Limit (year)	9.6	8.3	5.1
	Equipment Subsidy Ratio (%)	50	50	50
	Demand of Price Subsidy	0.5	1.1	2.1
	Retrieval Time Limit (year)	8.2	7.1	5.0

Note: *IRR=12% is break-even point
** Demand of Price Subsidy = Demand of Oil Price under No Subsidy – 13.3
** Ordinary fossil diesel sales price NT\$13.3/litre

Table 9. Analyses of Various Reward Rates and Price Subsidy and Equipment Subsidy of Oil Purchase Price

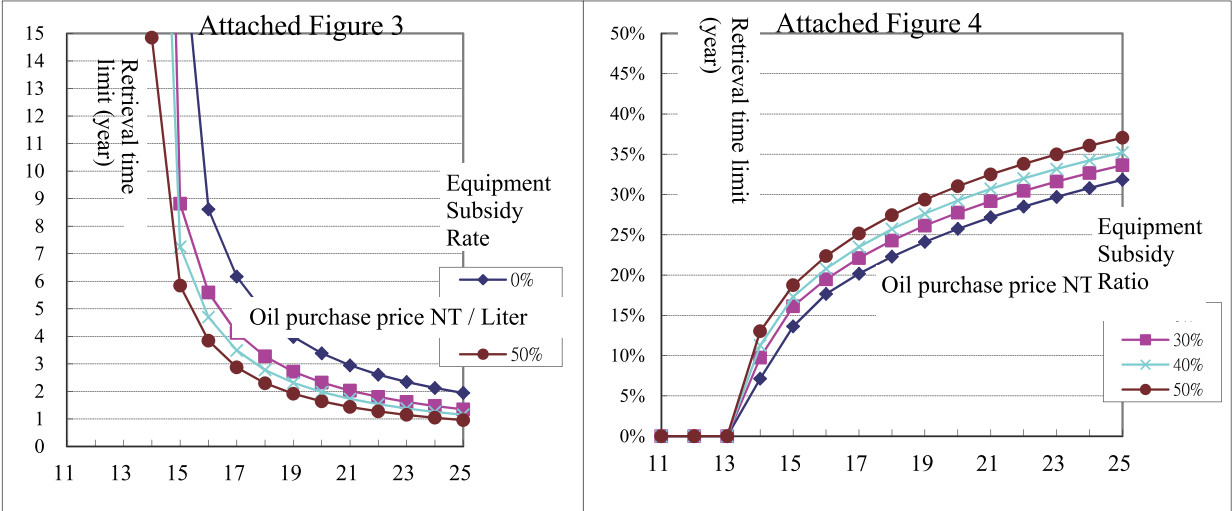
Oil purchase price NT\$ /Liter	Retrieval time limit (year)--Attached Figure 1				Internal Reward Rate (%) --Attached Figure 2			
	No Subsidy	30%Subsidy	40%Subsidy	50%Subsidy	No Subsidy	30%Subsidy	40%Subsidy	50%Subsidy
10	50.0	50.0	50.0	50.0	0.0%	0.0%	0.0%	0.0%
11	50.0	50.0	50.0	50.0	0.0%	0.0%	0.5%	2.1%
12	50.0	34.1	16.1	10.3	7.9%	11.5%	13.0%	15.0%
13	14.9	7.9	6.5	5.3	13.7%	17.0%	18.3%	19.8%
14	8.0	5.2	4.4	3.6	17.2%	20.2%	21.6%	23.2%
15	5.8	3.9	3.3	2.7	19.5%	22.8%	24.2%	25.9%
16	4.6	3.1	2.7	2.2	21.5%	24.9%	26.3%	28.1%
17	3.8	2.6	2.2	1.9	23.2%	26.7%	28.2%	30.0%
18	3.3	2.3	1.9	1.6	24.7%	28.2%	29.8%	31.6%
19	2.9	2.0	1.7	1.4	26.0%	29.6%	31.2%	33.0%
20	2.6	1.8	1.5	1.2	27.2%	30.9%	32.5%	34.3%



Fixed Conditions : Specification of Equipment : 1, 275kl/Annual Fuel Oil Output, 8 hours operation per day,
300 work days per year
Initial Investment Cost in Equipment: NT\$20, 770, 000
Discount Time Limit: 10 years
Discount Rate: 12%
The oil price is different from the measured benchmark of general diesel
The feedstock of biodiesel is waste eating oil, the purchase price per kilogram is NT\$0

Case 1. The feedstock is waste eating oil, the purchase price per kilogram is NT\$0. The interrelationship between subsidy ratio of biodiesel system equipment, retrieval time limit, internal reward rate and oil purchase proces.

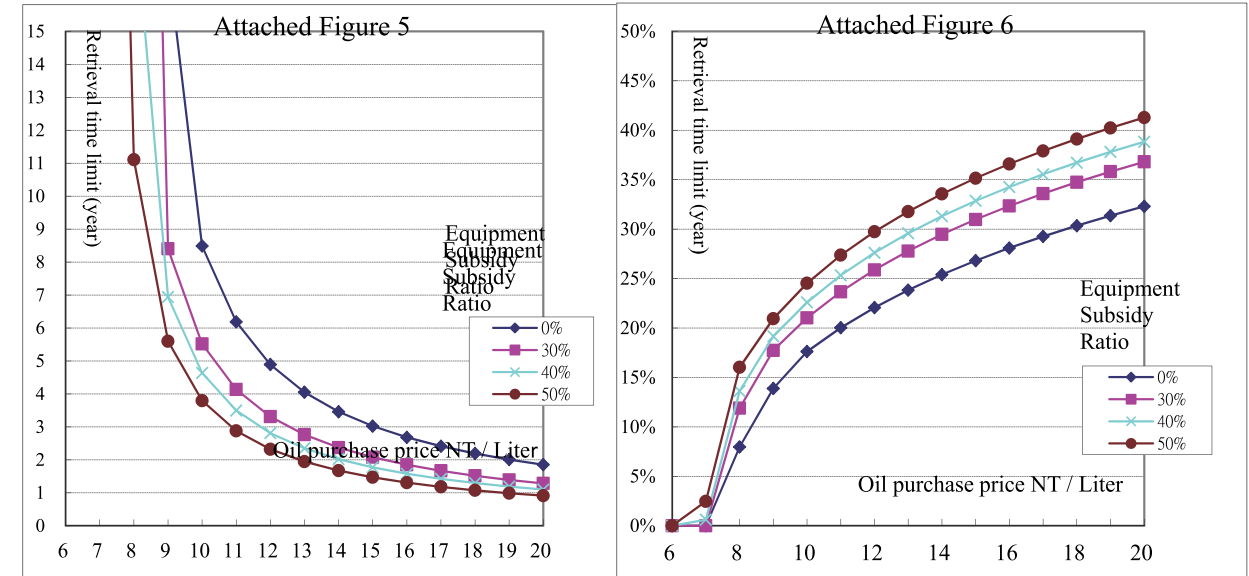
Oil purchase price NT\$ /Liter	Retrieval time limit (year)--Attached Figure 3				Internal Reward Rate (%) --Attached Figure 4			
	No Subsidy	30%Subsidy	40%Subsidy	50%Subsidy	No Subsidy	30%Subsidy	40%Subsidy	50%Subsidy
11	50.0	50.0	50.0	50.0	0.0%	0.0%	0.0%	0.0%
12	50.0	50.0	50.0	50.0	0.0%	0.0%	0.0%	0.0%
13	50.0	50.0	50.0	50.0	0.0%	0.0%	0.0%	0.0%
14	50.0	50.0	33.2	14.8	7.1%	9.8%	11.3%	13.0%
15	19.3	8.8	7.3	5.8	13.6%	16.1%	17.3%	18.7%
16	8.6	5.6	4.7	3.8	17.7%	19.5%	20.8%	22.4%
17	6.2	4.1	3.5	2.9	20.2%	22.1%	23.5%	25.1%
18	4.8	3.3	2.8	2.3	22.3%	24.3%	25.7%	27.4%
19	4.0	2.7	2.3	1.9	24.1%	26.1%	27.6%	29.4%
20	3.4	2.3	2.0	1.6	25.7%	27.7%	29.3%	31.0%
21	2.9	2.0	1.7	1.4	27.2%	29.2%	30.7%	32.5%
22	2.6	1.8	1.5	1.3	28.5%	30.5%	32.0%	33.8%
23	2.3	1.6	1.4	1.1	29.7%	31.6%	33.2%	35.0%
24	2.1	1.5	1.3	1.0	30.8%	32.7%	34.2%	36.1%
25	1.9	1.3	1.2	1.0	31.8%	33.6%	35.2%	37.1%



Fixed Conditions : Specification of Equipment : 1, 275kl/Annual Fuel Oil Output, 8 hours operation per day, 300 work days per year
Initial Investment Cost in Equipment: NT\$20, 770, 000
Discount Time Limit: 10 years
Discount Rate: 12%
The oil price is different from the measured benchmark of general diesel
The feedstock of biodiesel is waste eating oil, the purchase price per kilogram is NT\$5

Case 2. The feedstock is waste eating oil, the purchase price per kilogram is NT\$5. The interrelationship between subsidy ratio of biodiesel system equipment, retrieval time limit, internal reward rate and oil purchase proces.

Oil purchase price NT\$ /Liter	Retrieval time limit (year)--Attached Figure 5				Internal Reward Rate (%) --Attached Figure 6			
	No Subsidy	30% Subsidy	40% Subsidy	50% Subsidy	No Subsidy	30% Subsidy	40% Subsidy	50% Subsidy
6	50.0	50.0	50.0	50.0	0.0%	0.0%	0.0%	0.0%
7	50.0	50.0	50.0	50.0	0.0%	0.0%	0.6%	2.5%
8	50.0	50.0	18.9	11.1	8.0%	11.9%	13.6%	16.0%
9	17.1	8.4	6.9	5.6	13.9%	17.7%	19.2%	20.9%
10	8.5	5.5	4.6	3.8	17.6%	21.0%	22.6%	24.5%
11	6.2	4.1	3.5	2.9	20.0%	23.7%	25.3%	27.4%
12	4.9	3.3	2.8	2.3	22.1%	25.9%	27.6%	29.7%
13	4.1	2.8	2.4	1.9	23.8%	27.8%	29.6%	31.8%
14	3.5	2.4	2.0	1.7	25.4%	29.5%	31.3%	33.6%
15	3.0	2.1	1.8	1.5	26.8%	31.0%	32.9%	35.2%
16	2.7	1.8	1.6	1.3	28.1%	32.3%	34.3%	36.6%
17	2.4	1.7	1.4	1.2	29.3%	33.6%	35.5%	37.9%
18	2.2	1.5	1.3	1.1	30.4%	34.7%	36.7%	39.1%
19	2.0	1.4	1.2	1.0	31.4%	35.8%	37.8%	40.2%
20	1.9	1.3	1.1	0.9	32.3%	36.8%	38.8%	41.3%



Fixed Conditions Specification of Equipment : 1.275kl/Annual Fuel Oil Output, 8 hours operation per day,
300 work days per year
Initial Investment Cost in Equipment: NT\$21, 120, 000
Discount Time Limit: 10 years
Discount Rate: 12%
The oil price is the same as the measured benchmark of general diesel
The feedstock of biodiesel is waste eating oil, the purchase price per ton is NT\$900

Case 3. The feedstock is cooking residue, the purchase price per kilogram is NT\$900. The interrelationship between subsidy ratio of biodiesel system equipment, retrieval time limit, internal reward rate and oil purchase proces.

Table 10. The Evaluation of 1275 k litre /year Biodiesel Model Factory Subsidy Benefit

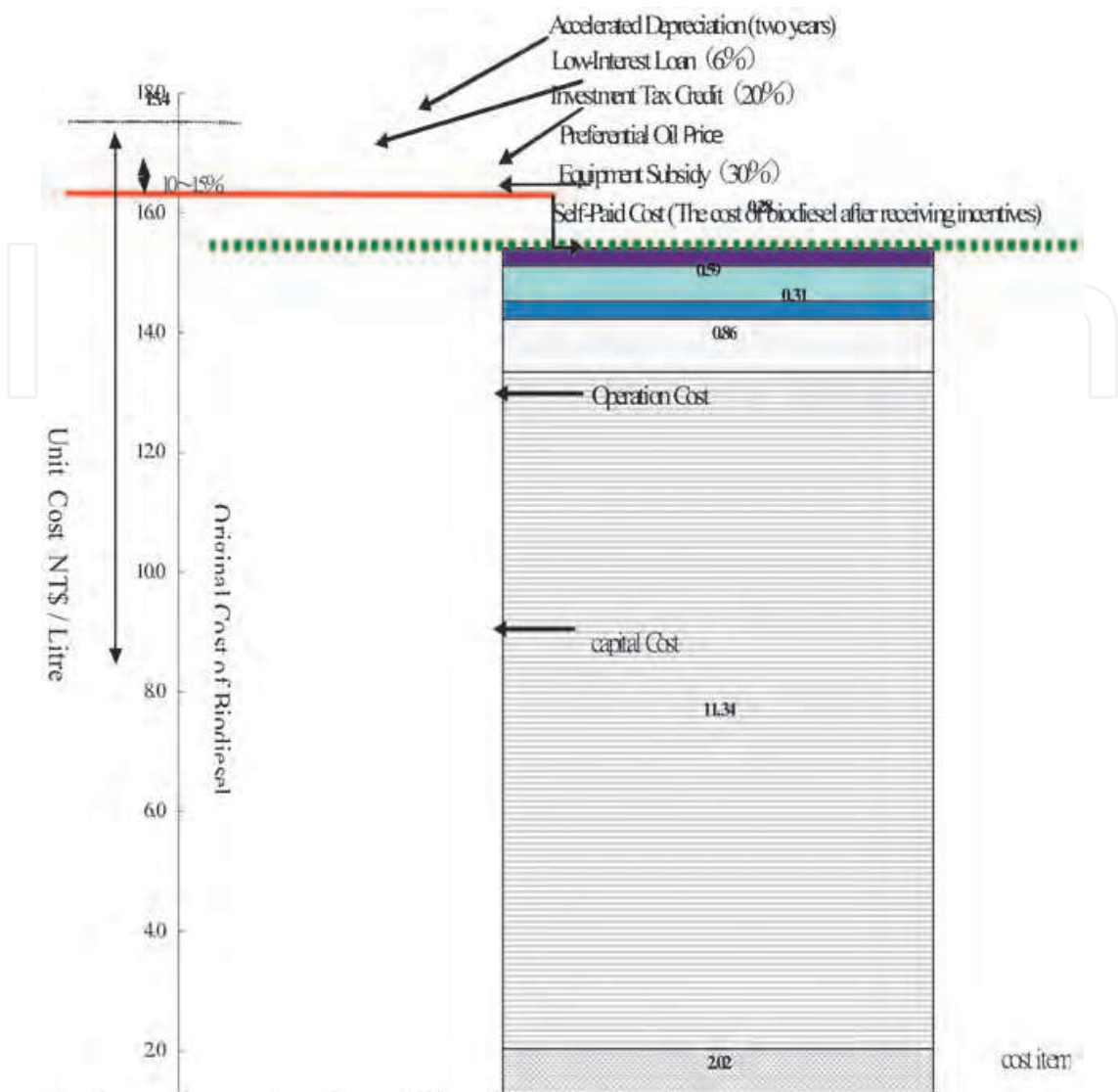


Fig. 7. Analyses of reward preferential benefit for biodiesel

From Fig. 7, we could learn that the unit production cost of biodiesel in Case 2 (purchase cost >0) is NT\$15.4/litre. Under no subsidy, equipment investment (expenditure) cost is NT\$2.88/litre, operation cost is NT\$12.52/litre; if we consider the equipment subsidy 30%, then equipment investment (expenditure) cost could reduce NT\$0.86/litre; if we consider financial subsidies, such as investment tax credit (20%), low-interest loan (6%) and speed up discount (two years), then the total financial subsidy could help to reduce the unit production cost by NT\$1.18/litre. Plus equipment subsidy, the total subsidies could reduce unit production cost by NT\$2.04/litre.

Comparing the model factory of output 1.275 kilolitres (Case 2) with the above-mentioned Irish model factory (uses 100% waste eating oil as feedstock) of output 3,000 tons (about 3,400 kilolitres), we obtain the unit production cost of biodiesel under current production conditions in Taiwan: NT\$15.4/litre, higher than the unit production cost of the factory in Ireland NT\$14.6/litre. The primary difference comes from the fact that in Taiwan, in addition to the cleansing and transportation cost, the cost of using waste eating oil has to include purchase price cost whereas in Ireland, they only include cleansing and

transportation cost. The other reason is unit equipment investment cost: NT\$2.88/litre in Taiwan is higher than the Irish NT\$2.31/litre. Through comparing unit production cost of model factories in two countries, we may estimate the unit production cost of biodiesel is between NT\$14-16/litre while unit equipment investment cost is between NT\$2.3-2.9/litre [10].

From promotion point of view, if the goal market is focused on the transportation utilization of the whole urban regions and public transport roads in Taiwan, the annual consumption quantity is 330 thousand KLOE of B20 bio-diesel; the annual market benefit is 4.3 billion NT dollars for the manufacture of bio-diesel, in addition, the annual CO₂ reduction quantity is about 880 thousand ton in Taiwan. Furthermore, the competition abilities were analyzed; the strategy trends were proposed, and, the policy issues were suggested from feedstock supply, manufacture & marketing sales point of views for the future bio-diesel application in Taiwan.

3. Conclusion

The production of the methyl linoleate was more over the one of the methyl pamitate during the processes for the manufacture of biodiesel from the waste cooking oil. The reaction balance can be achieved after 15 minute same as the feedstock soybean oil. The crude methyl ester volume was 528 ml, and the crude methyl ester yield was up to 97.77%. After distillation, the methyl ester volume was 512ml, and methyl ester volume yield was 94.81%. The loss caused by water washing reduced more, and low methyl ester volume was obtained.

The process of manufacturing biodiesel by waste cooking oil needs pre-processing to adjust. In the transesterification of fat, we have to strictly control the impurities, water and acid value in oil. The acid value of waste cooking oil must be modulated down to 0.26928(mg KOH/g) for the self-manufacture of the biodiesel to keep the normal processes of the transesterification reaction with alkali. And, the properties of the manufactured biodiesel meet the standard of the biodiesel almost.

Using bio-diesel to conduct engine test, the results showed that under the test of idle, when used petrochemical diesel, B20 and B100, the concentrations of carbon monoxide emitted by engine were almost the same. Under the test of full load, there was significant effect of reduction of pollution, particularly when use B100 to replace petrochemical diesel. But the reduction of brake horsepower of engines and the increase of oil-consumption signified that the effects are limited to the improvement of environment. Comparing petrochemical diesel, under the test of full load, when used B20 and B100, the concentration of carbon monoxide emitted by engine reduced 14% and 51% respectively and the concentration of sulphur dioxide reduced 68% and 73% respectively, the concentration of nitrogen oxide compound increased 1% and 13% respectively, the smoke reduced 8% and 69% respectively; brake horsepower reduced 8% and 10% respectively; oil-consumption increased 9.4% and 11.3% respectively.

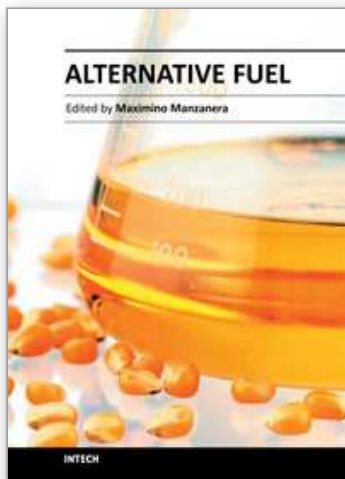
If we take current ordinary fossil diesel price NT\$13.3/litre as oil purchase price, then the subsidy demand of single price is NT\$1.3/litre; if not consider price subsidy, then the equipment subsidy ratio will be as high as 90% to make up difference with ordinary fossil diesel sales price. However, if we consider equipment subsidy ratio in couple with price subsidy (mixed subsidy), then we could reduce demand of price subsidy and equipment

subsidy ratio. For example, when IRR=12%, equipment subsidy 50%, demand of price subsidy is only NT\$0.5/litre, retrieval time limit could be reduced to around eight years.

If we want to encourage intention of investment and raise investment reward rate (IRR), for example 15~20%, then the demand of relative non-subsidy oil price will also be raised to NT\$16.9/kg, but the retrieval time limit will reduce to 6.4 years and the subsidy for the price difference will be increased to NT\$3.6/litre. If we only use equipment subsidy, it is impossible to make up the difference even if we use 100% subsidy. So we should have price subsidy in the same time to reach the goal of raising investment reward rate. For example, when IRR=20%, equipment subsidy 50%, then the price subsidy may only need NT\$2/litre and retrieval time limit could reduce to five years.

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Renewable energy sources such as biodiesel, bioethanol, biomethane, biomass from wastes or hydrogen are subject of great interest in the current energy scene. These fuels contribute to the reduction of prices and dependence on fossil fuels. In addition, energy sources such as these could partially replace the use of what is considered as the major factor responsible for global warming and the main source of local environmental pollution. For these reasons they are known as alternative fuels. There is an urgent need to find and optimise the use of alternative fuels to provide a net energy gain, to be economically competitive and to be producible in large quantities without compromising food resources.

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