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**ROLE OF FLY ASH IN HEAVY METAL REMOVAL
FROM FLUE GAS**

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by

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EXECUTIVE SUMMARY

The work is mainly focused towards investigating the sorption phenomena of a representative chalcophile, arsenic (As) species, on fly ashes at temperatures representative of the upper-furnace region (850-1200°C) and the economizer section (375-600°C). Arsenic is chosen because it is a highly toxic chalcophile and shows some affinity for fly ash but is also emitted from the stack as vapor and aerosol particles. Based on the preliminary thermodynamic analyses it was determined that under the temperature ranges of interest (400-600°C and 800-1000°C) arsenic trioxide (As_2O_3) is the main arsenic species in the flue gas environment and thus is considered as the source of arsenic species for further experimental studies. The two temperature zones have been chosen because most of the dry-sorbent injection technologies are being developed for application in these two regions. Also, various fly ash samples from different sources are being studied because their chemical composition and subsequently their chemical sorption characteristics would show a great deal of variation depending on their source.

Experimental studies were carried out in a differential bed reactor to study the arsenic sorption behavior of three fly ash samples, viz., NIST, Zimmer, and Pickway fly ash. Zimmer fly ash seems to show not only the highest capture among the three, it also showed the highest water non-leachable arsenic capture. Hence, it was proposed to conduct more mechanistic studies with Zimmer fly ash. Desorption studies with the post sorption sample has shown significant reduction in captured arsenic species content following exposure to high temperatures in an arsenic-free environment. These results strongly suggest that interaction between fly ash particles and arsenic species is physical in nature involving reversible physical adsorption.

Studies were also conducted with calcium hydroxide as the chosen representative dry sorbent. This served as comparative studies between fly ash and dry sorbents. This will enable us to predict the behavior of arsenic when exposed to both fly ash and sorbent which is the case under actual boiler conditions. Experimental results show that $\text{Ca}(\text{OH})_2$ captures significant amounts of arsenic species. To gain further insight into the capturing mechanism of calcium hydroxide experiments were performed at various temperatures and exposure times. Studies with $\text{Ca}(\text{OH})_2$ in the medium and high temperature ranges have yielded

interesting results. Amount of arsenic captured by the sorbent in both the temperature windows was found to be nearly identical. The effect of exposure time on amount of capture and the sorption capacity of the sorbent were also investigated. Experiments were conducted in the differential reactor for sorption times as low as 15 min. and as high as 24 hours. Sorbent showed high initial capturability but with increasing exposure time the amount of arsenic captured was found to asymptotically approach a saturation level.

An Entrained Flow Reactor (EFR) system was designed and constructed in order to study the short time As-Ca(OH)₂ interaction under entrained flow conditions. The EFR system was designed to conduct experiments with residence time in the range of 1-5 seconds and at temperatures upto 1000°C. Experiments were conducted in the EFR to test the capturability of arsenic species by Ca(OH)₂. Results from these experiments indicate that Ca(OH)₂ captured as much as 2250 ppm (0.252 wt % CaO utilization) of arsenic species for a residence time of 3 seconds under entrained conditions. Further more entrained flow reactor studies showed nearly identical arsenic capture by the sorbent at 600°C and 900°C reaction temperatures thereby corroborating the results obtained from differential bed reactor experiments.

I. OVERVIEW

A. Background and Scope:

The primary objective of this work is to study the fundamental phenomena involved in the sorption of trace chalcophilic elements by fly ash at high and medium temperatures. Chalcophiles are the low-boiling trace elements that are volatilized during pulverized coal combustion and are transferred to the gas phase, e.g., As, Pb, Cd and Se. Fly ash acts as a sink for some of these volatile trace toxics and a great deal of chemical interaction is speculated to take place under furnace conditions. This fly ash-chalcophiles interaction, though crucial to the control of chalcophilic emissions, is still very poorly understood. This is due, in part, to the lack of experimental studies and data on the behavior of fly ash and chalcophiles.

The main focus of this work is investigating the sorption phenomena of a representative chalcophile, arsenic (As) species on fly ashes at temperatures representative of the upper-furnace region (850-1200°C) and the economizer section (375-600°C). Arsenic is chosen because it is a highly toxic chalcophile and shows some affinity for fly ash but is also emitted from the stack as vapor and aerosol particles. Based on the preliminary thermodynamic analyses (project 4.2 OCDO Quarterly reports, 1993-1994) it was determined that under the temperature ranges of interest (400-600°C and 800-1000°C) arsenic trioxide (As_2O_3) is the main arsenic species in the flue gas environment and thus was considered as the source of arsenic species for further experimental studies. The two temperature zones have been chosen because most of the dry-sorbent injection technologies are being developed for application in these two regions. Also, various fly ash samples from different sources are being studied because their chemical composition and subsequently their chemical sorption characteristics would show a great deal of variation depending on their source.

B. Long Term Objectives:

The long term objective of this research project is to deliver the following:

1. identify the possible interaction between arsenic species in the flue gas and fly ash.
2. investigate the mechanism of arsenic interaction with fly ash.
3. identify and investigate the mechanism of interaction of arsenic species with various mineral sorbents.
4. if any, identify the chemical compound formed by As/sorbent interaction.

II. DIFFERENTIAL BED REACTOR STUDIES

A. Studies with Fly Ash:

In the first year of the project a novel differential bed reactor system was developed to study arsenic species interaction with various fly ash and mineral sorbent samples under two different temperature conditions, viz, medium temperature (400-600°C) and high temperature (800-1000°C). A part of the second year was spent on conducting experiments with fly ash samples procured from Pickway Thermal Power Plant operated by American Electric Power Company. Since fly ash from different sources can have substantially different chemical composition and properties and can therefore exhibit different sorption behavior, it was proposed to study fly ash from various sources. The Pickway plant utilizes southeastern Ohio coal for its operations. Information about the chemical composition of their fly ash was not available. The Pickway fly ash was analyzed in our laboratory for its arsenic content and its leachability. It was found to contain about 190 ppm of arsenic of which 100 ppm was found to be leachable by water. The non water leachable portion was analyzed by leaching with 20% H_2O_2 .

Following this analysis, differential reactor experiments were performed with Pickway fly ash. Runs were performed under the same conditions as the previous two fly ashes in order to draw a comparison of their sorption performances (data reported in first year Annual report). Post sorption analyses was carried out using Atomic Absorption Spectrometer (AAS) to determine the content of arsenic in the solid samples. The desorption studies with the port-sorption fly ash samples strongly indicate that the capture indeed involves physical adsorption and would suggest that the arsenic content of the post-sorption fly ash sample is contributed by the physically adsorbed As_2O_3 . Figure 1 shows the uptake after 4 hours of sorption by Pickway fly ash as compared to Zimmer and NIST fly ash. The conditions were 65 ppm (mg/m^3) concentration of As_2O_3 in the gas phase at a temperature of 500°C. As can be seen from the figure, Pickway fly ash seems to have much less affinity for arsenic as compared to Zimmer or NIST. Sorption studies with fly ash were carried out in the

Figure 1: Water leachable and total As captured by NIST, Zimmer and Picaway fly ashes at 773 K

differential bed reactor under nitrogen atmosphere and no effort was made to study the sorption of As_2O_3 by fly ash in flu gas environment.

It was originally proposed to study fly ash from 5 different sources around Ohio. We have so far performed studies with the three fly ashes. After considering the efforts involved in procuring, characterizing and studying fly ash sorption, it is proposed that we now concentrate our efforts on thorough studies with one particular fly ash. Zimmer fly ash seems to show not only the highest capture among the three, it shows the highest water non-leachable arsenic capture. Hence, it is proposed to conduct more mechanistic studies with Zimmer fly ash. Desorption studies with the post sorption sample has shown significant reduction in captured arsenic species content following exposure to high temperatures in an arsenic-free environment. These results strongly suggest that interaction between fly ash particles and arsenic species is physical in nature involving reversible physical adsorption of arsenic species (in this case, As_2O_3).

B. Mineral Sorbent Studies:

Studies were also conducted with calcium hydroxide as the chosen representative dry sorbent. This served as comparative studies between fly ash and dry sorbents. This will enable us to predict the behavior of arsenic when exposed to both fly ash and sorbent which is the case under actual boiler conditions. Further, since Project 4.1 is already working on studying sorption of selenium by calcium hydroxide, these experiments will add further insights into the sorption of different heavy metals by calcium hydroxide.

Figure 2 shows a sample result of our studies with Linwood hydrate sorption of arsenic trioxide. As can be seen, at 900°C with arsenic species vapor phase concentration of 13 ppm, the total capture by $\text{Ca}(\text{OH})_2$ is of the order of 1000 ppm which compares with about 1900 to 2000 ppm shown by NIST and Zimmer fly ash. This shows that calcium hydroxide sorption ability is not only comparable to that of fly ash, nearly 50% of the overall capture is not water leachable

Apart from testing $\text{Ca}(\text{OH})_2$ for arsenic species capture sorption studies have also been carried out with Kaolinite in the differential bed reactor. Figure 3 shows a comparison

Figure 2: Water leachable and total As captured by NIST fly ash, Zimmer fly ash and Ca(OH)_2 at 1173 K.

Figure 3: Comparison between Ca(OH)_2 and Kaolinite at 600°C for arsenic sorption; 1 hour of sorption.

between Ca(OH)_2 and kaolinite for arsenic species (As_2O_3) uptake at 600°C following sorption for 1 hour at a As_2O_3 concentration of about 13 ppm. As can be seen, hydrated lime shows nearly 4 times higher capture than kaolinite at 600°C . The amount captured by both these sorbents is predominantly water leachable. As a result, further studies were conducted with the hydrated lime to investigate the influence of temperature and the mechanism of capture. Figure 4 shows the amount of capture at three temperatures, 500, 600 and 900°C , following sorption for 1 hour at 13 ppm concentration. These temperatures represent the medium as well as the high temperature windows. The capture at all the three temperatures is of the order of 2000-6000 ppm of arsenic with 600°C showing the highest amount of capture. All the experiments are conducted with air as the diluent gas, and at 500°C , re-carbonation of the CaO plays a significant role. From studies with selenium sorption conducted as part of Project 4.1, it is known that at the medium temperatures of 400 and 500°C , the extent of carbonation is about 30-40% [1]. This is verified by heating a small amount of the post-reaction sorbent in a TGA immediately after withdrawal from the reactor. Further, carbonation occurs preferentially on and near the CaO surface, and CaCO_3 being highly non-porous may block access to the interior oxide surface. This phenomena in association with the loss of overall CaO can be used to explain the reduction in metal capture observed for the 500°C run. At 600°C and higher temperatures, carbonation of CaO is not very significant.

The actual mechanism of As_2O_3 sorption by CaO could involve either physisorption of As_2O_3 or some chemisorbed complex or some chemical reaction product from CaO and As_2O_3 or a combination of all these phenomena. Physical adsorption involves relatively weak attractive forces between the adsorbent and adsorbate, and the physisorbed amount decreases rapidly with increasing temperature. Further, physisorption is a nonactivated process and easily reversible. As a result, an increase in temperature or a decrease in gas phase concentration of the adsorbate species decreases the equilibrium amount of the physisorbed species [2].

Desorption studies were carried out with the post-sorption sample by passing As_2O_3 -free nitrogen gas at a specific temperature. Figure 5 shows the result of such isothermal desorption at 500°C for 1 hour following sorption at 500°C . Negligible loss of arsenic is observed following 1 hour of desorption at the temperature of sorption, indicating an irreversible capture of arsenic trioxide either via chemisorption or a chemical reaction.

Figure 4: Effect of temperature on arsenic sorption by $\text{Ca}(\text{OH})_2$; 1 hour of sorption; diluent stream: air
As vapor phase conc. : 13 ppm

Figure 5: Arsenic retention by $\text{Ca}(\text{OH})_2$ following desorption for 1 hour at 500°C under arsenic-free flow.

Further studies will be conducted with desorption at higher temperatures to study the influence of temperature of desorption.

In order to gain further insights into the actual mechanism of As_2O_3 /sorbent and As_2O_3 /flyash interaction, XRD studies have been carried out in detail. Calcium arsenate ($\text{Ca}_3\text{As}_2\text{O}_8$) is available commercially and has been procured. Its decomposition characteristics are being studied. However, it is a highly poisonous compound and extreme care needs to be taken in its handling etc. As a result, the existing TGA system is being improved with better exhaust and trapping facilities in order to carry out these studies. The XRD studies of calcium arsenate and its decomposition product were also being studied.

Studies with $\text{Ca}(\text{OH})_2$ in the medium and high temperature ranges have yielded interesting results. Figure 6 shows the effect of temperature on arsenic capture by $\text{Ca}(\text{OH})_2$. These experiments were conducted under an atmosphere of air but the reaction gases were purged of CO_2 by passing them through a CO_2 adsorbing zeolite bed. This is because, presence of CO_2 leads to re-carbonation of the CaO formed and the effect is quite pronounced at lower temperatures of 400 and 500°C. This has already been discovered and quantitatively analyzed during experiments with selenium sorption with $\text{Ca}(\text{OH})_2$. The 400, 500 and 600°C sorption studies were conducted by first calcining the sorbent at 600°C so that all sorbents possesses the same surface area and porosity at the three temperatures. Thus, the amount captured is an indication of the sorption kinetics alone without the interfering influence of surface area and porosity. Similarly for the 800 and 1000°C runs, the sorbent is first completely sintered at 1000°C before starting the arsenic vaporization and sorption. As can be seen, in both the windows, temperature has a significant influence. Further, the influence of temperature is stronger in the higher temperature window. Also, inspite of a significant difference in surface area between the two temperature windows, the amount of capture at 1000°C is almost comparable to that at 600°C which is indicative of the much increased rate of sorption at 1000°C.

Figure 7 shows how the amount of capture increases with increasing sorption time. Experiments were conducted in the differential reactor for sorption times as low as 15 minutes and the results show an almost linear increase in sorption with time. The expected leveling off of the capture curves did not occurred till 4 hours indicating more capacity of sorption on part of $\text{Ca}(\text{OH})_2$. Experiments were further carried out at extended exposure time

Figure 6: Arsenic capture by precalcined Ca(OH)_2 at different sorption temperatures (sorption time : 1 hr.).

(A) Ca(OH)_2 calcined at 600°C (S.A. is 20.5 m²/gm)

(B) Ca(OH)_2 calcined at 1000°C (S.A. is 4.5 m²/gm)

Figure 7: . Arsenic capture by $\text{Ca}(\text{OH})_2$ at different exposure times.
Sorption temperature : 600°C

in the differential bed reactor to determine the sorbent capacity for arsenic capture. Results from these extended exposure time studies are shown in Figure 8. As can be seen from the figure with increasing exposure time the rate of sorption capture finally started to decrease and the amount of arsenic present in the post-sorption sample per unit weight of the sample approaches a saturation value asymptotically, as would be expected. All these experiments were carried out at the reaction temperature of 600°C and arsenic trioxide vapor phase concentration of 65 ppm was maintained under air atmosphere.

Other studies conducted include desorption studies and XRD studies for exploring the mechanism of sorption. Figure 9 is a representative plot of desorption studies which are conducted immediately following sorption with the same flow rate conditions except without the presence of arsenic trioxide in the gas flow. As can be seen, there is negligible loss of captured arsenic following desorption indicating a irreversible capture of arsenic trioxide by Ca(OH)_2 . This was also corroborated with other tests. Figure 10 shows the results of one such corroborative test, namely the XRD spectrum of a reacted sample. These studies can help us identify the compound form in which arsenic exists in the captured state. Calcium hydroxide is easily seen to be one of the species. This is due to the exposure of the partially reacted CaO to atmosphere which leads to its hydration (by absorbing moisture from air). Another compound whose spectrum seems to be matching well with the peaks in the spectrum is calcium arsenate. It can be clearly seen from the spectrum that there is a strong evidence of the presence of calcium arsenate as the product of Ca(OH)_2 and As_2O_3 . This has been speculated in the available literature [3] but has never been proven. This study probably represents the first of its kind to show the presence of calcium arsenate during interaction of As_2O_3 and Ca(OH)_2 .

Figure 8 : Arsenic capture by $\text{Ca}(\text{OH})_2$ at different sorption times in a fixed bed reactor.

Vapor phase As conc.: 65 ppm

Reaction Temperature : 600°C

Figure 9: Effect of desorption temperature on arsenic retention by $\text{Ca}(\text{OH})_2$. 2 hours of desorption in arsenic-free flow.

Figure10: XRD spectrum (diffractogram) of partially reacted sample showing the presence of CaO and calcium arsenate.

III. ENTRAINED FLOW REACTOR STUDIES

A. Experimental System:

An Entrained Flow Reactor (EFR) system was designed and developed in conjunction with project 4.1. A schematic diagram, shown in Figure 11, illustrates the main features of the this high-temperature EFR system. This reactor system is capable of studying chemical reactions, in entrained conditions, with residence time in the range of 1-5 seconds and has a maximum operating temperature of 1000°C. The main component of the reactor system is a tubular reactor made out of Inconel 600 alloy. At the top, there is provision for mixing and entry of toxic-laden gas and sorbent powder. After traversing through the reactor section, the particle-gas mixture is quenched by dilution flow and the sorbent particles are separated from the gas using a cyclone and filter arrangement.

The main reactor consists of a 1.25" o.d. tube made of Inconel 600 and a wall thickness of 0.065". The length of the reactor is 24". Inconel 600 is superior to SS 316 for high temperature use and has the same ease of machinability, welding and fabrication [4]. The reactor tube will be housed inside a Thermcraft single-zone electric furnace. The furnace assembly is 18" in length and it will be placed vertically and has a split-hinge arrangement for ease of opening and closing. At the top of the reactor just above the furnace, there is a head section which has provision for entry of the reaction gases and sorbent. The top head section is fabricated separately from a SS 316 and is welded to the reactor tube. The bulk gas enters the reactor through the head section. The bulk gas tube is a 0.5" o.d. Inconel tube which is wrapped with heating tape in order to avoid condensation of vapor species. The bulk gas tube has provision for entry of the toxic-vapor laden gas and for the carrier gas transporting sorbent powder. Air (purged of CO₂) is used as the bulk/diluent gas and is preheated by passing it through the furnace in a 1/8" o.d. SS 316 tube. Both powder and vapor enter the top section of the reactor at an angle of 45° to the bulk gas. Pure inert nitrogen was used as the powder carrier and vapor carrier gas streams. This was done in order to protect the internal mechanical and electronic components of the microbalance from corrosion/oxidation.

Figure 11: Schematic of Entrained Flow Reactor System for arsenic sorption studies.

Design of the top head section is such that it provides rapid heating and mixing of powder and vapor laden gases.

The toxic vapor assembly is similar to the one being used for the fixed bed reactor assembly. It consists of the arsenic trioxide sample suspended from a microbalance assembly inside a quartz tube wrapped in heating tape. Temperature of the vaporization tube is monitored and controlled to maintain a steady As_2O_3 vaporization rate. The bottom of the quartz tube is connected to a flexible stainless steel tube which serves to transport the toxic-laden gas. The entire flexible tubing line is also wrapped in heating tape and covered with insulation in order to prevent any condensation of the arsenic vapor. Toxic vapors thus generated, are carried away by a continuous flow of nitrogen gas through the vaporization tube. Vapor-laden nitrogen gas exits the vaporization tube from the bottom and is transported to the top section of the reactor by the flexible stainless steel tube. The whole vapor transport assembly is carefully monitored and maintained at temperatures above the vaporization tube temperature.

The sorbent powder feeder is a fluidized bed microfeeder similar to the one developed for Project 1.1. It consists of a sorbent powder bed fluidized by nitrogen gas and the entrained powder is transported through a 1/8" o.d. tube. The tip of the off-take tube is held just above the surface of the powder bed. The sorbent powder is fed into the reactor in a continuous manner. Powder feeding rate is kept very low to achieve proper dispersion and avoid clogging of the powder transport line. The powder enter lies above the vapor entry. This design feature is included to avoid vapor condensation in the powder line (a local cold spot) and to prevent reaction from occurring outside of the reactor.

Dry nitrogen is used for the vapor transport as well as powder transport, while the bulk gas consists of air. The flow rate of the vapor-carrying gas is about 200 ml/min. This is limited by the accuracy of the weight reading desired from the microbalance. The flow rate of nitrogen gas through the feeder is maintained at 800ml/min. The powder carrier gas flow rate will be of the order of 0.5 lit/min, while the main bulk gas will be about 2.0 lit/min.

After traversing downwards through the reactor section, the gas-particle mixture exits from the bottom of the reactor. The gas-particle mixture flows out through a collection tube which is welded to the bottom head section. Bottom head is fabricated from SS 316 and is welded to the Inconel reactor tube. Before passing the gas-solid mixture through the phase

separation unit the mixture is cooled to quench the reaction. This is brought about by dilution of the hot reaction gases with cold purge nitrogen gas. Dilution of the reaction gases also reduce the concentration of the arsenic species in the gas phase thereby avoiding the excessive condensation of these vapor species. The saturation concentration of the arsenic trioxide is exponentially dependent on temperature. Cooling of the reaction gases to a temperature of about 200°C should be sufficiently low to prevent further reaction without causing condensation of the arsenic species in the line. Separation of solids from the gas stream is achieved by passing the suspension through a train of cyclones which are maintained at temperatures above the vaporization temperatures. Collected sorbent samples are analyzed for their captured arsenic content in an Atomic Absorption Spectrometer (AAS).

Residence time of the entrained species (sorbent particles) is calculated from the flow rate of the gases and the geometry of the reactor, after applying appropriate temperature corrections. The total flow rate of the gases was varied from 1.5 to 4.8 lpm (at STP) and the corresponding range of residence time was 1.25 to 4.0 seconds. Arsenic trioxide vapor concentration was maintained at 65 ppm for all the residence times studied.

B. Results of Entrained Flow Reactor Studies:

Sorption experiments were carried out to determine the amount of arsenic captured by Ca(OH)_2 , at low residence times, in the Entrained Flow Reactor (EFR) system. Experiments were performed at residence times of 1.25 and 3.0 seconds. As observed from the differential reactor studies similar amounts of arsenic were captured by Ca(OH)_2 at both high (800-1000°C) and medium (400-600°C) temperature ranges. Experiments, in EFR, carried out at temperatures of 600°C and 900°C corroborated the findings of the differential bed reactor studies. To obtain different residence times the bulk gas flow rates were varied from 1.0 to 3.8 lpm (STP). All entrained flow reactors were carried out for a duration of one hour so that sufficient amount of powder can be collected for post-sorption analyses. Figure 12 presents the amount of arsenic captured at two different residence times at a reaction temperature of 600°C and arsenic vapor phase concentration of 65 ppm. As can be seen from the figure, at 1.25 and 3.0 seconds the capture is 490 (0.06 wt % CaO utilization) and 2250 (0.252 wt % CaO utilization) ppm

Figure12: Arsenic capture by $\text{Ca}(\text{OH})_2$ at different residence times in an entrained flow reactor.
Vapor phase As conc. : 65 ppm
Reaction Temperature : 600°C

respectively. Effect of temperature on the amount of arsenic captured by the sorbent under entrained conditions is illustrated in Figure 13. For the same residence time (1.25 seconds) the amount of arsenic captured by the sorbent was found to be similar. As mentioned earlier, these results are consistent with those obtained in the differential bed reactor studies.

To determine the extent of arsenic capture, if any, by the sorbent particles exposed to reactant gas in the cyclones at much lower temperatures than the reaction temperatures, a set of experiments was performed. Ca(OH)_2 was fed into the reactor at reaction conditions similar to the experimental conditions described earlier but in the absence of any arsenic species. After sufficient amount of sorbent powder was collected in the cyclones, powder feeding was stopped and vaporization of the arsenic trioxide was started. Vaporization was carried out for an hour. Upon completion of the experiment, powder sample was recovered from the cyclones and analyzed for arsenic content. Results from these experiments show a very low (less than 20 ppm) arsenic capture by the partially calcined Ca(OH)_2 particles inside the cyclones, which is less than 5% of the arsenic captured at a residence time of 1.25 seconds.

Figures 12 and 13 illustrate that interaction of arsenic and Ca(OH)_2 under entrained conditions leads to a substantial amount of arsenic capture at both high and medium temperatures. These results also suggest the feasibility of Ca(OH)_2 injection, at either high or medium temperature range, as a possible control methodology for removal of arsenic species from hot flue gas.

Figure 13: Arsenic capture by Ca(OH)_2 at different reaction temperatures in an entrained flow reactor.
Vapor phase As. conc. : 65 ppm
Residence time : 1.25 seconds

IV CONCLUDING REMARKS

The main objective of this project was to investigate the sorption phenomena of a representative chalcophile, arsenic (As) on fly ashes and other mineral sorbents ($\text{Ca}(\text{OH})_2$) at temperatures representative of the upper furnace (850-1200°C) and economizer section (400-600°C) in a coal fired boiler.

Experimental studies were carried out in a differential bed reactor to study the arsenic sorption behavior of three fly ash samples, viz., NIST, Zimmer, and Pickway fly ash. Zimmer fly ash seems to show not only the highest capture among the three, it also showed the highest water non-leachable arsenic capture. Hence, it was proposed to conduct more mechanistic studies with Zimmer fly ash. Desorption studies with the post sorption sample has shown significant reduction in captured arsenic species content following exposure to high temperatures in an arsenic-free environment. These results strongly suggest that interaction between fly ash particles and arsenic species is physical in nature involving reversible physical adsorption.

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An Entrained Flow Reactor (EFR) system was designed and constructed in order to study the short time As- $\text{Ca}(\text{OH})_2$ interaction under entrained flow conditions. The

EFR system was designed to conduct experiments with residence time in the range of 1-5 seconds and at temperatures upto 1000°C. Experiments were conducted in the EFR to test the capturability of arsenic species by $\text{Ca}(\text{OH})_2$. Results from these experiments indicate that $\text{Ca}(\text{OH})_2$ captured as much as 2250 ppm of arsenic species for a residence time of 3 seconds under entrained conditions. Further more entrained flow reactor studies showed nearly identical arsenic capture by the sorbent at 600°C and 900°C reaction temperatures thereby corroborating the results obtained from differential bed reactor experiments.

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