RESEARCH ARTICLE

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IN-SITU DESULFURIZATION OF COAL BRIQUETTES BY LIME

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ABSTRACT

The combustion of coal briquettes causes corrosion and air pollution, which is due to sulfur in the coal. Coal briquette desulfurization by addition of lime was studied. Calcium oxide reacts with sulfur dioxide, evolved from combustion, according to the equation:

$$CaO + SO_2 + \tfrac{1}{2}O_2 \longrightarrow CaSO_4$$

The resulting calcium sulfate remains in the ash after combustion.

Variables that affected sulfur oxides capture by lime during combustion of coal briquettes at true operating conditions in bucket-type cooking stoves were found to be: amount of lime added in terms of mole ratio of CaO/S (from 0 to 4), percentage of clay used as binder (from 0 to 40), and types of coal fines used.

Lime was found to be highly effective in desulfurization, as the percentage of calcium sulfate in coal ash increased sharply with increasing CaO/S mole ratio from 0-2, and levelled off at higher ratios. The maximum in-situ *sulfur capture was 90-95%, based on the total sulfur present initially, leaving only 5-10% emitted as sulfur oxides. Clay produced a similar (but less pronounced) effect to that of lime.*

In conclusion, it is demonstrated that coal briquettes made from coal fines from various sources in Thailand can be well desulfurized by lime. The recommended value of CaO/S mole ratio is in the range of 2.0-2.5, together with a 20% addition of clay.

INTRODUCTION

Desulfurization of coal by limestone ($CaCO_3$), lime (CaO), or dolomite ($MgCO_3.CaCO_3$) injection into a fluidized bed combustor or a pulverized fuel combustor during combustion is a well known process.[1,2] From preliminary studies that produced small ovoid-shaped coal briquettes (from coal fines using brick clay as binder) which have been successfully tested in domestic cooking stoves,[3-6] the two concepts were simultaneously applied, complimentary to each other, to reduce the amount of sulfur oxides emission during combustion, which would, in turn, reduce the resulting odor and pollution. In this way it is hoped to make coal briquette use in domestic cooking more acceptable. Lime addition has a two-fold effect. Firstly, it reacts as a sorbent of SO_2 according to the equation:

$$CaO + SO_2 + \frac{1}{2}O_2 \longrightarrow CaSO_4$$

Secondly, lime acts as a binder during coal briquetting.[6]

Lime powder, if added and blended with coal powder and clay, and then briquetted, will remain in intimate contact with coal powder, and distribute uniformly within the briquette mass. When burned, it will stay intact for a long period of time. It is then hoped that the lime will capture sulfur oxides emitted during combustion much more efficiently and effectively than in the case where it is injected into a fluidizing coal bed in a combustor.

The double effect of lime addition is expected to lead to a better, more convenient, and more effective method of desulfurizing coal fines during combustion.

MATERIALS AND METHODS

Various shapes and sizes of coal briquettes can be made, e.g., cylindrical, pillow, honey-comb, and ovoid. In this experiment, ovoid shape briquetting (3×5 cm, approx. 15 g/piece) was selected because these briquettes were found to be suitable as a substitute for wood charcoal in Thai bucket-type domestic stoves, and may also be suitable for manual feeding in some types of industrial furnaces. Clay was selected as the binder from the results of a previous investigation, apart from the fact that it is suitably abundant and cheap.[3,4,7]

Materials

- Coals from five significant sources in Thailand
- Clay (brick clay type; 67.36% silica, 15.81% alumina, 1.68% CaO & MgO, 5.60% Fe_2O_3 and 5.26% ignition loss)
- Commercial lime (84.71% CaO)
- Chemicals, as specified in corresponding ASTM Standards

Apparatus and Equipments

- Hammer mill, with 3/8 in. aperture screen
- Ball mill

- Solids mixer
- Double ring roll machine, complete with screw feeder and hydraulic oil pump.
- Stove efficiency testing set, consisting of one of each of the following: 30 cm O.D., 28 cm O.D. bucket stoves, aluminum pot, balance, and small electric fan.

Variables studied

- CaO/S mole ratio (0-4)
- Clay (0-40%)
- Coal samples

Mae Moh	(MM)
Bang Pu Dum	(PD)
Klong Vai Lek	(KV)
Baan Pu	(BP)
Pa Ka	(PK)

Methods

A. Materials preparation

Coal samples All coal samples were air dried, then crushed in a hammer mill. These were coal samples for briquetting. Small portions were sampled and pulverized in a ball mill until all passed through a 60-mesh (250 μm) sieve. These portions were kept for further analyses, i.e., proximate analysis, heating value, and analyses for total sulfur and different forms of sulfur in ash.

Clay sample The clay sample was dried in a tray dryer, then milled and sieved to pass through a 60-mesh sieve.

B. Coal briquetting

For each batch, the following procedure was followed: 2½ kg of crushed coal was dried in a tray dryer for 3 hr to remove surface moisture then mixed with weighed portions of lime, clay, and water in the mixer. All calculations were based on the weight of dried coal. The moist mix was then fed continuously to the double ring roll machine. The unbriquetted portions were sifted out and recycled. Briquettes obtained were spread out on a tray and air dried under ambient conditions (7-10 days).

C. Stove efficiency testing

Dried coal briquettes were used in domestic stoves to test for their actual performance. All runs were conducted under similar conditions, particularly the initial ignition part.

Boiling water test method[5] was employed. 400 g of wood charcoal (7,100 cal/g) was the standard heat input for all runs. The weight of coal briquettes required to provide the equivalent heat output as wood charcoal was first calculated based on the respective heating values. To start up, a small piece of wood resin and a few pieces of wood chips were placed in the stove, in the centre on the fire clay grate, together with a few coal briquettes. After they were lit, a small electric fan was placed in front of the stove opening for a few minutes to facilitate initial ignition. When the smoke died down, the fan was turned off and the pot filled with water was placed on the stove. Once the water started boiling, the lid was removed and boiling allowed to continue until all briquettes finally burned out.

D. Ash analysis

Ash remaining in the stove was sampled and analysed for moisture, total sulfur, and forms of sulfur.

The following scheme illustrates the overall procedure.

Coal samples
↓
Hammer Mill
↓

Ball Mill
(100% pass 60-Mesh)
↓
Preliminary analyses
- Proximate analyses (ASTM D 3173)
- Heating value (ASTM D 3286)
- Total sulfur (ASTM D 3177)
- Forms of sulfur (ASTM D 2492)

Mixer
↓
Double ring roll machine
↓
Air-dry (7-10 days)
↓
Stove efficiency test
↓
Ash analyses
- Total sulfur (ASTM D 1757)
- Forms of sulfur (ASTM D 2492)

Tables 1 and 2 further exemplify the studies of various variables employing coal samples from different sources.

TABLE 1 Coal briquettes made with varying ratios of CaO/S at 20% clay

CaO/S Mole ratio	Coal samples				
	Mae Moh (MM)	**Bang Pu Dum (PD)**	**Klong Vai Lek (KV)**	**Baan Pu (BP)**	**Pa Ka (PK)**
0	*	*	*	*	*
1	*	*	*	*	
1.25					*
2	*	*	*	*	
2.5					*
3	*	*	*	*	
4			*	*	*

TABLE 2 Coal briquettes made with varying percentages of clay at CaO/S mole ratio = 2

Percent Clay	Coal samples		
	Mae Moh (MM)	**Klong Vai Lek (KV)**	**Pa Ka (PK)**
0	*		*
10	*	*	*
20	*	*	*
30	*	*	*
40	*	*	

RESULTS AND DISCUSSION

Analyses of coal samples

Five coal samples of different origins and ranks were analysed and the results are presented in Table 3.

TABLE 3 Basic properties of coal samples

Items \ Coal sample	Mae Moh (MM)	Bang Pu Dum (PD)	Klong Vai Lek (KV)	Baan Pu (BP)	Pa Ka (PK)
1) Proximate analysis, (%)					
Air-dried basis					
- Moisture	28.74	14.12	16.93	13.02	11.18
- Ash	14.73	17.02	11.61	21.87	17.56
- Volatile matter	28.33	34.76	38.52	34.22	36.51
- Fixed carbon	28.20	34.10	32.94	30.89	34.75
Dry basis					
- Ash	20.67	19.82	13.98	25.14	19.77
- Volatile matter	39.76	40.48	46.37	39.34	41.11
- Fixed carbon	39.57	39.70	39.65	35.52	39.12
2) Gross heating value, (Cal/g)	4,716	4,586	5,341	4,363	5,412
3) Sulfur, (%)					
Total sulfur (Eschka method)	5.66	4.93	4.22	2.50	1.90
Forms of sulfur					
- Sulfate	0.80 (14.13%)*	1.48 (30.02%)	0.70 (16.59%)	0.77 (30.80%)	0.58 (30.53%)
- Pyrite	2.13 (37.63%)*	1.09 (22.11%)	1.14 (27.01%)	0.42 (16.80%)	0.32 (16.84%)
- Organic	2.73 (48.23%)*	2.36 (47.87%)	2.38 (56.40%)	1.41 (56.40%)	1.00 (52.63%)

* (A%) per cent, relative to total sulfur in coal

Effect of lime and clay on stove efficiency

Figures 1 and 2 show stove efficiency plots against lime and clay contents respectively. With no lime and/or clay, stoves employing coal briquettes as fuel displayed low efficiencies. It was observed that such briquettes were more dense and burned more slowly and incompletely, leaving unburned carbon core inside the briquettes. With either lime or clay addition, the briquettes presumably, became more porous providing better air diffusion into the centre. However, as more and more lime or clay was added, the briquettes became harder and more dense, and their efficiencies again dropped. Fig. 1 shows optimum addition of lime in the range of 10-20% with 20% clay as binder, while Fig. 2 shows optimum clay addition in the range of 10-30% with CaO/S mole ratio = 2.

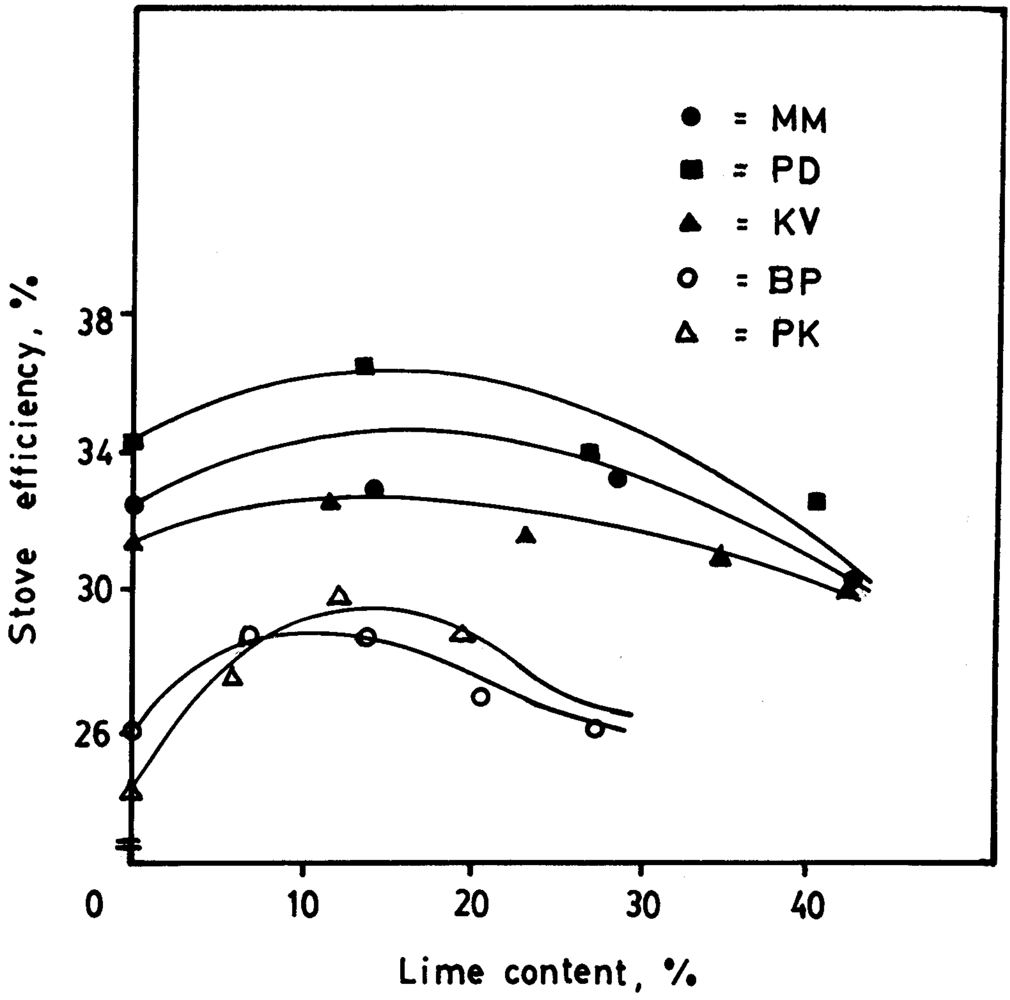

Fig. 1 Stove efficiency of briquettes made from coals of varying lime content (% clay = 20).

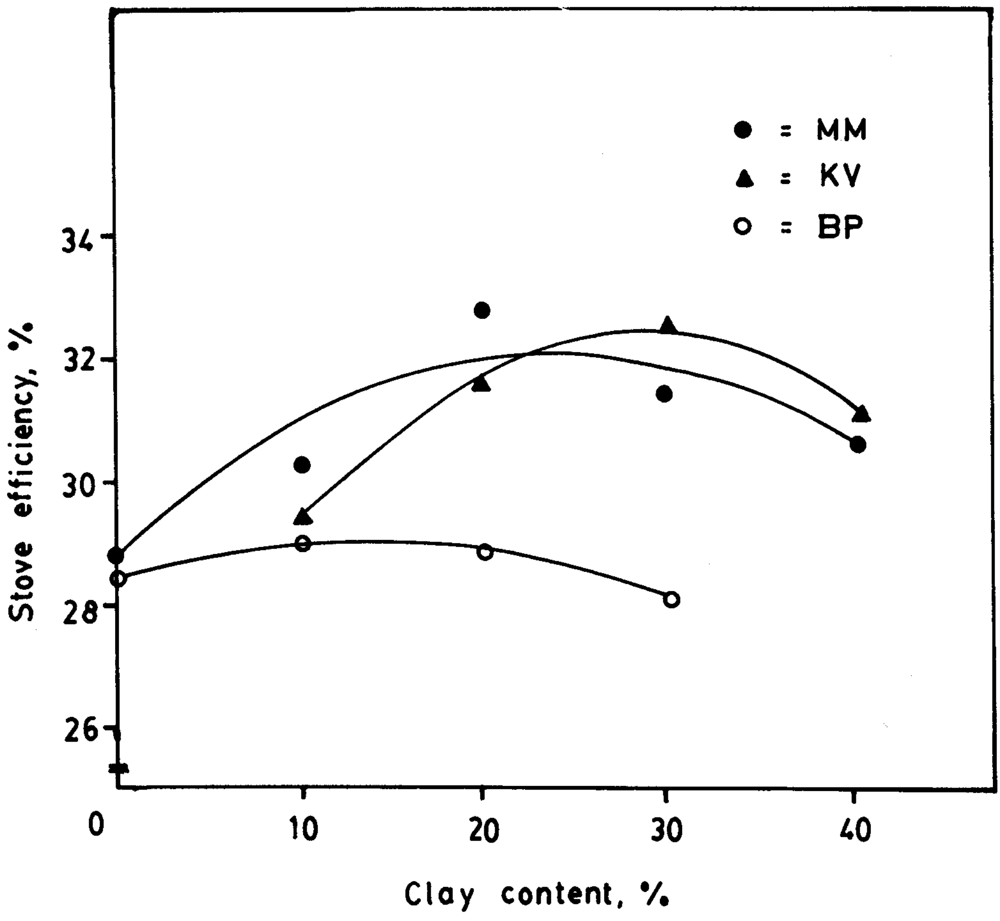

Fig. 2 Stove efficiency of briquettes made from coal of varying clay content (CaO/S = 2).

Another point to note is the discrepancies between the two groups of coal samples, the first one comprising of MM, PD, and KV, and the second of BP and PK. The first group produced 30-36% stove efficiency, while the second one produced only 24-30%. This observation correlates very well with the percentage of sulfur in these coal samples. As coal particles are being oxidized in the vicinity of the flame, the sulfur in the coal is also being oxidized into SO_2 before reacting further with lime to give $CaSO_4$. The overall effect is that the glowing char behaves closer to a black body owing to the high emission of SO_2, thus resulting in a higher radiant heat transfer to the receiving body (aluminum pot).

Effect of CaO/S mole ratio

To observe this effect, the amount of clay added was kept constant at 20% (dried coal basis), as it has been observed that at this composition, the coal mix could be easily briquetted and its performance in stoves was satisfactory.

Ashes remaining after combustion were analysed for forms of sulfur present. In this part of investigation, Mae Moh coal was used first since its sulfur content is high and any changes would be easily detected. Table 4 summarizes the results of the analyses in absolute percentages of sulfur in coal and ash while Table 5 shows the results in relative percentages of sulfur, based on the total sulfur present in coal before combustion.

TABLE 4 Total and various forms of sulfur in Mae Moh coal and in ash remaining after combustion in stoves using coal briquettes made with varying CaO/S mole ratios plus 20% clay

Sample	% Total Sulfur	% Sulfate Sulfur	% Pyritic Sulfur	% Organic Sulfur
Mae Moh Coal	5.66	0.80	2.13	2.73
Ash MM-0 (0%)*	0.94	0.76	0.03	0.15
Ash MM-1 (14.27%)	3.21	3.00	0.04	0.17
Ash MM-2 (28.55%)	4.51	4.48	0.00	0.03
Ash MM-3 (42.82%)	5.04	5.01	0.00	0.03

*MM-A (B%) indicates coal briquettes made from Mae Moh coal at CaO/S mole ratio = A or % lime = B %, dried coal basis. The same code format is applied thoughout this investigation.

TABLE 5 Total and various forms of sulfur in Mae Moh coal and in ash remaining after combustion in stoves using coal briquettes made with varying CaO/S mole ratios plus 20% clay. (Total sulfur in coal = 100)

Sample	% Total Sulfur	% Sulfate Sulfur	% Pyritic Sulfur	% Organic Sulfur
Mae Moh Coal	100.00	14.13	37.63	48.23
Ash MM-0 (0%)	16.61	13.43	0.53	2.65
Ash MM-1 (14.27%)	56.71	53.00	0.71	3.00
Ash MM-2 (28.55%)	79.68	79.15	0.00	0.53
Ash MM-3 (42.82%)	89.05	88.52	0.00	0.53

The results are plotted as shown in Fig. 3, from which the following conclusion can be drawn: with no lime addition, i.e. at CaO/S = 0, the amount of sulfur retained in the ash is only 16.61%, based on the total sulfur in the coal sample. In other words, 83.39% sulfur present initially in coal was oxidized, mostly to SO_2, and emitted into the atmosphere. With the addition of lime, however, the amount of sulfur retained increased markedly with increasing CaO/S ratio from 0-2. At higher ratios, the effect became less pronounced.

Most of the sulfur retained in the ash are sulfate sulfur, with little pyritic and organic sulfur remaining. This indicates that most sulfur compounds in coal are fully oxidized into stable sulfate forms (there are also certain sulfate compounds that decompose at very high temperatures). In the presence of lime, the sulfur dioxide formed reacts further with the lime in the oxidizing atmosphere to give calcium sulfate, thereby increasing its presence in the ash after combustion. With increasing CaO/S ratio, the sulfate concentration also increases, which results in an increase of total sulfur concentration. The small amount of organic sulfur remaining in the ash are most likely heterocyclic ring compounds whose carbon-sulfur resonance ring structures require very rigorous conditions to disrupt their stable, strong bonds.[8]

For coals from other sources, i.e., KV, PD, BP and PK, similar results were also obtained when CaO/S mole ratios were varied. The results are given in Table 6 together with Mae Moh coal and Fig. 4 is a plot showing a similar trend for all coals used. The optimum CaO/S mole ratio that retains sulfur in ash efficiently, yet also allows high stove efficiency is in the range of 2.0-2.5, which agrees very well with other reported values.[4]

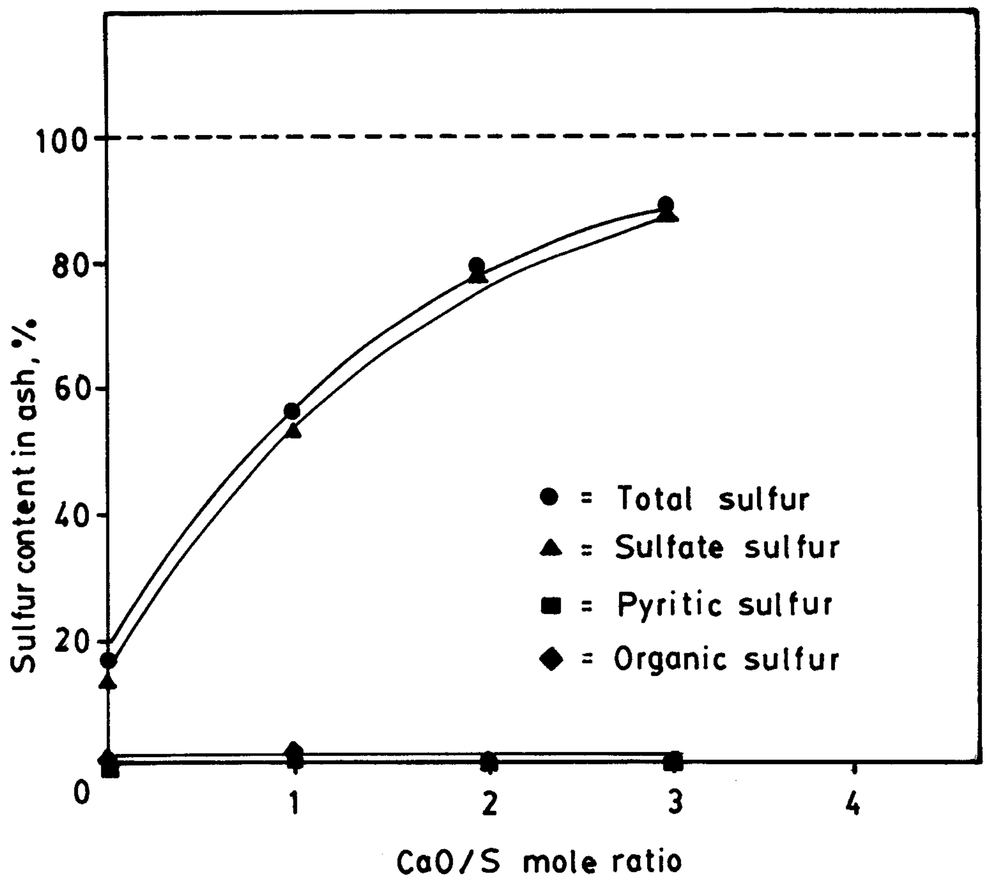

Fig. 3 Effect of CaO/S mole ratio on total and various forms of sulfur retained in ash obtained from Mae Moh coal briquettes (20% clay).

To sum up, all coals seem to follow the same trend in desulfurizing with lime and the correlation may be presented by a single line, as shown in Fig. 5. This correlation can be claimed to be a representation of all Thai coals, since coal samples studied are from sources that are presently significant, both in terms of proven reserves and contribution to industry and electricity generation.

Effect of clay as a binder

In this part of the investigation, the CaO/S mole ratio was kept constant at 2.0, because all coals show optimum lime/sulfur ratio in the range 2.0-2.5. MM, KV and BP coals were selected for the study, an account of their proven reserves and also their differing amounts of total and various forms of sulfur.

Results for Mae Moh Coal are given in Table 7 and the relative percentages of total sulfur and various forms of sulfur in ash are tabulated in Table 8. The tabulated data from Table 8 are plotted in Fig. 6. Clay, as a binder, has an added advantage of increasing the desulfurization efficiency. This can be explained partly by the resulting firm contact between lime and coal particles when clay is used as the binding agent, which therefore, increases the contact time between evolving gases from coal pores and lime particles. In other words, more sulfur dioxide gas is entrapped within the small voids inside the briquettes. Apart from this, clay itself contains 1.68% CaO and MgO which can also function as SO_2 sorbent. More importantly, clay contains 5.66% Fe_2O_3, whose catalytic effect on the sulfation reaction has been reported by other investigator.[9]

With the addition of clay, most of the sulfur remaining in the ash is in the sulfate form, with almost none of the pyritic sulfur left. It should also be noted that, 8.66% of sulfur in the form of organic sulfur remained in the ash when no clay was used, but when clay was added this sulfur form diminished significantly. At this stage, this observation can best be explained by the effect of SiO_2 and Al_2O_3 in the clay, which act as catalytic agents for the decomposition of some organic sulfur compounds, especially those in the form of heterocyclic rings which are very stable.[8]

For coals from other sources, i.e., KV and BP, similar trends were observed when the amount of clay in briquettes was varied. The results are compiled in Table 9. Fig. 7 shows the linear relationship between the percentage of total sulfur in the ash and the percentage of clay added. Total sulfur retained in the ash increased by 10-15% when up to 40% clay was added. In this aspect, clay is a very suitable binder for coal briquetting, and it is also abundant, cheap and has good binding properties. The optimum amount to be used depends on the balance between the quality of coal briquettes, the stove efficiency, and the effectiveness in desulfurization.

TABLE 6 Total and various forms of sulfur in coals and in ash remaining after combustion in stoves using coal briquettes made with varying CaO/S mole ratios plus 20% clay (Total sulfur in original coal sample = 100)

Sample	% Total Sulfur					% Sulfate Sulfur					% Pyritic Sulfur					% Organic Sulfur				
	MM	PD	KV	BP	PK	MM	PD	KV	BP	PK	MM	PD	KV	BP	PK	MM	PD	KV	BP	PK
Coal	100	100	100	100	100	14.13	30.02	16.59	30.80	30.53	37.63	22.11	27.01	16.80	16.84	48.23	47.87	56.40	56.40	52.63
Ash (CaO/S = 0)	16.61	19.88	30.33	25.60	32.11	13.43	15.82	27.73	19.60	30.00	0.53	0.20	0.24	0.80	0.53	2.65	3.85	2.37	5.20	1.58
Ash (CaO/S = 1)	57.71	64.10	70.38	64.40	–	53.00	60.45	68.96	63.20	–	0.71	0.00	0.48	0.40	–	3.00	3.65	0.95	0.80	–
Ash (CaO/S = 1.25)	–	–	–	–	72.11	–	–	–	–	68.42	–	–	–	–	0.53	–	–	–	–	3.16
Ash (CaO/S = 2)	79.68	88.44	87.20	83.60	–	79.15	81.74	85.07	82.00	–	0.00	0.00	0.24	0.40	–	0.53	6.69	1.90	1.20	–
Ash (CaO/S = 2.5)	–	–	–	–	85.79	–	–	–	–	83.16	–	–	–	–	0.53	–	–	–	–	2.11
Ash (CaO/S = 3)	89.05	95.13	89.34	97.20	–	88.52	90.06	88.15	96.00	–	0.00	0.00	0.48	0.40	–	0.53	5.07	0.71	0.80	–
Ash (CaO/S = 4)	–	–	89.57	99.60	100.00	–	–	89.10	98.80	97.37	–	–	0.24	0.40	0.53	–	–	0.24	0.40	2.11

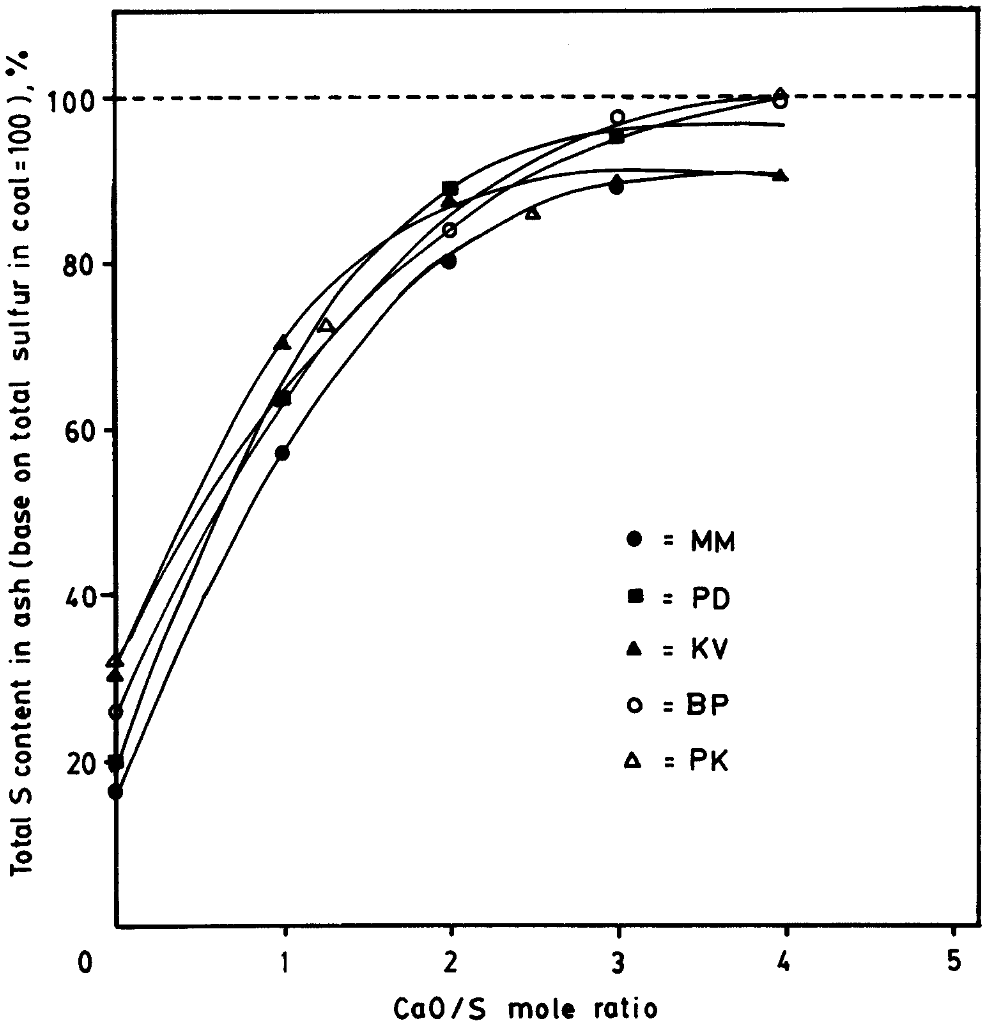

Fig. 4 Trend of total sulfur content in ash versus CaO/S mole ratio of coal briquettes made from various coal samples (% clay = 20).

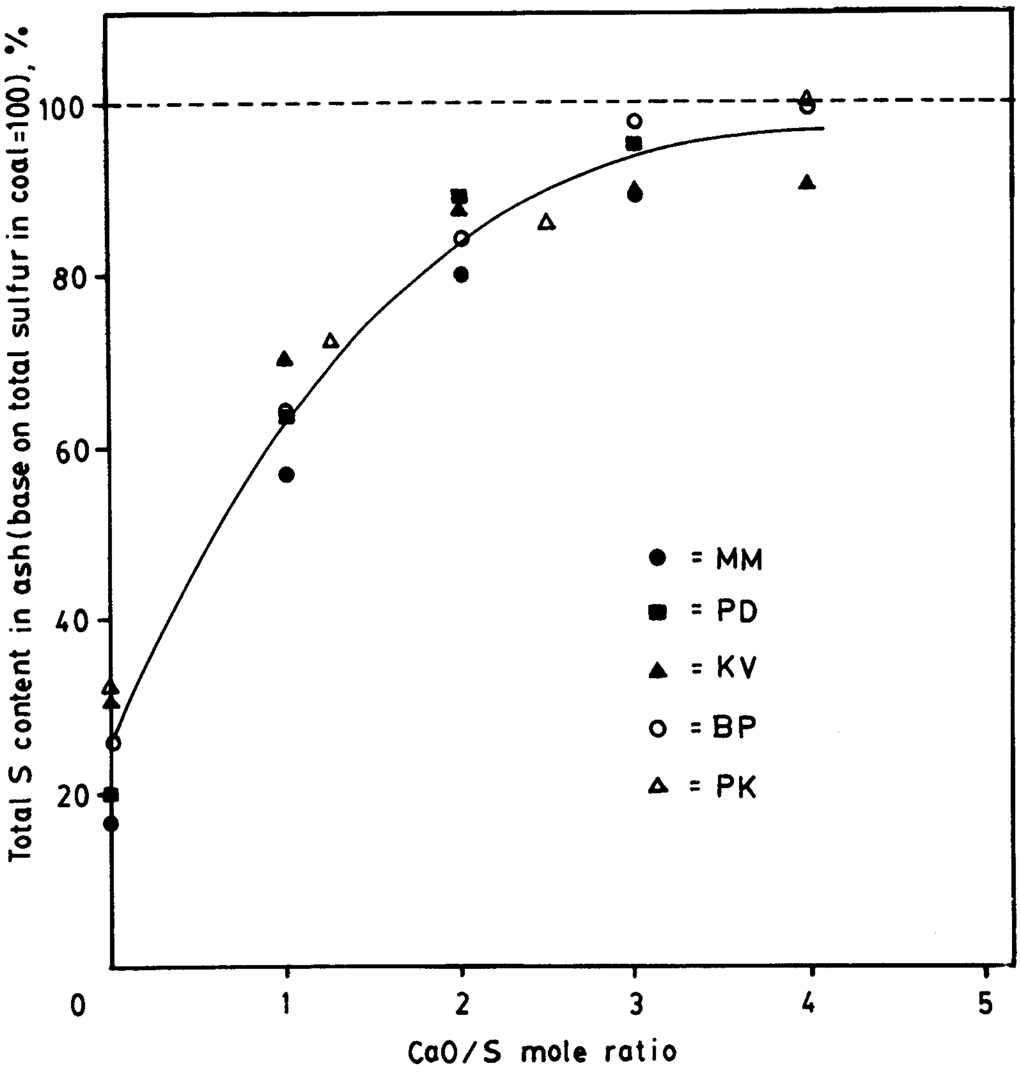

Fig. 5 General trend of total sulfur content in ash versus CaO/S mole ratio of coal briquettes made from various coal samples (% clay = 20).

TABLE 7 Total and various forms of sulfur in Mae Moh Coal and in ash remaining after combustion in stoves using coal briquettes made with varying percentages of clay and 2.0 CaO/S mole ratio

Sample	% Total Sulfur	% Sulfate Sulfur	% Pyritic Sulfur	% Organic Sulfur
Mae Moh coal	5.66	0.80	2.13	2.73
Ash MM-0%	4.38	3.87	0.02	0.49
Ash MM-10%	4.74	4.36	0.01	0.37
Ash MM-20%	4.51	4.48	0.00	0.03
Ash MM-30%	4.92	4.81	0.01	0.10
Ash MM-40%	5.11	4.98	0.01	0.02

TABLE 8 Total and various forms of sulfur in Mae Moh Coal and in ash remaining after combustion in stoves using coal briquettes made with varying percentages of clay and 2.0 CaO/S mole ratio (Total sulfur in coal = 100)

Sample	% Total Sulfur	% Sulfate Sulfur	% Pyritic Sulfur	% Organic Sulfur
Mae Moh coal	100.00	14.13	37.63	48.23
Ash MM-0%	77.39	68.37	0.35	8.66
Ash MM-10%	83.75	77.03	0.18	6.54
Ash MM-20%	79.68	79.15	0.00	0.53
Ash MM-30%	86.93	84.98	0.18	1.77
Ash MM-40%	90.28	87.99	0.18	2.12

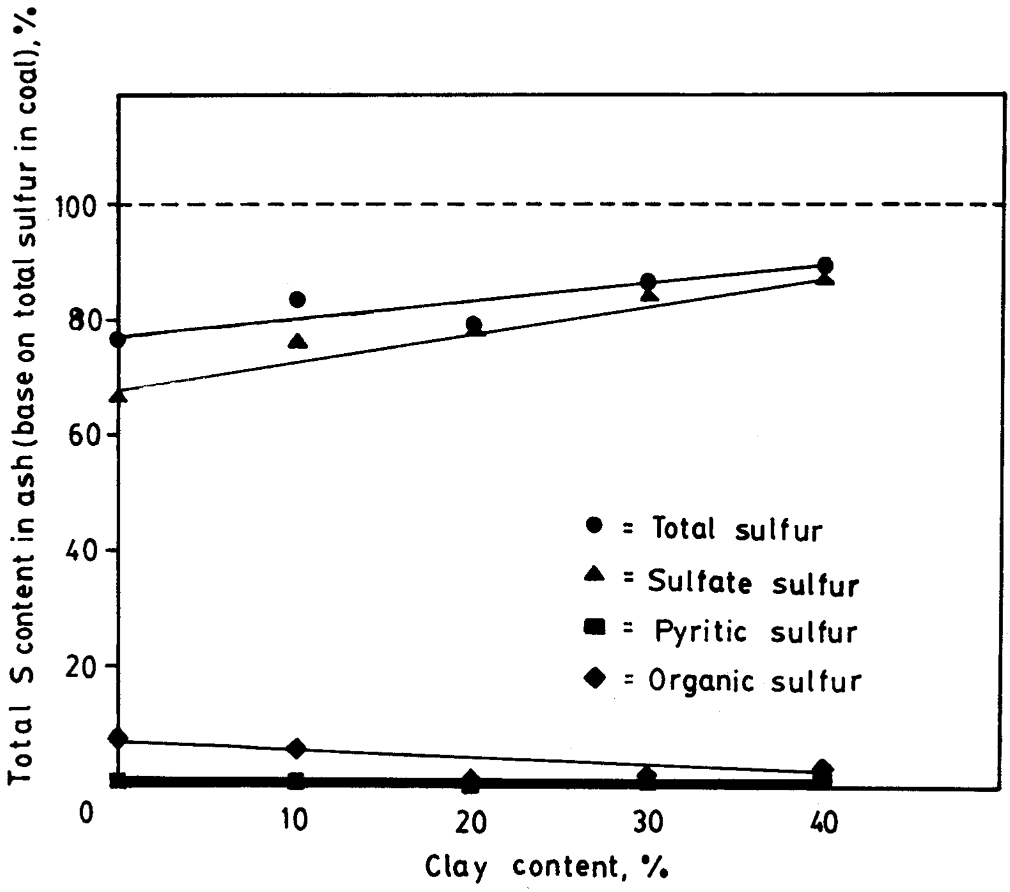

Fig. 6 Effect of clay on total and various forms of sulfur retained in ash obtained from Mae Moh coal briquettes (CaO/S = 2.0)

TABLE 9 Total and various forms of sulfur in coals and in ash remaining after combustion in stoves using coal briquettes made from varying % clay and CaO/S mole ratio = 2.0 (Total sulfur in original coal sample = 100)

Sample	% Total Sulfur			% Sulfate Sulfur			% Pyritic Sulfur			% Organic Sulfur		
	MM	KV	BP	MM	KV	BP	MM	KV	BP	MM	KV	BP
Coal	100	100	100	14.13	16.59	30.80	37.63	27.01	16.80	48.23	56.40	56.40
Ash (% clay = 0)	77.39	–	74.40	68.37	–	68.80	0.35	–	0.40	8.56	–	5.20
Ash (% clay = 10)	83.75	81.04	77.20	77.03	72.04	72.40	0.18	0.47	0.40	6.54	8.53	4.40
Ash (% clay = 20)	79.68	87.20	83.60	79.15	85.07	82.00	0.00	0.24	0.40	0.53	1.90	1.20
Ash (% clay = 30)	86.93	87.91	86.40	84.98	86.73	83.20	0.18	0.24	0.40	1.77	0.95	2.80
Ash (% clay = 40)	90.28	91.00	–	87.99	90.52	–	0.18	0.24	–	2.12	0.24	–

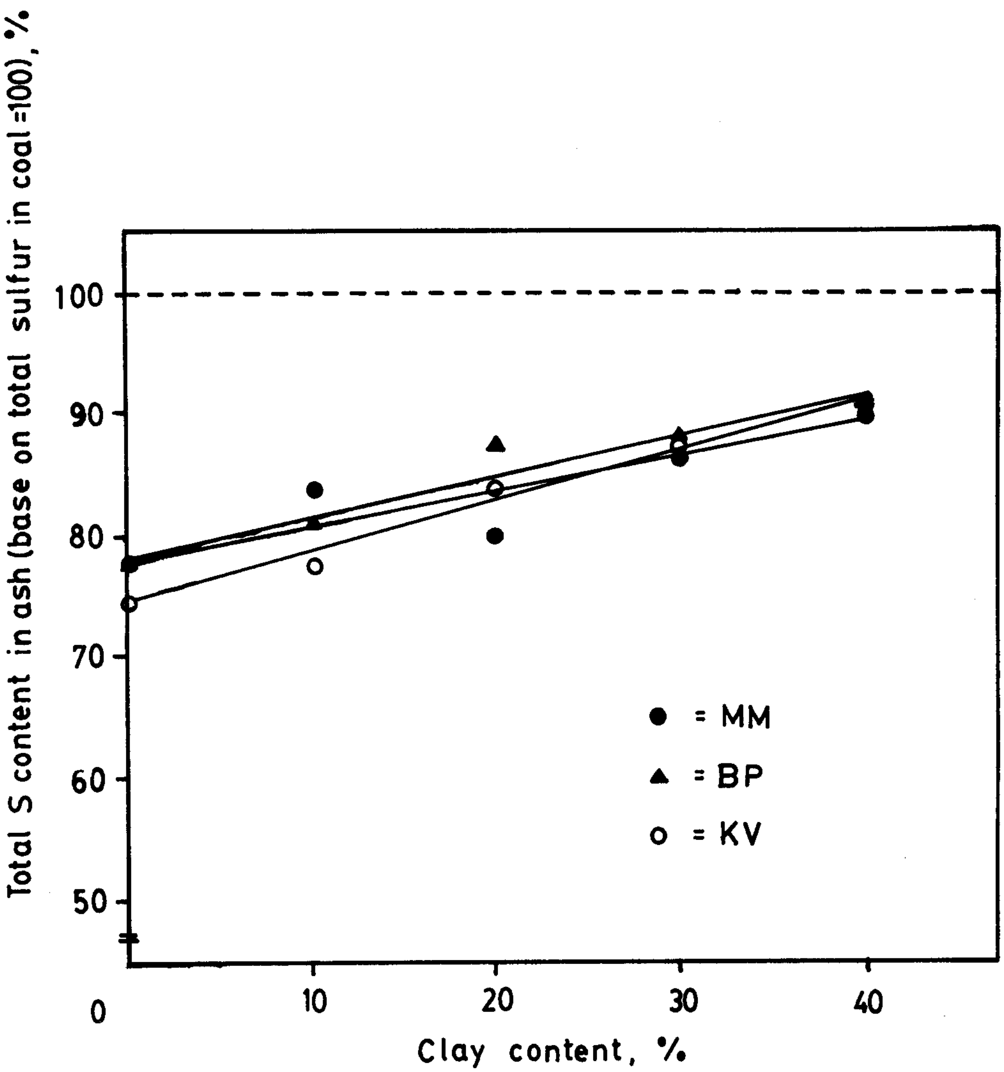

Fig. 7 Trend of % total sulfur in ash versus % clay in coal briquettes made from various coal samples (CaO/S mole ratio = 2.0).

CONCLUSION

Optimum addition of lime and clay in coal briquetting can improve the stove efficiency, and lime also functions as a desulfurizing agent very effectively. With no lime, only 15-30% of the sulfur originally present in coal will be retained in the ash after combustion, mostly in the form of sulfate sulfur, with the rest released into the atmosphere as sulfur oxides, thus causing pollution. With added lime, much more sulfur is retained in the ash after combustion. At a CaO/S mole ratio of less than 2, the amount of sulfur retained increases sharply, but levels off at a CaO/S ratio between 2-3. At CaO/S = 3-4, desulfurization is maximum, with 90-95% sulfur retained, indicating that only 5-10% sulfur is liberated into the atmosphere. Clay behaves as a good binder and also improves desulfurization, i.e. by adding clay from 0-40%, 10-15% more sulfur is retained in the ash. All coal samples under investigation show similar trends. Small discrepancies may result from the varying intrinsic properties of different coals, especially the contents of CaO, MgO, Fe_2O_3, and sulfates in the mineral matter parts of coals, which have catalytic effects on the sulfation reaction. Also, the presence of various forms of organic sulfur compounds in the coal can result in lower desulfurization efficiency.

In conclusion, for various coal samples from significant sources in Thailand the optimum addition of lime is 2.0-2.5 CaO/S mole ratio and of clay is 20%, for the production of good coal briquettes.

REFERENCES

1. Burdett, M.A., Cooper, J.R.P., Dearnley, S., Kyte, W.S. and Tunnicliffe, M.F. (1985). The Application of Direct Limestone Injection into UK Power Stations. *J. of the Institute of Energy* **64**, 64-69.
2. Chen, J.M. and Yang, R.T. (1979). Fluidized-bed Combustion of Coal with Lime Additives: Kinetics and Mechanism of Regeneration of Lime Sorbent. *Ind. Eng. Chem-Fund.* **18**(2), 134-138.
3. Nipa, Sethapisal (1985). Briquetting of Coal Fines for Household Uses. M.Sc. Thesis, Dept. of Chem. Tech., Chulalongkorn University, Bangkok, Thailand, ISBN 974-566-066-3 (Thai).
4. Arunratt, Wuttimongkolchai (1986). Variables Affecting Coal Briquette Quality. M.Sc. Thesis, Dept. of Chem. Tech., Chulalongkorn University, Bangkok, Thailand, ISBN 974-567-117-7 (Thai).
5. Osuwan, S. and Areerungruang, S. (1987). Heat Transfer Analysis in Cooking Stoves Using Coal Briquettes. Proceedings of the 4th Asian Pacific Confederation of Chemical Engineering Congress '87 Singapore, May, pp. 759-764.
6. Maust, E.E. (1980). Method for Enhancing the Utilization of Powdered Coal. Oct. 28, U.S. Pat. 4,230,460.
7. Bunyakiat, K., Osuwan, S. and Wuttimongkolchai, A. (1987). Variables Affecting Coal Briquette Quality. Proceedings of the 4th Asian Pacific Confederation of Chemical Engineering Congress '87 Singapore, May, pp. 95-100.
8. Altar, A. (1978). Chemistry, Thermodynamics and Kinetics of Reaction of Sulfur in Coal-Gas Reaction: A Review. *Fuel* *57*, 201-212.
9. Desal, N.J. and Yang, R.T. (1983). Catalytic Fluidized-bed Combustion. Enhancement of Sulfation of Calcium Oxide by Iron Oxide. *Ind. Eng. Chem. Process Des. Dev.* **22**, 119-123.

บทคัดย่อ

ปัญหาหนึ่งที่เกิดขึ้นเมื่อนำถ่านหินอัดก้อนมาใช้งานคือ มลภาวะจากก๊าซซัลเฟอร์ไดออกไซด์ ซึ่งเป็นผลมาจากกำมะถันในถ่านหิน จึงได้ศึกษาวิจัยถึงการขจัดกำมะถันในถ่านหินอัดก้อนโดยเติมปูนขาวในอัตราส่วนต่าง ๆ CaO ในปูนขาวจะทำปฏิกิริยาจับ SO_2 ที่เกิดขึ้นระหว่างการเผาไหม้ ตามสมการ; $CaO + So_2 + ½ O_2 \rightarrow CaSO_4$ $CaSO_4$ ที่เกิดขึ้นจะอยู่ในเถ้าหลังการเผาไหม้ งานวิจัยนี้ศึกษาถึงตัวแปรที่มีผลต่อการขจัดกำมะถันเมื่อทำการเผาไหม้ถ่านหินอัดก้อนในสภาวะการใช้งานจริงในเตาหุงต้ม ตัวแปรดังกล่าวคือ อัตราส่วน CaO/S (โดยโมล) ตั้งแต่ 0 ถึง 4, ร้อยละดินเหนียวที่ใช้เป็นตัวประสานตั้งแต่ 0 ถึง 40 และคุณภาพของถ่านหินจากแหล่งต่าง ๆ ได้แก่ แหล่งแม่เมาะ, บางปูดำ, คลองหวายเล็ก, บ้านปู และป่าคา

ผลการทดลองพบว่า ปูนขาวสามารถทำหน้าที่ขจัดกำมะถันในถ่านหินอัดก้อนได้ดีมาก กล่าวคือถ่านหินจากทุกแหล่งเมื่อเพิ่มปริมาณปูนขาว หรือเพิ่มอัตราส่วน CaO/S ในถ่านหินอัดก้อน กำมะถันที่ถูกปลดปล่อยไปในบรรยากาศเป็นมลภาวะถูกปูนขาวจับมาอยู่ในเถ้าในรูปสารประกอบซัลเฟต จึงทำให้กำมะถันรวมและกำมะถันซัลเฟตที่เหลือในเถ้ามีปริมาณเพิ่มขึ้นอย่างรวดเร็ว อัตราการเพิ่มขึ้นนี้จะช้าลงเมื่อ CaO/S มากกว่า 2 และคงที่ที่กำมะถันในเถ้าประมาณร้อยละ 90-95 เทียบกับกำมะถันรวมในถ่านหินเริ่มต้น แสดงว่ากำมะถันจากถ่านหินสูญหายไปในบรรยากาศเพียงร้อยละ 5-10 เท่านั้น สำหรับดินเหนียวในถ่านหินอัดก้อนนั้นมีส่วนช่วยในการขจัดกำมะถันบ้างเล็กน้อย คือเมื่อเพิ่มดินเหนียวจากร้อยละ 0 เป็น 40 กำมะถันรวมในเถ้าเพิ่มขึ้นประมาณร้อยละ 10-15 และเมื่อเปรียบเทียบผลการทดลองของถ่านหินแหล่งต่าง ๆ แนวโน้มเป็นไปในทำนองเดียวกัน

โดยสรุปแล้ว ถ่านหินอัดก้อนจากแหล่งที่สำคัญในประเทศไทย อัตราส่วน CaO/S ที่เหมาะสมอยู่ในช่วง 2.0-2.5 และดินเหนียวร้อยละ 20 ซึ่งจะให้ถ่านหินอัดก้อนคุณภาพดี ประสิทธิภาพการใช้งานสูง ในขณะเดียวกันไม่ก่อให้เกิดปัญหามลภาวะต่อสิ่งแวดล้อมด้วย