Energy Economical and Environmental Analysis of Industrial Boilers using Economizers

A.E. Atabani[*1], R. Saidur[1], S. Mekhilef [2], A.S. Silitonga [1]

[1]Department of Mechanical Engineering, University Malaya, 50603, Kuala Lumpur, Malaysia
[2]Department of Electrical Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia
a_atabani2@msn.com

Abstract- **It is believed that energy issue is one of the most sensitive and complicated issues in the globe. Industrial energy consumption varies from 30% to 70% of total energy used in some selected countries and the global average stands at 37%. As a result of the successful implementation of the industrialization plan in 1985; Malaysia has changed from an agricultural economy into industrial based economy. The industrial sector represents the highest consuming sector and accounts for about 48% of all total energy demand. The improvement of energy efficiency is a very important factor in industry to improve the environmental performance, emissions reduction and increase its profitability. This study is concerned with an energy saving, economic and environmental analysis of industrial boilers in Malaysia. The principle of installation of heat recovery systems in these boilers has been investigated. The implementation of economizer has proven its viability and shows that 2,529,779 kWh of energy, RM 238,573, 2,150 ton of CO_2, 6,324 kg of SO_2, 41,488 kg of NO_x and 506 kg of CO could be saved per annum.**

Keywords- Industrial Boilers; Economizers; Techno-Economic Analysis; Emissions Reduction

I. INTRODUCTION

A. Overview

It is believed that energy issue is one of the most sensitive and complicated issues in the globe. In some countries, industrial energy consumption varies from 30% to 70% of total energy and the global average stands at 37% as shown in **Figure 1** [1-2].
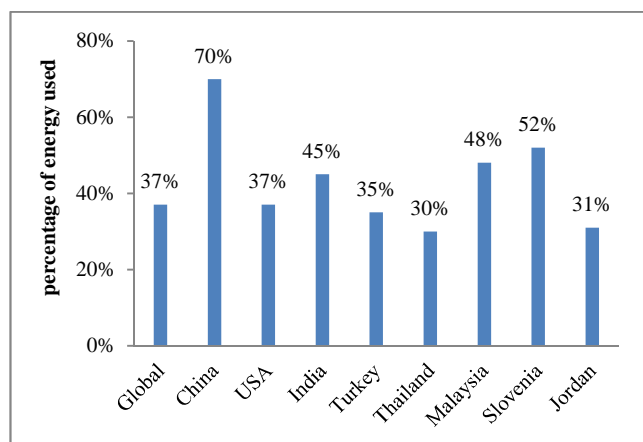

Figure 1 Industrial energy consumption of few selected countries [1, 11]

The industrial development across the world will result in more concentration of greenhouse gases such as carbon dioxide, sulphur dioxide, nitrogen oxide and carbon monoxide which all have disastrous consequences for the earth [3]. The Intergovernmental Panel on Climate Change (IPCC) reported that continued emissions will lead to a temperature increase of between 1.4 and 5.8°C over the period from 1990 to 2100. Furthermore, The Department of Energy (the United States of America) highlighted that, global carbon emissions are rising more than 2% per year and by 2015 may be more than 50% above the level of 1997 [4]. Prior studies have reported that implementing a few options with little cost in the industrial sector could reduce 10-30% of GHG emissions [1]. Using energy more efficiently is the key method to reduce energy's costs while retaining its benefits. Improving energy efficiency depends on many technical, economic, institutional, and political factors. Such factors have changed since the 1970s, when most federal energy policy was formulated in USA [5].

The improvement of energy efficiency is a very important factor in industry to reduce emissions and increase profitability. In UK, the estimated energy savings is 31.4% across all sectors. In industry, this translates to an estimate of 23.8% potential savings, which would drop its share of UK energy consumption to around 22%, with an annual saving of a staggering £1,380 million [6]. In the United States, improving thermal efficiency of boiler from 80% to 94% will result in carbon dioxide emission reduction from 66.3 to 56.4 kg/MMBtu when using natural gas a fuel [7]. In China an industrial boiler-efficiency improvement program (IBEI) has been carried out. The results show that, if the average efficiency of industrial boilers was improved from 60% to 70%, 3 million tons of coal and 5 million tons of CO_2 emissions could be saved annually at a cost of less than US$2 per ton of CO_2 [8].

Because of the economic expansion, Malaysia is one of the most developed countries among the Association of Southeast Asian Nations (ASEAN) members. The successful implementation of the Industrialization Plan in 1985 has brought forth rapid economic growth and structural transformation away from agricultural-based economy [9]. The progress in the industrial sector harshly affected the ability to preserve the fuel supply and the ecological balance [1, 10].

One of the recent studies has shown that Malaysian economy grew at a rate of 5% in 2005 and the overall energy demand is expected to increase at an average rate of 6% per annum [1]. Another study indicated that between

2000 and 2005 energy consumption grew at a fast rate of 5.6% to achieve 38.9 Mtoe in 2005. The final energy consumption is expected to reach 98.7 Mtoe in 2030, nearly three times the 2002 level as shown in Figure **2**. The industrial sector will have the highest growth rate of 4.3%, followed by transport at 3.9%, residential at 3.1% and commercial at 2.7% [10]. In 2007, the industrial sector represents the highest energy consuming sector and accounted for some 48% of total energy use as shown in Figure 3 [2].
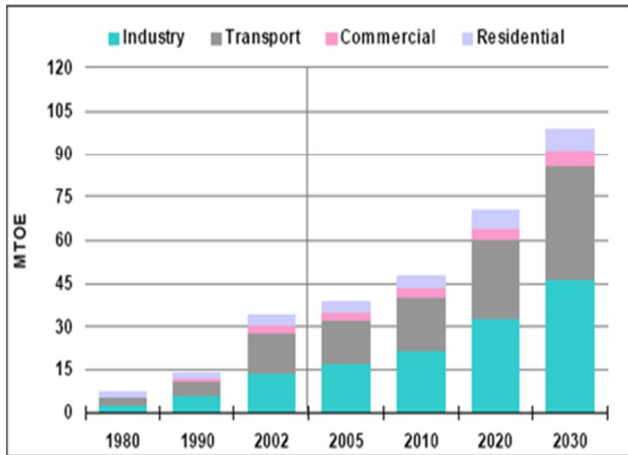
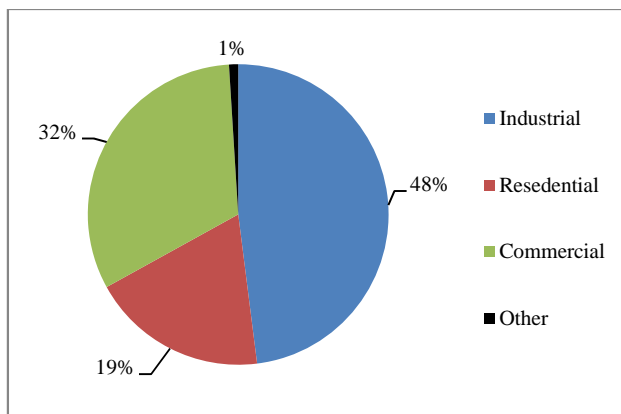Figure 2 Statistics of energy uses in Malaysia from 1980-2030 [10]

Figure 3 Statistics of energy uses in Malaysia in 2007 [2]

B. Objectives of the Paper

Having recognized the industrial sector as the biggest energy consumer in Malaysia, and proven the importance of improving the efficiency in the industrial sector, this paper shows a case study that has been undertaken in Malaysian pulp and papers industries to investigate energy saving, emissions reduction and cost benefits analysis when installing heat recovery systems.

II. THEORY OF ECONOMIZER

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose [11, 12]. Economizer is a device used to recover the waste heat from

the flue gas and consists of a series of horizontal tubular elements and can be characterized as bare tube and extended surface types. The bare tube usually includes varying sizes which can be arranged to form hairpin or multi-loop elements. Tubing forming the heating surface is generally made from low-carbon steel [13].

A. Benefits of Economizers

Benefits of waste heat recovery can be broadly classified in two categories [11]:

1) Direct Benefits:

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

2) Indirect Benefits:

a) Reduction in pollution: Economizers can reduce the environmental level of a number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals.

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

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

B. Criteria of Using Economizers

It is necessary to assess the benefits of using economizer on the basis of financial analysis such as investment, depreciation, payback period and rate of return. Moreover, the possible reduction in the stack temperature and the operating hours of boilers must be examined. Generally, the possible reduction in flue gas temperature should be at least 25°c to 30°c to make it economically viable to install a heat recovery system. Also the advice of experienced consultants and suppliers must be obtained for rational decision [11].

C. Potential of Heat Recovery in Boilers

The average boiler efficiency of industrial boilers in 75-77% and 23-25% of the energy input is lost in the form of blowdown, radiation, convection and hot flue gas as can be seen in Figure 4 [14]. Heat can be recovered from the flue gas by passing it through a heat exchanger (commonly called an economizer) as shown in Figures 5 and **6**. The recovered heat can be used to preheat boiler feedwater, combustion air, or for other applications. The amount of heat recovered depends on the flue gas temperature and the temperature of the fluid to be heated [15]. Economizers typically increase

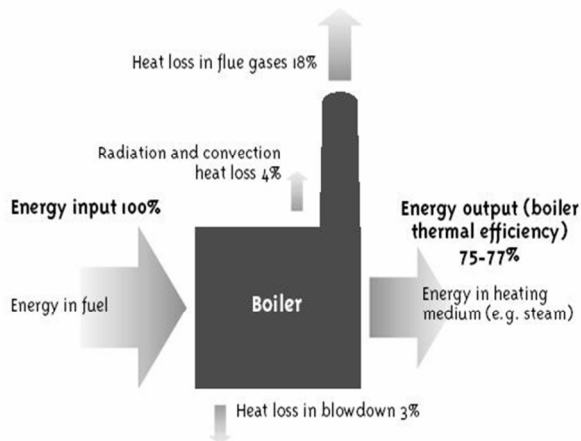boiler efficiency by 5% to 30%. Adding an economizer can result in saving of $13,000-$21,000 per year [16, 17].
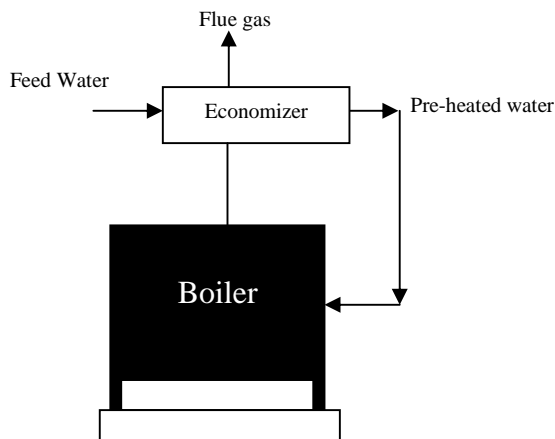

Figure 4 Typical heat losses [14]
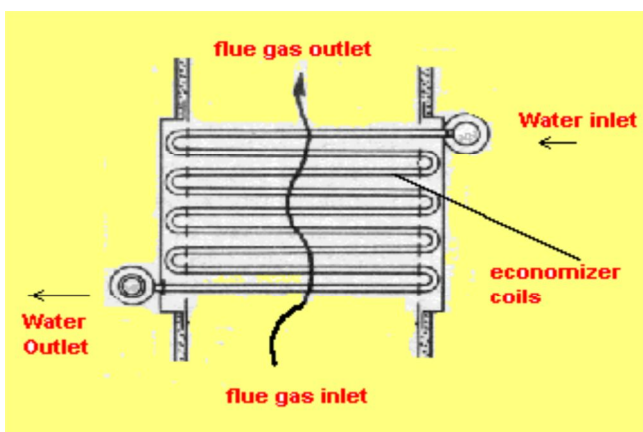

Figure 5 Arrangement of a typical economizer [15]

Figure 6 Economizer [11]

III. METHODOLOGY

A. *Targeted Manufacturing Factories and Audit Data Collection*

The targeted pulp and paper industries in this paper have

been taken from PTM (Pusat Tenaga Malaysia) throughout a personal communication and shown Table I.

TABLE I RESULTS OF THE INDUSTRIAL MALAYSIAN ENERGY AUDIT [19]

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

B. *Energy Saving When Using Heat Recovery Systems (Economizer)*

Total energy saving when installing heat recovery systems is equal to total annual diesel energy consumption multiply by the heat losses in the flue gas and the efficiency of the heat recovery system (economizer). Table II shows fuel price, density and energy content of diesel. Table III shows average percentage of heat losses in flue gas and the efficiency of economizer.

TABLE II PRICES, DENSITY AND ENERGY CONTENT OF DIESEL [20]

Fuel type	Unit fuel price	Density (kg/m³)	Energy content (kJ/kg)
Diesel	1.002 RM/Litre	0.85	45,000

TABLE III AVERAGE PERCENTAGE OF HEAT LOSSES IN FLUE GAS AND EFFICIENCY OF HEAT RECOVERY SYSTEM [14, 17]

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

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

$$ADC_{kg} = ADC \qquad \ldots \qquad (1)$$

$$ADC_k = ADC_{kg} \qquad DEC \qquad (2)$$

$$ADC_k = \frac{C}{3600} \qquad (3)$$

$$AE_R = ADC_k \qquad \%_g \quad \%_R \qquad (4)$$

Percentage of increasing in thermal efficiency of boiler can be calculated as follow:

$$\%B = \frac{T \quad S}{C} \qquad (5)$$

C. *Emission Reduction When Using Heat Recovery Systems (Economizer)*

The environmental impact of the heat recovery systems is a potential reduction of greenhouse gasses or other element that give negative impact to the environment. The common potential reductions in this study include CO_2, SO_2, NO_x and CO. The emission factors of all these gases are shown in the Table IV. The annual emissions reduction is a function of total annual energy saving and the emission factor of the particular fuel. Emissions reduction when using

heat recovery systems can be calculated as follow:

$$AER_{CO} = AE_R \quad EF_{CO} \tag{6}$$

$$AER_O = AE_R \quad EF_O \tag{7}$$

$$AER_{CO} = AE_R \quad EF_{CO} \tag{8}$$

$$AER_{SO} = AE_R \quad EF_{SO} \tag{9}$$

TABLE IV EMISSION FACTORS OF FOSSIL FUELS FOR ELECTRICITY GENERATION [3]

Fuels	CO$_2$	SO$_2$	NO$_x$	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Gas	0.53	0.0005	0.0009	0.0005
Hydro	0.00	0.0000	0.0000	0.0000
Others	0.00	0.0000	0.0000	0.0000

D. Cost Benefit Analysis When Using Heat Recovery Systems (Economizer)

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

$$TABS_R = \frac{3600 \quad DP}{D} \tag{10}$$

Knowing that installation cost of economizer is RM 30,000 [18], payback period equals to the installation cost of heat recovery divided by total annual bill saving when using heat recovery systems. This can be represented mathematically from the following equation:

$$PBP_R = \frac{C}{T \quad S} \tag{11}$$

IV. RESULTS AND DISCUSSION

A. Energy Saving When Using Economizer

Based on the input data in Tables (I-III), and Equations (1-4) respectively, the results of total annual energy saving in Malaysia factories when using economizer are illustrated in Figure 7.
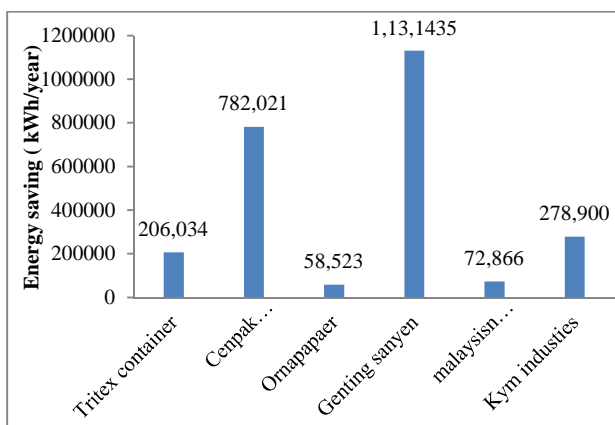

Figure 7 Total energy saving (kWh/year) at different factories when installing economizer

The results in **Figure 7** show that the total annual energy savings is 2,529,779 kWh. These results represent a huge

amount energy saving that can be achieved by economizers. Based on Equation (5) the percentage of increasing in thermal efficiency of boiler due to installation of economizer has been found to be 5.4%. This result is similar to what have already been found in the Literature as the economizer can increase thermal efficiency of boiler by 5% [11].

B. Emissions Reduction When Using Economizer

Based on the input data in Table 1V, results obtained in Figure **7** and Equations (6-9) respectively, the results of emissions reduction at different factories are tabulated in Table V. These results show that the total emissions reduction are about 2,150 ton of CO$_2$, 6,324 kg of SO$_2$, 41,488 kg of NO$_x$ and 506 kg of CO when using economizer. These results show similar result to what have been found in the Literature and represent a huge amount of emissions reduction achievement.

TABLE V EMISSIONS REDUCTION (KG) AT DIFFERENT FACTORIES WHEN INSTALLING ECONOMIZER

Factory name	CO$_2$ reduction	SO$_2$ Reduction	CO Reduction	NO$_x$ Reduction
Tritex container	175,129	3,379	41	515
Cenpak holdings	664,718	12,825	156	1,955
Orna paper	49,744	960	12	146
Gentingsanyen	961,720	18,556	226	2829
Malaysian newsprint	61,639	1,195	15	182
Kym Industries	237.065	4,574	56	697
Total	**2,150,000**	**6,324**	**506**	**41,888**

C. Cost Benefit Analysis When Using Economizer

Based on the installation cost of economizer of RM 30,000 [18], Figure 7, Table II, and Equations (10 and 11) respectively, the results of total annual bill saving (RM/year) and payback periods (years) are illustrated in Figures 8 and **9** respectively. The results from Figure 8 show that the total annual bill savings is about RM 238,573. These results show similar result to what have been found in the Literature and represent a huge amount of bill saving that can be achieved when installing economizers.
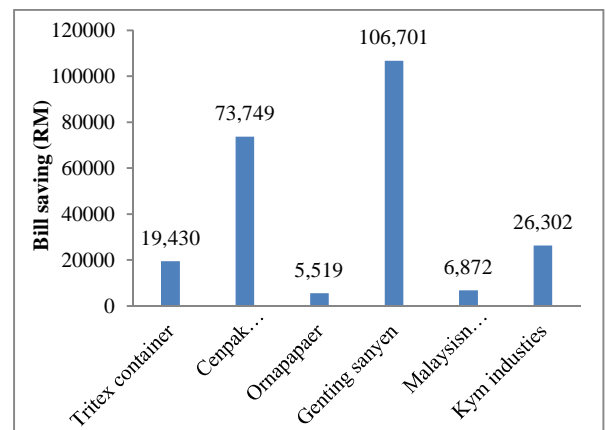

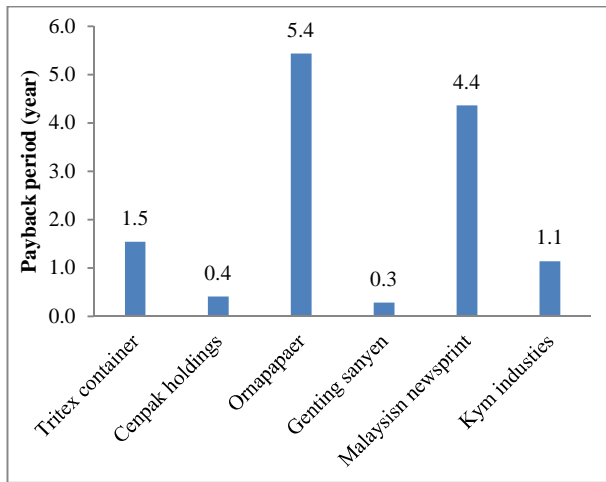Figure 8 Bill saving (RM) at different factories when using economizer

Figure 9 Payback period (years) at different factories when using economizer

The results from Figure 9 show that payback periods range from 0.3 year in Gentingsanyen to 5.4 years in Orna paper factories. It can be observed that payback period is quite high in Orna paper and Malaysian news print factories. This is because annual energy consumption of these factories is low. However in other factories like Tritex, Cenpak, Genting and Kym industries payback period is very acceptable and boost installing this application. These results indicate that economizer can be a useful device for short term purposes in Malaysia when the annual energy consumption of boilers is very high and the payback period is 3 years.

V. CONCLUSION AND RECOMMENDATIONS

This study is concerned with an energy saving, economic and environmental analysis of industrial boilers in paper and pulp industries Malaysia. Installing heat recovery systems (economizers) has been investigated in this study. Installation of economizers has been proved to be an effective method. It has been found that a total amount of 2,529,779 kWh, 2,150 ton of CO_2, 6,324 kg of SO_2, 41,488 kg of NO_x, 506 kg of CO and RM 238,573 could be saved annually. These results indicate that economizer is an energy saving, economically viable and emissions reduction application and can be used in a small developing country like Malaysia.

As a recommendation for future work, there are many energy saving measures that can be employed. Some of these measures include: improving combustion efficiency, minimizing radiation and conduction losses and Automatic blowdown control.

NOMENCLATURE

ADC_k	Annual diesel energy consumption (kJ/year)
ADC_k	Annual diesel energy consumption (kWh/year)
ADC_{kg}	Annual diesel consumption (kg/year)
$AER_{CO_2}, AER_{CO}, AER_{c}, AER_{SO}$	Annual emissions reduction of CO_2, CO, SO_2 and NO_x (kg/year)
DEC	Diesel fuel energy content (kJ/kg)
$EF_{CO_2}, EF_{CO}, EF_{SO}, EF_{c}$	Emission factor of CO_2, CO, SO_2 and NO_x (kg/kWh)

I_k	Incremental cost of heat recovery system (Economizer) (RM)
PBP_k	Payback period of heat recovery (Years)
$\%_k$	Percentage of heat losses in flue gas
$\%B$	Percentage of increasing in thermal efficiency of boiler due to economizer
$\%_k$	Efficiency of heat recovery system
AB_k	Total annual bill saving of heat recovery (RM/year)
AE_k	Total annual energy saving of Heat recovery (kWh/year)
UDP	Unit diesel price (RM/Litre)
	Density of a diesel fuel (kg/m³)
3600	Conversion factor from kWh to kJ

REFERENCES

[1] Saidur, R., Rahim, N.A., Masjuki, H.H., Mekhilef, S., Ping, H.W., Jamaluddin M.F., 2009. End-use energy analysis in the Malaysian industrial sector.*Energy* 34, 153-158.

[2] Saidur, R., Rahim, N.A., Ping, H.W., Jahirul, M.I., Mekhilef, S., Masjuki H.H., 2009. Energy and emission analysis for industrial motors in Malaysia.*Energy Policy* 37, 3650-3658.

[3] Mahlia, T.M.I., 2002. Emissions from electricity generation in Malaysia.*Renewable Energy* 27, 293-300.

[4] Mahmoud, A., Shuhaimi, M., Abdel Samed, M., 2009. A combined process integration and fuel switching strategy for emissions reduction in chemical process plants. *Energy* 34,190-195.

[5] U.S. Congress, Office of Technology Assessment, 1993. Industrial Energy Efficiency. [Online] Available at: http://www.fas.org/ota/reports/9330.pdf, [Accessed: 1stFebruary 2012].

[6] Goligher, Scott., 2002. Analysis of the Optimisation Potential of an Industrial Boiler System. Master of Science Thesis, University of Strathclyde, UK, [Online] Available at: http://www.esru.strath.ac.uk/Documents/MSc_2002/goligher.pdf, [Accessed: 15thJanuary 2012].

[7] U.S. Environmental Protection Agency, 2008. Industrial Boiler Efficiency. [Online] Available at: http://www.epa.gov/climateleaders/documents/resources/industrial_boiler_protocol.pdf, [Accessed: 1stMarch 2012].

[8] Fang, J., Li, G., Aunan, K., Vennemo, H., Seip, H., M., Oye, K., A., Beer, J., M., 2002. A proposed industrial-boiler efficiency program in Shanxi: potential CO_2-mitigation, health benefits and associated costs. *Applied Energy* 71, 275-285.

[9] Gan, P.Y., Li, Zhi Dong., 2008. An econometric study on long-term energy outlook and the implications of renewable energy utilization in Malaysia.*Energy Policy* 36, 890-899.

[10] Asia Pacific Energy Research Centre (APERC), 2006. Energy demand and supply Outlook. [Online] Available at: http://www.ieej.or.jp/aperc/2006pdf/Outlook2006/Whole_Report.pdf, [Accessed: 15thFebruary 2012].

[11] Bureau of Energy Efficiency, 2009. Waste heat recovery. [Online] Available at: http://www.em-ea.org/Guide%20Books/book-2/2.8%20Waste%20Heat%20Recovery.pdf, [Accessed: 5thMarch 2012].

[12] E.A. Abdelaziz a, R. Saidur a,*, S. Mekhilef., 2011.A review on energy saving strategies in industrial sector.Renewable and Sustainable Energy Reviews 15, 150-16.

[13] Zeitz, R.A., 1997. CIBO ENERGY EFFICIENCY HANDBOOK. [Online] Available at: http://www1.eere.energy.gov/industry/bestpractices/pdfs/steamhandbook.pdf, [Accessed: 25thFebruary 2012].

[14] Willems, D., 2009. Advanced system control and energy savings for

industrial boilers. [Online] Available at: https://docs.google.com/viewer?a=v&q=cache:CfMOhmytbagJ:www.c bboilers.com/Energy/Technical%2520Articles/Citrus%2520Engineerin g%2520Conference%2520paper%2520rev%2520h.%2520doc.doc+Ad vanced+system+control+and+energy+savings+for+industrial+boilers& hl=en&gl=my&pid=bl&srcid=ADGEESg5u2uzdJrF026ohFQPwiwdM OUx7MV6yhGCHnV7L- HPg_cGxBieELhAdcfr3HHFjuYHE1yJVMp2vlqyOltaTyeCPlbI8B- 9KV9IWOnTj_TFUFvWWkj0rzC3xhWgfvnWSQM0Drsx&sig=AHI EtbRzSU0gaHJfVbJQLMcVWrth3hlfeg, [Accessed: 5thFebruary 2012].

[15] Jayamaha, L., 2006. Energy-Efficient Building Systems. McGraw-Hill, New York.

[16] U.S. Department of energy, 2005. Install Waste Heat Recovery Systems for Fuel-Fired Furnaces. [Online] Available at: http://www1.eere.energy.gov/industry/bestpractices/pdfs/insta ll_waste_heat_process_htgts8.pdf, [Accessed: 5thFebruary 2012].

[17] Willems, D., Pipkin, W., 2009. Does Your Boiler Need a Retrofit?. [Online] Available at: http://www.fmlink.com/ProfResources/Magazines/article.cgi? AFE:afe012308a.html, [Accessed: 20thJanaury 2012].

[18] Manan, Z., 2003. Identifying energy saving opportunities in a process plant through preliminary energy audit.Jurnal technology University Technology Malaysia 38(A), 37-48.

[19] PTM, 2007. Personal Communication.PusatTenaga Malaysia (PTM), Malaysia.

[20] PTM, 2009. CDM Potential in the Energy Sector. PusatTenaga Malaysia (PTM), Malaysia.