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SO_2 REDUCTION USING MERIT PILA COAL BLENDING TECHNIQUE IN FLUIDISED BED COMBUSTION

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ABSTRACT

Coal has advantages over other sources of fuels due to vast world reserves, estimated to the five folds that of gas and oil put together. From economies of scale, coal-fired power generation is the cheapest, contributing to 40% of world energy power generation. However, burning coal creates environmental effects although modern cleanup technologies are able to reduce the impact. However, clean-up facilities will cause high capital and operational costs besides creating an additional impact due to discharge of processing wastes including treatment of discharged water. Research into new technologies depending on sizes and its technological complication requires high financial investment. Therefore, coal blending technique needs to be investigated simply because it requires little modifications with small investment to the existing plants.

It is the objective of this research to optimize local coal consumption by paring with other types of imported coals as blending partners. The main focus of the research is to observe in detail the reaction of blending local coal so as to obtain the optimum ratio for the blended coal to improve combustion performance. Secondly, to obtain a responsive reaction of coal blending in combustion to reduce SO_2 emission. Merit Pila coal as a local coal is blended with other types of imported coals such as Blair Athol, Tanito Harum, Ulan and Datong at 10% step ratio for each blend.

In the coal combustion test, a fluidized bed test-rig of $0.123m^2$ was successfully designed, fabricated and commissioned by local experts and fabricated using local materials. One of the special components of the test rig is the distribution plate with tapped distribution nozzles to promote good distribution of air to form well equal bubbles and at the same time to avoid the fluidized bed material re-entering into the air distribution tube.

From coal blending combustion tests in the fluidized bed test-rig, the SO_2 emission profiling is quite similar to that shown by the sulphur contents analysis. If a linear equation is taken from 100:0 ratio to 0:100, it can be seen that the SO_2 profile will cut the line at around 50:50 with the first half curving upward and the second half curving downward. The profiling behavior is related to the chemical reaction between sulphur and the mineral content of blended coals. For SO_2 analysis, the emission can be correlated with other parameters, as in the derived equation *where linear relationship can be achieved. The linear equation is determined by the difference of reaction from sulphur to SO_2 and sulphur in ash. By estimating the sulphur content in the ash, several simulations can be carried out until the calculated SO_2 of the coal reaches the actual values of measured SO_2 analysis. Thus, the emission of SO_2 could be reduced substantially using local coal blending techniques. The coal blending combustion test has shown that 70%-80% of imported coal blended with Merit Pila coal will achieve 20%-30% reduction of SO_2. The finding will give more options for cheaper and simple techniques to reduce the emission of SO_2 from coal fired power stations compared to traditional methods such as commonly Flue Gas Desulphurisation FGD which would require a quarter of the plant total cost.*

1.0 INTRODUCTION

Generally all major energy sources have problems, including coal. As solid fuels, it is much harder to transport, burn and mine. Coal is not the cleanest source of energy as seen in its 600 years history of usage even though modern technology is capable of cleaning almost all types of coal firing related pollution. Meanwhile, the cleaning technology would definitely add up to the construction and operation costs of coal-fired power stations due to the additional equipment. Although pollution cleaner devices are installed, the burning of coals still produce more carbon dioxide than the other major fuels. It is estimated that 50% of greenhouse effect is from coal-fired generation plants. In order to reduce the carbon dioxide emission, the only way is to reduce the burning of more coals, as CO_2 reduction technology is messy and uneconomical.

Coal has distinct advantages over other fuel sources [1]. It has huge reserves. The world's coal reserves are estimated to be five times bigger than the oil and gas reserves. Statistical review from 1994 BP Statistic Review of World Energy estimated that the coal reserves are 1,039,183 million ton metric. Fractions of coal reserves can almost be found in every part of the world. Generally, the location is much simpler to explore compared with oil and natural gas. In many countries, coal is the main source of fuels for power generation usually used in conjunction with a device to reduce pollution caused by coal combustion. With this, coal is capable of maintaining high percentage of world's energy market in the region of 30%. In economic scale, coal can lower the cost of power generation, constituting 40% of total power generation globally. The fraction of the use of coals is expected to be consistent in the future considering that existing power stations will still be operating in a long term.

Although coals are already blended by the coal-fired power stations for all the reasons stated, the conversion of an old plant to a high technology power station (like integrated coal gassification combined cycle, IGCC and pressurized fluidized bed combustion, PFBC systems) could just provide other options. The increased efficiency and reduced pollution makes these systems prime candidates for future generating systems. Coal blending system, if considered carefully, is capable of competing with the high technology system [2] or the advanced power generation systems [3].

For Malaysia, under the new power generation programs totaling up to 6,060MW, at least two of the Independent Power Producers (IPPs) accounting for almost 60% capacity will be coal-fired plants. A third plant could also be coal-fired and thus increasing coal's share of the next IPP round of installed capacity up to 75%. The largest of the newly planned IPP station is a 2,100MW coal-fired TNB Janamanjung plant to be completed by 2004. Also consisting of two units of 700MW, the second largest IPP being planned is the 1,400MW coal-fired Automan Power project at Lukut near the newly opened Sepang International Airport due for completion by 2005. The other large station planned for the next IPP is a 1,000MW at Pulau Bunting which is to be completed by 2005.

However, the recent economic downturn that swept across the country resulted in a drastic increase in coal prices due to the falling of Malaysian Ringgit compared to US Dollar. The possibility of coal blending is seen to be more generous in balancing up the fluctuation of fuel prices. It is the objective of this study to identify what blend ratio could be tolerated by the boiler using existing alternative coals and future alternative coals potentially available on the spot market, and what coal handling plant modification would be required to provide those blends.

2.0 BLENDING TECHNIQUES

In Malaysia, the power producers see coal blending as profitable as the indigenous coal is traded in Ringgit Malaysia. Therefore, study on the feasibility of coal blending using Merit Pila coal has to be done in order to determine any possibility that occurs from overall reactions and boiler performance.

Coal blending combustion is not new to Kapar Power Station. The coal-blending project has started since 1990 on the two coal boilers 2x300MW using Merit Pila as base coal. Blending of 30% Merit Pila with 70% Blair Athol has been implemented successfully [4]. The test was done in order to determine the amount of alternative coal blending, i.e. Merit Pila coal that can be added in ratio. Blending of 50% alternative coal has been tried but its success is only for a short duration. Several test series were done but the problem identified was from the true coal-blending ratio.

In order to fulfill the objective, several types of combustion systems were identified and studied from the technological aspect, justification of building and overall costs to build the test rig. Comparisons have been made to suit with the objective of the next test that is to investigate coal blending influences on the behavior of combustion and SO_2 emission rates.

3.0 TEST-RIG DESIGN

Fluidized bed technology is capable of investigating the combustion behavior because the characteristics of coal used can be modified according to the design specifications of boiler with the blending technique. The behaviour of combustion is related to the coal characteristics itself [5]. The coal blending techniques, being the latest manifestation to give thorough solution for the application of indigenous coal in power generation, are among the main objective of this study. The coal blending is done using Merit Pila coal (an indigenous coal type). The testing of combustion process is done by $0.0123m^2$ Atmospheric Fluidized Bed Laboratory Scale Combustor using local design and expertise.

Fluidized bed combustion can be said as new generation in clean coal technology. This type of combustion is flexible because it can suit various types of coals from bitumen to lignite. It can also preserve and control environmental pollution without auxiliary equipment to handle emitted gases especially sulfur dioxide, SO_2 and nitrogen oxide, NOx [6] [7]. In other words, it is environmental friendly considering the nature of the works. Furthermore, initial optimal condition in combustion can be achieved by controlling the feeding and mixing of new coals together with the fired coal in the rig although the calorific value is different. This is because the combustion function and heat transfer can be separated with several coal quality without changing or modifying any boiler equipment.

The basic principles of fluidized bed combustion are simple. The combustion chamber contains a bed, which consists of fine particles for example silica sand. The air is blown into the bed and causes the bed to move up until the molecule is in turbulent condition and behaves like liquid, the bed is thus said to be in a fluidized condition [8]. The bed is pre-heated to over 500°C using an electric coil. Coal is fed into the bed until it reaches a temperature where it will ignite and the combustion process begins. Heat from the coal combustion will maintain the bed temperature and heat transfer can stabilize the temperature of the whole bed.

Low combustion temperature in the region of 850°C prevents the bed particles from crushing or melting. Transfer of heat not only occurs through radiation, but also through direct conduction from bed molecules to the surface of heat exchanger similar to a typical boiler. The emissions of NOx can be reduced with low combustion temperature. Therefore, it is the objective of the research to optimize the indigenous coal combustion with the use of coal blending technique with imported coals. The main target of the research is to look in detail the indigenous coal reaction characteristics when it is blended with commonly used coals. This is to ensure the right combination that will fulfill boiler's specifications. Second, to get the reaction of blend coals during combustion with the hope that it can reduce SO_2 emission and increase combustion efficiency.

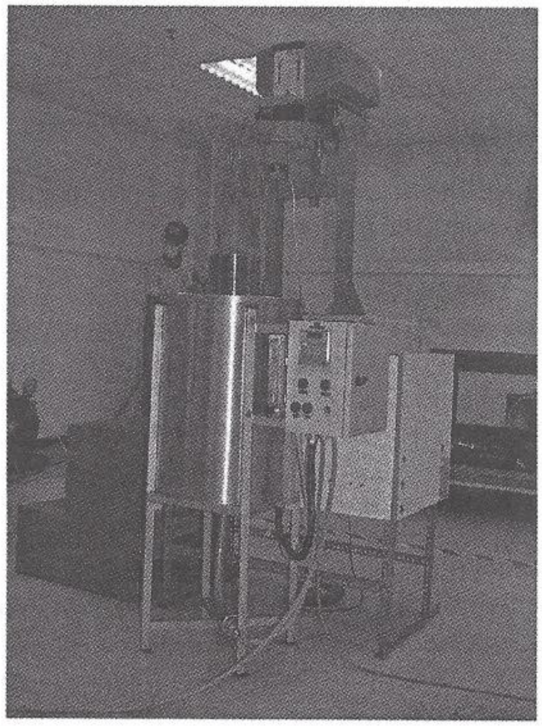

Figure 1 Fluidised bed combustion test rig

Based on local design, the above $0.123m^2$ fluidised bed combustion test-rig was built by the Combustion & Fuel Technology Group in TNB Research Laboratory (Figure 1). For this test-rig, special stainless steel plate of thickness 10mm is used as air distribution grid. The distribution grids consist of several nozzles for the following reasons;

i. air box is not required
ii. no return of fluidised bed material into the air chamber
iii. easy to install
iv. act as a support for the fluidised material.

4.0 SAMPLE PREPARATION

Coal samples were prepared through combinations of different types between Merit Pila and Blair Athol, Merit Pila and Ulan, and Merit Pila and Tanito Harum at an interval of 10% step ratios using riffle box (Figure 2). The other two separate coal analyse performed are calorific value (CV) determination, ultimate and proximate analysis.

All samples to be blended underwent preparation processes. Coal samples need to be dried to avoid occurrence of pockets of similar coal during blending. After crushing, the coal samples were sieved to 1.25mm size and air dried at about 40^0C [9]. After drying, the samples will be weighed in accordance with their respective step ratio of 10%.

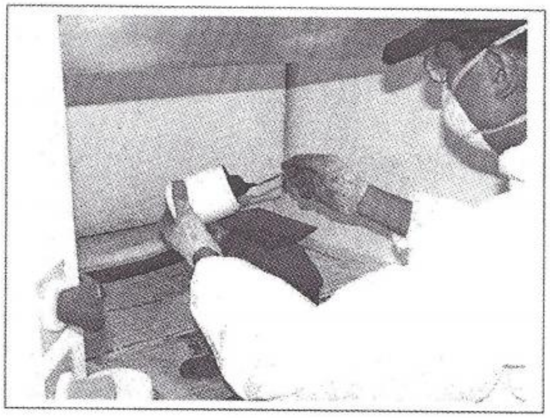

Figure 2 Blending method using riffle

After mixing, the coal samples were homogenous using riffle box for about 50 times (Figure 2). All samples were preserved in the control cabinet prior to combustion test.

5.0 RESULT AND ANALYSIS

The bench scale fluidised bed combustion test-rig has passed through several testing processes to optimise the combustion performance by varying the bed material sizes and the rate of coal feeding into the furnace. With sufficient air pressure, combustion temperature is maintained at 850°C for about 6 hours operation. For combustion testing, Merit Pila coal was blended with three other coals, Tanito Harum from Indonesia, Ulan from Australia and Datong from China. The intention of the study is to determine the reaction of blending ratio of the emission of SO_2 whereas NO_x is not obvious due to lower temperature in the fluidised bed combustion. Other techniques of SO_2 reduction is not covered in the study, such as adding of limestone $CaCO_3$ which is said to be effective in SO_2 reduction involving fluidised bed combustion. Post-combustion cleaning processes such as filter bag and electrostatic precipitator will also not be discussed in the study.

One of the main intentions of coal blending is to satisfy in controlling the SO_2 reduction and the success would be able to reduce expensive capital and operational cost for cleaning equipment such as flue gas desulphurization, FGD

[10]. During coal combustion, sulphur is said to be undergoing chemical reaction and transformed into SO_2. Thus, the reaction of sulphur content is assumed to be additive without further reaction with other positive ions such as Na, Al, Mg, Mn and other minerals which actually react to form ashes that are disposed after combustion. To simplify the calculation for SO_2 emission, weighted average method is used. It is an accepted method worldwide.

Sulphur reaction with soil mineral is included although the percentage is very small. From chemical aspects, formation of SO_2 from sulphur is entirely due to chemical reaction with the following reaction;

$S + O_2 = SO^-$
$SO^- + O_2 = SO_2$
$SO_2 + O_2 = SO_3^-$
$SO_3^- + Fe^{2+} = Fe_2SO_3$ (ferrous sulphate)
$SO_3^- + Mg^{2+} = Mg_2SO_3$ (mg sulphate)

Part of SO_3 will be absorbed by soil mineral to form sulphate in the fly and bottom ash. Several equations can be used to predict the formation of SO_2, some using retention factor. For this study, an equation was derived from a linear equation of two coals blending by including a correction factor [11]. This equation will also take into account the retention ash that is not emitted form the chimney. The equations are as follows;

$$\frac{10{,}000 * S_i * (1 - X_{ash}) * 100}{CV_i} \quad (1)$$

where,

SO_{2i} = sulphur dioxide
S_i = sulphur content in coal
X_{ash} = percentage of sulphur in ash
CV_i = calorific values

$$SO_{2bl} = [SO_{2i} * N] + [SO_{2ii} * (1-N)] \quad (2)$$

where,

SO_{2bl} = SO_2 emission of blended coal
SO_{2i} = SO_2 emission in coal A
SO_{2ii} = SO_2 emission in coal B
N = coal blending ratio

From the results of flue gas analysis of Merit Pila/Tanito Harum blend, the SO_2 emission follows almost similar profile to the result of sulphur analysis (Table 1).

If a straight line is taken from 100:0 ratio to 0:100, it can be seen that the SO_2 profile will cut the line at around 50:50 with the first half curving upward and the second half curving downward. The profiling behavior is related to the chemical reaction between sulphur and mineral content of the blended coals (as shown in Figure 3).

Table 1 Combustion result of Merit Pila/Tanito Harum

Ratio (%)	**SO_2** (ppm)	**NO_x** (ppm)	**CO_2** (ppm)	Theori **SO_2** (ppm)
100:0	0.00	25.43	2.75	0.00
90:10	5.67	30.67	3.66	2.82
80:20	10.07	30.71	3.80	5.59
70:30	13.47	31.87	3.33	8.39
60:40	14.47	33.20	4.18	11.18
50:50	15.27	35.93	3.70	13.98
40:60	15.80	40.73	2.66	16.77
30:70	15.87	42.73	2.53	19.57
20:80	16.07	40.57	3.48	22.36
10:90	19.60	41.20	2.70	25.16
0:100	27.93	40.93	2.69	27.96

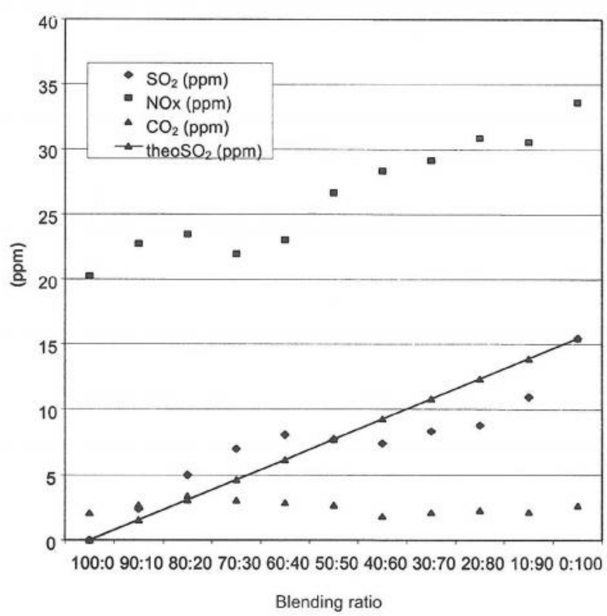

Figure 3 Coal Combustion Test Merit Pila/Ulan Flue Gas Analysis

For SO_2 analysis, the emission can be correlated with other parameters, as in equation 1 where a linear relationship can be achieved. The linear equation is determined by the difference of reaction from sulphur to SO_2 and sulphur in ash. By estimating the sulphur content in the ash, several simulations can be carried out until $SO_{2Tanito}$ reaches the actual values of SO_2 Tanito Harum analysis. The SO_{2Merit} value is not required due to the fact that there is no sulphur content in Merit Pila coal. This equation is considered sufficient in the study because the result of sulphur reaction in combustion will form into SO_2 while the rest will be accumulated in the ashes. From the calculation of the above equations, $SO_{2Tanito}$ is as follow;

S_{ash} = 32.60%
S_{Merit} = 0.00%
S_{Ulan} = 1.23%
CV_{Merit} = 26,641 kJ/kg
CV_{Tanito} = 29,655 kJ/kg
SO_{2Merit} = 0.000 ppm
$SO_{2Tanito}$ = 27.96 ppm

Although sulphur content is considered as an additive, predicting the SO_2 emission should take into account sulphate absorption in the ash. With known ash content, predicting of SO_2 emission will be more accurate. From the calculation using equation 1, the percentage of sulphur in ash is estimated to be 32.60% of the total ash content in Tanito Harum coal. The rate of sulphur absorption in ash of Tanito Harum coal is advantages that reduce the formation of SO_2. From the SO_2 profile it shows that the reduction of SO_2 is lesser at blending ratio more than 50% Merit Pill/Taint Harem.

Table 2 Combustion results of Merit Pill/Ulan

Ratio (%)	SO_2 (ppm)	NO_x (ppm)	CO_2 (ppm)	Theoretical SO_2 (ppm)
100:0	0.00	20.27	1.90	0.00
90:10	2.25	20.41	1.97	1.51
80:20	4.94	20.27	2.03	3.03
70:30	6.95	20.14	2.10	4.54
60:40	7.81	20.18	2.16	6.06
50:50	8.42	20.23	2.25	7.57
40:60	7.44	20.32	2.26	9.09
30:70	8.39	20.55	2.29	10.60
20:80	8.81	20.82	2.30	12.12
10:90	10.50	20.86	2.38	13.63
0:100	15.16	21.09	2.45	15.15

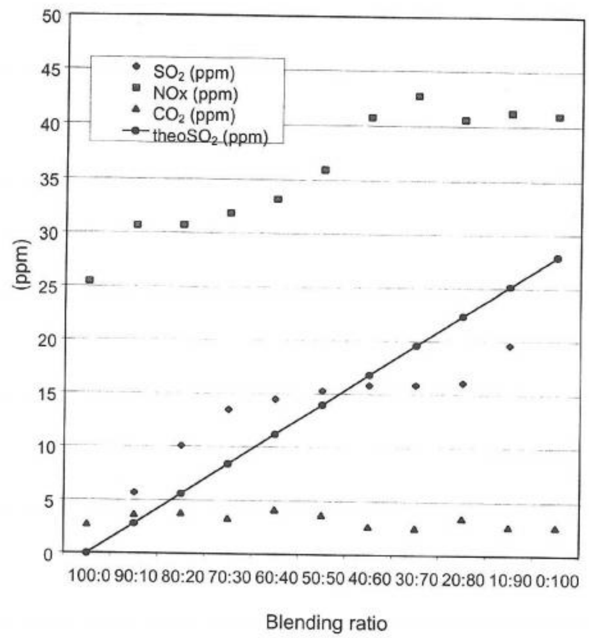

Figure 4 Coal Combustion Test for Merit Pila/Ulan Flue Gas Analysis

Similarly for flue gas analysis in Merit Pill/Ulan blend, the SO_2 emission follows almost a similar profile to the result of sulfur analysis (Table 2). If a straight line is taken from 100:0 ratio to 0:100, it can be seen that the SO_2 profile will also cut the line at around 50:50 with the first half curving upward and the second half curving downward. The profiling behavior is related to the chemical reaction between sulfur and mineral content of the blended coals (as shown in Figure 4).

For SO_2 analysis, the emission can be correlated with other parameters, as in equation 1 where linear relationship can also be achieved. The linear equation is determined by the difference of reaction from SO_2 analysis, the emission can be correlated with other parameters, as in equation 1 where linear sulphur to SO_2 and sulphur in ash. From the calculation of the above equation, $SO_{2Tanito}$ is as follow;

S_{ash} = 14.5%
S_{Merit} = 0.00%
S_{Ulan} = 0.52%
CV_{Merit} = 26,641 kJ/kg
CV_{Ulan} = 29,347 kJ/kg
SO_{2Merit} = 0.000 ppm
SO_{2Ulan} = 15.15 ppm

For flue gas analysis in Merit Pila/Datong blend, the SO_2 emission follows almost a similar profile to the result of sulphur analysis (Table 3). The profiling behaviour is related to the chemical reaction between sulphur and mineral content of the blended coals (as shown in Figure 5).

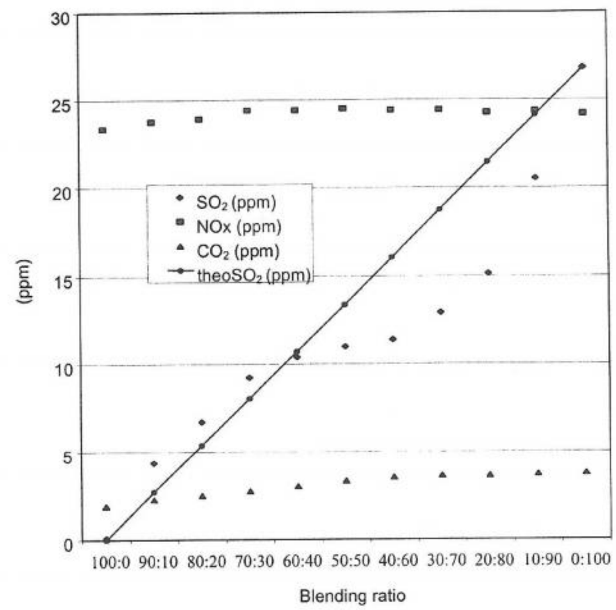

Figure 5 Combustion Test of Merit Pila/Datong Flue Gas Analysis

Table 3 Combustion results of Merit Pill/Dating

Ratio	SO_2 (ppm)	NO_x (ppm)	CO_2 (ppm)	Theoretical SO_2 (ppm)
100:0	0.08	23.33	1.88	0.00
90:10	4.36	23.75	2.23	2.68
80:20	6.71	23.92	2.48	5.36
70:30	9.23	24.42	2.72	8.04
60:40	10.40	24.42	3.00	10.71
50:50	11.00	24.50	3.29	13.39
40:60	11.38	24.42	3.51	16.07
30:70	12.93	24.42	3.60	18.75
20:80	15.13	24.25	3.60	21.43
10:90	20.50	24.33	3.68	24.11
0:100	26.80	24.17	3.73	26.79

6.0 CONCLUSIONS

In this coal blending study, Merit Pila coal has been utilised as the paring coal for blending with other imported coals such as Tanito Harum, Ulan and Datong. The following conclusions were obtained from the above study;

i. Local coals including Merit Pila could be potentially utilized as a blended coal with other imported coals. This could lessen the over dependence on imported coals and at the same time will spur the local coal industries especially in Sabah and Sarawak.

ii. The emission of SO_2 could be reduced substantially using local coal blending techniques. The coal blending combustion test results have shown that blending imported coals in the range of 70%-80% with Merit Pila coal will result in SO_2 reduction in the range of 20%-30% compared to theoretical values. Thus, the finding will give more options for cheaper and simpler techniques to reduce the emission of SO_2 from coal fired power stations compared to traditional methods, such as the Flue Gas Desulphurisation FGD, may require a quarter of the plant total cost.

iii. Bench scale $0.123m^2$ Fluidised bed combustion test rig was successfully designed, fabricated and commissioned by local experts and using local components at TNB Research Laboratory. This kind of research will be able to develop and enhance local expertise in combustion technology and help accelerate the country's development.

REFERENCES

1. Carpenter, A. M., 1988. Coal classification, London, *IEA Coal Research*, IEACR/12: 104.
2. Mahr, D., 1988, Blending coal for quality control. *Coal quality control: fundamental and application*, pp. 25-29.
3. Mateer, R. S., 1994, Coal blending for sulfur compliance. *Transactions society for mining metallurgy and exploration incorporated* 296: pp. 1103.
4. SJSSAA Power Station, 1995, The Firing of Tanito Harum Coal on Unit 3 & 4 of SJSSAA. *Efficiency & Test Section Report.*
5. Sathyaraj, S. P. & Gollahalli, S. R., 1991, *A laboratory scale study f sulphur dioxide emission from combustion of pulverized coal blends*. American Societies of Mechanical Engineers. pp. 7-14.
6. Lim, K. J., Waterland, L. R., Chiba, Z. & Higginbotham, E. B. 1980, *Process Evalution and Environmental of Coal Fired Utility Boiler NO_x Control Technologies*, The American Institute of Chemical Engineers 23.pp. 38-76.

7. Abdul Halim, S. 1992, *Clean Coal Technology*, Proc. ASEAN Sub-Committee on Non Conventional Energy Research, Kuching, Sarawak, pp 3-9.
8. Basu, P. 1984, *Fluidised Bed Combustor: Design and Application*, Toronto, Pergamount Press (pp. 54-46, 101-104, 155-169).
9. Mater, H., Spliethoff, H. Kicherer, A. & Fingerle, A., 1994, Effect of coal blending and particle size on NO_x emission and burnout. *Fuel Guildford* 9: pp. 1447.
10. Bibbo, P. P., 1994. The impact of coal blending and switching on the performance of air pollution equipment. *Proceeding Engineering Foundation conference on coal blending and switching of low sulfur western coals*. pp. 301-321.
11. Mac Alister, J., 1987, Nomogram calculates combustion emissions from coal blends. Power Engineering 191: pp. 24-25.