ENERGY, EXERGY, AND ENVIRONMENTAL ANALYSIS FOR ENERGY INTENSIVE INDUSTRIAL EQUIPMENT IN MALAYSIA

By

MD. HASANUZZAMAN

B. Sc. Eng. (BUET), M. Eng. Sc. (UM)

THESIS SUBMITTED TO THE FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA IN FULFILLMENT OF
THE REQUREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2011

Original Literary Work Declaration

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Abstract

Worldwide, industrial sector accounts for about 35% of the total energy used. In Malaysia, 48% of total energy is used in this sector. Boilers, furnaces and electric motors are the energy intensive equipment of almost every industry and consume a significant amount of energy. The aim of the thesis is analyze the utilization of energy and exergy, energy saving and emission reduction for the energy intensive industrial equipment. In this study, the useful concept of energy and exergy is analyzed to investigate the energy and exergy efficiencies, energy and exergy losses in boilers, furnaces, heat exchangers and economizer. Energy use, energy and bill savings, payback periods and emission reduction of different energy saving options (i.e. economizer, variable speed drive) for boilers, furnaces, and electric motors were analyzed and presented in this thesis.

From the comparative analysis, it is found that the average energy efficiency of the boilers is 68.7%. It is also found that average exergy efficiency of the boilers is 22%. The average energy efficiency of furnaces found to be 30%. The average exergy efficiency of the furnaces has been calculated and found to be 19%. The major exergy destruction was found in the combustion chamber (55%) of the boilers and annealing chamber (62%) of the furnaces. Energy effectiveness of counter flow heat exchangers has been investigated and found to be 65% where the exergy effectiveness found to be 59%. By applying a heat recovery system, about 10% of the boilers and 30% of the furnaces energy can be saved with payback periods less than 1 year in the most cases. The energy effectiveness of economizer varied from 66% to 73%. Exergy effectiveness also calculated and found to be varied from 47% to 65%. It has been estimated that annually 67,868 MWh energy and 4,343,531 US$ bill can be saved by replacing standard motors with high efficiency motors. On the other hand, 51,510 tons of CO_2 385 tons of SO_2 and 141 tons of NO_x emission can be reduced against the aforementioned energy savings. By introducing variable speed drive in motor drive systems to match load requirements, energy savings estimated to be annually 542,941 MWh, 900,789 MWh and 1,098,222 MWh for 20%, 40% and 60% motor speed reduction, respectively. And corresponding annual bill savings found to 34,748,244 US$, 57,650,496 US$ and 70,286,221 US$, respectively. Emissions could be reduced by 836,831 tons of CO_2, 6217 tons of SO_2 and 2285 tons of NO_x by motor speed reduction of 60%. By improving the power factor near unity, about 10% of energy can be saved in the Malaysian industrial sector.

Based on the results, it is found that a sizable amount of energy can be saved by applying different energy savings measures and sizable amount of emissions can be reduced with reasonable payback periods.

Abstrak

Di seluruh dunia, sektor industri menyumbang sekitar 35 % dari jumlah keseluruhan tenaga yang digunakan. Khususnya di Malaysia, 48 % dari jumlah keseluruhan tenaga yang digunakan adalah dari sektor ini. Dandang, relau dan motor elektrik adalah peralatan bertenaga tinggi yang digunakan di setiap sektor industri dan mengguna sejumlah besar tenaga di sektor ini. Objektif kajian thesis ini adalah untuk menganalisa penggunaan tenaga dan exergy, penjimatan tenaga dan pengurangan pelepasan untuk peralatan industri bertenaga tinggi. Dalam kajian ini, konsep faedah tenaga dan exergy dihuraikan untuk mengetahui tenaga tenaga dan kecekapan exergy, dan kerugian exergy dalam dandang, relau dan penukar haba. Penggunaan tenaga, penjimatan tenaga dan bil, tempoh pulangan dan pengurangan pembebasan dari penjimatan tenaga yang berbeza pilihan (iaitu economizer, variable speed drive) untuk dandang, relau, dan motor elektrik dianalisis dan dibentangkan dalam tesis ini.

Dari analisis perbandingan, didapati bahawa kecekapan tenaga purata dandang adalah 68,7%. Hal ini juga mendapati bahawa exergy kecekapan purata dandang adalah 22.1 %. Kecekapan tenaga purata dari relau didapati berjumlah 30.1 %. Pengiraan kecekapan exergy purata relau telah memberikan jumlah nilai 19.3 %. Kerosakan exergy utama ditemui di dalam ruang bakar (55.4 %) dari dandangr dan ruang pemijar (61.8 %) dari relau. Tenaga keberkesanan penukar haba counter flow telah diteliti dan keputusannya menunjukkan ianya 64.8 % di mana keberkesanan exergy adalah 59.4 %. Dengan menggunakan sistem pemulihan haba, sekitar 10 % dari dandang dan 30 % daripada tenaga relau boleh dijimatkan dengan tempoh pulangan kurang dari 1 tahun untuk kebanyakan kes. Keberkesanan tenaga economizer adalah dalam lingkungan 66 % sehingga73 %. keberkesanan Exergy jugatelah dikira dan ianya bervariasi dari

47 % sehingga 65 %. Dianggarkan bahawa setiap tahun 67,868 MWH tenaga dan US$ 4,343,531 billion dapat dijimatkan dengan menukarkan motor biasa kepada motor berkecekapan tinggi. Tambahan pula, pembebasan 34,824 tan CO2, 257 tan SO2 dan 96 tan NOx dapat dikurangkan dengan penjimatan tenaga tersebut. Dengan memperkenalkan variable speed drive pada sistem penggerak motor untuk menyesuaikan keperluan beban, penjimatan tenaga dianggarkan 542,941 MWH, 900,789 MWH dan 1,098,222 MWH, masing-masing untuk 20 %, 40 % dan 60 % pengurangan kelajuan motor setiap tahun,. Hasilnya, penjimatan bil tahunan dianggarkan berjumlah US$ 34,748,244, US$ 57,650,496 dan US$ 70,286,221. Pembebasan yang dapat dikurangkan ialah 836,831 tan CO2,, 6217 tan SO2 dan 2285 tan NOx dengan pengurangan kelajuan motor sebanyak 60 %. Dengan memperbaiki faktor kuasa berhampiran kesatuan, sekitar 10 % daripada tenaga dapat dijimatkan dalam sektor industri di Malaysia.

Berdasarkan keputusan yang diperolehi, didapati bahawa sejumlah besar tenaga dapat dijimatkan dengan mengaplikasikan pelbagai langkah-langkah penjimatan tenaga dan sejumlah besar pelepasan dapat dikurangkan dengan tempoh pulangan yang munasabah.

Acknowledgements

In the Name of Allah, The Beneficent, The Merciful, I would like to express my utmost gratitude and thanks to the almighty Allah (s.w.t) for the help and guidance that He has given me through all these years. My deepest appreciation to my father, mother, brothers and sisters for their blessings and supports.

I would like to express my deepest appreciation and gratitude to my supervisors, **Associate Professor Dr. Saidur Rahman** and **Professor Dr. Nasrudin Abd Rahim** for their brilliant supervision, guidance, encouragement and supports in carrying out this research work. I am deeply indebted to them. Special thanks to the Research Centre for Power Energy Dedicated Advanced Centre (UMPEDAC), University of Malaya for the financial supports.

Finally, thanks to all in Energy Laboratory and UMPEDAC in helping me and for suggestion, ideas, discussions and advice in completing this research work.

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Nomenclatures

Abbreviation	**Full Term**	**Unit**
A	Area	m^2
AF_s	Stoichiometric air fuel ratio	
AES	Annual energy savings	kWh/year
AEU	Annual energy use	kWh/year
c	Cost of electricity	USD/kWh
CNG	Compressed natural gas	kg/s
C_p	Specific heat	kJ/kg.k
$COEF_{i,j}$	CO2 emission coefficient of fuel (tCO2/volume) taking into account the carbon content of the fuels used by the relevant power sources j and the percent oxidation of the fuel in year y	
$\dot{E}$	Rate of energy input/output	kJ/s
EA	Excess air	%
EB	Energy bill	USD/kWh
EF_{CO2}	CO_2 emission per unit of energy of the fuel i	
e_I	Energy effectiveness	%
e_{II}	Eexergy effectiveness (%)	%
$F_{i,j,y}$	Amount of fuel *i* consumed by relevant power sources j in year y	
$GEN_{i,j}$	Electricity delivered to the grid by source j	MWh
hp	Motor power	hp
h	Enthalpy	kJ/kg
hr	Annual operating hours	hr
H_{ff}	Higher heating value	kJ/kg

HHV	Higher heating value	kJ/kg
i	Type of gas (i.e. CO_2, NO_x)	
$\dot{I}_C$	Rate of exergy destruction of the combustion chamber	kJ/s
$\dot{I}_H$	Rate of exergy destruction of the heat exchanger of boiler	kJ/s
$\dot{I}_E$	Rate of exergy destruction of the economizer	kJ/s
j	Refers to the power sources delivering electricity to the grid not including low-operating cost and must run plants, including imports to the grid	
$kVAR_{cap}$	Capacitor (kVAR) required for targeted power factor	
k	Thermal conductivity	W/m. K
kW_{load}	Load of the system	kW
L	Load factor	%
LFO	Light fuel oil	kg/s
LHV	Lower heating value of fuel	kJ/kg
LPF	Lagging power factor	
$LPFP$	Lagging power factor penalty	
MFO	Medium fuel oil	kg/s
$\dot{m}$	Mass flow rate	kg/s
N_i	Mole fraction of component i	
M	Multiplying factor	
NCV_i	Net calorific value of the unit of fuels i	
N	number of mole	
n	Number of motors	
$OXID$	Oxidation factor of the fuel	
$MGTC$	Malaysia Green Technology Corporation	
PF_{target}	Target PF for the system	
P	Active power	kW
PF_{exist}	Existing PF before applying capacitors	

$\dot{Q}$	Heat transfer rate	kJ/s
Q	Reactive power	kVAR
S	Apparent power	kVA
s	Specific entropy	kJ/kg.K
T	Temperature	^{0}C
$\dot{W}$	Rate output work	kJ/s
$\dot{X}$	Rate of exergy input/output	kJ/s

Greek letters

γ	Grade function	
Δ	Change rate with the system	
ε	Specific exergy	kJ/kg
η	Energy efficiency	%
θ	Phase angle	
ψ	Exergy efficiency	%

Subscripts

a	Air
AC	Annealing chamber
c	Cold fluid
C	Combustion chamber
cv	Constant volume
ee	High energy efficiency motor
f	Fuel
g	Flue gas
gen	Generation
h	Hot fluid

in	Inlet of fluid
loss	Losses in the system
o	Reference state
out	Outlet of fluid
r	Recovery
std	Standard motor
s	Stream
SP	Stream production chamber
sys	System
w	Water

CHAPTER 1: INTRODUCTION

1.1 Background

Energy is the key input and basic need in industrial facilities all over the world for the development, economic growth, automation and modernization. Automation and modernization are increasing rapidly in the industrial sectors. However, global energy demands are increased rapidly and this concern is addressed internationally to fulfill the demand of energy for the future world. The usage of energy will be increased by 33 % within 20 years in the overall world (Abdelaziz et al., 2011). Figure 1.1 shows the world marketed power demand. World power demand rises from 145 billion MW in 2007 to 218 billion MW in 2035 (i.e. increases by 49 %).

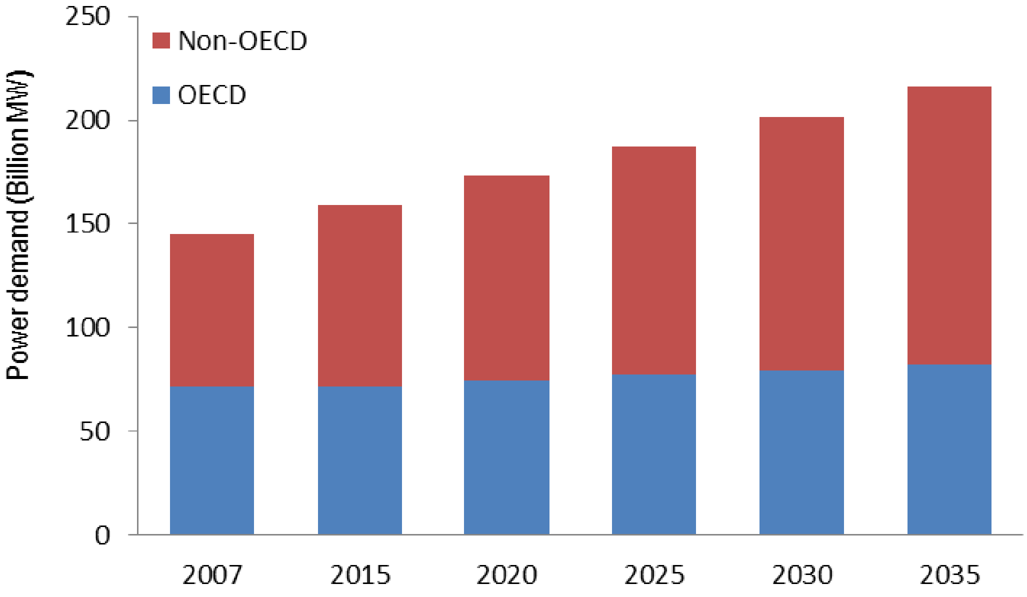

Figure 1.1 World marketed power demand
(EIA, 2010)

The overall power demands from 1990 to 2007 in Malaysia are shown in Figure 1.2. The power demand in Malaysia is increased more than 2 times between 1990 to 2007.

As a result, the power plant installation also increases. The power plant capacity is increased from 14,291 MW to 21,815 MW between 2000 to 2007 (NEBM, 2007).

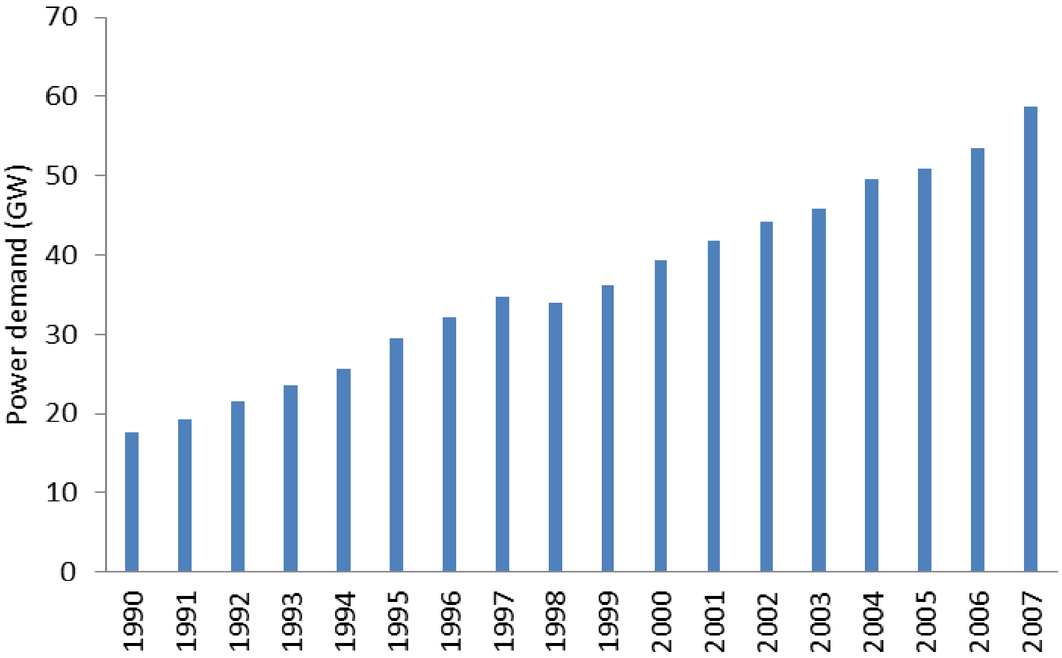

Figure 1.2 Overall power demand in Malaysia
(NEBM, 2007)

1.2 Study of energy use in industrial boiler, furnace and electric motor

Industrial sector consumes more than one third of total world energy consumption. It is also predicted that the share of energy consumption in this sector will be increased in future. Energy demand is increased due to the increasing the economic activities and automation in the industrial sector. So, it is an important task to analyze and predict energy uses in the industrial sector for the future (Greening et al., 2007; Hashim, 2010). Energy used in the industrial sector is more compared to any other sector of the world's total energy used. The demand of energy in the industrial sector depends on the region, country, level of economic activities, industrial product, production process, technological development etc. Figure 1.3 shows the world power demand in industrial sector. Energy consumption in the industrial sector increases rapidly in the non-OECD countries due to quick growth of their economy and predicted that the annual average rate will be 1.8 % from 2007 to 2035. Table 1.1 shows the statistic of energy use of industrial sector of different countries in the world.

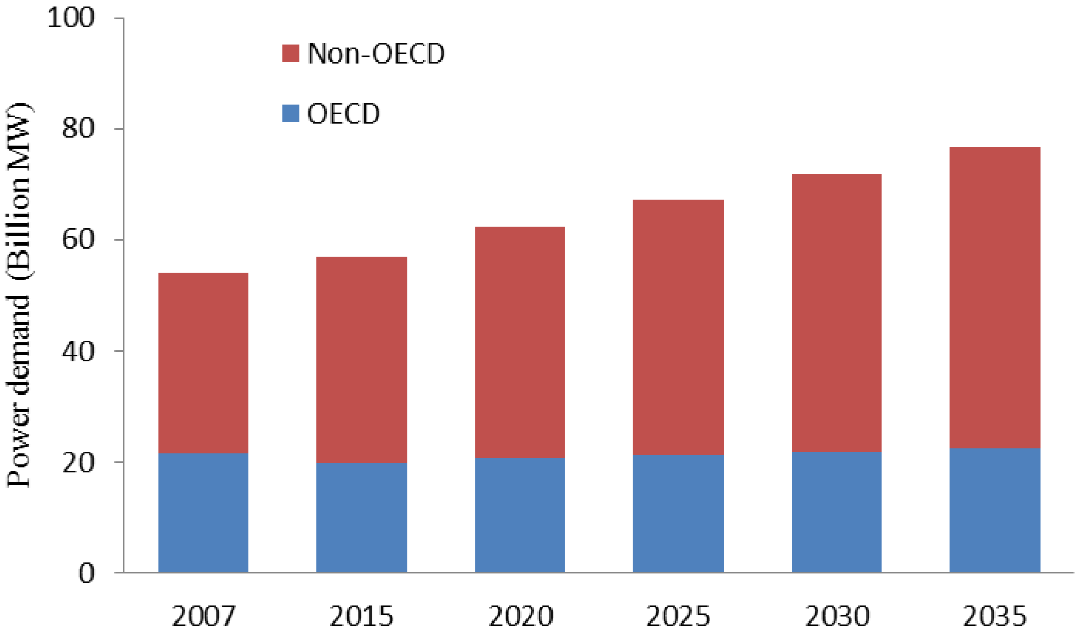

Figure 1.3 World power demand in the industrial sector
(EIA, 2010)

The industrial sector also one of the major energy users in Malaysia. The industrial power demands from 1990 to 2007 in Malaysia are shown in Figure 1.4. The power demand increasing rate of industrial sector was higher compared to whole Malaysian demand increasing rate between 1990 and 2007 (NEBM, 2007).

Table 1.1 Statistics of energy used in industrial sector for some selected countries

Country	Energy use (%)	References
Brazil	41	(Henriques et al., 2010)
China	70	(Zhou et al., 2010)
Colombia	34	(Martínez, 2009)
Germany	28	(Martínez, 2009)
India	45	(Gielen & Taylor, 2009)
Jordan	31	(Al-Ghandoor et al., 2008)
Malaysia	48	(Saidur et al., 2009b)
Norway	40	(IET, 1998)
Slovenia	52	(Al-Mansour et al., 2003)
South Africa	44	(Oladiran & Meyer, 2007)
Sweden	38	(Johansson & Söderström, 2011)
Taiwan	51	(Chan et al., 2007)
Thailand	36	(Hasanbeigi et al., 2010)
Turkey	35	(Önüt & Soner, 2007)
US	33	(EIA, 2004)
World	35	(Gielen & Taylor, 2009)

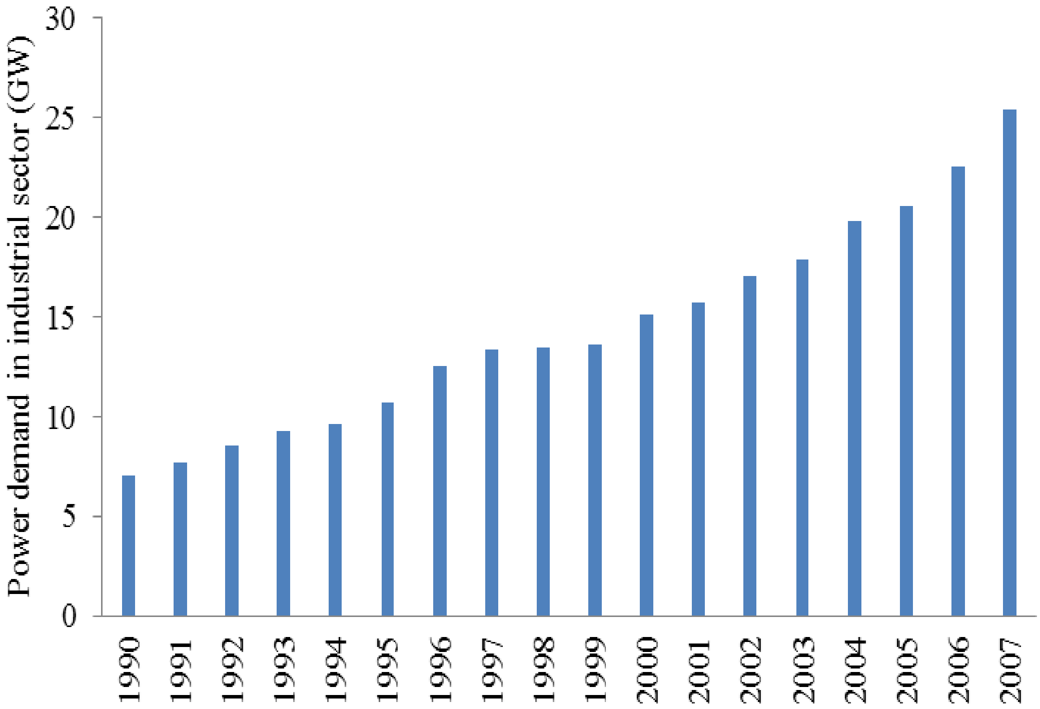

Figure 1.4 Power demand in industrial sector in Malaysia
(NEBM, 2007)

Boiler, furnace and electric motor are most common equipment in the industries. Major portion of energy is consumed by boiler, furnace and electric motor in the industries. In United States, industrial boilers consume 37% of total energy consumption in the industries (ETSAP, 2009). About 12 % of total energy is used for the metal (i.e. iron, steel, etc.) industries (Çamdali et al., 2003) where approximately 25% of the energy is used in the furnaces (ECSI, 2011). Energy consumption by electric motors is about 30 % to 80 % of total energy used in industrial sector for some selected countries in the world as presented in Table 1.2.

Table 1.2 Energy used by electric motor for selected countries

Country	Motor Energy usage (%)	Reference
US	75	(Bouzidi, 2007; Lu, 2006)
UK	50	(Mecrow & Jack, 2008)
EU	65	(Tolvanen, 2008)
Jordan	31	(Al-Ghandoor et al., 2008)
Malaysia	48	(Saidur et al., 2009a)
Turkey	65	(Kaya et al., 2008)
Slovenia	52	(Al-Mansour et al., 2003)
Canada	80	(Sterling, 1996)
India	70	(Prakash et al., 2008)
China	60	(Yuejin, 2007)
Korea	40	(KERI, 2007)
Brazil	49	(Soares, 2007)
Australia	30	(EEMDS, 2009)
South Africa	60	(Khan, 2009)

1.3 Emissions of industrial boiler, furnace and electric motor

Climate change is an important environmental problem which potentially leads to rises in sea levels, loss of coastal land, and ecological shifts. A major cause of climate change is emissions of greenhouse gases (Yang, 1997). Energy is an important factor to the development and economic growth for a country. Economic growth also depends on the energy security, amount of energy used and technological improvement since higher the economic growth, higher the energy consumption (Ang, 2008). However, to fulfill the energy demand, energy generation sector contribute to the environmental degradation (i.e. emission, air pollution, acid rain, climate change etc.) (Rahman & Lee, 2006). The Intergovernmental Panel on Climate Change (IPCC, 2007) reported that the great and serious problem for the environment of its global warming. To save the earth by curbing global warming has become a common mission of all humanity (Ekholm et al., 2010). In order to the response this challenge, eco-efficiency approach is inducted to restrain an emission (Mao et al., 2010). The energy-related CO_2 emissions were 26.3 Gt in 2004 in the world (IEA, 2007). The industrial sector emitted about 37% of the total emissions (i.e. direct and indirect emissions). Increasing rate of CO_2 emissions by the energy used in industrial sector was an annual average of 1.5% from 1971 to 2004 (IPCC, 2007). The importance of national energy plans, Jordan was investigated and found that electricity generation and associated emissions will be raised about 63% by 2019 (Al-Ghandoor et al., 2008). In Brazil about 81% of CO_2 emissions by the country's industrial sector come from energy use (Henriques et al., 2010). The combustion of fossil fuels contributes emissions of various gases, trace of heavy metal contaminants and organic compounds that have an undesirable effect on environment (i.e. climate changes). Emissions release by the burning of fossil fuels have a serious greenhouse effect (i.e. acid rain, ice melting, temperature rises) on mankind (Mahlia, 2002). More the energy used more the CO_2 emission and the have a quadratic relationship for the long run (Ang, 2007). Kyoto Protocol took first serious step in 1997 for emissions reduction. According to the Kyoto Protocol targets and their framework, the total emissions in developed countries must be reduced at least 5% below 1990 levels in the year of 2008 to 2012 (Balaras et al., 2005; Mirasgedis et al., 2004). Since the emissions is directly depends on the usage of fossil fuels, so reduction of energy consumption is the direct way of control emission's problem (Soytas & Sari, 2009).

Boiler, furnace and electric motor are the major end energy user in the industrial sector. In the boiler and furnace, fossil fuel (i.e. CNG, Diesel) is directly used in the industry. This is one of the major emission sources that are directly burning fossil fuel. Motor consume electric energy that is produced in the power plant by burning fossil fuel (i.e. Coal, Diesel). Amount of emissions depends on the fuel type, emission factor, percentage of excess air, burner efficiency, etc. Malaysia has to evaluate and exploit each feasible ways to reduce emission while maintaining its economic growth to meet this commitment of emissions reduction. Thus, a comprehensive and representative industrial emission analysis is needed to assess the feasibility of numerous potential strategies to reduce emissions in Malaysia. Such an analysis can be conducted for the comparative evaluation and estimation for a policy making tool to achieve Malaysia's overall emission reduction commitment. Future industrial CO_2 emissions depend on the fuel, technology and industrial activity. So, the investigation and estimation of the trends of emissions and reduction potential is very important in order to make a plan for low carbon society.

1.4 Importance of energy and exergy study

Known energy sources are exhausted rapidly due to increasing the energy consumption. So, it is very importance the efficient and effective use of energy. The collection and analysis of industrial data and other energy end used sectors are basic conditions in the purpose to set targets of energy savings. The basic and important method is energy balance to investigate a process. The energy balance analysis makes possible to improve the process optimization (Utlu et al., 2006). The analysis results would disclose the efficient utilization of energy. Exergy is the modern thermodynamic concept that is used for the process evaluation likes an advanced tool (Szargut, 1989). The energy is analyzed based on the first law of thermodynamic, whereas the exergy is analyzed on the basis of both the first and second laws of thermodynamic (Jayasinghe et al., 2011). The exergy analysis is used to discover the causes of the imperfection of a thermal process and the magnitude of the imperfection. The first law of thermodynamics normally fails to detect losses of work and potential improvements or the effective use of energy in a process (Simpson & Kay, 1989). However, the second law of thermodynamics (i.e. exergy) analysis takes the entropy portion into consideration by including irreversibilities (Dincer, 2002). Exergy is a measure of the maximum work capacity of a system in a specified final state in equilibrium with its surroundings.

Exergy destruction is the measure of irreversibility that is the source of performance loss (Aljundi, 2009a). It can be painted that the prospective effectiveness of exergy study in sectoral energy used is crucial for energy policy making activities (Dincer et al., 2004a, b). Exergy analysis could be helpful to design efficient thermal processes to reduce the sources of energy and exergy losses. Efficiency improvement can often contribute to achieve energy security as well as clean environment (Akpinar & Bicer, 2005). Exergy analysis is usually used to identify the sites, causes and true magnitude of irreversibility (Kanoglu et al., 2005, 2007). It is found that energy and exergy analysis is a vital important for energy planning, environmental issue and greenhouse gasses reduction.

1.5 Limitation of the study

In this work actual energy consumption and different operating parameters of boiler, furnace, heat exchanger, economizer and electric motor have been taken from different sources (i.e. MGTC). However, it is very difficult to do experiment in the laboratory to get data of all machineries due to several reasons:

- Boiler and furnace are very much expensive to establish laboratory to conduct experiment.
- There is no funding source for this work.
- There is no experimental facility for investigating energy and exergy efficiency of boiler, furnace, heat exchanger and economizer.

1.6 Objectives of the research

Boiler, furnace and electric motor are the major energy end user in the industrial sector. But very few researcher works on energy use and efficiency improvement has done in this sector in Malaysia. Moreover, the work reported in the literature is very few and not complete for the analysis of boiler, furnace, heat exchanger, economizer and electric motor. This study is trying to fill that gap to analyze on energy, exergy, energy savings and emissions reduction of the above equipment in industrial sector in Malaysia.

The objectives of the research are as follows:

- To investigate energy and exergy performance of boiler, furnace, heat exchanger, economizer and motor
- To apply energy savings measures and estimate energy and bills savings for the above equipment
- To analyze emissions produced by burning fossil fuels in the industries and power station.
- To estimate emission reduction by applying different energy savings strategies in the industries.
- To carry out cost-benefit analysis of different energy savings measures

1.7 Contribution of the research

The research has focusd on proper utilization of energy and exergy, energy savings as well as emissions reduction in the energy intensive industries in Malaysia. The useful concept of energy and exergy is analyzed to investigate the energy and exergy efficiencies, energy and exergy losses in boilers, furnaces, heat exchangers and economizer. For the analysis, the necessary equations have been modified or developed where the standard equations were not available. Energy use, energy and bill savings, payback periods and emission reduction of different energy saving options (i.e. economizer, recuperator, boiler and furnace retrofitting, variable speed drive, high efficiency motor, power factor correction, etc.) for boilers, furnaces, and electric motors were analyzed and the result as well as conclusions have been presented in this thesis to provide the useful guide for industries as well as researchers.

1.8 Outline of the thesis

This thesis comprises five chapters. The contents of the individual chapters have been outlined as follows:

Chapter 1: Background information about the energy, exergy, and emission, importance of the research and research gap, aim and objectives of the research and outline of the thesis have been presented in this chapter.

Chapter 2: In this chapter, a review of literature on energy, exergy, boiler, furnace, heat exchanger, electric motor, energy savings, cost benefit analysis and emissions reduction were discussed in details.

Chapter 3: Information on the sources of data and methodologies used to estimate the different parameters is presented in this chapter. Analytical model Analysis of various parameters of boiler, furnace and heat exchanger to calculate energy, exergy, energy and exergy efficiency, energy and exergy losses, irreversibilities were carried out in this chapter. Approaches used in calculating energy consumption. Energy efficiency is outlined as well. Energy saving policy measures to calculate energy savings, bill savings and payback periods were elaborated in this chapter as well. Emission produced by burning fossil fuels and emission reduction by different policy measures were also discussed in this Chapter.

Chapter 4: The energy and exergy use, energy and exergy efficiency, energy and exergy losses, irreversibilities in the boiler, furnace, heat exchanger and energy use of electric motor are described with necessary Tables and Figures. It is also described the energy savings, bill savings, payback periods and emissions reduction of the industrial sector.

Chapter 5: General conclusions and recommendations for future work are presented in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter contains an overview of other related studies, its approach development and its significance to this study in order to set up the objectives of this research. Pertinent literatures in the form of PhD and Master Thesis, journal articles, reports, conference papers, internet sources, and books collected from different sources are used for this study. It may be mentioned that about 80-90% of the journal papers collected from most pertinent and prestigious peer reviewed international referred journals such as Applied Energy, Energy, Energy and Buildings, Energy Conversion and Management, Energy Policy, Building and Environment, Applied Thermal Engineering, Exergy-An International Journal, and International Journal of Energy Research. Moreover, the substantial amount of relevant information has been collected through personal communication with the key researchers around the world in this research area.

2.2 General overview of energy and exergy

Energy and exergy are useful concept that is dealing with the thermodynamics. Energy, entropy and exergy concepts are applicable to science and engineering related fields. Thermodynamics plays important role in the analysis of processes in which energy transfers and energy transformations occur. According to the first law of thermodynamics, energy could never be destroyed and just transformed into other forms. However, it is realized that there are different forms of energy (i.e. electricity, heat, mechanical power, light) that are theoretically possible to transform into each other (Dikici & Akbulut, 2011). Nature allows the conservation of work completely into heat. But, heat cannot be entirely converted into work and doing so requires the device (Dincer & Rosen, 2007). At first the half of the 19th century, Carnot stated the second thermodynamic that there is a maximum efficiency for transformation. Taking his finding as a basis, it could be stated that some energy (i.e. electricity, mechanical power, etc.) can be transformed with theoretically no losses (ordered energy). But others form of energy (i.e. heat) can be transformed with a certain amount of losses (disordered energy). It could be stated that there is a quality factor for energy. The convenient standard energy quality is the maximum work capability which can be produced from a given reference state (temperature, pressure, etc.). Exergy is a measure of the maximum capacity of a system to perform useful work as in a specified final state in equilibrium with its surroundings (Aljundi, 2009a). Exergy is energy, which is totally exchangeable into other types of energy. Common energy carriers like fossil fuels supply high valued energy. The destruction of order, or the creation of chaos, is a form of environmental damage. Entropy is the fundamental measure of chaos (Rosen & Dincer, 1997a). A higher entropy system is more chaotic or disordered than the lower entropy system. Therefore, the exergy of an ordered system is greater than that of a chaotic one (Saidur, 2008).

The energy analysis only identifies losses of work and effective use of resources of a process. However, exergy analysis takes the entropy portion into consideration by including irreversibilities of the process (Dincer, 2002). Exergy analysis is usually used to identify the sites of irreversibilities, causes of irreversibilities and true magnitude of irreversibilities (Kanoglu et al., 2005, 2007). Exergy destruction is the measure of irreversibility of the process of performance loss (Aljundi, 2009a). Exergy analysis of the energy utilization has been carried in USA (Reistad, 1975), Canada (Rosen, 1992) Japan, Finland and Sweden (Wall, 1990), Italy (Wall et al., 1994), Turkey (Özdogan & Arikol, 1995; Rosen & Dincer, 1997b; Utlu & Hepbasli, 2003, 2005), UK (Hammond & Stepleton, 2001), Norway (Ertesvåg, 2005; Ertesvåg & Mielnik, 2000), China (Ji &

Chen, 2006), Malaysia (Saidur et al., 2007a, b, c) and Saudi Arabia (Dincer et al., 2004a, b, c). Authors use the exergy concept to analyze the residential, commercial and industrial sectoral energy use, efficiency and losses.

2.3 An overview on energy and exergy review of the boilers

Boiler is the most common equipment in most of the industry. Most of the heating process, although not all, boiler is employed to supply hot water and steam. Since industrial processes are different for different process, but hot water and steam process is common (Einstein et al., 2001b). Analysis of energy and exergy for diverse industrial systems have been analyzed in other countries (Al-Ghandoor et al., 2009; Chen et al., 2012; Hammond, 2007; Hammond & Stepleton, 2001; Kanoglu et al., 2005, 2007; Karakus et al., 2002; Mondal, 2008; Som & Datta, 2008). Exergy performance had been studied of a power plant and found that exergy efficiency of the combustion chamber of the boiler was 18.9% and high losses in a boiler (Jamil, 1994). Energy and exergy have been analyzed of the process components individually to identify and quantify the sites of energy and exergy losses of Al-Hussein power plant in Jordan found that maximum exergy destruction in the boiler system (77%) (Aljundi, 2009a). Boiler is the main contributor of the total plant's inefficiency where the total plant and boiler irreversibilities vary from 61.20 % to 46.13 % and 53 % to 34% repectively**.** Energy and exergy were investigated by using first and second law of thermodynamic of a CNG fired industrial boiler (Saidur et al., 2010). The authors found that combustion chamber and stream production chamber are the main parts of exergy loss and energy efficiency is higher compared to exergy efficiency. Modern boiler could utilize only 37% of chemical exergy of the fuel for the steam generation where the rest 63% is lost due to combustion irreversibilities (Kamate & Gangavati, 2009). Energy and exergy has been analyzed of a combined-cycle power plant and found the combustion chambers, gas turbines and heat recovery steam generators are the main causes of irreversibilities that is represented more than 85 % of the overall exergy losses (Cihan et al., 2006). Exergy has been analyzed to evaluate and estimate the exergy and found 57.9% of the total input exergy losses where about 28.1 % due to the irreversibilities for the components and 26.1% in the boiler exhaust gas (Wang et al., 2009). The rapid temperature reduction is one of the reasons of exergy destruction. Beside the temperature difference, the irreversibilities due to the combustion reaction also causes of the exergy destruction (Aneta & Gheorghe, 2008). The major exergy destruction was found in the boiler that is about 81 % of the total power plant cycle exergy destruction (Ameri et al., 2009). Energy efficiency improvement in the industrial sector is the most importance option to save energy as well as emission reduction. To improve energy efficiency, energy consumption of the production process needs to analyze. Boiler efficiency has influence on heat transfer to the water where various losses by hot flue gas, radiation, unburned fuel, moisture content of the air and fuel, and blow-down etc (ERC, 2004; Mario, 1998; Nattapong & Thaweesak, 2008). About 10% to 30% of energy losses through flue gas of the boiler (Beggs, 2002; Jayamaha, 2008). Fuel represents the biggest cost in power generation and in other industrial process. Consequently, getting all the useful energy from the fuel into the working fluid of the boiler is necessary to produce higher boiler productivity and improved boiler efficiencies. However, efficiency is sometimes overlooked because the traditional and tactical approach to boiler operations is to focus on operations not energy management (Taplin, 1996).

The literature shows that energy and exergy analysis are the potential field for proper utilization of energy and energy savings. In this research, energy and exergy have been analyzed on combustion chamber, heat exchanger and overall boiler individually to investigate the energy and exergy efficiencies, exergy destruction, potential energy and utility bill savings of the boiler.

2.4 Review on energy and exergy of the furnaces

Annealing is the process where the metal, glass and other materials are treated to make them less brittle and more workable for the use of the different purpose. In the steel industry, steel is heated and control the profile with time and temperature according to the desired properties. Steel strip, rod and wire products are usually heat treated in a controlled atmosphere during their manufacture to maintain the quality and formability. Continuous annealing furnaces work separately or as parts of a continuous process line provide higher surface quality than batch furnaces (Stanescu et al., 2003). Energy processes in the industries can be analyzed through economic assessment (i.e. losses associated with the production phases). Several authors have been analyzed the efficient use of energy in different phases of industrial processes (Bisio et al., 2000; Çamdali & Tunç, 2003; Çamdali et al., 2003; Guihua et al., 2011; Karimi & Saidi, 2010). After the employee cost, energy cost (about 30 % of the total) is the second highest cost in the steel industries. Approximately 12 % of the total world energy is consumed in this industrial sector (Çamdali et al., 2003). Therefore, to reduce the cost of energy, it is essential to discover sources of losses. After discovering the sources of losses, it can reduce the losses of the process (Çamdali et al., 2001; Danon et al. 2011). The energy consumption reduction is a major concern of the steel industry.

The blast furnace is the major energy consumption equipment in the steel making industry. The use of coke, gas, coal dust as fuels have become more expensive, so efficient utilization is mandatory (Bisio, 1996). In the case of free-burning arcs, only 10 % to 15 % of the energy is transferred to the furnace wall and 5 % to10 % to the furnace roof (Bisio et al., 2000). Exergy is analyzed of a ladle furnace in an alloyed and steel production. During the analysis, temperature of steel and flue gas and production time has been considered to calculate the actual work and irreversibility. Exergy efficiency of the furnace was 50 % and irreversibility increase with increasing the temperature. A suitable temperature control is one of the energy savings option of the furnace (Çamdali et al., 2001). Heat is lost through the production process or line of the steel making process in the industry and about 36 % of losses in the furnace (Mohsen & Akash, 1998). The second law has been analyzed in electric arc furnace and found when the actual work and reversible work increased, the irreversibility decrease slowly (Çamdali et al., 2003). The first and second of thermodynamic has been analyzed of an electric arc furnace and found the energy efficiency 96 % and the exergy efficiency 55 %. The overall exergy losses is 44.5 % and the main causes of losses due to the chemical reactions and heat transfer of the electric arc furnace (Çamdali & Tunç, 2003). A gas-fired radiant tube-heating furnace has been investigated and found that the exergy efficiencies, destructions, losses, and entropy generation of the furnace were 9.6%, 12.53 kW, 44.28 kW, and 6.6 kW, respectively (Caliskan & Hepbasli, 2010). The applications of exergy in the thermal process in thermal plants are many research works in the literature. Although, insufficient quantity research in the field of iron and steel industrial sector (Çamdali et al., 2001).

The literature shows that energy and exergy analysis are the potential field but very limited works has been done on furnace for proper utilization of energy and energy savings. In this research, energy and exergy have been analyzed on combustion chamber, annealing chamber and overall furnace individually to investigate the energy and exergy efficiencies, exergy destruction, potential energy and utility bill savings of the furnace.

2.5 An overview on energy and exergy of the heat exchangers

Energy conservation is one of the key goals of the world energy saving as well as economy. Efficient use of energy is the most effective way to reduce energy demand.

Heat exchanger is widely used to transfer thermal energy between two or more media which is widely applied to the power plant, petroleum refineries, chemical industries, food industries, etc. (Guo et al., 2009; Wu et al., 2007). In the past decade, enhancement of heat transfer developed and extensively used in heat exchanger (Eiamsa-ard & Promvonge, 2005). In the augmentation technique's effectiveness of heat exchanger can be improved by using active and passive methods. By using the passive method, the improvement of heat transfer can be achieved without adding extra energy where the active method needs extra energy (Durmus et al., 2009). At the levels of low performance, the heat exchanger effectiveness is governed by film heat transfer coefficients (Ahuja & Green, 1998). The purpose of augmenting is to increase high heat transfer rate. That is why; analysis of exergy and energy are essential parameters for the design of heat exchanger (Durmus et al., 2009). The losses of exergy in the heat exchanger are due heat loss due to temperature difference and pressure drop (Yilmaz et al., 2001). It is found that efficiency increases with increasing surface contact area and mass flow rate of fluid of the heat exchanger (Durmus et al., 2009). The thermal performance and pressure drop of a helical-coil heat exchanger with and without helical crimped fins has been investigated by using a shell and helically coiled tube unit consisting of two different coil diameters. Cold and hot water are used as working fluids in shell side and tube side where the cold and hot water mass flow rates ranging between 0.10 and 0.22 kg/s, and between 0.02 and 0.12 kg/s, respectively. The inlet temperatures of cold and hot water are between 15 and 25 °C, and between 35 and 45 °C, respectively. It is found that the average heat transfer rate increases with increasing the mass flow rate of hot and cold water and the friction factor decreases. Inlet hot and cold water mass flow rates and inlet hot water temperature have significant effect on the heat exchanger effectiveness (Naphon, 2007). A cross flow plate type heat exchanger, operating with unmixed fluids, was analyzed with balanced cross flow and found that when the dimensionless heat transfers area increases, the optimum dimensionless mass velocity decreases (Ogulata et al., 2000). Exergy transfer effectiveness has been investigated to describe the performance of heat exchangers operating above/below the surrounding temperature with/without finite pressure drop. The effects of heat transfer unit's number, the ratio of the heat capacity of cold fluids to that of hot fluids and flow patterns on exergy transfer effectiveness of heat exchangers has investigated. The pressure drop exerts the greatest effect on parallel flow heat exchanger, the second is cross flow and the least is counter flow (Wu et al., 2007). Energy conservation is vital for the development of world economy. To use energy more efficiently is one of important measures for saving energy.

The literature shows that very little work has been done on heat exchanger about energy and exergy analysis, energy savings and efficiency improvement. It is also found that energy and exergy analysis, energy savings and efficiency improvement are the potential field for proper utilization of energy and energy savings. In this research, energy and exergy have been analyzed on heat exchanger to investigate the energy and exergy efficiencies, exergy destruction, potential energy savings and efficiency improvement.

2.6 Review on energy and exergy of the economizers

Economizer is one of the heat exchanger where the heat is transferred flue gas to boiler feed water. When the stream production increased, the economizer was more effective and the cost savings in the fuel consumption (Ghosh & De, 2003). In the case of boiler, an economizer is used to utilize the flue gas heat to pre-heat the boiler feed water. Energy costs are the highest in recent history. Implementation of energy efficiency ways in thermal processes is a vital element in streamlining rising energy cost (SECE, 2010). Economizer is one of the waste energy recovery ways to improve the thermal efficiency of the boiler. By increasing feed water temperature through captured flue gas, economizers also provide a significant improvement in steam (BE, 2010). Heat recovery from the flue gas depends on the effectiveness of the economizer (Osakabe, 2000). The energy effectiveness of the economizer ranged from 50 % to 64 % (Mario, 1998). Analysis of energy and exergy of economizer is most important for improving the energy and exergy effectiveness. There is no work on exergy analysis of economizer.

The literature shows that very little work has been done on economizer on energy and exergy analysis and efficiency improvement. Energy and exergy analysis is the potential to improve economizer effectiveness. In this research, energy and exergy have been analyzed to investigate the energy and exergy effectiveness of economizer in the industrial boiler.

2.7 An overview on energy end use by electric motor in industry

The industrial sector is one of the largest end energy users all over the world. Electric motor consumed a major fraction of total industrial energy usage. Electric motors have broad applications in industry for the powering a variety of equipments (i.e. wind blowers, water pumps, compressors, machine tools, etc.). In industrially developed and large developing countries, electric motors consumes a major portion of total national energy consumption (Saidur, 2010). The induction motor is the main driven system in the modern industrial society (Corino et al., 2008). In Malaysia, a major amount of electricity consumption in the industrial and commercial sectors is by electric motors. The industrial activities and processes are greatly dependent on electric motors for compacting, cutting, grinding, mixing, fans, pumps, materials conveying, air compressors and refrigeration. Energy losses in a large number of industries are prevailing and potential energy efficiency improvements are imminent (Mohsen & Akash, 1998). Figure 2.1 presents an idea on the distribution of energy consumption by motors for various applications in a typical plant.

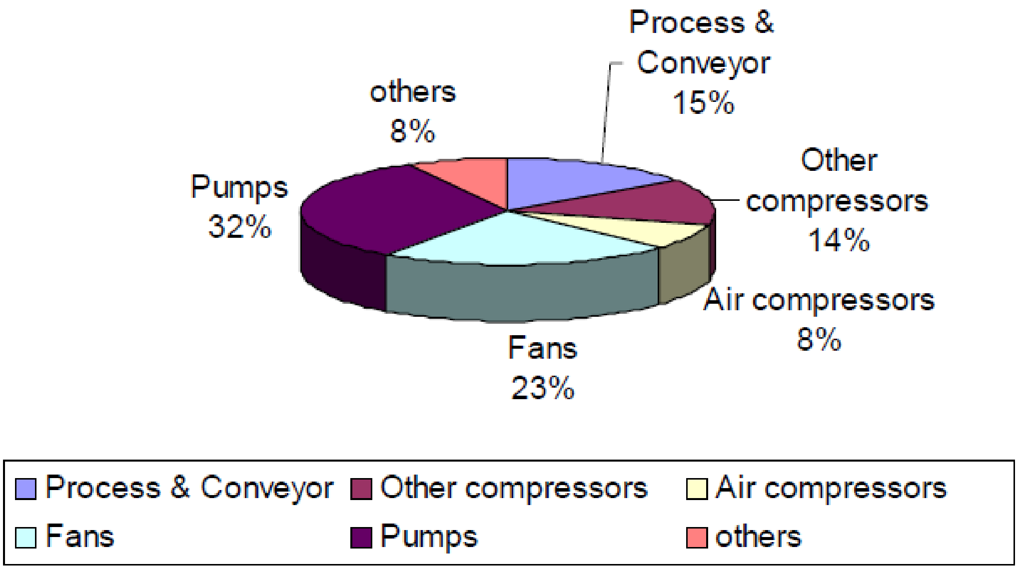

Figure 2.1 Energy end use by motors in the typical plant.
(Cheng, 2003)

Motor efficiency depends on the intrinsic (fixed and variable) losses that can be minimized by energy efficient motor design. Figure 2.2 shows the various losses of a typical motor. Fixed losses are not depending of motor load and involve of magnetic core losses and friction and windage losses. The magnetic core losses consist of eddy current and hysteresis losses in the stator. Friction and windage losses are due to friction in the bearings of the motor. Variable losses depend on load consists of resistance losses in the stator and rotor and miscellaneous stray losses. Stray losses arise from a variety of sources and are difficult to either measure directly or to calculate, but are generally proportional to the square of the rotor current (Saidur, 2010). A motor is used to convert electrical energy to mechanical energy for the implementation of useful work. Even though standard motors efficiency in the typical range of 83 % to 92 % but the energy-efficient motors efficiency much better. An efficiency improvement from only 92% to 94 %, results in 25 % reduction in losses. Since motor losses result in heat rejection into the atmosphere and the reduction of those losses can significantly retard cooling loads on an industrial air conditioning system. Motor energy losses can be classified into five main areas, each of which is influenced by design and constructions (Capehart et al., 2005; ERC, 2004; Gilbert et al., 1993; Jayamaha, 2008; Jordan, 1994)

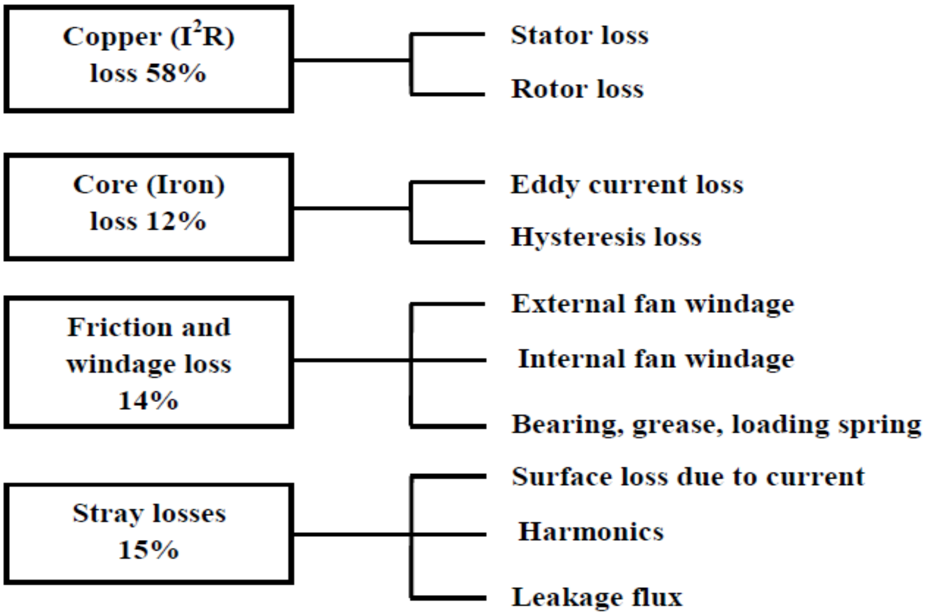

Figure 2.2 Various losses of eletric motor
(BEE, 2009; Jayamaha, 2008)

A common cause of motor failure is the problem of motor windings, and the solution often is to rewind the old motor. Because it is economical in terms of initial cost, rewinding of motors is very common, particularly for motors of higher horsepower (Mikail, 2010). However, the motor rewinding process often results in a loss of motor efficiency. It is normally cost effective to replace motors under 20 hp with new high-efficiency motors rather than rewind them. To make a decision to buy a new motor or rewind the old motor, it is wise to consider the cost difference between the rewind and a new high-efficiency motor and relevant energy costs to operate it (i.e. cost benefit analysis). A paperboard plant with 485 motors where an average of 3 motors was repaired per month, of which about 70% required rewind or replacement (IPTM, 1996). The facility operated 8000 hours/year. Collected motor information is shown in Table 2.1.

Table 2.1 Analysis of motor capacity and motor repair.
(IPTM, 1996)

Motor capacity	Number of motors
< 20 hp	347 (Replace, no repair)
20	15
25	10
30	2
40	3
50	27
75	18
100	21
125	32
400	6
750	4

A robust and efficient motor usually converts 90% to 95% of input electrical energy to mechanical work. However, the significant amounts of energy they use, a minor change in efficiency have a great effect on its operating costs. In the High Efficiency Motor (HEM), specific materials are used to reduce core and copper losses. Therefore, less heat is generated and requires smaller cooling fans to cool the motor (Akbaba, 1999).

In the literature a number of works were reported about use of high efficiency motors to reduce energy consumption of motors. However, there is no detailed work on the cost effectiveness of rewind motors. Aim of the present study is to analyze the energy consumption of the rewind, standard and high efficiency motors with different capacities and loading operation.

2.8 Review on energy savings, economic analysis and emission reduction

Fuel prices and environmental taxes are increasing rapidly; as a result industrial sector searching and applying substantial cost savings ways by installing different energy savings options (i.e. economizer, recuperator, variable speed drive, high efficient motor, etc.) of the boiler, furnace, motor etc. The oil price has increased more than 60-70% in the last 15 years. As a result, the encouragement to recover waste energy becomes more and more obvious for the energy saving. The indirect effects of the waste heat recovery are lower exhaust gas volumes as well as lower emissions to the atmosphere. The direct benefit of the waste heat recovery is the lower fuel consumption (i.e. fuel saving, emission reduction etc.) (EHRS, 2010). In the boiler and furnace system, flue gas energy loss is one of the major losses. About 16 % to 20 % of the total energy is generated by using the boiler (Willems, 2005) where huge amount of energy is lost through the flue gas. An economizer can be used to recover the waste heat from the flue gas to pre-heat the boiler feed water. In alternative way, the recovered waste heat also used to preheat combustion air of the boiler. In both cases, a huge amount of fuel can be saved of the boiler. In other words, for every 6 ^{0}C rise in feed water temperature through an economizer, there is 1 % saving of fuel in the boiler (BEE, 2010; Willems, 2005). In the case of eeconomizers, heat is transferred from exhaust gas to the feed water in the form of sensible heat. As a result, exhaust gas temperature reduces while preheating the boiler feed water as well as overall system efficiency also increased. Normally boiler efficiency increases by 2.5 % to 4 % due to use of economizer which depends indirectly on the tube number, tube fins, pressure drop and directly on feed water temperature (Willems, 2005). High stack temperature meant that useful heat was rejected to the surrounding; however, the economizer recovered 57 % of the heat rejected. As a result, the fuel consumption was reduced and the boiler efficiency was improved. E-tech heat recovery systems are more compatible for any type of fuel burning boiler (i.e. wood, oil, coal, etc.). Boiler with economizer can normally expect for every 22 ^{0}C drop in flue gas temperature increases the efficiency of 1% (BE, 2010). In the air pre-heater, the waste heat is used to pre heat the combustion air which is saved energy both of boiler and furnace. In the air preheating system, for every 22 ^{0}C reduction of flue gas temperature by passing through an air preheater (i.e. recuperator) 1% fuel can be saved in the boiler (BEE, 2010; TEE, 2010; Willems, 2005). By installing an condensing economizer, up to 20% energy can be saved to recover the waste heat from the flue gas of boiler (SECE, 2010). The economizer is a very simple technology and there are no moving parts that make the system relatively maintenance-free and long life cycle. The boiler performance improvement was studied by using economizer and found to be 57 % of cost saving (Gonzalez, 1998). The simple payback of the condensing economizer is normally less than 2 years (SECE, 2010). Fuel consumption can be reduced about 25% by using the preheated air of high temperature of about 1327 ^{0}C (Hasegawa et al., 2000).

Significant amount energy is lost through the flue gas in the furnace (Davenport & Rogers, 2011) and the losses can be reduced by using of recuperators to preheat combustion air (Davenport & Rogers, 2011). In many cases, flue gases contain 50% to 70% of the total furnace heat input. Performance and overall economics of a heat recovery device whether it is used for combustion air preheating or charge preheating depends on the nature of flue gases passing through the heat recovery device. Preheating of combustion air by using flue gas heat is more commonly used than charge preheating (Keiser et al., 2007). Heat transfer from the flue gas to the air is occurred through the rotating matrix in rotary air recuperator where recovery efficiency about 85-90% (Drobnic et al., 2006; Ferroli, 2010) and recovery efficiency of the tubular recuperator about 55-60% (Ferroli, 2010). Thermal efficiency of recuperative gas turbine is higher (i.e. about 62%) than without recuperator cycle (i.e. about 40%) (Aquaro & Pieve, 2007;

Franco & Casarosa, 2002). Recuperators are generally used to enhance energy efficiency in industries to preheat combustion air of the furnaces (Seong et al., 2000). Energy efficiency has become a top priority in the steel and heat treating industries. Above the 1000 °C process temperature, at least 50% of the input energy is lost through exhaust gas (Wünning, 2007). By applying recuperator to preheat the combustion air of the industrial furnace up to 30% of energy can be saved (IEE, 2008). A recuperative furnace can be saved 44% energy with air preheating up to 770 ^{0}C (Beerkens & Muysenberg, 1992). By using radiation type recuperator about 35% increase in the thermal efficiency and 44% reduction in the fuel consumption of the furnace (Oyelami & Adejuyigbe, 2006). Potential savings depends on flue gas temperature and rise in combustion air temperature. Raising air temperature of each 100 ^{0}C results in fuel savings about 6% of the furnace (Edmeston, 2011). Keiser et al. (2007) found that energy savings increase from 13% to 51% when the glue gas temperature varied from 538 ^{0}C to 1316 ^{0}C.

Teitel et al. (2008) investigated motor energy consumption by using a variable frequency drive to match the operating load and found energy saving about 64 %. Use of variable speed drives to match the operating load to reduce energy consumption of electric motor has been found an economically sustainable solution (Saidur, 2010). Almeida et al. (2003) analyzed energy saving and cost-effectiveness of the application of variable speed drive and found payback period of less than three years. It was also observed that payback periods are shorter for the higher percentage of speed reduction (i.e. 60% speed reduction) and larger horse power motors (i.e. 10 HP and above). Saidur et al. (2009a) investigated the application of variable speed drive and found that the payback periods for larger motors are reasonable (i.e. within 1–3 years).

The industrial sector is one of the significant contributors for emissions among the various sectors. To ensure the energy security for the economic growth, the usage of coal and gas is increasing day by day and raises its excessive emissions. As a result, Malaysia is facing a challenge of balancing of energy usages and cut down of emissions (Jafar et al., 2008; Koh & Lim, 2010). In the last 28 years, energy and electricity consumption increased by an average of 6.8% and 9.2% annually respectively (Shafie et al., 2011). As a result in the past 33 years, the average emission growth rate also increased for the increasing the use of coal and gas (Shekarchian et al., 2011). Thus, reduction of emissions from the industrial sector ensures the reduction of global emissions. Conservation of energy reduces energy consumption that reduces emissions. Implementation of energy saving options, at a little cost can be reduced emissions by10 % to 30 % in the industrial sector (Ghaddar & Mezher, 1999; IPCC, 1996). Energy saving and emission reduction can be attained by reducing total energy consumption or by increasing the production rate per unit end use energy. Total emissions of greenhouse gases from industry present 29 % of all emission in Slovenia (Al-Mansour et al., 2003). The instantaneous emissions for generation of electricity vary with energy demand. The mixture of fuel for electricity generation changes with power plants activated to supply the demand amount of energy required and fluctuated the corresponding emissions (Voorspools & D'Haeseleer, 2000). The carbon dioxide emissions reduction afforded by a demand-side intervention in the electricity system is typically assessed by means of an assumed grid emissions rate, which measures the CO_2 intensity of electricity not used as a result of the intervention. This emissions rate is called the marginal emissions factor (MEF). Accurate estimation of MEF is crucial for performance assessment because their application leads to decisions regarding the relative merits of CO_2 reduction strategies (Hawkes, 2010). Electricity generation has recently focused on the problems of urban air pollution, acid deposition, contamination from nuclear accidents and nuclear wastes, and increased concentration of carbon dioxide and other greenhouse gases in the atmosphere (Levine et al., 1995). The electricity generation sector in Korea is under pressure to mitigate emission as directed by the Kyoto Protocol (Park & Lim, 2009). Energy efficienct improvement is the crucial option to reduce emissions. Therefore, the research organizations and governments of many countries are actively involved for developing the methods of energy efficiency to save energy and emissions reduction (Saidur et al., 2009b). So, it is found that efficient energy use and energy savings are crucial for the global environmental issue and reduction of pollution.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The aim of this chapter is to describe the data collection and processing, to develop the theoretical concept and introduce the various parameters that are used in the research. Data has been collected from different sources such as Industries, Malaysia Green Technology Corporation (formerly known as Pusat Tenaga Malaysia), Literatures, Internet resources, Personal communication, etc. Calculations of energy use, energy and exergy efficiencies, exergy destruction, energy efficiency of motor, energy savings and emissions reduction are discussed here. It is also introduced and deduced the related equations that are used in the research. Figure 3.1 shows the details flowchart diagram of the research methodology.

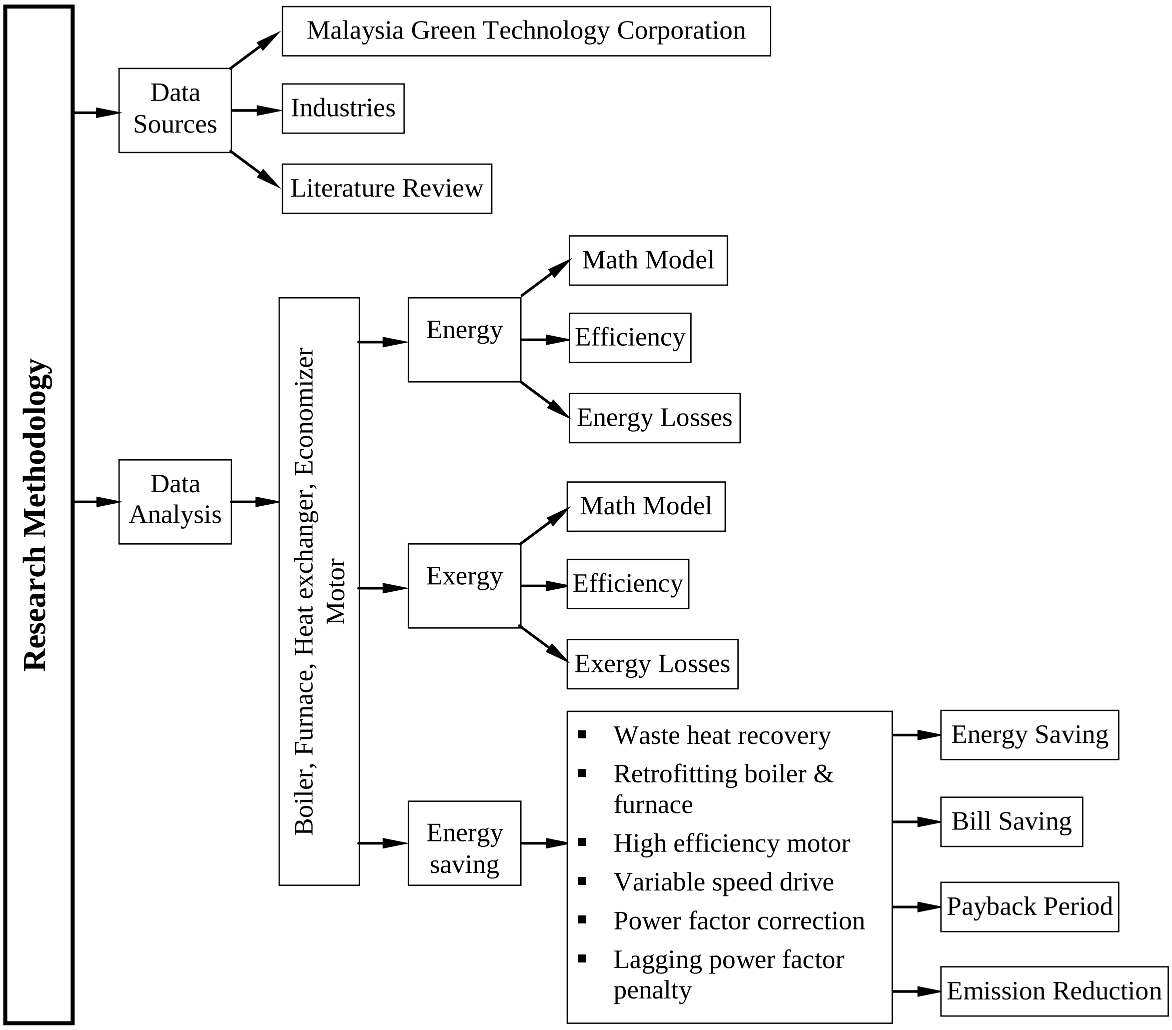

Figure 3.1 Flowchart diagram of the research methodology

3.2 Data sources and collection procedure

In this section, the data sources, technique of data collection and data used in the work has been discussed.

3.2.1 Data sources

The research is based on the analysis of energy and exergy, energy savings and emission reduction of industrial boiler, furnace, heat exchanger, economizer and electric motor. It is very difficult to get complete data from a single source because no such relevant work has been done in Malaysia. Major sources of data that have been used for this work are as following:

- Malaysia Green Technology Corporation (MGTC)
- Standard and Industrial Research Institute of Malaysia (SIRIM)
- Industries visit
- From published literatures in journals

MGTC is the main source of data for this work, which is a not-for-profit company administered by the Ministry of Energy, Communications and Multimedia, Malaysia. MGTC is established to fulfill the need for a national energy research to co-ordinate various activities, specifically energy planning and research, energy efficiency. The necessary data to compare energy consumption, energy and exergy efficiencies and exergy destruction of different types of heat exchanging equipment in Malaysia with other countries have been collected from literatures. It may be mentioned that equipment are used and operated almost in a similar way even though there might have some variation from country to the country, region to the region. However, to get an insight, their data has been used for the purpose of comparison.

3.2.2 Data collection techniques

Energy audit consist of a systematic study undertaking the major energy consuming equipment and sector to identify the flow of energy, utilization of energy and pin-point waste of energy. A well-conducted energy audit reveals the site of waste of energy and suggests energy saving options. Energy audit consists of the amount of energy in the form of electricity, gas, fuel, oil to identify and quantity the energy and cost saving that are likely to be realized through investment in an energy saving measure. There are well trained staffs in MGTC for conducting details energy audit. MGTC has equipment for data collection for conducting details energy audit are shown in Table 3.1.

Table 3. 1 List of equipment that are used for data collection for energy audit.

No.	Equipment	Type	Model
1	Portable Ultrasonic Stream/air leakage tester	U.E.	UP100KT
2	Portable dissolved solids meter	Hanna	HI 9034
3	Portable true-spot smoke tester	Woehler	RZ 95
4	Portable electronic combustion analyser	Testo	350
5	Portable temperature meter	Testo	950
6	Portable humidity/ temperature meter	Testo	645
7	Portable infrared pyrometer	Testo	860 T2
8	Portable air velocity meter	Testo	435
9	Portable electronic pressure meter	Testo	525
10	Portable illuminance meter	Testo	545
11	Portable strobo-tachometer	Testo	475
12	Portable wood moisture content meter	Testo	Hygrotest 6500
13	Portable multi-power meter	Elcontrol	VIP System3
14	Portable power analyser	Dewetron	PNA 550
15	Multi-channel data logger	Logic Beach	HL-1
16	Portable infrared camera	FLIR	PM 675
17	Digital photo camera	Canon	PRO70

3.2.3 Data collection of heat exchanging equipment

Fuel consumption, excess air, stream production rate, pressure and temperature, air temperature, inlet and outlet temperature of hot and cold fluids, inlet and outlet temperature of flue gas and water of boiler, furnace, heat exchanger and economizer are shown in Tables 3.2 to 3.5. Boiler, furnace, heat exchanger and economizer number is (i.e. serial number 1, 2, 3) used just to identify them during the analysis. A detailed survey was conducted on consumer behavior towards electricity use and end usage of electricity in the industrial sector in Malaysia in 2006 to investigate of the total energy use, type of energy supply, different type of equipment and energy consumption, usage behavior, etc. Energy consumption of electric motor in the industrial sector in Malaysia has been presented in Table 3.6.

Table 3.2 Fuel consumption, excess air, stream production rate, pressure and temperature of boilers.

Boiler serial number	Fuel type	Fuel consumption (kg/s)	Excess air (%)	Stream production rate (kg/s)	Stream pressure (kpa)	Stream temperature (^{0}C)
1	LFO	0.026	90	0.34	1000	180
2	LFO	0.027	100	0.34	1000	180
3	CNG	0.062	90	0.62	1024	250
4	MFO	0.087	100	0.92	1000	316
5	MFO	0.036	110	0.36	1000	316
6	MFO	0.166	100	1.80	1600	316
7	MFO	0.160	110	1.75	1600	316
8	MFO	0.170	100	1.78	1600	316
9	MFO	0.166	100	1.67	1600	316
10	CNG	0.060	80	0.60	800	300
11	MFO	0.050	130	0.67	750	180
12	MFO	0.059	120	0.76	800	180

Table 3.3 Fuel consumption, excess air, air temperature, heat input to product and flue gas temperature of annealing furnaces

Furnace serial number	Fuel type	Fuel consumption (kg/s)	Excess air	Combustion air inlet temperature (^{0}C)	Heat input product (kJ/s)	Flue gas temperature (^{0}C)
1	MFO	0.278	1.300	283	2028	700
2	MFO	0.328	1.300	310	10347	583
3	MFO	0.011	1.300	30	86	210

Table 3.4 Mass flow rate, inlet and outlet temperature of hot and cold fluids of heat exchangers

Heat exchanger serial number	Hot side			Cold side		
	Inlet temperature (^{0}C)	Outlet temperature (^{0}C)	Mass flow rate (kg/s)	Inlet temperature (^{0}C)	Outlet temperature (^{0}C)	Mass flow rate (kg/s)
1	73	41	0.89	33	57	0.74
2	54	40	13.56	33	44	15.84
3	52	40	0.79	33	--	0.63
4	70	45	1.31	33	--	1.12

Table 3.5 Stream production rate, inlet and outlet temperature of flue gas and water of economizers

Economizer serial number	Stream production rate (kg/s)	Flue gas temperature (^{0}C)		Feed water temperature (^{0}C)	
		Inlet	Outlet	Inlet	Outlet
1	0.34	295	150	30	108
2	0.34	275	150	30	108
3	0.62	157	60	29	90
4	0.92	238	180	30	95
5	0.36	225	180	30	95

Table 3.6 Energy used by electric motor in industrial sector for year 2006 in Malaysia

Industry	No of Industry	Energy use (MWh/year)
Food and Beverages	5	22,293
Textile	2	5835
Fabricated Metal	2	32
Paper Industry	5	96,648
Glass	4	100,097
Wood	7	47,710
Basic Iron Steel	4	633,541
Automobile	2	27,531
Chemical	2	56,640
Rubber	11	29,791
Plastic	3	28,405
Cement	4	99,131
Petrochemical	2	55,738
Consumer Appliances	3	3,635
Electronics	3	26,929
Total	59	1,233,957

3.3 Mathematical formulation for the energy and exergy analysis

This section discussed basic of exergy, exergy in the fuel, reference environment, mathematical formula of energy and exergy for the boiler, furnace, heat exchanger and economizer.

3.3.1 Exergy

According to the thermodynamic concept, exergy is denoted the maximum output work which is produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment (Akpinar et al., 2006; Dincer et al., 2004b). Exergy can be destroyed due to the irreversibilities in the real processes. The exergy destruction is proportional to the entropy generation due to irreversibilities in the processes.

3.3.2 Exergy for a fuel

Exergy of the fuel depend on the heating value and specific heat. Exergy of the fuel has been calculated by using the higher heating value and specific heat as following Equation (3.1):

$$\varepsilon_f = h_f - T_o s_f \tag{3.1}$$

3.3.3 Chemical exergy

At the ambient conditions, the exergy of fuel (i.e. hydrocarbon) is equivalent to chemical exergy of fuel that can be estimated by using Equation (3.2) (Dincer et al., 2004c; Saidur et al., 2010):

$$\varepsilon_{ff} = \gamma_{ff} H_{ff} \tag{3.2}$$

Table 3.7 shows the typical value of H_{ff}, ε_{ff} and γ_{ff} for the fuel. Typically, the fuel chemical exergy at ambient temperature and pressure is equal to higher heating value of that specific fuel (Dincer et al., 2004c).

Table 3.7 Properties of selected fuels.

Fuel	H_{ff} (kJ/kg)	ε_{ff} (kJ/kg)	γ_{ff}	Reference
Diesel	46,100	45,444	0.99	---
Natural gas	55,448	51,702	0.93	(Saidur et al., 2007c)
Gasoline	47,849	47,394	0.99	(Rosen & Dincer, 1997b; Saidur et al., 2007c)
Fuel oil	47,405	47,101	0.99	(Rosen & Dincer, 1997b; Saidur et al., 2007c)
Kerosine	46,117	45,897	0.99	(Rosen & Dincer, 1997b; Saidur et al., 2007c)

3.3.4 Exergy for the hot product and flue gases

Hot product (gases in combustion chamber) and flue gas are the mixture of different gases. The enthalpy and entropy of a mixture are calculated by using the partial molar properties (Aljundi, 2009b). The mathematical formula of the enthalpy and entropy of the mixture can be written as Equations (3.3) and (3.4):

$$h = \sum N_i h_i \tag{3.3}$$

$$s = \sum N_i s_i \tag{3.4}$$

3.3.5 Energy and exergy balances for a process

Balance of energy and exergy of an unsteady flow process in a finite time interval can be written as Equations (3.5) and (3.6) (Dincer et al., 2004c; Saidur et al., 2007b):

Energy input – Energy output = Energy accumulation (3.5)

Exergy input – Exergy output – Exergy consumption = Exergy accumulation (3.6)

3.4 Reference environment

Reference environment (i.e. temperature, pressure etc.) is an important factor for exergy analysis. Specific exergy is always estimated with its reference environment. For exergy analysis, reference environment is considered as stable equilibrium that is acted as the infinite system (Dincer et al., 2004b; Esen et al., 2007; Hepbasli, 2004). According to the Malaysian weather and climate, in the calculations, the temperature (T_o) and pressure (P_o) of the environment are often taken as standard-state values, such as 25 ^{0}C and 100 kPa (Ozgener et al., 2005; Saidur et al., 2010).

3.5 Estimation of energy and exergy efficiencies for the processes

According to the thermodynamic, energy and exergy efficiencies for all the processes in the research work are estimated by using the Equations (3.7) and (3.8) (Dincer & Rosen, 2007):

$$\eta = \frac{E_{out}}{E_{in}} = 1 - \frac{E_{loss}}{E_{in}} \tag{3.7}$$

$$\psi = \frac{X_{out}}{X_{in}} = 1 - \frac{X_{loss} + X_{destroyed}}{X_{in}} \tag{3.8}$$

3.6 Concept of first and second law of thermodynamic

In this section, use and usage efficiencies of energy and exergy, exergy destruction for boiler, furnace, heat exchanger and economizer has been described. Boiler, furnace, heat exchanger and economizer are considered as the steady flow process. Energy, exergy, irreversibility, energy and exergy efficiencies can be calculated by using the balance Equations (Dincer et al., 2004d; Hepbasli & Akdemir, 2004; Utlu et al., 2006).

3.6.1 Mass balance

Each equipment can be modeled as an open thermodynamic system which can exchange heat, work and mass with its surroundings. Based on the principle of mass conservation applied to an open thermodynamic system, the mass balance Equation (3.9):

$$\dot{m}_{in} - \dot{m}_{out} = \Delta \dot{m}_{sys} \tag{3.9}$$

From the above consideration and in the case of steady-flow processes, the mass balance Equation (3.10):

$$\dot{m}_{in} = \dot{m}_{out} \tag{3.10}$$

3.6.2 Energy balance

The first law of thermodynamics (i.e. the principle of energy conservation) states, energy can neither create nor destroy. Based on the principle, for an open thermodynamic system, the energy balances Equations (3.11):

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys} \tag{3.11}$$

From the above consideration and in the case of steady-flow processes, the energy balance Equation (3.12):

$$\dot{E}_{in} = \dot{E}_{out} \tag{3.12}$$

3.6.3 Exergy balance

In a process or a system, the total amount of exergy is just conserved but destroyed due to internal irreverisbilities. In a thermodynamic system, exergy can transfer in the form of heat, work and mass which are considered the system boundaries. The exergy transfer rate by heat can be express as Equation (3.13):

$$\dot{X}_{in} = (1 - \frac{T_o}{T_{sys}}) \times \dot{Q} \tag{3.13}$$

In the case of mass flow crossing the system boundaries, the exergy transfer by mass flow can be expressed as Equation (3.14):

$$\dot{X}_{mass} = \dot{m}\varepsilon \tag{3.14}$$

The exergy of unit mass can be express as Equation (3.15):

$$\varepsilon = (h_{sys} - h_o) - T_o(s_{sys} - s_o) \tag{3.15}$$

The rate of change of exergy can be expressed as Equation (3.16):

$$\dot{X}_{in} - X_{out} - \dot{X}_{destroyed} = \Delta \dot{X}_{sys} \tag{3.16}$$

In the case of a steady flow process, exergy does not change within the system. So, the exergy balance can be expressed as Equation (3.17):

$$\dot{X}_{in} = \dot{X}_{out} + \dot{X}_{destroyed} \tag{3.17}$$

Exergy destruction rate in a process depends on the rate of entropy generation. Exergy destruction rate can be written as Equation (3.18):

$$\dot{X}_{destroyed} = \dot{S}_{gen} \times T_o \tag{3.18}$$

3.7 Energy and exergy of the energy intensive equipment

In a heat exchanging equipment, heat is transferred from one fluid stream to another. Boiler, furnace, heat exchanger and economizer are the main energy intensive equipment in the industrial sector.

3.7.1 Energy flow of the boilers and furnaces

Energy balance is based on the first law of thermodynamics which is the primary method to analyze energy use characteristics of the boiler unit. This method is used to analyze the situation of energy use and evaluate integrity of systems or equipment according to the conservation of energy, which may be expressed as follows: the net energy exchange of a system is equal to the difference between the total energy entering and leaving the system during that process (Tong et al., 1995; Waheed et al., 2008; Zaili et al., 2010). Basic component of a fire tube has been shown in Figure 3.2. Figure 3.3 shows the general energy flow and loess at the different step in the boiler system.

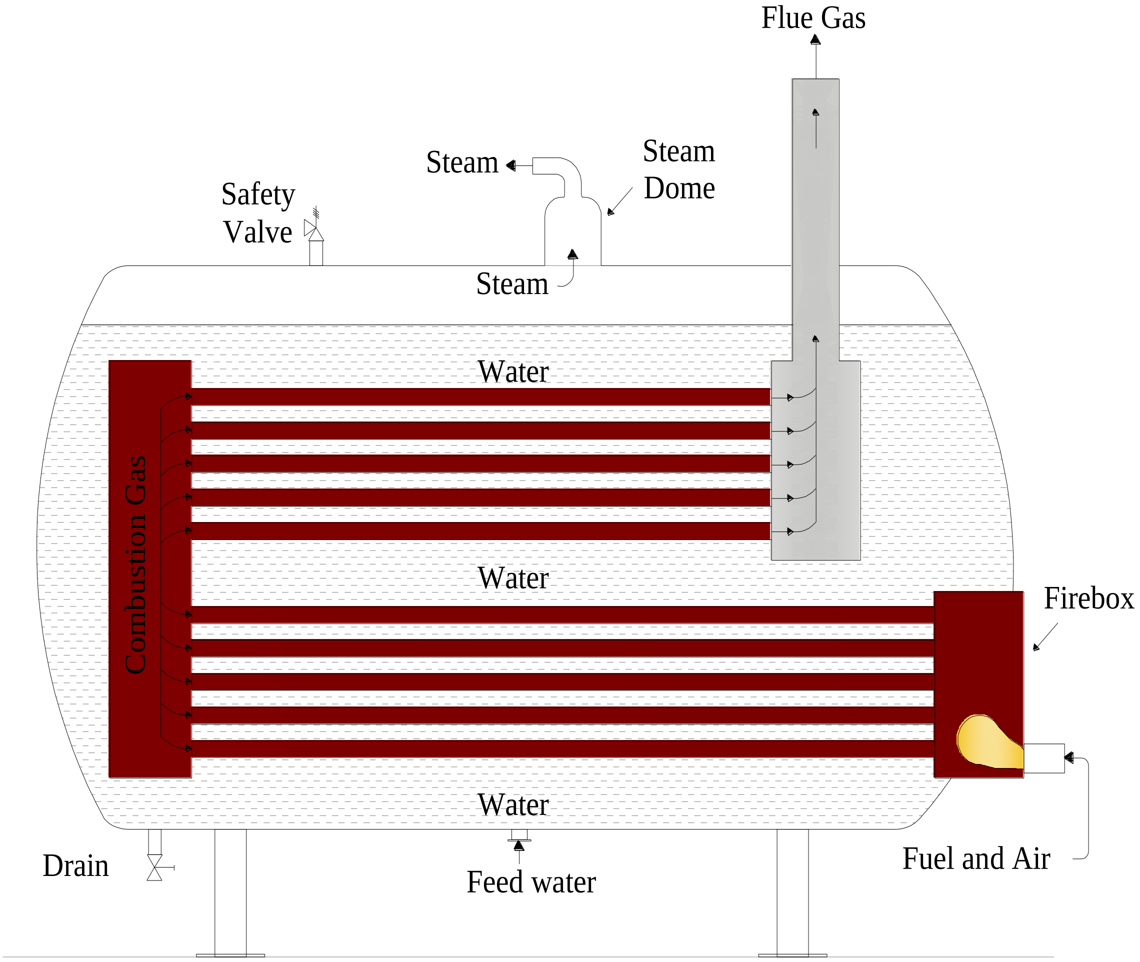

Figure 3.2 Energy flow diagram of a fire tube boiler

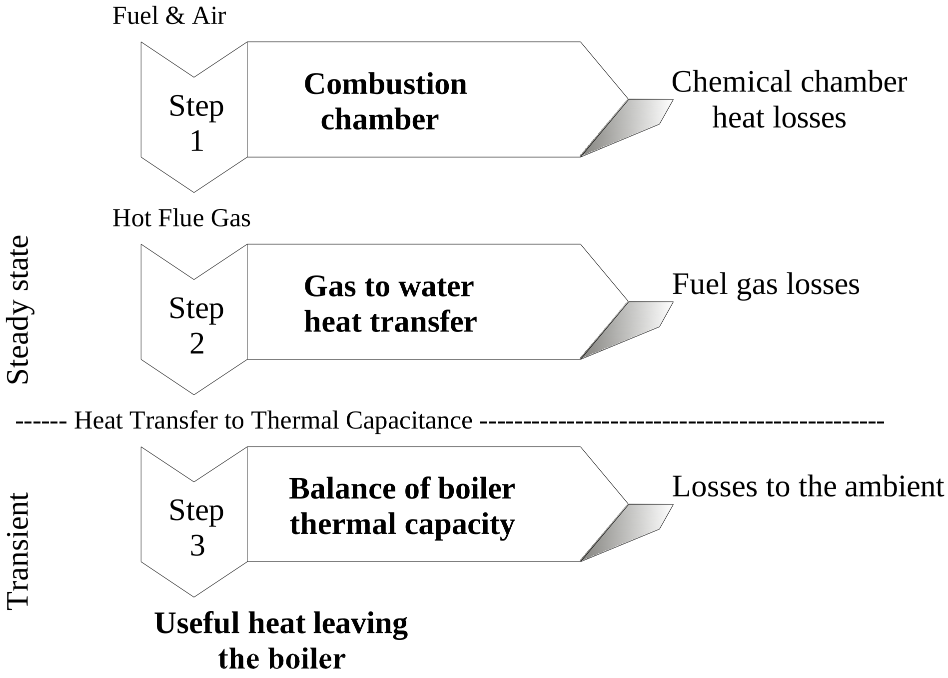

Figure 3.3 General concept of the boiler model

(Haller et al., 2009)

There are two basis parts in the fire tube boiler: combustion chamber and fire tube as shown in Figure 3.4. The energy and exergy analysis of the combustion chamber and fire tube have been discussed below.

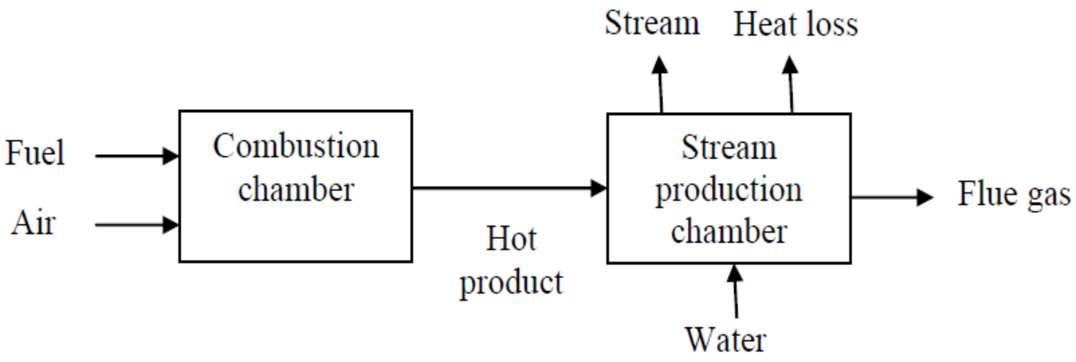

Figure 3.4 Schematic diagram of combustion chamber and stream production chamber of a fire tube boiler.

Heat balance is based on the first law of thermodynamics that is the primary method to analyze energy use characteristics in the furnace. This method is used to analyze the situation of energy use and evaluate integrity of systems or equipment according to the conservation of energy. The net change of energy of the furnace system is equal to the difference between the energy enter and the leave the system during the process (Tong et al., 1995; Zaili et al., 2010). A furnace can be divided into two parts: combustion chamber and annealing chamber as shown in Figure 3.5.

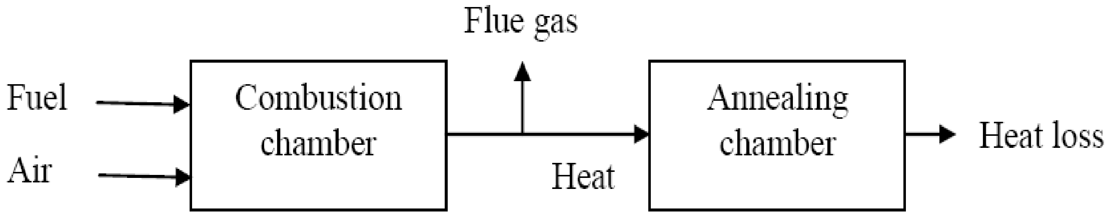

Figure 3.5 Schematic diagram of combustion chamber and annealing chamber of a furnace

3.7.2 Energy and exergy for a combustion chamber

3.7.2(a) Chemical reaction in a combustion chamber

It is very important to the chemical energy released during the combustion process. If the combustion process is considered as adiabatic, no work or no change in kinematic or potential energy, then the temperature of the products is considered as the adiabatic flame temperature (Mario, 1998; Wylen et al., 1994). Therefore, the maximum flame temperature of the combustion at a given temperature and pressure is accomplished using the stoichiometric mixture. As a result, the adiabatic flame temperature can be controlled by controlling the percentage of excess air (Wylen et al., 1994).

The composition of the reactants (fuel and air) of a combustible mixture and the composition of the products depend on the conservation of mass of each chemical element in the reactants. By using sufficient oxygen, fuels (i.e. hydrocarbon fuel) are oxidized completely during the combustion. The carbon to carbon dioxide (CO_2) and hydrogen to water (H_2O) are converted. Considering the complete combustion of a fuel of composition C_aH_b, the combustion can be expressed as Equation (3.19):

$$C_aH_b + (a+\frac{b}{4})(O_2 + 3.77N_2) = aCO_2 + \frac{b}{2}H_2O + 3.77(a+\frac{b}{4})N_2 \tag{3.19}$$

Considering the medium fuel oil (diesel) as fuel of the boiler, the chemical reaction during the combustion in the combustion chamber is considered as following Equation (3.20):

$$C_{12}H_{23} + \left(O_2 + 3.77N_2\right) \rightarrow CO_2 + H_2O + N_2 \tag{3.20}$$

In this study, complete combustion has been considered. Stoichiometric mixture (air-fuel mixture) is taken for the calculation as following Equation (3.21):

$$2C_{12}H_{23} + 35.5\left(O_2 + 3.76N_2\right) \Rightarrow 24CO_2 + 23H_2O + 133.5N_2 \tag{3.21}$$

Considering the CNG (methane) as fuel of the boiler, in the case of stoichiometric mixture and complete combustion the chemical reaction during the combustion in the combustion chamber is considered as following Equation (3.22):

$$CH_4 + 2\left(O_2 + 3.76N_2\right) \Rightarrow CO_2 + 2H_2O + 7.52N_2 \tag{3.22}$$

The combustion temperature can be determined by energy balancing during the combustion, where the chemical energy of fuel is converted into sensible energy of the flue gas. The combustion temperature depends on the inlet combustion air temperature, fuel heating value, amount of excess air, stoichiometric air fuel ratio and combustion gas specific heat that can be estimated as Equation (3.23) (Carpenter et al., 2007).

$$T_c = T_a + \frac{LHV}{\{1 + (1 + EA)AF_s\}C_{p,p}} \tag{3.23}$$

3.7.2(b) Adiabatic flame temperature

As the result of this combustion chemical reaction, the products are generated carbon dioxide, water and nitrogen. When the combustion occurred with excess air, oxygen also produced as a combustion product. If there is no work or no changes in kinetic or potential energy or no heat loss to the surrounding, the adiabatic flame temperature of combustion can be calculated by using following Equation (3.24):

$$\Sigma N_p (h_{for} + h + h_o)_p = \Sigma N_r (h_{for} + h + h_o)_r \tag{3.24}$$

The calculation of the enthalpy of products is not straightforward because of the temperature of hot products is not known. Therefore, the determination of adiabatic flame temperature requires the use of an iterative technique, unless equations for the sensible enthalpy changes of the combustion products are available. Once the reactants and the states are specified, the enthalpy of reactants can be easily determined. A temperature is assumed for the product gases, and the enthalpy is determined for this temperature. If it is not equal to enthalpy of reactant, calculations are repeated with another temperature. The adiabatic flame temperature is then determined from these two results by interpolation (Cengel & Boles, 2006; Mario, 1998). The fuel adiabatic flame temperature is not unique and depends on the states of reactant, percentage of excess air, etc. The adiabatic flame temperature is maximum if combustion is completed by using the theoretical air. Thermodynamic properties (enthalpy and entropy) of different input and output parameters have been taken from the properties table of a thermodynamic book (Changel & Boles, 2006) and some of them are calculated by using the formula described above in the theoretical and formulation section.

3.7.2(c) Energy analysis for a combustion chamberr

Combustion chamber is the most important part of the boiler and furnace. Heat is produced by burning fuel in combustion Chamber that is transferred to the stream production chamber to produce stream. Usually the combustion chamber is well insulated to reduce heat dissipation into the surrounding, and the heat dissipation is almost zero. That is why, only input energy (air and fuel) and output energy (hot produced) are to consider for analysis. According to the conservation of energy, the input energy is equal to the output energy that is shown in the Figure 3.6:

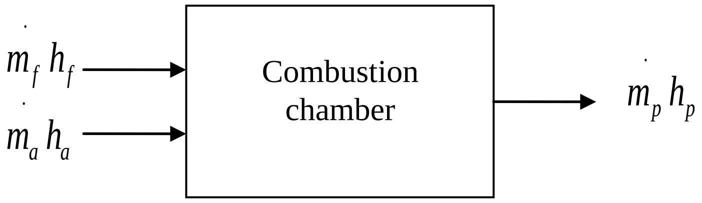

Figure 3.6 Schematic energy flow diagram of combustion chamber

Considering the steady flow process, energy balance can be written as Equations (3.25), (3.26) and (3.27) (Saidur et al., 2010):

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys} = 0 ==> steady \qquad (3.25)$$

$$\dot{m}_f h_f + \dot{m}_a h_a - \dot{m}_p h_p = 0 \qquad (3.26)$$

$$\dot{m}_f h_f + \dot{m}_a h_a = \dot{m}_p h_p \qquad (3.27)$$

The combustion efficiency is measurement of the how much percentage of energy from fuel can be transferred to the hot product after combustion. The amount of energy supply by the fuel is considered as the amount of higher heating value of the fuel. By using Equation (3.28), the combustion efficiency can be calculated (Carpenter et al., 2007).

$$\eta = \frac{AF_s(1+EA)\times C_{p,p}(T_c - T_g)}{HHV} \qquad (3.28)$$

3.7.2(d) Exergy analysis for a combustion chamber

Exergy is the measurement of the maximum capacity of work during the combustion. Exergy normally does not follow the conservation principle as energy; it destroys in during the proces. Amount of the destruction of exergy is the amount of irreversibility (i.e. sources of losses) (Aljundi, 2009a). The maximum output power is estimated by using exergy balance with the reference environment (Aljundi, 2009b; Dincer & Rosen, 2007). The changes of exergy in the system are the differences between the net exergy enter and the exergy destroyed in the system due to the irreversibilities that is shown in Figure 3.7. Exergy balance in the combustion system can be express as following Equations (3.29), (3.30) and (3.31) (Aljundi, 2009a; Antar, 2010; Kalinci et al., 2010; Saidur et al., 2010):

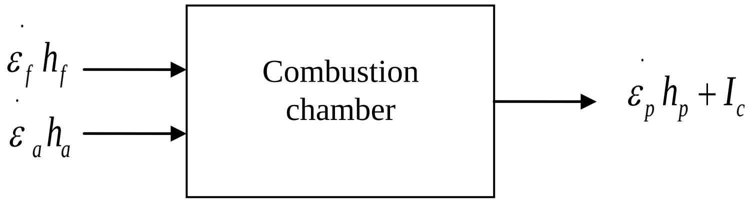

Figure 3.7 Schematic exergy flow diagram of a combustion chamber

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroyed} = \Delta \dot{X}_{sys} = 0 ==> steady \tag{3.29}$$

$$(m_f \varepsilon_f + m_a \varepsilon_a) - m_p \varepsilon_p - I_C = 0 \tag{3.30}$$

$$\dot{I}_C = \dot{m}_f \varepsilon_f + \dot{m}_a \varepsilon_a - \dot{m}_p \varepsilon_p \tag{3.31}$$

Using the Equation (3.8) and the above assumptions, exergy efficiency (ψ_C) for combustion chamber can be written as Equation (3.32):

$$\psi_C = \frac{\dot{m}_p \varepsilon_p}{\dot{m}_f \varepsilon_f} \tag{3.32}$$

3.7.3 Energy and exergy analysis for a stream production chamber of boiler

3.7.3(a) Energy analysis for a stream production chamber of boiler

The performance of the stream production chamber plays an important role of the boiler efficiency. Heat transfer through the fire tube from hot product to water. There are no work interactions in the fire tube ($w = 0$) and changes of kinetic and potential energy are negligible for the fluid stream. In the boiler, the flue gas is used as hot fluid and the water as the cold fluid. The energy balance of the stream production chamber is shown in Figure 3.8.

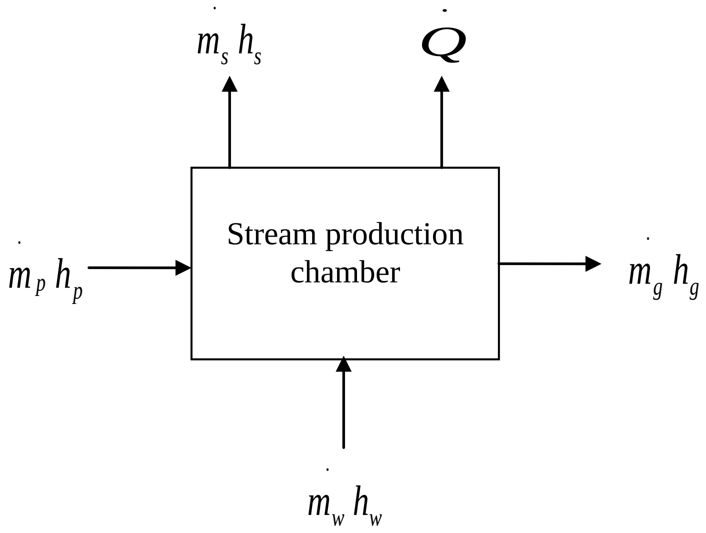

Figure 3.8 Schematic energy flow diagram of the stream production chamber.

As there is no mixing of the fluid each other, according to the conservation of mass, mass flow rate of hot side and cold side fluid should be constant ($\dot{m}_p = \dot{m}_g = \dot{m}_h$ *and* $\dot{m}_w = \dot{m}_s = \dot{m}_c$). Energy balance equation can be written as following Equations (3.33), (3.34) and (3.35) (Cangel & Boles, 2006; Dincer & Rosen, 2007):

$$\dot{E}_{in} - \dot{E}_{out} = \Delta E_{sys} = 0 ==> steady \tag{3.33}$$

$$(\dot{m}_p h_p + \dot{m}_w h_w) - (\dot{m}_g h_g + \dot{m}_s h_s) - \dot{Q} = 0 \tag{3.34}$$

$$\dot{m}_h (h_p - h_g) = \dot{m}_c (h_s - h_w) + \dot{Q} \tag{3.35}$$

According to the above Equation (3.7), the energy effectiveness (e_I) of the stream production chamber can be written as follow Equation (3.36):

$$e_I = \frac{\dot{m}_c (h_s - h_w)}{\dot{m}_h (h_p - h_g)} \tag{3.36}$$

3.7.3(b) Exergy analysis for a stream production chamber of boiler

Exergy depends on the matter or energy flow and environmental conditions. It is always conserved in the reversible processes, but destroyed in the irreversible processes (Dincer, 2002). The exergy balance of the stream production chamber is shown in Figure 3.9. By considering exergy changing rate in the fire tube is zero and at reference environment, the exergy balance in the stream production chamber can be written as following Equations (3.37), (3.38) and (3.39) (Aljundi, 2009a; Kalinci et al., 2010; Saidur et al., 2010):

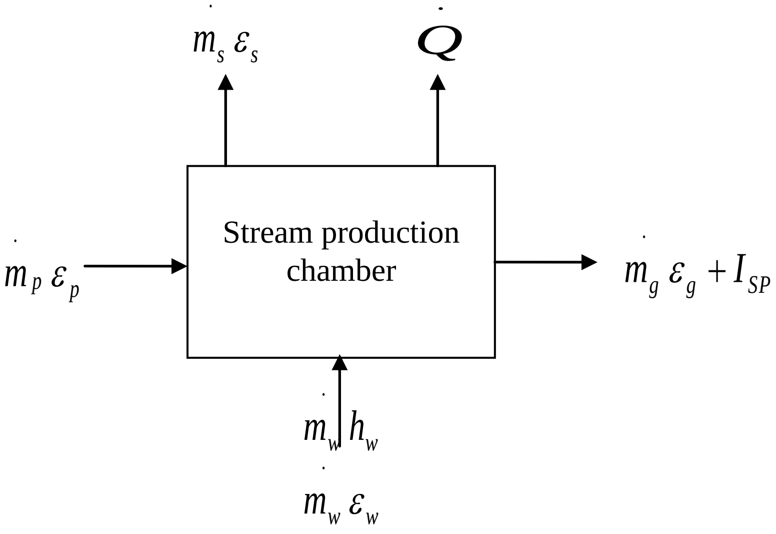

Figure 3.9 Schematic exergy flow diagram for stream production chamber.

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroyed} = \Delta \dot{X}_{sys} = 0 => steady \tag{3.37}$$

$$(\dot{m}_p \varepsilon_p + \dot{m}_w \varepsilon_w) - (\dot{m}_g \varepsilon_g + \dot{m}_s \varepsilon_s) - \dot{I}_{SP} = 0 \tag{3.38}$$

$$\dot{I}_{SP} = \dot{m}_h(\varepsilon_p - \varepsilon_g) + \dot{m}_c(\varepsilon_w - \varepsilon_s) \tag{3.39}$$

Using the Equation (3.8) and the above assumptions, the exergy effectiveness (e_{II}) of stream production chamber can be written as Equation (3.40):

$$e_{II} = \frac{\dot{m}_c(\varepsilon_s - \varepsilon_w)}{\dot{m}_h(\varepsilon_p - \varepsilon_g)} \tag{3.40}$$

3.7.3(c) Boiler overall efficiency

The overall energy efficiency of the boiler can be calculated by using following Equation (3.41):

$$\eta_B = \frac{\dot{m}_c(h_s - h_w)}{\dot{m}_f\, h_f} \tag{3.41}$$

The boiler overall exergy destruction is estimated by using the Equation (3.42):

$$\dot{I}_B = \dot{I}_C + \dot{I}_{SP} \tag{3.42}$$

The boiler overall exergy efficiency can be estimated by using the Equation (3.43):

$$\psi_B = \frac{\dot{m}_c(\varepsilon_s - \varepsilon_w)}{\dot{m}_f\, \varepsilon_f} \tag{3.43}$$

3.7.4 Energy and exergy analysis for an annealing chamber of the furnace

The furnace can be considered as a heat reservoir where heat is supplied indefinitely at a constant temperature. Exergy of the heat is its useful work that can be extracted from the heat (Changel & Boles, 2006).

3.7.4(a) Energy analysis for an annealing chamber

Annealing chamber is considered as the furnace part where the product is heated inside the furnace. In the analysis, $\dot{Q}_{AP}$ is considered only the rate of heat input to the product processing in the annealing process that is shown in the Figure 3.10.

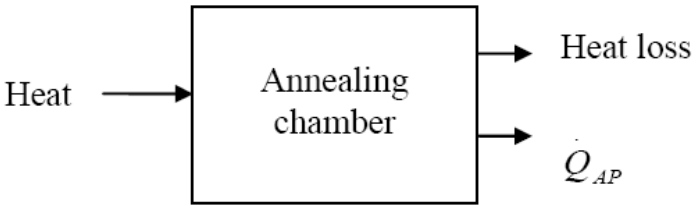

Figure 3.10 Energy flow diagram of annealing chamber in a furnace

According to the above Figure, the energy efficiency for annealing chamber can be calculated as following Equation (3.44):

$$\eta_{AC} = \frac{\dot{Q}_{AP}}{\dot{m}_h(h_p - h_g)} \tag{3.44}$$

3.7.4(b) Exergy analysis for an annealing chamber

Annealing furnace is considered as a reservoir where the heat is input in the annealing chamber. Temperature in the annealing chamber is carefully controlled. In the analysis, temperature of the annealing chamber is considered as the average temperature of the annealing process. Considering the furnace as heat engine, energy efficiency can be calculated as following Equation (3.45) (Changel & Boles, 2006; Dincer et al., 2004b):

$$\eta_{AC} = 1 - \frac{T_{AC}}{T_C} \tag{3.45}$$

Energy may be in its different form (i.e. heat, work); the quality of energy is the important parameter for it works potential. The energy sources should not be evaluated base on the quantity alone. In the case of thermal energy, Carnot represents the efficiency is the part of energy which is converted into work (Dincer et al., 2004b). Exergy of thermal energy can be estimated by using the Equation (3.46) (Çamdali & Tunç, 2003; Dincer et al., 2004b):

$$\text{Rate of exergy of heat transfer} = (1-\frac{T_{AC}}{T_C})\dot{Q}_{AP} \tag{3.46}$$

Rate of exergy destruction of the annealing chamber is calculated by the Equation (3.47):

$$\dot{I}_{AC} = \dot{m}_h(\varepsilon_p - \varepsilon_g) - (1-\frac{T_{AC}}{T_C})\dot{Q}_{AP} \tag{3.47}$$

Using Equation (3.8) and the above assumptions, exergy efficiency (ψ_{AC}) for annealing chamber can be written as Equation (3.48):

$$\psi_{AC} = \frac{(1-\frac{T_{AC}}{T_C})\dot{Q}_{AP}}{\dot{m}_h(\varepsilon_p - \varepsilon_g)} \tag{3.48}$$

3.7.4(c) Furnace overall efficiency

Overall energy efficiency for the furnace is calculated by using the Equation (3.49):

$$\eta_F = \frac{\dot{Q}_{AP}}{\dot{m}_f\, h_f} \tag{3.49}$$

Overall exergy destruction of the furnace is obtained by estimating the rate of exergy destruction of a combustion chamber and annealing chamber as the following Equation (3.50):

$$\dot{I}_F = \dot{I}_C + \dot{I}_{AC} \tag{3.50}$$

Overall furnace exergy efficiency can be calculated by using Equation (3.51):

$$\psi_F = \frac{(1-\frac{T_{AC}}{T_C})\dot{Q}_{AP}}{\dot{m}_h \varepsilon_f} \tag{3.51}$$

3.7.5 Heat transfer, energy and exergy for a heat exchanger

3.7.5(a) Energy analysis for a heat exchanger

Energy exchange of a counter flow heat exchanger has been shown in Figure 3.11.

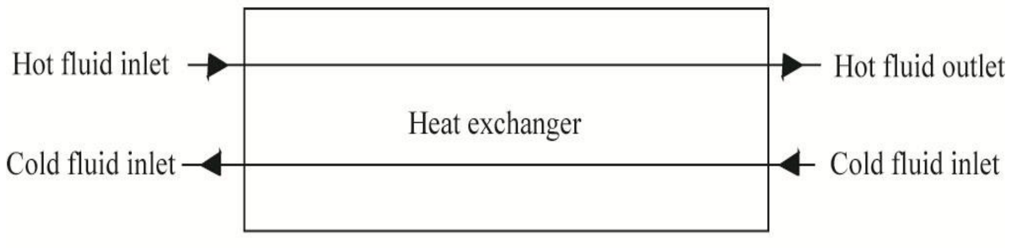

Figure 3.11 Schematic diagram of counter flow heat exchanger energy exchange system

Heat transfer rate is considered the function of the fluid mass flow, inlet and outlet temperature different that can be written as Equation (3.52):

$$\dot{Q} = f(\dot{m}, T) \tag{3.52}$$

The rate of heat transferred from hot fluid to cold fluid (Durmus et al., 2009; Eiamsa-ard & Promvonge, 2005; Hasanuzzaman et al., 2009; Naphon, 2007):

$$\dot{Q}_h = \dot{m}_h C_{ph}(T_{h,in} - T_{h,out}) \tag{3.53}$$

and the rate of heat received by the cold fluid can be calculated by using Equation (3.54):

$$\dot{Q}_c = \dot{m}_c C_{pc}(T_{c,in} - T_{c,out}) \tag{3.54}$$

In the heat exchanger, maximum heat exchange is occurred when the fluid temperature will be $T_{h,in} = T_{c,out}$ or $T_{h,out} = T_{c,in}$ in a constant mass flow rate of the fluids. The maximum heat transfer rate ($\dot{Q}_{\max}$) is calculated by using the Equation (3.55) (Wongwises & Naphon, 2006):

$$\dot{Q}_{\max} = (\dot{m}C_p)_{\min}(T_{h,in} - T_{c,in}) \tag{3.55}$$

The function of heat exchanger is to exchange heat between two moving fluid streams without mixing. The hot fluid is releasing heat to the cold and the changes of kinetic and potential energy negligible (Cengel & Boles, 2006; Saidur et al., 2010). The energy balance of heat exchanger is shown in Figure 3.12.

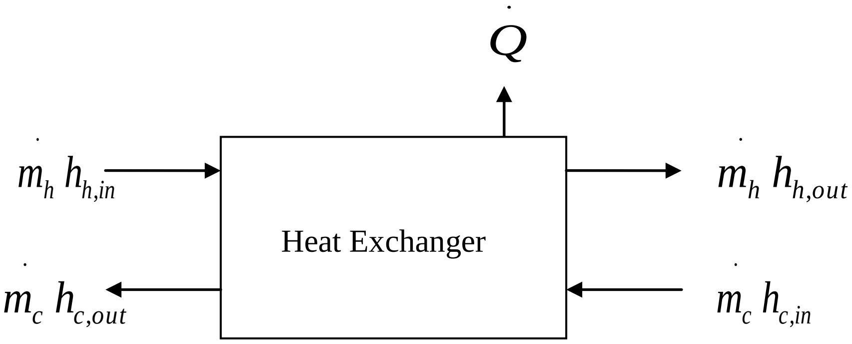

Figure 3.12 Schematic energy flow diagram of heat exchanger.

As there is no mixing of the fluid each other, according to conservation of mass, the mass flow rate of hot side and cold side fluid should be constant. Energy balance equation can be written as Equations (3.56), (3.57) and (3.58) (Cangel & Boles, 2006; Dincer & Rosen, 2007):

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroyed} = \Delta \dot{X}_{sys} = 0 => steady \tag{3.56}$$

$$(\dot{m}_h\, h_{h,in} + \dot{m}_c\, h_{c,in}) - (\dot{m}_h\, h_{h,out} + \dot{m}_c\, h_{c,out}) - \dot{Q} = 0 \tag{3.57}$$

$$\dot{m}_h(h_{h,in} - h_{h,out}) = \dot{m}_c(h_{c,out} - h_{c,in}) + \dot{Q} \tag{3.58}$$

According to the above assumption and consideration, the effectiveness of the heat exchanger is calculated as following Equation (3.59):

$$e_I = \frac{\dot{m}(h_{out} - h_{in})}{\dot{m}_{\min}(h_{h,out} - h_{c,in})} \tag{3.59}$$

3.7.5(b) Exergy analysis for a heat exchanger

Exergy depends on the matter or energy flow, environments conditions. It is always conserved in reversible processes and destroyed irreversible processes (Dincer, 2002). Exergy balance in heat exchangers is shown in Figure 3.13. Exergy balance in heat exchanger can be written as following Equations (3.60) and (3.61) (Aljundi, 2009a; Kalinci et al., 2010; Saidur et al., 2010):

Figure 3.13 Schematic exergy flow diagram of a heat exchanger

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroyed} = \Delta \dot{X}_{sys} = 0 ==> steady \tag{3.60}$$

$$(\dot{m}_h \, \varepsilon_{h,in} + \dot{m}_c \, \varepsilon_{c,in}) - (\dot{m}_h \, \varepsilon_{h,out} + \dot{m}_c \, \varepsilon_{c,out}) - \dot{I}_H = 0 \tag{3.61}$$

Exergy transfer rate can be estimated by using Equation (3.62):

$$\dot{X}_h = \dot{m}_h (h_{h,in} - h_{h,out}) + \dot{m}_h T_o (S_{h,out} - S_{h,in}) \tag{3.62}$$

and the rate of exergy received by the cold fluid can be estimated by using Equation (3.63):

$$\dot{X}_c = m_c (h_{c,in} - h_{c,out}) + T_o \, \dot{m}_c (S_{c,out} - S_{c,in}) \tag{3.63}$$

In the heat exchanger, maximum heat exchange is occurred when the fluid temperature will be $T_{h,in} = T_{c,out}$ or $T_{h,out} = T_{c,in}$ in a constant mass flow rate of the fluids. Maximum exergy transfer rate ($\dot{X}_{\max}$) can be estimated by using Equation (3.64):

$$\dot{X}_{\max} = m_{\min}[(h_{h,in} - h_{c,in}) + T_o(S_{h,in} - S_{c,in})] \tag{3.64}$$

The exergy losses of heat exchanger are expressed by using Equations (3.65) and (3.66):

$$\dot{I}_H = \sum \dot{m}_{in}(h_{in} - T_o S_{in}) - \sum \dot{m}_{out}(h_{out} - T_o S_{out}) + \sum \dot{Q}\ (1 - \frac{T_o}{T_h}) - \dot{W}_{cv} \tag{3.65}$$

$$\dot{I}_H = m_c(h_{c,in} - T_o S_{c,in}) + \dot{m}_h(h_{h,in} - T_o S_{h,in}) - m_c(h_{c,out} - T_o S_{c,out}) - \dot{m}_h(h_{h,out} - T_o S_{h,out}) \tag{3.66}$$

By rearranging this equation can be written as the following Equation (3.67):

$$\dot{I}_H = m_c(h_{c,in} - h_{c,out}) + \dot{m}_h(h_{h,in} - h_{h,out}) + T_o[\dot{m}_c(S_{c,out} - S_{c,in}) + \dot{m}_h(S_{h,out} - S_{h,in})] \tag{3.67}$$

Exergy transfer effectiveness (e_{II}) of the heat exchanger can be written by using Equation (3.68) (Wu et al., 2007):

$$e_{II} = \frac{m[(h_{out} - h_{in}) - T_o(s_{out} - s_{in})]}{m_{\min}[(h_{h,in} - h_{c,in}) - T_o(s_{h,in} - s_{c,in})]} \tag{3.68}$$

3.7.6 Energy and exergy analysis for an economizer

A huge amount of heat (i.e. energy) is lost and dissipated into the environment through flue gas of the boilers. This energy can be recovered and used to preheat feed water that will absolutely reduce operation cost and save energy.

3.7.6(a) Energy analysis for an economizer

The economizer can be considered as heat exchanger. The function of economizer is to exchange heat between two moving fluid (i.e. flue gas to feed water) without mixing. The energy balance of (flue gas to feed water) economizer is shown in Figure 3.14.

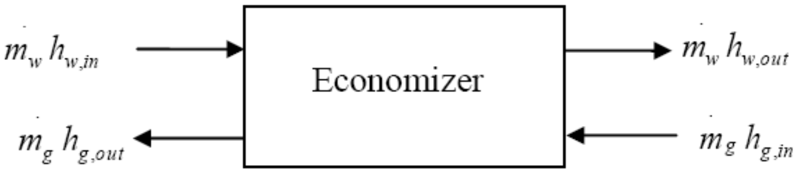

Figure 3.14 Schematic energy flow diagram of economizer

Energy balance of economizer can be calculated by the Equations (3.69) and (3.70):

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys} = 0 ==> steady \tag{3.69}$$

$$\dot{m}_g (h_{g,in} - h_{g,out}) - \dot{m}_w (h_{w,out} - h_{w,in}) - \dot{Q}_{loss} = 0 \tag{3.70}$$

According to the above Equation (3.7), the energy effectiveness (e_I) of the economizer can be written as following Equation (3.71):

$$e_I = \frac{\dot{m}_w (h_{w,out} - h_{w,in})}{\dot{m}_g (h_{g,in} - h_{w,in})} \tag{3.71}$$

3.7.6(b) Exergy analysis for an economizer

Exergy transfer dependent on the energy flow and on the environment parameters. The exergy balance of recuperator is shown in Figure 3.15. Exergy balance in the recuperator can be calculated as the Equations (3.72) and (3.73):

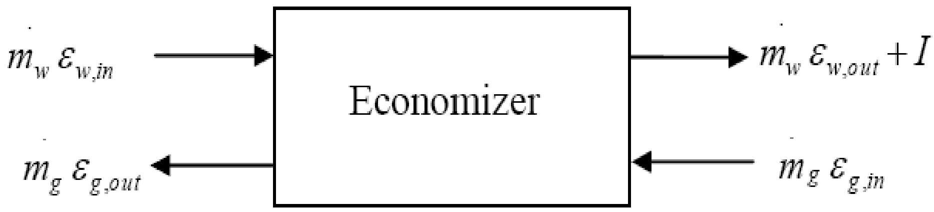

Figure 3.15 Schematic exergy flow diagram of economizer

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroyed} = \Delta \dot{X}_{sys} = 0 ==> steady \tag{3.72}$$

$$\dot{m}_g(\varepsilon_{g,in} - \varepsilon_{g,out}) - \dot{m}_w(\varepsilon_{w,out} - \varepsilon_{w,in}) - I_E = 0 \tag{3.73}$$

Using Equation (3.8) and the above assumptions, the exergy effectiveness for economizer can be written as the following Equation (3.74):

$$e_{II} = \frac{\dot{m}_w(\varepsilon_{w,out} - \varepsilon_{w,in})}{\dot{m}_g(\varepsilon_{g,in} - \varepsilon_{w,in})} \tag{3.74}$$

3.8 Energy saving options for the boilers and furnaces

Energy efficiency and proper utilization of energy is the most important option to save energy as well as reduce the environmental pollution (i.e. emissions reduction). There are many options to save as well proper utilization of energy of boiler and furnace. Waste heat recovery, excess air control; preheat of combustion air, high efficiency motor, variable speed drive, efficient burner, thermal insulation both for boiler and furnace can apply to improve efficiency as well as energy savings. Feed water preheating, stream temperature and pressure also important option to improve efficiency as well as save energy of boiler.

3.8.1 Waste heat recovery

Recovered heat from the flue gas can be reused for preheating feed water or combustion air help that is improved boiler and furnace efficiency. Heat is recovered by passing flue gas through heat exchanging equipment (i.e. economizer, recuperator etc.). The rate of heat recovery is calculated as the following Equation (3.75):

$$\dot{Q}_r = \dot{m}_g \times c_p \times \Delta T_d \tag{3.75}$$

3.8.2 Excess air control

In the boiler and furnace, combustion air is always supplied more than the stoichiometric mixture due to ensure complete combustion. However, the efficiency of combustion is very dependent on the amount of air (i.e. ratio of air and fuel). The effect of excess air in the combustion system has been discussed above combustion section. Therefore, the amount of combustion (i.e. excess) air needs to be optimized for increasing combustion efficiency. For complete combustion, amount of air flow of a fan is controlled by using following control methods:

(i) Inlet damper

(ii) Inlet vane

(iii) Variable speed drive (VSD)

The VSD is the way of efficient control method that is provided the required power to load. Currently, VSD is commonly used in modern boiler and furnace in the industrial sector. The modern boiler and furnace are designed and equipped with the method. The diagram of VSD system has been shown in Figure 3.16.

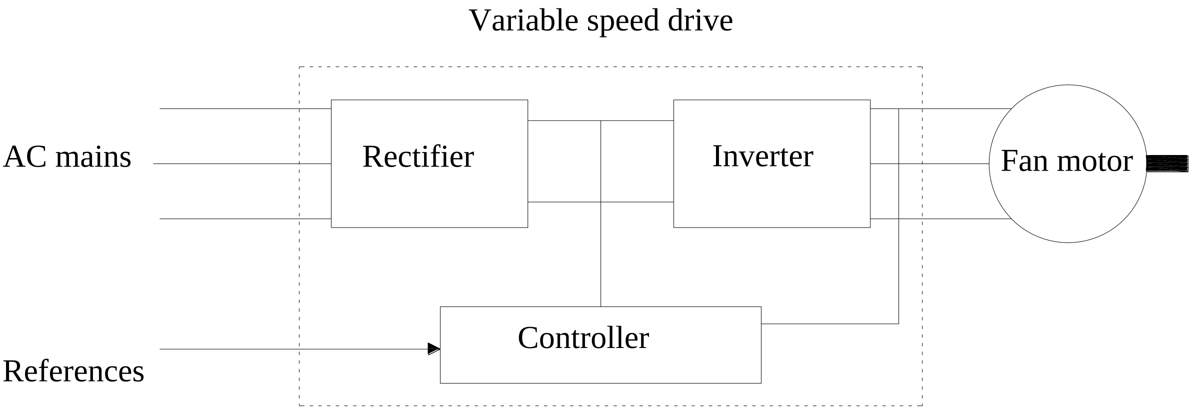

Figure 3.16 The schematic diagram of VSD.
(Ozdemir, 2004)

3.9 Motor energy analysis and energy savings

In this section, formulations for estimating energy use, energy savings by using HEM, VSD, capacitor bank, bill savings and payback period has been discussed.

3.9.1 Mathematical formulations for estimating energy use

Annual electric energy used by motor can be estimated by using Equation (3.76):

$$AEU = n \times hp \times 0.746 \times L \times hr \qquad (3.76)$$

3.9.2 Mathematical formulations of energy savings by using high efficiency motor

The main terget of a motor manufacture is to reduc production costs. A efficienct motor can be manufactured by improving the design. Magnetic core of ferrosilicon alloy, more copper in the slot, large rotor conductor, and improve of air-gaps, core head, fan and bearing, dimensional design. Cost of high-efficient motor is typically 10 % to 25 % more compared to standard motor (Garcia et al., 2007). Annual energy savings (AES) by replacing standard motor with high efficient motor can be estimated by using Equation (3.77) (Garcia et al., 2007):

$$AES = hp \times L \times 0.746 \times hr \times \left[\frac{1}{\eta_{std}} - \frac{1}{\eta_{ee}} \right] \times 100 \tag{3.77}$$

Annual energy savings by replacing rewind motor with high efficient motor can be estimated by using Equation (3.78):

$$AES = hp \times L \times 0.746 \times hr \times \left[\frac{1}{\eta_{rd}} - \frac{1}{\eta_{ee}} \right] \times 100 \tag{3.78}$$

3.9.3 Mathematical formulation for estimating energy saving by using VSD

Energy savings by using VSD for electric motors of different applications in industry is used the method found in (Anon, 2008). Energy consumption of motors varies according to the speed of third power. As a result, small change of motor speed a huge amount of energy can be saved. Energy saving of electric motors by using VSD can be calculated by using Equation (3.79):

$$ES_{VSD} = n \times hp \times 0.746 \times hr \times S_{SR} \tag{3.79}$$

Table 3.8 shows the speed reduction and energy saving by using VSD of the electric motors in the industrial sector (Anon, 2002, 2008). Cost of VSD of the different motor size has been calculated by using regression method with the help of the Table 3.9.

Table 3.8 Potential energy saving by using VSD.

(Anon, 2008)

Speed reduction (%)	Potential energy saving (%)
10	22
20	44
20	61
40	73
50	83
60	89

Table 3.9 Incremental price for VSDs.

(Anon, 2008; Saidur et al., 2009b)

Motor power (hp)	Incremental price (US$)
5.5	2500
7.5	3376
10	3349
11	4176
15	4176
19	5123
20	5316
22	5853
25	6123
30	6853

3.9.4 Formulation of bill savings and payback period

Annual bill saving due to energy saving measures can be calculated by using the following Equation (3.80):

$$Savings = AES \times c \tag{3.80}$$

A simple payback period due to the different energy saving measures can be calculated by using Equation (3.81):

$$\text{Payback period (years)} = \frac{\text{Incremental cost}}{\text{Annual dollar savings}} \tag{3.81}$$

3.9.5 Motor efficiency and rewind cost

Motor is operated at maximum efficiency when fully loaded and efficiency drops rapidly below 70 % load. Over size motor is often used in the industries due to ensure the reliability (Payton, 2009). A motor can be rewind for two reasons: (i) if the motor is over heated and damage insulation, current pass through winding to winding; (ii) if winding has been separated at a place not near the end of the coil. When motor is rewound, the efficiency is degraded. The effect of motor rewinding has been investigated and found that the efficiency of motor is degraded due to rewinding each time. However, the degradation of efficiency due to the rewinding is about 1 % to 2 % each time (Xenergy, 2000). According to a recent investigation by the Green Motor Practices Group, there is no efficiency loss if the electric motor is properly rewinds. Improved performance as well as efficiency is also depend on the technology and advance in material. Automatic coil developing technology and precise use of insulation tape confirm reliable coil duplication to improve installation as well as operation. A skilled and expert service provider can confirm the rewound motor get original efficiency (Payton, 2009). The larger capacity motor is better to rewind compared to a smaller motor as shown in the Table 3.10. Green motor practices group investigated rewind motor efficiency that is shown in Figure 3.17 (QMREEM, 2008). Based on their findings, the best fitted equation is used to calculate the efficiency of rewind motor and shown in the Table 3.11. Efficiency of standard, rewind and high efficiency motor at the different loaded operation is calculated using Figure 3.18 and shown in Table 3.12. Incremental price of high efficiency motor is estimated based on Table 3.13. (Saidur et al., 2009a) and shown in Table 3.14.

Table 3.10 Motor rewind practices.

(Xenergy, 2000)

Motor hp	Failed Motor Rewind (%)
1-5	20
6-20	61
21-50	81
51-100	90
100-200	91
>200	95

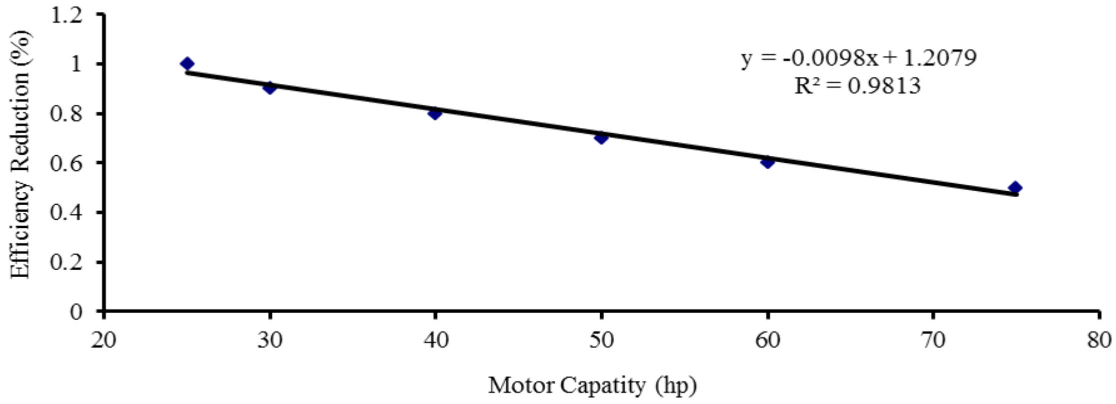

Figure 3.17 Efficiency reduction of rewind motor.

(QMREEM, 2008)

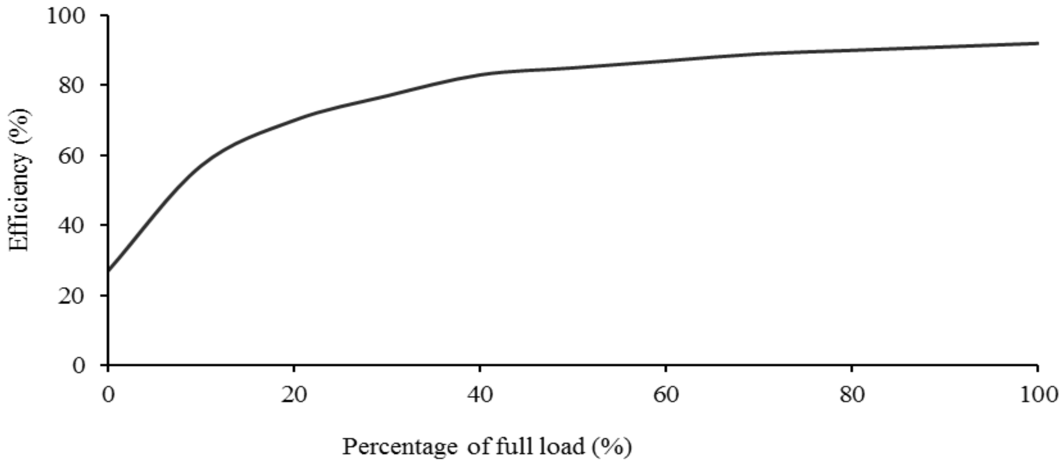

Figure 3.18 Percentage of motor load and efficiency.

(Saidur, 2010)

Table 3.11 Typical motor efficiency and cost.

(Stephen, 2009)

Motor HP	Rewind Cost (US$)	High Efficiency Motor Cost(US$)	Motor Efficiency		
			Standard	Rewind	High Efficient
5	330	375	83	81	91
7.5	380	525	84	82	91
10	500	638	86	84	92
15	550	825	87	85	93
20	600	975	87	86	93
25	660	1238	89	88	94
30	760	1500	89	89	94
40	880	1950	90	89	95
50	980	2325	90	90	95
60	1100	3750	91	90	95
75	1320	4500	91	90	95
100	1650	5325	91	91	96
125	2200	7385	91	90	95
150	2400	8650	92	91	96
200	2650	10,620	92	92	96
250	2860	13,650	93	93	96
300	3080	15,100	93	93	96
400	3500	20,000	93	92	96

Table 3.12 Efficiencies of standard, rewind and high efficiency motors at different loads

Motor HP	Load (50%)			Load (75%)			Load (100%)		
	E_{std}	E_{rd}	E_{ee}	E_{std}	E_{rd}	E_{ee}	E_{std}	E_{rd}	E_{ee}
5	70	68	77	74	72	81	83	81	91
7.5	71	69	78	75	73	82	84	82	91
10	73	72	79	77	75	83	86	84	92
15	74	72	79	78	76	83	87	85	93
20	74	73	79	78	77	83	87	86	93
25	75	75	80	79	79	84	89	88	94
30	76	75	80	80	79	84	89	89	94
40	76	76	80	80	80	85	90	89	95
50	77	76	81	81	80	85	90	90	95
60	77	77	81	81	81	85	91	90	95
75	77	77	81	81	81	85	91	90	95
100	77	77	81	82	81	86	91	91	96
125	77	77	81	81	81	85	91	90	95
150	78	78	81	82	82	86	92	91	96
200	79	78	81	83	82	86	92	92	96
250	79	79	81	83	83	86	93	93	96
300	79	79	82	83	83	86	93	93	96
400	79	78	82	83	83	86	93	92	96

Table 3.13 Increment price of high efficiency motor over standard motor (Saidur et al., 2009a)

Motor hp	Increment price (US$)
1	24
2	25
3	27
4	60
5.5	65
7.5	91
15	147
20	197
25	246
30	257
40	231
50	281
60	574
75	518

Table 3.14 Life cycle of different capacities electric motor. (Andreas, 1992)

Motor hp	Average (year)	Range (year)
<1	12.9	10-15
1-5	17.1	13-19
5.1-20	19.4	16-20
21-50	21.8	18-26
51-125	28.5	24-33
> 125	29.3	25-38

3.9.6 Electric motor energy savings by using capacitor bank

In this section, power factor improvement by using capacitor bank, size and cost of the capacitor, output power increasing by improving power factor, reduction of distribution losses and lagging power factor penalty has been discussed.

3.9.6(a) *Power factor improvement by using capacitor*

Real power is considered the work producing power (mechanical output of a motor) measured in watts (W) or kilowatts (kW). Reactive power does not work but needs to operate equipment (i.e. motor, transformer, fluorescent light, power electronic and induction furnace) (Kwiatkowski, 2009). Power factor is the ratio of the real power to apparent power and represent how much real power used of the electric equipment (Sagiroglu et al., 2006). Power factor is equal to the cosine of phase angle in between voltage and current of the system. About 80–90% of the apparent power is converted into useful work by the induction motors where the remaining is used to form electromagnetic field. The field expands and collapse by turns once each cycle. Therefore, average power drawn by the field is zero and a reactive power does not record on a kilowatt-Hour meter (Kwiatkowski, 2009). The reactive power is used into the inductive elements to establish magnetic field to rotate. Real, apparent and reactive power of an electrical system (Gilbert et al., 1993) has been shown in Figure 3.19.

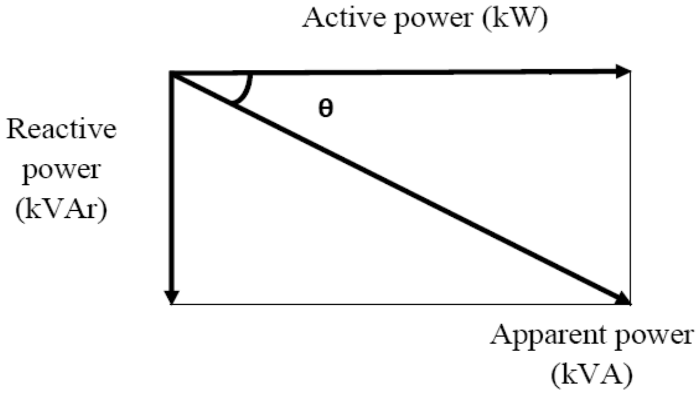

Figure 3.19 Real, apparent and reactive power of an electrical system.
(Gilbert & John, 2000; Sagiroglu et al., 2006; Saidur, 2010)

The power factor of an electrical system can be calculated by using the following Equations (3.82) and (3.83):

$$P.F = \frac{\text{Active Power (kW)}}{\text{Apparent Power (kVA)}} = \frac{P}{S} = \cos\theta \qquad (3.82)$$

$$S = \sqrt{P^2 + Q^2} \qquad (3.83)$$

The alternating current draws active and reactive powers in electrical systems where only active power is produced usefull energy (i.e. heat, light and mechanical energy). That is why; the effect of reduction of capacitance of the production, transmission and distribution line is the lower power factor and needs correct it (Sagiroglu et al., 2006). Capacitor bank is the common and cost-effective option to increase power factor that is shown Figure 3.20. Current passes through the inductive load lags the voltage where the capacitor leads the voltage and serves as leading reactive power (Kwiatkowski, 2009).

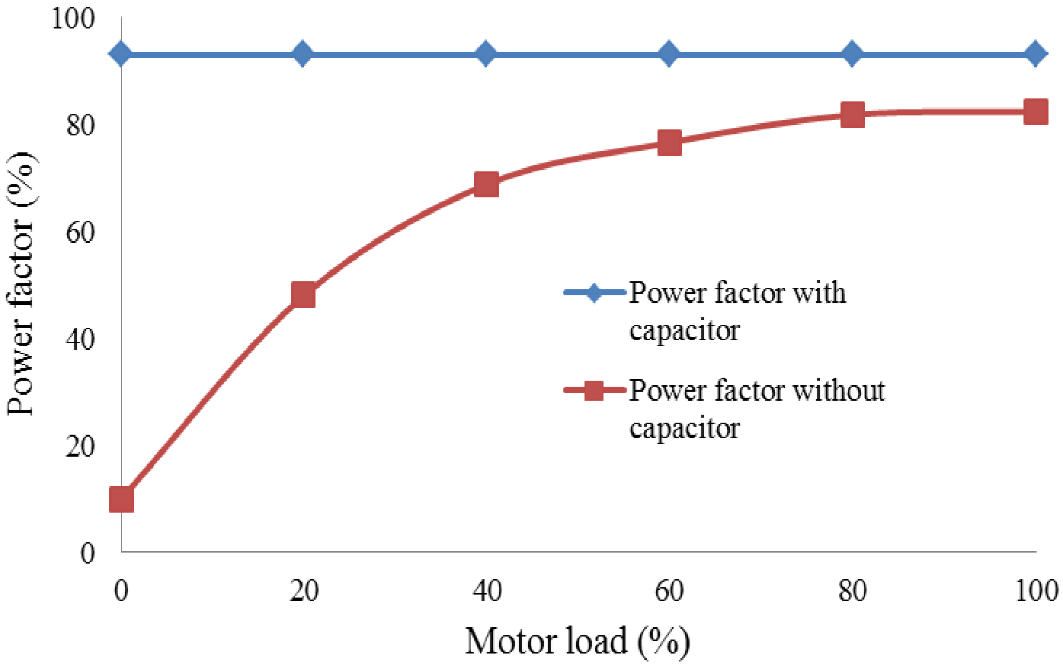

Figure 3.20 Improvement of power factor.

Table 3.15 Power factor of the Malaysian industry.
(Saidur et al., 2009a)

Industry	Average power factor	Range
Food products	0.88	0.75-0.94
Wood and wood products	0.87	0.85-0.92
Paper and paper products	0.88	0.85-.092
Chemicals	0.91	0.89-0.95
Petroleum refineries	0.89	0.86-0.90
Rubber and rubber products	0.91	0.90-0.93
Plastic and plastic products	0.92	0.90-0.95
Glass and glass products	0.89	0.85-0.90
Iron and steel	0.92	0.90-0.94
Fabricated metal products	0.90	0.85-0.90
Cement	0.88	0.85-0.92
Average	0.90	

The selection of type, size, number and setting position of capacitors is important. The options of power factor improvement by using the capacitor are as follows:

(i) Individual motor compensation

(ii) Centralized compensation

(iii) Use of synchronous motor

The best benefit of the correction of power factor is achieved by using capacitor at the sources of reactive current (Gilbert & John, 2000). Position to set capacitors for power factor correct in motor is shown in Figure 3.21.

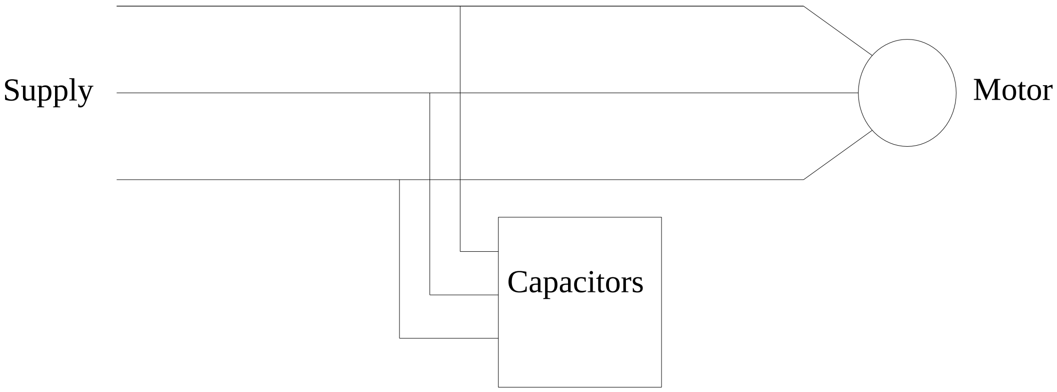

Figure 3.21 Static power factor correction in motor.
(Jayamaha, 2008)

3.9.6(b) Capacitor size and cost

If power factor of a system is known, the reactive power required by installing of capacitor (kVAR) can be calculated by using the following Equations (3.84) and (3.85) (Kwiatkowski, 2009):

$$kVAR_{cap} = M \times kW_{load} \tag{3.84}$$

$$M = \sqrt{\frac{1}{PF_{exist}} - 1} - \sqrt{\frac{1}{PF_{t\arg et}} - 1} \tag{3.85}$$

Table 3.16 also can be used for the calculation of the capacitor for the specific application. The capacitor size for the power factor correction can be estimated by multiplying the factor in the table with motor capacity (i.e. kW). The installation cost of capacitor are about 6 - 12 USD/kVAR at higher voltage level (Gilbert & John, 2000). The capacitor bank market price about 11.4 USD/kVAR and costs to consumer: (i) investment: 11.4 USD/kVAR; (ii) O&M costs: 0.57 USD/kVAR/yr (5% of investment cost) (Yang, 2006).

Table 3.16 Multiplying factor to calculate the size of capacitor (Kilovars required) to improve targeted power factor.

(Gilbert & John, 2000)

Present power factor	Targeted power factor / multiplying factor						
	0.80	0.85	0.90	0.92	0.95	0.98	1.00
0.61	0.6	0.7	0.8	0.9	1.0	1.1	1.3
0.62	0.5	0.7	0.8	0.8	0.9	1.1	1.3
0.63	0.5	0.6	0.8	0.8	0.9	1.0	1.2
0.64	0.5	0.6	0.7	0.8	0.9	1.0	1.2
0.65	0.4	0.6	0.7	0.7	0.8	1.0	1.2
0.66	0.4	0.5	0.7	0.7	0.8	0.9	1.1
0.67	0.4	0.5	0.6	0.7	0.8	0.9	1.1
0.68	0.3	0.5	0.6	0.7	0.8	0.9	1.1
0.69	0.3	0.4	0.6	0.6	0.7	0.9	1.1
0.70	0.3	0.4	0.5	0.6	0.7	0.8	1.0
0.71	0.2	0.4	0.5	0.6	0.7	0.8	1.0
0.72	0.2	0.3	0.5	0.5	0.6	0.8	1.0
0.73	0.2	0.3	0.5	0.5	0.6	0.7	0.9
0.74	0.2	0.3	0.4	0.5	0.6	0.7	0.9
0.75	0.1	0.3	0.4	0.5	0.6	0.7	0.9
0.76	0.1	0.2	0.4	0.4	0.5	0.7	0.9
0.77	0.1	0.2	0.3	0.4	0.5	0.6	0.8
0.78	0.1	0.2	0.3	0.4	0.5	0.6	0.8
0.79	--	0.2	0.3	0.4	0.5	0.6	0.8
0.80	--	0.1	0.3	0.3	0.4	0.6	0.8
0.81	--	0.1	0.2	0.3	0.4	0.5	0.7
0.82	--	0.1	0.2	0.3	0.4	0.5	0.7
0.83	--	0.1	0.2	0.3	0.3	0.5	0.7
0.84	--	--	0.2	0.2	0.3	0.4	0.7
0.85	--	--	0.1	0.2	0.3	0.4	0.6
0.86	--	--	0.1	0.2	0.3	0.4	0.6
0.87	--	--	0.1	0.1	0.2	0.4	0.6
0.88	--	--	0.1	0.1	0.2	0.3	0.5
0.89	--	--	--	0.1	0.2	0.3	0.5
0.90	--	--	--	0.1	0.2	0.3	0.5
0.91	--	--	--	--	0.1	0.3	0.5
0.92	--	--	--	--	0.1	0.2	0.4
0.93	--	--	--	--	0.1	0.2	0.4
0.94	--	--	--	--	--	0.2	0.4
0.95	--	--	--	--	--	0.1	0.3

3.9.6(c) *Output power increasing by improving power factor*

Motor output power depends on the power factor (PF). Output power is increased with increasing the power factor. For a constant power demand motor, utility power is reduced with increasing the power factor. Output power increasing can be estimated by using Equation (3.86) (Gilbert & John, 2000):

$$OP = (1 - \frac{PF_{exist}}{PF_{target}}) \times 100 \tag{3.86}$$

As output power of motor increased with increasing the power factor, so energy saving can be estimated by Equation (3.87):

$$AES = AEU \times (1 - \frac{PF_{exist}}{PF_{target}}) \tag{3.87}$$

3.9.6(d) *Reduction of distribution losses*

Distribution loss of a system can be optimized by using capacitor (i.e. increasing power factor). The losses are calculated by adding the losses in the transformer and cables. By improving power factor, distribution losses can be reduced. Percentage of reduction of distribution losses (RDL) can be estimated by using Equation (3.88) (Kwiatkowski, 2009):

$$RDL = (1 - \frac{PF_{exist}^{\ 2}}{PF_{target}^{\ 2}}) \times 100 \tag{3.88}$$

3.9.6(e) *Lagging power factor penalty*

Sarawak electricity supply corporation (SESCO) bill rates and calculation of electric energy shows a strict concern about the lagging power factor (LPF). The demand sides (i.e. commercial, residential or industrial) are charged extra due to the LPF with the electric bill. The lagging PF charge is calculated by using Equations (3.89) and (3.90) (MLPFP, 2006):

When the LPF is in between 0.85 and 0.75:

$$LPFP = (0.85 - LPF) \times 1.5 \times EB \tag{3.89}$$

And when the LPF is 0.75 and below:

$$LPFP = (0.85 - 0.75) \times 1.5 \times EB + (0.75 - LPF) \times 3 \times EB \tag{3.90}$$

3.10 Mathematical formulation for emission calculation

Malaysian energy centre was calculated the baseline emission factor of a power plant by using the combined margin in Malaysia (MEC, 2008). The combined margin involves of operating margin and builds margin factors (GTM, 2005; MEC, 2008; MT, 2009). The analysis of the baselines was then calculated by using simple operating margin and simple adjusted operating margin because the low-cost/must run resources in Peninsular, Sarawak as well as Sabah constitute less than 50% and found that the results were similar to the simple operating margin. This is due to the fact that low-cost/must run sources constitute less than 50% of the total grid generation. The calculations of the baseline are focus and based on the simple operating margin (GTM, 2005; MEC, 2008).

3.10.1 Formulation of simple operating margin

The operating margin discusses to the adjustments of the existing grid mix for the short-term project activity. Therefore, marginal cost for the short term activity (i.e. operating costs of the last unit production by the plant to meet demand) is relevant. The production of emissions by the plants can be calculated by using the following Equation (3.91) (GTM, 2005; MEC, 2008):

$$EF_{OM,y} = \frac{\sum_{i,j} F_{i,j,y} \times COEF_{i,j}}{\sum_{j} GEN_{j,y}} \tag{3.91}$$

The coefficient of CO_2 emission ($COEF_{i,j}$) is calculated as the following Equation (3.92):

$$COEF_{i,j} = NCV_i \times EF_{CO2} \times OXID \tag{3.92}$$

3.10.2 Formulation of build margin

The build margin stands for the investment alternatives in other sources of electricity. The planning horizon is rather long-term. Planned projects may be entirely displaced or only delayed by the project, and it also represents the trend or types of technology and fuels used for new installed capacity power generation. Build margin emissions factor can be calculated as the generation-weighted average emission factor by using the following Equation (3.93) (MEC, 2008):

$$EF_{OM,y} = \frac{\sum_{i,m} F_{i,m,y} \times COEF_{i,m}}{\sum_{m} GEN_{m,y}} \qquad (3.93)$$

3.10.3 Formulation of combined margin

To calculate the baseline emission factor, the final step is to apply the consolidated methodology for the baseline determination. This is calculated as the weighted average of the emissions factor of the operating margin and build margin. The formula that is used to calculate this weighted average emission factor is the following Equation (3.94) (GTM, 2005; MEC, 2008):

$$EF_y = w_{OM} \times EF_{OM,y} + w_{BM} \times EF_{BM,y} \qquad (3.94)$$

The emissions factors of the operating margin and build margin are weighted equally, each 50%, by default, although different weightage may be used with appropriate justification. By using data from Figure 3.22, emission has been calculated that is shown in Table 3.17.

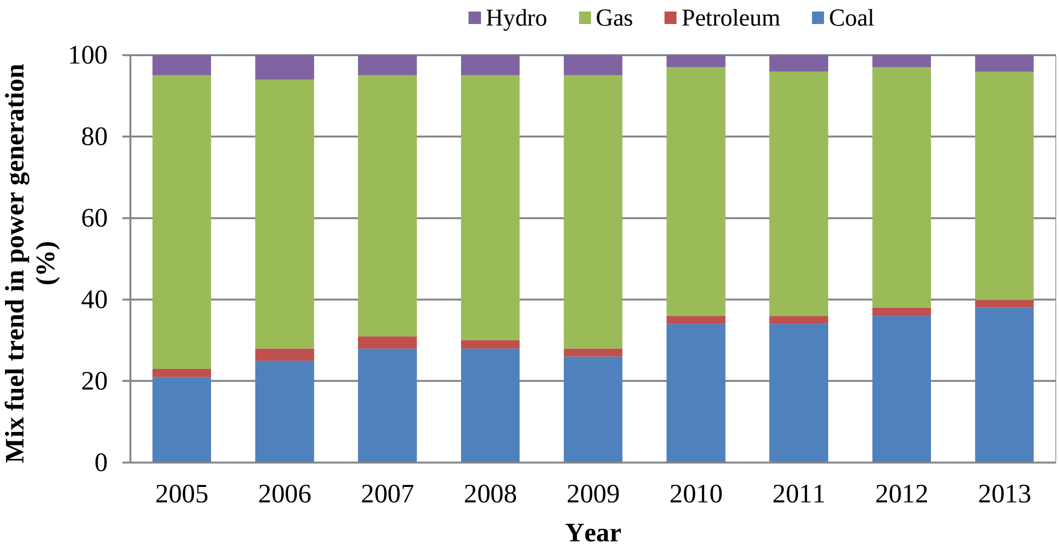

Figure 3.22 Power generation based on mix fuel in Malaysia.
(Jaffar, 2009; Razak & Ramli, 2008)

Table 3.17 Combined marginal emission factors of year 2006 in Malaysia

Emission factor (ton/MWh)		
CO_2	SO_2	NO_x
0.7584	0.0056	0.0021

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The aim of this chapter is to describe the results and discussions of the boiler, furnace heat exchanger, economizer and electric motor. Energy and exergy use, energy and exergy efficiencies, energy and exergy losses, irreversibilities in the boiler, furnace, heat exchanger and economizer are described with necessary Tables and Figures. It is also described the energy use, energy and bill savings, payback period and emissions reduction of electrical motor in the industrial sector with necessary Tables and Figures.

4.2 Energy and exergy of the hot products in combustion chamber

Enthalpy and exergy of the combustion products increased with increaseing the adiabitc flame temperature that is shown in Figures 4.1 and 4.2. It is found that energy and exergy increases linearly with increasing the temperature. In the case of CNG, energy and exergy increasing rate is higher compared to diesel. Coskun et al. (2009) investigated the specific heat of flue gas and found that specific heat increased with incraesing the temperature. They also found that the specific heat of CNG is higher compared to fuel oil. As $h = C_p \Delta T$, so it is clear that enthalpy increased with increasing temperature and enthalpy of CNG is higher than the enthalpy of diesel.

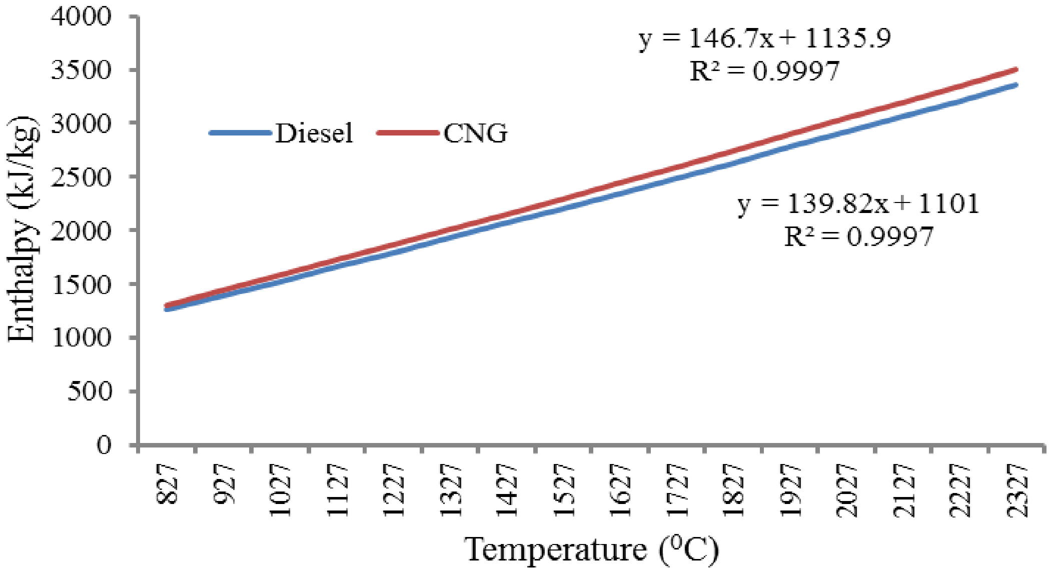

Figure 4.1 Enthalpy of hot product at different adiabatic flame temperature

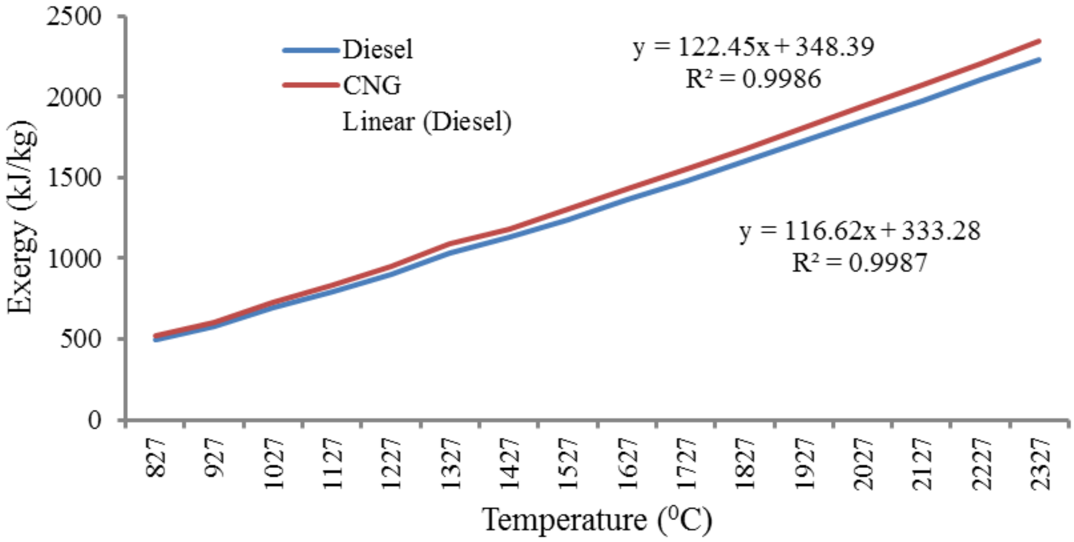

Figure 4.2 Exergy of hot product at different adiabatic flame temperature

4.3 Adiabatic flame temperature and excess air

Thermal properties of the fluids very much depend on the temperature. Enthalpy of fluids increased with increasing the temperature. In the case of combustion, adiabitc flame temperature is the most important factor for the properties of the combustion products. Fuels adiabatic flame temperature depends on the number of carbon, h/C ratio, percentage of excess air etc. Figure 4.3 shows the adiabatic flame temperature of diesel and CNG at the different percentage of excess air. Flame temperature of diesel is more compared to CNG and decreasing with increasing the excess air. Rate of decreasing flame temperature is high with increasing the excess air that is shown in Figure 4.3. Decreasing rate is higher in the case of CNG compared to diesel. The adiabatic flame temperature increases with increasing the carbon percentage of a hydrocarbon fuel (Ferguson & Kirkpatrick, 2001). Glaude et al. (2010) investigated the adiabatic flame temperature different type of biofuels and fossil fuels and found that flame temperature increased with decreasing the H/C ratio. The adiabatic flame temperatures are maximum at the stoichiometric mixture and decreases with increasing of excess air (Ferguson & Kirkpatrick, 2001).

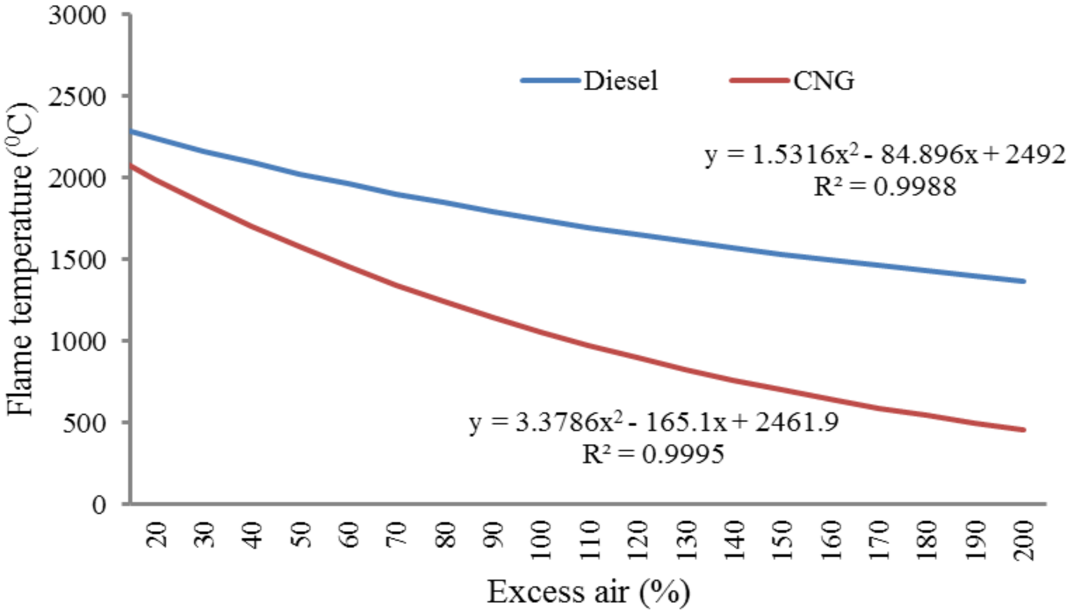

Figure 4.3 Adiabatic flame temperature of different percentage of excess air

4.4 Energy and exergy of the heat exchanging equipment

In this section, energy, exergy, exergy destruction and efficiencies of heat exchanging equipment have been analyzed and compared with literature.

4.4.1 Energy and exergy efficiencies for combustion chamber of the boilers

In the boilers, only fuel is used as an energy supply. According to the thermodynamic analysis, air also included in the energy balancing that is described in the theoretical section. In the boiler system, the combustion chamber is considered as an adiabatic system. The combustion chamber of boiler is considered as an adiabatic system and fuel enthalpy is equal to the higher heating value. Energy and exergy efficiencies have been calculated that is shown in Figure 4.4. It is found that energy efficiency is higher compared to exergy efficiency. Energy and exergy efficiencies of combustion chamber varied from 63% to 90% and from 30% to 40% of the boiler respectively. Average energy and exergy efficiencies of combustion chamber of the boilers are 73.1% and 33.6% respectively.

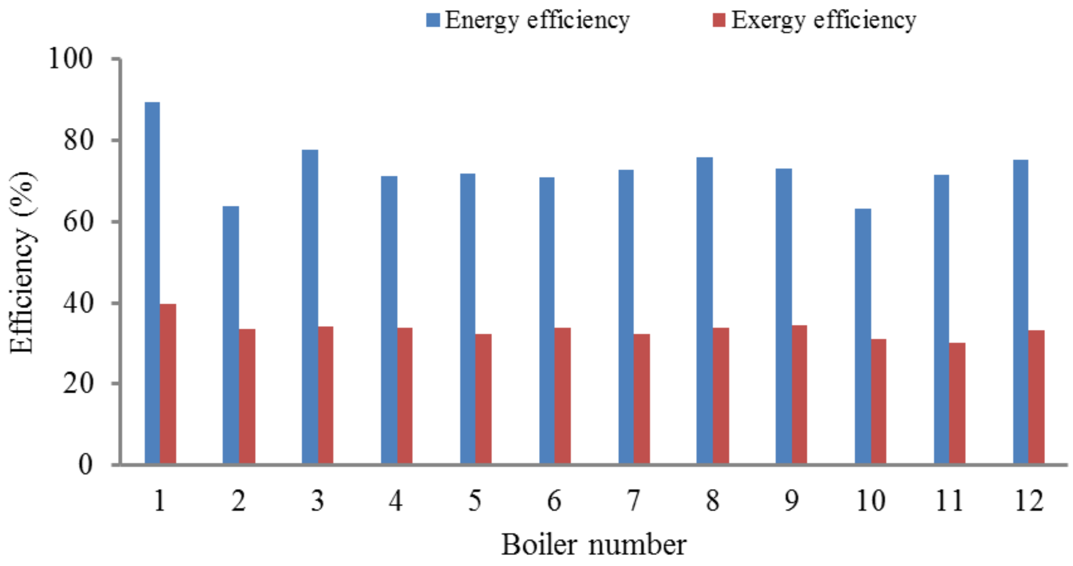

Figure 4.4 Energy and exergy efficiencies of combustion chamber of boilers

4.4.2 Energy and exergy efficiencies for stream production chambers of boilers

In the boiler, heat is transferred from flue gas to the water to generate stream. The energy and exergy efficiencies of the stream production chamber have been calculated that is shown in the Figure 4.5. Energy efficiency of stream production chamber is higher compared to exergy efficiency. Fire tube energy and exergy efficiencies are varied from 44 % to 68 % and 18 % to 24 % respectively. Average energy and exergy efficiencies of stream production chamber of the boilers are 52% and 22% respectively.

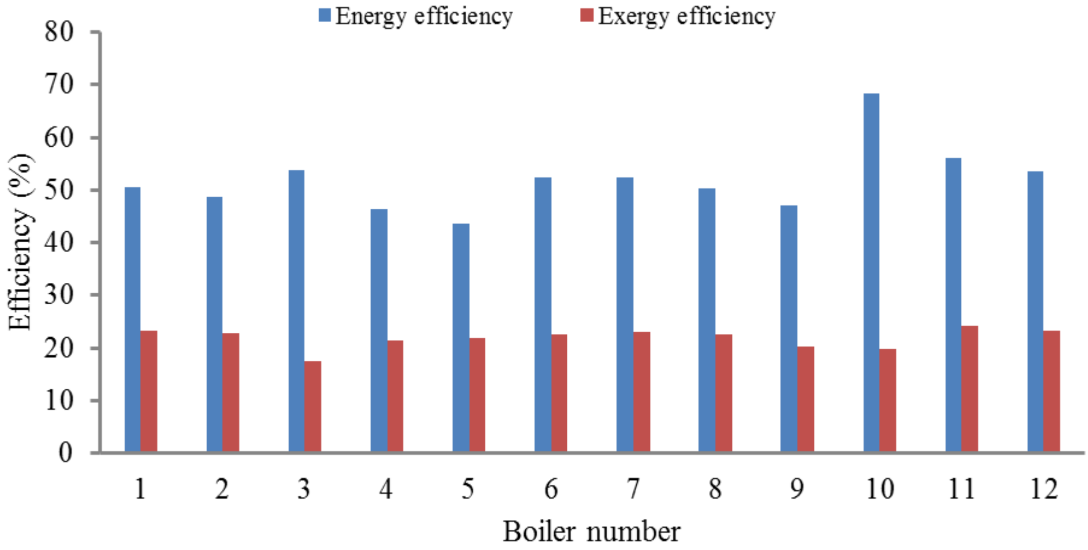

Figure 4.5 Energy and exergy efficiencies of stream production chamber.

4.4.3 Energy and exergy for overall boiler and comparison

The overall boiler energy and exergy efficiencies have been calculated that is shown in the Figure 4.6. It is found that overall boiler energy and exergy efficiencies varied from 56 % to 76% and 18% to 25% respectively. The average energy and exergy efficiencies of boilers are about 68.7 % and 22.1 % respectively. It is investigated that second law efficiency of boiler from 24 % to 27 % (Ayhan & Demirtas, 2001). The exergy efficiency of steam boilers is varied from 21.8 % to 26.6 % respectively (Aneta & Gheorghe, 2008). The CNG fired boiler has been analyzed and found that energy and exergy efficiencies are 72.4 % and 24.9 %, respectively (Saidur et al., 2010). According to the measurements and analysis, boiler energy and exergy efficiencies were obtained around 88.3% and 36.7%, respectively (EMPS, 2010). Therefore, the present result is comparable with previous researcher's results. This small variation is due to type of boiler, fuel type, size and age of the boilers.

The rate of exergy losses has been also calculated of the combustion chamber and stream production chamber of the boilers individually. The rate of exergy losses of boiler has been also calculated by adding the losses of the combustion chamber and stream production chamber. The exergy is efficiency is low due to irreversibility of the system. Temperature of the hot product is higher compared to stream temperature in the boiler. The temperature difference is very high between the hot product and stream in the boiler as a result exergy destroyed. Beside temperature variation, exergy is destroyed due to irreversibilities during the combustion (Aneta & Gheorghe, 2008).

The rate of exergy destruction of combustion chamber and the fire tube of the boilers have been calculated and presented in Figure 4.7. The exergy destruction rate of the combustion chamber is higher (about 55.4 %) compared to the stream production chamber (about 42.6 %) of the boilers. The main sources of exergy destruction are the combustion reactions where destruction affected by amount of excess air, inlet air temperature etc. (Aljundi, 2009a). It is a typical irreversible phenomenon that heat is transferred due to the limited temperature differences, thus there is exergy loss existing in this process. Exergy loss due to heat transfer is also cause of temperature difference. The greater temperature difference, the greater exergy loss; on the contrary, the smaller temperature difference, the smaller exergy loss (Zaili et al., 2010).

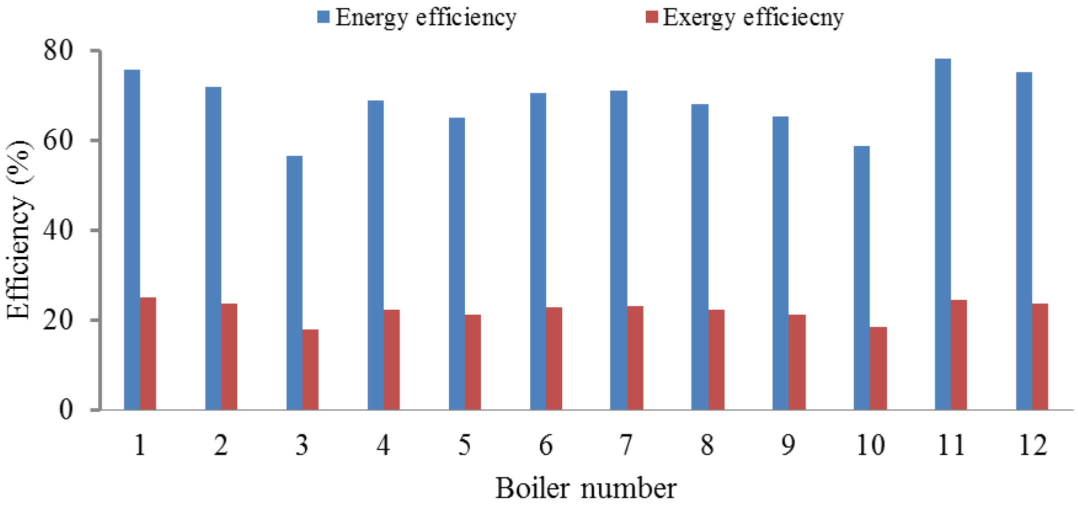

Figure 4.6 Energy and exergy efficiencies of boilers

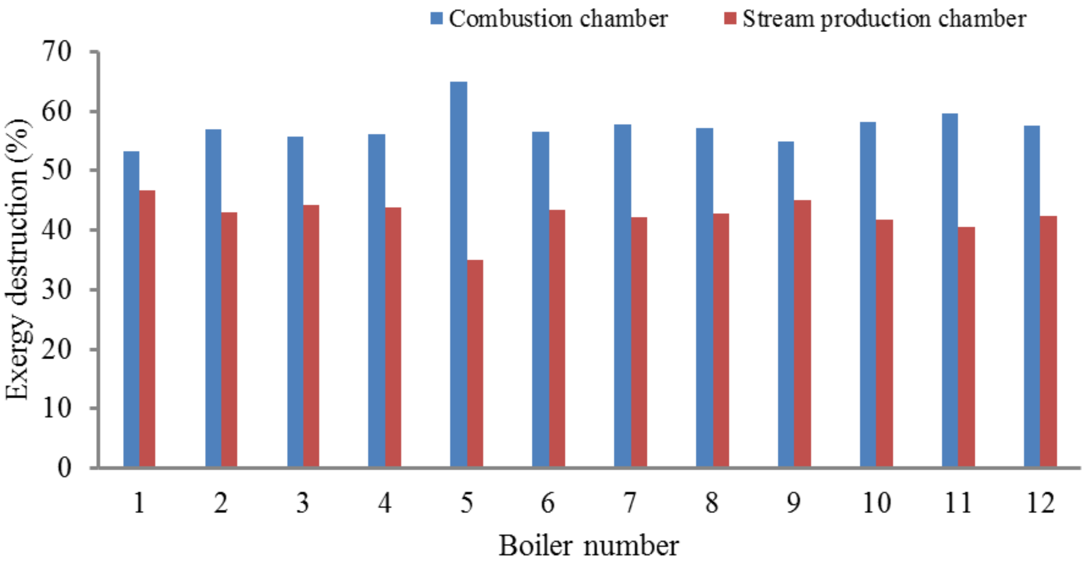

Figure 4.7 Exergy destruction of boilers

4.4.4 Irreversibility and exergy losses of the boilers

Since there is no process that is completely reversible, so some entropy is generated during the processes. More the irreversible processes, more the entropy are generated. For the real processes, input exergy is always more than output exergy for the causes of irreversibilities. Both exergy destruction and waste represent exergy losses. However, larger the exergy destruction need more energy use to input same amount of exergy that affect the environment (Wall, 2002). In this study, the average exergy losses are about 78 %. Aljundi (2009a) investigated exergy as well as amount of exergy destruction of the power plant along with the exergy efficiencies and found the exergy destruction ia about 77 % . Wang et al. (2009) analyzed the performance to estimate exergy losses and found that the major exergy losses due to the irreversibilities in the turbine and boiler. Exergy has been analyzed of a combined-cycle power plant and found that the combustor, gas turbine and steam generator are major source of irreversibilities and represents about 85% exergy losses (Cihan et al., 2006; Dincer et al., 2003). Exergy analysis found the combustor, steam generator, water injection and water recovery are major source of losses that is about 80% exergy losses (Fiaschi & Manfrida, 1998). About 63% of exergy losses in combustion irreversibilities in the boiler (Kamate & Gangavati, 2009).

4.4.5 Energy and exergy efficiencies of combustion chamber of furnace

Energy and exergy efficiencies of combustion chamber of the furnace have been calculated by using the same method as combustion chamber of boiler that is shown in Figure 4.8. It is also found that energy efficiency is higher compared to exergy efficiency. Energy and exergy efficiencies of combustion chamber varied from 48% to 73% and from 30% to 31% of the furnace respectively. Average energy and exergy efficiencies of combustion chamber of the furnace are 60.3% and 30.6% respectively.

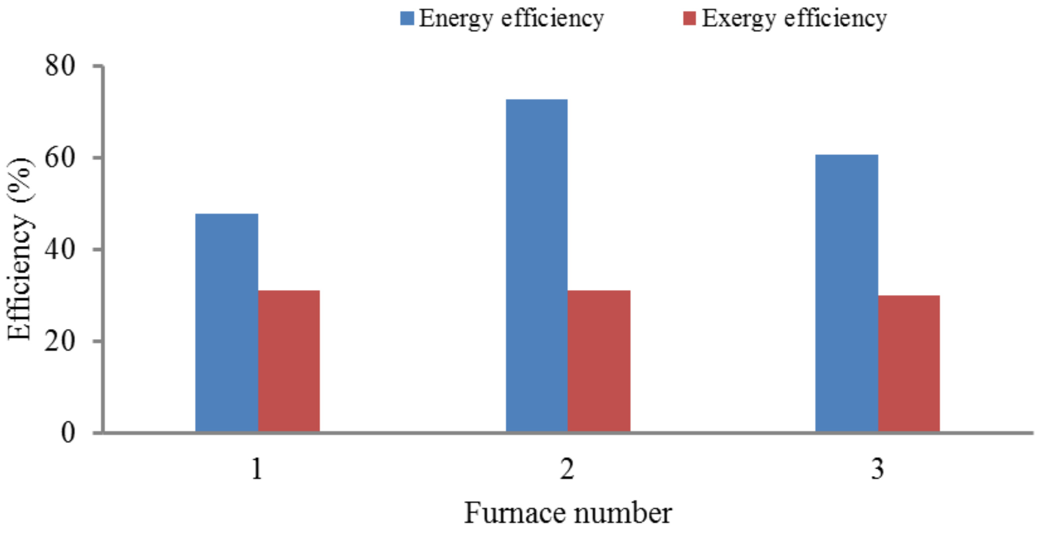

Figure 4.8 Energy and exergy efficiencies of combustion chamber of furnaces

4.4.6 Energy and exergy efficiencies for annealing chamber of furnaces

In the analysis of annealing furnace, one dimensional heat transfer is considered where the heat is transferred from combustion hot product to steel product of annealing chamber. Energy and exergy efficiencies of the annealing chamber have been calculated and presented in the Figure 4.9. Furnace analysis shows that the energy efficiency is higher compared to exergy efficiency. Energy and exergy efficiencies of annealing chamber varied from 14% to 51% and from 12% to 40% of the furnace respectively. Average energy and exergy efficiencies of combustion chamber of the furnaces are 27.4% and 21.8% respectively.

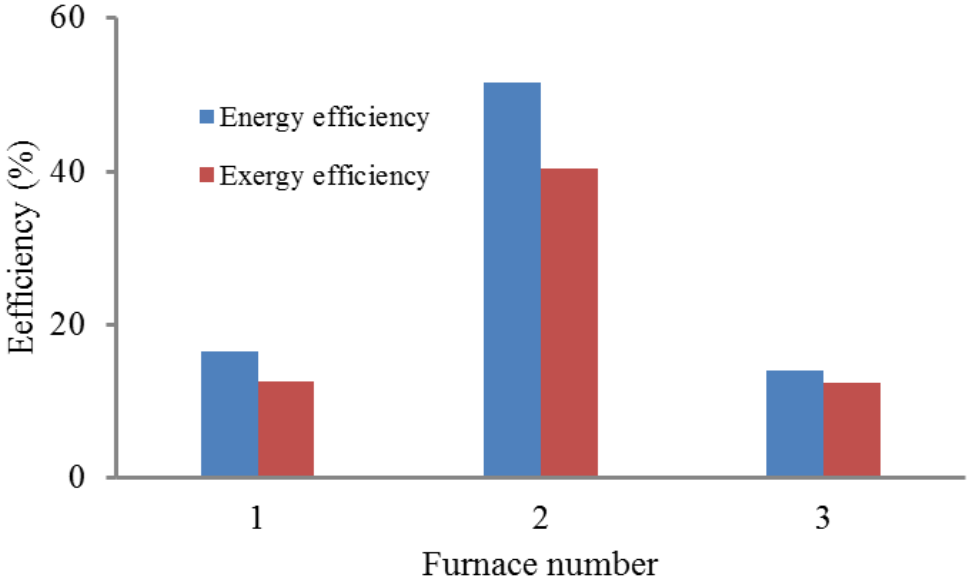

Figure 4.9 Energy and exergy efficiencies for annealing chamber of furnaces

4.4.7 Energy and exergy for overall furnaces and comparison

The overall furnace energy and exergy efficiencies have been calculated that is shown in the Figure 4.10. It is found that overall furnace energy and exergy efficiencies varied from 16 % to 55% and 10% to 35% respectively. The average energy and exergy efficiencies of furnace are about 30.1 % and 19.3 % respectively. This small variation is due to type of furnace, fuel type, size and age of the furnace. The rate of exergy losses has been also calculated of the combustion chamber and annealing chamber of the furnaces individually. The rate of exergy losses of furnaces has been also calculated by adding the losses of the combustion chamber and annealing chamber. The exergy efficiency is low due to irreversibility of the system.

The rate of exergy destruction of combustion chamber and annealing chamber of the furnaces have been calculated and presented in Figure 4.11. The rate of exergy destruction in annealing chamber is higher (about 61.8 %) compared to the combustion chamber (about 38.2 %) of the furnaces.

It is a typical irreversible phenomenon that heat is transferred due to the limited temperature differences, thus there is exergy loss existing in this process. Exergy losses due to heat transfer are related to temperature differences. The greater temperature difference, the greater exergy loss; on the contrary, the smaller temperature difference, the smaller exergy loss (Zaili et al., 2010). Oil fired reheating furnace efficiency is about 25 % (direct method), 24 % (indirect method) (EPAF, 2009). It is found that rate of exergy destruction affects both energy and exergy efficiencies. Energy and exergy efficiencies increase with decreasing the rate of exergy destruction. It is also found the exergy efficiency is increased with increasing the energy efficiency. Since there are no processes are completely reversible, as a result some entropy is generated. The more irreversible the processes, more the entropy generated (Changel & Boles, 2006).

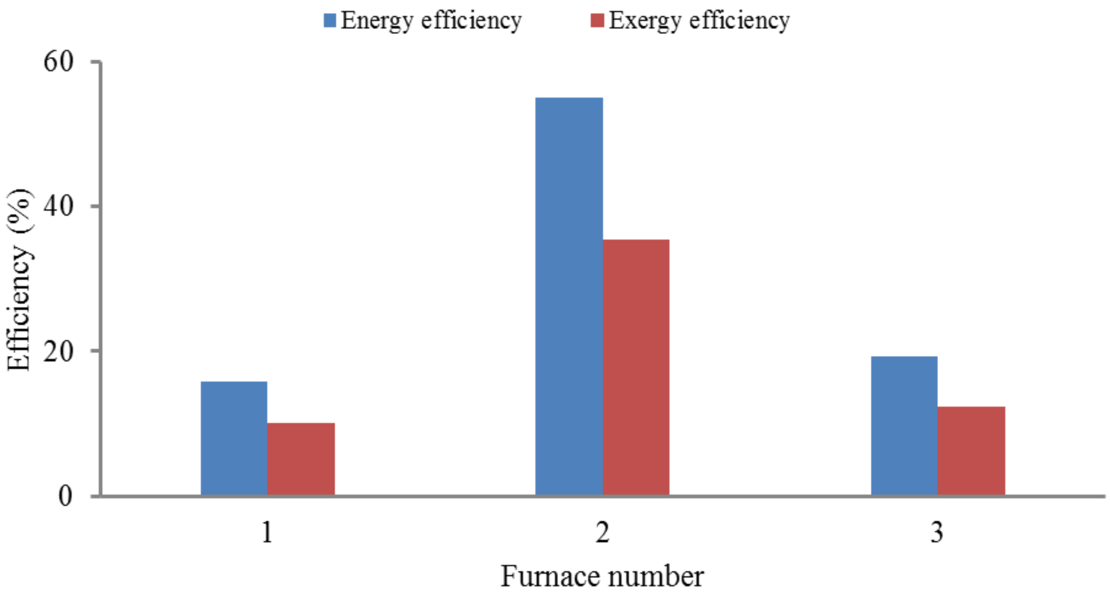

Figure 4.10 Furnaces energy and exergy efficiency

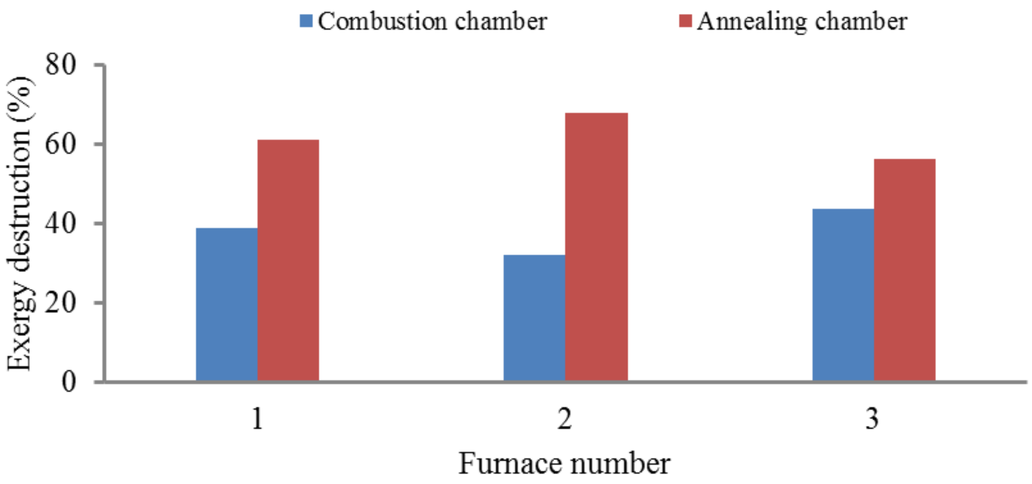

Figure 4.11 Furnaces energy and exergy destruction

4.4.8 Irreversibility and exergy losses of the furnaces

In the annealing chamber, steel is heated to change its properties at a fix temperature. To keep the demand temperature, heat is provided from the combustion chamber to the annealing chamber. In this process, heat is transferred due to the temperature difference between them. In the annealing furnace, exergy losses are more in the annealing chamber (i.e. average 61.2% of the total losses).

4.4.9 Energy and exergy effectiveness of heat exchangers

Energy and exergy effectiveness of the heat exchanger is presented in Figure 4.12. Figure 4.12 shows energy and exergy effectiveness of heat exchangers varied from 61% to 68% and 56% to 63% respectively. Naphon (2007) investigated the thermal performance of heat exchanger by changing flow rate and inlet temperature of fluids in the same heat exchanger. Author found the effectiveness of the heat transfer varied from 40% to 92%. It was also found that a great effect of flow rate as well as inlet temperature of hot and cold fluids on effectiveness of heat exchangers (Li et al., 2010). Thirumarimurugan et al. (2008) investigated the effectiveness of heat exchanger by varying flow rate of cold fluids in same heat exchanger. Authors found effectiveness of heat exchangers are increased from 74.8% to 87.6% by changing mass flow rate of cold fluid (i.e. cold water) increased from 118.8 kg/h to 656.9 kg/h when hot fluid mass flow rate average 51.2 kg/h. They also investigated the effectiveness of the heat exchanger increased from 53.0% to 74.1% by changing mass flow rate of cold fluid (i.e. 10% acetic acid water solution) increased from 120.2 kg/h to 664.1 kg/h when hot fluid mass flow rate average 97.6 kg/h. It is also found that there is a great effect of flow rate of hot and cold fluids on effectiveness of heat exchanger.

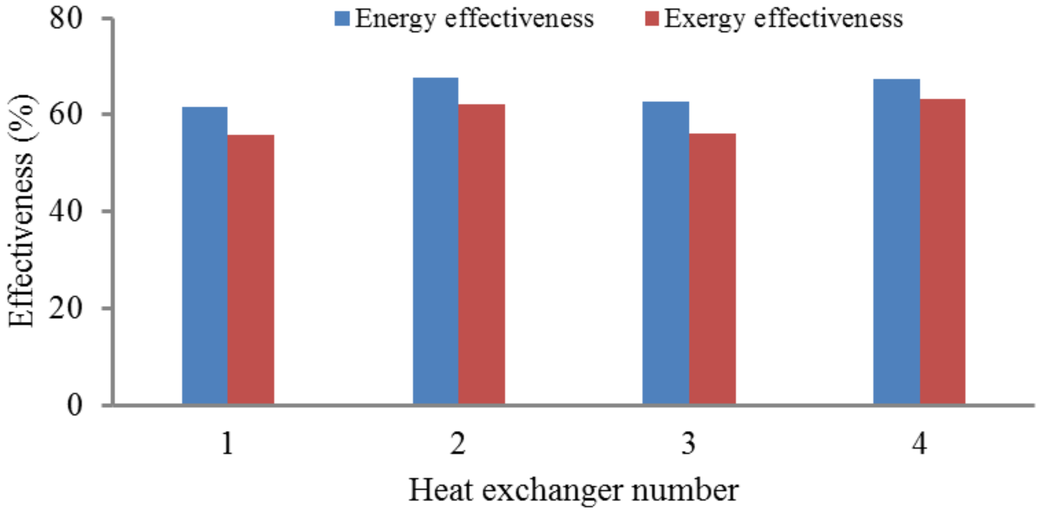

Figure 4.12 Energy and exergy effectiveness of heat exchangers

4.4.10 Energy and exergy of economizers

Energy and exergy effectiveness of economizers has been analyzed that is presented in Figure 4.13. Figure 4.13 shows that energy and exergy effectiveness of economizer varied from 66% to 73% and 47% to 65% respectively. Mario (1998) investigated the exergy effectiveness of an economizer and found that varied from 50% to 64%.

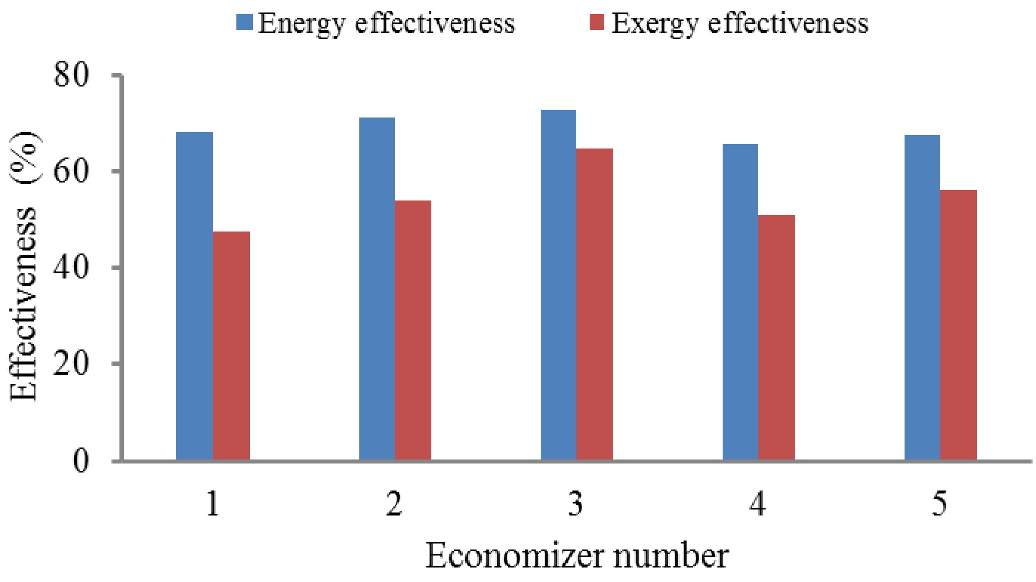

Figure 4.13 Energy and exergy effectiveness of the economizers

4.5 Energy savings of the boilers and furnaces

In this section, energy savings by excess air control in combustion, heat recovery from flue gas, retrofitting to increase the efficiency, improve efficiency by energy-efficient burner and replacement of boiler or furnace, potential cost benefit analysis of the energy saving options has discussed.

4.5.1 Excess air control in the combustion of the boilers and furnaces

Excess air control in the combustion system is important factors for combustion efficiency. Excess air reduces the adiabatic flame temperature (i.e. enthalpy of the combustion product). Processors can control the setting of fuel valve to match air fuel ratio. The combustion efficiency can be increased at the low firing by reducing fan speed. The control of fan motor speed is easy way by using electronic control. By using the speed controller, burner turndown is improved without negotiating combustion efficiency that can save energy (i.e. fuel). The use of VSD to slow down motor causes energy saving (i.e. 50 % speed reduction can save 80 % energy). Hence, by using VSD, not only efficiency of boiler and furnace increases, but also save electrical energy

(Ozdemir, 2004). Boiler efficiency increases about 1% for every 15% decrease of excess air. A modern burner control with excess air trim can save fuel up to 3% (Kilicaslan & Ozdemir, 2005). Excess air (i.e. more air than ideal stoichiometric) is essential to ensure complete combustion and to reduce NOx. Boiler of reduces excess air from 140% to 15% can be saves about 8% energy (Einstein et al., 2001a).

4.5.2 Waste heat recovery and energy savings

A huge amount of heat loss occurred through the flue gas of the boilers and furnaces. Since the allowable stack gas temperature is 120 ^{0}C (Saidur et al., 2010), by reducing temperature of exhaust gas can be recovered the waste heat. Recovering heat can improve the boiler and furnace efficiency. Heat is normally recovered by passing flue gas through the heat exchanging equipment (i.e., economizer, recuperator). The heat can be reused to preheat feed water, combustion air, fuel oil etc. that will absolutely save the energy. It is also proposed that a sensor be installed to ensure that the minimum allowable temperature of the flue gases is more than 120 ^{0}C. This is to prevent the sulfur condensation at the tubes of the flue gases outlet as the dew point of sulfur is at 120 ^{0}C. Once the sulfur condensates forms, it can clog up the tubes and cause corrosion that will damage the economizer.

4.5.2(a) Energy saving by using economizer

Economizer is the heat exchanging equipment (flue gas to feed water) located near the flue gas duct that can be recovered heat from the flue to preheat feed water. A condensing economizer can be saved up to 20% of fuel by recovering the waste heat from flue gas. Condensing economizer has a wide range sizes, real energy and cost saver for industrial sector (SECE, 2010). The company analyzed the possible energy savings by using their economizer at different inlet temperature of feed water and flue gas that is shown in Figure 4.14. The cost of the economizer is about 30,000 USD

(MGTC, 2010). The potential savings for the boilers after the installation of economizers are shown in Table 4.1. It is found that about 56,867 L, 49,951 L, 73,743 L, 127,676 L and 20,495 L fuel can be saved annually by installing the economizer number 1, 2, 3, 4 and 5 respectively. The fuel cost savings about 38,101 USD, 33,467 USD, 49,408 USD, 85,543 USD, and 13,732 USD can be saved annually by installing the economizer number 1, 2, 3, 4 and 5 respectively. The payback periods have been found 0.8, 0.9, 0.6, 0.4 and 2.2 year for economizer number 1, 2, 3, 4 and 5 with the energy savings of 16.3%, 14.1%, 10.9%, 6.5% and 5.1% respectively. It is also found that fuel savings reduce the CO_2 emission about 144, 126, 187, 323 and 52 tons annually for economizer number 1, 2, 3, 4 and 5 respectively. In the economizer, there is no moving part that gives it very long life cycle and less maintenance cost. It is also found that the payback period is lower when operating hour is comparatively high. Payback period of condensing economizer is normally less than 2 years (SECE, 2010). About 1% energy (i.e. fuel) can be saved for every 25 ^{0}C temperature reduction of flue gas (Einstein et al., 2001a; Ganapathy, 1994).

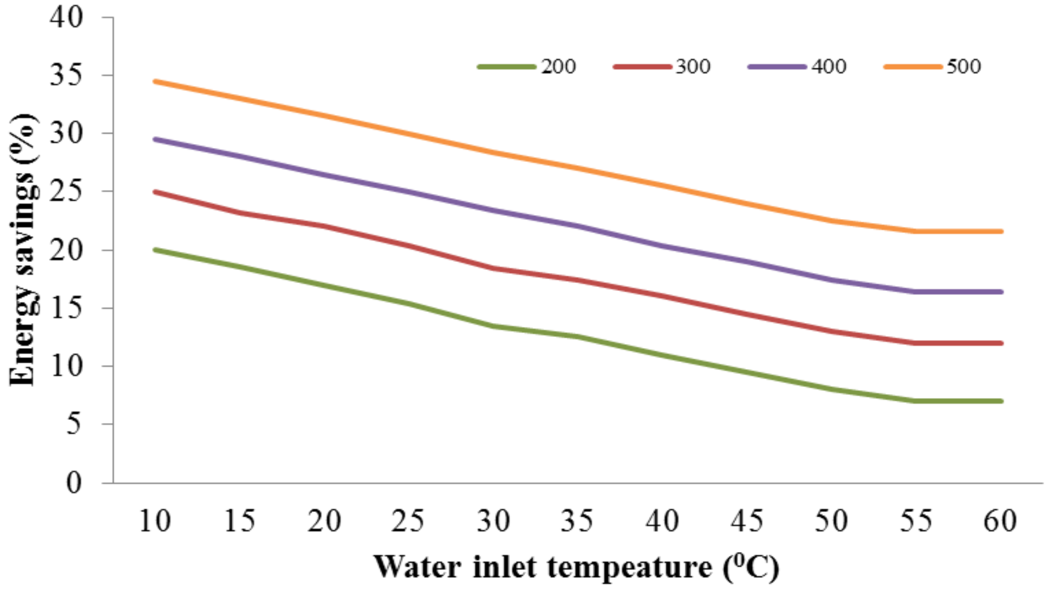

Figure 4.14 Energy savings from flue gas by using an economizer. (SECE, 2010)

Table 4.1 Fuel and utility bill savings, payback period for economizer of the boilers.

Boiler no	Fuel savings (L/year)	Utility bill savings (USD/year)	Payback period (year)	CO_2 emission reduction (tons)
1	56,867	38,101	0.8	144
2	49,951	33,467	0.9	126
3	73,743	49,408	0.6	187
4	127,676	85,543	0.4	323
5	20,495	13,732	2.2	52

4.5.2(b) Energy saving by using recuperator

Temperature of the flue gas of the furnaces is very high that means energy losses through the flue gas is also high. This energy can be recovered and used to preheat combustion air. Cost of the recuperator is about 600,000 USD (Kaya & Eyidogan, 2010). The potential savings for the furnaces after the installation of recuperator are shown in Table 4.2. It is found that about 1,732,077 L, 1,326,634 L and 16,858 L fuel can be saved annually by installing the recuperator in the furnace number 1, 2 and 3 respectively. The fuel cost savings about 1,160,492 USD, 888,845 USD and 11,295 USD can be saved annually from the furnace number 1, 2 and 3 respectively. The payback periods have been found 0.5, 0.7 and 53.1 year for furnace number 1, 2 and 3 with the energy savings of 47%, 30% and 11% respectively. It is also found that fuel savings reduce the CO_2 emission about 4386, 3359 and 43 tons annually for furnace number 1, 2 and 3 respectively. Fuel savings by using the radiation recuperator of the furnace has been shown in Figure 4.15. Modern burner can burn high temperature preheated air during the combustion (EED, 2010). The input energy is the flue gas. Fuel consumption can be reduced about 25% by using the preheated air of high temperature of about 1327 ^{0}C (Hasegawa et al., 2000). Rising air temperature of each 100 ^{0}C result in fuel savings about 6% of the furnace (Edmeston, 2011).

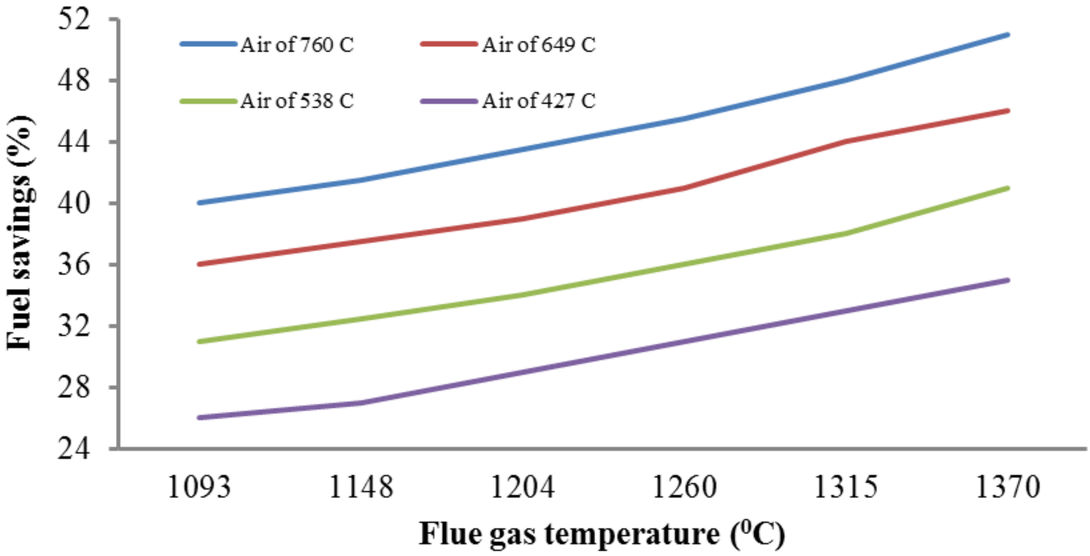

Figure 4.15 Fuel savings by using a radiation recuperator.
(RR, 2011)

Table 4.2 Fuel and utility bill savings, payback period for recuperator of the furnaces

Furnace number	Fuel savings (L/year)	Utility bill savings (USD/yearr)	Payback period (year)	CO_2 emission reduction (tons)
1	1,732,077	1,160,492	0.5	4386
2	1,326,634	888,845	0.7	3359
3	16,858	11,295	53.1	43

4.5.3 Retrofitting boiler and furnace to increase the efficiency

Retrofitting is one of the options to increase the efficiency boilers and furnaces without replacing. The upgrades improve the efficiency of the boilers and furnaces but potential costs benefit analysis of retrofitting should be analyzed instant of replacing new furnace or boiler. There are many retrofitting that are possible both for the gas and oil boilers and furnaces, but before retrofitting should be considered the potential savings as well as benefits. The some of the possible retrofits is discussed in the following:

4.5.3(a) Vent dampers

The vent damper is the most common retrofitting both for boiler and furnace. By using the vent damper chimney losses can be prevented by controlling the vent when it is not firing. After finishing the heating process, automatic vent damper closes the top of the water heater. The automatic flue damper traps heat around heat exchanger instead of rising up the flue. After turning off the burners and venting the noxious gases, automatic vent damper is closed by a small motor. If the burners are ignited with the automatic flue damper in the closed position then dangerous noxious combustion fumes would build up in the area that causes dangerous conditions for the occupants. Moreover, the flames cannot burn correctly as the combustion gas vents direct place. A properly functioning automatic vent damper can save energy as well as operating costs (GFBF, 2010).

4.5.3(b) Intermittent ignition devices

Old boilers and furnaces having pilot light can retrofitting by the intermittent ignition device to increase efficiency. The cost of the intermittent ignition devices about 250 USD which is normal payback period of not more than 10 years (GFBF, 2010). Even though the intermittent ignition device save energy, but it is not always economic (i.e. cost effective). In the case of aging equipment, it is not cost effective. Before installing intermittent ignition devices, potential cost benefits should be analyzed.

4.5.3(c) Derating gas burners

In the industrial sector, most of the boilers and furnaces are oversized. These boilers and furnaces energy efficiency can be improved by derating gas burner. By optimizing the capacity of gas burner (i.e. size of the orifice) that can make the boiler or furnace more efficient. Derating of gas burner cost is less than 100 USD that can save energy up to15% (GFBF, 2010).

4.5.3(d) Derating oil burners

Boilers and furnaces energy efficiency can be improved by derating oil burner. By optimizing the capacity of oil burner (i.e. size of the orifice) that can make the boiler or furnace more efficient. An old boiler or furnace with inefficient burner, it can be replaced the burner only. Flame retention burners can save energy up to 20% where the cost is about 500 USD.

4.5.4 Improve efficiency of the boilers and furnaces by using energy-efficient burner

4.5.4(a) Energy efficient gas burner

The purpose of the burner is to mix molecules of fuel with molecules of air. Burners should be designed to maximize combustion efficiency and minimize the release of emissions. Burner mechanically mixes fuel and air to inject the mixture into the combustion chamber. Burner is the most important to optimize burning condition and efficiency of boiler and furnace. So, periodic inspection and combustion optimization is essential for efficient operation of the burner (Verma et al., 2011). The power burners basically provide complete combustion and maintain flame stabilization. However, different burners require different amounts of the air-fuel and turndown ratio. The efficient gas burners need 10 % to 15 % of excess air (EEB, 2004). Most of the gas burners require turndown ratios of 10:1 or 12:1. Some burners require turndown ratio up to 35:1. The higher turndown ratio improves load control and fuel saving, reduces refractory wear and purge-air necessities and saves wear-and-tear of the burner. Without continuous adjustment, the efficient burner can provide accurate air-fuel mixture throughout the firing rates. The use of servomotors with parallel location to self-sufficiently controlled the air-fuel for the burner head in a modern burner is increasing.

4.5.4(b) Energy efficient oil burner

The basic purpose of the oil burner is to continue the degree of atomization to confirm stable flame in the boiler or furnace. Currently a large number of various oil burners of various design and type have availed in the market for the industrial furnace and boiler. It is noted that about 70% of burn are used of low air pressure atomization. In case of lap burners, about 25-30% of excess air is used for proper atomization. There is a suitable scope to improve the efficiency of lap burner by using low amount of excess air and broader turn down ratio. The improved low excess air film burner can save about 10-15% of energy (EEB, 2004).

4.5.5 Replacing boilers and furnaces

Even though the old boiler and furnace efficiency ranges of 56%–70%, the modern boiler and furnace has efficiency much better than old system. If the boilers or furnaces are not efficient or significant oversize, the easiest solution is to replace by modern high-efficient boiler or furnace. Old coal burner that is converted to oil or gas fired is also main candidate to replace it. Before replacing by new boiler or furnace or improving, first should be analyzed energy efficiency as well as economic. Energy-efficiency improvements can be saved money on a new boiler or furnace compared to old boiler or furnace. Before buying high-efficiency boiler or furnace, energy star label should be checked carefully. Annual energy savings can be estimated by using Table 4.3. The annual fuel utilization efficiency (AFUE) represents the real annual operating efficiency of a boiler or furnace (ES, 2010). Higher the AFUE, more the fuel efficiency unit. Higher efficiency boiler or furnace produces the same amount of heating as lower efficiency units of the same output, while saving money by using less gas or oil. Currently, the lowest efficiency products available from most manufacturers are 80%, although it is still significantly higher than older unit's efficiencies, which are sometimes as low as 60%. Boiler and furnace of multiple efficiency levels are from

80% AFUE to 95% AFUE. The higher the AFUE, the higher the initial investment cost of the equipment, but the lower the operating cost. These products offer the same level of performance and features, and may be able to reduce utility bills due to lower energy consumption (ECE, 2010).

Table 4.3 Estimated fuel savings by increasing annual fuel utilization efficiency. (ES, 2010)

Existing system AFUE (%)	New/upgraded system AFUE (%) and fuel savings (%)								
	55	60	65	70	75	80	85	90	95
50	9	17	23	29	33	38	41	44	47
55	-	8	15	21	27	31	35	39	42
60	-	-	8	14	20	25	29	33	38
65	-	-	-	7	13	19	24	28	32
70	-	-	-	-	7	13	18	22	26
75	-	-	-	-	-	7	12	17	21
80	-	-	-	-	-	-	6	11	16
85	-	-	-	-	-	-	-	6	11
90	-	-	-	-	-	-	-	-	5

4.6 Analysis of energy use and energy savings of electrical motor

In this section, energy use and energy savings of high efficiency motor, standard motor, and fail motor, variable speed drive has been analyzed and compared with literature.

4.6.1 Failed motor rewind or replace with a high efficient motor

Energy savings, bill savings and the payback period related with energy savings as a result of applying high efficiency motor over fail rewind motor have been analyzed and shown in Table 4.4 for different motor size and load. Replacement of failed motor instead of rewinding motor saves energy in the various ways. The industrial analysis found that end users rewind 40 % of their motor in the industry that is failed each year and the number of motor rewind increases with increasing the hp of the motors (Xenergy, 2000). According to the energy saving's analysis; by applying the high efficiency motor usually saves energy but increase initial cost to buy new motor. Amount of energy savings is directly related to motor load (i.e. savings increases with increasing load). The payback period estimation shows that payback period is increased with increasing hp of the motor. From the estimation, it is also found the payback period is decreased with increasing the percentage of operating load of motor. Better to rewind larger hp motor compared to small motor. It is also found that about more than 81 % of more which capacity is more 20 hp is being rewound and the rewinding percentage is increased with increasing the motor capacity (Xenergy, 2000).

4.6.2 New standard efficient motor or high efficient motor

Energy savings, bill savings and the payback period related with energy savings as a result of applying high efficiency motor over standard motor have been analyzed that is shown in the Table 4.5 for different motor size and load. According to the energy saving's analysis; using the high efficiency motor can save energy and shown in Table 4.5. The amount of energy savings is increased with increasing motor capacity (i.e. hp) and operating load. The payback period analysis shows that the payback period is less than 1 year even though the motor is operated at 50 % load. Where the average motor life is more than 12 years (Andreas, 1992). It is also found the payback period decreases with increasing the percentage of motor operating load.

Table 4.4 Energy and bill savings, payback period for high efficient motor over failed rewound standard motor at different percentage of loads.

Motor HP	Increment Price (US$)	Energy Savings (kWh/year)			Bill Savings (US$/year)			Payback Period (year)		
		50 %	75 %	100 %	50 %	75 %	100 %	50 %	75 %	100 %
5	45	1855	2643	3154	85	122	145	0.5	0.4	0.3
7.5	145	2541	3620	4320	117	167	199	1.2	0.9	0.7
10	138	2744	3909	4665	126	180	215	1.1	0.8	0.6
15	275	3813	5433	6483	175	250	298	1.6	1.1	0.9
20	375	4873	6942	8284	224	319	381	1.7	1.2	1.0
25	578	4956	7060	8425	228	325	388	2.5	1.8	1.5
30	740	5490	7820	9332	253	360	429	2.9	2.1	1.7
40	1070	7020	10,001	11,935	323	460	549	3.3	2.3	1.9
50	1345	8188	11,664	13,919	377	537	640	3.6	2.5	2.1
60	2650	9199	13,104	15,638	423	603	719	6.3	4.4	3.7
75	3180	12,202	17,383	20,744	561	800	954	5.7	4.0	3.3
100	3675	14,911	21,242	25,349	686	977	1166	5.4	3.8	3.2
125	5185	19,569	27,877	33,267	900	1282	1530	5.8	4.0	3.4
150	6250	19,024	27,102	32,341	875	1247	1488	7.1	5.0	4.2
200	7970	23,377	33,302	39,740	1075	1532	1828	7.4	5.2	4.4
250	10,790	23,026	32,803	39,144	1059	1509	1801	10.2	7.2	6.0
300	12,020	27,514	39,196	46,774	1266	1803	2152	9.5	6.7	5.6
400	16,500	45,215	64,412	76,866	2080	2963	3536	7.9	5.6	4.7

Table 4.5 Energy and bill savings, payback period for high efficient motor over standard motor at different percentages of loads

Motor HP	Increment Price (US$)	Energy Savings (kWh/year)			Bill Savings (US$/year)			Payback Period (year)		
		50 %	75 %	100 %	50 %	75 %	100 %	50 %	75 %	100 %
5	63	1459	2078	2480	67	96	114	0.9	0.7	0.5
7.5	80	2020	2878	3435	93	132	158	0.9	0.6	0.5
10	97	2090	2977	3552	96	137	163	1.0	0.7	0.6
15	132	2955	4210	5023	136	194	231	1.0	0.7	0.6
20	167	3819	5440	6491	176	250	299	1.0	0.7	0.6
25	202	4110	5854	6986	189	269	321	1.1	0.7	0.6
30	237	4591	6540	7805	211	301	359	1.1	0.8	0.7
40	306	5964	8496	10,138	274	391	466	1.1	0.8	0.7
50	376	7051	10,045	11,987	324	462	551	1.2	0.8	0.7
60	446	8041	11,455	13,670	370	527	629	1.2	0.8	0.7
75	550	10,990	15,656	18,683	506	720	859	1.1	0.8	0.6
100	725	13,316	18,970	22,637	613	873	1041	1.2	0.8	0.7
125	899	17,553	25,005	29,840	807	1150	1373	1.1	0.8	0.7
150	1073	16,668	23,745	28,336	767	1092	1303	1.4	1.0	0.8
200	1422	20,269	28,875	34,458	932	1328	1585	1.5	1.1	0.9
250	1770	19,208	27,364	32,654	884	1259	1502	2.0	1.4	1.2
300	2119	23,861	33,992	40,564	1098	1564	1866	1.9	1.4	1.1
400	2816	40,281	57,383	68,477	1853	2640	3150	1.5	1.1	0.9

4.6.3 Motors energy savings by using variable speed drive

Energy savings, utility bill savings and payback period have been calculated, and the results are presented in Tables 4.6. It is estimated that by using VSD about 14 MWh, 24 MWh and 29 MWh of energy can be saved for a 20%, 40% and 60% speed reduction of a 5 hp electric motor and the corresponding bill savings of USD 920, USD 1527 and USD 1861 for 20%, 40% and 60%, respectively. It is also found that payback periods are shorter for a higher percentage of speed reduction (i.e. 60% speed reduction) and larger motors (i.e. larger hp motor).

Table 4.6 Energy and utility bill savings, payback period by using VSD at certain percentage of speed reduction

Motor HP	Increment price (US$)	Energy savings (MWh/year)			Bill savings (USD/year)			Payback period (year)		
		20%	40%	60%	20%	40%	60%	20%	40%	60%
5	2500	14	24	29	920	1527	1861	2.72	1.64	1.34
7.5	3376	22	36	44	1380	2290	2792	2.45	1.47	1.21
10	3349	29	48	58	1840	3053	3722	1.82	1.10	0.90
15	4176	43	72	87	2760	4580	5583	1.51	0.91	0.75
20	5316	58	95	116	3680	6106	7445	1.44	0.87	0.71
25	6123	72	119	145	4601	7633	9306	1.33	0.80	0.66
30	6853	86	143	174	5521	9159	11167	1.24	0.75	0.61
40	8732	115	191	233	7361	12213	14889	1.19	0.72	0.59
50	10516	144	239	291	9201	15266	18612	1.14	0.69	0.57
60	12300	173	286	349	11041	18319	22334	1.11	0.67	0.55
75	26616	216	358	436	13802	22898	27917	1.93	1.16	0.95
100	35523	288	477	582	18402	30531	37223	1.93	1.16	0.95
125	44431	359	596	727	23003	38164	46529	1.93	1.16	0.95
150	53338	431	716	872	27604	45797	55835	1.93	1.16	0.96
200	71153	575	954	1163	36805	61063	74446	1.93	1.17	0.96
250	88968	719	1193	1454	46006	76328	93058	1.93	1.17	0.96
300	106783	863	1431	1745	55207	91594	111669	1.93	1.17	0.96
400	142413	1150	1908	2326	73609	122125	148892	1.93	1.17	0.96

4.6.4 Energy and bill savings and emission reduction in Malaysian industrial sector

In this section, Energy and bill savings and emission reduction by using high efficiency motor (HEM) and VSD has been discussed in the audited Malaysian industrial sector.

4.6.4(a) Energy and bill savings and emission reduction by using HEM

The amount of energy savings, bill savings and emissions reduction has been calculated that is shown in Table 4.7. A survey result of 59 industries in Malaysia shown that the total amount of energy can be saved 67,868 MWh/year and the corresponding bill savings US$ 4,343,531 per year. In Malaysia, there are about 3,000 industries in different sectors. If HEMs could be used in all these industries, about 345,084 MWh/year of energy could be saved. GHG emission reduction is one of the most important challenges. By applying high energy efficiency motors, GHG emissions could be reduced by 51,510 tons of CO_2 385 tons of SO_2 and 141 tons of NO_x in the 59 industries surveyed in Malaysia.

Table 4.7 Energy and bill savings and corresponding emissions reduction in the surveyed industries in Malaysia

Industry	Energy Savings (MWh/year)	Bill Savings (US$/year)	Emission reduction (ton)		
			CO_2	SO_2	NO_x
Food and Beverages	1226	78,471	930	7	2
Textile	321	20,540	244	2	1
Fabricated Metal	2	113	1	--	--
Paper Industry	5316	340,200	4035	31	12
Glass	5505	352,341	4178	32	12
Wood	2624	167,939	1991	15	5
Basic Iron Steel	34,845	2,230,064	26,447	197	73
Automobile	1514	96,909	1150	8	3
Chemical	3115	199,373	2364	17	7
Rubber	1639	104,866	1245	9	3
Plastic	1562	99,986	1186	9	3
Cement	5452	348,943	4138	32	12
Petrochemical	3066	196,199	2327	17	7
Consumer Appliances	200	12,795	152	1	0
Electronics	1481	94,790	1124	8	3
Total	67,868	4,343,531	51,510	385	141

4.6.4(b) Energy and bill savings and emission reduction by using VSD

The amounts of energy savings, bill savings and emissions reductions are shown in Tables 4.8 and 4.9. A result of the survey industries in Malaysia showed that the annual energy savings would be 542,941 MWh, 900,789 MWh and 1,098,222 MWh by motor speed reduction of 20 %, 40 % and 60 % and the corresponding bill savings of 34,748,244; 57,650,496 and 70,286,221 respectively. By introducing VSD, GHG emissions could be reduced by 836,831 tons of CO_2, 6217 tons of SO_2 and 2285 tons of NO_x by motor speed reduction of 60 % in the 59 industries surveyed in Malaysia.

Table 4.8 Energy savings and bill savings by applying VSD at a certain percentage of speed reduction

Industry	Energy Savings (MWh/year)			Bill Savings (USD/year)		
	20%	40%	60%	20%	40%	60%
Food and Beverages	9,809	16,274	19,841	627,771	1,041,529	1,269,809
Textile	2,567	4,260	5,193	164,316	272,614	332,366
Fabricated Metal	14	23	28	901	1,495	1,823
Paper Industry	42,525	70,553	86,017	2,721,608	4,515,395	5,505,070
Glass	44,043	73,071	89,086	2,818,732	4,676,532	5,701,525
Wood	20,992	34,828	42,462	1,343,514	2,229,011	2,717,562
Basic Iron Steel	278,758	462,485	563,851	17,840,515	29,599,036	36,086,495
Automobile	12,114	20,098	24,503	775,273	1,286,248	1,568,166
Chemical	24,922	41,347	50,410	1,594,982	2,646,221	3,226,214
Rubber	13,108	21,748	26,514	838,929	1,391,860	1,696,926
Plastic	12,498	20,736	25,280	799,885	1,327,082	1,617,949
Cement	43,618	72,366	88,227	2,791,541	4,631,419	5,646,525
Petrochemical	24,525	40,689	49,607	1,569,597	2,604,104	3,174,866
Consumer Appliances	1,599	2,654	3,235	102,362	169,827	207,050
Electronics	11,849	19,658	23,967	758,321	1,258,123	1,533,876
Total	542,941	900,789	1,098,222	34,748,244	57,650,496	70,286,221

Table 4.9 Reduction of emissions due to energy in surveyed industries

Industry	Emission (ton)								
	20%			40%			60%		
	CO_2	SO_2	NO_x	CO_2	SO_2	NO_x	CO_2	SO_2	NO_x
Food and Beverages	7474	56	21	12,401	93	34	15,118	112	41
Textile	1957	15	5	3246	24	9	3958	29	11
Fabricated Metal	11	--	--	17	--	--	22	--	--
Paper Industry	32,404	240	89	53,761	400	147	65,544	486	179
Glass	33,560	250	92	55,678	413	153	67,882	505	185
Wood	15,996	119	44	26,538	197	73	32,356	240	88
Basic Iron Steel	212,409	1578	580	352,408	2618	961	429,647	3193	1173
Automobile	9230	69	25	15313	113	41	18671	138	51
Chemical	18,990	141	52	31,505	234	85	38,412	286	105
Rubber	9989	74	27	16,572	123	45	20,203	150	56
Plastic	9524	71	25	15801	118	43	19262	143	53
Cement	33,236	247	92	55,142	410	150	67,228	499	184
Petrochemical	18,687	138	51	31,004	230	84	37,800	281	102
Consumer Appliances	1219	9	3	2022	15	5	2466	19	7
Electronics	9028	66	24	14,980	111	40	18,262	135	50
Total	413,714	3074	1129	686,388	5100	1873	836,831	6217	2285

4.7 Power factor improvement and energy savings by using capacitor bank

In this section, power factor correction, reduction of distribution losses, energy savings and lagging power factor penalty has been discussed.

4.7.1 Power factor correction

To operate the induction motor requires reactive power with the active power. The active power is used to produce work. Power factor depends on both active and reactive power. By applying a suitable capacitors bank, the power factor can be improved. However, in practice, the power factor improvements fall between 0.90 to 0.95 (Sagiroglu et al., 2006). Han (2008) designed the passive filer to reduce the main harmonics by using the low impedance route and compensate the essential reactive power necessary by the non-linear load; the compensating current of the voltage source inverter can be optimized. The control of harmonic-free power factor corrector can be achieved a near the unity power factor that is shown in Table 4.10.

Table 4.10 Power factor by implementing near the unity power factor control scheme (Han et al., 2008)

Power factor	Before correction	After correction
Ideal grid voltage	0.893	0.994
Non-ideal grid voltage	0.901	0.992

Harmonic current and low power factor is created by non-linear load which is the responsible for the power losses. If the power factor is low, need to supply more current to the equipment for a specified amount of power used. Industrial facilities have lot of power electronics equipment with a lagging power factor where current lags in the voltage (i.e. induction motor). The windings of the motor act as inductors. Capacitors have opposite effect of the inductor and can reimburse for the inductive motor winding. Capacitor banks are used for the resolution of increasing power factor near the unity power factor to save on energy charge. Whenever electromagnetic equipment's (i.e. electric motor) are operated, the current lags the voltage with a phase angle. This reactive current is created magnetic field but cannot do any useful output. Large phase angle (low PF) is undesirable for the utility. Figure 4.16 shows how the active device is generated the leading VARs by reducing phase angle and increased power factor.

If there are many small motors (i.e. motor capacity 1/2 to 10 hp) in the plant, it is better to make group the motors to use capacitor bank at the motor control center. The capacitor bank at a central location (i.e. at the substation) and automatic switching system when the motors are started that is more economical as all motors not use continuously or simultaneously. By improvement PF can maximize power system capacity and voltage quality and decrease power losses (Bayindir et al., 2009). PF coreection not to be overcorrect, because the overcorrection also greater problems (i.e. over voltage, insulation breakdown). The recommended power factor should be above 90 % and below unity (100%) for the better system performance.

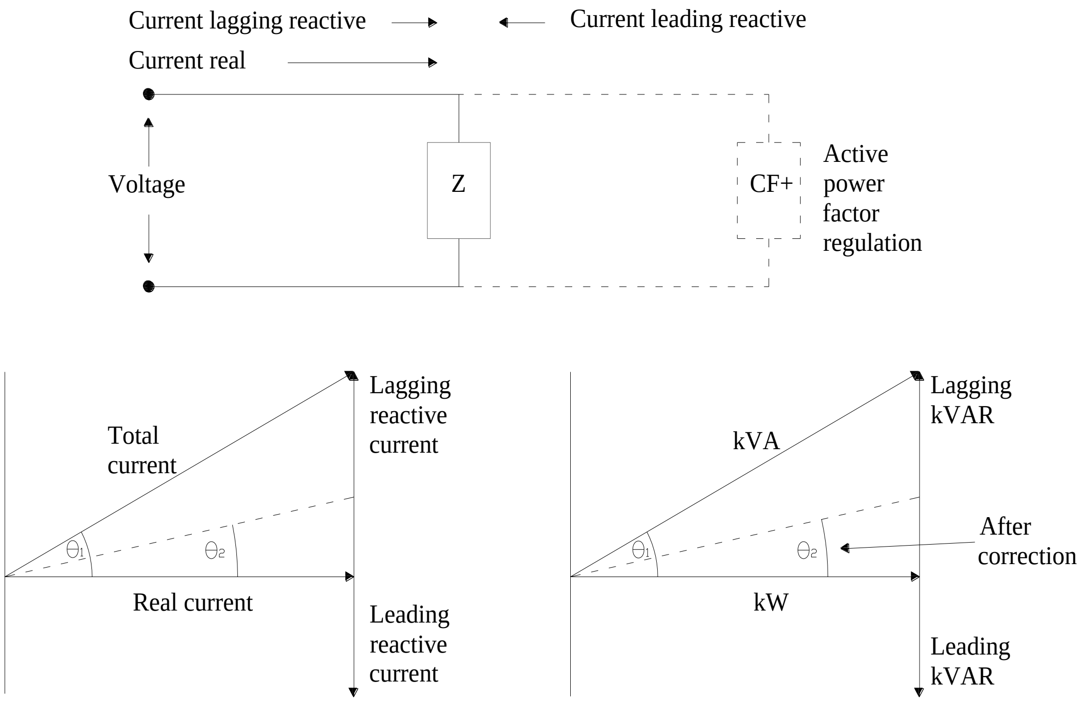

Figure 4.16 Power factor diagram before and after correction.
(PFC, 2010)

4.7.2 Reduction of distribution losses

The loads of low power factor use more current than the loads of high power factor for a specific amount of output power that causes the more line losses. Low power factor is created by non-linear load that is increased power loss in the distribution line (PFC, 2011). A low PF utility plant needs higher current to provide a particular load. Figure 4.17 shows that power factor and current relation a system. It is found that if the power factor decreases 0.5, current will be increased about 100%. Figure 4.18 shows the reduction of distribution losses with the targeted power factor. It is found that the distribution losses are linearly proportional to the current. Distribution analysis also found that for each 0.01 increased the power factor, the distribution losses decrease about 2%. The average power factor of the Malaysian industrial sector is 0.90 (Saidur et al., 2009a). Han et al. (2008) fund that power factor can be achieved a near the unity. If the Malaysian industrial sector improves the power factor near unity, about 20% of distribution losses can be decreased. Kwiatkowski (2009) measured typical industrial facilities of cable losses and found about 1%. According to the 59 audited industry electricity consumption (i.e. 1,233,957 MWh/year), about 2468 MWh/year can be saved due to distribution losses by increasing power factor from 0.90 to 0.99. Kwiatkowski (2009) investigated that distribution losses reduced about 29 % improving the power factor from 0.8 to 0.95. Gilbert and John (2000) investigated two plants of real power demand (kW) same, but one plant has a PF of 0.85 while the other 0.70, the second plant needs to supply 21 % more current level to fulfill the same demand to the first one. Equipment (i.e. conductor, transformer) in the second plant need 21% more capacity (i.e. wire, switch, circuit breaker etc.) than first plant. Moreover, distribution loss also 46% greater than the second plant in the same configuration. It is also found that about 18% distribution loss can be decreased by improving power factor from 0.91 to near unity.

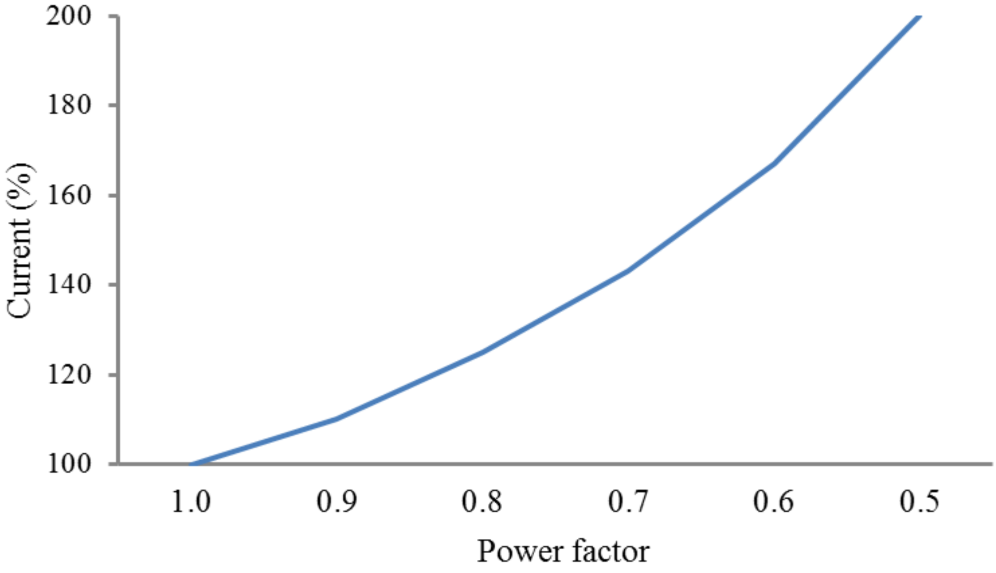

Figure 4.17 Percentage of current at different power factor.
(Kwiatkowski, 2009)

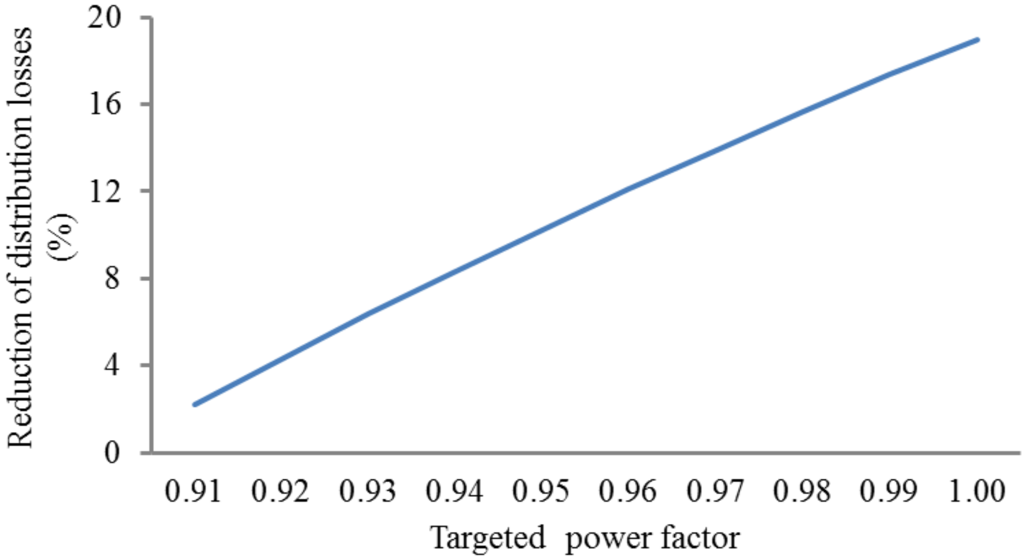

Figure 4.18 Reduction of distribution losses by using capacitor bank.

4.7.3 Energy saving by improving power factor

High power factor can be used the maximum electric power where the low power factor shows poor use of electric power. Having a low power factor leads to purchase more power equipment to obtain the same load (kW) that consumed more energy. For a machine (i.e. electric motor) output power increase with increasing the power factor. Figure 4.19 shows the percentage of output power increased with increasing the power factor. The output power increases about 10% by increasing the power factor of 0.1. If the Malaysian industrial sector improves the power factor near unity, about 10% of energy can be saved. According to the 59 audited industry electricity consumption (i.e. 1,233,957 MWh/year), about 123,396 MWh/year can be saved due to by increasing power factor from 0.90 to 0.99. It is investigated that there are two 4,000 hp motor driven, one of them has power factor of 0.95 and another with a power factor of 0.98 as well as operating 8760 hr/year. The result in energy savings of 902.5 MW/year by using the 0.98 power factor driven motor compared to the 0.95 power factor motor (ES, 2011). By correcting the power factor of a container cranes, about 6 to 10% energy can be saved (PFC, 2011).

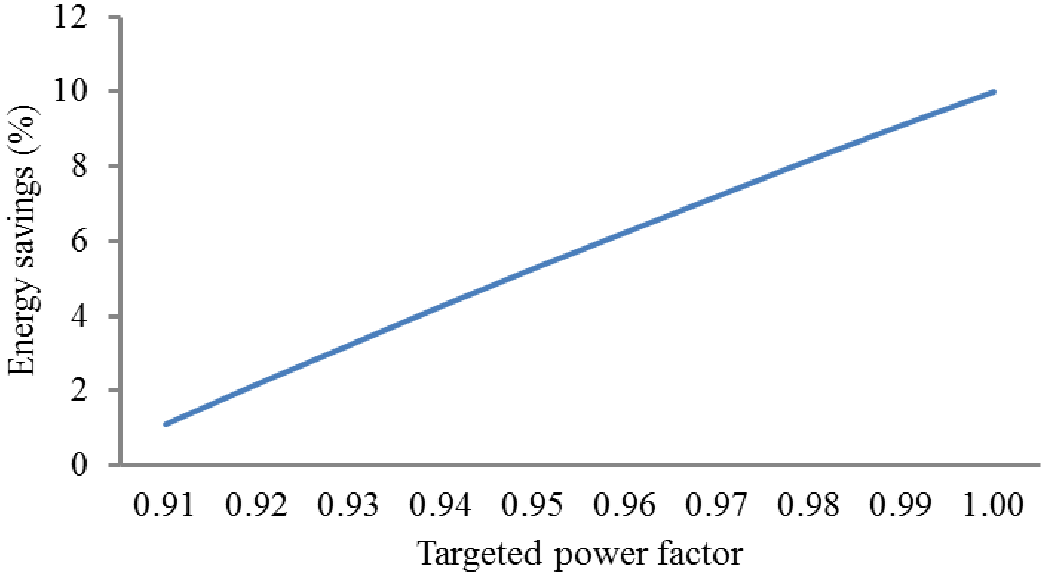

Figure 4.19 Percentage of output power increased with increasing the power factor.

4.7.4 Lagging power factor penalty

Power factor is one of the most important factors for the equipment (i.e. motor) output power. Output power increased means losses of energy decreases. That is why, some of the company put lagging power factor penalty to maintain the sustain level of the power factors to reduce losses. Even though in Malaysia, Sarawak electricity supply corporation has a tariff rate of electric energy including the strictly considering the lagging power factor at the demand side (i.e. commercial, residential, industrial etc.) in the electric bill (MLPFP, 2006). If the power factor is less than 0.85, lagging power factor penalty is imposed with the electric bill. There are two categories of penalty (i) penalty for power factor in between 0.85 to 0.75 and (ii) lower than power factor 0.75. A percentage of penalties due to lagging power factor have been calculated that is shown in the Figure 4.20. The figure shows that the increasing rate of penalty is more below power factor 0.75. It is also found that the penalty up to 60% of the electric bill. This is the only way to avoid lagging power factor penalty to improve the power factor and save electric bill.

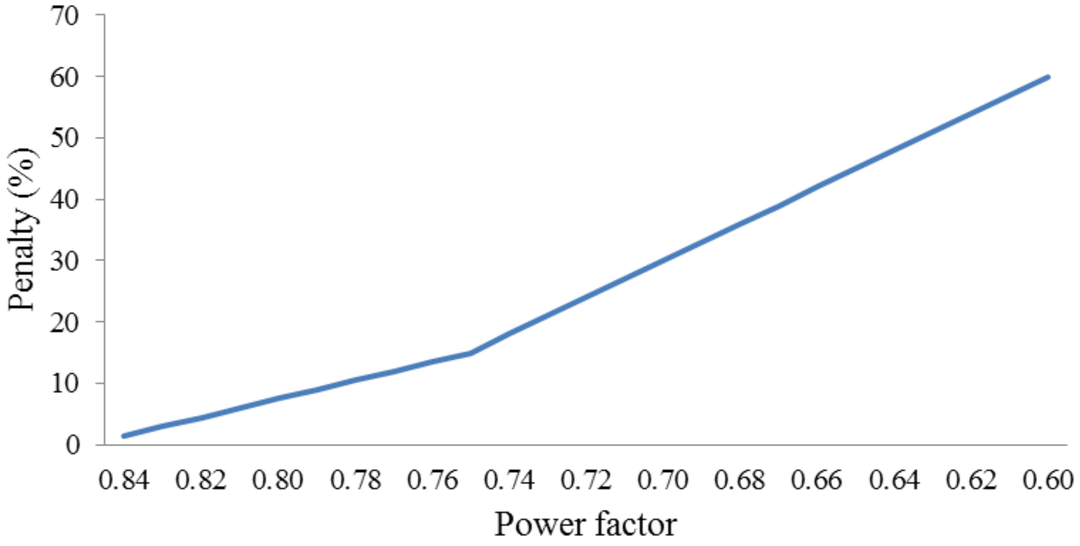

Figure 4.20 Percentage of lagging power factor penalties.

Table 4.11 and 4.12 show the summaries energy and bill savings, pay back periods and emission reduction of different energy saving options for boiler, furnace and electric motor.

Table 4.11 Summaries of average fuel and bill savings, pay back periods and emission reduction of different energy saving options for boiler and furnace.

Equipment	Energy saving options	Fuel savings (L/year)	Utility bill savings (USD/year)	Payback period (year)	CO2 Emission reduction (tons/year)
Boiler	Economizer	65,747	44,050	Most of the cases less than one year	166
Furnace	Recuperator	1,025,190	686,877		259

Table 4.12 Summaries of average energy and bill savings, pay back periods and emission reduction of different energy saving options for electric motor.

Energy savings option	Operating load/speed reduction (%)	Annual energy savings (kWh/hp)	Annual utility bill savings (USD/hp)	Payback period (year)	Annual emission reduction (kg/hp)		
					CO_2	SO_2	NO_x
High efficient motor over failed rewound standard motor	50	126	6	Most of the cases less than 2 years	96	1	--
	75	180	8		137	1	--
	100	215	10		163	1	--
High efficient motor over standard motor	50	110	5		83	1	--
	75	156	7		118	1	--
	100	186	9		141	1	--
Variable speed drive	20	2875	184		2180	16	--
	40	4771	305		3618	27	--
	60	5816	372		4411	33	--

Note:

- Percentage of operating load in the case of high efficient motor
- Percentage of speed reduction in the case of variable speed drive

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

It is found that energy and exergy efficiencies, exergy destruction, amount of energy savings and payback periods of the heat exchanging equipment and electric motor are varied. From the comparative analysis and evaluati1on, the conclusions can be drawn as follows:

- It is found that the boilers energy efficiency varied from 56% to 76% with an average of 69%. It is also found that boilers exergy efficiency varied from 18% to 25% with an average of 22%.
- The rate of exergy destruction in the combustion chamber is higher (i.e. about 55 %) compared to the stream production chamber of the boilers.
- It is found that the furnaces energy efficiency varied from 16% to 55% with an average of 30%. The comparative analysis also shows that the furnaces exergy efficiencies varied from 10% to 35% with an average of 19.3%.
- The rate of exergy destruction in the annealing chamber is higher (i.e. about 62%) compared to the combustion chamber of the furnaces.
- It is found that the energy effectiveness of heat exchanger varied from 61% to 71% where the exergy effectiveness of heat exchanger varied from 56% to 63%.
- The energy effectiveness of the economizers varied from 66% to 73%. Exergy effectiveness also calculated and found to be varied from 47% to 65%.
- By applying the heat recovery system, about 10% of the boilers and 30% of the furnaces energy can be saved with payback periods less than 1 year in the most cases.

- By applying high efficiency motor in the industrial sector, about 5.5% of the end used energy can be saved. Payback period of applying high efficiency motor is 0.5 to 2 years, even though the motor operating at 50% load.
- By applying high efficiency motor in the industrial sector in Malaysia huge amount of energy can be saved as well as emissions can be reduced. The proper planning of rewinding and replacing motors (with HEMs) can be saved about 6% of the total annual energy consumption. Energy savings and emissions reduction are higher at higher motor operation load.
- By introducing variable speed drive in motor drive systems to match load requirements, energy savings estimated to be annually 542,941 MWh, 900,789 MWh and 1,098,222 MWh for 20%, 40% and 60% motor speed reduction, respectively and corresponding annual bill savings found to 34,748,244 US$, 57,650,496 US$ and 70,286,221 US$, respectively. Emissions could be reduced by 836,831 tons of CO_2, 6217 tons of SO_2 and 2285 tons of NO_x by motor speed reduction of 60%.

5.2 Recommendations

- End-use energy demand in the industrial sector is increasing rapidly the as a result global temperature is rising significantly. In near future, this will seriously affect industrial energy consumption as well as economic growth. Moreover, usage pattern, behavior, ownership increasing rapidly. So a systematic long term data collection by concerned government authorities like Statistical department of Malaya may conduct the data collection survey built comprehensive database in the industrial sector to take the necessary steps for overcoming the challenge.

- As boiler, furnace and electric motor are major energy consumer in the industrial sector, there should be more emphasize the research of more energy efficient design. It may be recommended that computer tool can be developed for modeling of industrial energy consumption with respect to Malaysian usage pattern/behaviors, climate conditions, culture, and market trends.

APPENDIX A: RELATED PUBLICATIONS

Journal:

1. **M. Hasanuzzaman,** N. A. Rahim, R. Saidur and S. N. Kazi, Energy savings and emission reduction for rewinding and replacement of industrial motor, Energy, 36 (1), 2011, 233-240 (ISI/Scopus Cited Publication) **(Q-1, IF:2.952)**

2. R. Saidur, N. A. Rahim and **M. Hasanuzzaman**, A review on compressed air energy use and energy savings, Renewable and Sustainable Energy Reviews, 14(4), 2010, 1135-1153 (ISI/Scopus Cited Publication) **(Q-1, IF:4.842)**

3. M. Thirugnanasambandam, **M. Hasanuzzaman,** R. Saidur, M.B. Ali, S. Rajakarunakaran, D. Devaraj and N.A. Rahim, An Analysis of Electrical Motors Load Factors and Energy Savings in an Indian Cement Industry, Energy 36(7), 2011, 4307-4314 (ISI/Scopus Cited Publication) **(Q-1, IF:2.952)**

4. **M. Hasanuzzaman**, R. Saidur and N.A. Rahim, Energy, exergy and economic analysis of an annealing furnace, International Journal of Physical Sciences, 6(6), 2011, 1257-1266 (ISI/Scopus Cited Publication) **(Q-2, IF:0.554)**

5. R. Saidur, **M. Hasanuzzaman** and N.A. Rahim, Energy, economic and environmental analysis of the Malaysian industrial compressed-air systems, Clean Technologies and Environmental Policy, (In press, Corrected Proof, Available online 18 May 2011) (doi:10.1007/s10098-011-0386-9) (ISI/Scopus Cited Publication) **(Q-3, IF:1.016)**

6. **M. Hasanuzzaman**, R. Saidur, N.A. Rahim and I.M. Mahbubul, Energy savings in the combustion based process heating in industrial sector: a review, Renewable and Sustainable Energy Reviews (Under Review) (ISI/Scopus Cited Publication) **(Q1, IF: 4.567)**

7. R. Saidur, **M. Hasanuzzaman** and N.A. Rahim, Energy Use, Energy Savings and Environmental Analysis of Industrial Boilers and Compressors, International Journal of Thermal and Environmental Engineering, 1(1), 2010, 29-36 (None ISI/None Scopus Cited Publication)

Conference:

8. **M. Hasanuzzaman,** N.A. Rahim and R. Saidur, Analysis of energy, exergy and energy savings of a fire tube boiler, The proceeding of the 2011 IEEE first Conference on Clean Energy and Technology (CET 2011), Legend Hotel, Kuala Lumpur, Malaysia, 27-29 June, 2011 [ISBN:978-1-4577-1352-1]: 291-296
9. **M. Hasanuzzaman,** R. Saidur and N.A. Rahim, Effectiveness enhancement of heat exchanger by using nanofluids, The proceeding of the 2011 IEEE first Conference on Clean Energy and Technology (CET 2011), Legend Hotel, Kuala Lumpur, Malaysia, 27-29 June 29, 2011 [ISBN:978-1-4577-1352-1]: 98-103
10. **M. Hasanuzzaman,** N. A. Rahim and R. Saidur, Analysis of Energy Savings for Rewinding and Replacement of Industrial Motor, the Proceeding of 2010 IEEE International Conference on Power and Energy (PECon 2010), Sunway Resort Hotel and Spa, Kuala Lumpur, Malaysia, 29 November-1 December 2010: 212-217
11. **M. Hasanuzzaman,** N.A. Rahim and R. Saidur, Analysis of Energy Savings for Rewinding and Replacement of Industrial Motor, the Proceeding of 2010 IEEE International Conference on Power and Energy (PECon 2010), Sunway Resort Hotel and Spa, Kuala Lumpur, Malaysia, 29 November-1 December 2010: 212-217
12. **M. Hasanuzzaman,** R. Saidur and N.A. Rahim, Analysis of Energy and Exergy of an Annealing Furnace, Proceeding of the 2010 International Conference on Mechanical and Aerospace Engineering (ICMAE 2010) , 26-28 November 2010, Mines Wellness Hotel, Kuala Lumpur, Malaysia: 60-64
13. R. Saidur, N.A. Rahim and **M. Hasanuzzaman,** Energy and environmental analysis in industrial boilers and compressors, Proceedings of the International Engineering Conference on Hot Arid Regions (IECHAR 2010), Al-Ahsa, Kingdom of Saudi Arabia, 1-2 March, 2010 (ISBN:978-603-08-0083-4): 161-166.
14. R. Saidur, **M. Hasanuzzaman** and N.A. Rahim, Energy Consumption, Energy Savings and Emission Analysis for Industrial Motors, Proceedings of the International Conference on Industrial Engineering and Operations Management (IEOM2010), Paper ID: 224, Dhaka Bangladesh, 9-10 January, 2010, ISBN No**.** 978-984-33-0988-4.
15. R. Saidur and **M. Hasanuzzaman**, Energy and Environmental Analysis of Electrical Motor in Industrial Boilers, Proceedings of the International Conference on Energy and Environment 2009 (lCEE2009), Hotel Equatorial Malacca, Malaysia, 7-8 December 2009: 492-500.

APPENDIX B: CV

Md. Hasanuzzaman holds a M. Eng. Sc. (Mech) from, University of Malaya (UM), Malaysia and a B. Sc. Eng. (Mech) from Bangladesh University of Engineering and Technology (BUET), Bangladesh. He has published 28 papers in international, regional and local journal and presented / published 22 papers in international, regional and local conferences. He works in the field of Heat Transfer, Energy, Energy Efficiency, Exergy, Exergy Analysis, Emissions and Environment Analysis, Renewable Energy, Industrial Energy Use and Energy Savings. He is also reviewer of several international, regional and local journal and conferences. He received Technical Scholarship from BUET, Bangladesh Scholarship Council and the Nippon Foundation, Japan, 2003-2004, Scholarship of Graduate Research Assistantship Scheme, UM. He is currently a member of The Institution of Engineers Bangladesh (IEB), ASHRAE and BSME.

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