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Predicting Coal Ash Fusion Temperature of South Sumatera's Blended Coal with Coal Blending Simulation and Laboratory Analysis

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ABSTRACT

Coal blending is the method to get good characteristic of blended coal for power plant. Ash fusion temperature (AFT) is parameter target in blended coal. AFT are parameter that having influence formation of slaging and fouling on heat transfer system of boiler. Beside using laboratory analysis, this study use simulation for prediction coal ash fusion temperature of blended coal. The name simulation are coal blending simulation. Coal blending simulation is a practically and quickly prosedur to get coal ash fusion temperature of blended coal without doing laboratory analysis. 13 coal samples as parent coals from South Sumatera, Indonesia were analyzed at Energy Fosil Laboratory B2TE-BPPT and including 21 blended coal. The simulation formula is taken away from Chen, W. M (China). Chen, W.M use multiple linier regression to predict coal ash fusion temperatures especialy coal ash softening temperature. The result of comparing AFT value between laboratory analysis and statical model/modelling are the maximum fractional error is 0.49, the minimum error is 0.01 and the average error is 0.05.

Key Word: coal blending, simulation, laboratory analysis, modelling.

1. INTRODUCTION

A part of the low rank coal at South Sumatera is not yet been exploited because of the low rank coal is not efficient and didn't have high price to sell. Using low rank coal for the power station will influence the power station efficiency. Boiler system of power station has certain operating condition and it is designed to use coal with spesific characteristic. Using coal with the different characteristic will cause some problems such as combustion efficiency degradation, hot transfer efficiency degradation that effect the slagging and foulling in convection area at the boiler system. The low rank coal contain high water and can cause the calorific value is lower because water of coal is the proportional with calorific value of coal. If the low rank coal used as fuel boiler at power station hence needed amount a lot of coal to produce electricity if using coal with high calorific value at the same yield of electricity.

To increase the using of low rank coal of three alternative scenarios of raw coal for power station, i.e. (1) using coal upgrading to increase quality of coal and (2) using coal blending (3) The change boiler design. Coal Upgrading system is the system to increase quality of coal without blending with other coal from various sources but it is only use a process such as thermal process, UBC process, mechanical proces and the other process. Coal upgrading have higher expense than coal blending process. Making of a new boiler design for handling of low rank coal is needed researchs that have long time and very expensive. If boiler design has been obtained, it has the highly of investment and operate cost. One method has a lower expense and no long time research is coal blending.

Coal blending is generally has been done by the coal miners when the coal is out of market specification or is not technically suitable for the boiler. For practical consideration, heating value (HV) and moisture (TM) content are normally to be the major parameters for the coal blending.

Sulphur (S) and ash contents are also sometimes considered mainly due to tight environmental limitations. In general, the resulted contents of the above parameters in the product of blended coals are simply calculated proportionally. Fusion temperature of ash in coal (AFT) is also important, particularly when concerning the operability of the running boiler, regardless the use of single or blended coals. AFT refers to the fusing temperature of the ash that remains after coal combustion, and is identified as four deformation temperatures, i.e. initial deformation (IT or ID), softening (ST), hemispherical (HT), and fluid (FT) temperatures. To avoid ash deposition, coal should have AFT higher than furnace exit gas temperature (FEGT) in the pulverized boiler, which is usually designed at about 1,200 °C.

Blending coal is to produce the blended coals having characteristics suitable for the boiler specification and/or marketable properties. To meet the specifications, two or more parent coals may require blending. Then, a comprehensive investigation is required to elucidate the effect of elemental ash in coal on AFT of the blended coals. In this preliminary stage, however, the study was limited to the assessment of blended coals from two parent coals only.

Laboratory analysis of blended coal have high cost, sufficient time and high correctness. Coal blending simulation is a practically and quickly prosedur to get coal ash fusion temperature of blended coal without doing laboratory analysis for kinds of coal resources and blending ratio.

2. EXPERIMENTAL

2.1. Coal Samples

Coal samples of South Sumatera were taken from the selected Districts, i.e. ten samples from Musi Rawas (MURA 1 until MURA 5) and Tanjung Enim (ENIM 1 until ENIM 5) and three samples from Musi Banyuasin (MUBA 1 until MUBA 3). Preparation and laboratory analysis of the coal samples refer to standard procedures, i.e. ASTM. AFT analysis was carried out in both reduction and oxidation atmosphere. Table 1, table 2, figure 1 and figure 2 shows ash fusion temperature and Composition of ash parent coal samples of parent coal samples from the results of laboratory analysis. From figure 1, ash fusion temperature of parent coal for initial temperature (IT) have eight samples can not used as raw material in power plant. Its because the value of initial temperature less than standard AFT for boiler. But for softening temperature (ST), there is only two samples of parent coal, the value is not include range in standard boiler.

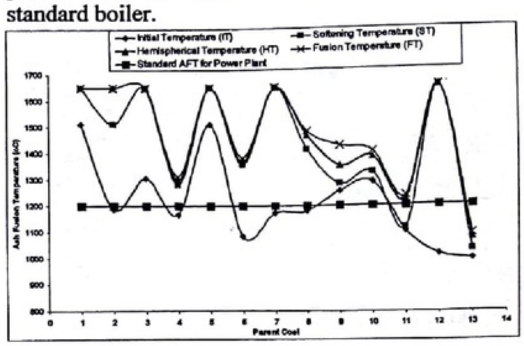

Figure 1. Ash fusion temperature of parent coal samples from the results of laboratory analysis.

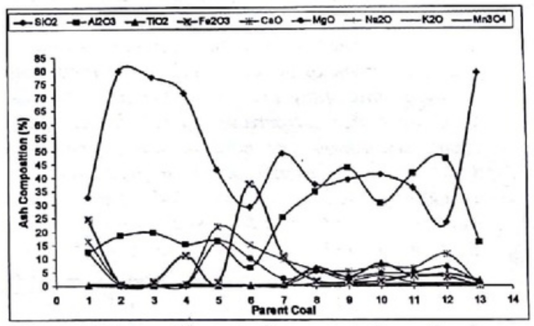

Figure 2. Composition of ash parent coal samples from the results of laboratory analysis.

2.2. Blended Coals

Too many matric and ratio of blended coal for analized. In this study, for technical reasons, a 70 : 30 (by weight) blending ratio was selected for each blended coals and 21 matric of blended coal. Table 3, table 4, figure 3 and figure 4 shows ash fusion temperature and the ash composition of blended coal samples from the results of laboratory analysis.

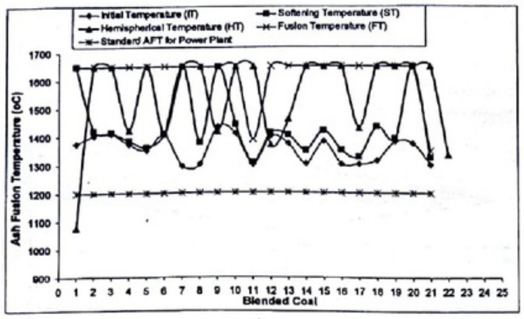

Figure 3. Ash fusion temperature of blended coal samples from the results of laboratory analysis.

From figure 3, ash fusion temperature for all blended coal have the value include range in standard boiler except one sample of blended coal (Enim 1 + Mura 2) that have the different value.

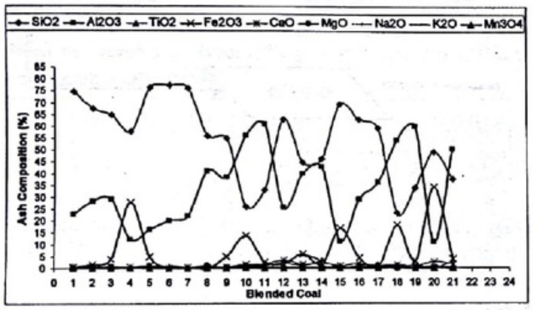

Figure 4. Composition of ash blended coal samples from the results of laboratory analysis.

Effect of blending the coals on AFT is shown in table 3 and composition of ash blended coal samples is shown in table 4 and figure 4. The results were compared to the AFT obtained by calculation proportionally and laboratory analysis from the AFT of individual parent coals and blended coal as given in figure 5 and figure 6. In this study, the softening temperature was more concerned. As shown in figure 5 and 6, the resulted AFT of the blended coals lies between the AFT of individual parent coals. However, blending of the coals were considered to give synergistic effect on ST for some blended coals at the 70 : 30 blended coals ratio. This can be explained from the the softening temperature values obtained from AFT analysis which were higher than those obtained from calculation, and these differences were mostly higher than experimental error which is normally less than 50 °C. However, the results on figure 5 and figure 6 show that larger synergistic effects were obtained for some coals. The ST of blended coal s obtained from AFT analysis was not only higher than individual parent coals, but also even lower than those of individual parent coals.

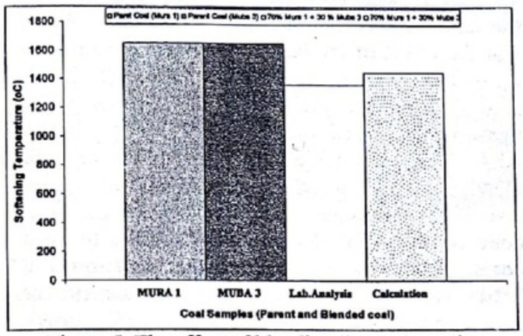

Figure 5. The effect of blending the coals on the softening temperature between calculation and laboratory analysis for parent and blended coal

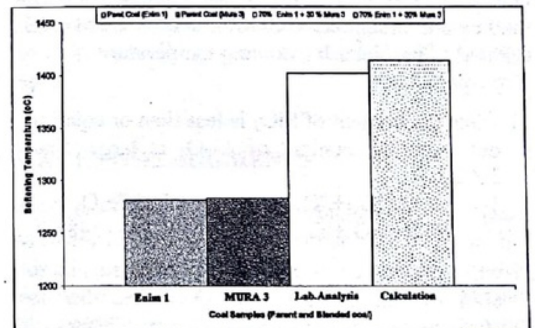

Figure 6. The effect of blending the coals on the softening temperature between calculation and laboratory analysis for parent and blended coal

While for parameter the softening temperature of ash is obtained by the result of different analysis with the calculation of proporsional and blended coal lower than value of AFT of parent coal or each coal before blending (looked at figure 5 and figure 6). This result gives the indication that AFT represent difficult parameter estimated, so that before has to through steps laboratory analysis.

2.3. Mathematic Model to Predict the Fusing Temperature of The Ash

Several of researchers have described the relationships the exist between coal blending measure AFT and elemental ash composition. Bryers and Taylor (1976) proposed a multiple linier regression of AFT as a function of the percent basic constituents in the ash, viz. (Fe_2O_3,

MgO, CaO, Na_2O + K_2O), and its square. Winegarther and Rhodes (1975) used the mole percent rather than weight percent of the oxides and employed normalisation to eliminate some of the analytical errors. Huggins et al (1981) found that the effect of the basic component is to add to the effect of the major basic oxide ((FeO) or (CaO)). Rhinehart and Attar (1987) developed a thermodynamically based model for predicting AFT. The use of alkali based additives for alleviating boiler slagging has been studied by Cui, e.al.(1993). However, little investigation has been done on the AFT characteristics for the blended coals. Ash fusion characteristics and mineral behaviour have been investigated for a series of two component blended ash (Qiu, et.al, 1999). From study the value of coal ash softening temperature is not linearly affected by blending ratio and is strongly influenced by the mineral contents. From this consideration, simulation used mathematic model/equation from Chen, W. M et.al (China) to predict ash softening temperature.
The equation are

1) when the content of SiO_2 is less than or equal to 60% and the content of Al_2O_3 is larger than 30%
$$T_2 = 69.94SiO_2 + 71.01Al_2O_3 + 65.23Fe_2O_3 + 12.16CaO + 68.31MgO + 67.19a - 5485.7$$
2) when the content of SiO_2 is less than or equal to 60% and the content of Al_2O_3 is less than to 30% and the content of Fe_2O_3 less than 30%
$$T_2 = 92.55SiO_2 + 97.83Al_2O_3 + 84.52Fe_2O_3 + 83.67CaO + 81.04MgO + 91.92a - 7891$$
3) when the content of SiO_2 is less than or equal to 60% and the content of Al_2O_3 is less than to 30% and the content of Fe_2O_3 large than 30%
$$T_2 = 1531 - 3.01SiO_2 + 5.08Al_2O_3 - 8.02Fe_2O_3 - 9.69CaO - 5.86MgO + 3.99a$$
4) when the content of SiO_2 is large than to 60%
$$T_2 = 1531 - 3.01SiO_2 + 5.08Al_2O_3 - 8.02Fe_2O_3 - 9.69CaO - 5.86MgO + 3.99a$$

where: $a = 100 - (SiO_2 + Al_2O_3 + Fe_2O_3 + CaO + MgO)$.

Flow chart to predict softening temperature of parent and blended coal for coal blending simulation can be looked below;

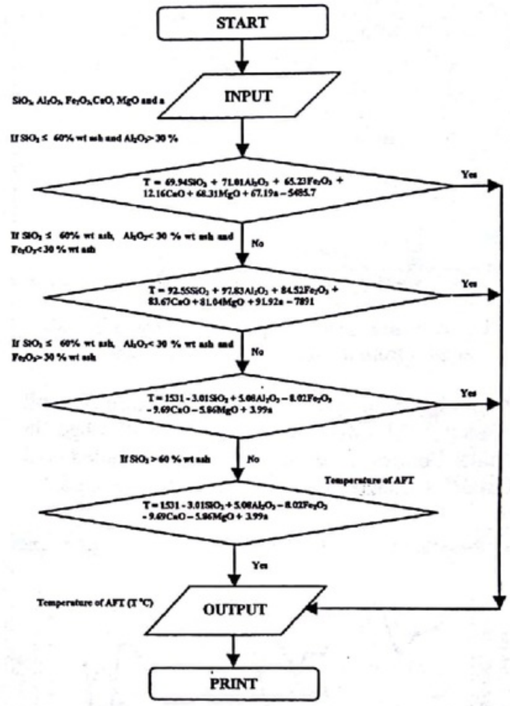

Figure 6. Flow chart to predict ash fusion temperature (softening temperature) for coal blending simulation

3. RESULTS AND DISCUSSION

3.1. Prosedure to create coal blending simulation

Prosedur to create coal blending simulation for prediction coal ash fusion temperature are

1. Making data base throught input data for several parent coal samples are obtained from South Sumatera and other location. For create base data used *Microsoft SQL Server Software* that connect to *Visual Basic Program*. Base data include proximate and ultimate analysis, AFT and chemical compound of ash).
2. Making formulas for calculate of the heating value, total moisture, ash, sulfur content, ash softening temperature (AFT). (*Basic Program* used to make formulas for calculate of the heating value, total moisture, ash, sulfur content, ash softening temperature (AFT) and they are connect to *Visual Basic Program*).

3.2 The Comparison for The Softening Temperature

Figure 4 shows ash fusion temperature of blended coal samples from the results of laboratory analysis and calculation with mathematic model.

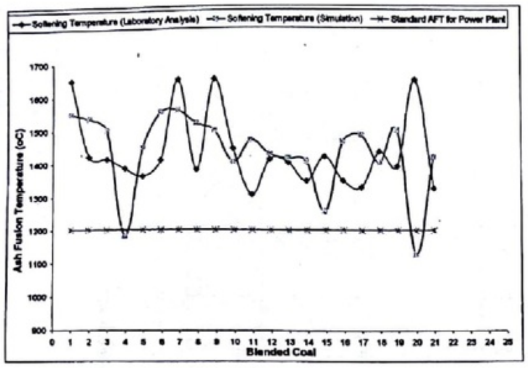

Figure 4 ash fusion temperature of blended coal samples from the results of laboratory analysis and calculation with mathematic model.

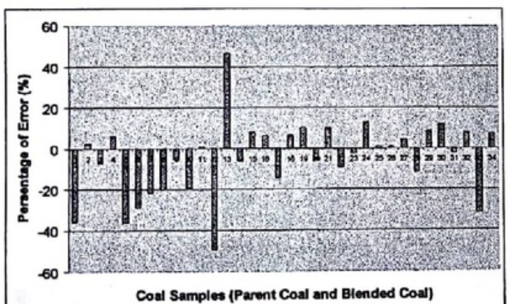

Figure 6. The comparison between laboratory analysis and coal blending simulation (statistical model) for the softening temperature value.

Figure 6 showns comparison of simulation (statistical model) and laboratory analysis for all samples of parent and blended coal to measurement of ash softening temperature. The result of comparing AFT value between laboratory analysis and statical model/modelling are the maximum fractional error is 0.49, the minimum error is 0.01 and the average error is 0.05. This average error percentage is less than 10 %, so its enough accurate. So that, to get a small different value of ash softening temperature between laboratory analysis and statistical model (modelling), the equation used in modelling must be change with a new equation.

4. CONCLUSION

The results of investigation confirmed to previous studies that the AFT of blended coals is not proportional to the coal blending ratio. It can lie between or lower or higher than that of individual parent coals.

It's a close corellation exists between the softening temperature of coal and its chemical composition. The result of comparing AFT value between laboratory analysis and statical model are the maximum fractional error is 0.49, the minimum error is 0.01 and the average is 0.05.

This prosedurs is not very precise especially in used mathematic model for all prediction quality of coal. But this prosedur as practically can become more effective and efficient to get characteristic blended coal than traditional method. So that to get a small different value of ash softening temperature between laboratory analysis and statistical model (modelling), the equation used in modelling must be change with a new equation.

5. ACKNOWLEDGMENTS

This work was supported financially by the State Ministry of Research and Technology of Republic of Indonesia and the Local Government of South Sumatera Province under RUSNAS (National Strategic Research). Laboratory works have been conducted by research groups of B2TE (Energy Technology Center) – BPPT (Agency for the Assessment and Application of Technology) and Sriwijaya University.

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Winegartner E.C., Rhodes B.T. 1975. An Empirical study of the Relation of Chemical properties to Ash Fusion Temperatures, Journal of Engineering for Power, 97, 395 – 400.

Table 1 Laboratorium Analysis of Ash Fusion Temperature of parent coal samples from South Sumatera

AFT (Red.)	PARENT COAL												
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Mura1	Mura2	Mura3	Enim1	Muba1	Muba2	Muba3	Enim2	Enim3	Enim4	Enim5	Mura4	Mura7
IT	1512	1186	1306	1166	1510	1085	1174	1181	1256	1290	1102	1016	998
ST	1650	1512	1650	1281	1650	1356	1650	1414	1283	1326	1116	1650	1032
HT	1650	1650	1650	1296	165	1367	1650	1466	1352	1384	1224	1650	1078
FT	1650	1650	1650	1312	1650	1385	1650	1483	1428	1405	1238	1650	1091

Sources: *Energy Fosil Laboratory B2TE-BPPT*

Table 2 Composition of ash parent coal samples from South Sumatera

Composition of Ash (Metal Oksida)	1 Mura1	2 Mura2	3 Mura3	4 Enim1	5 Muba1	6 Muba2	7 Muba3	8 Enim2	9 Enim3	10 Enim4	11 Enim5	12 Mura4	13. Mura7
SiO_2	32.8	79.7	77.6	71.4	42.90	29.1	49.1	37.6	39.24	41.18	36.26	23.58	78.8
Al_2O_3	12.4	18.49	19.6	15.38	16.5	6.75	25.3	34.73	43.62	30.53	41.52	46.98	16.07
TiO_2	0.256	0.243	0.245	0.575	0.25	0.199	0.683	6.68	3.29	8.32	3.58	4.41	2.11
Fe_2O_3	24.7	0.387	1.521	11.3	1.3	37.7	11.17	1.73	1.45	1.73	3.9	3.36	0.01
CaO	16.5	0.568	0.758	0.569	22	15.1	9.8	6.15	5.4	7.17	6.67	11.73	0.058
MgO	12.3	0.067	0.09	0.165	16.5	10.1	2.73	5.43	3.21	4.75	5	7	0.946
Na_2O	0.001	0.033	0.038	0.018	0.002	0.001	0.01	4.95	2.06	3.94	1.03	0.82	0.633
K_2O	0.35	0.499	0.068	0.568	0.436	0.186	0.005	0.818	0.629	0.576	0.778	0.84	0.632
Mn3O4	0.173	0.011	0.007	0.013	0.01	0.184	0.421	0.002	0.002	0.002	0.002	0.002	0.001
TOTAL	99.48	99.998	99.927	99.988	99.898	99.32	99.219	98.09	98.901	98.198	98.74	98.722	99.26

Sources: *Energy Fosil Laboratory B2TE-BPPT*

Table 3 Ash fusion Temperature of blended coal samples from South Sumatera

AFT (Red.)	BLENDING COAL										
	1	2	3	4	5	6	7	8	9	10	11
	70%Enim1 30%Mura2	70%Mura1 30%Mura2	70%Mura1 30%Mura3	70%Mura1 30%Muba1	70%Mura1 30%Muba3	70%Mura3 30%Mura2	70%Mura3 30%Muba1	70%Muba1 30%Mura2	70%Muba3 30%Mura2	70%Muba3 30%Mura3	70%Muba3 30%Muba1
IT	1375	1402	1410	1372	1350	1405	1294	1302	1436	1410	1298
ST	1650	1420	1414	1385	1362	1410	1650	1380	1650	1442	1306
HT	1650	1650	1422	1650	1412	1650	1650	1415	1650	1650	1368
FT	1650	1650	1650	1650	1650	1650	1650	1650	1650	1650	1388

Sources: *Energy Fosil Laboratory B2TE-BPPT*

Continue from table 3

AFT (Red.)	BLENDING COAL									
	12	13	14	15	16	17	18	19	20	21
	70%Enim1 30%Mura1	70%Enim1 30%Mura3	70%Enim1 30%Muba1	70%Enim1 30%Muba3	70%Muba2 30%Mura1	70%Muba2 30%Mura2	70%Muba2 30%Mura3	70%Muba2 30%Muba1	70%Muba2 30%Muba3	70%Muba2 30%Enim1
IT	1398	1372	1302	1382	1302	1302	1314	1382	1375	1298
ST	1412	1402	1348	1420	1350	1328	1436	1392	1650	1326
HT	1460	1650	1650	1650	1428	1650	1650	1650	1650	1335
FT	1650	1650	1650	1650	1650	1650	1650	1650	1650	1348

Sources: *Energy Fosil Laboratory B2TE-BPPT*

Table 4 Composition of ash parent coal samples from South Sumatera

Composition of Ash (Metal Okside)	1	2	3	4	5	6	7	8	9	10	11
	70%Enim1 30%Mura2	70%Mura1 30%Mura2	70%Mura1 30%Mura3	70%Mura1 30%Muba1	70%Mura1 30%Muba3	70%Mura3 30%Mura2	70%Mura3 30%Muba1	70%Muba1 30%Mura2	70%Muba3 30%Mura2	70%Muba3 30%Mura3	70%Muba3 30%Muba1
SiO_2	74.6	67.63	64.9	57.9	76.48	77.5	76.1	56.1	55.1	26	33
Al_2O_3	22.96	28.52	29.32	12.13	16.37	20.18	22.22	41.1	38.6	56.4	61.1
TiO_2	0.578	0.476	0.224	0.447	0.164	0.72	0.308	0.538	0.319	0.725	0.428
Fe_2O_3	0.453	1.56	3.83	28	4.83	0.38	0.443	0.009	4.85	13.8	2.67
CaO	0.792	0.633	0.833	0.587	1.09	0.202	0.462	0.503	0.506	1.65	1.54
MgO	0.133	0.885	0.833	0.046	0.965	0.004	0.043	1.33	0.382	1.06	1.13
Na_2O	0.045	0.011	0.005	0.012	0.016	0.033	0.016	0.006	0.002	0.013	0.016
K_2O	0.397	0.265	0.02	0.404	0.039	0.932	0.327	0.362	0.256	0.004	0.013
Mn3O4	0.017	0.001	0	0.209	0.001	0.004	0.008	0	0.008	0.293	0.001
TOTAL	99.975	99.981	99.965	99.735	99.955	99.955	99.927	99.948	100.023	99.945	99.898

Sources: Energy Fosil Laboratory B2TE-BPPT

Continue from table 4

Composition of Ash (Metal Okside)	12	13	14	15	16	17	18	19	20	21
	70%Enim1 30%Mura1	70%Enim1 30%Mura3	70%Enim1 30%Muba1	70%Enim1 30%Muba3	70%Muba2 30%Mura1	70%Muba2 30%Mura2	70%Muba2 30%Mura3	70%Muba2 30%Muba1	70%Muba2 30%Muba3	70%Muba2 30%Enim1
SiO_2	63.1	44.8	46.4	69.6	63	59.4	23.5	34.03	49.4	37.7
Al_2O_3	25.89	40.2	43.1	11.36	29.1	36.4	54.5	60.16	11.33	50.58
TiO_2	0.444	0.435	0.5	0.419	0.261	0.706	0.667	0.314	0.508	0.434
Fe_2O_3	1.85	5.96	1.44	17.01	4.52	0.784	18.13	3.22	34.3	3.9

CaO	3.38	1.55	2.18	1.012	1.75	0.903	1.26	0.949	2.594	1.923
MgO	2.39	1.08	2.87	0.146	1.12	1.33	1.151	0.955	0.351	2.49
Na_2O	2.59	5.598	3.03	0.035	0.011	0.007	0.011	0.009	0.007	2.562
K_2O	0.316	0.321	0.427	0.294	0.185	0.458	0.006	0.265	0.66	0.324
Mn3O4	0	0.003	0.001	0.017	0	0	0.53	0	0.176	0.001
TOTAL (%)	99.96	99.947	99.948	99.893	99.947	99.988	99.755	99.902	99.326	99.914

Sources: *Energy Fosil Laboratory B2TE-BPPT*

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