ENERGY ECONOMICAL AND ENVIRONMENTAL ANALYSIS OF INDUSTRIAL BOILERS

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ABSTRACT

As a result of the successful implementation of the industrialization plan in 1985; Malaysia has changed from an agricultural economy into industrial based economy. The industrial sector represents the highest consuming sector across all other sectors and accounts for about 48% of all total energy demand.

This study is concerned with an energy saving, economic and environmental analysis of industrial boilers in Malaysia. There are three principles that have been investigated: Installation of variable speed drive; fuels switching between diesel and other types of fuels such as natural gas and biomass; and installation of heat recovery systems in these boilers. After implementation of VSD, the results obtained when reducing the speed of water pumps by 60% show that 4 GWh, 93.6% of energy, RM 863,375 and 2,160 ton of CO_2 could be saved annually which all represent high energy saving, environmental and economic benefits. Also it has been found that when switching between diesel fuel and biomass gas by a percentage of 50% for both instead of using 100% of diesel fuel, 11,946 ton of CO_2 and RM 1,872,532 could be saved annually. Finally installation of economizer has proven its viability with 2,529,779 KWh energy saving, RM 238,573 bill saving and 2,150 ton of CO_2 per annum.

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NOMENCLATURE

$ABCS_{Kg}$	Annual biomass consumption when switching (Kg/year)
$ABECS_{KWh}$	Annual biomass energy consumption when switching (KWh/year)
$ABEPS_{CO2}$	Annual biomass emissions production of $CO_2$when switching (Kg/year)
$ABPS_{RM}$	Annual biomass price when switching (RM/year)
ABS_{VSD}	Annual bill saving of VSD (RM/year)
ADC_{KJ}	Annual diesel energy consumption (KJ/year)
ADC_{KWH}	Annual diesel energy consumption (KWh/year)
ADC_{L}	Annual diesel consumption (Liter/year)
ADC_{Kg}	Annual diesel consumption (Kg/year)
$ADCS_{L}$	Annual diesel consumption when switching (Kg/year)
$ADCS_{KWH}$	Annual diesel energy consumption when switching (KWh/year)
$ADEP_{NOx}$	Annual diesel emissions production of NO_x (Kg/year)
$ADEP_{SO2}$	Annual diesel emissions production of SO_2 (Kg/year)
$ADEP_{CO2}$	Annual diesel emissions production of CO_2 when switching (Kg/year)

$ADEPS_{CO2}$	Annual diesel emissions production of CO_2 when switching (Kg/year)
$ADEPS_{NOx}$	Annual diesel emissions production of NO_x when switching (Kg/year)
$ADEPS_{SO2}$	Annual diesel emissions production of SO_2 when switching (Kg/year)
ADP_{RM}	Annual diesel price (RM/year)
$ADPS_{RM}$	Annual diesel price when switching (RM/year)
AEC_{BAU}	Annual energy consumption without variable speed drive (KWh/year)
AEC_{NP}	Annual energy consumption with variable speed drive (KWh/year)
AER_{CO2}	Annual emissions reduction of CO_2 (Kg/year)
AER_{CO}	Annual emissions reduction of CO (Kg/year)
AER_{NOx}	Annual emissions reduction of NO_X (Kg/year)
AER_{SO2}	Annual emissions reduction of SO_2 (Kg/year)
AES_{VSD}	Annual energy saving when using variable speed (KWh/year)
$ANGPS_{RM}$	Annual natural gas price when switching (RM/year)
$ANGCS_{L}$	Annual natural gas consumption when switching (Liter/year)
$ANGECS_{KWh}$	Annual natural gas energy consumption when switching (KWh/year)
$ANGEPS_{CO2}$	Annual natural gas emission production of CO_2 when switching (Kg/year)

$ANGEPS_{NOx}$	Annual natural gas emission production of NO_X when switching (Kg/year)
$ANGEPS_{SO2}$	Annual natural gas emission production of SO_2 when switching (Kg/year)
BEC	Biomass energy content (KJ/Kg)
DEC	Diesel fuel energy content (KJ/Kg)
EF_{CO2}	Emission factor of CO_2 (Kg/KWh)
EF_{CO}	Emission factor of CO (Kg/KWh)
EF_{SO2}	Emission factor of SO_2 (Kg/KWh)
EF_{NOx}	Emission factor of NO_x (Kg/KWh)
IC_{VSD}	Incremental cost of VSD (RM)
IC_{HR}	Incremental cost of heat recovery system (Economizer) (RM)
P_{Hp}	Pump horsepower (Hp)
$NGEC$	Natural gas energy content (KJ/Kg)
N_{pumps}	Number of pumps
OPH	Operating hours in year (Hours/year)
PBP_{HR}	Payback period of heat recovery (Years)
PBP_{VSD}	Payback period of VSD (Years)

$\%B_{FS}$	Percentage of biomass fuel switching
$\%D_{FS}$	Percentage of diesel fuel switching
$\%VSD_{ES}$	Percentage of energy saving of VSD
$\%F$	Percentage of fuel (%)
$\%_{fg}$	Percentage of heat losses in flue gas
$\%B_{th}$	Percentage of increasing in thermal efficiency of boiler due to economizer
$\%NG_{FS}$	Percentage of natural gas switching
$\%_{HR}$	Efficiency of heat recovery system
SR_{ratio}	Speed reduction ratio
$TABS_{HR}$	Total annual bill saving of heat recovery (RM/year)
$TABS_{RM}$	Total annual bill saving (RM/year)
$TAES_{HR}$	Total annual energy saving of Heat recovery (KWh/year)
UEP	Unit energy price (RM/KWh)
UFP_f	Unit fuel price (RM/Liter or RM/Kg)
η_{pump}	Efficiency of pump
ρ_f	Density of a particular fuel (Kg/m^3)

0.4	Percentage of CO_2 emission avoided by palm oil when replacing fossil fuel
0.7456	Conversion factor from horsepower to kilowatt
3600	Conversion factor from KWh to KJ

CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays energy issue is one of the most sensitive and complicated issues in the globe. Energy and its primary sources has become a real worry for many counties. For example, Fossil fuels which are the main source of energy in the world are depleting and there is a rising anxiety around the world about their negative effect on the atmosphere and the environment. Because of the economic expansion, Malaysia is one of the most developed countries among the Association of Southeast Asian Nations (ASEAN) members. The successful implementation of the Industrialization Plan in 1985 has brought forth rapid economic growth and structural transformation away from agricultural-based economy (Gan *et al.*, 2007). The progress in the industrial sector harshly affected the ability to preserve the fuel supply and the ecological balance (Saidur *et al.*, 2009a).

The industrial development across the world will result in more energy use and in tandem will lead eventually to more concentration of greenhouse gases such as carbon dioxide (CO_2) and other emissions such as sulfur dioxide (SO_2), nitrogen oxide (NO_x) and carbon monoxide (CO) which all have disastrous consequences for the earth‟s climate like rising temperature, drought, floods, famine and economic chaos (Mahlia, 2002). The Intergovernmental Panel on Climate Change (IPCC) reported that continued emissions will lead to a temperature increase of between 1.4 and 5.8 °C over the period from 1990 to 2100. Furthermore, The Department of Energy (The United States of America) highlighted that, global carbon emissions are rising more than 2% per year and by 2015 may be more than 50% above 1997 level, all of which because of increasing energy demand and inefficient way of utilizing energy (Mahmoud *et al*., 2009).

In order to deal with the above-mentioned problems the international community has been trying for many years to find a solution for this arising problem, the concept of sustainable development has been suggested as one of the radical ways to deal with this problem. This concept came as a result of the „„Brundtland Report"" which was produced by the World Commission on Environment and Development (WCED) under the leadership of the former Prime Minister of Norway, Gro Harlem Brundtland. This report showed that the time had come to combine economy and ecology in one term and the international community must take the responsibility for both the causes and consequences of environmental damage. The WCED defined sustainable development as a way of meeting „„the needs of the present without compromising and affecting the ability of future generations to meet their own needs"" (Hammond, 2007).

To achieve sustainability; the concept of rational use of energy is one of the ways to reduce the energy use. This indicates that the procedures that lead to a more rational use of energy showed the advantages over the actual current situation. Therefore, energy conservation means less dependence on energy imports and, thus, less GHG emissions. Prior studies have reported that implementing a few options with little cost in the industrial sector could reduce 10–30% of GHG emissions (Saidur *et al.*, 2009a).

1.2 Background of study

Before talking about industrial boilers we must firstly understand what energy is and the importance of energy saving or improvements. In general, energy can be defined as an integral component of a modern economy. It is an essential ingredient in nearly all goods and services, but its use exacts heavy financial, environmental, and security costs. A key method of reducing energy‟s costs while retaining its benefits is to use it more efficiently. Improving energy efficiency depends on many technical, economic, institutional, and political factors. Such factors have changed since the 1970s, when most federal energy policy was formulated in USA (U.S. Congress, Office of Technology Assessment, 1993).

The improvement of energy efficiency is a very important factor in industry to improve the environmental performance, emissions reduction and increase its profitability. The relationship between energy and environment will be the key figure behind improving energy efficiency, although there is no any severe legislation that forces companies to implement; only the appreciation of cost effective opportunities for savings can work.

To show the importance of energy saving policies in the world, UK has been selected as an example. The estimated potential for energy savings in the UK is 31.4% across all sectors. In industry, this translates to an estimate of 23.8% potential savings, which would drop its share of UK energy consumption to around 22%, with an annual saving of a staggering £1,380 million. The main factors that will affect the levels of realization are economic, which are usually cost effective, and technological, which is mature (Goligher, 2002).

Industrial boilers are used for generating hot water or steam for many purposes in industrial process application. In the United States There are approximately 43,000 industrial boilers. (71%) of these boilers are used in the food, paper, chemicals, refining, and primary metals industries. Achieving energy efficiency improvements in these boilers can be done in the steam/hot water distribution system, electrical motors, boiler auxiliaries, flue gas or in process efficiency improvements. For instance, improving the thermal efficiency of boiler from 80% to 94% will result in carbon dioxide emission reduction from 66.3 to 56.4 kg/MMBtu when using natural gas a fuel and from 91.4 5 to 77.8 kg/MMBtu when using Distillate Fuel Oil (U.S. Environmental Protection Agency, 2008).

In China an industrial boiler-efficiency improvement program (IBEI) has been carried out, The results show that, if the average efficiency of industrial boilers were improved from 60 to 70%, 3 million tons of coal could be saved, and CO_2 emissions be reduced by 5 million tons annually at a cost of less than US$2 per ton of CO_2. The health benefits are valued at about US$86 million per year, including the avoidance of about 700 premature deaths annually (Fang *et al*., 2002).

Engin Ozdemir (2004) in his study shows that in order to improve the boiler efficiency, a fan motor speed is decreased to 400 rpm from 1450 rpm by using variable speed drive (VSD). After implementation of the VSD, the results obtained were a reduction in stack temperature from 195 to 145 °C, increasing of the boiler efficiency 2.5% and 8000 kWh electrical energy saving in a month. This study represents remarkable and useful results when applying energy efficiency methods in the boilers.

Using economizers in boilers is also an effective way to save energy and improve boiler‟s efficiency. For instance, it has been found that for every 22^0 C reduction in the flue gas temperature by passing it through an economizer or a pre-heater, there is 1% saving of fuel in the boiler depending on the type of heat transfer surfaces and the allowable pressure drop (Bureau of Energy Efficiency, 2009).

Malaysian economy grew at 5% in 2005 and the overall energy demand is expected to increase at an average rate of 6% per annum (Saidur *et al.*, 2009a). In parallel with Malaysia‟s rapid economic development, final energy consumption grew at rate of 5.6 percent between 2000 and 2005 to reach 38.9 Mtoe in 2005. The final energy consumption is expected to reach 98.7 Mtoe in 2030, nearly three times the 2002 level. The industrial sector will have the highest growth rate of 4.3 percent, followed by transport at 3.9 percent, residential at 3.1 percent and commercial at 2.7 percent. Industrial sector accounted for some 48% of total energy use in 2007 which represents the highest percentage (APEC Energy Demand and Supply Outlook, 2006).

In Malaysian industrial sector electric motors used the highest quantity of energy (47%), pumps is the second consumer with (14%), followed by air compressors (9%), air conditioning systems (7%), workshop machines (6%,), lighting (6%), overhead cranes (3%), ventilation (2%), furnace (1%), conveyor system (1%), boiler (1%), refrigeration system (1%) and other equipment (4%) (Saidur *et al.*, 2009a).

All these figures indicate that Malaysia should take more concern about its energy source and use specially in the industrial sector to ensure more sustainability of it is resources and to stay in safe from the arising energy problem and to avoid emission effects on the environment which is regarded as a global problem and responsible of causing many health problems.

1.3 Objectives of the study

Having recognized the industrial sector as the biggest consumer of energy in Malaysia, and proven the necessity and the importance of improving the energy performance of the industrial processes, this dissertation will show the importance of, and exhibit the way to improve the performance of paper and pulp boilers energy systems in terms of energy saving, emissions reduction and cost-benefit analysis.

To achieve these improvements a case study has been undertaken to investigate the following aspects:

(i) Energy saving when installing variable speed drives and heat recovery systems.

(ii) Emissions reduction when installing variable speed drive, heat recovery systems and applying fuel switching approach.

(iii) Cost benefits analysis including bill saving and payback period when installing variable speed drive and heat recovery systems and applying fuel switching approach.

The outcome of this investigation is expected to give the operators many useful choices in many applications.

1.4 Scope of the study

The scope of this study is based on applying the following concepts in the industrial pulp and paper boilers sector in Malaysia:

1.4.1 Variable speed drives installation

(i) The data of motors horsepower, maximum motors speed, and number of motors, emission index, variable speed drive price and quantities of industrial boilers in Malaysia are all obtained from literatures.

(ii) The percentage of speed reduction by using VSD ranges from 10-60%.

(iii) Types of greenhouse gases that have been considered are CO_2, CO, SO_2 and NOx.

(iv) Only bill saving and payback period are included in the cost benefits analysis of this study.

1.4.2 Fuel switching method

(i) Six paper and pulp industries in Malaysia have been considered to study the importance and benefits of applying fuel switching method.

(ii) Biomass and natural gas have been considered as alternative fuels to replace diesel fuel in these factories.

(iii) Fuel consumption has been obtained from the data of the six paper and pulp industries.

(iv) Emission index, energy contents of fuel and fuel prices in Malaysia are all obtained from literatures.

(v) Types of greenhouse gases that have been considered to estimate emissions reduction when using natural gas as an alternative fuel are CO_2, NO_x, and SO_2.

(vi) Types of greenhouse that has been considered to estimate emissions reduction when using biomass as an alternative fuel is CO_2.

1.4.3 Heat recovery system installation

(i) Six paper and pulp industries in Malaysia have been considered to study the benefits of installing hear recovery systems.

(ii) Emission index and fuel prices in Malaysia are all obtained from literatures.

(iii) Types of greenhouse that has been considered to estimate emissions reduction are CO_2, CO, SO_2 and NO_x.

(v) Only bill saving and payback period are included in the cost benefits analysis.

1.5 Organization of dissertation

This dissertation is made up of five chapters. The chapters are organized as follows:

Chapter 1 gives a brief introduction or overview of the research topic. It starts with giving an introduction to emission issue; it is effect, importance of sustainability and suggests it as a solution for the current world energy crisis, followed by a background of the study that shows the importance of energy saving and giving some examples around the world specially for industrial boilers and finally the objectives and scope of the study.

Chapter 2: this chapter provides a literature review for the study. It will start by giving a historical overview of energy demand trend in Malaysia and specifically industrial sector demand followed by comprehensive definitions of variable speed drive, fuel switching, and heat recovery approaches. The next part of each approach gives a historical background for all of these application, energy saving associated with these approaches and their latest development around the world their existing application in Malaysia.

Chapter 3 explains in detail the research methodology and design. In this chapter an explanation for methods that are applied to calculate energy saving, emission reduction and cost benefit analysis when applying the three concepts of VSD, fuel switching and heat recovery methods in the industrial boilers in Malaysia has been provided.

Chapter 4 is dedicated to show all the results that have been obtained from the input data and present the findings of the study followed by a detailed discussion and analysis of all findings besides comparing it with the existing results included in the literature.

Chapter 5 provides a summary of the key findings in the light of the research and puts some recommendations for the future studies.

CHAPTER 2

LITERATURE REVIEW

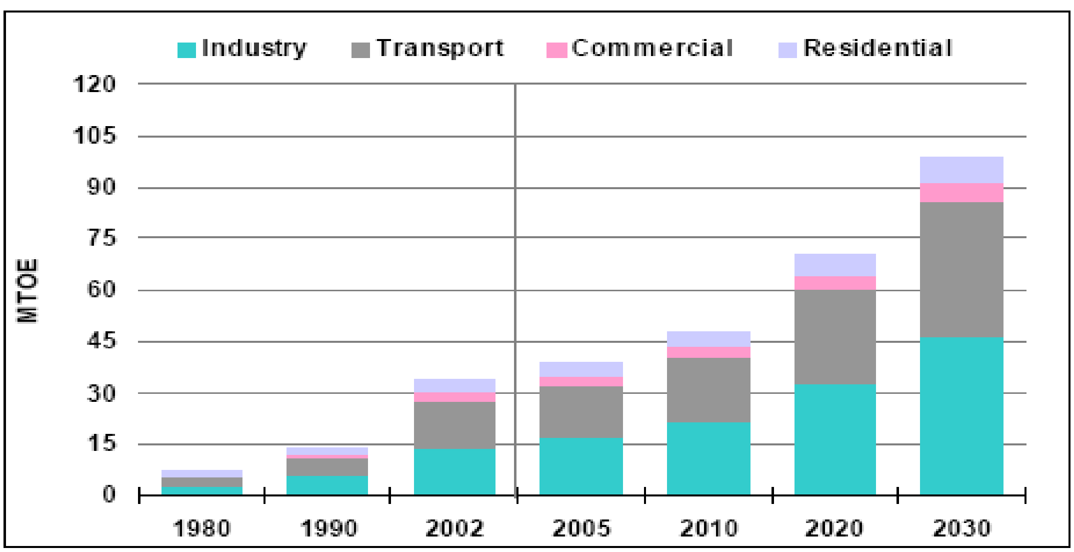
2.1 Introductions

Literature review attempts to discover major publications that will provide an insight understanding about the topic and related issues. The review also reveals the limitations encountered in the area of research which is related to the industrial boilers in Malaysia specifically paper and pulp industry.

This chapter starts by giving an overview of energy demand trend in Malaysia especially for the industrial sector which is the topic of this dissertation. This part is dedicated to show the importance of tracing and tracking energy demand in Malaysia and combining it with the efforts towards improving energy efficiency by the methods which will be covered later in the study. This will be followed by describing what variable speed drive is; its benefits, technical description and applications in Malaysia beside its potential to be used further in the industrial boilers sector. Part three is about fuel switching. In this part we Firstly begin by defining what fuel switching is, identifying the possible alternative fuels in Malaysia especially biomass as a consistent renewable source of energy and discussing the national biodiesel Policy of Malaysia towards using biodiesel as an alternative fuel and its expected benefits for the country. Finally, the possibility of fuel switching in the industrial boilers in Malaysia will be discussed. Last part of this chapter will be specified to talk about heat recovery systems.

2.2 Energy demand trend in Malaysia

One of the recent studies has shown that Malaysian economy grew at a rate of 5% in 2005 and the overall energy demand is expected to increase at an average rate of 6% per annum (Saidur *et al*., 2009a). Another study indicated that between 2000 and 2005 energy consumption grew at a fast rate of 5.6 percent to achieve 38.9 Mtoe in 2005. The final energy consumption is expected to reach 98.7 Mtoe in 2030, nearly three times the 2002 level as shown in Figure. 2.1. The industrial sector will have the highest growth rate of 4.3 percent, followed by transport at 3.9 percent, residential at 3.1 percent and commercial at 2.7 percent (APEC, 2006). The most striking feature amongst all Malaysian sectors" consumption is that the Industrial sector accounted for some 48% of total energy use in 2007 which represents the highest percentage among all other sectors, as shown in Figure 2.2 (Saidur *et al*., 2009b).



Source: APERC Analysis (2006)

Figure 2.1 Statistics of energy uses in Malaysia from 1980-2030 (APEC, 2006).

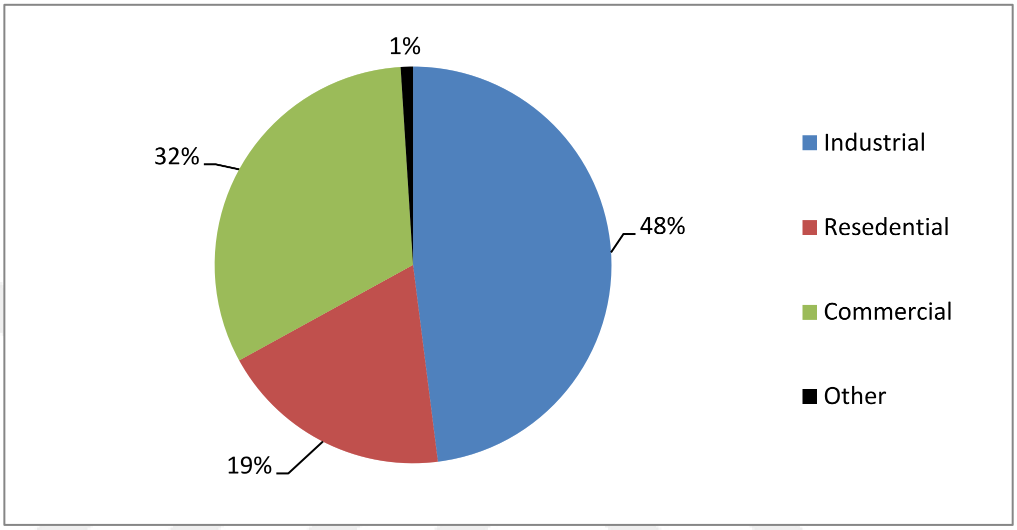


Figure 2.2 Statistics of energy uses in Malaysia in 2007 (Saidur *et al*, 2009b).

In the Malaysian industrial sector, it has been found that in 2007 industrial electrical motors consumed the highest amount of energy (47%) followed by pumps (14%), air compressors (9%), air-conditioning systems (7%), workshop machines (6%,), lighting (6%), overhead cranes (3%), ventilation (2%), furnace (1%), conveyor system (1%), boiler (1%), refrigeration system (1%) and other equipments (4%) as shown in figure 2.3 (Saidur *et al*., 2009b).

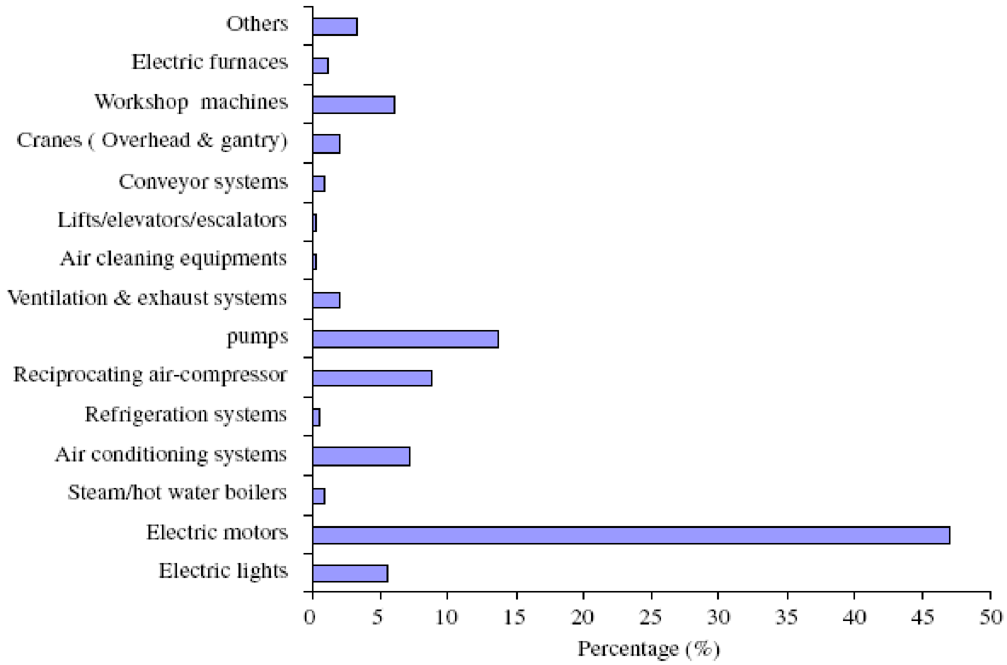


Figure 2.3 End use energy breakdowns in Malaysian industrial sector (Saidur *et al*., 2009b).

Taking into account the growing energy consumption and domestic energy supply constraints, Malaysian government formulated the National Depletion Policy in 1980 which set the daily limit of oil and gas production levels. In 2005 statistics show that oil reserves are expected to last another 19 years while natural gas reserves are expected to last for about 33 years, also this policy has set the concept of sustainable development and diversification of energy sources, as the economy‟s main energy policy goals. The Five-Fuel Strategy has recognizes renewable energy resources (RE) as the economy‟s fifth fuel after oil, coal, natural gas and hydro in the long term. Nevertheless, substantial governmental intervention and support are necessary to implement this policy (APEC, 2006).

Another way that has been introduced by the Malaysian government to deal with this phenomenon is by introducing the concept of improving energy efficiency, which means using less energy while keeping the same level of service (Saidur *et al.*, 2009a).

2.3 Variable speed drive

2.3.1 Introduction:

A variable speed drive can be defined as an electronic power converter that generates a multi-phase, variable frequency output that can be used to drive a standard ac induction motor, and to modulate and control the motor‟s speed, torque and mechanical power output (ECA energy technology criteria, 2009). AC drive can be described by different terms. AFD, variable speed drives (VSD), VFD and inverters all are employed, but have the same meaning. VSD‟s have been used to provide significant savings in a number of applications around the world (Saidur *et al*., 2009b).

The EU-funded SAVE II Project identified large-scale application of variable-speed drives as the motor systems technology having the most significant energy savings potential. Savings within the electrical drive system alone are projected to be 6 billion kWh per annum in the UK (Mecrow and Jack, 2008).

2.3.2 Benefits of Variable speed drive.

There are many and diverse reasons for using variable speed drives. Some applications, such as paper making machines, cannot run without them while others, such as centrifugal pumps, can benefit from energy savings. Generally, variable speed drives are used to match the speed of a drive to the process requirements, match the torque of a drive to the process requirements and save energy and improve efficiency. The affinity Laws (also called the cubic Laws) states that pump output or flow are directly proportional to the speed of the pump. Static pressure is proportional to the fan speed squared, and pump required HP is proportional to the pump speed cubed. Therefore, according to the Affinity Laws of speed, pressure, and horsepower, to produce 50% flow, the pump would be run at 50% speed. At this operating point, the pump would produce 25% of rated pressure (0.5 X 0.5 = 0.25), and would require only 12.5% of rated horsepower (0.5 X 0.5 X 0.5 = 0.125 or 12.5%) which is regarded as a significant energy saving (Lönnberg, 2007). VSD also offers a significant annual bill saving and emissions reduction; for example, the food manufacturer Northern Foods in the UK has implemented VSD and achieved an annual energy saving of 769 MWh/year, over £30,000 saving a year in electricity costs, payback period of just 10 months and annual CO_2 reduction of 338 ton (Tolvanen, 2008).

From a mechanical benefit standpoint, bearings run at reduced speeds typically last much longer than their full speed counterparts. Also, drives inherently "soft start" the driven mechanical equipment. This soft start extends not only the life of the motor and bearings, but also drastically reduces belt wear and tear to achieve more reliability the additional time periods between maintenance or breakdowns can be accurately computed. (Tolvanen, 2008).

2.3.3 Variable speed control system

The speed of a motor can be adjusted by two ways, firstly by changing the frequency which is applied to the motor or by changing the number of poles, but this is a physical change to the motor. It would require rewinding, and result in a step change to the speed. Thus, changing the frequency of the motor is the best solution for more convenience, cost efficient and précised design. In order to change the motor torque the volts per Hertz ratio (V/Hz) must be changed. A drive provides many different frequency outputs. At any given frequency output of the drive, it gets a new torque curve. In order to obtain constant maximum torque, the ratio of applied motor voltage to supply frequency (V/Hz) is held constant by increasing motor voltage directly with frequency. This type of control is generally termed constant volts per Hertz. One of the many possible circuits to control the speed of an induction motor is schematically represented in Figure 2.4 (Ozdemir, 2004).

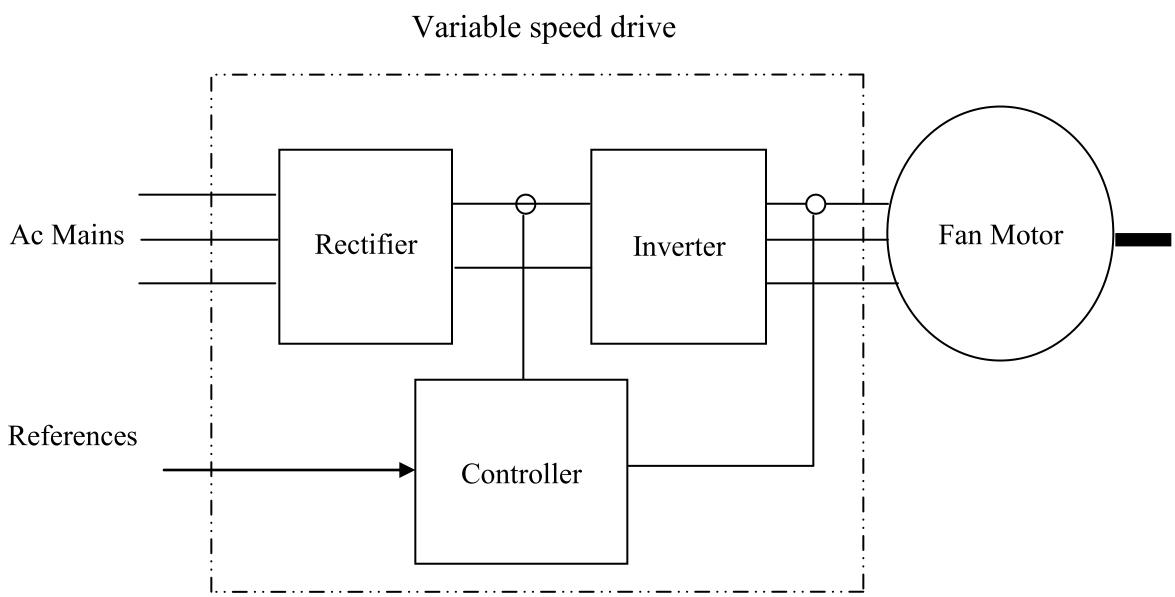


Figure 2.4 The block diagram of the variable speed drive system (Ozdemir, 2004).

2.3.4 Energy saving through VSD

The benefits of energy savings are not always fully understood by many people. These savings are particularly apparent with centrifugal pumps and fans, where load torque increases as the square of the speed and power consumption as the cube of the speed. Substantial cost savings can be achieved by VSD in some applications.

Many users favor traditional control methods because these methods are easy to implement and straightforward to understand. Many of those same users justify their approach by assuming that the cost of the wasted energy is less than that of buying a VSD. However, this is not true. Unlike much other energy saving methods that may only reduce energy consumption by one or two percent, the significant savings produced by a VSD means payback is often achieved in a year or less. The application will then continue to make a significant contribution to energy savings, year after year, for as long as it remains in use (Tolvanen, 2007).

The energy saved by retrofitting a boiler system by running variable frequencies translates easily to dollars. For example, a 50 hp motor operating at a slower speed and utilizing only 40 hp, 12 hours per day, 365 days per year, with a load factor of one and motor efficiency of 86%, will save $3,360 per year (based on $0.10/kWh) (Willems and Pipkin, 2009).

Engin Ozdemir (2004) shows in his study that In order to improve the boiler efficiency, a fan motor speed is decreased from 1450 to 255 rpm by using variable speed drive (VSD) to reduce the amount of excess air that is not needed in low loads. After implementation of the VSD, the results obtained were a reduction in stack temperature from 195 to 145 °C, increasing of the boiler efficiency 2.5%, 8000 kWh electrical energy saving in a month and payback period of 1.8 month. Table 2.1 shows some measured electrical values such as speed, voltage, frequency, current and power before and after variable speed drive application.

Table 2.1 Measured electrical values after and before variable speed drive application (Ozdemir, 2004).

Value	Without variable frequency control application	With variable frequency control application
Speed (rpm)	1,460	255
Voltage (V)	380	31
Frequency	50	8.5
Current (A)	25	8
Power (W)	13,500	365

Another example of VSD, is when a fan motor speed is slowed by 50%, an 80% electrical energy savings is achieved (Ozdemir, 2004). Table 2.2 shows the potential energy savings associated with the speed reduction using VSD for industrial motors (Saidur *et al*., 2009b).

Table 2.2 Potential saving of VSD when reducing the speed (Saidur *et al*., 2009b).

Average speed reduction (%)	Potential energy saving (%)
10	22
20	44
30	61
40	73
50	83

2.3.5 Potential of using VSD in industrial boilers:

In boilers some auxiliary equipment such as feedwater pumps, boiler draft fans and hot water circulating pumps consume an appropriate amount of energy. Therefore, significant energy savings can be done by ensuring that they are operated only when required and at the capacity required to maintain system requirements. Generally, each boiler has its own feedwater pump, which is automatically switched off and on to maintain the level water in the boiler. Their operation is interlocked with the boiler so that the feedwater pump is switched off when the boiler is not in operation (Jayamaha, 2006).

In larger systems, multiple boilers can be served by a common set of feedwater pumps, as shown in Figure 2.5 in such an arrangement, individual boilers take the required water flow by opening and closing the feedwater valves to maintain the water level in the boilers. The excess water is returned to the feedwater tank, which results in wastage of pumping energy (Jayamaha, 2006).

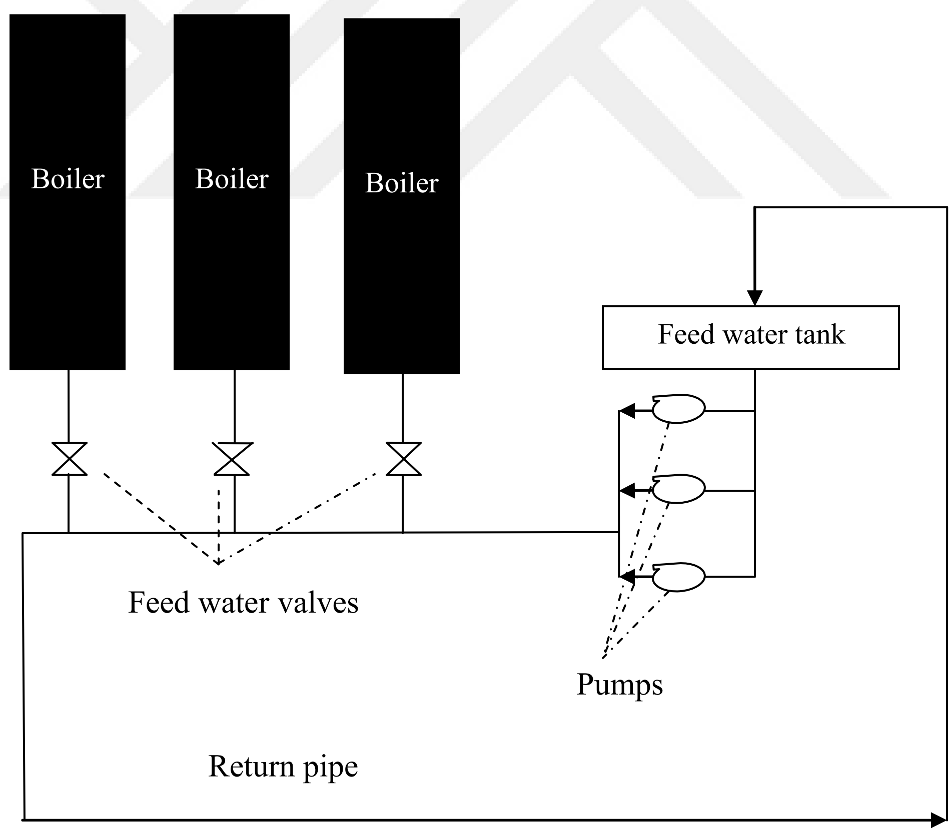


Figure 2.5 Feed water pump arrangement for a multiple boilers (Jayamaha, 2006).

This system can be improved to reduce the energy consumption of the pumps by varying the capacity (speed) of the feedwater pumps, which helps maintain a set pressure in the feedwater header pipe, as shown in Figure 2.6. A pressure-activated valve (normally closed) can be installed on the return pipe as a safety measure, so that it opens if the pressure exceeds a set value (which may occur due to failure of the pump control system) (Jayamaha, 2006).

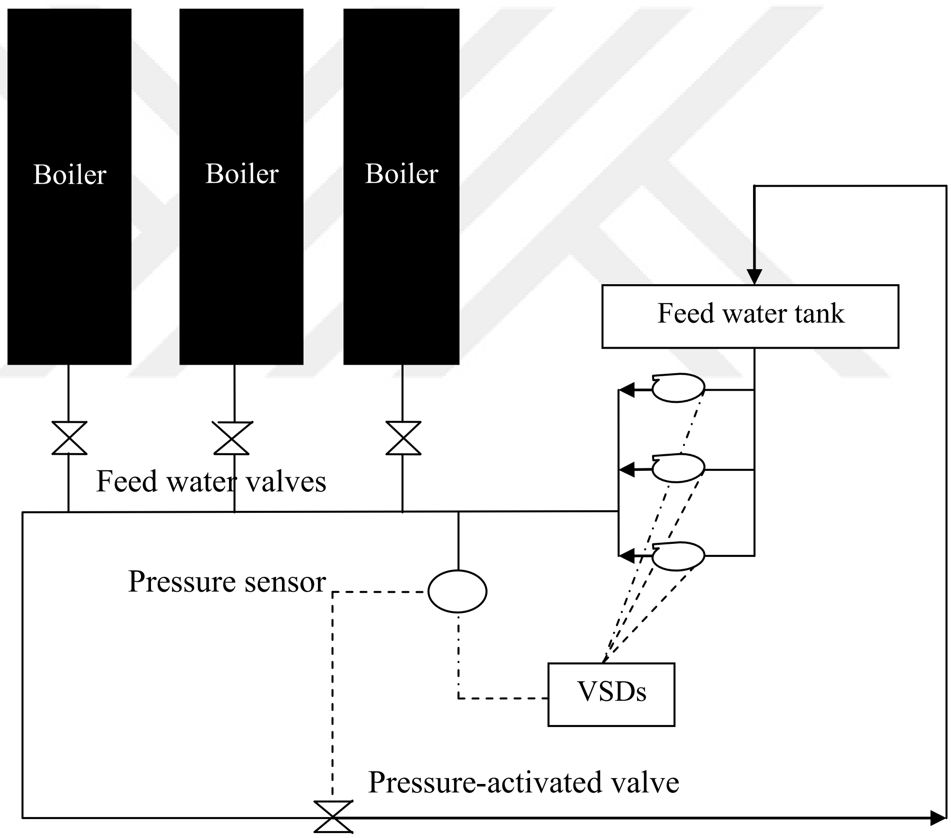


Figure 2.6 Suggested feed water pump arrangement for a multiple boilers operation (Jayamaha, 2006).

The application of this energy saving procedures depends mainly on the load variation of the boiler. If the load is highly variable and results in the boiler operating at low loads for long periods of time, incorporating variable speed drives in boilers represents a good choice to be implemented (Jayamaha, 2006). Payback periods is an another factor to judge the economical viability of installing variable speed drives in pumps. Variable speed drives seem very cost-effective as their payback period is less than one third of the motor life which is estimated to be 20 years as an average (Saidur, 2009c).

2.4 Fuel switching

2.4.1 Introduction and benefits of fuel switching

Fuel switching can be defined as an emission control measure that involve the exchange of a less pure fuel to a cleaner one, also it can be defined as the use of alternative fuel or the substitution of one type of fuel for another, especially the use of a more environmentally friendly fuel as a source of energy in place of a less environmentally friendly one. This will help to reduce energy cost and emissions production. In Malaysia it has been found that the gradual fuel substitution for electricity generation from harmful fossil fuels to less harmful fuels such as natural gas and renewable fuels such as hydro and biomass will contribute to CO_2 reduction for about 167,618,280 ton from 2001-2020 as shown in Figure 2.7 (Masjuki *et al.*, 2002).

In Europe, it has been found that when switching a modern coal-fired plant into a gas-fired plant in different eight European countries including Germany, Netherlands, Spain, Belgium, Italy, Portugal, Switzerland and France, a GHG emission reduction of 19.4% can be attained in the eight modeled zones (Delarue and D‘haeseleer, 2009). Mahmoud *et al.*

(2009) showed in their study that switching crude oil pre-heat train to natural gas has achieved a satisfactory target emissions reduction of 32.7%.

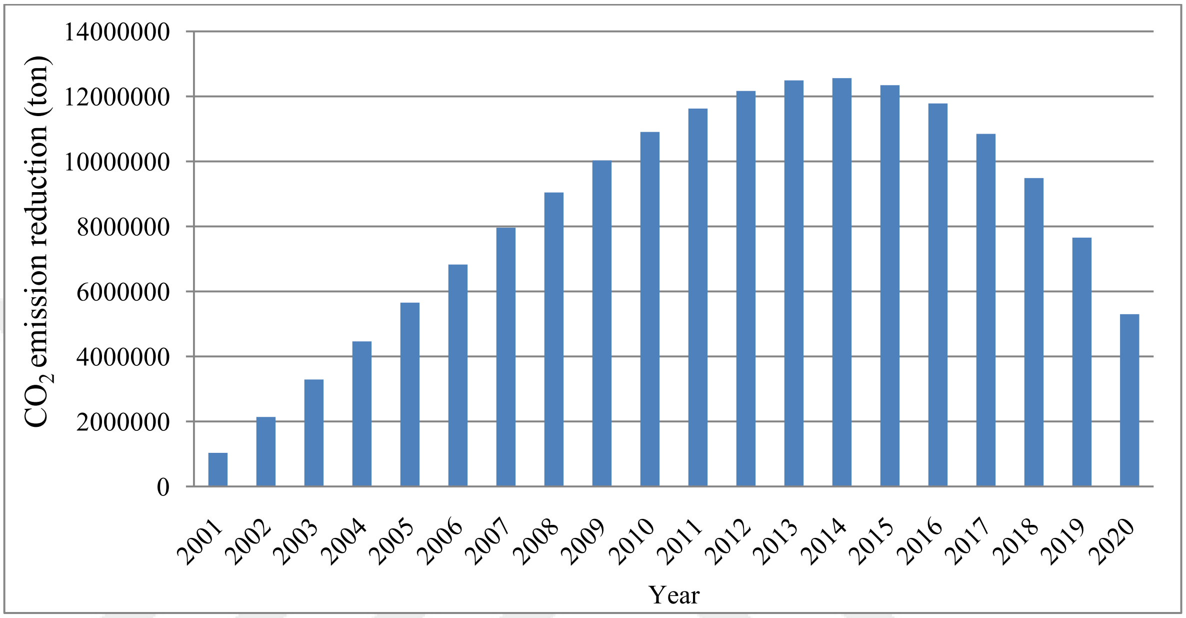


Figure 2.7 Potential CO_2 reduction due to the changes of energy sources for electricity generation in Malaysia (Masjuki *et al.*, 2002).

2.4.2 Conditions of implementing fuel switching

For the switching to occur, several conditions have to be fulfilled. First, an economical incentive must be present for customer, which means alternative fuels must be offered in a good and competitive price in comparison to conventional types. Second, the physical and technical potential to implement fuel switching approach must exist such as dispatchability factor and technical modifications to the prime mover to suite the proposed type of alternative fuel (Delarue and D‟haeseleer, 2009; Eggertson, 2006).

2.4.3 Possible alternative fuels in Malaysia

It is known that global warming and other environmental problems are by far the greatest threat and challenge in the new millennium. In order to prevent global warming, acid rain, soil erosion, water pollution, provide cost effective method and to maintain sustainable development, renewable energy has been suggested as an ideal solution to achieve both goals. Malaysia has promoted renewable energy resources as a fifth fuel in the eighth Malaysia Plan period (2001–2005). Biomass has been suggested as a clean source of energy that can replace conventional fuels such as oil or at least reduce the dependency on these harmful fuels (Jaafar *et al.*, 2003; Demirbas, 2005).

2.4.3.1 Introduction of biomass

Biomass is the name given to the all earth‟s living matter and is the general term for material derived from growing plants or from animal manure. It is a rather simple term for all organic materials that seems from plants, trees, crops and algae. Biomass as the solar energy stored in chemical form in plant and animal materials is among the most precious and versatile resources on earth. The components of biomass include cellulose, hemicelluloses, lignin, extractives, lipids, proteins, simple sugars, starches, water, HC, ash, and other compounds (Demirbas, 2005). There are many types of biomass; Figure 2.8 shows some common types of biomass.

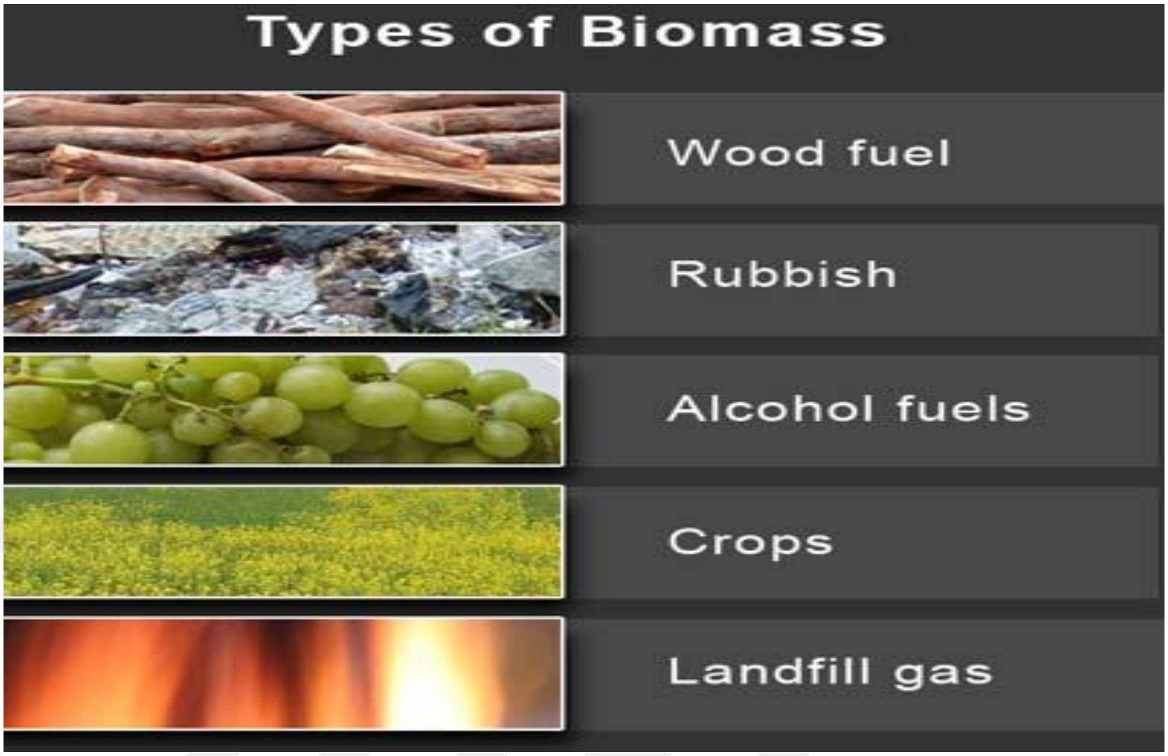


Figure 2.8 Types of biomass

2.4.3.2 Benefits of biomass

There are many benefits of using biomass including:

(i) Economic benefits: biomass could replace some of the money spent on oil.

(ii) Environmental benefits including:

• Preservation of agricultural land that otherwise would be sold for residential development or industrial use.

• Sustainable agricultural techniques for these crops can restore and ensure soil stability and health and minimize chemical residues and habitat destruction.

• Methane is 20 times more powerful greenhouse than CO_2. Capturing methane from producers such as cows or rice fields and using it as fuel will significantly reduce this greenhouse gas.

• Increased carbon sequestering from the crops grown for biomass.

• Use of waste from agricultural and timber industries.

• No net increase in atmospheric carbon dioxide.

2.4.3.3 Availability of biomass in the world and Malaysia

Biomass is an attractive renewable fuel to supplement fossil fuels in energy demand because it is readily available around the world. In 1995 the percentage share of biomass was 62.1% of total renewable energy sources as shown in Table 2.3. Currently biomass accounts for 35% of primary energy consumption in developing countries, raising the world total to 14% of primary energy consumption higher than that of coal (12%) and comparable to those of gas (15%) and electricity (14%). The importance of biomass in different world regions is given in Table 2.4 (Demirbas, 2005).

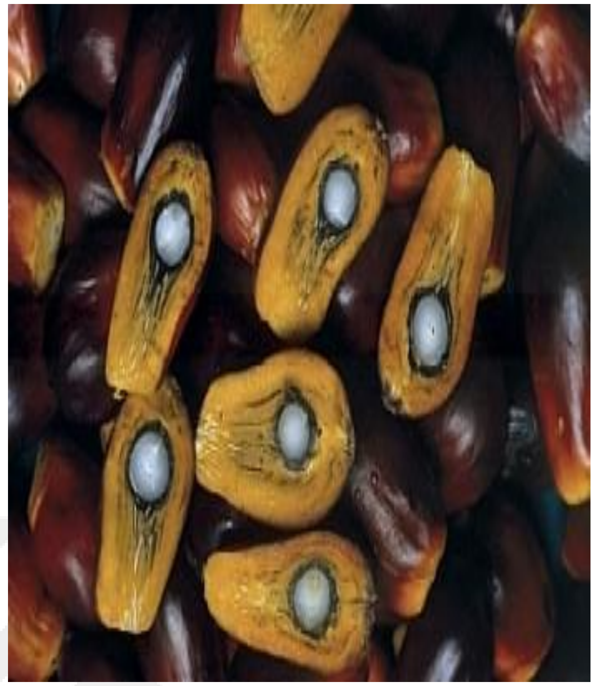
Table 2.3 Percentage share of each renewable energy source in 1995 (Demirbas, 2005).

Resource	Percentage %
Biomass	62.1
Hydro	33.6
Geothermal	3.2
Wind	0.7
Solar	0.4

Table 2.4 The Percentage of biomass in different world regions (Demirbas, 2005).

Region	Share of biomass in final energy consumption %
Africa	60.00
South Asia	56.30
East Asia	25.10
China	23.50
Latin America	18.20
Europe	3.50
North America	2.70
Middle East	0.30

In Malaysia there is a good potential of using palm oil as a resource of biomass. The first commercial oil palm estate in Malaysia was set up in 1917 at Tennamaran Estate, Selangor. Figure 2.9 shows oil palm tree, oil palm fruit and oil palm biomass (Sumathi *et al*, 2008). Currently palm oil represents 85.5% of total biomass production in Malaysia as shown in Figure 2.10. Presently million hectares of land in Malaysia is occupied with oil palm plantation generating huge quantities of biomass. Malaysia is regarded as the second largest producer of palm oil with 15.88 million tonnes which represents 43% of the total world supply as shown in Figure 2.11 Indonesia is the world‟s largest producer of palm oil with 15.9 million tonnes of oil or 44% of the total world supply. In 2007, plantations of oil palm in Malaysia are 4.3 million hectares, a 3.4% increase from year 2006 which stood at 4.2 million hectares (Shuit *et al.*, 2009).



Oil palm tree Oil palm fruit

Oil palm biomass

Figure 2.9 Pictures of oil palm tree, oil Palm fruit and oil palm biomass (Sumathi *et al*, 2008)

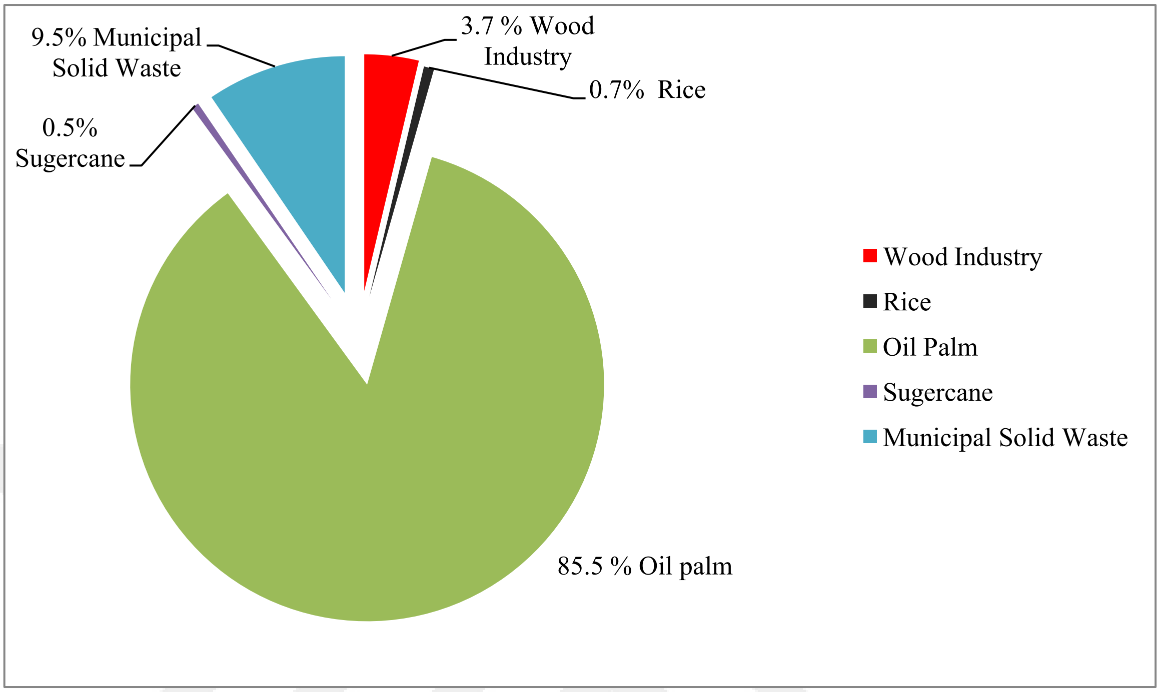


Figure 2.10 Biomass produced from different industry in Malaysia (Shuit *et al.*, 2009).

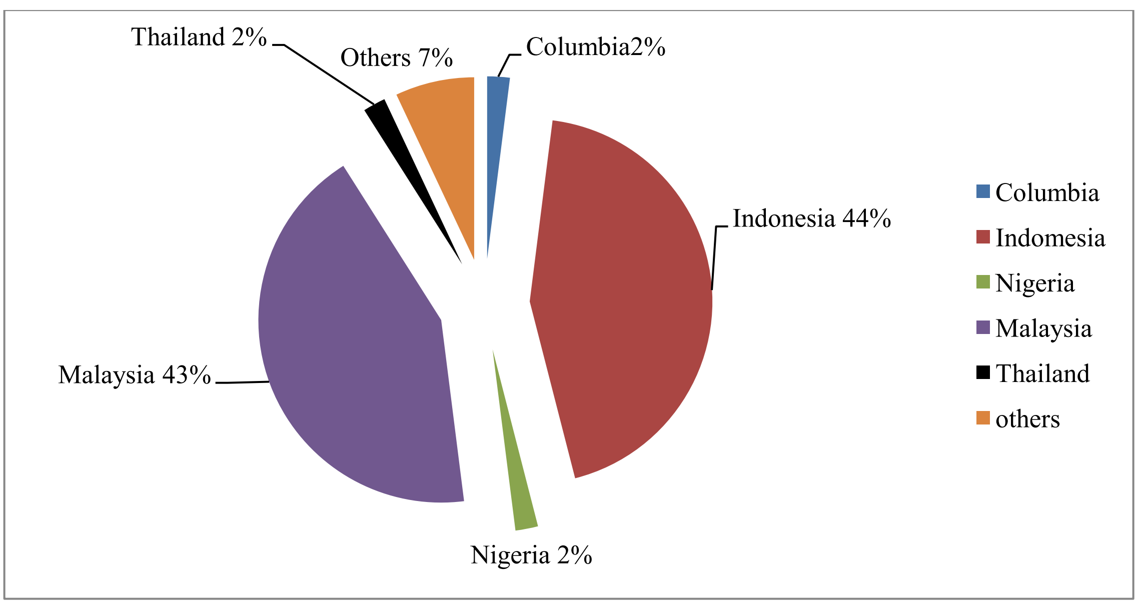


Figure 2.11 Top world producers of oil palm in 2006 (Shuit *et al.*, 2009).

The cultivation of oil palm has been increasing in Malaysia. Figure 2.12 shows evolution of oil palm plantation area from 1975 to 2006. The increase in oil palm plantation area in Malaysia is mainly because of growing global demand for edible oil especially palm oil (Shuit *et al.*, 2009).

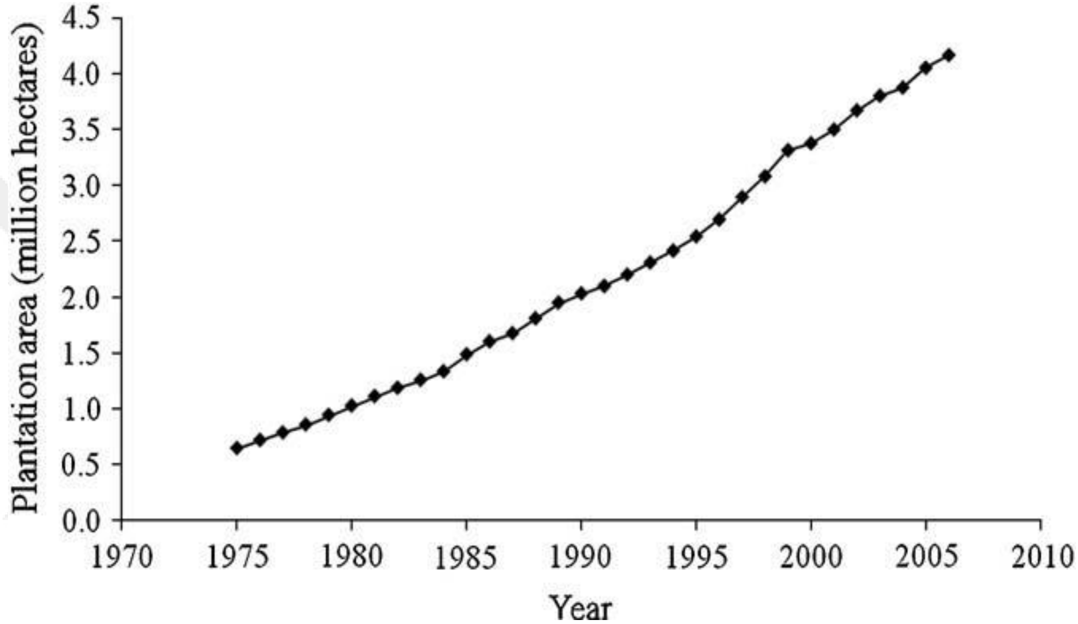


Figure 2.12 Plantation area of oil palm in Malaysia from 1975 to 2006 (Shuit *et al.*, 2009).

2.4.3.4 Sustainability and quality of oil biomass in Malaysia

Sustainability of palm oil In Malaysia is judged by a body called Roundtable on Sustainable Palm Oil (RSPO). This body defines sustainable palm oil production as a legal, economically viable, environmentally appropriate and socially beneficial management and operations.

The environmental sustainability of oil palm biomass comes from when burning it to generate energy. Based on current typical industry practices for palm oil production in

Malaysia, using palm oil for bio-fuel applications renders an average net CO_2 reduction of approximately 60%. In other words, the CO_2 emissions incurred in the palm oil supply chain are roughly 40% of the CO_2 emissions avoided by replacing fossil fuels (Zutphen and Wibrans, 2007). This will alleviate a certain amount of carbon that otherwise would have been released to the environment by burning fossil fuels alone even if the biomass has to be transported from a distance far away. Another factor is that biomass is a waste product and can be utilized to reduce the country dependence on fossil fuel and ensure sustainable source of fuel, since biomass are renewable. Recently some studies have shown that oil palm plantations are more effective carbon sink (an area of dry mass that is capable to absorb harmful greenhouse gases such as carbon dioxide) comparing to rainforest. Oil palm plantation assimilates up to 64.5 tonnes of carbon dioxide per hectare per year while virgin rainforest only can assimilate 42.2 tonnes per hectare per year (Shuit *et al.*, 2009).

Utilization of oil palm biomass could also ensure social sustainability by creating new employment opportunities in rural areas in the developing country like Malaysia. This is because labor requirement for biomass energy is relatively high, especially in the cultivation of energy crops (Shuit *et al.*, 2009).

Malaysia"s palm oil industries are really committed towards sustainable palm oil production and development since Malaysia has always been an active member of RSPO with government agencies and private companies taking vital roles and position in the organization. Malaysia has definitely practiced the principles and criteria stated in RSPO that will make sure of sustainable development in oil palm plantation and production (Shuit *et al.*, 2009).

2.4.4 Malaysian national biodiesel policy and its benefits

The strategies of the National biofuel Policy in Malaysia can be categorized into short, medium and long terms. On a short term basis, the Malaysian government is trying to establish Standard specifications for palm oil-based fuel for domestic use as well as for export.

The introduction of biofuel as a source of energy will directly reduce the dependency on fossil fuel. The palm oil will also reduce imports of petroleum diesel to directly translate as the reduction in foreign exchange. The Malaysia‟s economy will benefit through the creation of new markets of palm oil locally and overseas. For example, blending 5% of processed palm oil with diesel will create new demand for 500,000 tonnes of palm oil which is equivalent to 40 – 50% of the current national stock of palm oil (Abdullah *et al.*, 2009) Figure 2.13 shows immediate and long term benefits of the National biofuel policy.

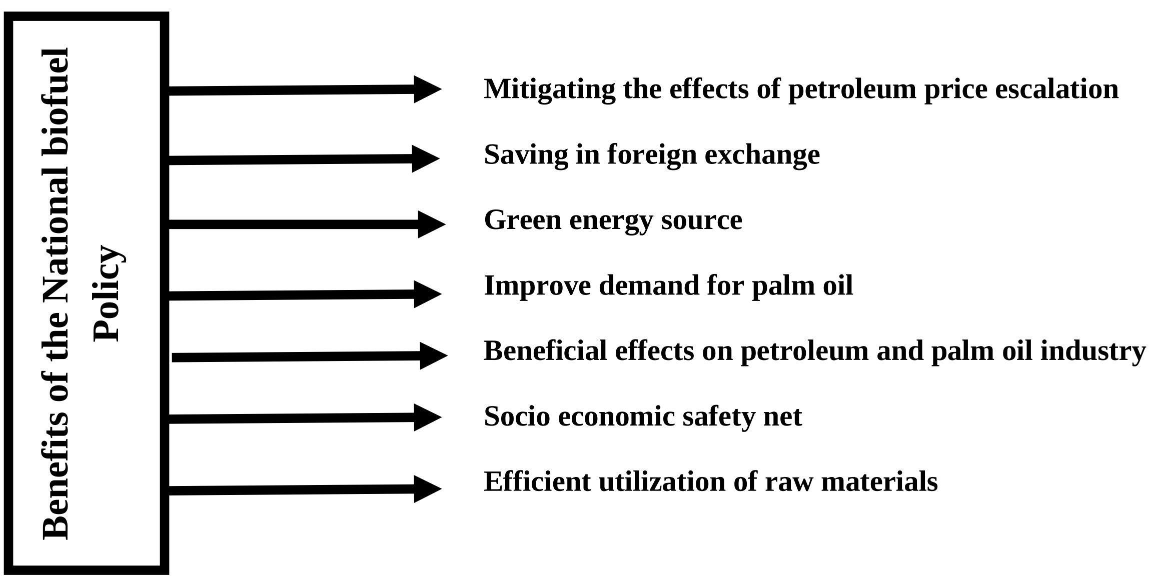


Figure 2.13 Immediate and long term benefits of the National biofuel Policy (Abdullah *et al.*, 2009).

2.4.5 Possibility of fuel switching in the industrial boilers sectors in Malaysia

Many modern boilers are the dual-fuel type and can operate on different fuels like fuel oil, gas or biomass. Since most of the cost of operating a boiler plant is accounted for by fuel cost, switching between fuels can help reduce energy cost (Jayamaha, 2006).

The cost of fuels, such as oil and gas, can vary depending on seasonal factors and due to other reasons. Therefore, a particular fuel may not be the most economical to use at all times and switching between fuels can help minimize fuel cost (Jayamaha, 2006).

The switch over from one fuel to another can be done manually by plant operators or automatically in some boilers. The decision on when to switch should be used based on cost can made by comparing the cost of fuel per unit heat content. The heat content of fuels vary depending on factors such as their composition, but the actual heat content of a particular fuel used can normally be obtained from the fuel supplier (Jayamaha, 2006).

2.5 Waste heat recovery from flue gas by economizer

2.5.1 Introduction:

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved (Bureau of Energy Efficiency, 2009).

Economizer is a device used to recover the waste heat from the flue gas and consists of a series of horizontal tubular elements and can be characterized as bare tube and extended surface types. The bare tube usually includes varying sizes which can be arranged to form hairpin or multi-loop elements. Tubing forming the heating surface is generally made from low-carbon steel (Zeitz, 1997).

2.5.2 Benefits of economizers

Benefits of waste heat recovery can be broadly classified in two categories:

2.5.2.1 Direct Benefits:

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected by reduction in the utility consumption & costs, and process cost.

2.5.2.2 Indirect Benefits:

a) Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc, releasing to atmosphere when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.

b) Reduction in equipment sizes: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipments such as fans, stacks, ducts, burners, etc.

c) Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc (Bureau of Energy Efficiency, 2009).

2.5.3 Criteria of using economizers

It is necessary to assess the benefits of using economizer on the basis of financial analysis such as investment, depreciation, payback period, rate of return etc. In addition to, how much the stack temperature can be reduced the inlet temperature of the fluid to be heated, and the operating hours of the boiler. Generally, the possible reduction in flue gas temperature should be at least 25 to 30°c to make it economically viable to install a heat recovery system. Also the advice of experienced consultants and suppliers must be obtained for rational decision (Bureau of Energy Efficiency, 2009).

2.5.4 Potential of heat recovery in boilers

The efficiency of a boiler itself is commonly measured using the input/output (fuel-to-steam) calculation where the fuel input and steam output are measured over a period of time and the work done in the form of steam generated is divided by the heat added in the form of fuel. These efficiencies are typically in the area of 75-85% depending on the type of fuel burned, operating pressure, inherent boiler design, and control system capability (Willems, 2009). However losses from steam piping, surface blow down, bottom blow down, deaerator venting, poor combustion repeatability, changes in stack O_2 levels, fan losses, etc. must be determined.

A significant amount of heat energy is lost through flue gases as all the heat produced by the burning fuel cannot be transferred to the water or stream in the boiler. As the temperature of the flue gas leaving a boiler typically ranges from 150 to 250°c, about 10 to 20 percent of the heat energy is lost through it (Jayamaha, 2006).

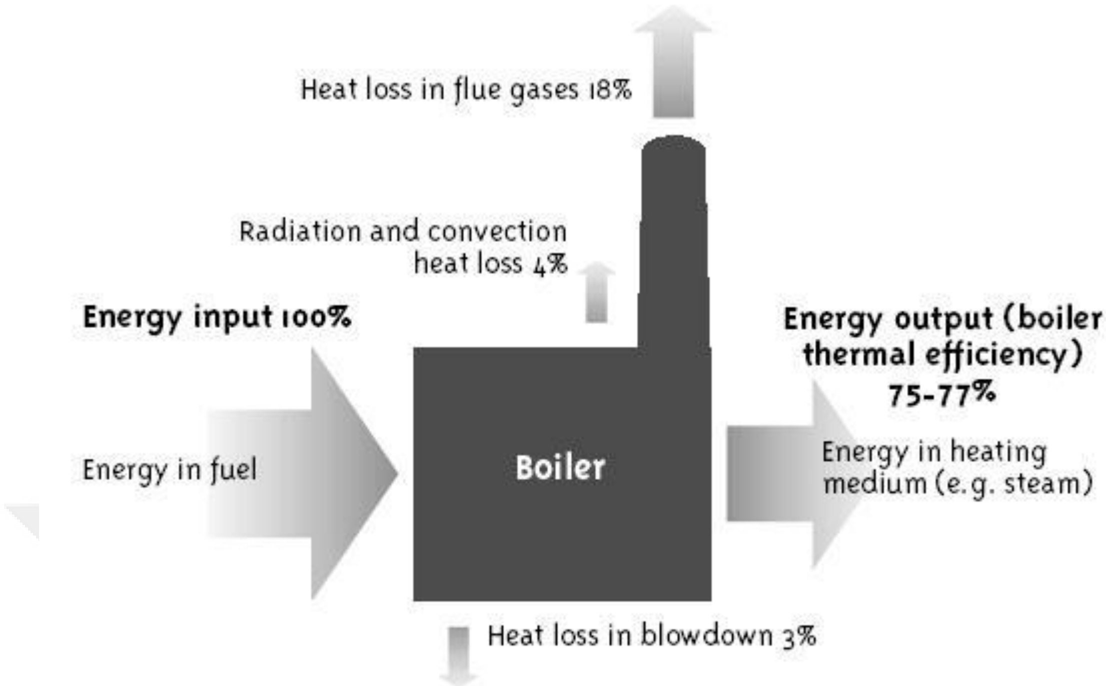


Figure 2.14 Typical heat losses (Willems, 2009).

Figure 2.14 shows typical heat losses from an industrial boiler. As indicated, the average boiler efficiency of industrial boilers in 75-77% and 23-25% of the energy input is lost in the form of blowdown, radiation, convection and hot flue gas (Willems, 2009).

Therefore, recovering part of the heat from flue gas can help to improve the efficiency of the boiler. Heat can be recovered from the flue gas by passing it through a heat exchanger (commonly called an economizer) installed after the boiler, as shown in figure 2.15 and 2.16 the recovered heat can be used to preheat boiler feedwater, combustion air, or for other applications. The amount of heat recovered depends on the flue gas temperature and the temperature of the fluid to be heated (Jayamaha, 2006).

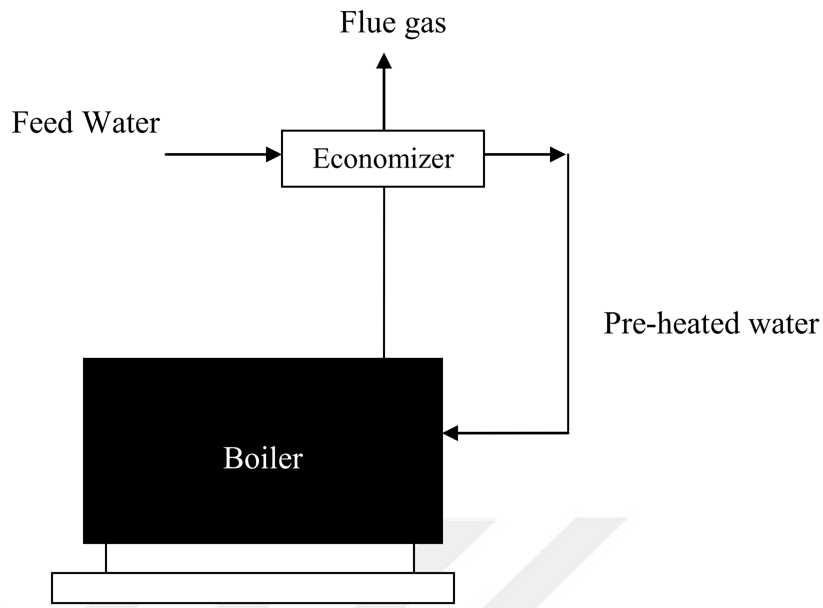


Figure 2.15 Arrangement of a typical economizer (Jayamaha, 2006).

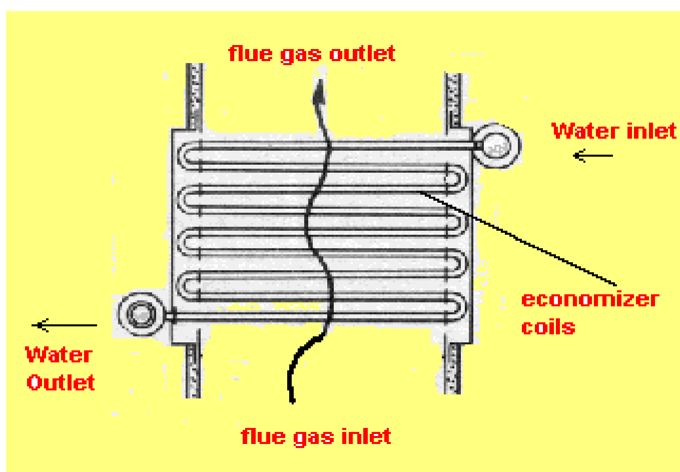


Figure 2.16 Economizer (Bureau of Energy Efficiency, 2009).

Typically, the flue gases leaving a modern 3-pass shell boiler are at temperatures of 200 to 300 ^{o}C. Thus, there is a potential to recover heat from these gases. The flue gas exit temperature from a boiler is usually maintained at a minimum of 200 ^{o}C, so that the sulphur oxides in the flue gas do not condense and cause corrosion in heat transfer surfaces. When a clean fuel such as natural gas, LPG or gas oil is used, the economy of heat recovery must be worked out, as the flue gas temperature may be well below 200 ^{o}C

The potential for energy saving depends on the type of boiler installed and the fuel used. For a typically older model shell boiler, with a flue gas exit temperature of 260 ^{o}C, an economizer could be used to reduce it to 200 ^{o}C, increasing the feed water temperature by 15 ^{o}C. Increase in overall thermal efficiency would be in the order of 3%. For a modern 3-pass shell boiler firing natural gas with a flue gas exit temperature of 140 ^{o}C a condensing economizer would reduce the exit temperature to 65 ^{o}C increasing thermal efficiency by 5% (Bureau of Energy Efficiency, 2009).

For every 22^{0} C reduction in flue gas temperature by passing through an economizer or a pre-heater, there is 1% saving of fuel in the boiler depending on the type of heat transfer surfaces and the allowable pressure drop. In other words, for every 6^{0} C rises in feed water temperature through an economizer, or 20^{0}C rise in combustion air temperature through an air pre-heater, there is 1% saving of fuel in the boiler (Bureau of Energy Efficiency, 2009). Economizers typically increase boiler efficiency by 5% to 30% adding an economizer can result in saving of $13,000 – $21,000 per year (Willems and Pipkin, 2009; U.S. Department of energy, 2005).

Another example of heat recovery potential in boilers is for an average flue gas temperature of 205°c, the use of heat exchanger between flue gas and the boiler feedwater in a finned tube economizer will allow the flue gas to be cooled to 120°c. For an average price of RM 0.01 per MJ, approximately 5.1% of energy can be reduced through the use of this technology. This represents saving of RM 25,800 (Manan, 2003)

Since economizer induce extra pressure losses on the flue gas and the liquid being heated, care should be taken to ensure that the combustion fan and the pump for the liquid being heated have adequate capacity to overcome these losses

CHAPTER 3

METHODLOGY

3.1 Introduction

Research methodology is a crucial factor to bring in an effective research with accredited results. It can be defined in many ways such as procedures, ways, methods and techniques that are applied to incorporate and gather all relevant information for the research.

This chapter explains how the whole research was conducted and shows the methods by which energy saving, emission reduction and cost benefits analysis have been calculated when applying variable speed drive, fuel switching and heat recovery systems in the industrial paper and pulp sector in Malaysia.

3.2 Variable speed drives:

3.2.1 Targeted manufacturing factories and Audit data collection

The targeted pulp and paper industries in this section have been taken from a previous survey that focused on the overall industrial sector in Malaysia in different regions within Peninsula Malaysia as shown in Table 3.1. The results of the energy audit are shown in Table 3.2.

Table 3.1 Locations and number of audited factories in all Malaysian industrial sectors (Saidur, 2009b).

Location	Number of audit factories
Central (Selangor, Kuala Lumpur)	41
North (Perak, Penang, Kedah and Perlis)	25
South (Johor, Melaka and Negeri Sembilan)	14
East (Pahang and Terengganu)	11
Total (East coast of Malaysia)	91

Table 3.2 Results of industrial Malaysian energy audit (Saidur, 2009b).

No	Pumps output power (HP)	Pumps quantity	Pump speed (rpm)	Operating hours	Pumps efficiency
1	15	165	3600	6000 Hours	95%
2	20	3306	3600		
3	25	992	3600		
4	30	331	3600		
5	40	661	3600		
6	50	331	3600		
7	60	827	3600		
8	75	165	3600		

Based on the fact that boilers represent 1% of the overall Malaysian industrial sector‟s consumption as previously shown in Figure 2.3 (Saidur, 2009b) and on the assumption that paper and pulp industries represent about 40% of boilers electricity consumption (PTM, 2009). The results of energy audit for paper and pulp sector are shown in Table 3.3 below.

Table 3.3 Results of energy Audit for paper and pulp sector

No	Pumps output power (HP)	Pumps quantity	Pump speed (rpm)	Operating hours	Pumps efficiency
1	15	1	3600	6000 Hours	95%
2	20	13	3600		
3	25	4	3600		
4	30	1	3600		
5	40	3	3600		
6	50	1	3600		
7	60	3	3600		
8	75	1	3600		

3.2.2 Energy saving when using VSD

Annual energy consumption of water pumps without using variable speed drive can be expressed mathematically from the following equation:

$$AEC_{BAU} = \frac{P_{Hp} \times 0.7456 \times N_{pumps} \times OPH}{\eta_{pump}} \quad \text{(3.1)}$$

Annual energy consumption when using variable speed drive depends on annual energy consumption without using VSD and speed reduction ratio. This can be calculated from the following equation:

$$AEC_{NP} = AEC_{BAU} \times (1 - SR_{ratio})^3 \quad \text{(3.2)}$$

Annual energy saving when using VSD is therefore the difference between annual energy consumption without using VSD and annual energy consumption when using VSD. The annual energy saving equals:

$$AES_{VSD} = AEC_{BAU} - AEC_{NP} \quad (3.3)$$

Thus energy saving percentage (%) can be calculated as follow:

$$\% \, VSD_{ES} = \frac{\mathrm{AES_{VSD}}}{AEC_{BAU}} \quad (3.4)$$

3.2.3 Emission reduction when using VSD

The environmental impact of the VSD is a potential reduction of greenhouse gasses or other element that have a negative impact on the environment. The common potential reductions in this study include carbon dioxide CO_2, sulfur dioxide SO_2, nitrogen oxide NO_x and carbon monoxide CO. This study is concern with all these emissions. The emission factors of all these gases and the percentage of electricity generation based on fuel types are shown in the Table 3.4 and 3.5.

Table 3.4 Emission factors of fossil fuels for electricity generation (Mahlia, 2002)

Fuels	Emission factor (kg/kWh)			
	CO_2	SO_2	NO_x	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Gas	0.53	0.0005	0.0009	0.0005
Hydro	0.00	0.0000	0.0000	0.0000
Others	0.00	0.0000	0.0000	0.0000

Table 3.5 Percentage of electricity generation based on fuel types (Mahlia. 2002)

Fuel type	Coal	Petroleum	Gas	Hydro
Percentage	15.00%	5.00%	70.00%	10.00%

The emissions reduction is a function of energy saving, percentage of fuel used and emission factor of the particular fuel. Thus emissions reduction can be calculated using the following equations:

$$AER_{CO2} = AES_{VSD} \times \sum(\%F \times EF_{CO2}) \quad (3.5)$$

$$AER_{SO2} = AES_{VSD} \times \sum(\%F \times EF_{SO2}) \quad (3.6)$$

$$AER_{NOx} = AES_{VSD} \times \sum(\%F \times EF_{NOx}) \quad (3.7)$$

$$AER_{CO} = AES_{VSD} \times \sum(\%F \times EF_{CO}) \quad (3.8)$$

3.2.4 Cost benefit analysis when using VSD

When using VSD annual bill saving is related to annual energy saving and the unit price of energy. The formula that associated with the above cost savings method can be calculated as:

$$ABS_{VSD} = AES_{VSD} \times UEP \quad (3.9)$$

Table 3.6 Incremental costs of VSD (Saidur, 2009b)

Pump power (HP)	Incremental cost (USD)
15	4,331
20	5,195
25	6,060
30	6,925
40	8,655
50	10,385
60	12,114
75	14,709

Payback period is the function of the incremental cost of VSD divided by the annual bill saving of VSD in a particular year. Incremental prices of VSD are shown in Table 3.6 Thus

Payback period can be expressed mathematically from the following equation:

$$PBP_{VSD} = \frac{IC_{VSD}}{ABS_{VSD}} \quad \text{……………………………………………………..……………} \quad (3.10)$$

3.3 Fuel switching

3.3.1 Targeted manufacturing factories and audit data collection

The targeted pulp and paper industries in this section have been taken from PTM (Pusat Tenaga Malaysia) throughout a personal communication as shown in Table 3.7.

Table 3.7 Results of the industrial Malaysian energy audit (PTM, 2007)

Factory name	Location	Diesel consumption (Liter/year)
Tritex container	Selangor (Centre)	359,100
Cenpak holdings	Johor (South)	1,363,000
Orna paper	Melaka (centre)	102,000
Genting sanyen	Selangor (Centre)	1, 972,000
Malaysian newsprint	Pahang (North)	127,000
Kym industries	Selangor (Centre)	486,100
Total		4,409,200

3.3.2 Cost saving of fuel switching

In this study two types of fuels have been suggested to switch with diesel in Malaysian paper and pulp industries. In Malaysia biomass and natural gas represent a very good choice to switch with diesel especially biomass as an abundant source. Table 3.8 shows fuel price, density and energy content of diesel, natural gas and biomass.

Table 3.8 Prices, density and energy content of diesel, natural gas and biomass (PTM, 2009)

Fuel type	Unit fuel price	Density (kg/m^3)	Energy content (KJ/Kg)
Diesel	1.002 RM/Liter	0.85	45,000
Natural gas	0.6012 RM/Liter	0.717	55,000
Biomass	15 RM/Ton	N/R	6,000

N/R ≡ Not Required

When using diesel as the main source of energy (100%) in Malaysian paper and pulp‟s boilers the equations that used to calculate annual diesel energy consumption and fuel price are as follow:

$$ADC_{Kg} = ADC_L \times \rho_D \quad (3.11)$$

$$ADC_{KJ} = ADC_{Kg} \times DEC \quad (3.12)$$

$$ADC_{KWh} = \frac{ADC_{KJ}}{3600} \quad \text{(3.13)}$$

$$ADP_{RM} = ADC_L \times UFP_D \quad \text{(3.14)}$$

When switching between diesel, natural gas and biomass in these boilers, annual energy consumption and fuel prices of diesel, biomass and natural gas will be as follow:

$$ADCS_{KWh} = ADC_{KWh} \times \%D_{FS} \quad \text{(3.15)}$$

$$ANGECS_{KWh} = ADC_{KWh} \times \%NG_{FS} \quad \text{(3.16)}$$

$$ABECS_{KWh} = ADC_{KWh} \times \%B_{FS} \quad \text{(3.17)}$$

$$ADCS_L = \frac{ADCS_{KWh} \times 3600}{\rho_D \times DEC} \quad \text{(3.18)}$$

$$ADPS_{RM} = ADCS_L \times UFP_D \quad \text{(3.19)}$$

$$ANGCS_L = \frac{ANGECS_{KWh} \times 3600}{\rho_{NG} \times NGEC} \quad \text{(3.20)}$$

$$ANGPS_{RM} = ANGCS_L \times UFP_{NG} \quad \text{(3.21)}$$

$$ABCS_{Kg} = \frac{ABECS_{KWh} \times 3600}{BEC} \quad \text{(3.22)}$$

$$ABPS_{RM} = ABCS_{Kg} \times UFP_B \quad \text{(3.23)}$$

Thus, total bill saving when applying fuel switching equals to the result of subtracting annual diesel fuel price without switching from the summation of annual diesel, natural gas and biomass fuel price when switching. Total annual bill saving can be represented as follow:

$$TABS_{RM} = ADP_{RM} - (\ ADPS_{RM} + ANGPS_{RM} + ABPS_{RM}) \ \dots\dots\dots\dots \ (3.24)$$

3.3.3 Emissions reduction of fuel switching

The environmental impact of the fuel switching methods is a potential reduction of greenhouse gasses or other element that give negative impact to the environment. The common potential reductions include carbon dioxide CO_2, sulfur dioxide SO_2 and nitrogen oxide NO_x. This study is concern with all these emissions when using natural gas and just CO_2 when using biomass. The emission factors of all these gases have already been shown in the Table 3.4. The emissions production is a function of annual energy consumption and the emission factor of the particular fuel. Emissions production when burning diesel can be calculated as follow:

$$ADEP_{CO2} = ADC_{KWH} \times \ EF_{CO2} \ \dots\dots\dots\dots \ (3.25)$$

$$ADEP_{NOx} = ADC_{KWH} \times \ EF_{NOx} \ \dots\dots\dots\dots \ (3.26)$$

$$ADEP_{SO2} = ADC_{KWH} \times \ EF_{SO2} \ \dots\dots\dots\dots \ (3.27)$$

When switching between diesel and natural gas in these boilers, annual emissions productions of CO_2, SO_2 and NO_x depends on the percentage by which each fuel has been used and emission factor of each fuel. This can be expressed as follow:

$$ADEPS_{CO2} = ADCS_{KWh} \times \ EF_{CO2} \dots\dots\dots\dots \ (3.28)$$

$$ADEPS_{SO2} = ADCS_{KWh} \times \ EF_{SO2} \dots\dots\dots\dots \ (3.29)$$

$$ADEPS_{NOx} = ADCS_{KWh} \times EF_{NOx} \quad (3.30)$$

$$ANGEPS_{CO2} = ANGECS_{KWh} \times EF_{CO2} \quad (3.31)$$

$$ANGEPS_{SO2} = ANGECS_{KWh} \times EF_{SO2} \quad (3.32)$$

$$ANGEPS_{NOx} = ANGECS_{KWh} \times EF_{NOx} \quad (3.33)$$

Annual emissions reduction of CO_2, SO_2, CO and NO_x equals to the result of subtracting annual diesel emissions production from the annual diesel and natural gas emissions production when switching depending on the percentage of each fuel used. This can be equal to:

$$AER_{CO2} = ADEP_{CO2} - (ADEPS_{CO2} + ANGEPS_{CO2}) \quad (3.34)$$

$$AER_{SO2} = ADEP_{SO2} - (ADEPS_{SO2} + ANGEPS_{SO2}) \quad (3.35)$$

$$AER_{NOx} = ADEP_{NOx} - (ADEPS_{NOx} + ANGEPS_{NOx}) \quad (3.36)$$

When switching between diesel and biomass in these boilers, annual emissions productions of carbon dioxide depends on the percentage by which each fuel has been used and emission factor of biomass. It has been found that the CO_2 emissions produced when burning biomass are roughly 40% of the CO_2 emissions produced by fossil fuels (Zutphen and Wibrans, 2007). Annual biomass emissions production of $CO_2$when switching can be expressed as follow:

$$ABEPS_{CO2} = (ADEP_{CO2} - ADEPS_{CO2}) \times 0.4 \quad (3.37)$$

Thus, Annual emissions reduction of CO_2 equals to the result of subtracting annual diesel emissions production from the annual diesel and biomass emissions production when switching depending on the percentage of each fuel used. This can be equal to:

$$AER_{CO2} = ADEP_{CO2} - (ADEPS_{CO2} + ABEPS_{CO2}) \quad \text{.......................................} \quad (3.38)$$

3.4 Heat recovery using economizer

3.4.1 Targeted manufacturing factories and Audit data collection

The targeted pulp and paper industries in this section are the same with those obtained in fuel switching methodology in Table 3.6 section 3.3.1.

3.4.2 Energy saving when using heat recovery systems (Economizer)

Total annual energy saving when installing heat recovery systems in the factories that have been already shown in Table 3.7 equals to total annual diesel energy consumption in kWh multiplied by the heat losses in the flue gas and the efficiency of the heat recovery system (economizer), Table 3.9 shows average percentage of heat losses in flue gas and the efficiency of economizer.

Table 3.9 Average percentage of heat losses in flue gas and efficiency of heat recovery system (Willems, 2009; Willems and Pipkin, 2009)

Percentage of heat losses in flue gas (%)	Efficiency of heat recovery systems (%)
18	30

Total annual energy saving can be calculated from the following equation:

$$TAES_{HR} = ADC_{KWH} \times \%_{fg} \times \%_{HR} \quad (3.39)$$

Percentage of increasing in thermal efficiency of boiler due to installation of economizer can be calculated from the following equation

$$\%B_{th} = \frac{TAES_{HR}}{ADC_{KWH}} \quad (3.40)$$

3.4.3 Emission reduction when using heat recovery systems (Economizer)

The environmental impact of the heat recovery systems is a potential reduction of greenhouse gasses or other element that give negative impact to the environment. The common potential reductions in this study include carbon dioxide CO_2, sulfur dioxide SO_2, nitrogen oxide NO_x and carbon monoxide CO. The emission factors of all these gases are shown in the Table 3.4. The annual emissions reduction is a function of total annual energy saving and the emission factor of the particular fuel. Emissions reduction when using heat recovery systems can be calculated as follow:

$$AER_{CO2} = TAES_{HR} \times EF_{CO2} \quad (3.41)$$

$$AER_{NOx} = TAES_{HR} \times EF_{NOx} \quad (3.42)$$

$$AER_{CO} = TAES_{HR} \times EF_{CO} \quad (3.43)$$

$$AER_{SO2} = TAES_{HR} \times EF_{SO2} \quad (3.44)$$

3.4.4 Cost benefit analysis when using heat recovery systems (Economizer)

Total annual bill savings associated with the above energy savings equals to total annual energy saving multiplied by diesel fuel price. It can be calculated from the following equation:

$$TABS_{HR} = \frac{TAES_{HR} \times 3600 \times UFP_D}{DEC \times \rho_D} \quad (3.45)$$

Knowing that installation cost of economizer is RM 30,000 (Manan, 2003), payback period equals to the installation cost of heat recovery divided by total annual bill saving when using heat recovery systems. Payback period of this application can be calculated from the following equation:

$$PBP_{HR} = \frac{IC_{HR}}{TABS_{HR}} \quad (3.46)$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the results of implementing variable speed drives, fuel switching and heat recovery systems in the industrial boilers in Malaysia. The energy savings, economic benefits and emissions reduction are all calculated to examine the potential of all these approaches.

4.2 Variable speed drive results

4.2.1 Energy saving when using variable speed drives

When installing variable speed drives in the industrial boilers which have already been shown in Table 3.3 and based on the equations (3.1-3.4), the results of total annual energy saving in KWh and energy saving percentage (%) of this application have been quantified and illustrated in Figures 4.1 and 4.2 respectively.

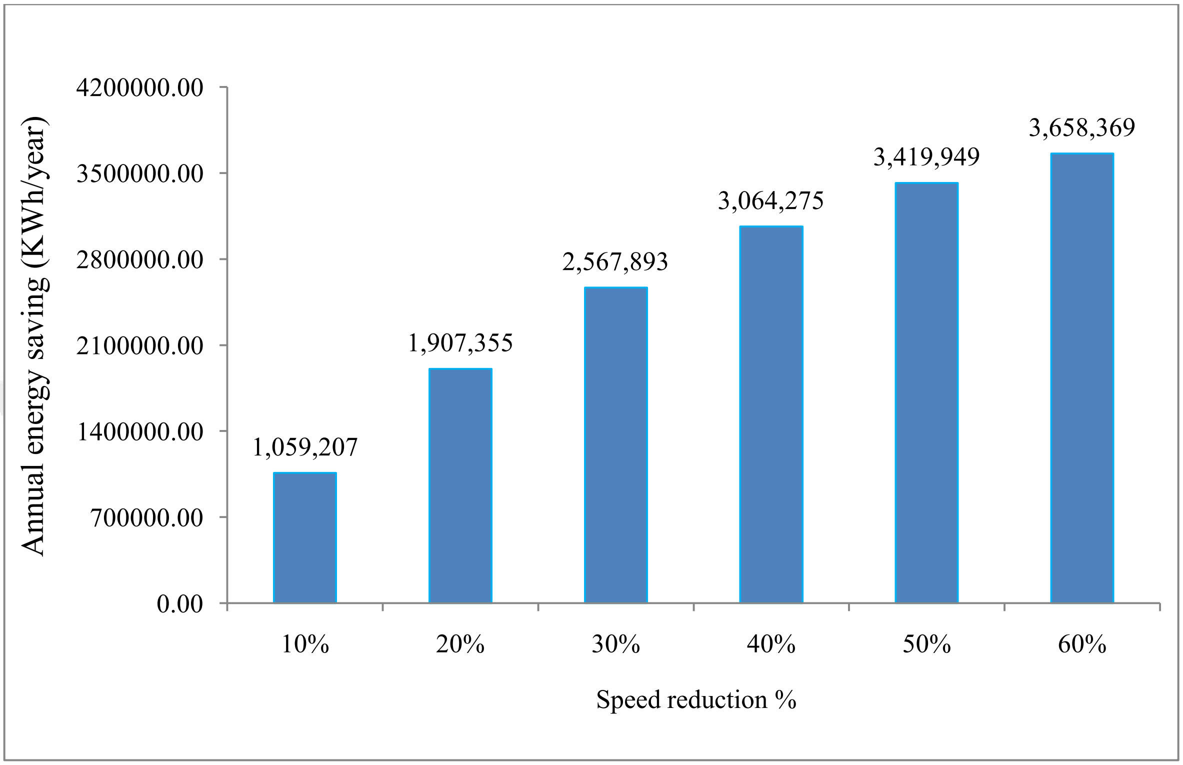


Figure 4.1 Total annual energy saving (KWh/year) at different speed reduction

The results from Figure 4.1 show that the total annual energy savings in the industrial boilers covered in this study can be increased significantly when increasing the speed reduction percentage of motors. For example, Annual energy saving increased from 1,059,207 KWh in 10% speed reduction to 3,658,369 KWh in 60% speed reduction. These results represent a huge amount of energy saving that can be achieved when applying VSD in boilers" water pumps. Figure 4.2 shows energy saving percentage at different speed reduction percentage as follow:

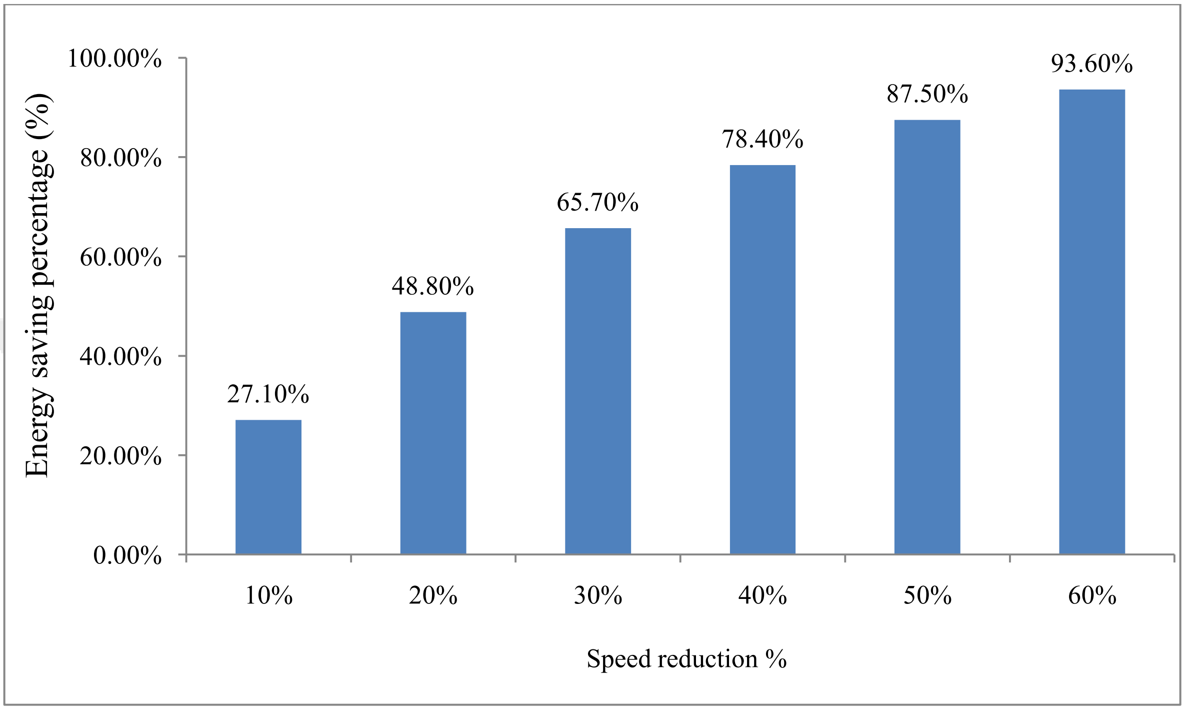


Figure 4.2 Energy saving percentage (%) at different speed reduction

The results from Figure 4.2 indicate that energy savings percentage in the industrial boilers when reducing the speed of motors can be improved when increasing the speed reduction percentage, and ranges from 27.1% in 10% speed reduction to 93.6% in 60% speed reduction. These results confirm that energy saving can be achieved when applying VSD in boilers‟ water pumps.

Table 4.1 shows energy saving percentage taken from the literature at different speed reduction percentage when using variable speed drive (Saidur, 2009b).

Table 4.1 Potential saving of VSD when reducing the speed (Saidur, 2009b).

Average speed reduction (%)	Potential energy saving (%)
10	22
20	44
30	61
40	73
50	83

When comparing between Table 4.1 which has been found in the literature and Figure 4.2 in this study, it can be ensured that increasing the speed reduction percentage of pumps will result in increasing energy saving percentage.

4.2.2 Emissions reduction when using variable speed drives

Based on the input data in Tables 3.4, 3.5, Figure 4.1 and equations (3.5-3.8), the results of total annual CO_2, SO_2, CO and NO_x emissions reduction when using VSD have been quantified and tabulated in Table 4.2:

Table 4.2 Total annual emissions reduction at different speeds reduction

Speed Reduction %	CO_2 (Ton)	SO_2 (Kg)	No_x (Kg)	CO (Kg)
10%	625	3,448	1,626	413
20%	1,126	6,208	2,928	744
30%	1,516	8,358	3,942	1,001
40%	1,809	9,974	4,704	1,195
50%	2,019	11,132	5,250	1,334
60%	2,160	11,908	5,616	1,427

The results from Table 4.2 show that the total emissions reduction are about 2,160 ton of CO_2, 11,908 Kg of SO_2, 5,616 Kg of NO_x and 1,427 Kg of CO when reducing the speed of pumps by 60% in the industrial boilers. These results represent a huge amount of emissions reduction that can be achieved when applying VSD in industrial boilers‟ water pumps in a small developing country like Malaysia.

4.2.3 Cost benefit analysis when using variable speed drives

Based on the input data of VSD incremental price in Table 3.6 and total annual energy saving Figure 4.1 and equations (3.9 and 3.10), the results of total annual bill saving with an average electricity price of RM 0.236/KWh and average payback period have been quantified and illustrated in Figures 4.3 and 4.4 respectively:

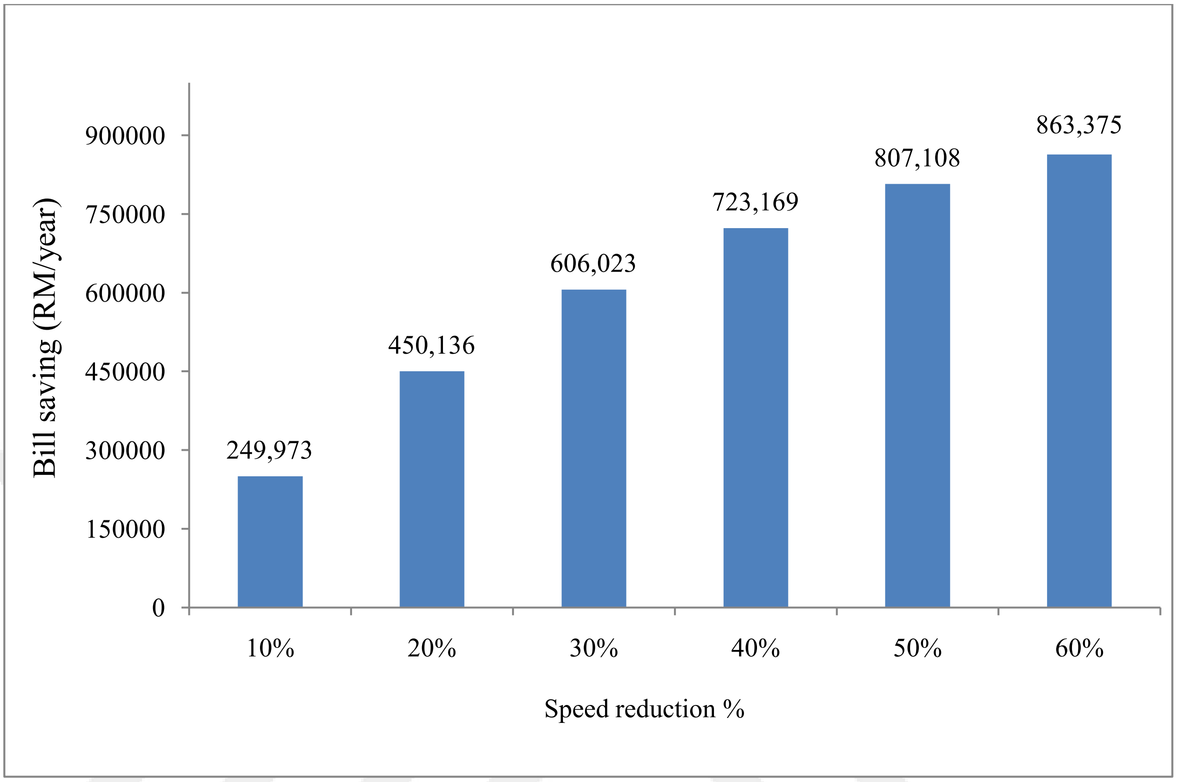


Figure 4.3 Total annual bill saving (RM/year) at different speed reduction

The results from Figure 4.3 show that the total annual bill savings when installing VSD in the covered industrial boilers in this study are about RM 249,973 in 10% speed reduction, RM 723,169 in 40% speed reduction and RM 863,375 in 60% speed reduction. These results represent a huge amount of bill saving that can be achieved when applying VSD in boilers‟ water pumps in a small developing country like Malaysia.

Table 4.3 shows annual bill saving at different speed reduction percentage for different motor horsepower when using variable speed drives (Saidur, 2009b).

Table 4.3 Annual bills saving at different speed reduction for different motors horsepower (Saidur, 2009b)

Motor Power (Hp)	10%	20%	30%	40%	50%	60%
15	16,071	32,141	44,559	53,325	60,630	65,013
20	417,206	834,412	1,156,799	1,384,366	1,574,005	1,687,789
25	155,980	311,959	432,489	517,569	588,469	631,009
30	62,392	124,784	172,996	207,028	235,387	252,403
40	166,378	332,757	461,322	552,073	627,700	673,076
50	103,986	207,973	288,326	345,046	392,312	420,672
60	313,850	627,700	870,220	1,041,411	1,184,070	1,269,666
75	773,970	1,547,940	2,146,008	2,568,173	2,919,978	3,131,060
Total	2,009,833	4,019,666	5,572,719	6,461,963	7,582,551	8,130,688

When comparing between Table 4.3 from the literature and Figure 4.3, it can be observed that increasing the speed reduction percentage of pumps will result in increasing total annual bill saving.

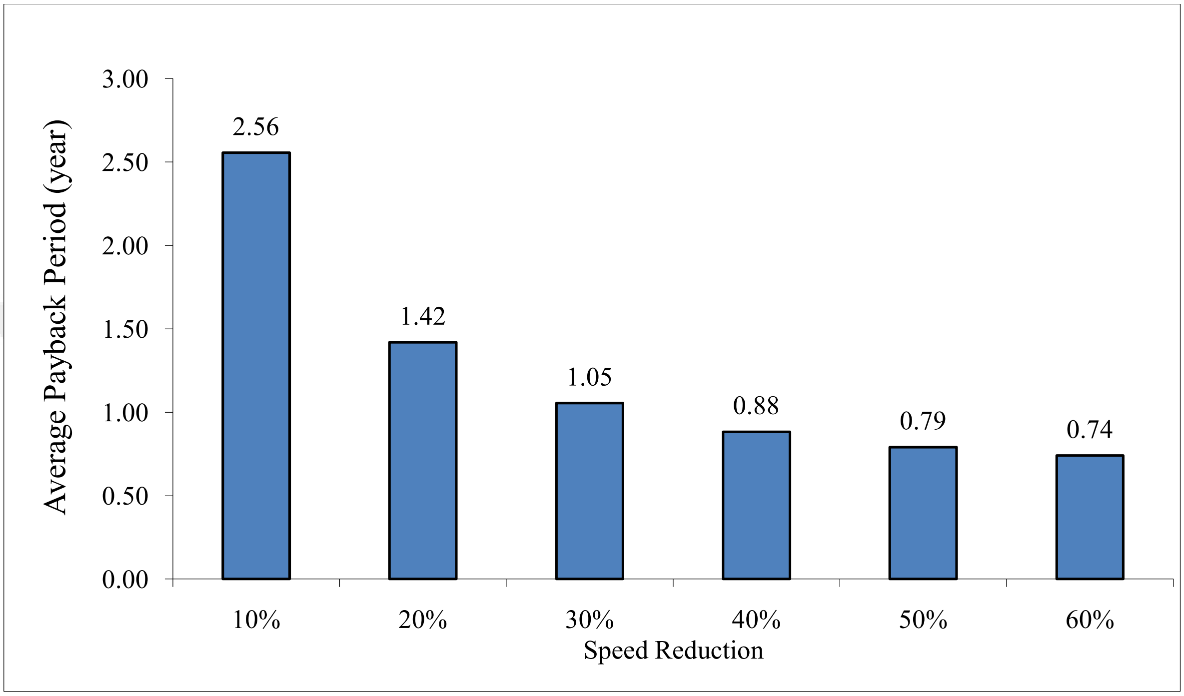


Figure 4.4 Average payback periods at different speed reduction

The results from Figure 4.4 show that the average payback periods are about 2.56 year in 10% speed reduction and 0.74 year in 60% speed reduction in the industrial boilers. It can be observed that payback period decreased when increasing the speed reduction percentage of water pumps.

Table 4.4 shows average payback periods at different speed reduction percentage for different motor horsepower when using variable speed drives (Saidur, 2009b).

Table 4.4 Payback periods (year) at different speed reduction (Saidur *et al*., 2009b).

Motor Power (Hp)	10%	20%	30%	40%	50%	60%
15	4.62	2,31	1.66	1.39	1.22	1.14
20	4.15	2.08	1.5	1.25	1.1	1.03
25	3.88	1.94	1.4	1.17	1.03	0.96
30	3.69	1.85	1.33	1.11	0.98	0.91
40	3.46	1.73	1.25	1.04	0.92	0.86
50	3.32	1.66	1.2	1.00	0.88	0.82
60	3.23	1.61	1.16	0.97	0.86	0.8
75	3.14	1.57	1.13	0.95	0.83	0.78
Average	3.69	1.84	1.33	1.11	0.98	0.91

The results that have been obtained in Figure 4.4 shows similar results to those already found in Table 4.4 taken from the literature. These results indicate that VSD is an economically viable application as it has payback period less than one third of the motor life which is estimated to be 20 years as an average.

4.3 Fuel switching results

4.3.1 Natural gas and diesel switching

4.3.1.1 Cost saving of natural gas and diesel switching

Based on the input data in Tables 3.7 and 3.8, and equations (3.11-3.24), the results of total annual cost saving when switching between natural gas and diesel in different percentage are illustrated in Figures 4.5:

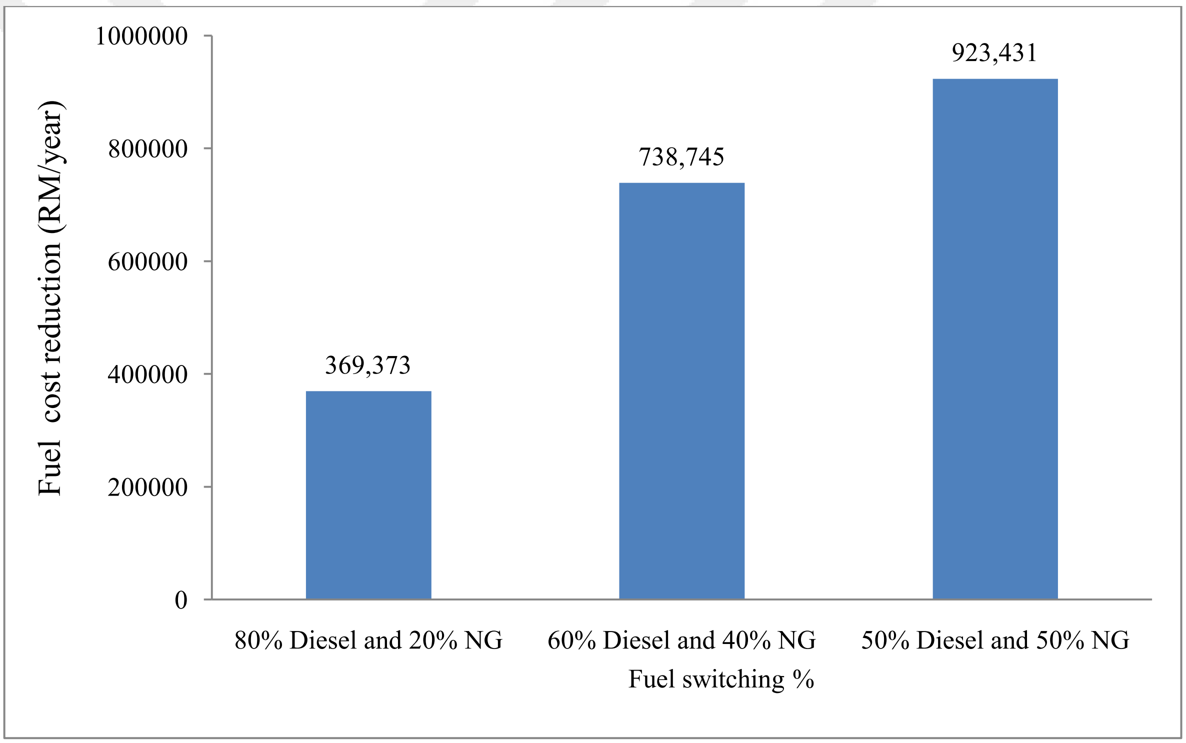


Figure 4.5 Total fuel cost reduction (RM/year) at different natural gas and diesel switching

The results in Figure 4.5 show that the total annual bill saving when switching in different percentage between natural gas and diesel in the Malaysian industrial boilers are about RM 369,373 in case of 80% diesel and 20% natural gas consumption, RM 738,745 in case of 60% diesel and 40% natural gas consumption and RM 923,431 in case of 50% diesel and 50% natural gas consumption respectively. It can be observed that total annual bill saving increases with the increased percentage of natural gas consumption. These results represent a huge amount of annual bill saving that can be achieved when increasing the percentage of natural gas consumption in Malaysian industrial boilers.

4.3.1.2 Emissions reduction when switching between natural gas and diesel

Based on the input data in Table 3.4 and equations (3.25-3.36), the results of annual emissions reduction of CO_2, NO_x and SO_2 when switching between natural gas and diesel are tabulated in Table 4.5:

Table 4.5 Total emissions reduction (Kg) when switching between natural gas and diesel

Fuel switching percentage	80% diesel and 20% NG	60% diesel and 40% NG	50% diesel and 50% NG
CO_2 reduction	2,998,256	5,996,512	7,495,640
SO_2 reduction	148,976	297,952	372,440
NO_x reduction	14,991	29,983	37,478

The results in Table 4.5 show that the total emission reduction of CO_2, NO_x and SO_2 when switching in different percentage between natural gas and diesel are about 2,998,256 Kg, 14,991 Kg and 148,976 Kg respectively in case of 80% diesel and 20% natural gas consumption. In case of 60% diesel and 40% natural gas consumption, the total annual emission reduction of CO_2, NO_x and SO_2 are about 5,996,512 Kg, 29,983 and 297,952 respectively. Finally in case of 50% diesel and 50% natural gas consumption, the total annual emission reduction of CO_2, NO_x and SO_2 are about 7,495,640 Kg, 37,478 Kg and 372,440 Kg respectively. It can be observed that total emissions reduction increase with the increased percentage of natural gas consumption. These results represent a huge amount of total emissions reduction that can be achieved when increasing the percentage of natural gas consumption in Malaysian industrial boilers.

4.3.2 Biomass and diesel switching

4.3.2.1 Cost saving of biomass and diesel switching

Based on the input data in Table 3.7 and 3.8 and equations (3.11-3.24), the results of total annual bill saving when switching between biomass and diesel are illustrated in Figures 4.6:

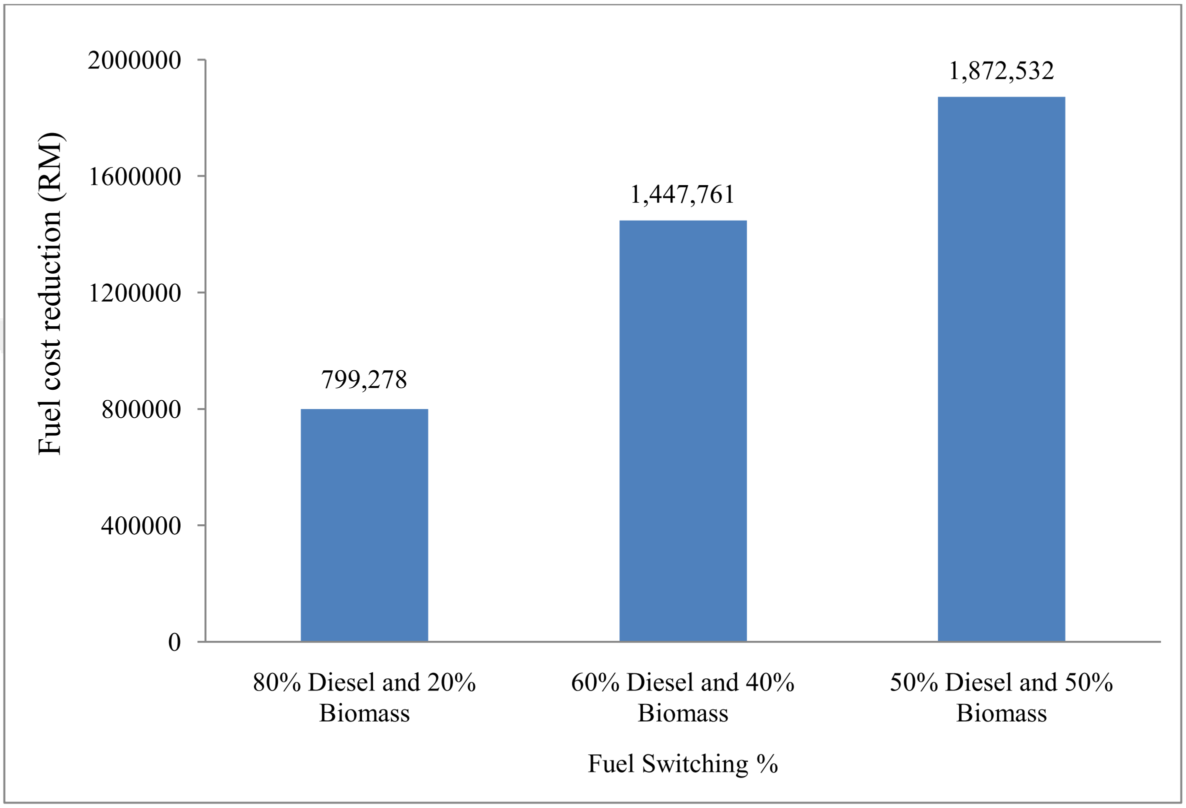


Figure 4.6 Total fuel cost reduction (RM/year) when switching between biomass and diesel

The results in Figure 4.6 show that the total annual bill saving when switching in different percentage between biomass and diesel in the Malaysian industrial boilers are about RM 799,278 in case of 80% diesel and 20% biomass consumption, RM 1,447,761 In case of 60% diesel and 40% biomass consumption and RM 1,872,532 in case of 50% diesel and 50% biomass consumption respectively. It can be observed that total annual bill saving increases with the increased percentage of biomass consumption. These results represent a huge amount of annual bill saving that can be achieved when increasing the percentage of biomass consumption in Malaysian industrial boilers.

4.3.2.2 Emissions reduction of biomass and diesel switching

Based on the input data in equations (3.25, 3.28, 3.37 and 3.38) respectively, the results of total annual emission reduction of CO_2 when switching between biomass and diesel are illustrated in Figures 4.7:

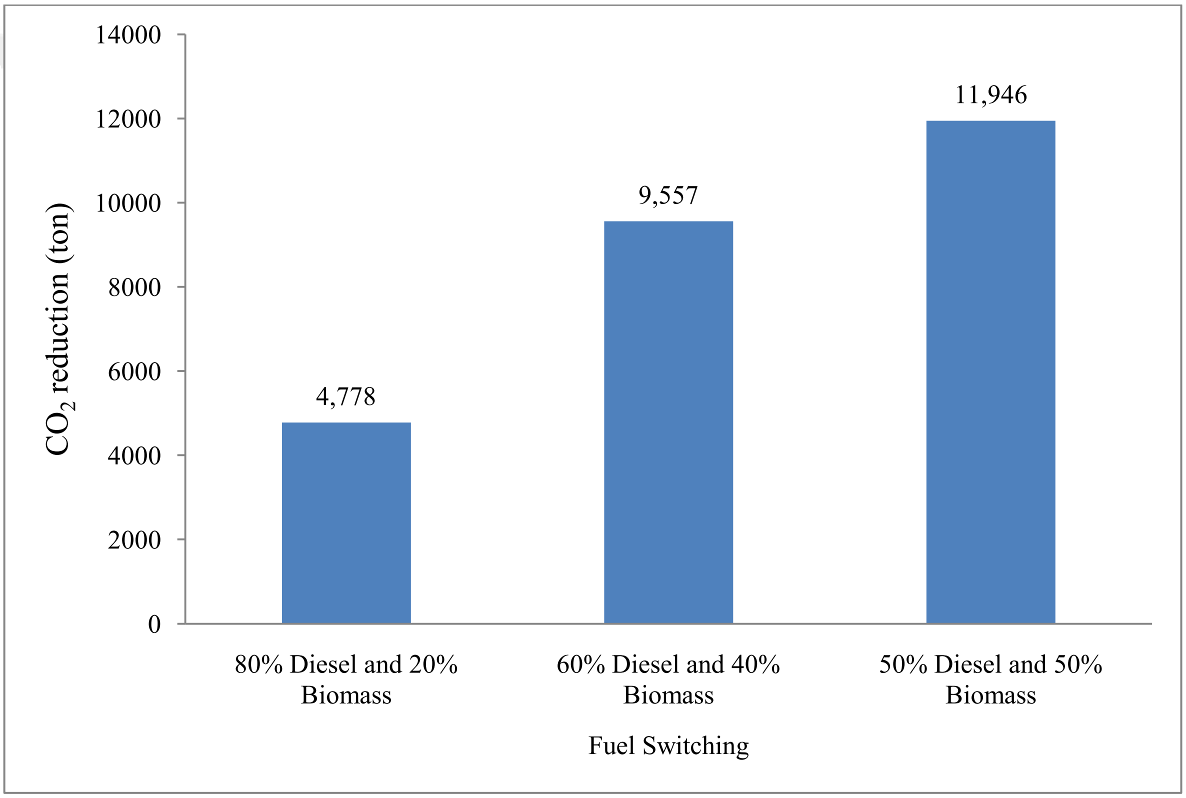


Figure 4.7 Total CO_2 reduction (ton) when switching between biomass and diesel

The results in Figure 4.7 show that the total emission reduction of CO_2 when switching in different percentage between biomass and diesel are about 4,778 ton in case of 80% diesel and 20% biomass consumption, 9,557 ton in case of 60% diesel and 40% biomass and 11,946 ton in case of 50% diesel and 50% biomass consumption. It can be observed that total emissions reduction increase with the increased percentage of biomass consumption. These results represent a huge amount of total emissions reduction that can be achieved when increasing the percentage of biomass consumption in Malaysian industrial boilers.

From the results that have been obtained in section 4.3.1 and 4.3.2 respectively, it has been found that total annual cost saving is higher when switching between diesel and biomass than diesel and natural gas. For instance, RM 1,872,532 can be saved annually in case of 50% diesel and 50% biomass fuel switching, however in case of 50% diesel and 50% natural gas RM 923,431 could be saved annually.

Carbon dioxide reduction is an another evidence of the advantage of using biomass over natural gas with 11,946 ton of CO_2 reduction in case of 50% diesel and 50% biomass fuel switching and 7,496 ton reduction in case of 50% diesel and 50% natural gas fuel switching.

Also this study confirms the results in the literature which stated that when utilities switch to other renewable energy sources, such as biomass, substantial emissions reduction could be achieved.

4.4 Heat recovery results

4.4.1 Energy saving when using economizer

Based on the input data in Table 3.7, 3.8 and 3.9, and equations (3.11, 3.12, 3.13 and 3.39) respectively, the results of annual energy saving in different factories in Malaysia when using economizer are illustrated in Figures 4.8:

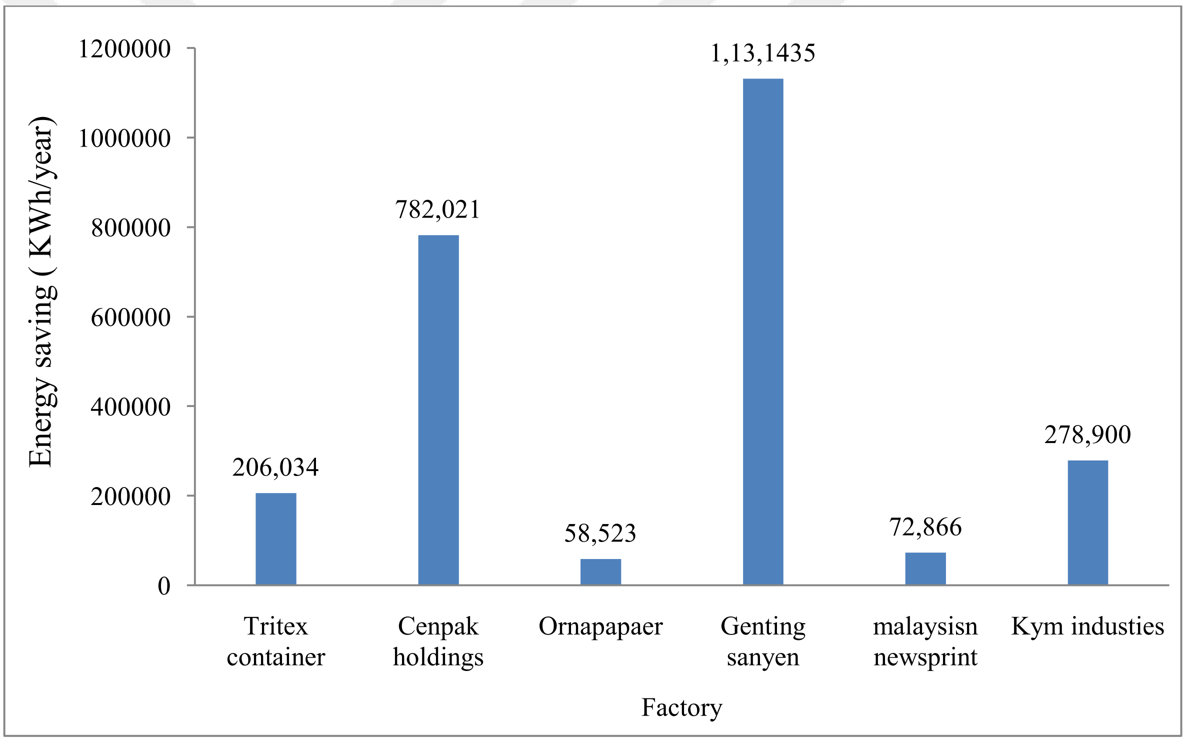


Figure 4.8 Energy saving (KWh/year) at different factories when installing economizer

The results in Figure 4.8 show that the total annual energy savings when installing economizer in all factories is 2,529,779 KWh. These results represent a huge amount energy saving that can be achieved when installing economizer in boilers

Based on equation (3.40) the Percentage of increasing in thermal efficiency of boiler due to installation of economizer has been found to be 5.4%. This result is similar to what have already been found in the literature review as the economizer can increase thermal efficiency of boiler by 5% (Bureau of Energy Efficiency, 2009).

4.4.2 Emissions reduction when using economizer

Based on the input data in Table 3.4 and equations (3.39, 3.41, 3.42, 3.43 and 3.44) respectively, the results of emissions reduction at different factories when installing economizer are tabulated in Table 4.6:

Table 4.6 Emissions reduction (kg) at different factories when installing economizer

Factory name	CO_2 reduction	SO_2 Reduction	CO Reduction	NO_x Reduction
Tritex container	175,129	3,379	41	515
Cenpak holdings	664,718	12,825	156	1,955
Orna paper	49,744	960	12	146
Genting sanyen	961,720	18,556	226	2829
Malaysian newsprint	61,639	1,195	15	182
Kym Industries	237.065	4,574	56	697
Total	2,150,000	6,324	506	41,888

The results from Table 4.6 show that the total emissions reduction are about 2,150 ton of CO_2, 6,324 Kg of SO_2, 41,488 Kg of NO_x and 506 Kg of CO when using economizer in the industrial boilers. These results show similar result to what have been found in the literature and represent a huge amount of emissions reduction that can be achieved when installing economizer in boilers.

4.4.3 Cost benefit analysis when using economizer

Based on the installation cost of economizer of RM 30,000 (Manan, 2003), Tables 3.7, 3.8 and 3.9, and equations (3.39, 3.45 and 3.46) respectively, the results of total annual bill saving (RM/year) and payback periods (years) at different factories when using economizer are illustrated in Figures 4.9 and 4.10 respectively:

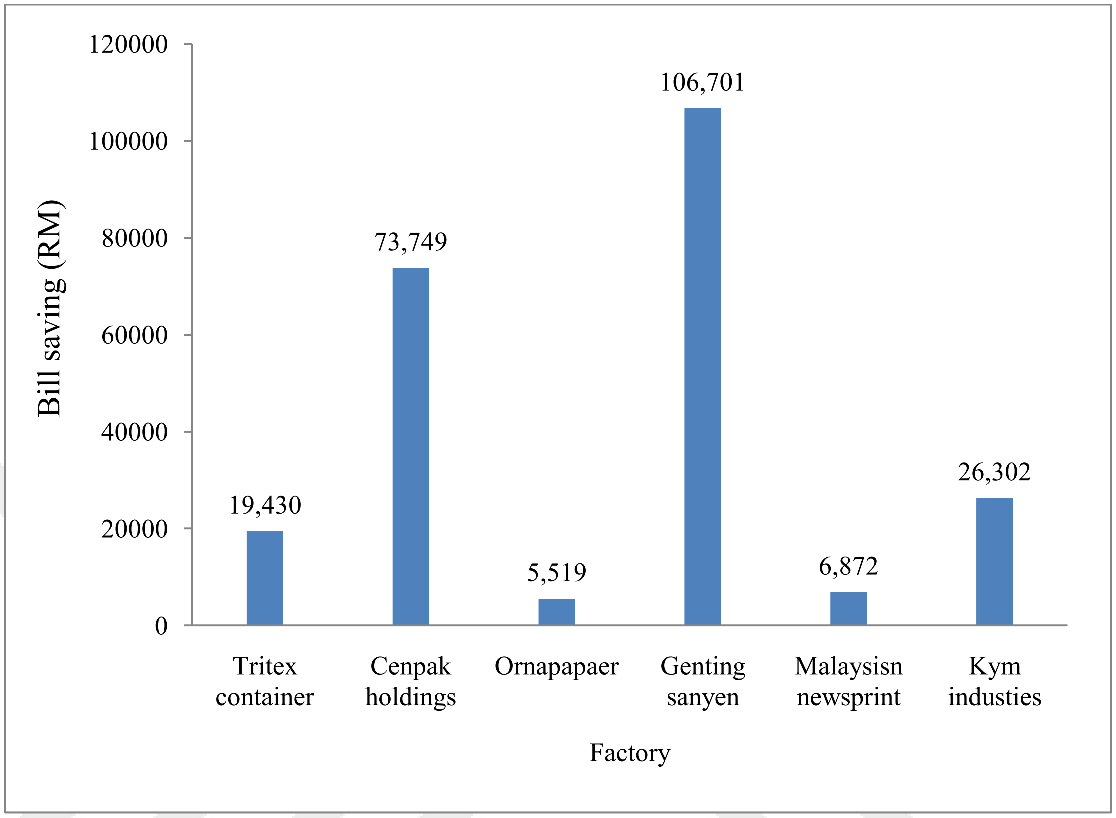


Figure 4.9 Bill saving (RM) at different factories when using economizer

The results from Figure 4.9 show that the total annual bill savings of economizer in the covered industrial boilers is about RM 238,573. These results show similar result to what have been found in the literature and represent a huge amount of bill saving that can be achieved when installing economizers in a small developing country like Malaysia.

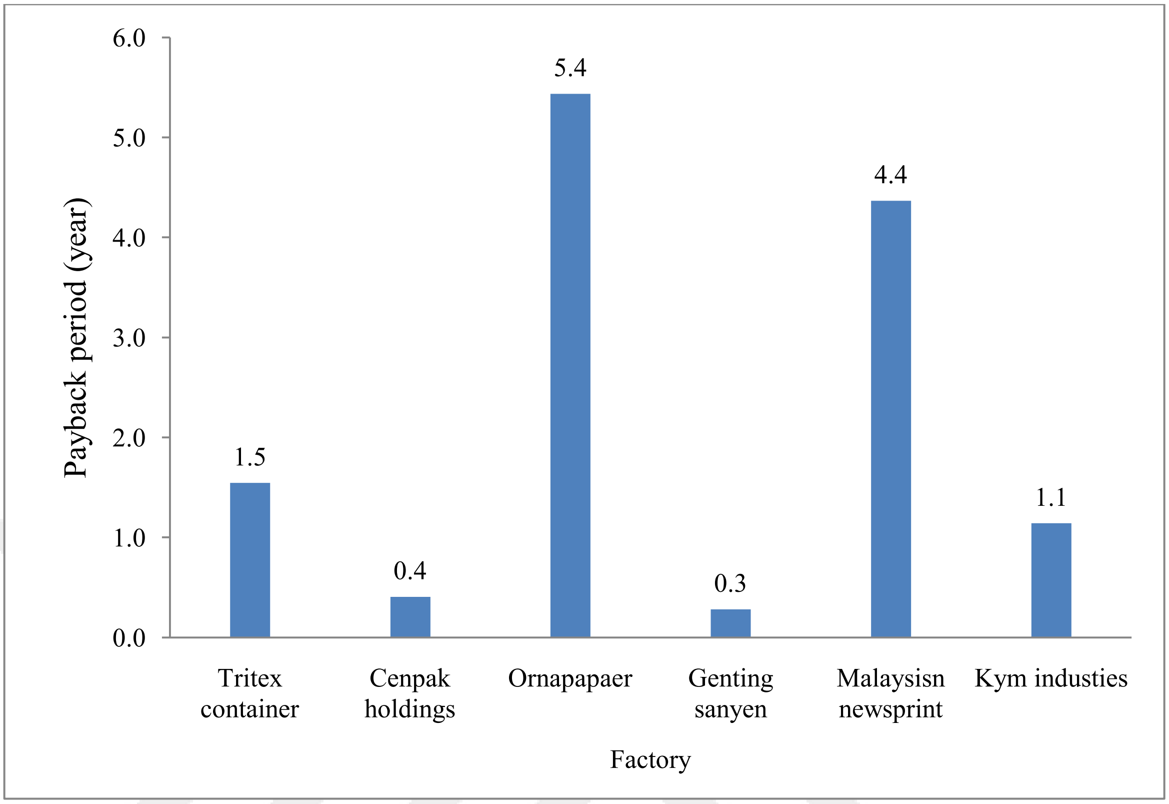


Figure 4.10 Payback period (years) at different factories when using economizer

The results from Figure 4.9 and 4.10 show that payback period when installing economizer in the covered factories range from 0.3 year in Genting sanyen to 5.4 years in Orna paper factories. It can be observed that payback period is quite high in Orna paper and Malaysian news print factories. This is because annual energy consumption of these factories is low. However in other factories like Tritex, Cenpak, Genting and Kym industries payback period is very acceptable and boost installing this application. These results indicate that economizer can be a useful device for short term purposes in Malaysia when the annual energy consumption of boilers is very high and the payback period is 3 years.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This study is concerned with an energy saving, economic and environmental analysis of industrial boilers in paper and pulp industries in Malaysia. There are three principles that have been investigated: Installation of variable speed drive; fuels switching between diesel and other types of fuels such as natural gas and biomass; and installation of heat recovery systems in these boilers.

When installing variable speed drive in these boilers, it has been found that total annual amount of 3,658,369 KWh of energy saving, 93.6% energy saving percentage, 2,160 ton of CO_2, RM 863,375 bill saving and 0.74 average payback period could be achieved when reducing the speed of these pumps by 60%. These results indicate that VSD is an energy saving, economically viable and emissions reduction application specially when increasing the speed reduction percentage of pumps and can be used in a small developing country like Malaysia.

Also when applying the principle of fuel switching in these boilers, it has been found that total annual cost saving is higher when switching between diesel and biomass than diesel and natural gas. For instance, RM 1,872,532 can be saved annually in case of 50% diesel and 50% biomass fuel switching, however in case of 50% diesel and 50% natural gas RM 923,431 could be saved annually. Carbon dioxide reduction is another evidence of the advantage of using biomass over natural gas with 11,946 ton of CO_2 reduction in case of 50% diesel and 50% biomass fuel switching and 7,496 ton reduction in case of 50% diesel and 50% natural gas fuel switching. This study satisfies the results in the literature which stated that when utilities switch to other renewable energy sources, such as biomass, substantial emissions reduction could be achieved.

Installation of heat recovery systems (economizers) in these boilers has been proved to be an effective method. It has been found that a total amount of 2,529,779 KWh, 2,150 ton of CO_2, 6,324 Kg of SO_2, 41,488 Kg of NO_x and 506 Kg of CO and RM 238,573 could be saved annually. These results indicate that economizer is an energy saving, economically viable and emissions reduction application and can be used in a small developing country like Malaysia.

5.2 Recommendations for future Work

This study examines the potential of applying VSD, fuel switching and heat recovery systems in Malaysian industrial boilers to improve efficiency, reduce emissions and achieve bill savings. The findings of this study proved the viability of all these methods. However, it is recommended that future researches should continue for further studies of other energy saving measures for industrial boilers. There are many methods which can be used to improve industrial boilers performance.

Improving combustion efficiency is one of the methods that can be adopted to improve boilers efficiency. Insufficient air for combustion results in wastage of fuel due to incomplete combustion and reduces the heat transfer efficiency due to soot build up on heat transfer surfaces.

Another measure of improving boilers efficiency is minimizing radiation and conduction losses which represent 4% of typical heat losses in boilers. These losses occur primarily because boilers, auxiliary equipments, and distribution piping of steam systems are much hotter than the surrounding areas. To minimize heat loss, all hot surfaces should be insulated with materials that have sufficient resistance to heat transfer. Further, the insulation should be of adequate thickness and it should be in good condition.

Automatic blowdown control represents another solution to remove sludge and solids from boilers which are responsible for corrosion, scaling, and fouling of the heat transfer surfaces of the boiler and represents a real money saving process. Blowdown involves discharge of water at steam temperature, which has to be replaced by an equivalent amount of cold water. Energy losses resulting from blowdown can be minimized by installing automatic blowdown systems such as a blowdown flash tank which allows the high-pressure blowdown to flash to a lower pressure steam and then can be used as a steam source to the deaerator.

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APPENDIX A

SAMPLE OF CALCULATIONS WHEN USING VARIABLE SPEED DRIVE

1. Energy saving when using VSD:

From equation 3.1, annual energy consumption without using variable speed drive for a pump output of 15 HP can be calculated as follow:

$$AEC_{BAU} = \frac{P_{Hp} \times 0.7456 \times N_{pumps} \times OPH}{\eta_{pump}} = \frac{15 \times 0.7456 \times 1 \times 6000}{0.95} = 70{,}636 \text{ KWh.}$$

From equation 3.2, annual energy consumption when using variable speed drive at 10% speed reduction for a pump output of 15 HP can be calculated as follow:

$$AEC_{NP} = AEC_{BAU} \times (1 - SR_{ratio})^3 = 70{,}636 \times (1-0.1)^3 = 51{,}493 \text{ KWh.}$$

From equation 3.3, Annual energy saving when using variable speed drive at 10% speed reduction for a pump output of 15 HP can be calculated as follow:

$$AES_{VSD} = AEC_{BAU} - AEC_{NP} = 70{,}636 - 51{,}493 = 19{,}142 \text{ KWh}$$

From equation 3.4 energy saving percentage (%) can be calculated as follow:

$$\% \, VSD_{ES} = \frac{AES_{VSD}}{AEC_{BAU}} = \frac{19{,}142}{70{,}636} = 27.1\%.$$

When repeating the same calculations for other pumps that have been shown in Table 3.3 and using equation 3.1, 3.2 and 3.3 and Table 3.3 respectively, the result of annual energy saving at 10% speed reduction are as follow:

For 20 HP, $AES_{VSD} = 331{,}800$ KWh

For 25 HP, AES_{VSD} = 127,615 KWh

For 30 HP, AES_{VSD} = 38,285 KWh

For 40 HP, AES_{VSD} = 153,138 KWh

For 50 HP, AES_{VSD} = 63,808 KWh

For 60 HP, AES_{VSD} = 229,708 KWh

For 75 HP, AES_{VSD} = 95,711 KWh

Thus, total annual energy saving in all water pumps and in 10% speed reduction is equal to:

19,142 + 331,800 + 127,615 + 38,285 + 153,138 + 63,808 + 229,708 + 95,711 = ***1,059,207 KWh.***

2. Emissions reduction when using VSD:

When using equations 3.5, 3.6, 3.7 and 3.8 and based on Table 3.4 and 3.5 respectively, the total annual emissions reduction of CO_2, SO_2, NO_X and CO when using VSD in different water pumps that have been showed in Table 3.3 and in 10% speed reduction are as follow:

$AER_{CO2} = AES_{\ VSD} \times \sum(\%F \ \times \ EF_{CO2})$=

1,059,207 × (0.15×1.18+0.05×0.85+0.7×0.53) = ***625 ton.***

$AER_{SO2} = AES_{\ VSD} \ \times \sum(\%F \times EF_{SO2})$=

1,059,207 ×(0.0139×0.15+0.05×0.0164+0.7×0.0005) = ***3.448 Kg.***

$AER_{NOx} = AES_{\ VSD} \ \times \sum(\%F \ \times \ EF_{NOx}) =$

1,059,207 × (0.15×0.0052+0.05×0.0025+0.7×0.0009) = ***1,626 Kg.***

$AER_{CO} = AES_{VSD} \times \sum(\%F \times EF_{CO})$=

1,059,207 ×(0.0002×0.15+0.05×0.0002+0.0005×0.7) = ***413 Kg.***

3. Cost benefit analysis when using VSD:

Based on equation 3.9, annual bill savings when using VSD in different water pumps that have been showed in Table 3.3 and in10% speed reduction are as follow:

For 15 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 19,142 × 0.236 = RM 4,518

For 20 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 331,800 × 0.236 = RM 78,305

For 25 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 127,615 × 0.236 = RM 30,117

For 30 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 38,285 × 0.236 = RM 9,035

For 40 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 153,138 × 0.236 = RM 36,141

For 50 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 63,808 × 0.236 = RM 15,059

For 60 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 229,708 × 0.236 = RM 54,211

For 75 HP, $ABS_{VSD} = AES_{VSD} \times UEP$ = 95,711 × 0.236 = RM 22,588

Thus, total annual bill saving in all water pumps and in 10% speed reduction is equal to:

4,518 + 78,305 + 30,117 + 9,035 + 36, 141 + 15,059 + 54,211 + 22,588 = ***RM 249,973***

Based on equation 3.10 and incremental costs of VSD showed in Table 3.6, payback period when using VSD in different water pumps that have been showed in Table 3.3 and in 10% speed reduction are as follow:

For 15 HP, $PBP_{VSD} = \frac{14464}{4518} = 3.2$ years

For 20 HP, $PBP_{VSD} = \frac{17353 \times 13}{78,305} = 2.88$ years

For 25 HP, $PBP_{VSD} = \frac{20241 \times 4}{30117} = 2.69$ years

For 30 HP, $PBP_{VSD} = \frac{23130 \times 1}{9035} = 2.56$ years

For 40 HP, $PBP_{VSD} = \frac{28907 \times 3}{36141} = 2.4$ years

For 50 HP, $PBP_{VSD} = \frac{34685 \times 1}{15059} = 2.3$ years

For 60 HP, $PBP_{VSD} = \frac{40462 \times 3}{54211} = 2.24$ years

For 75 HP, $PBP_{VSD} = \frac{49128 \times 1}{22588} = 2.17$ years

The average payback period in this study is equal to:

$$\frac{3.2+2.88+2.69+2.56+2.4+2,3+2,24+2,17}{8} = \boldsymbol{2.56\ years}$$

APPENDIX B

SAMPLE OF CALCULATIONS OF FUEL SWITCHING

1. Cost saving of fuel switching between natural gas and diesel

Based on equation (3.11-3.24) and Tables 3.7 and 3.8 respectively, total annual bill saving in case of switching of 80% diesel and 20% natural gas can be calculated as follow:

$ADC_{Kg} = ADC_L \times \rho_D$ = 4,409,200 × 0.85= 3,747,820 Kg.

$ADC_{KJ} = ADC_{Kg} \times DEC$ = 3,747,820 × 45,000 = 1.68652E+11 KJ.

$ADC_{KWh} = \frac{ADC_{KJ}}{3600} = \frac{1.68652E+11}{3600}$ = 46,847,750 KWh.

$ADP_{RM} = ADC_L \times UFP_D$ = 4,409,200 × 1.002 = RM 4,418,018.

$ADCS_{KWh} = ADC_{KWh} \times \%D_{FS}$ = 46,847,750 × 0.8 = 37,478,200 KWh.

$ANGECS_{KWh} = ADC_{KWh} \times \%NG_{FS}$ = 46,847,750 × 0.2 = 9,369,550 KWh.

$ADCS_L = \frac{ADCS_{KWh} \times 3600}{\rho_D \times DEC} = \frac{37{,}478{,}200 \times 3600}{0.85 \times 45000}$ = 3,527,360 Litre.

$ADPS_{RM} = ADCS_L \times UFP_D$ = 3,527,360 × 1.002 = RM 3,534,415.

$ANGCS_L = \frac{ANGECS_{KWh} \times 3600}{\rho_{NG} \times NGEC} = \frac{9{,}369{,}550 \times 3600}{0.717 \times 55{,}000}$ = 855,341 Liter.

$ANGPS_{RM} = ANGCS_L \times UFP_{NG}$ = 855,341 × 0.6012 = RM 514,231.

$TABS_{RM} = ADP_{RM} - (ADPS_{RM} + ANGPS_{RM} + ABPS_{RM})$ = 4,418,018 – (3,534,415 + 514,231) = ***RM 369,373.***

1. Emissions reduction of fuel switching between natural gas and diesel

Based on equation (3.25-3.36) and Tables 3.4 respectively, total emissions reduction of CO_2, SO_2 and NO_X in case of switching of 80% diesel and 20% natural gas can be calculated as follow:

$ADEP_{CO2} = ADC_{KWH} \times EF_{CO2}$ = 46,847,750 × 0.85 = 39,820,587 Kg.

$ADEP_{NOx} = ADC_{KWH} \times EF_{NOx}$ = 46,847,750 × 0.0025 = 117,119 Kg.

$ADEP_{SO2} = ADC_{KWH} \times EF_{SO2}$ = 46,847,750 × 0.0164 = 768,303 Kg.

$ADEPS_{CO2} = ADCS_{KWh} \times EF_{CO2}$ = 37,478,200 × 0.85 = 31,856,470 Kg

$ADEPS_{SO2} = ADCS_{KWh} \times EF_{SO2}$ = 37,478,200 × 0.0164 = 614,642 Kg

$ADEPS_{NOx} = ADCS_{KWh} \times EF_{NOx}$ = 37,478,200 × 0.0025 = 93,696 Kg

$ANGEPS_{CO2} = ANGECS_{KWh} \times EF_{CO2}$ = 9,369,550 × 0.53 = 4,965,862 Kg

$ANGEPS_{SO2} = ANGECS_{KWh} \times EF_{SO2}$ = 9,369,550 × 0.0005 = 4,685 Kg

$ANGEPS_{NOx} = ANGECS_{KWh} \times EF_{NOx}$ = 9,369,550 × 0.0009 = 8,433 Kg

$AER_{CO2} = ADEP_{CO2} - (ADEPS_{CO2} + ANGEPS_{CO2})$ = 39,820,587 – (31,856,470 + 4,965,862) = ***2,998,256 Kg.***

$AER_{SO2} = ADEP_{SO2} - (ADEPS_{SO2} + ANGEPS_{SO2})$ = 768,303 – (614,642 + 4,685) = ***148,976 Kg.***

$AER_{NOx} = ADEP_{NOx} - (ADEPS_{NOx} + ANGEPS_{NOx})$ = 117,119 – (93,696 + 8,433) = ***14,991 Kg.***

APPENDIX C

SAMPLE OF CALCULATIONS WHEN USING HEAT RECOVERY SYSTEMS

1. Energy saving when using heat recovery systems (Economizer)

Based on equation 3.39 and 3.40 and Table 3.9, total energy savings in all factories when using economizers in the factories that have been in Table 3.7 can be calculated as follow:

$TAES_{HR} = ADC_{KWH} \times \%_{fg} \times \%_{HR}$ = 46,847,750 × 0.18 × 0.3 = **2,529,779 KWh**.

$\%B_{th} = \frac{TAES_{HR}}{ADC_{KWH}} = \frac{2{,}529{,}779}{46{,}847{,}750}$ **= 5.4%.**

2. Emission reduction when using heat recovery systems (Economizer)

Based on the equations 3.39, 3.41, 3.42, 3.43 and 3.44 and Table 3.4, annual emissions reduction when using economizer can be calculated as follow:

$AER_{CO2} = TAES_{HR} \times EF_{CO2}$ = 2,529,779 × 0.85 **= 2,150 ton.**

$AER_{NOx} = TAES_{HR} \times EF_{NOx}$ = 2,529,779 × 0.0025 = **6,324 Kg.**

$AER_{CO} = TAES_{HR} \times EF_{CO}$ = 2,529,779 × 0.0002 = **506 Kg.**

$AER_{SO2} = TAES_{HR} \times EF_{SO2}$ = 2,529,779 × 0.0164 = **41,888 Kg.**

3. Cost benefit analysis when using heat recovery systems (Economizer)

Based on equations 3.45 and 3.46, annual bill saving and payback period when using economizer in Tritex factory can be calculated as follow:

$$TABS_{HR} = \frac{TAES_{HR} \times 3600 \times UFP_D}{DEC \times \rho_D} = \frac{206{,}034 \times 3600 \times 1.002}{45000 \times 0.85} = \textbf{RM 19,430}$$

$$PBP_{HR} \;\; \frac{IC_{HR}}{TABS_{HR}} = \frac{30{,}000}{19{,}430} = \textbf{1.5 year.}$$