

Investigation of Calcium Aluminate Cement Phases Under High Gaseous Pressure*

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The chemical degradation of refractory cement castable liners is important in the coal gasification process. The system $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ has been investigated at high temperature and pressure. A pseudobinary reaction diagram was constructed for the system $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ in steam at 1000 psig. Several experiments were conducted in the $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ system in CO_2 , CH_4 , and CO .

Key words: Alumina cements; $\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$; coal gasification; refractory cements.

1. Introduction

The process of coal gasification requires the handling and containment of corrosive gases at high temperature and pressure. Although the chemical composition of the gaseous environment found to occur in coal gasification reactors varies depending on the processes employed, they generally contain CO , CO_2 , H_2 , H_2O , and CH_4 as major constituents and C_2H_6 , H_2S , and N_2 as minor constituents. This investigation was concerned with the chemical degradation produced by the interaction of high pressure H_2O , CO , and CO_2 with some of the phases forming the hot castable high purity calcium aluminate liner material found in many operating coal gasifiers. The principal constituents of this castable liner material are calcium aluminates and alumina.

2. Specimen Preparation and Test Methods

For most of the hydration experiments, pure, well-characterized, starting materials were employed. The compositions $3\text{CaO} \cdot \text{Al}_2\text{O}_3$, $\text{CaO} \cdot \text{Al}_2\text{O}_3$, $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$, and $\text{CaO} \cdot 6\text{Al}_2\text{O}_3$ were prepared from high purity CaCO_3 and Al_2O_3 . These admixtures were ground and calcined at 700°C for 60 hours, 1000°C for 16 hours, and 1500°C for 60 hours. The three compositions highest in Al_2O_3 content were reheated for an additional 60 hours at 1550°C . All of these materials, synthesized in air, were characterized by x-ray powder diffraction techniques and found to be single phase.

These single phase materials were placed in small platinum tubes, with calculated, weighed amounts of H_2O and sealed. The tubes were heated by conventional hydrothermal techniques, quenched, opened, and dried. The reaction products were identified by x-ray powder diffraction. Materials reacted in other environments were treated similarly except that they were heated in open platinum tubes in the absence of introduced H_2O .

3. Results and Discussion

3.1. System $\text{CaO-Al}_2\text{O}_3$ in Steam

Considerable information on the $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ system has been reported in the literature. The work of Peppler and Wells [1]¹ and Majumdar and Roy [2] summarize most of our present knowledge of this system. Nurse et al. [3] found that $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$ melts congruently at 1392°C in atmospheric air. In dry air, preformed $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$ melts incongruently to $\text{CaO} \cdot \text{Al}_2\text{O}_3$ and a liquid at 1374°C . He further concluded that the $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$ compound did not have a field of stability in the strictly anhydrous $\text{CaO-Al}_2\text{O}_3$ system.

For the purpose of studying the solid state reactions encountered with steam in a coal gasifier the solubility data of Peppler and Wells were reinterpreted with the view of integrating the data with those of Majumdar and Roy. This was accomplished by constructing the diagram, figure 1, from the data given by Peppler and Wells and Majumdar and Roy and from the data in table I. From these low temperature data, it was possible to predict the behavior at 1000°C . Therefore, it was necessary only to verify that portion of the system which could directly affect the operation of a coal gasifier at 1000°C and 1000 psig² of steam.

To verify the reactions which occur in the $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ system at high temperatures and pressures a series of experiments were conducted and the results are given in table II. A pseudobinary reaction diagram, figure 2, was constructed from the data in table II. In constructing figure 2, it was necessary to neglect the starting phases and assume the various starting materials would approach the same equilibrium products in any given temperature, pressure, time sequence.

From figure 2 it can be seen that the first hydrate formed, $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$, is unstable and dissociates, above room temperature, to form $\text{Ca}(\text{OH})_2$ and $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$.

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¹ Figures in brackets indicate the literature references at the end of this paper.

² The use of psi, psig, bar, and kbar follows the current common practice of workers in the field. Note that 1 bar = 10^5 N/m^2 (or pascal) = 0.9869 atm = 14.504 psi. The accepted international standard (SI) unit of pressure is the pascal or newton per square meter.

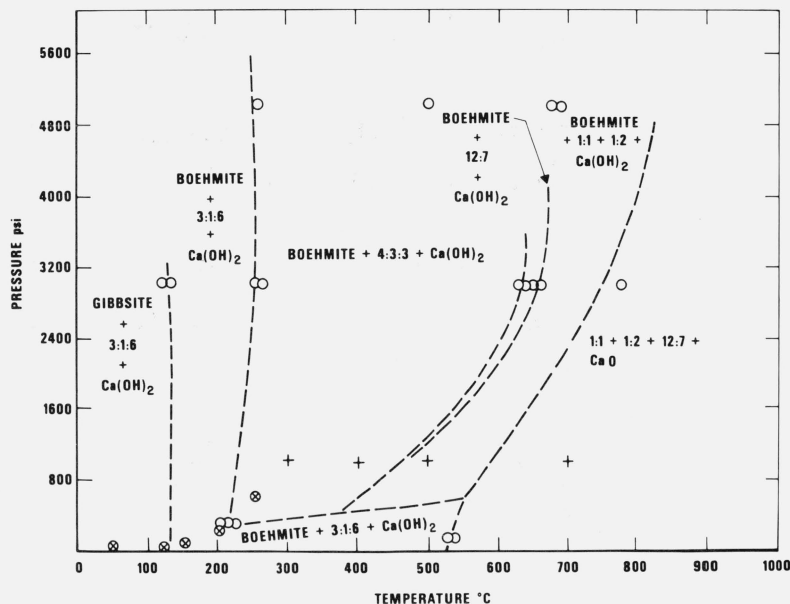


FIGURE 1. Proposed constitution diagram.

- ⊗ Peppler and Wells
- Majumdar and Roy
- + Waring et al. (this work)

Table I. Experimental Data Used to Construct the Pressure-Temperature Diagram for the System $\text{CaO}-\text{Al}_2\text{O}_3-\text{H}_2\text{O}$.

Starting Material ^{1/}	Temperature °C	Pressure psig	Time days	X-ray Diffraction Analysis	Conclusion
1:2	300	1000	7	1:2 + 4:3:3 + boehmite	1:2 → boehmite + 4:3:3
1:2	700	1000	7	1:2	1:2 → 1:2
1:1	700	1000	7	1:1 + trace 1:2	1:1 → 1:1
1:2	400	1000	11	1:2 + boehmite + 4:3:3	1:2 → boehmite + 4:3:3
1:2	500	1000	11	1:2	1:2 → 1:2
1:1	400	1000	11	1:1	1:1 (?)
1:1	500	1000	11	1:1 may have faint trace of 1:2	1:1 → 1:1

^{1/} 1:2 = $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$

1:1 = $\text{CaO} \cdot \text{Al}_2\text{O}_3$

4:3:3 = $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$

$\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ = boehmite

Preformed $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ was found to have a minimum dissociation temperature in excess of 1000 °C and 1000 psig steam. The 1000 °C and 1000 psig data were obtained using a TZM (titanium-zirconium-molybdenum alloy)³ apparatus.

³ Certain commercially available materials or instruments are identified in this publication for the purpose of providing a complete description of the work performed. The experiments reported do not constitute a complete evaluation of the performance characteristics of the products so identified. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards nor does it imply that the items identified are necessarily the best available for the purpose.

The maximum and minimum dissociation temperatures for the $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$ have not been established. However, the minimum dissociation temperature is probably in excess of 400 °C and the compound should be stable up to the melting point of 1392 °C. The hydrate $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ forms in a wet atmosphere at about 20 °C and is stable up to about 600 °C in 1000 psig steam. The compounds $\text{CaO} \cdot \text{Al}_2\text{O}_3$ and $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$ were found to exist at temperatures in excess

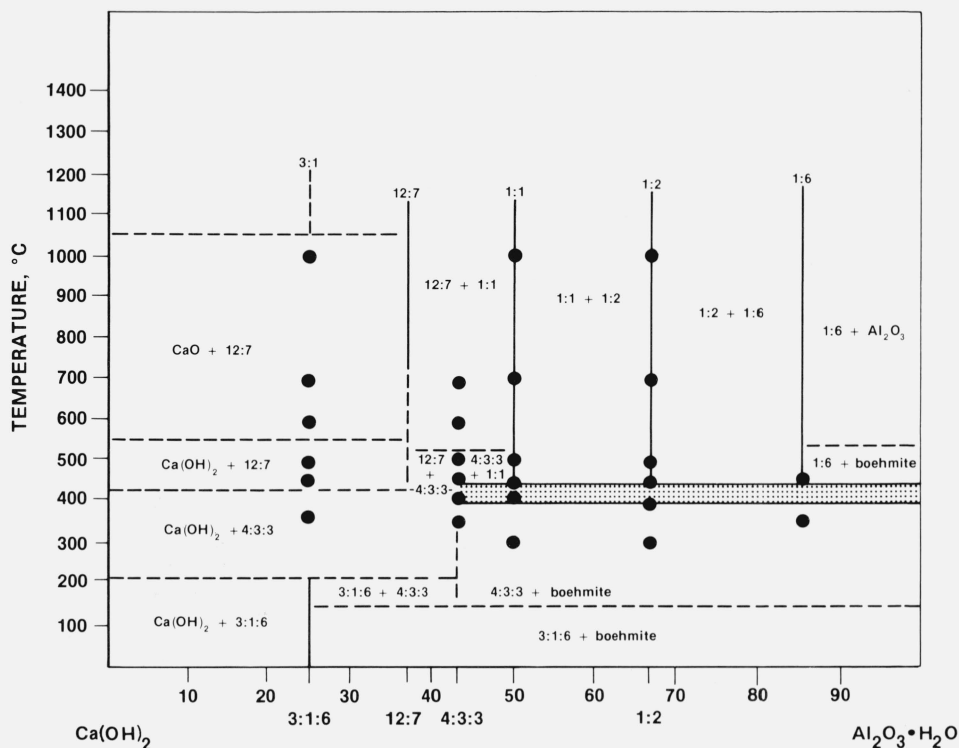
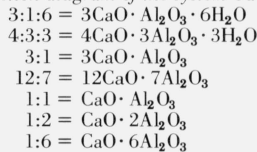


FIGURE 2. Tentative pseudobinary reaction diagram of the system $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ at 1000 psig.



$\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ = boehmite
 ▨ = region of undetermined equilibria
 ● = experimental points

of 1000 °C and to hydrate below 400 °C. The compounds $\text{CaO} \cdot \text{Al}_2\text{O}_3$, $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$ and $\text{CaO} \cdot 6\text{Al}_2\text{O}_3$, experimentally, appear to have the same minimum temperature of stability since at these relatively low temperatures the reactions occur very slowly. It has not been possible to delineate these boundaries; therefore, the region of uncertainty is shaded in the diagram, figure 2. At a temperature below approximately 400-450 °C, these phases dissociate into boehmite ($\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. The phase transition between boehmite and Al_2O_3 in the pressure range of 1000 psig was not determined.

In a cement which initially consists of $\text{CaO} \cdot \text{Al}_2\text{O}_3$ and $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$ with Al_2O_3 grog, the $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$ originally formed after the addition of H_2O will transform rapidly upon the increase of pressure and temperature to form $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. This phase will then react at slowly increasing temperatures to form, first, $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$ plus $\text{CaO} \cdot \text{Al}_2\text{O}_3$ and then, eventually, $\text{CaO} \cdot 6\text{Al}_2\text{O}_3$ plus Al_2O_3 , if the whole product attains equilibrium.

3.2. System $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ in CO_2

Several experiments were conducted at high temperature in CO_2 (860 psig) and the results are given in table III.

The data given in table III indicate that the reactions which occur in a CO_2 environment are similar to those occurring in steam. There are several exceptions. The $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ phase at 500 °C is stable in steam but in CO_2 partially decomposes to $\text{CaCO}_3 + \text{Al}_2\text{O}_3$. At 600 °C/860 psig CO_2 , that portion of the $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, which has not reacted with the CO_2 , dehydrates to form a cubic phase with $a \cong 8.9$ Å, which is apparently the aluminate analog of sodalite ($\text{Ca}_4\text{Al}_6\text{O}_{13}$, analogous to $\text{Na}_4\text{Al}_3\text{Si}_3\text{O}_{12}\text{Cl}$). The occurrence of the calcium aluminate analog of sodalite was reported by Ponomarev, Kheiber, and Belov [4] to form by dehydration in air from hydrothermally grown single crystals. Several experiments indicate that other $\text{CaO-Al}_2\text{O}_3$ phases may also be stable with respect to the $\text{CaCO}_3\text{-Al}_2\text{O}_3$ system under these conditions.

Table II. Experimental Data for Compositions in the System CaO-Al₂O₃-H₂O at 1000 psig Steam Pressure.

Starting Material ^{1/}	Temp. °C	Pressure psig	Time hrs	X-ray Diffraction Analysis	Conclusions
3:1:6	350	1000	720	4:3:3 + Ca(OH) ₂ + hydrate	3:1:6 → 4:3:3 + hydrate
3:1:6	450	1000	720	4:3:3 + Ca(OH) ₂ + 3:1:6 + hydrate	3:1:6 → 4:3:3 + hydrate
3:1	350	1000	720	3:1 + Ca(OH) ₂ + 12:7	3:1 → 12:7 + Ca(OH) ₂
3:1	450	1000	720	3:1 + Ca(OH) ₂ + 12:7	3:1 → 12:7 + Ca(OH) ₂
3:1	500	1000	168	3:1 + 12:7 + Ca(OH) ₂	3:1 → 12:7 + Ca(OH) ₂
3:1	600	1000	168	12:7 + 3:1 + CaO	3:1 → 12:7 + CaO
3:1	700	1000	168	3:1 + 12:7 + CaO	3:1 → 12:7 + CaO
3:1	1000	945	120	12:7 + CaO	3:1 → 12:7 + CaO
4:3:3	350	1000	720	4:3:3 + boehmite	Ca(OH) ₂ + amorphous Al ₂ O ₃ + 4:3:3 → 4:3:3 + boehmite
4:3:3	400	1000	86	4:3:3 + Ca(OH) ₂	4:3:3 + amorphous Ca(OH) ₂ + amorphous Al ₂ O ₃ → 4:3:3 + Ca(OH) ₂
4:3:3	450	1000	720	4:3:3	4:3:3 + amorphous Ca(OH) ₂ + amorphous Al ₂ O ₃ → 4:3:3
4:3:3	500	1000	86	4:3:3 + Ca(OH) ₂	4:3:3 + amorphous Ca(OH) ₂ + amorphous Al ₂ O ₃ → 4:3:3 + cryst Ca(OH) ₂
4:3:3	500	1000	168	4:3:3	4:3:3 + amorphous Al ₂ O ₃ + amorphous Ca(OH) ₂ → 4:3:3
4:3:3	600	1000	168	4:3:3 + 12:7 + CaO	4:3:3 → 12:7 + CaO
4:3:3	700	1000	168	(leaked) 12:7 + 1:1	---
1:1	300	1000	168	4:3:3 + 1:1 + boehmite	1:1 → boehmite + 4:3:3
1:1	400	1000	240	1:1	1:1(?)
1:1	450	1000	240	1:1 + 4:3:3	1:1 → 4:3:3
1:1	500	1000	264	1:1	1:1 → 1:1
1:1	700	1000	168	1:1 + 1:2	1:1 → 1:1
1:1	1000	945	120	1:1	1:1 → 1:1
1:2	300	1000	168	1:2 + 4:3:3 + boehmite	1:2 → boehmite + 4:3:3
1:2	400	1000	264	1:2 + boehmite + 4:3:3	1:2 → boehmite + 4:3:3
1:2	450	1000	240	1:2	1:2 → 1:2
1:2	500	1000	264	1:2	1:2 → 1:2
1:2	700	1000	168	1:2	1:2 → 1:2
1:2	1000	945	120	1:2	1:2 → 1:2
1:6	350	1000	945	1:6 + 4:3:3 + Al ₂ O ₃	1:6 → 4:3:3 + Al ₂ O ₃ (+ boehmite-?)
1:6	450	1000	945	1:6 + Al ₂ O ₃	1:6 → 1:6 + Al ₂ O ₃

^{1/} 3:1:6 = 3CaO·Al₂O₃·6H₂O Al₂O₃·H₂O = boehmite
 1:2 = CaO·2Al₂O₃
 3:1 = 3CaO·Al₂O₃
 4:3:3 = 4CaO·3Al₂O₃·3H₂O
 12:7 = 12CaO·7Al₂O₃
 1:1 = CaO·Al₂O₃
 1:6 = CaO·6Al₂O₃
 hydrate = hydrated calcium aluminate of unknown composition

3.3. System CaO-Al₂O₃-H₂O in CH₄

Two specimens consisting of CA-25, a commercially available calcium aluminate cement, and 4CaO·3Al₂O₃·3H₂O were heated in a methane environment at 800 °C for two weeks at 1000 psig. The x-ray powder pattern of the CA-25 specimen showed the CaO·Al₂O₃, CaO·2Al₂O₃ and Al₂O₃ which were present in the original CA-25 plus an unknown phase with a line at about 24° 2θ (CuKα radiation). This

unknown phase did not appear to be calcium formate. The 4CaO·3Al₂O₃·3H₂O contains 12CaO·7Al₂O₃ and CaO·Al₂O₃. These are the same reaction products as those occurring under 1000 psig steam at the same composition and temperature. Table IV summarizes the results.

3.4. System CaO-Al₂O₃-H₂O in CO

Four compositions were heated in CO (Table V) at 1000 psig and 700 °C for 110 hours. The x-ray pattern of the

Table III. Experimental Data for Compositions in the System $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ in 860 psig of CO_2 .

Starting Material ^{a/}	Temp. °C	Pressure psig	Time hrs	Results ^{b,c/} X-ray Diffraction Analysis	Conclusions
3:1	600	860	72	3:1	3:1 → 3:1
3:1	700	860	72	3:1 + 12:7 + CaCO_3	3:1 → 12:7 + CaCO_3
3:1	700	860	144	3:1 + 12:7 + CaCO_3	3:1 → 12:7 + CaCO_3
3:1:6	500	860	336	CaCO_3 + 4:3:3	3:1:6 → CaCO_3 + 4:3:3
3:1:6	600	860	384	CaCO_3 + 12:7 + 1:2	3:1:6 → CaCO_3 + 12:7 + 1:2
3:1:6	800	860	144	CaCO_3 + unknown ^{e/} + 1:2	3:1:6 → CaCO_3 + unknown ^{e/} + 1:2
4:3:3	500	860	288	4:3:3 + Al_2O_3 + CaCO_3	4:3:3 → CaCO_3 + Al_2O_3
4:3:3	600	860	384	"sodalite" ^{d/} + CaCO_3	4:3:3 → "sodalite" ^{d/} + CaCO_3
4:3:3	700	860	144	1:1 + CaCO_3 + unknown(s) ^{e,f/}	4:3:3 → 1:1 + CaCO_3 + unknown(s) ^{e,f/}
4:3:3	800	860	144	1:1 + 1:2 + CaCO_3 + unknown ^{e/}	4:3:3 → 1:1 + 1:2 + CaCO_3 + unknown ^{e/}
1:1	500	860	288	1:1 + Al_2O_3 + CaCO_3	1:1 → Al_2O_3 + CaCO_3
1:1	600	860	72	1:1	1:1 → 1:1
1:1	700	860	72	1:2 + CaCO_3	1:1 → 1:2 + CaCO_3
1:1	800	860	144	1:1	1:1 → 1:1
1:2	500	860	720	1:2	1:2 → 1:2
1:2	700	860	192	1:2	1:2 → 1:2
1:6	500	860	720	1:6 + tr $\alpha\text{-Al}_2\text{O}_3$	1:6 → 1:6

^{a/} All bulk starting materials, which were spectrographically pure, were mixed and calcined for sufficient time and at a temperature to obtain single phase materials. These specimens were heated in a conventional hydrothermal bomb in open Pt tube and were quenched by water immersion from the temperatures indicated.

^{b/} The phases identified are given in order of the amount present (greatest amount first) at room temperature. These phases are not necessarily those present at the temperature to which the specimen was heated.

^{c/} The following short notations were used for clarity:

- 3:1 = $3\text{CaO}\cdot\text{Al}_2\text{O}_3$
- 3:1:6 = $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 6\text{H}_2\text{O}$
- 12:7 = $12\text{CaO}\cdot 7\text{Al}_2\text{O}_3$
- 4:3:3 = $4\text{CaO}\cdot 3\text{Al}_2\text{O}_3\cdot 3\text{H}_2\text{O}$
- 1:1 = $\text{CaO}\cdot\text{Al}_2\text{O}_3$
- 1:2 = $\text{CaO}\cdot 2\text{Al}_2\text{O}_3$
- 1:6 = $\text{CaO}\cdot 6\text{Al}_2\text{O}_3$

^{d/} The "sodalite" dehydration product (major peak, $d = 3.642$)

^{e/} Unknown dehydration product (major peak, $d = 3.697$)

^{f/} Unknown dehydration product (major peak, $d = 3.620$)

sample which was initially $\text{CaO}\cdot\text{Al}_2\text{O}_3$ showed a mixture of $\text{CaO}\cdot\text{Al}_2\text{O}_3$ and $\text{CaO}\cdot 2\text{Al}_2\text{O}_3$. The $4\text{CaO}\cdot 3\text{Al}_2\text{O}_3\cdot 3\text{H}_2\text{O}$ showed the same decomposition products as those heated in CO_2 . The CA-25 x-ray pattern showed mixtures of CaCO_3 , Al_2O_3 , $\text{CaO}\cdot 2\text{Al}_2\text{O}_3$ and $\text{CaO}\cdot\text{Al}_2\text{O}_3$. The $\text{CaO}\cdot 2\text{Al}_2\text{O}_3$ showed no reaction.

4. Summary

Many questions remain unanswered which could not be investigated in this study. However, the following observations should be noted:

1. At 1000 psig steam pressure, the phase boundaries are essentially those which can be predicted from a combination of the published data of Peppler and Wells [1] and Majumdar and Roy [2].
2. The cementitious phases $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 6\text{H}_2\text{O}$ and $4\text{CaO}\cdot 3\text{Al}_2\text{O}_3\cdot 3\text{H}_2\text{O}$ are not stable at any higher temperature in 1000 psig steam than they are at atmospheric pressure.
3. The compound $4\text{CaO}\cdot 3\text{Al}_2\text{O}_3\cdot 3\text{H}_2\text{O}$ decomposes to metastable phases in dry atmospheres such as CO_2 or CO and directly to the stable phases in steam.

Table IV. Experimental Data for Compositions in the System $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ in CH_4 .

Starting Materials ^{a/}	Temp. °C	Pressure psig	Time hrs	Results ^{b,c/}		Conclusions
				X-ray	Diffraction Analysis	
CA-25	800	1000	316	1:2 + 1:1 + $\alpha\text{-Al}_2\text{O}_3$ + unknown ^{d/}		
4:3:3	800	1000	316	12:7 + 1:1		4:3:3 → 12:7 + 1:1

^{a/} All bulk starting materials, which were spectrographically pure, were mixed and calcined for sufficient time and at a temperature to obtain single phase materials. These specimens were heated in an open platinum tube in a conventional hydrothermal bomb.

^{b/} The phases identified are given in order of the amount present (greatest amount first) at room temperature. These phases are not necessarily those present at the temperature to which the specimen was heated.

^{c/} 4:3:3 = $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$

1:2 = $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$

1:1 = $\text{CaO} \cdot \text{Al}_2\text{O}_3$

12:7 = $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$

CA-25 = A commercial cement containing 1:1, 1:2 and $\alpha\text{-Al}_2\text{O}_3$

^{d/} Specimen contains an unknown phase with the major x-ray diffraction powder line occurring at about 3.7 \AA .

Table V. Experimental Data for Compositions in the System $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ in CO_2 .

Starting Materials ^{a/}	Temp. °C	Pressure psig	Time hrs	Results ^{b/}		Conclusions
				X-ray	Diffraction Analysis	
1:1	700	1000	110	1:1 + 1:2		
4:3:3	700	1000	110	1:1 + "sodalite" ^{c/} + CaCO_3		4:3:3 + 1:1 + CaCO_3
1:2	700	1000	110	1:2		1:2 + 1:2
CA-25	700	1000	110	CaCO_3 + $\alpha\text{-Al}_2\text{O}_3$ + 1:2 + 1:1		

^{a/} All bulk starting materials, which were spectrographically pure, were mixed and calcined for sufficient time and at a temperature to obtain single phase materials. These specimens were heated in an open platinum tube in a conventional hydrothermal bomb.

^{b/} The phases identified are given in order of the amount present (greatest amount first) at room temperature. These phases are not necessarily those present at the temperature to what the specimen was heated.

^{c/} This material is a dehydration product which appears to be the calcium aluminate analog of sodalite.

4:3:3 = $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$

1:2 = $\text{CaO} \cdot 2\text{Al}_2\text{O}_3$

1:1 = $\text{CaO} \cdot \text{Al}_2\text{O}_3$

CA-25 = A commercial cement containing 1:1, 1:2 and $\alpha\text{-Al}_2\text{O}_3$

4. Most of the phases in the $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ system are not stable in CO_2 (860 psig) with respect to the system $\text{CaCO}_3\text{-Al}_2\text{O}_3$.

In order to determine the possible deleterious effects of the combined gaseous atmospheres present in a coal gasifier, a considerably more detailed study must be made of the $\text{CaO-Al}_2\text{O}_3\text{-H}_2\text{O}$ system, especially in CH_4 and in various gaseous combinations.

5. References

- [1] Peppler, R. B., and Wells, L. S., J. Res. Nat. Bur. Stand. (U.S.), 50, No. 2, 75-92 (1954) RP2476.
- [2] Majumdar, A. J., and Roy, R. J., J. Am. Ceram. Soc. **38**, 568 (1956).
- [3] Nurse, R. W., Welch, J. H., and Majumdar, A. J., Trans. Brit. Ceram. Soc. **64**, [9] 409 (1965).
- [4] Ponomarev, Y. I., Kheiber, D. M., and Belov, N. V., Soviet Physics **15** [5] 799, (1971).