ANALYSIS OF COCONUT OIL MIXED WITH KEROSENE AS A SUBSTITUTE FOR CONVENTIONAL DIESEL : A CASE STUDY IN THE SAENG ARUN AGRICULTURAL GROUP, THAP SAKAE, PRACHUAP KHIRIKHAN PROVINCE

POOMPOL PU-ON

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ABSTRACT

This thematic research studies the substitution of coconut oil mixed with kerosene for conventional diesel, focusing on factors which affect the substitution and air pollution reduction. The study site was the Saeng Arun agricultural community group, Thap Sakae district, Prachuap Khirikhan province. The data obtained included primary data from interviewing a number of users, and secondary data from involved organizations. These data were analyzed in terms of the factors influencing the development of this substitution and emissions.

The findings revealed that there were 2 major factors that affected the decisions to use the substitute fuel. These were the selling price difference between the substitute fuel and conventional diesel, and the quality of the substitute fuel. The selling price differences were 1-2 baht/ liter and 3-4 baht/ liter respectively depending on whether the consumers were agricultural diesel users or light-duty diesel users. However, the selling price difference did not affect the heavy-duty diesel users. Additionally, the quality of the substitute was found to cause a clot problem in fuel filters of farm diesel engines and light-duty diesel engines. For heavy-duty diesel engines, the substitute’s quality possibly led to the damage of diesel engines. Besides, some air emissions were found increased whereas some were decreased.

The findings of the research provide helpful information, covering the technical problem to diesel engines, led by the quality of alternative fuel, the potential of selling price difference between both fuels, including the impact on air pollution from diesel engine combustion, which was regarded as environmental concern. The results show more and more the importance of adopting a holistic viewpoint in handling problems involving the economy, society and environment in order for the researchers to wisely select appropriate ways to enhance the substitution of vegetable oil for feasible implementation.

KEY WORDS : ALTERNATIVE FUEL / FUEL SUBSTITUTION / COCONUT OIL / AIR POLLUTION

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การศึกษาการใช้น้ำมันมะพร้าวผสมน้ำมันก๊าดทดแทนน้ำมันดีเซล กรณีศึกษากลุ่มเกษตรกรทำสวนตำบลแสงอรุณ อำเภอทับสะแก จังหวัดประจวบคีรีขันธ์ (ANALYSIS OF COCONUT OIL MIXED WITH KEROSENE AS A SUBSTITUTE FOR CONVENTIONAL DIESEL: A CASE STUDY IN THE SAENG ARUN AGRICULTURAL GROUP, THAP SAKAE, PRACHUAP KHIRIKHAN PROVINCE)

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บทคัดย่อ

การศึกษาครั้งนี้เป็นการวิจัยเชิงสำรวจเพื่อศึกษาการใช้น้ำมันมะพร้าวผสมน้ำมันก๊าดทดแทนน้ำมันดีเซล โดยศึกษาถึงปัจจัยที่มีผลต่อการตัดสินใจใช้น้ำมันมะพร้าวผสมชนิดนี้ทดแทนน้ำมันดีเซล และผลกระทบด้านคุณภาพอากาศจากการเผาไหม้ของเครื่องยนต์ดีเซล พื้นที่ศึกษาคือ กลุ่มเกษตรกรทำสวนตำบลแสงอรุณ อำเภอทับสะแก จังหวัดประจวบคีรีขันธ์ ข้อมูลที่ใช้ศึกษาเป็นข้อมูลระดับปฐมภูมิและทุติยภูมิ ข้อมูลปฐมภูมิเป็นข้อมูลการสัมภาษณ์ผู้ที่ใช้น้ำมันมะพร้าวผสมชนิดนี้ ข้อมูลทุติยภูมิเป็นข้อมูลสถิติทั้งข้อมูลการทดสอบคุณภาพอากาศและข้อมูลปริมาณน้ำมันมะพร้าวผสมที่จำหน่ายได้ในปี พ.ศ. 2545 ที่ถูกเก็บบันทึกไว้ของหน่วยงานที่เกี่ยวข้อง

ผลการศึกษาปัจจัยที่มีผลต่อการตัดสินใจใช้น้ำมันมะพร้าวผสมชนิดนี้ทดแทนน้ำมันดีเซล มีสองปัจจัยสำคัญ ปัจจัยแรกคือ ราคาขายของน้ำมันมะพร้าวผสมที่จะต้องถูกกว่าราคาของน้ำมันดีเซลอย่างมีนัยสำคัญต่อกลุ่มของผู้บริโภค กล่าวคือ ราคาขายของน้ำมันมะพร้าวผสมทดแทนควรจะถูกกว่าอย่างน้อย1-2 บาทต่อลิตรสำหรับกลุ่มผู้ใช้เครื่องยนต์ดีเซลการเกษตร และถูกกว่าอย่างน้อย 3-4 บาทต่อลิตรสำหรับกลุ่มผู้ใช้รถยนต์ดีเซล แต่สำหรับผู้บริโภคในกลุ่มรถดีเซลบรรทุกปัจจัยด้านราคาไม่มีผลต่อการตัดสินใจ และปัจจัยที่สองคือคุณภาพของน้ำมันมะพร้าวผสมทดแทนน้ำมันดีเซลที่มีผลต่อเครื่องยนต์ โดยพบว่าน้ำมันมะพร้าวผสมทดแทนทำให้เกิดปัญหาหลักคือไส้กรองอุดตันในเครื่องยนต์ดีเซลการเกษตรและเครื่องยนต์รถยนต์ และทำให้เกิดความเสียหายต่อเครื่องยนต์โดยตรงในรถบรรทุก ส่วนผลการศึกษาผลกระทบด้านคุณภาพอากาศ พบว่ามลพิษที่สำคัญบางตัวมีปริมาณเพิ่มขึ้นและบางตัวมีปริมาณลดลง

การศึกษาครั้งนี้ให้ข้อมูลพื้นฐานการใช้น้ำมันมะพร้าวผสมน้ำมันก๊าดทดแทนน้ำมันดีเซลทั้งปัญหาด้านราคาขายของน้ำมันมะพร้าวผสมที่มีผลต่อการตัดสินใจทดลองใช้ของผู้บริโภค ปัญหาด้านเทคนิคที่เกิดขึ้นกับตัวเครื่องยนต์ดีเซลที่มีผลจากคุณภาพของน้ำมันมะพร้าวผสมชนิดนี้ และข้อมูลด้านสิ่งแวดล้อมเชิงผลกระทบด้านคุณภาพอากาศ ข้อมูลเหล่านี้เป็นข้อมูลเชิงบูรณาการที่มีความสำคัญในการใช้วิเคราะห์ปัญหาแบบองค์รวมมากขึ้น โดยเป็นข้อมูลที่เกี่ยวเนื่องทั้งในเชิงเศรษฐกิจ สังคม และสิ่งแวดล้อม ทั้งนี้เพื่อเป็นองค์ประกอบสำคัญที่ใช้ในการตัดสินใจเลือกแนวทางที่เหมาะสมในการทดลองวิจัยพัฒนาการใช้น้ำมันมะพร้าวผสมทดแทนน้ำมันดีเซลเพื่อนำไปสู่การใช้ทดแทนน้ำมันดีเซลได้จริงต่อไป

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CHAPTER 1
INTRODUCTION

1.1 Background Information

Over years petroleum crises, resulting mainly from continuously increasing prices and the uncertainties of petroleum depletion which is forecasted to be used up within the next 50 years (Machacon, et al., 2001) have been major concern for global energy use. Focusing on fossil diesel fuel, though diesel-powered vehicles play a vital part of transportation systems all over countries in the world, air exhaust emissions from those diesel engines would contribute to air pollution into the environment at the same time. The conventional diesel fuel containing large amounts of aromatics and sulphur leads to a great quantity of particulate matter (PM), unburned hydrocarbon (HC), oxides of nitrogen (NO_X), carbon dioxides (CO_2) and oxides of sulphur (SOx) when fueled in diesel engines. Moreover, NO_X as well as CO_2 are widely regarded as greenhouse gases, which eventually contribute to global warming.

As a consequence, these reasons encouraged scientists to find alternative fuels in order to cope with and solve such stressed problems. The concept of bio-fuel is one of key alternatives because bio-fuel is non-toxic, domestic, renewable and their physicochemical properties are comparable with diesel fuel (Asfar & Hamed, 1997). With such basic properties, bio-fuel has broadly been paid attention to for decades.

Especially, one source of alternative bio-fuel, which has widely been used in many countries to replace conventional diesel, is vegetable oils and their derivatives. However, as a matter of fact, the basic trouble of using vegetable oil as the substitute is its high viscosity property, compared with that of fossil diesel fuel. Hence, to solve the problem, these vegetable oils can be used to replace fossil diesel through 2 main means. Firstly, their properties such as viscosity, are modified through some chemical process called trans-esterification, in order to be suitably applied. Secondly, vegetable oils in ordinary form can also be mixed with only some additives such as kerosene, to reduce their viscosity.

In Thailand, the development of the studies on the substitution of vegetable oils for conventional diesel was not in a continuous progress due predominantly to the obstacle of various technical problems and economic feasibility, meaning that this substitute was more expensive than current diesel fuel at that moment. However, at any time there is an concurrent occurrence of a crisis of petroleum fuel availability causing a high growth of diesel price, as well as the decreasing price of agricultural crops resulting in economic problem to agricultural communities, the interest of local crop application through the substitution of vegetable oils for diesel is then recognized. This is because the substitution may not only partly cushion the agricultural crop industry’s dependence on the fluctuating demand in the market, but also significantly offers fuel security for the community and thus the country.

So, although almost all studies in Thailand have still not been reached a stage of commercialization as already in many other countries, there have been many studies on many agricultural crops such as palm and soy been as raw materials for the substitution of vegetable oils for conventional diesel since 1981.

Even surprisingly, during the period of 2001and early 2003 there was a true application of mixed coconut oil in some locally agricultural community in Thailand, eventually. The agricultural community in Thap Sakae district, Prachuap Khirikhan province named Saeng Arun agricultural community group attempted to apply the concept of substitution of their local crop product, coconuts. They used their community-based knowledge to produce fuel for diesel engines by mixing crude coconut oil from copra, dried coconut meat, with kerosene as a solvent additive in order to reduce oil’s viscosity, at a ratio of 20:1 by volume respectively. A while after use, it was found that there were both some advantages and drawbacks of this substitution.

For main disadvantage, the substitute caused technical problems to diesel engines, probably resulting from the suitability of such a oil mixture to the combustion of diesel engine. In contrast, advantages include revitalizing the rural economies, as well as environmental benefits, in particular.

1.2 Statement of the problem

Focusing on environmental benefits, many people believed by their own perceptions that this benefit would rise from healthier air quality of cleaner exhaust emissions due to the natural crop property of the substitute. Moreover, many of experienced users also seemed to support this air advantage as they perceived clearer smoke and weaker odor from diesel engine's exhausts, in comparison to those caused by conventional diesel (Supannee Autsawasirileous, 2544).

Though many people and experienced users seemed to believe that there would be some benefit of better air quality from the coconut oil substitution for diesel, in fact the substitution of mixed coconut oil would probably not lead to such an outcome because there were no real investigations on those air quality by any official authorities on actual site at that time to actually prove that better air quality. Only experienced consumer's perceptions might not be strong rationales enough to prove that the substitution really led to air exhaust emission reduction because those perceptions were actually not built by scientific measurements. In stead, they came from a moment emotion and were in fact involved in many factors such as educational background and experience in air pollution.

Therefore, this thematic paper will study the potential of the substitution of coconut oil mixed with kerosene for conventional diesel, sold by Saeng Arun agricultural group in 2002. The study will be focusing on the factors influencing the potential of this substitution. In addition, the study will also follow up the environmental benefit in term of air pollution reduction released by diesel engine combustion.

Figure 1.1 The map showing the area where there was once a true application of the substitution of coconut oil mixed with kerosene for diesel in 2002.

1.3 Objectives of the study

1. To study the potential factors for the substitution and how they influence the substitution of coconut oil mixed with kerosene for diesel.
2. To estimate air emission reduction, resulting from the substitution of coconut oil mixed with kerosene for diesel sold by Saeng Arun pumping station in 2002.

1.4 Scope of the study

This research studies the substitution of coconut oil mixed with kerosene for conventional diesel, only sold by Saeng Arun pumping station in Thap Sakae district, Prachuap Khirikhan province all along the year of 2002.

1.5 Expected Outcomes

1. To realize the potential of factors influencing the progress of the substitution in order to have the appropriate opportunities to encourage and develop its progress.

2. To gain the data information of the level of the air emission reduction, resulting from diesel engine combustion of the substitution of coconut oil mixed with kerosene for conventional diesel.

3. To receive some useful information whether it is worth supporting this sort of idea in substituting vegetable oils for diesel in Thailand and in what condition if so.

4. To foresee the inclination of appropriate and functional directions or applications to which this sort of alternative fuel should move forward in order to utilize its optimum advantages for our entire nation.

CHAPTER 2
LITERATURE REVIEWS

This section consists of useful information as basic knowledge, for assisting and amplifying the understanding in this research study. It covers several aspects as follow :

- 2.1 Alternative fuels.
- 2.2 Engines.
- 2.3 Diesel engine classifications.
- 2.4 Engine design and operating parameters.
  - 2.4.1 Engine power.
  - 2.4.2 Fuel consumption.
  - 2.4.3 Diesel engine exhaust emissions.
- 2.5 Diesel injection system.
- 2.6 Types of diesel combustion systems
  - 2.6.1 Direct-Injection systems (DI)
  - 2.6.2 Indirect-Injection systems (IDI)
- 2.7 Fuels.
  - 2.7.1 Diesel fuel specifications.
  - 2.7.2 Diesel fuel classifications and properties.
- 2.8 Coconuts and Coconut oils.
- 2.9 Relevant researches.

2.1 Alternative fuels

As a result of increasing concerns about fossil fuel reserves and disadvantages of using fossil fuel, alternative fuels initially gained attention in the 1970s as potential substitutes for petroleum-based fuels. A number of greatest interest of the alternative fuels are compressed natural gas, alcohols and biodiesel (Challen & Baranescu, 1999).

2.1.1 Compressed natural gas (CNG)

Even though CNG is already used in heavy-duty, spark-ignited engines, its high octane number renders it unsuitable for direct use in compression-ignition engines.

2.1.2 Alcohols

Either methanol or ethanol alcohol fuel can be used as alternative diesel fuel. It can also be used directly in diesel engines with big amounts of cetane-enhancing additives. This approach can vastly reduce NO_X and particulate emissions, but the additives greatly raise the fuel cost and the effect of the fuel on engine durability is still questionable.

2.1.3 Biodiesel

Biodiesel is actually an alkyl monoesters from fatty acids in the oil, produced by chemically reacting an animal fat or vegetable oil with an excess of alcohol known as transesterification, mostly methanol, in the a presence of a catalyst. Biodiesel may be used as neat or blends with conventional diesel fuel. It is nontoxic and biodegradable, and tends to reduce soot, carbon monoxide, unburned hydrocarbons emissions but NO_X and the soluble portion of the particulate is likely to increase.

Biodiesel has obtained increasing attention during the last several years as it is perceived to be an environmentally friendly fuel. In the United States, it is mainly derived from soybean oil while it is principally produced from rapeseed oil in Europe. Additionally, biodiesel can be used in existing diesel engines with a minimum of changes. However, biodiesel cost fluctuates with the commodity price of the oilseed stock, expressing the primary production expense.

2.2 Engines

Engine is a device that produce mechanical power from the chemical energy contained in the fuel. It can principally divided into 2 major groups namely internal and external combustion engine.

2.2.1 Internal combustion engines

The purpose of internal combustion engines is the production of mechanical power from the chemical energy contained in the fuel. The energy is discharged by burning or oxidizing the fuel inside engine cylinder. The mixture of fuel-air ahead of combustion, along with the burned products after combustion are the actual working fluids. The work transfers that afford the desired power yield arise directly between these working fluids and the mechanical components of the engine. These conventional engine types are gasoline or petrol engines (spark-ignition, SI) and diesel engines (compression-ignition, CI). In SI engines, the air and fuel are usually mixed up together properly by an equipment called carburetor, in the intake system prior to entry to the engine cylinder while air alone, in CI engines, is conducted into the cylinder and compressed with high pressure till high enough temperature occurs; then the fuel in injected directly in the cylinder just before the combustion process in required to begin (Heywood, J. 1988). These 2 types of engines have commonly been found in a wide range of application in transportation, including power generation.

2.2.2 External combustion engines

In principle, the main difference from internal combustion engines is that the fuel is burnt outside the engine cylinder in external combustion engines such as steam turbine and closed cycle gas turbine. Nonetheless, diesel engine as internal combustion one is emphasized on, according to the study.

2.3 Diesel Engine Classifications

Diesel engines can normally be categorized by :

- **Application** such as automobile, truck, locomotive, marine and power generation.
- **Basic engine design** such as reciprocating engines and rotary engines.
- **Working cycle** namely four-stroke cycle : naturally aspirated, supercharged and turbo-charged, two-stroke cycle : crankcase scavenged, supercharged and turbocharged.
- **Fuel** such as gasoline (or petrol), diesel fuel, natural gas and liquid petroleum gas.
- **Combustion chamber design**.
- **Method of cooling** such as water cooled, air cooled and uncooled.

2.4 Engine Design and Operating Parameters

The significant parameters regularly used to characterize engine operation are :

1. Engine's performance over its operating range.
2. Engine's fuel consumption within this operating range and the cost of required fuel.
3. The engine's noise and air pollutant emissions within this operating range.
4. The initial cost of the engine and its installation.
5. The reliability and durability of the engine, its maintenance requirements, and how these affect engine availability and operating costs.

Commonly, these aspects determine total engine operating costs; usually the principal consideration of the user, including whether the engine in operation can satisfy environmental regulations (Heywood, 1988). According to Pramote Onprapai (2542) engine performance can be described by the inter-relation among key factors, which are engine power, torque, fuel consumption and engine speed, as usually displayed by performance curve from diesel vehicle makers. For engine speed, it is estimated by average speed of engine cylinder, which is about 300 m/ min., 600 m/ min. and 900 m/ min. for low, medium and high engine speed respectively (Pramote Onprapai, 2542).

However, this study is concerned primarily with the **power**, **fuel consumption** and **emission** characteristics of engines in order to correspond to the secondary data received; the oversight of the other factors listed above does not lessen their importance.

2.4.1 Engine power

Engine power generally measured in a unit of horse power (hp) is defined as the quantity of energy or work, which is able to carry or move a 4,500 kg object for 1 meter long or high in a minute (Pramote Onprapai, 2542).

To measure engine power, it includes the following factors ;

1. Indicated horse power (IHP) , described as power generated at the first place in engine cylinder, which converts heat energy to mechanical power.
2. Friction horse power (FHP), described as the total lost power in the engine.
3. Brake horse power (BHP), described as the value of engine power or the usable power delivered by the engine to the load. This kind of engine power is the key as it is the practical engine power to be used to do work. The **chassis dynamometer** is used to measuring equipment in this study. This brake horse power has a unit of kilo-watt.

Thereby, BHP (kW) = IHP-FHP

2.4.2 Fuel consumption

In engine measurements, the fuel consumption is assessed as a flow rate-mass flow per unit time. A more helpful parameter is the **specific fuel consumption** (SFC), the fuel flow rate per unit power output, measuring how effectively an engine is using the fuel supplied to generate work. Significantly, it is more useful when comparing specific fuel consumption with brake horse power called brake specific fuel consumption (BSFC). It can be computed as (Utsa Jirakorn and Cheua Chukum, 2539).

$$BSFC = \rho V / (BHP) t$$

where BSFC = Brake specific fuel consumption (kg/ kW h)

ρ = Fuel density (g/ cm^3)

V = Fuel volume (cm^3)

t = Measure time (sec)

BHP = Brake horse power (kW)

2.4.3 Diesel engine exhaust emissions.

Diesel engine emission are released largely from motor vehicles; other sources are stationary, railway locomotive and ship diesel engines. The exhausts from diesel motor vehicles have been well described, but the individual results are frequently not comparable due to differences in parameters such as engine type, driving cycle and fuel composition.

According to different types of diesel engines, though heavy-duty vehicles release larger relative amounts of particulates, there is principally no difference between the quality and quantity of exhaust emissions from light- and heavy-duty engines. Emissions rely on driving cycle (transient or steady state), engine conditions (injection and aspiration methods, maintenance, total mileage), and fuel composition (sulfur content, aromaticity, volatility); alteration of the engine plays a major role.

In combustion, if the diesel fuel or any hydrocarbon fuel, were to completely combust in the engine, then just carbon dioxide (CO_2) and water (H_2O) would be structured in the exhaust. Nonetheless, combustion is in reality always imperfect. Therefore, diesel engine emissions commonly contain hundreds of chemical compounds, which are emitted partly in the gaseous phase and partly in the particle phase of the exhaust. The main gaseous products of combustion are carbon dioxide, oxygen, nitrogen and water vapor; carbon monoxide, sulfur dioxide, nitrogen oxides, and hydrocarbons and their derivatives are also present. Toluene and benzene exist in the lower range (percentage by weight) in the gaseous part of the hydrocarbon fraction. Other gaseous exhaust components are low-relative-molecular-mass polycyclic aromatic hydrocarbons (PAHs) (WHO, 1996).

Presently, oxides of nitrogen (NO_X), carbon monoxide (CO), total hydrocarbons (HC), particulates and visible smoke are the regulated exhausts, controlled by law in a number of countries (Challen & Baranescu, 1999).

Some pollutant emissions such as carbon monoxide, organic compounds, and particulates, the formation and destruction reactions are intimately coupled with the primary fuel combustion process; hence, an understanding of the formation of these pollutants need knowledge of the combustion chemistry while some other pollutant emissions namely nitrogen oxides and sulfur oxides, the formation and destruction processes are not part of the fuel combustion process. Anyhow, the reactions which produce these emissions occur in an atmosphere created by the combustion reaction, so the two processes are still intimately linked (Heywood, 1988). Important exhaust emissions are as follows :

2.4.3.1 Carbon dioxide (CO_2)

Carbon dioxide (CO_2) occurs naturally in the atmosphere and is a normal product of combustion. Ideally, combustion of a hydrocarbon fuel should produce only carbon dioxide and water (H_2O). The relative proportion of these two depends on the carbon-to-hydrogen ratio in the fuel, around 1 : 1.75 for ordinary diesel fuel.

The emission of CO_2 from the combustion of fossil fuels has recently attracted considerable attention as atmospheric levels of CO_2 have been raising up as a result of the widespread and ongoing growing combustion of fossil fuels for power, encouraging global temperature increase, known as global warming. However, as an unavoidable end-point of combustion, CO_2 cannot practically be decreased by after-treatment (such as by catalytic converters). Actually, the catalytic oxidation of CO and HCs will increase CO_2 emissions very slightly.

2.4.3.2 Unburned hydrocarbon (HC)

Unburned hydrocarbon (HC) are composed of fuel, which is incompletely burned or only partially burned. The term HCs means organic compounds in the gaseous state as well as solid hydrocarbons are part of the particulate matter. In diesel engine, HC emissions are caused by difficulty of fuel and air mixing, and are mainly unaffected by the overall air-fuel ratio. There are two principal mechanisms by which fuel escapes the main combustion in a diesel; over-mixed, over-lean regions formed before ignition, and under-mixed fuel injected at low velocity near the end of combustion (Challen & Baranescu, 1999). The hydrocarbons in the exhaust may also condense to form white smoke during engine starting and warm-up.

While total hydrocarbon emission is a useful measure of combustion inefficiency, it is unnecessarily a key index of pollutant emissions. Even so, sources of HCs are wall quench and misfire (no combustion) (Heywood, 1988).

2.4.3.3 Carbon monoxide (CO)

It is an intermediate product in the combustion of a hydrocarbon fuel, then its emission is led by incomplete combustion and is toxic. Emissions of CO are thereby greatly dependent on the air-fuel ratio relative to the stoichiometric proportions. Fuel-rich combustion invariably generates CO, and exhausts increase nearly linearly with the deviation from stoichiometric. Any CO from a diesel engine is due to incomplete mixing : combustion taking place in locally rich conditions. As diesel engines operate with an overall lean limits and not of much concern.

2.4.3.4 Oxides of nitrogen (NO_X)

Nitrogen oxides (NO_X) consist of nitric oxide (NO) and nitrogen dioxide (NO_2). In diesel engines, the majority of proportion of the total NO_X are composed of 70-90% of NO. Dissimilar to other exhaust emissions, NO_X is a side-effect of combustion, not an incomplete step in it. The formation of NO depends on plentiful oxygen and high temperatures and NO_2 forms from NO; quenching by excess air in the cylinder can freeze NO_2 levels at well above equilibrium concentrations.

The early part of combustion is crucial for NO_X, almost all NO_X is formed in the first 20^o of crank angle after the combustion starts. Therefore, this stage of combustion is focused on in order to control NO_X. Besides, the local air-fuel ration is a principal factor in NO_X production. Interestingly, indirect injection (IDI) diesel engines produce low NO_X emissions not only as a result of their higher heat losses to the swirl chamber walls and throat, but because their pre-mixed burning occurs under locally rich (oxygen deficient) conditions also.

According to the method to control the amount of NO_X, most of the techniques diminish the combustion temperatures, and so extract penalties in hydrocarbon emissions, particulate emissions, and fuel consumption. It is common to refer to the 'trade-offs' between NO_X emissions and particulates and fuel consumption for diesel engines.

2.4.3.5 Particulate matters (PM)

Most particulate matters rise from incomplete combustion of fuel hydrocarbon and others are from the lubricating oil. The constituents of the particulate matters depend upon the conditions in the engine exhaust and particulate collection system. Diesel particulates are composed mainly of soot (carbonaceous solid matter similar to carbon black). Soot is formed in the engine cylinder, from heavy hydrocarbons in the gas phase, which condense and combine in the oxygen deficient regions in the rich core of the fuel sprays. However, the evidence shows soot formation can be adjusted by changes in engine design and operating parameters. The particle size distribution can vary with engine speed, load, and perhaps with engine and fuel type as well.

To human health, particulate matters cause concern about the health risk, harming human health and the natural environment. In particular, an attention has recently focused on the PM_{10} component of particulates, particles with an aerodynamic diameter of less than 10 μm. These are a significant health concern as their small size allows them to penetrate further into the human lung and it may remain there to do physiological damage. The effects of engine design and operation on the formation of such particles have been known very little. Furthermore, the methodology for sampling and measuring exhaust particulate size is not well-defined. Thus, it is likely that this kind of particles will be a special concern to the automotive industry and will be the focus of future research (Challen & Baranescu, 1999).

2.4.3.6 Smoke

Smoke may be defined as particles, either liquid (aerosols) or solid, suspended in the exhaust gases, blocking, reflecting or refracting light (Challen & Baranescu, 1999). Diesel engine smoke can be classified by 2 main sorts :

1. **Blue/ white** in appearance under direct illumination, and composed of a blend of fuel and lubricating oil particles in an unburnt, partly burnt.
2. **Grey/ black** in appearance, and consisting of solid particles of carbon from otherwise complete combustion of fuel.

The blue composition results primary from an excess of lubricating oil in the combustion chamber while the white component is mainly a result of too low a temperature in the combustion chamber during the fuel injection period. For grey/ black smoke is generated near or at full load if fuel in excess of the maximum designed value is injected, or if the air intake is restricted. The main reason of excessive black smoke are either incorrect setting of the fuel injection pump, or poor maintenance of air filters and/ or fuel injectors.

Smoke emissions consist significantly of carbon particles of a variety of sizes, ranging from 0.02 μm upwards to over 0.12 μm mean diameter. The size distribution relies at some extent on the sort of combustion system. Then, generally open chamber systems (direct injection) show a rather gradual increase while swirl chamber systems (indirect injection) tend to have very rapid increase in exhaust visibility when increasing fuelling. To be remembered, however, there are some carbon particles exist in the diesel emissions under any operating conditions, and so zero smoke exhausts is not possible. By the way, visible smoke fro heavy-duty diesels at high load is regulated (Heywood, 1988).

2.5 Diesel Injection System

Fuel injection system for the cylinder at the appropriate time in the cycle is a necessary part for operation of diesel engine as it is called on to start and to control the combustion process. To accomplish these goals, a number of function items are needed:

2.5.1 Low pressure pump. It is needed to lift fuel from a tank.

2.5.2 Fuel filter. As the main flow of fuel passes directly, the fuel filter should be made quit dense to remove particles of dirt less than 1 μ in size from the fuel stream. The filter cartridge is made of either cotton, paper, synthetic fibers or cellulose to absorb the contaminants in the fuel.

2.5.3 Injection pump. It should distribute equally the metered fuel among the cylinder, metering the quantity of fuel required by the speed of, and the load on, the engine, inject the fuel at the accurate rate and right time in the cycle.

2.5.4 Spray nozzle. The main purpose of this part is to deliver the fuel into the combustion chamber in a finely atomized. Spray nozzle should inject the fuel in a pattern and atomization demanded by the design of the combustion chamber. Also, it should begin and end the injection sharply without leaking or after-injections.

2.6 Types of Diesel Combustion Systems

The number of different combustion chamber types offered and tried since the creation of diesel engine development is substantial. Nonetheless, over decades through the evolution and increased understanding of the physical and chemical processes related, only a few designs rooted in a sound principle have survived.

Thus far, diesel engines can be divided into 2 fundamental categories in accordance with their combustion chamber design, which are direct-injection engines (DI) and indirect-injection engines (IDI). In each type there are several different chamber geometry, air-flow, and fuel-injection arrangements.

2.6.1 Direct-Injection systems

These types of engines have a single open combustion chamber into which fuel is injected directly. They are normally used in large, medium and small sizes of engines such as automobiles because the momentum and energy of the injected fuel jets are adequate to attain ample fuel distribution and rates of mixing with the air. When engine size is reduced, rising amounts of air swirl will be used to achieve faster fuel-air mixing rates. This air swirl results from suitable design of the inlet port.

2.6.2 Indirect-Injection systems

The important point is that when inlet generated air swirl has not offered adequately high fuel-air mixing rates for small high-speed diesels; thus, indirect-injection systems will be used instead as it is where the dynamic motion required during fuel injection is generated during the compression stroke. Therefore, the chamber of these engine systems is divided into 2 parts and the fuel is injected into the "pre chamber", connected to the main chamber via a nozzle or orifices. Generally, IDI engine designs are only applied in the smallest engine sizes.

2.7 Fuels

Almost all of the fuel for the combustion engine is derived from petroleum, which is a complex mixture of hydrocarbon compounds. Hydrocarbons are molecules that contain only hydrogen and carbon. The simplest hydrocarbon molecule, methane, is formed when four hydrogen atoms attach to a carbon.

Diesel fuel is the product of crude petroleum by refining process, which in Thailand has 2 grades, namely automotive diesel fuel and industrial diesel fuel.

2.7.1 Diesel fuel specification

There have been many standard specifications for diesel fuels; however, in the United States, the most common specifications used are established by ASTM Standard D975. This standard covers three grades of diesel fuel, varying in accordance with their service applications.

Grade No.1-D

This light distillate fuel requires a higher volatility fuel for rapidly fluctuating loads and speeds, as in light trucks and buses. One main use for No.1-D fuel is to blend with No.2-D during winter to provide developed cold flow properties.

Grade No.2-D

A middle distillate fuel does not require a high volatility fuel. Common applications are high-speed engines that operate for sustained periods at high load.

Grade No.4-D

This heavy distillate fuel is viscous and may be needed fuel heating for proper atomization of the fuel. This is primarily used in low- and medium- speed engines.

2.7.2 Diesel fuel classifications and properties.

This kind of fuel is characterized by a number of properties that provide the basis for fuel specification. The important properties are as the following;

2.7.2.1 Density

Diesel's density is one of indicators for its distillation range. Generally, heavier fuels have higher boiling points. The energy contents of hydrocarbon fuels are very similar on a weight basis that higher-density fuels have more energy per unit volume.

2.7.2.2 Ignition indices

This property is one of the most important properties, expressing diesel fuel's readiness to auto-ignite at the temperatures and pressure present in the cylinder when the fuel is injected. Even though criticized in recent years for not accurately reflecting the auto-ignition conditions in modern turbocharged engines, **the** cetane number is still the standard measure of this property. Also, cetane index is a calculated quantity, which is intended to approximate the cetane number.

2.7.2.3 Cold flow properties

One of important problems for diesel fuel is to get crystallized or gelled. Some indicators to determine are the following :

Cloud point

It is the temperature at which a cloud of wax crystals first appears in a fuel sample that is cooled under controlled conditions. The cloud point is determined by visually inspecting a normally clear fuel for a haze.

Pour point

It is the lowest temperature at which movement of the fuel sample can be determined when the sample container is leant.

Low-temperature flow test

The low-temperature flow test (LTFT) is designed to evaluate whether a fuel can be expected to pass through an engine fuel filtration system.

The cloud point is the highest temperature used for characterizing cold flow and the pour point is the lowest. The LTFT is somewhere between the cloud and pour point.

2.7.2.4 Flash point

It is the lowest temperature at which a combustible mixture can be formed above the liquid fuel. It is important for fire safety considerations and depends on both the lean flammability limit of the fuel as well as the vapor pressure of the fuel constituents. The flash point is determined by heating a sample of the fuel in a stirred container and passing a flame over the surface of the liquid. If the temperature is at or above the flash point, the vapor will ignite and an easily detectable flash can be observed.

2.7.2.5 Viscosity

Viscosity is a measurement of fluid resistance to flow. The larger the viscosity, the less readily the liquid flows. Normally, the viscosity decreases as the temperature increases. The viscosity of the fuel exerts a strong influence on the shape of the fuel spray. The effect of viscosity may be critical; therefore, maximum and minimum values also would be specified.

2.7.2.6 Miscellaneous properties

Carbon residue

After fuels are burnt with a limited amount of oxygen, a residual is usually obtained, known as carbon residue. This symbolizes the heavier ends of the liquid fuel, which most probably will escape complete combustion and therefore yield carbon in the engine.

Sulfur content

Petroleum includes a large number of sulfur-containing compounds. Sulfur can contribute to higher engine wear, can poison catalysts and produce sulfates, forming part of the exhaust particulate matter.

Ash

The residue is an ash that usually originates fro soluble metallic compounds or contaminants such as dirt and rust.

2.8 Coconuts and Coconut oil

2.8.1 The introduction to Coconuts and Coconut oil (Persley, 1992)

Coconut is an integral part of the functioning of local communities, often called the 'tree of life', as almost every corner is used to make some item of value to the village communities. The essence of coconut is then closely associated with its suitability in supplying food, drink and shelter at the village level, as well as copra, coconut oil and other products for local cash sale and export earnings. Also, coconuts are a major providers to human nutrition, contributing a source of energy and vitamins.

Coconut has two naturally occurring types, the tall and the dwarf. In addition, coconut hybrids, mainly led by tall and dwarf crosses, have been bred in many countries. Coconut grows in various range of environments. However, yield is affected by climatic factors, especially temperature and rainfall. For optimum production, it requires an average temperature of 29^{o}C, with a diurnal fluctuation not exceeding 7^{o}C, and an annual rainfall of at least 1800 mm, evenly allocated all over the year. It is the best possible choice of a plant to prevent degradation of the costal areas and enhance the flexibility of these sensitive environments. It can tolerate a larger degree of soil salinity than many other plants.

The tree is vastly prolific, and a figure of 60 nuts per tree, per year, is easily accomplished with no effort beyond gathering nuts. The mature nuts have a hard shell, which can be made into brilliant charcoal, surrounded by a thick, tough, fibrous husk used as insulation and packing material under the name of “coir”, which can also be utilized as fuel and kindling. Inside the shell is the coconut water that is remarkably nutritious and an efficient vermifuge, and the white “meat” from which coconut “milk” is expressed.

The most significant products in world trade are copra, coconut oil, copra meal, desiccated coconut, coir fiber, shell charcoal and an increasing amount of coconut milk. The coco-chemicals, which are developing into more and more important and valuable are mythylesters, fatty alcohols, and glycerine.

The production of copra is the main industrial use of coconut. To make copra, mature nuts are initially harvested, dehusked and split into halves and dried, which can be done by the process either of kiln or sun-drying so as necessarily to lessen the moisture content of the meat from around 50% to 5%, to have weight reduced, prevent microbiological deterioration, and allow concentration of the oil.

To further step, those copra is made to generate coconut oil and copra meal in the proportion of around 63% of coconut oil and the rest percentage of meal, moisture and waste. Coconut oil consists of approximately 48% lauric acid, with the balance being chiefly myristic, caprylic and palmitic acids. The chemical composition of coconut oil makes it different from other vegetable oils as a result of the high percentage of lauric acid, and other shorter chain fatty acids, allowing it to be used for a variety of edible and non-edible purposes.

The timber can be used for load-bearing structures in buildings and for the manufacture of furniture, while the leaves are plaited for roofing material. The husk is used to make fibers for ropes and matting. The shell is heated to make charcoal as a local fuel source. A variety of artifacts are produced by the leaf and the shell.

While coconut meal (the residue left after the oil is removed from the copra) is used for animal feed, coconut oil is typically used for cooking, lighting and lubrication, and for the manufacture of margarine, fats, soaps and detergents. Noticeably, instead of continuing production of highly refined, edible oil whose market value is steadily eroded by palm oils, such oil could be processed to non-traditional products like biodiesel and their glycerin derivatives, which is relatively considered as new market value products being able to offer a lot of profitability.

In aspect of economy, compared to Indonesia and the Philippines, Thailand is a small coconut maker, which harvest mainly in southern Thailand, producing adequate to meet its own needs for coconut commodities, but rarely exports them. Nonetheless, this crop has to face with the problem of price fluctuations. Actually, vegetable oil prices are among the most volatile of all basic commodities. Copra and coconut oil prices prove to be the least stable of all the commodities, affecting considerable price risks for both producers and consumers, compared to other crop oils.

Regularly, coconut oil can be graded by its quality and application into 2 main types, which are :

1.**Crude oil**. It is composed of characteristics of color, smell, taste and contaminants. This crude oil is not edible and will easily become fatty when low temperature.

2. **Purified oil**. When crude oil has been purified through some process with no chemicals mixed up, the result is called purified oil. This oil has no smell, color and precipitations (Nantana Yakum, 2528).

2.8.2 The process of vegetable oil production

Vegetable oils are normally derived from crops whose oil composition is available. The process of vegetable oil production depends on the types and the oil availability of individual raw vegetable products. In an overview, there are 2 main methods in process of vegetable oil production.

The first is the process called Pressing. This method is usually used for such a crop, which is composed of the minimum of 25% oil in its composition such as oil palm, copra in coconut nuts. An oil is pressed by expeller. The second is the process known as Solvent Extraction. This mean is typically used for crops, which consist of the maximum of 25% oil in their compositions such as soybean. Such crops is extracted for oils by some sorts of solvent such as Hexane.

However, the oil that has been derived is still in the form of raw oil, which has a component of free-fatty acid, smell, color and some contaminations and then is not edible yet. Subsequently, it may be needed to be purified before next application.

2.8.3 The production process of crude coconut oil mixed with kerosene as the substitution by Saeng Arun agricultural community in Thap Sakae. (by interview)

In general, coconut meat is scraped out of the shell, then sun-dried exposed so-called Copra. Such copra is cut into pieces and extracted for oil by expeller. The resulting coconut oil, which usually has a contamination of residue of coconut pieces, will be filtered to become pure crude coconut oil.

Afterwards, the fuel petrol station owner will mix up such pure crude coconut oil with kerosene in the ratio of 20:1 (crude coconut oil: kerosene) by volume in a tank, which will be stirred by agitators for a short period of time because they are easily blended each other. Some fuel petrol station owners might add some heat energy while stirring. Finally, this mixture of crude coconut oil and kerosene is ready for put on the market.

Figure 2.1 The picture showing coconut meats being scraped out of the shell and sun-dried, and thus a copra

2.8.4 The substitution of vegetable oil for conventional diesel fuel

Currently, there are 2 major process of applying the substitution of vegetable oil for diesel. Firstly, it is to modify vegetable oils for properly using in diesel engine. Secondly, it is to modify diesel engine to appropriately suit for vegetable oil use as fuel. **However, in this study, the way of substituting vegetable oil for diesel will follow the first process concept** (Pissamai Janewanichpunjakul, 2544).

To modify vegetable oil for suitably use as a substitute for diesel engine, a major factor to be concerned is about **a viscosity property of vegetable oil** since normal viscosity of vegetable oil is relatively quite higher than those of fossil diesel. It is a strong difficulty for the step of fuel injection into diesel engine combustion process.

Thus, this problematic property of vegetable oil is needed to be improved till reach the similar level of diesel's viscosity property. According to Pissamai Jenwanichpanjakul (2544), 2 ways are proposed.

The first way is **to proceed vegetable oil through the chemical process so-called transesterification,** with the addition of methanol or ethanol and NaOH or KOH as catalyst. This process will generate methyl ester or ethyl ester, internationally well-known as biodiesel. This biodiesel actually provides overall properties as close as conventional diesel does. Globally, this type of alternative fuel is well-known and widely used in many countries, including the US and Germany. However, this biodisel product is not yet broadly adopted in Thailand due mainly to the initial cost of production.

The second way is **the addition of some solvent such as diesel itself and kerosene, in order to reduce vegetable oil's viscosity.** It is noted that the additional solvent should be mixed up at some proper ratio of the blend in regard of many concerns such as the effect to diesel engine in the long run and the weather's temperature and the economical reason as well.

2.9 Relevant researches

Kalam and et al. evaluated the exhaust emissions and combustion of coconut oil-powered indirect injection diesel engine. They used ordinary Malaysian coconut oil (COCO) blended with conventional diesel. The results showed the addition of 30% COCO with diesel generated higher brake power and net heat release rate with a decrease in emissions such as HC, NO_x, CO, smoke and polycyclic aromatic hydrocarbon (PAH). Above that ratio of the mixture such as 40% and 50% blends led to lower brake power and less heat release rate but a reduction of emissions still.

Machacon and et al. studied the effect of a coconut oil as diesel fuel alternatives or as direct fuel blends in a single-cylinder, direct-injection diesel engine. Important results showed that the viscosity of coconut oil was the main adjustment in value of diesel spray. Though no engine modification, the operation of test engines through a variety of the ratio of fuel blends and different operating conditions showed normal running operations. Furthermore, neat coconut oil gave lower smoke and less NO_x emissions, compared to mixed fuel blends.

Almeida conducted the performance of a diesel generator fuelled by palm oil by testing a naturally aspirated MWM 299 direct injection four-stroke 70 kW diesel-generator fuel with 100% palm oil, which was heated up to 100 ^oC. The results demonstrated that high viscosity of palm oil resulted in poor atomization, carbon deposits, clogging of fuel lines and starting difficulties in low temperatures. Anyhow, when heated up to 100 ^oC, palm oil presented lower viscosity, better combustion, less deposits, increasing amount of CO and HC exhaust emissions.

Asfar and et al. studied the combustion of various kerosene-diesel and alcohol-diesel fuel blends to investigate the effect of fuel blends on the combustion process and pollutants in the exhausts. The results explained that mixing vegetable oil with light oil such as diesel, kerosene and alcohol improved the combustion process and thermal efficiency and reduced pollutants and smoke concentration in exhaust emissions. However, a slight increase in NO_x was unavoidable.

Pissamai and et al. reported in using peanut oil as fuel in common diesel engine named YANMA for short-term test. The result showed that diesel engine was unsmooth running at low speed and presented incomplete combustion whereas at high speed peanut oil fuel generated the similar power output from engine to those led by diesel fuel. The use of pure peanut oil in diesel engine caused some problems due mainly to its high viscosity. Mixing pure peanut oil with some fuels namely diesel at ratio of diesel : pure peanut oil, and kerosene : pure peanut oil about 60 : 40 and 50 : 50 showed better combustion result and engine ran more smoothly.

Jaruwat and et al. investigated the use of coconut oil-kerosene fuel blends in diesel engine. Kerosene : coconut oil at ration of 20 : 1 offered the best performance in aspect of engine power output; however, coconut oil tended to get gelled when temperature below 25 ^{o}C. So, heat exchangers used to heat the fuel blends before inlet into injection pump were installed.

CHAPTER 3
METHODOLOGY

The thematic paper on the substitution of coconut oil mixed with kerosene for conventional diesel, focuses mainly on 2 main points, which are

1. The air pollution reduction, released from the diesel engine exhausts between fueled by the mixed coconut oil and fueled by conventional diesel fuel.
2. The potential factors, influencing this substitution.

Therefore, the methodology of this study in order to achieve those goals is composed heavily of data collection and general analysis.

3.1 Data collection

Data to be analyzed in this study were composed of both primary and secondary data.

3.1.1 Primary data

This research study received this data from interviewing the experienced users on actual site, Thap Sakae area, Prachuap Khirikhan. Thus, it was divided to interview 2 main groups of consumers :

A. Pumping station owners i.e. Thap Sakae and Saeng Arun agricultural group.

B. Fuel consumers, which were divided into 3 main types;

Ones, using heavy-duty diesel vehicles such as 10 wheel trucks.

Ones, using light-duty diesel vehicles namely 4 wheel vehicles.

Ones, using agricultural diesel engines or farming engines.

This interview was to obtain useful information of individual consumer's perceptions on the substitution of coconut oil mixed with kerosene for conventional diesel, relating to their general ideas to volume of fuel consumption, types of diesel engines they used fuel consumption and their own reasons for trying the substitute. Further, their perceptions were involved in diesel engine power output, its price competitiveness, rate of fuel consumed and the advantages and disadvantages of this substitution.

Lastly, the interview concerned the consumer's final decision on the substitution in term of encouragement or discouragement and/ or with some conditions, including some recommendations.

Figure 3.1 The map showing the area where Saeng Arun agricultural group was located in.

3.1.2 Secondary data

This type of data consisted of :

3.1.2.1 Air pollution results and other results of diesel engine performances of light-duty diesel vehicle, measured by Pollution Control Department (PCD).

3.1.2.2 The monthly sale volume and selling price of coconut oil mixed with kerosene, kindly given by Saeng Arun agricultural group. They could provide us those data in the year of 2002 only.

3.1.2.3 The monthly selling price of conventional diesel was given by provincial commercial department of Prachuap Khirikhan province, used in order to compare with those of the substitute.

3.2 Analysis

This research attempts to analyze 2 focal aspects ;

3.2.1 Air pollution reduction, emitted from the exhaust of diesel vehicles. This item is evaluated corresponding to secondary data, received from PCD.

3.2.2 The potential factors, influencing the progress of the substitution. This item is assessed by using data result to make comparing tables and graphs of sale volume of the substitute and both fuel's selling price each month all over the year of 2002. This is to evidently observe the potential factors to the substitution.

Figure 3.2 The sign expressing the place of Saeng Arun pumping station, selling the coconut oil mixed with kerosene as the substitute for diesel in 2002.

CHAPTER 4
RESULTS AND DISCUSSIONS

There are a range of benefits, resulting from the substitution of mixed coconut oil for diesel such as a reduction of diesel import and encouraging national energy security as well as some environmental benefits. A large number of consumers and other involved stakeholders considered the advantage of air pollution reduction as by-product benefit. However, in a holistic viewpoint, air pollution reduction should no longer be realized as little important. Rather, it should also be included as first level of concern, especially within areas, where there are a large number of diesel-powered vehicles, causing serious air pollution such as cities and downtown areas.

In the study, this focuses on the factors that influence this substitution expansion in order to encourage the potential of air pollution reduction from the substitution of coconut oil mixed with kerosene for diesel. Furthermore, the study will evaluate environmental benefits, in term of air pollution reduction from emission exhausts released by diesel vehicles, which normally occurs from combustion process.

As a matter of fact, the potential of resulting benefits certainly depends in large part on the consumption volume of the mixed coconut oil. The more consumption of the substitute, the less diesel amount consumed, and thus, the more benefits from using less conventional diesel. This fuel consumption is generally influenced by 2 major factors, which are the selling price and the quality of the mixed coconut oil itself, compared to those of diesel. Thereby, in this section the issues presenting are

4.1 Total amount of mixed coconut oilsold by Saeng Arun pumping station in 2002.
4.2 The effect of the substitute’s selling price on its sale consumption.
4.3 The effect of the substitute’s quality on its sale consumption.
4.4 Air pollution reduction from the substitution of mixed coconut oil.
4.5 Assumption for the potential of selling price factor of the substitute these days.

4.1 The total amount of coconut oil mixed with kerosene, sold by Saeng Arun pumping station in 2002.

As the well-known situation of the substitution of mixed coconut oil for diesel fuel in Thap Sakae district, Prachuap Khirikhan province in 2002, there were indeed 3 recognized crude coconut oil pumping stations, which belonged to each agricultural group namely Thap Sakae agricultural community, Saeng Arun agricultural community and Angthong agricultural community. Thap Sakae agricultural group possessed the biggest share of the total sale volume of mixed coconut oil (Supannee Aussawasirileous, 2544).

However, as for this study, only Saeng Arun agricultural group as a pumping station was kindly willing to provide the data of sale volume of mixed coconut oil, sold in 2002. Primary was received by interviewing and secondary data was the recorded raw data, given by authorized representative. Secondary data was composed of sale volume of the coconut fuel sold each month in 2002 as well as their selling price in corresponding months. To simply illustrate their trend throughout the year of 2002, these data are shown in the following table and plotted as graph in figure 4.1.

Table 4.1 The sale volume and monthly corresponding selling price of mixed coconut oil , sold by Saeng Arun pumping station in the year of 2002.

Months	Coconut oil mixed with kerosene	
	Sale Volume (liters)	**Selling price(baht/ liter)**
January	16,432.5	11.00
February	14,030.7	11.00
March	13,828.4	11.00
April	15,376.3	11.00
May	17,682.3	11.00
June	13,937.5	11.00
July	13,247.6	11.00
August	13,943.3	11.00
September	9,896.5	11.00
October	9,980	11.00
November	8,864.7	11.00
December	6,347	11.00
Average	12,797.23	11.00
Total	153,566.80	11.00

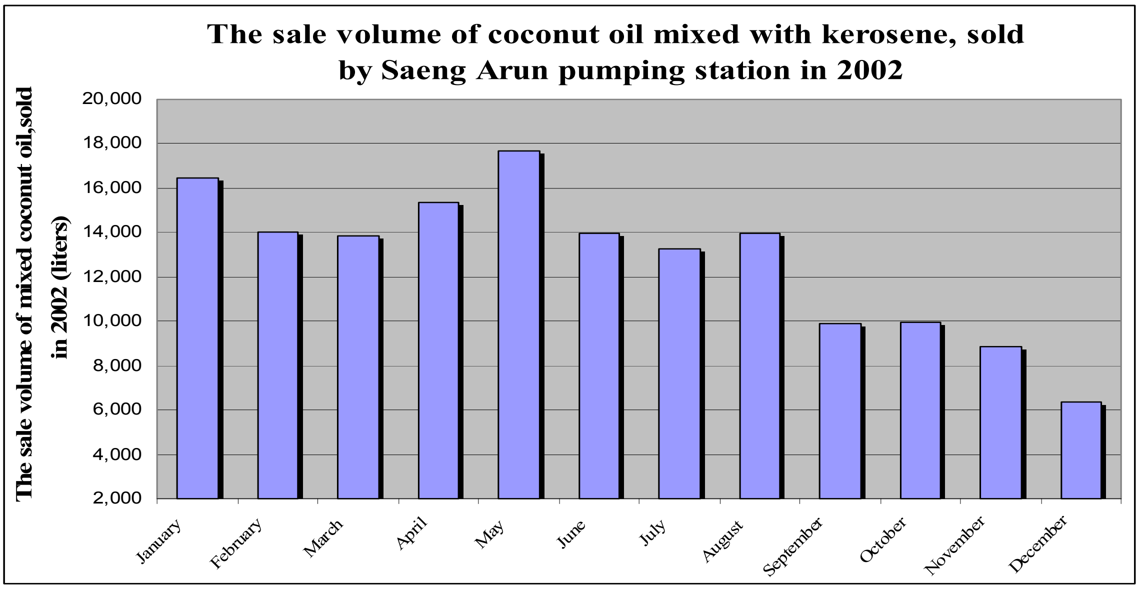

Figure4.1 The sale volume of mixed coconut oil fuel by Saeng Arun pumping station in 2002 each month.

According to the graph above, the sale volume of mixed coconut oil, from January to August, was fluctuated around 15,000 liters/ month in average with the highest peak of the sale amount almost around 18,000 liters in May. On the contrary, in the last 4 months this sale quantity showed a decreasing trend until December, which was apparently lower than those in the first 8 months.

Regarding this movement all over the year of 2002, it may be estimated that there would be 2 main factors, influencing such sale amount of mixed coconut oil. The first was the price difference between conventional diesel and the new substitute, considered as economic aspect, and the second factor was the quality of mixed coconut oil to diesel engines, compared with those of conventional diesel fuel, considered as technical or engineering aspect.

4.2 The effect of selling price factor of mixed coconut oil on its sale consumption, sold in 2002 (Economic Aspect).

As for the fuel selling price (baht/ liter), the group of raw data of monthly selling price of diesel was recorded by several owners of local petrol stations such as PTT, SHELL and ESSO while those selling price data of mixed coconut oil was recorded by itself Saeng Arun agricultural pumping station officers. Later, the researcher evaluated those rough data so as to have the representative value of such selling prices in each month by making an average.

Very generally, the selling price of product is absolutely one of potential factors for attracting consumers. Basically, consumers tend to buy goods, which is cheaper in case of the quality of the products are relatively the same. Unlike, according to mixed coconut oil, only its cheaper selling price of mixed coconut oil would not play a key role to have an enough potential to catch the attention of consumers due to the uncertainty of the quality of mixed coconut oil to each consumer's perception as a new product in the market, compared with those of existing diesel.

However, in this case these consumers would probably be pay more attention to the gap of price difference between both fuels if it is clearly obvious. In other words, consumers would emphasize on how much the selling price of mixed coconut oil is cheaper than that of diesel. As a result, such gap would be able to compensate the uncertainty of new product's quality. Hence, in this case the gap of price difference between both fuels would be an right representative factor for consumers to decide whether or not it is worth trying new substitute in fuelling their diesel vehicles, instead of fossil diesel fuel.

What is more, over the period of time in 2002 the raw data of selling price of both fuels in unit of baht per liter were fluctuated, and so it would be better to view their selling price difference gap in a comparable base unit by converting such differences from baht per liter to the difference in unit of percentage.

By this, this research assumes the selling price of diesel as the reference base and then calculate for the percentage of selling price change of mixed coconut oil, which was cheaper. The simple formulation for computing this percentage of cheaper selling price of mixed coconut oil, compared to selling price of conventional diesel, was in **Appendix A**.

In the table below, the actual selling price data and the data of the percentage of price difference, derived from a calculation between both types of fuels are shown in the table 4.2 and figure 4.2 as follow, for further development.

Table 4.2 Data showing selling price between mixed coconut oil and diesel fuel, and the percentage of cheaper price difference of mixed coconut oil, compared to those of diesel in 2002.

Month	Selling price of fuels on average (baht/ liter)		Cheaper price difference of mixed coconut oil, compared to diesel's	
	Diesel	Mixed coconut oil	In baht/ liter	In percentage (%)
January	11.86	11.00	0.86	7.3
February	11.96	11.00	0.96	8.0
March	12.56	11.00	1.56	12.4
April	14.76	11.00	3.76	25.5
May	13.75	11.00	2.75	20.0
June	13.06	11.00	2.06	15.8
July	13.05	11.00	2.05	15.7
August	13.05	11.00	2.05	15.7
September	13.75	11.00	2.75	20.0
October	14.85	11.00	3.85	26.0
November	14.15	11.00	3.15	22.3
December	13.95	11.00	2.95	21.1
Average	13.40	11.00	2.4	17.5

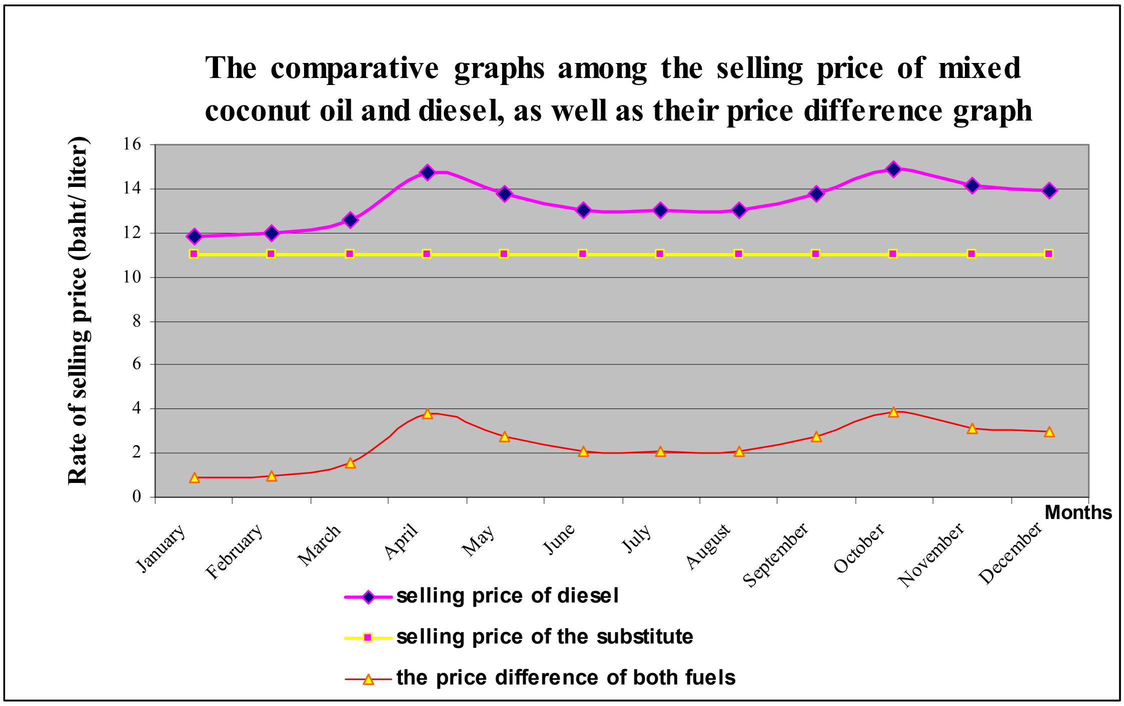

Figure 4.2 The comparative graphs showing the selling price between mixed coconut oil, sold in 2002 and diesel, as well as their selling price differences in unit of baht/ liter each month.

As mentioned earlier the interesting point of this section would be concerning the gap of price difference between both types of fuels, expressing the potential of price factor of the new substitute fuel in attracting customer's attention in order to be able to gain an opportunity of replacing fossil diesel fuel eventually.

Specially, as the potential of such price difference impact directly to diesel vehicle fuel consumption; hence, to clearly consider that potential, such a gap of price difference would be analyzed all along with the consumption of substitute, sold by Saeng Arun each month over the year of 2002 concurrently. Then, these data will be put together into the table and compared again in graph pattern on the same comparative scale. The table of such data and their comparative graph are shown as below.

Table 4.3 The data of the percentage of cheaper price difference of mixed coconut oil, compared to diesel's selling price, and the sale volume of mixed coconut oil in 2002.

Months	The percentage of cheaper price- difference of mixed coconut oil (%)	The sale volume of mixed coconut oil sold in 2002 (liters)
January	7.3	16,432.5
February	8.0	14,030.7
March	12.4	13,828.4
April	25.5	15,376.3
May	20.0	17,682.3
June	15.8	13,937.5
July	15.7	13,247.6
August	15.7	13,943.3
September	20.0	9,896.5
October	26.0	9,980
November	22.3	8,864.7
December	21.1	6,347

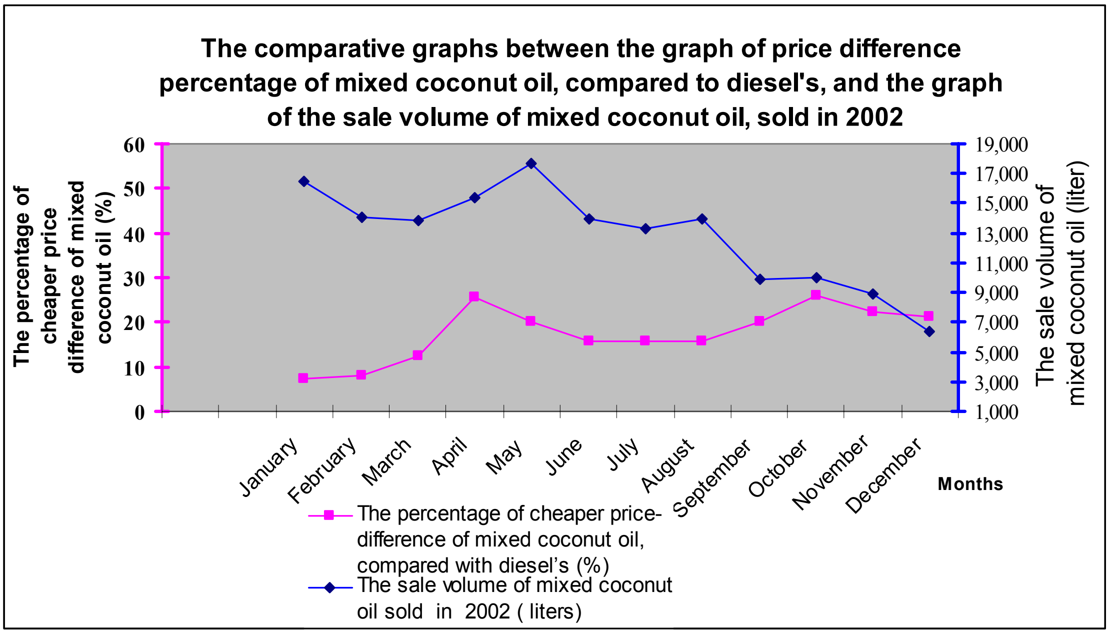

Figure 4.3 The comparative graphs between the percentage graph of cheaper price difference and the sale amount graph of mixed coconut oil, sold in 2002.

To illustrate the figure 4.3, there are 2 graphs, which firstly are the pink graph line presenting the percentage (%) of cheaper selling price of mixed coconut oil, compared with diesel 's (on the vertical axis on the left hand side, varied from 0% to 60%) and secondly the dark blue graph line presenting the sale amount of mixed coconut oil (on the vertical axis on the right hand side, varied from 6,000 liter to 20,000 liter of substitute's consumption). Both graphs were pointed on the same comparative scale at the same period of time in 2002 (on the horizontal axis) because it would relatively provide some correlations of the potential of such a percentage of price difference on the sale amount of mixed coconut oil all along specific period of time.

In general, these 2 graphs show the similar inclination over the period of first 8 month in 2002 but the different trend during the remaining months in 2002.

Actually in the first 8 months, the correspondence of these 2 graphs began with the graph of the percentage of cheaper selling price of substitute fuel around 7% in January and then gradually increased until March about 12% and progressively reached the peak in April around 25% and then dropped until August around 16%, with some plateau since June around 16%. Likewise, the inclination of the sale volume graph followed this trend by presenting about 16,500 liters in January and then decreasing a bit before reaching the peak nearly about 18,000 liters in May and decreasing until 14,000 liters in August afterwards. Interestingly, even if the peak of sale volume of mixed coconut oil was occurred a month later after the peak of the percentage in April due probably to the dissimilarity in dates of recording data of both responsible authorities, the relation of the 2 graphs still showed their similar trends.

Noticeable point was that at the different rate of cheaper price difference could draw different amount of attentions to consumers.

As shown in figure 4.3, when the gap of such a percentage kept some stability more or less 10% from January to March, presenting only a little cheaper selling price of substitute fuel about 1 baht per liter, a small number of consumers decided to try the substitute whereas some unknown consumers did not try yet due to their own reasons.

So, not surprisingly, the graph of sale volume of mixed coconut oil during this period still presented the stability of its sale volume due probably to trying the substitute of such a number of consumers only. Anyway, when there was even larger gap of the percentage occurred around 26% in April, representing nearly around 4 baht per liter cheaper for using mixed coconut oil, a huge sale volume of the substitute, reaching around 18,000 liters was then found in later time, May (Figure 4.2).

In short, the similar correspondence of 2 graph lines should represent that the gap of price difference between both 2 types of fuels would possibly be the potential factor, influencing the consumer's decisions in trying to substitute mixed coconut oil for typical diesel and subsequently encouraging its sale volume, especially when that different price gap is obviously larger, leading to a large sale amount of the substitute around April and May. If really so, this would mean that the gap of even cheaper selling price of new substitute may raise up itself importance until it was capable enough to grab the attention of new groups of users owing to effectively offering the big amount of money to be saved, which was potentially dissolving the point of consumer's uncertainty on the quality of mixed coconut oil at the same time.

On the other hand, during the last 4 months in 2002, such a gap of cheaper price difference seemed to be unable to maintain that significant level any longer to those groups of consumers in using the mixed coconut oil, according to the different trend of graph correlation between 2 lines during this period. As can be seen in the figure 4.2, the noticeable point started occurring since September when the inclination of correlation of both lines moved opposite ways. The graph of the price different percentage increased whereas the graph of mixed coconut oil's consumption decreased, meaning even cheaper the substitute, less amount of the substitute fuel consumed during this moment.

Moreover, apart from the viewpoint to the different correlation of both graph's inclination, if looking directly into the graph of sale volume of mixed coconut oil itself only, it was very interesting that there was a huge decrease of the fuel consumption on average between the first 8 months and the rest period in 2002, despite a larger percentage of cheaper price difference.

To make it clearer, the data of both graphs in table 4.3 are divided into 2 sections between from January to August and from September to December and then calculated on average afterwards. Such comparing data is summarized in the table below.

Table 4.4 The comparing data on average between the sale volume and the percentage of cheaper price difference of mixed coconut oil during January to August and September to December.

Items	**Data on average during 2 separate period of time in 2002**	
	From January to August	**From September to December**
Sale volume of mixed coconut oil (liters)	15,000	9,000
The percentage of cheaper selling price of mixed coconut oil (%)	15 %	22%

In regard to the table above, it represents the gap of cheaper price difference of mixed coconut oil, compared to those of diesel. Although around 15 % of the gap during January to August could be the factor, encouraging about 15,000 liters of mixed coconut oil consumption/ month, the increased gap up to 22% during September to December could lead only to 9,000 liters of that/ month, in contrast.

In other words, even if the gap of cheaper selling price of mixed coconut oil in the second period in 2002 expressed some rise of the percentage of cheaper price (from 15% to 22%), meaning that more money to be saved or more economical for consumers, and then the substitute should have been sold much more than 15,000 liters then. In fact, however, its sale volume in the last 4 months was sold much less amount (only 9,000 liters/ month), than it had been sold in the first 8 months.

The question should consider why such both graph lines from September to December could not maintain the corresponding trend as in first 8 months but demonstrated an apparent opposite inclination of graph movement instead.

This obviously showed that the factor of cheaper price difference of mixed coconut oil was no longer be only main reason influencing the decision-making of various types of consumers after a while of substituting diesel fuel. There must be some other factors, which had strong potential, affecting the sale volume of mixed coconut oil too.

Normally, when consumers have substituted the mixed coconut oil for diesel for long enough, they would experience more and more in an appropriateness of the qualtity of mixed coconut oil to their diesel engines, compared to existing diesel fuel's. Thereby, this should possibly be another reason, involving the consumer's final decision-making in selecting types of fuels.

4.3 The effect of the quality of mixed coconut oil on its fuel consumption, sold in 2002 (Technical Aspect).

With regard to the substitution of mixed coconut oil for diesel in Thap Sakae, Prachuap Khirikhan province more or less 2 years ago, the quality of mixed coconut oil is exactly also a main concern, creating an different level of uncertainty to different types of consumers, especially when those people did still not have strong confidence for trying new alternative fuel. Even more, there were no official and scientific tests of the quality of the substitute to diesel engines, compared with those of diesel on site at that moment. Only some resulting parameters tested in lab-scale level by Pollution Control Department (PCD) were found. For these reasons, this uncertainty to the new substitute's quality would definitely impact eventually the consumption of the substitute.

In this section, the data of quality of the substitute fuel were derived from 2 sources. Firstly, it was given by an interview from direct experienced local consumers. Secondly, it was from the test results of rate of fuel consumption and engine power, measured by PCD.

Nevertheless, unluckily there were weak points on the interview data due to a small number of interviewees. This was because during a time of surveying on site, this substitution activity in Thap Sakae and Saeng Arun area had already stopped proceeding the substitution around 6 months earlier. So, a large number of potential consumers as main targets were scattered and then it was not easy to have them interviewed. Moreover, there were also personal constraints on the study during collecting data such as a capacity of manpower per interviewees, budget and the difficulty of transportation on site. Even the previous research, studied by Supannee Aussawasirileous (2544), although they had a number of man power, vehicles for transportation, budget and doing the research during the active period of this substitution, they could have around 30 interviewees only.

In this thematic paper, nonetheless, those 12 persons interviewed on actual site were fairly varied and covered types of real consumers. The interview results to represent the general idea of those consumers to this substitution are shown below.

The result of the quality of mixed coconut oil from an interview on site.

All persons, who were interviewed, could be classified into 2 major groups :

1. The mixed coconut oil pumping station owners
    1.1 Thap Sakae agricultural group.
    1.2 Saeng Arun agricultural group.
2. The common consumers used the mixed coconut oil. This type of interviewees can also be divided into 3 main groups, according to their duty applications be :
    2.1 Consumers, using heavy-duty diesel vehicles such as 10 wheel trucks.
    2.2 Consumers, using light-duty diesel vehicles such as 4 wheel cars.
    2.3 Consumers, using agricultural diesel engines or farming engines.

Table 4.5 The interview result by local agricultural groups, who experienced substituting mixed coconut oil for diesel

Issues	**Types of Interviewees**			
	Pumping station owners	Heavy – duty diesel users	Light – duty diesel users	Farming diesel users
Interviewees (persons)	2	3	4	3
Used fuel volume (liter/ vehicle/ month)	3,000~5,000	1,000-3,000	300-500	2-100
Reasons in substituting mixed coconut oil for diesel	Falling price of typical coconut oil	Much cheaper selling price	Cheaper selling price	Helping a local coconut oil business
	Apply coconut oil for other uses	N/A	Try	Cheaper selling price
	To lower diesel import	N/A	N/A	N/A
RESULTS				
Engine power by perception	Nearly same	Nearly same/ a bit lower	Nearly same	Nearly same
Rate of fuel consumption by perception	Nearly same	Nearly same	Nearly same	Nearly same
Advantages	Helping local planters	Cost saving	Cost saving	Helping planters
	Clearer smoke	N/A	Clearer smoke	Clearer smoke
	To lower diesel import	N/A	Weaker smell	Weaker smell
Cost saving on average (baht/ vehicle/ month)	7,000-30,000	2,000-3,000	600-1,300	40-200

Table 4.5 The interview result by local agricultural groups, who experienced substituting mixed coconut oil for diesel (**continued**)

Disadvantages	Clotted gel appearance in filter	Clotted gel appearance in filter	Clotted gel appearance in filter	Clotted gel appearance in filter
	Harm engine	Harm engine within first 3-4 months	Trouble in engine in 6~8 months	N/A
Problem-solving	Change filter	Change filter	Change filter	Change filter
	Change engine	Change engine	N/A	N/A
	Stop using	Stop using	N/A	N/A
Opinions for the substitution of mixed coconut oil for diesel ,with conditions	**Encourage** with : 1.No filter block trouble 2. Minimum of cheaper selling price ~ 2-3 baht/ liter.	Discourage with no concern of selling price difference	**Encourage** with : 1. No filter block 2.Minimum of cheaper selling price ~ 3-4 baht / liter.	**Encourage** with : 1.No filter block trouble 2.Minimum of cheaper selling price ~ 1 baht / liter.
Recommendations	R&D of technical problems	N/A	N/A	N/A
	Needs for governmental support	N/A	N/A	N/A
	Needs for the official pilot study	N/A	N/A	N/A

Note : N/A = not available

Regarding the table above, briefly, the issues presented in the table were selected corresponding to experience of consumer's general concerns for the substitution of mixed coconut oil for conventional diesel. Descriptive involving those data are expressed below.

For the mixed coconut oil consumption, pumping station owners and heavy-duty diesel users such as 10, 18 wheel truck drivers, tended to be the potential users due to a vast amount of fuel consumption (~ 3,000 liter/ vehicle/ month); and so they actually had the strong potential, affecting the sale volume of mixed coconut oil either increase or decrease, whereas light-duty diesel drivers and farming engine users possessed respectively less potential (~ 500 and ~ 100 liter/ vehicle/ month in that order). For the issue of reasons of using the substitute, cheaper selling price was the main reason for most consumers. Also, the group of consumers, generally using agricultural and farming diesel engines added the reason of social benefits by supporting their local product's applications.

To be noted that the result of both diesel engine power and rate of fuel consumption, the reasons given were commonly judged by their individual's perceptions. Accordingly, such 2 results expressed the similar level of those results, in comparison between fuelling diesel engines by the substitute and that by diesel. Nevertheless, these 2 issued were scientifically measured by Pollution Control Department (PCD) as well. PCD found that in order to compare the same engine performance of fuelling engine by both types of fuels, mixed coconut oil possessed the higher rate of fuel consumption, compared to that of diesel (13.47% higher). Furthermore, diesel engine fueled by the substitute showed less power output(13.54% less), compared to that fueled by diesel. In other words, it found that, using the mixed coconut oil as the substitute fuel instead of conventional diesel in diesel engines caused a bit less of engine performance, according to PCD.

At this point, it may conclude that it should be aware of using only individual's perceptions as main tools to summarize any incidence because it may possibly make some mistake of any determinations, leading to incorrect understanding and wrong knowledge in matters.

Besides, almost all consumers gave cost saving as primary reasons for the advantage of this substitution (economic aspect), and then clearer smoke and weaker smell (air quality benefits) subsequently. The meaning of cost saving also shows that consumers, who used heavy, light and agricultural diesel engines could get earning of money to be saved about a few tens of thousand, few thousands and a few hundred baht per vehicle per month respectively. Interesting point of this issue from actual interview was that the heavy-diesel users were totally concerned only with the cost saving since they used a huge consumption of fuel, meaning a lot of money they could save (a few tens of thousand baht saved per car per month). In this case, if it was not economically worth applying the substitute, they would not substitute the mixed coconut oil for diesel.

However, all consumers experienced the main difficulty in technical problem to their engines but at different level of damage. They largely found that the substitute easily became clotted-gel and then blocked a fuel filter. This leads to the engine problem when running. To solve these technical problem, light-duty diesel and agricultural diesel engines were needed to only change fuel filter while heavy-duty diesel users was needed to change fuel filter within somewhat short period of time and, even worse, this problem finally hurt directly the engines. Some claimed that they had to buy new diesel engines within 3-4 months after first trial of the mixed coconut oil. Thus, this type of users had better stopped substituting the mixed coconut oil for diesel later, finally.

This would mean that after substituting for a while, heavy-duty diesel users were mostly concerned with the quality of mixed coconut oil. As this type of customers consumed a vast amount of mixed coconut oil, when they stopped using, this affected extremely the sale volume of the mixed coconut oil that was sole in 2002 unavoidably.

Unlike, the other 2 types of diesel vehicle users still needed to weight the potential between quality and cost saving factors before final decision whether or not substitution.

As for opinions with some conditions for this substitution, only heavy-diesel consumers expressed a discouragement of mixed coconut oil idea to replace conventional diesel with a decision of no more concerns of cheaper price difference of mixed coconut oil after first try for a while. This should ensure the strong severity of the quality of the mixed coconut oil to heavy-duty diesel engines.

On the contrary, the remaining types of consumers stated some opinions of support, with some conditions such as technical improvement as well as the minimum of cheaper selling price. That they still partly supported might be due to 2 main reasons, which were the less severity of damage to their diesel engines (do not directly harm engines) and concerns of other several advantages more than money saving only.

For recommendation, only pumping station owners could give apparent answers. They do need the sincerity from the government in supporting the development of the substitution of mixed coconut oil for conventional diesel in term of knowledge-based support of technical improvement and some funding or incentive. Also, they made a claim of official pilot study.

To talk about the effect of the quality of mixed coconut oil on its sale volume over the year of 2002. The figure 4.3 is brought once again to discuss, showing the trend of sale volume and the percentage of cheaper price difference of the mixed coconut oil, compared to diesel's.

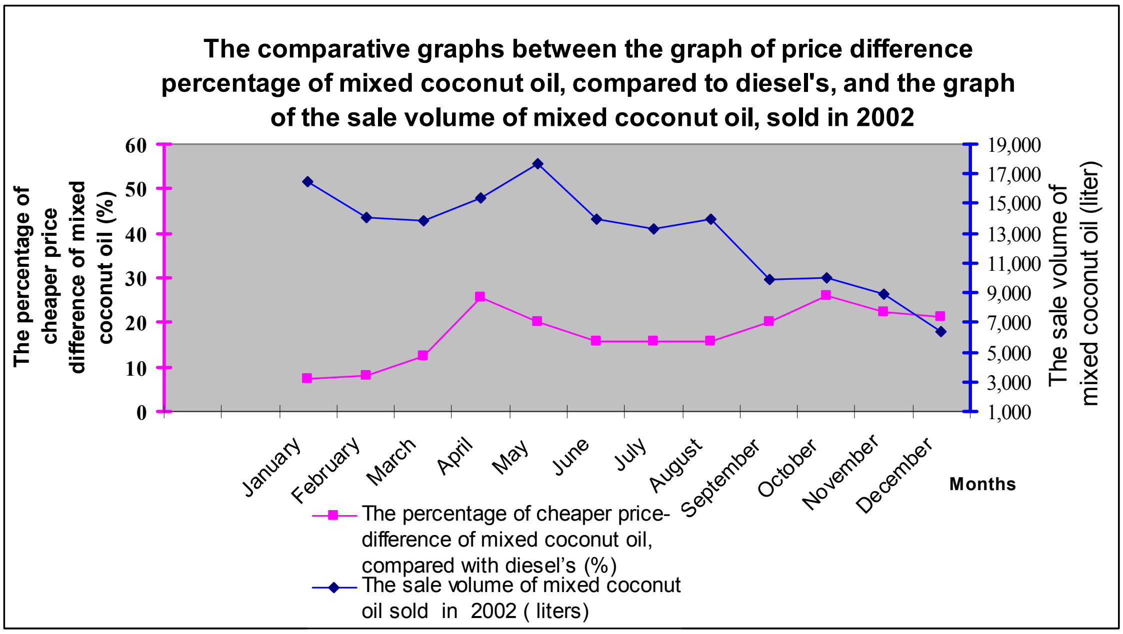

Figure 4.4 The graph same as the figure 4.3, showing circled in different parts of interesting points of the substitute's sale volume, sold by Saeng Arun agricultural group in 2002.

For the first 8 months the cheaper price difference of the mixed coconut oil seemed to possess strong potential to the sale volume of the substitute. However, from September to December, the graph of sale amount went down continually despite the increase of price gap, and so the quality of the mixed coconut oil would seem to be another key factor, playing a key role to impact the sale volume.

To support this assumption, those secondary data from both an interview and official evidence, tested by Pollution Control Department (PCD) are raised up. For engine power and rate of fuel consumption, even though the result of these 2 issues showed less performance of using the mixed coconut oil as fuel instead of diesel, those less performance might not be so important that it could powerfully impact the sale volume of the mixed coconut oil. Additionally, at that moment all types of consumers interviewed perceived nearly the same results of fuelling diesel engine between diesel and the substitute, and thus they should see no sign of impact on their substitution.

They would make no negative response, resulting from these 2 issues to their final decision-making on the substitution.

Rather, it would really be the trouble of technical diesel engine problems from the quality of mixed coconut oil to consumer's diesel engines.

As the correlation of both graph lines in figure 4.4 during the first 8 months, main potential consumers in encouraging that level of sale consumption of the mixed coconut oil could be heavy-duty and light-duty diesel users due to their large fuel consumptions, back up by the interview data in table 4.5. In particular, when the sale volume graph reached the peak in May, this incidence may be supported by more fuel volume consumed by existing interested consumers, probably including new users among them because of the potential of a lot of cheaper price difference. In particular, heavy-duty diesel users might most likely to be a key factor for this big increase of the sale volume of the mixed coconut oil because they were concerned only with a lot of money to be saved, according to the interview. Thus, when there was a massive difference of cheaper price, they may possibly try the new substitute, replacing conventional one, leaving the concerning point of product quality behind for a while.

Till the sale volume graph line drop rapidly in September in spite of the increase of the rate of cheaper price difference. So, there should be the question of why that sale volume of the mixed coconut oil in this month jumped down amazingly despite of the increase of the rate of cheaper price difference of the substitute.

With the limit of data classification of the mixed coconut oil consumption on each type of users, it is really hard to ensure the true reasons, influencing such direction of sale volume graph line. However, some assumptions may be needed in order to foresee an inclination of possible reasons of that occurrence.

In reality, there should be all types of consumers supporting the fuel sale consumption during the first 8 months. However, due to the larger mixed coconut oil consumption, compared to those of the other 2 types of consumers remaining, heavy-duty diesel users truly performed the strong potential to the fuel consumption. So, to answer the question earlier, one key possibility perhaps may result from the response of this main potential consumer to the substitution of mixed coconut oil. That is, heavy-duty diesel users may possibly take a response action to the quality of substitute after a while of first use.

Regarding an interview of heavy-duty diesel users, they claimed that they decided to stop using the mixed coconut oil 3-4 months later after first trial with no more concern of the rate of cheaper price difference of the mixed coconut oil anymore. Thus, these responses of heavy-duty diesel users as strong potential consumer might be the main factor in the occurrence, causing a large decrease of substitute's consumption (the high volume of fuel they consumed, the big loss of fuel consumption when they stop using) in spite of the increase of cheaper price difference of the substitute (this would refer to the reason of no more concern of cheaper price difference anymore in the interview). Especially, the big loss of substitute's volume in the graph line happened in September (this matched the interview stating that they stopped using any longer 3-4 months after first use; therefore, in case that heavy-duty diesel users consumed a lot of substitute in May, and so 3-4 months after May would possibly be September).

By these possible assumptions, this heavy-duty diesel users might probably be the main factor, influencing such the occurrence. This was because they faced the serious technical diesel engine problems from the quality of mixed coconut oil. They found their heavy-diesel engines were seriously damaged, according to the interview.

Apart from, the large decline of substitute's sale volume in September could partly be supported by another reason, resulting from the decrease of using the substitute by some proportion of the other 2 remaining types of diesel users. As an interview, even though they did not express the stop using reason, they still found gel-clotted trouble of substitute fuel and needed to change fuel filters. Thus, this might maybe show the chance for reducing the substitution of the mixed coconut oil for conventional diesel as well because of their own reasons such as the cost of both fixing money for fuel filter and loss of time.

As a consequence, both major and minor reasons above would be the potential factors, explaining the rapid decrease of sale volume of the substitute graph in September 2002.

By the way, to notice that the factor of the quality of the mixed coconut oil would contribute to the technical problems in different level of severity to different types of users. Otherwise, there should have been none of sale volume of the mixed coconut oil since September onwards, resulting from stop using response.

Beyond September when the percentage of price difference rose once again and reached the peak of 25% cheaper, presenting 4 baht/ liter to be saved, the sale amount graph of the substitute showed the plateau for 1 month from September to October. Afterwards, when the graph on right hand side of the percentage of gap of cheaper price difference started going down again till December, the graph of sale amount of the mixed coconut oil displayed the decrease till last month of the year.

This should imply that the cheaper price difference of the substitute would still own the meaning to the remaining types of consumers. The main consumers at this point of condition would possibly be light-duty diesel users owing to their fuel consumption, compared to that of farming diesel users. This could be possible as interview data, expressing opinions with conditions of light-duty diesel consumers. They offered the decision of encouragement of the substitution (do not stop using only) with condition of the minimum of cheaper price difference around 3~4 bath per liter. This corresponded to the cheaper price condition in September, showing 4 baht cheaper in substituting the mixed coconut oil for diesel fuel; and thus the graph of sale volume during the same period of time presented a plateau.

Even more, when the gap of price difference dropped gradually during November to December, stating the minimum of cheaper price difference lower than 3 baht/ liter, the graph of sale consumption fell rapidly again during the same period of time. It might be due mainly to light-duty diesel consumer's reaction to this situation. They might not support the mixed coconut oil in condition of saving money less than 3 baht per liter from using the substitute because they may think that it would be beyond the worthwhile point of taking the risk of substituting between saved money and after-effects from the product quality after use such as technical problems to their diesel engines. These would also stand for their comments given in the interview.

To condense the effect of the quality of mixed coconut oil to its sale volume, sold by Saeng Arun in 2002, the correlation between the gap of price difference and the sale consumption of the mixed coconut oil, relating to data from interview on actual site are used altogether for estimation. It would be concluded that the quality of the mixed coconut oil would absolutely be one of key factors, influencing the sale volume of substitute actually. Noticeable point is that it would deliver its potential to various types of consumers in different levels of concerns, not same for all. Consequently, these dissimilar levels of concerns impact directly on the final decision-making of types of consumers for the substitution probably in different ways, relying on the conditions of individual's perceptions and applications.

4.4 Air pollution reduction, resulting from the substitution of the coconut oil mixed with kerosene for conventional diesel.

As widely believed that the clear benefit of the substitution of mixed coconut oil for diesel fuel, in aspect of environment, would be air pollution benefit. Together with, in this study consumers in Thap Sakae district, who perceived directly by their own real experiences supported that they could see clearer smoke and took breaths with weaker smell. Therefore, it is attractive and useful to follow the actual result of air pollution reduction from the substitution of mixed coconut oil in order to possibly prove those perceptions.

However, at the moment of substituting coconut oil mixed with kerosene for diesel on actual site in 2002, there was unluckily no official air emission test, resulting from fuelling diesel engines with the substitute derived from Saeng Arun formula, which consisted of both coconut oil and kerosene at the ratio of 20:1 by volume (about 95%: 5% respectively). Only Pollution Control Department (PCD) was an official organization, concerned with this substitution for diesel and testing the result of air emissions. The test was done in lab-scale in Prathumthani province in 2001.

However, there was a dissimilarity of fuel composition between Saeng Arun formula and PCD formula. The following table shows the composition between Saeng Arun substitute used on actual site, and PCD substitute used for test at its laboratory.

Table 4.6 The data showing the different composition of the substitute between Saeng Arun formula and PCD formula.

Constituents	The percentage of the substitute's composition (%)	
	Saeng Arun formula	PCD formula
1. Coconut crude oil	~ 95	79
2. Diesel	0	17
3. Kerosene	~ 5	4
Total	**100**	**100**

Though the formula of the substitute in which PCD investigated so as to estimate the air emission outcomes was exactly not the same as the real Saeng Arun formula on actual site, it may probably be the most similar one that was officially measured the air emission results by such recognized organization, PCD, with reliable methods.

As such, this results of air exhaust emissions investigated by PCD is presumably brought as the result data in this research study, in order at least to evaluate the tendency of this air pollution reduction, resulting from the substitution of mixed coconut oil for conventional diesel.

Moreover, before measuring the results of air exhaust emission, the substitute of PCD formula was checked some fuel properties, compared to conventional diesel's. The data of those properties between both types of fuels was shown in the table below.

Table4.7 The comparing results of both mixed coconut oil tested by PCD and fossil diesel fuel, showing their important properties.

Detail items	Standard value of diesel fuel for vehicles		Result of mixed coconut oil fuel
	Standard	High speed diesel fuel	
Specific gravity at 15.6 °C.	ASTM D1298	0.81-0.87	0.906
Cetane number	ASTM D613	≥ 47	-
Viscosity at 40 °C.	ASTM D445	1.8-4.1	16.6
Pour point (°C)	ASTM D97	≤ 10	15
Flash point (°C)	ASTM D93	≥ 52	88

For diesel engine, PCD used light-duty diesel car of TOYOTA HILUX, registered car number of 6ฌ-8938 (Bangkok), having the volume of cylinder of 2,446 cm^3 in the test.

To be noted that there was another limit point in this study. Indeed there were heavy-, light- duty and farming diesel engines, consumed the substitute on site, and thus it might have some different trend of air emissions among those. As this official air emission test by PCD was only evaluated in light-duty diesel vehicle, thus the result could not express even the possible inclination of possible change of air exhaust emissions among those types of engines.

In this section, types of measurements are in the table below.

Table4.8 The comparing results of both air emissions and other involved parameters, resulting from fuelling diesel engine by diesel and by mixed coconut oil.

Test items	Pollutants (g/ km)*		% Difference of comparing results of mixed coconut oil, compared to diesel	Measuring method
	Diesel	Mixed coconut oil		
CO	0.503	0.541	**7.56 % increased**	Equipment with Constant Volume Sampling system (CVS), according to 94/12/EC
CO_2	249.21	262.03	**5.15% increased**	
HC	0.063	0.039	38.10% reduced	
NO_X	1.513	1.404	7.20% reduced	
PM	0.104	0.094	9.62% reduced	
Smoke (%)	-	-	34.19% reduced	Smoke Opacity Meter
	-	-	36.88% reduced	Smoke Filter Meter
Rate of fuel using up (km/ liter)	-	-	13.47% increased	*Weighing equipment set as 94/12/EC*
Engine power (kW)	-	-	13.54% reduced	*Chassis Dynamometer* **

Remarks : * The result was in accordance with Hot Emission Test.

** The result of engine power was checked at constant speed of 80 km/hr.

The testing results above are showing the diesel engine performance of light-duty vehicles, powered by the substitute of mixed coconut oil in formula tested by PCD, compared to those fueled by conventional diesel. As can be seen, those result would be categorized into 3 main groups, which are exhaust emissions, fuel consumption and engine power. For emissions, those tested are the regulated air emissions for diesel exhausts (Challen & Baranescu, 1999). As a result, HC (hydrocarbon) and Smoke show a large amount of decreased air pollution around 38% and 34-37% reduced respectively. Furthermore, NO_X and PM (particulate matter) show the reduction tendency of diesel air exhausts as well at different level of decrease about 7% and 9-10% respectively. By contrast, CO and CO_2 emissions are found the rising inclination about 7-8% and 5% correspondingly.

For other parameters, the results show around 13% increase of fuel using up, meaning that this tested diesel-powered vehicle seemed to need more volume of the mixed coconut oil, than that of conventional diesel, when used to perform the same amount of work. For engine power, the diesel car shows around 13-14% less power engine when it was fueled by the mixed coconut oil in PCD formula, compared to that fueled by common diesel.

Discussion as concept of bio-fuel to be environmentally friendly, if the air quality, led by the substitution of mixed coconut oil, were able to be only evaluated by 2 specific air pollutants namely smoke and particulate matter as the community's perceptions did, this substitution would highly tend to create environmental benefit in term of air quality, according to the test results and especially 34-36% Smoke dropped.

However, in fact, there are several more air pollutants, which are also concerned as the regulated exhausts from diesel engine combustion. Therefore, to truly assess the environmental benefit from air pollution reduction in this case, it should cover the reduction inclination of all regulated air pollutants. Thus, it would certainly not be able to summarize that the substitution of the mixed coconut oil in PCD formula generates air quality benefit because there are the relative increase of CO and CO_2 (about 8% and 5% rose respectively) and more importantly any concerned stakeholders cannot really underestimate even such little increase of those air amount but the individual poison of different types of air pollutants.

Regarding the air emission results tested by PCD in this section, it would be one of best possible official secondary data of air exhausts from the substitution for conventional diesel the research could find out. So, though there was the dissimilarity in the formula composition between the substitute in this Lab-test by PCD and the substitute applied on the actual site in Thap Sakae, Prachuap Khirikhan, this results tested by PCD would at least represent the similar outcomes of air exhaust emissions to the air result, assessed by mixed coconut oil in Saeng Arun formula, as a result of the similarity of both constituents and proportion between these 2 types of mixed coconut oil formulas.

4.5 Assumption the potential of selling price factor of the substitute these days.

To estimate the potential of substitute's selling price in present time situation, the study would calculate the selling price of mixed coconut oil corresponding to the ratio of mixed coconut oil: kerosene at 20: 1 by volume respectively. The prices of involved products are as follow :

1. Coconut nut price was 8.00-8.50 baht/ liter (Department of Internal Trade, 2005)
2. Copra (90% grade) whole sale price was 11.00-11.10 baht/ liter
3. The price of coconut crude oil was about 22.00-24.00 baht/ liter. The actual selling price depends on its sale volume when purchased.(a coconut oil inndustrial factory, personal communication, January 26, 2005).
4. Kerosene price was around 21.00 baht/ liter (Office of Natural Resources and Environmental Policy and Planning; personal communication, January 26, 2005)

The crude oil price quoted above was given by one of only 3 main factories existing in Thap Sakae area, and thus it could be regarded as representative of coconut crude oil selling price. Then, to compute the selling price, the total 21 liters of the substitute formula would cost around 461 baht (total 20 liter of 22 baht/ liter coconut crude oil plus 1 liter of 21 baht/ liter kerosene). Finally, the selling price of the substitute may cost more or less 21.95 baht/ liter (461 baht/ 21 liters).

At such a level of current selling price of the substitute, it is far more expensive than it cost about 11 baht/ liter during 2002 actually. This is because in reality the initial cost of the substitute is the result of raw material's cost, namely coconut nuts, which depend on macro economy. In this case, thereby, the current mix coconut oil has no potential at all in gaining the attention of consumers for the substitution as a result of its high cost, compared to diesel price (21.95 baht/ liter with about 15 baht/ liter respectively). So, in this case, it has no chance of feasibility for running the substitution of coconut oil mixed with kerosene for conventional diesel.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The thematic paper is studying the substitution of coconut oil mixed with kerosene for diesel, sold by Saeng Arun agricultural group in Thap Sakae area, Prachuap Khirikhan province in 2002, focusing firstly on the potential factors, influencing the development of the substitution, so as to proceed this project constantly, meaning to sustainably obtain the resulting benefits and secondly on the air emission reduction from diesel engine combustion as environmental benefit.

5.1 The factor of the selling price difference of the substitute

The gap of cheaper price difference of the substitute, compared to the selling price of conventional diesel, indeed affect the sale volume of the substitute. However, as there are several types of diesel engine users, such gap of the substitute then means in a different way to the different kinds of consumers in dissimilar level of importance. For this reason, it impacts effectively on the sale volume of the substitute directly.

Regarding the result, it may conclude that on one hand the gap of price difference had no more potential after first trial to heavy-duty diesel users, leading to a potential loss of sale volume of the substitute; on the other hand it still performed some significant level to light-duty diesel and farming diesel users, possibly resulting in either an increase or a decrease of the sale volume of mixed coconut oil; all in all it relied on the level of such cheaper price difference of the substitute (cost saving) and the substitute's quality to their individual's applications.

5.2 The factor of the quality of the substitute

According to the relation between the sale consumption graph of the mixed coconut oil, and the data from interview on the site, it would very clearly be concluded that the quality of the mixed coconut oil would absolutely be one of key factors, influencing the sale volume of substitute actually.
Nevertheless, the degree of concern depends on types of consumers. Data show that the substitute's quality seemed to be very poor to the heavy-duty diesel engines due to the reason of engine damage. Thus, this matter would potentially impact on a gigantic reduction of the substitute's sale volume.

However, to light-duty diesel and farming diesel users, though the quality of the substitute causes the trouble of engine application by blocking fuel filters as a result of gel-clotted problem of the substitute, it was not so strong that damage diesel engines. Thereby, the substitute's quality may offer compromising value to light-duty diesel and farming diesel engines with some conditions, depending on their own perception and application.

5.3 Air pollution reduction as environmental benefit

Even if there was the difference in the formula composition of the mixed coconut oil between the substitute used on the actual site in Thap Sakae, Prachuap Khirikhan and the substitute measured in the Lab-test by PCD as data in this study, the results of air pollution reduction from this substitution in case of Saeng Arun formula may likely to correspond and have the same trend as those results in PCD formula due to the similarity of major composition of both fuels.

As for air reduction from diesel engine in this study, the six concerning air pollutants namely CO, CO_2, HC, NO_X, PM (particulate matter) and smoke, were measured the change of their level. The results could be categorized into 3 groups as follows :

5.3.1 The apparent air pollution reduction.

HC and Smoke express the big amount of air reduction, around 35-40% reduced.

5.3.2 The tendency of air pollution reduction.

NO_X and PM are presenting a number of air pollution reduction about 7-10% dropped.

5.3.3 The increase inclination of air pollution.

CO and CO_2 are only 2 air pollutants among those, having the 5-8% increase.

As a consequence, though there were a relatively larger amount of 4 air pollutant reduction, especially HC and Smoke, the increase even in a small number of CO and CO_2 were also expressed, which may probably be more significant in term of the hazard per unit, contributing to the environments.

Hence, it is inconclusive that the substitution of the mixed coconut oil absolutely generates air quality benefit. Anyhow, due to the relatively large decrease of Smoke and Particulate matter reduction , this could be an helpful information to somehow apply to have practicable benefit if utilized in appropriate directions such as an application in the transportation areas with enormous dust, possibly causing cancer to communities nearby.

5.4 Assumption the selling price potential of mixed coconut oil in present time

It is concluded that the substitute of mixed coconut oil currently has no potential in term of selling price aspect because at the time of writing the selling price of the substitute is much more expensive than diesel's (~22 baht/ liter of mixed coconut oil and ~ 15 baht/ liter of diesel).

However, if such current diesel price could not be subsidized to maintain the price at 15 baht/ liter as at the time of writing but increased till 20-22 baht/ liter, especially in case of ongoing increase of diesel price, together with some fall of coconut crude oil price, the activity of substitution would probably be reviewed, resulting from a potential price competitiveness of mixed coconut oil. Additionally, to be possibly able to meet the feasibility of the substitution of mixed coconut oil on its business, it would need the government's support in subsidizing money as a compensation in order to at least equalize or lower the selling price of mixed coconut oil than that of diesel.

In summary, the 2 factors of both selling price difference and quality essentially influence the enhancement of the substitution and would be considered together for various consumers in finalizing their ultimate decision-making whether they should support the substitution. They would rely in large part on the conditions of individual consumer's perceptions and applications such as the amount of cost saving, severity of technical problem to each sort of diesel engine and the difficulty of engine repairing. Lastly, that decision would maybe lead to advantages of the substitution for diesel in national-scale such as saving foreign currency from lower amount of imported diesel.

5.5 Recommendations

In order to successfully substitute conventional diesel with mixed coconut oil or any other resemble sources, the results suggest that the following two aspects must be thoroughly investigated.

5.5.1 Cost aspect

The substitute's price needs to be laid down on the principle of lowest possible raw material cost, together with the best possible quality in order to be able to compete with conventional diesel. The research would focus on the productive types of coconuts, characteristic of oils and yield. Additionally, the research could study on constructive conditions of planting coconut trees so that growers could harvest high yield per area unit, and subsequently on the effective processes to make coconut oils.

The information to be attained will be urgently needed in order to ensure successful substitution of mixed coconut oil for diesel. Then, it may construct and bring about not only economic benefit both macro-scale from foreign currency cost saving and micro-scale from local cost saving, but also environmental benefit from air pollution reduction, which would lead to the minimization of some related social problems such as health concerns to Thais, among current socioeconomic and environmental stresses.

5.5.2 Technical aspect

A. The research should study the results of using the substitute in types of diesel engines used in Thailand, with important parameters in measurements, including technical problems, power engine, rate of fuel consumption and exhaust emissions. The results would be beneficial for the relevant sectors.

B. The substitute fuel would possibly be adjusted in aspects of quality and/ or formula whereas diesel engines as well as the processes of combustions may be adapted or modified so as to match the alternative fuel. This is crucial to formulate feasible implementation frameworks for the optimum benefits from best application within such constraints and limit conditions.

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APPENDIX

The cheaper percentage of mixed coconut oil 's selling price = A x 100 (%)

where,

$$A = \frac{\text{Value of selling price (of diesel – of mixed coconut oil) (baht /liter)}}{\text{Value of diesel 's selling price (baht / liter)}}$$

For instance, the cheaper percentage of mixed coconut oil's selling price in January 2002 was;

Step 1, to find A value first,

$$A = \frac{11.86 \text{ baht / liter} - 11.00 \text{ baht / liter}}{11.86 \text{ baht / liter}}$$

thus, A = 0.0725

Step 2, The cheaper percentage of mixed coconut oil's selling price in January 2002

= 0.0725 x 100 %

= 7.25 %

Therefore, the cheaper percentage of mixed coconut oil's selling price in January 2002, compared to diesel's equaled to 7.25 % or about 7.3 % lower.

Above is the example of calculating for such a percentage. Then, the researcher followed this method to find the other 11 months remaining for every month in 2002. Finally, when all are done, such data would be made a graph to easily understand how the change of the cheaper percentage of mixed coconut oil's selling price each month in 2002 was.

สรุปการทดสอบเปรียบเทียบปริมาณมลพิษจากไอเสียรถยนต์ขนาดเล็กที่ใช้เครื่องยนต์ดีเซล
ระหว่างการใช้เชื้อเพลิงประเภทน้ำมันดีเซลมะพร้าวดิบ (สูตรทับสะแก) และน้ำมันดีเซล

ผู้รับบริการ กรมควบคุมมลพิษ สถาบันวิจัยวิทยาศาสตร์ และเทคโนโลยีแห่งประเทศไทย และนายยุทธชัย วิวัฏฏ์กุลธร (เจ้าของน้ำมันดีเซลมะพร้าวดิบ)

รายละเอียดตัวอย่าง รถยนต์บรรทุกขนาดเล็ก (ปิกอัพ) หมายเลขทะเบียน 6ฌ-8938 ยี่ห้อ TOYOTA HILUX ปี คศ.1991 ปริมาตรความจุกระบอกสูบ 2446 ลบ.ซม. (ก่อนกำหนดมาตรฐาน ผลิตภัณฑ์อุตสาหกรรม)

รูปแบบการทดสอบ 1. มาตรฐานผลิตภัณฑ์อุตสาหกรรม มอก. 1435-2540 (94/ 12/ EC) ปริมาณสารมลพิษภายหลังติดเครื่องยนต์ขณะร้อน (Hot Emission Test) ตรวจสอบ 2 ครั้ง และหาเฉลี่ย

2. มาตรฐานกระทรวงวิทยาศาสตร์เทคโนโลยี และสิ่งแวดล้อม ควันดำและระดับเสียง (ตรวจสอบหลังจบการทดสอบปริมาณสารมลพิษหลังติดเครื่องยนต์ขณะร้อน) ตรวจสอบ 2 ครั้ง และหาเฉลี่ย

ผลการตรวจวัดสารมลพิษ

ข้อกำหนด	ว.ด.ป.	ระยะทาง (กิโลเมตร)	สารมลพิษ (มอก. 1435-2540) (กรัม ต่อกิโลเมตร)					การสิ้นเปลือง เชื้อเพลิง (กิโลเมตร ต่อ ลิตร)	มลพิษ(มาตรฐาน กระทรวงวิทยาศาสตร์ฯ)		
			THC	NO_x	CO	CO_2	PM		ควันดำ % (OPACITY)	ควันดำ % (FILTER)	ระดับเสียง (dBA)
น้ำมันดีเซล (เครื่องร้อน)	14, 16/ 6/ 44	160279	0.063	1.513	0.503	249.212	0.104	10.228	4.68	26.30	97.25
ดีเซลมะพร้าวดิบ (เครื่องร้อน)	19, 20/ 6/ 44	160467	0.039	1.404	0.541	262.037	0.094	8.850	3.08	16.60	97.46
ผลต่าง	--	188	-0.024	-0.109	+0.038	+12.825	-0.010	-1.378	-1.60	-9.70	-0.21
ผลต่าง (%)	--	188	ลดลง 38.095%	ลดลง 7.204%	เพิ่มขึ้น 7.555%	เพิ่มขึ้น 5.146%	ลดลง 9.615%	เพิ่มขึ้น 13.473%	ลดลง 34.188%	ลดลง 36.882%	--

สรุปการทดสอบเปรียบเทียบประสิทธิภาพเครื่องยนต์ของรถยนต์ขนาดเล็กที่ใช้เครื่องยนต์ดีเซล
ระหว่างการใช้เชื้อเพลิงประเภทน้ำมันดีเซลมะพร้าวดิบ (สูตรทับสะแก) และน้ำมันดีเซล

ผู้รับบริการ กรมควบคุมมลพิษ สถาบันวิจัยวิทยาศาสตร์ และเทคโนโลยีแห่งประเทศไทย และนายยุทธชัย วิวัฏฏ์กุลธร (เจ้าของน้ำมันดีเซลมะพร้าวดิบ)

รายละเอียดตัวอย่าง รถยนต์บรรทุกขนาดเล็ก (ปิกอัพ) หมายเลขทะเบียน 6ฌ-8938 ยี่ห้อ TOYOTA HILUX ปี คศ.1991 ปริมาตรความจุกระบอกสูบ 2446 ลบ.ซม. (ก่อนกำหนดมาตรฐาน ผลิตภัณฑ์อุตสาหกรรม)

รูปแบบการทดสอบ ตรวจวัดประสิทธิภาพของเครื่องยนต์เมื่อเครื่องยนต์ขับเคลื่อนไดนาโมมิเตอร์ (Chassiss dynamometer) ด้วยความเร็วคงที่ที่ความเร็วต่างๆกันในเกียร์ 3 ผลที่ได้ประสิทธิภาพของเครื่องยนต์ที่ เกียร์ 3 ที่ความเร็วต่างๆ ขณะเครื่องยนต์ร้อน (กิโลวัตต์) ตรวจสอบ 2 ครั้ง และหาเฉลี่ย

ผลการตรวจวัดประสิทธิภาพเครื่องยนต์

ข้อกำหนด	ว.ด.ป.	ระยะทาง (กิโลเมตร)	ผลการตรวจวัด (กิโลวัตต์)													
			ความเร็ว (กิโลเมตร ต่อ ชั่วโมง)	30	35	40	45	50	55	60	65	70	75	80	85	90
น้ำมันดีเซล	14, 16/ 6/ 44	160395	แรงม้า (kW)	19.58	23.18	26.16	29.10	32.11	33.76	35.02	36.56	37.88	38.12	37.37	36.77	31.77
ดีเซล มะพร้าวดิบ	19, 20/ 6/ 44	160647	แรงม้า (kW)	19.13	22.15	25.11	27.52	29.82	31.63	32.53	33.41	34.32	33.16	32.31	31.54	28.07
ผลต่าง	--	--		-0.45	-1.03	-1.05	-1.58	-2.29	-2.13	-2.49	-3.15	-3.56	-4.96	-5.06	-5.23	-3.70
ผลต่าง (%)	--	--		2.30	4.44	4.01	5.43	7.13	6.31	7.11	8.61	9.40	13.01	13.54	14.22	11.65

BIOGRAPHY

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