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SELENIUM EMISSION CONTROL AT HIGH TEMPERATURES WITH MINERAL SORBENTS

Final Report for the Period
September 1, 1993 to August 31, 1994

by

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EXECUTIVE SUMMARY

The focus of this project is on toxic heavy metal removal by sorbent injection in the upper-furnace region of a coal-fired boiler. Selenium is chosen as the candidate heavy metal to be studied because of its high volatility and associated difficulty in removal. Mercury being the most volatile of all the heavy metals, has already been singled out for extensive studies by different research programs, funded by EPA, DOE, and EPRI. However, results of the proposed work can be suitably extended to tackle emission problems of other heavy metals.

The preliminary sorbent screening experiments were performed in a differential reactor, built in the first year of this project. A host of sorbents, such as, alumina, kaolinite, limestone and also hydrated lime were tested at a reaction temperature of 900°C, and for reaction duration of 4 hrs. The reason for choosing these minerals was because of their proven moderate to high capability of lead and cadmium capture, and also for moderate selenium capture at high temperatures, reported by recent studies. The sorbent screening experiments have used selenium dioxide as the Se source, since in the oxidizing atmosphere of the furnace, that is reported to be the existing form of selenium species.

The preliminary sorbent screening experiments have shown that $Ca(OH)_2$ is the most promising sorbent for selenium capture out of all the sorbents tested. A careful review of the sorption results for $Ca(OH)_2$ has also revealed the strong possibility for occurrence of a chemical reaction. Since Se belongs to group VI of the periodic table along with sulfur, and shares many common properties with the latter, formation of a calcium selenite ($CaSeO_3$) or selenate ($CaSeO_4$) compound is likely by the reaction of CaO with SeO_2. The captured selenium has exhibited poor leachability in water, a property which is also shared by $CaSeO_4$. The presence of $CaSeO_4$ is confirmed by the X-ray diffraction analysis of the sorbent sample. Preliminary studies for investigating the effect of temperature on $SeO_2/Ca(OH)_2$ reaction have shown that the percent of water-leachable selenium increases with decreasing reaction temperature. This strongly suggests an enhancement of physical adsorption with decreasing temperature, since SeO_2 is characterized by its high solubility in water. However, sorption results show a greater capture at 900°C, than for 800 and 1000°C. Further examination of the temperature effect and proper characterization of the reaction product is required before drawing a reasonable conclusion.

Following up on first year's work, second year of the project will initially concentrate on performing more reaction studies with $Ca(OH)_2$ sorbents in the differential reactor. The objective for this work will be to determine the most favorable temperature window for selenium capture by chemical reaction. Moreover, the duration of reaction time will be shortened to few minutes instead of hours for a preliminary feasibility testing of whether calcium hydroxide will be effective in capturing sufficient amount of selenium during its short stay in the high-temperature window of the upper-furnace region.

Once the fundamental information about product compound, and optimum temperature range are obtained from the differential reaction results and X-Ray Diffraction study, the reaction will be carried out in a flow reactor to simulate the entrained-flow condition of above---the-flame region of the furnace. A high-temperature, flow reactor will be built in the second year for carrying out such studies. The typical residence time of the hydroxide sorbent in the entrained-flow reactor will vary between less than 100 milliseconds to few seconds. Rate of selenium capture by chemical reaction at high temperature, and for sorbent flow conditions will be the primary focus of the study.

I. OVERVIEW

A. Background and Scope

The focus of this project is on heavy metal removal by mineral sorbent injection in the upper-furnace region (800°-1100°C) of a coal fired boiler. Selenium is chosen as the candidate heavy metal to be studied because of its high volatility and associated difficulty in removal. Selenium content of Ohio coals is substantially higher in comparison to national and world averages. The present technology is inadequate to meet the anticipated toxic emission standards, expected to be enforced by EPA in near future. As the regulations on toxic emissions from the coal-fired utility plants are getting stricter, idea of a single process capable of substantially reducing most of the toxic emissions sounds very appealing. Proposed study is the first step towards developing such a process.

A promising technique for removal of metal vapors from hot flue gases is by injecting sorbents into the gas stream. Although the work on high-temperature removal of heavy metals by sorbent is scarce, its appeal is great considering the relative success of various sorbent injection studies for the flue gas desulfurization. With this goal, the purpose of this project is to identify the most efficient sorbent available in removing Se and its compounds from the flue gas and to investigate the feasibility of furnace sorbent injection technique for the control of trace metal emission from coal fired combustors.

The preliminary sorbent screening experiments are performed. A host of sorbents, such as, alumina, kaolinite, limestone, and hydrated lime are chosen as candidates for preliminary sorbent screening. Preliminary sorbent screening experiments are carried out in a differential reactor, choosing the most efficient sorbent(s) and eliminating the rest. The reason for choosing these minerals was there proven moderate to high capability of lead and cadmium capture, and also because of their moderate success in capturing selenium as reported by recent studies. Eventhough the thrust of this project is on upper-furnace sorbent injection for selenium removal, i.e., an entrained flow condition for solids, the proposed first year reaction studies are designed to be carried out in a differential reactor system. This would provide much valuable information, such as, sorbent efficiency, removal mechanism, and optimum sorption temperature. Basing on these information, the experimental plans for flow reactor studies can be formulated.

Mechanistic understanding of Se/sorbent interaction is essential to determine the various parameters which influence this interaction. This knowledge would ultimately lead to the development of a better and more efficient sorbent. Information regarding the mechanistic steps involved in trace metal capture by sorbent is inadequate. Although it is proposed that an adsorption/surface chemical reaction mechanism could be used to explain the overall phenomena.

B. Long Term Objectives

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

1. identify those mineral sorbents which show most promise in capturing selenium.
2. investigate the mechanism of Se capture by the sorbents.
3. if any, identify the chemical compound formed by Se/sorbent interaction
4. determine the feasibility of injection technique in Se removal from flue gas by conducting short contact time studies in an entrained flow reactor within the applicable temperature window.

II. THERMODYNAMIC STUDIES

A. Introduction

The exact chemical speciation of Se in the flue gas (in both gas phase as well as particulate phase) has been a subject of disagreement among researchers in this community. Selenium has been identified in elemental as well as oxide forms. Se exhibits valency states of -2, 0, +4 and +6 and can thereby form different oxides, halides, sulfides, as well as intermetallic compounds. Even though not all of them have a stable existence under high temperature conditions of the flue gas, the number of possible compounds is still high. This study hopes to gain some theoretical insights into the thermodynamics of the various Se species under the actual flue gas conditions. A free energy minimization program developed partly by NASA is available to do such thermodynamic equilibrium composition studies.

B. Thermodynamic Free Energy Minimization Results and Discussion

Thermodynamic free energy minimization studies to determine the nature and equilibrium composition of selenium species in the flue gas have been performed as part of the 1st year's work. These studies were carried out in order to determine the exact speciation of Se in flue gas. Since selenium exhibits a large number of valency states, the possibility for formation of a host of compounds in the flue gas atmosphere is substantial. The free energy minimization of the flue gas composition was the underlying principle of this study, which was performed by using a software called CHEMQ. CHEMQ is a modified version of NASA free energy program, NASA CET 1989. For equilibrium calculation, a representative composition of flue gas was considered which included O_2 as 5%, N_2 as 67%, H_2O as 8%, CO_2 as 17% and SO_2 as 0.3%. Trace amounts of Cl_2 (0.00075%) was also included in the calculation. Selenium, arsenic, lead and mercury were considered as existing trace heavy metals. The output from the program gives the final equilibrium composition of the flue gas for a given condition of pressure and temperature. The equilibrium composition of the flue gas is then analyzed for its distribution of selenium species.

Elemental selenium (in the form of Se, Se_2, Se_3, Se_6, and Se_8), SeO, SeO_2, and various selenium chlorides were introduced into the input file as the possible selenium forms. Other selenium compounds such as selenium trioxide and sulfides were not considered as these compounds do not occur in gas phase in the temperature range considered for this study. At a temperature of 500 K, representative of conditions upstream of the ESP, more than 70% of the Se in the flue gas is found to be in SeO_2 form and rest in the elemental form Se_3. In the temperature window of 750-1000 K, however, selenium is found to exist mainly as oxide forms of SeO and SeO_2. For temperatures beyond 1000 K, SeO becomes the dominant species. Furthermore, it is also obtained from this study that at higher temperatures, elemental selenium exists mainly in Se_2 and Se_8 forms. Figure 1 illustrates the speciation of selenium in flue gas at various temperatures. Chloride and sulfide forms of selenium are found only in trace quantities for the entire temperature range. Moreover, increasing SO_2 concentration in the flue gas does not appreciably alter the metal speciation. Equilibrium calculation does not support the hypothesis of Andren et al. [1975], that SO_2 reduces the oxide form of selenium to produce elemental Se. Although the thermodynamic studies are completed successfully, the obtained compositions of the flue gas are at the conditions of equilibrium without giving any regards to

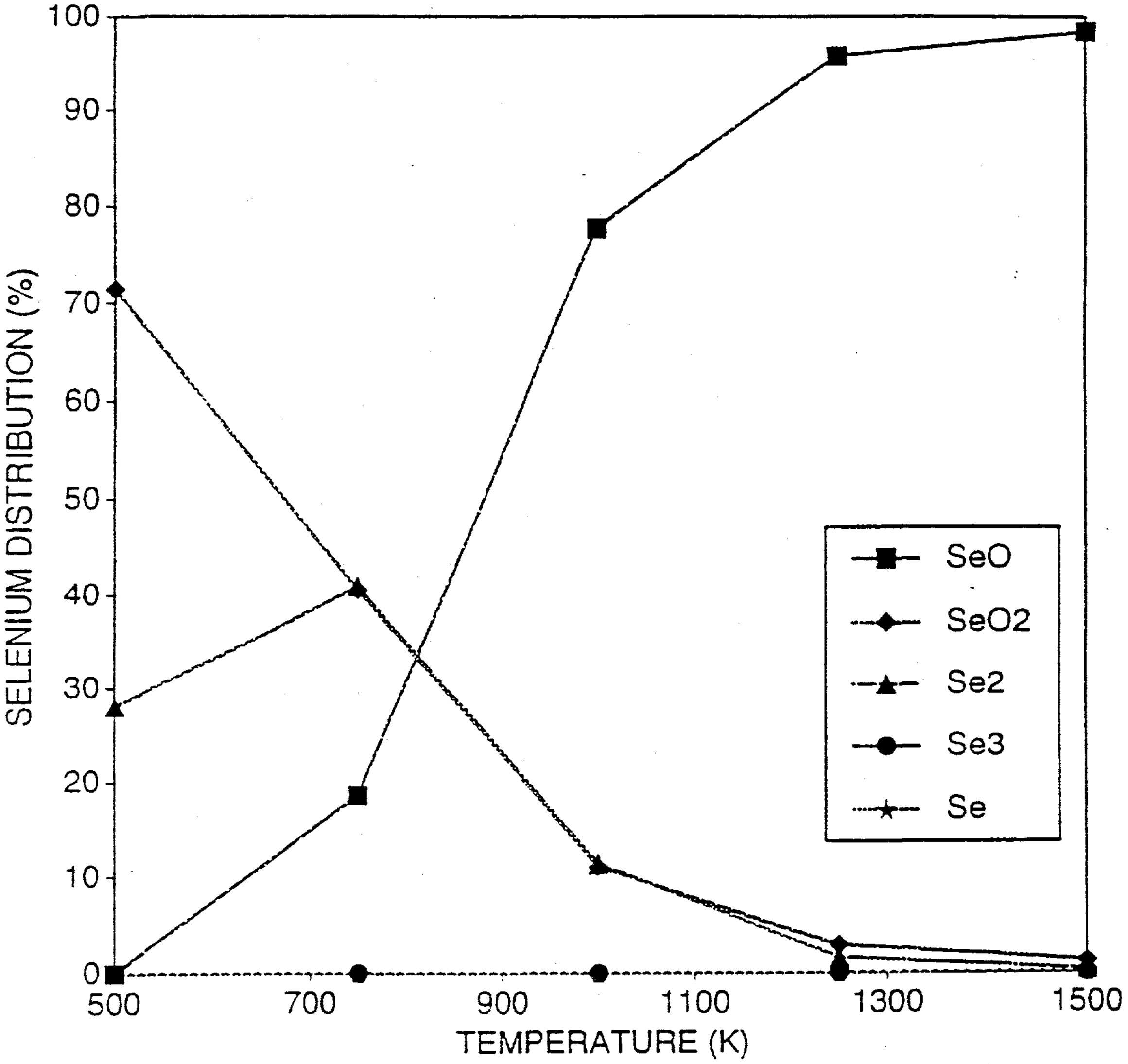

Figure 1: Distribution of Selenium species in the flue gas at different temperatures

the rate or kinetics of each reaction leading to the formation of different selenium compounds,which imposes a severe limitation upon complete validity of this data. Since free energy minimization program ignores the kinetics of the species formation, and thus can only reasonably be used for elimination of specific selenium compounds. However, determination of the exact nature of Se existence demands kinetic information.

III. EXPERIMENTAL SYSTEM

A. Introduction:

The objectives for first year's work were to build a differential reactor and study selenium capture capability of various mineral sorbents at high temperatures (800-1100°C), thereby performing a preliminary screening of these sorbents. Another goal was to investigate the mechanism of Se capture by these mineral sorbents. The most efficient sorbent(s) were to be singled out for further testing to identify the optimum temperature window and other process conditions in order to maximize their sorption capacity.

B. Set-up of the Differential Reactor System:

As phase 1 of first year's work, a differential reactor system was designed and developed, the schematic of which is shown in Figure 2. The main components of the set-up are;

Vaporization tube

Selenium sample kept in the pan hanging from the micro-balance assembly is housed in a vaporization tube made up of pyrex. Initial design involved a 720 mm long vaporization tube with an outside diameter of 18 mm, thus requiring long hang down wire from the balance. This caused static charge pick-up and excessive swaying of the hang down wire resulting in reduced accuracy and increased instability of the balance measurement. In order to obtain high precision in balance reading, a vaporization tube with larger O.D. (25.4 mm) and shorter length (12.7 mm) was installed along with a reduction in the size of the sample pan. Vaporization of the Se sample placed inside the vaporization tube requires heating to an elevated temperature, and this is achieved by wrapping the whole vaporization tube with a heating tape and maintaining proper

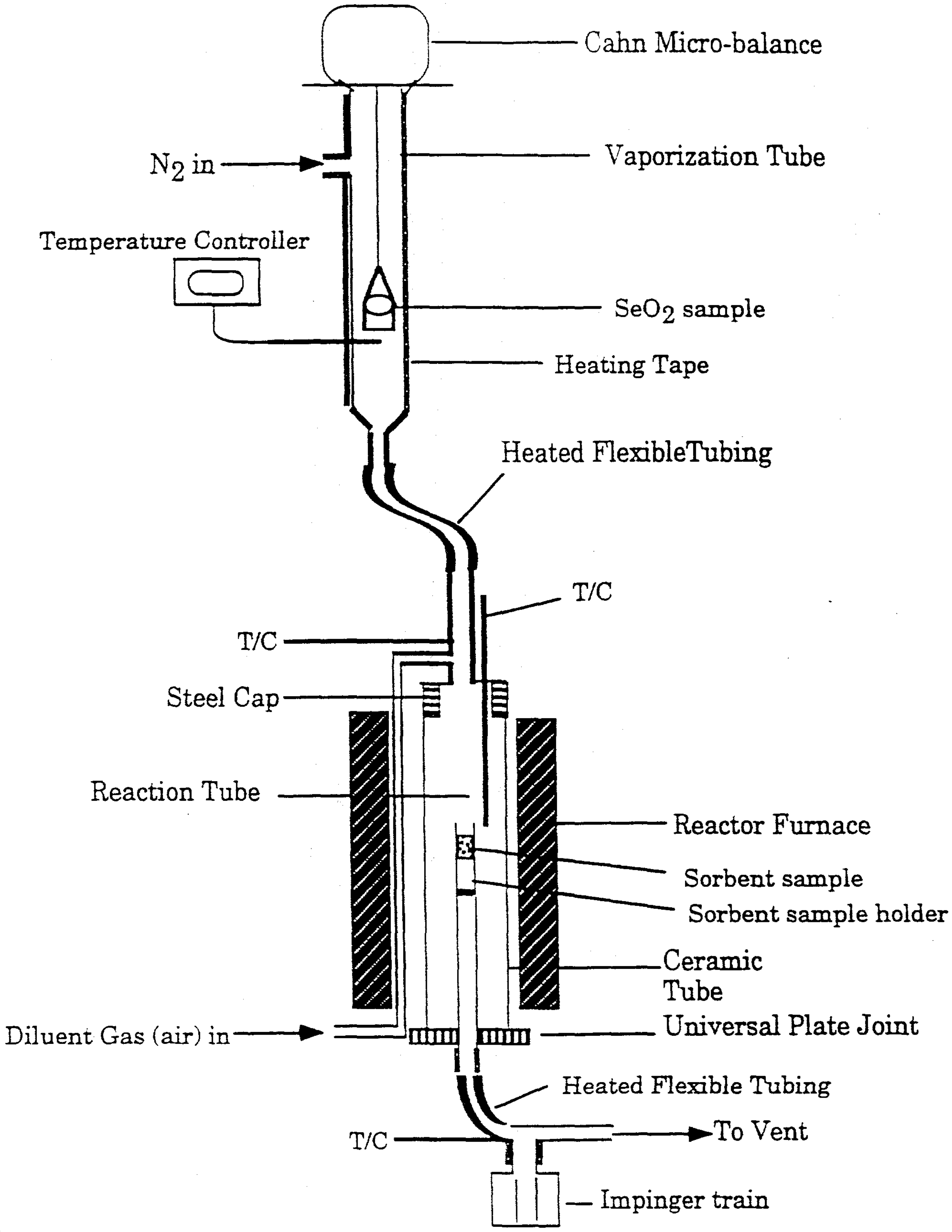

Figure 2: Schematic of high-temperature Selenium Sorption Experiment

temperature control. Vaporization temperature was decided upon after considering the vaporpressure data for SeO_2, required concentration of Se needed in the reactor, and after performing some trial vaporization runs. Se vapors are carried from the vaporization tube to the reactor by a carrier gas. Dry nitrogen at 100 cc/min (STP) is used as the carrier gas.

Microbalance

Microbalance used in the set-up is purchased from ATI Cahn Instruments. The model number D-200 is a hangdown type, digital recording balance with a capacity of 3.5 gms and a maximum sensitivity of 0.1 μg. For monitoring and recording of data, microbalance is interfaced with a PC. The whole microbalance assembly, which includes the hangdown wire and the accompanying hardware and software, is extremely sensitive to any vibrations or static pickup. Therefore, to minimize disturbances, microbalance is installed on a support structure, isolated from the frame used for the furnaces and other components of the set-up. A complete installation of the microbalance involves installation of the accompanying software in a personal computer. Balance is tested under various flow conditions before actually starting the experiments.

Transport line between reactor and vaporization tube

SeO_2 vapor laden carrier gas enters the reactor from the vaporization tube via a 3.2 mm O.D. flexible stainless steel transport line. In order to avoid condensation of Se species in the transport line, its length is kept to a minimum and maintained at a higher temperature than the vaporization tube.

Diluent Gas:

Before the carrier gas enters the reactor, it is mixed with air acting as the diluent gas.

Diluent gas is added to adjust the concentration of Se species in the reactor to desired levels. Typically for all the reaction studies, diluent gas flow is maintained at 1 lpm (STP). In order to avoid any selenium species condensation due to lowering in temperature upon mixing, the diluent gas is preheated by passing the air transport line (3.2 mm O.D., stainless steel) through the reactor furnace. Mixing of diluent gas and carrier gas takes place just before the selenium carrying gas enters the reactor.

Reactor Assembly :

Reactor assembly includes a reactor tube, a 1200°C Lindberg single-zone furnace and a sorbent holder assembly. Reactor tube consists of a ceramic (mullite) tube of 2.54 cm O.D.(1.9 cm I.D., 45.7 cm long), cemented to a stainless steel cap at the top and a universal stainless steel plate joint at the bottom. Universal plate joint was chosen at the bottom of the reactor because of relative ease in opening the reactor for cleaning purposes and also in sorbent loading and removal. Reactant gas enters the reactor from the top. A thermocouple is also inserted into the reactor tube from the top to monitor the reaction temperature of the differential sorbent bed. The sorbent to be studied is dispersed on a small amount of quartz wool, which is supported on a sorbent holder. The design of the quartz sorbent holder assembly is shown in Figure 3. Sorbent holder is designed to have custom made joint at the bottom, which fits tightly on a 9.5 mm O.D., 15.2 cm long quartz tube, which in turn is cemented to 12.7 mm O.D. and 38.1 cm long stainless steel tube through which all the gases are carried out after flowing through the sorbent bed. Sorbent holder assembly is inserted inside the reactor from the bottom and is positioned such that the differential sorbent bed is in the lower half of the furnace heating section. Using small amount of sorbent and maintaining relatively high concentration of metal

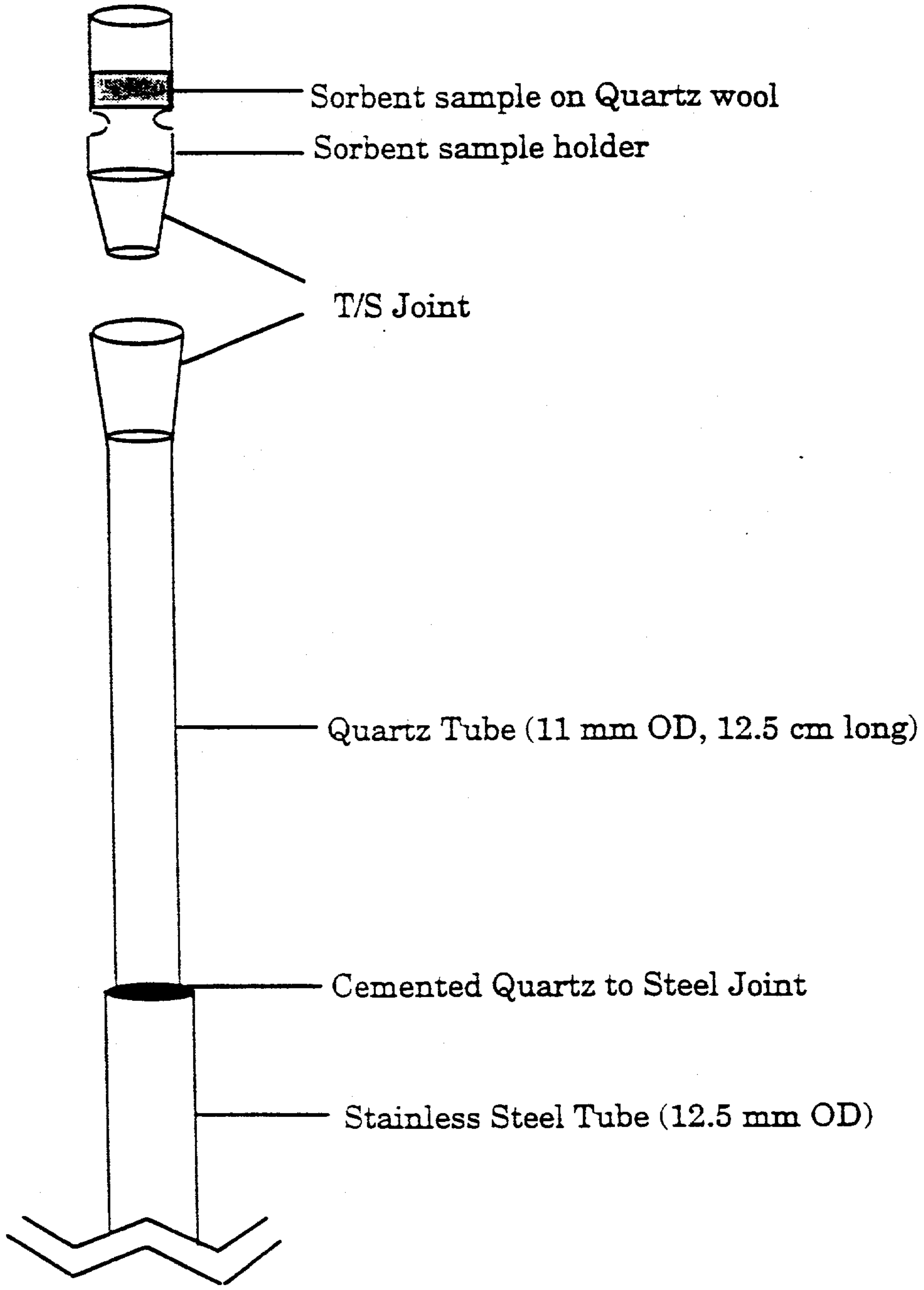

Figure 3: Schematic of Sorbent Sample Holder Assembly

ensure differential reaction conditions for the experimental studies. Gas coming out from the outlet is sent to a train of impingers before exiting to atmosphere. The transport line between the reactor and the impingers is kept heated above the vaporization temperature of the Se speciesto avoid any condensation in this line. This provision helps to trap all the unreacted Se species in the impinger assembly.

Impingers:

Before venting the gases coming out from the reactor they are passed through a train of two impingers. 5% Sodium-acetate solution is used as impinger solution. Design of impinger ensures proper diffusion of gases through the solution for efficient capture of Se Species before venting to the atmosphere, although a trade-off has to be made between higher dispersion and increased back pressure in the system.

Post Reaction analysis:

In order to measure the selenium concentration of the reacted sorbents, known amount of the samples are be dissolved in a $H_2O/(CH_3COO)Na$ (5% by volume) solution. The selenium content of the solution is determined by atomic absorption spectroscopy. Separate water leaching experiments are performed to determine the water soluble fraction of the captured selenium. The leaching can be conducted in an ultrasonic bath at room temperature for few hours. The selenium content of the solution can be subsequently determined by atomic absorption spectroscopy. X-ray diffraction analysis is also performed to identify the primary product formed during selenium adsorption/reaction process.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. Experimental procedure

Selenium sorption studies in the differential reactor are performed with an objective to screen the sorbents and to identify potential sorbents exhibiting high selenium capture. Initial experiments are performed at a temperature of 900°C and the results are used as a guideline for formulation of further experimental studies. For the initial sorbent screening experiments, $Ca(OH)_2$, $CaCO_3$, Alumina, and Kaolinite are tested as the candidate mineral sorbents. The reason for choosing these minerals is because of their proven moderate to high capability of lead and cadmium capture from hot flue gases [Uberoi and Shadman; 1990; 1991], and also for their recently reported selenium capture ability [Gullett and Raghunathan, 1993]. Since quartz wool is used as a support for dispersing these sorbents, a blank run with only quartz wool in the sample holder is performed to determine its Se capture. Results of this blank run indicate no significant selenium capture by the wool. During experimental run, SeO_2 is vaporized as the selenium sample, and the vaporization is controlled by measured heating to produce a selenium conc. of less than 10 ppm in the reactor with the various gas flow rates set at values as mentioned before. Sorbent holder containing about 15 mg of sorbent is inserted into the reactor from the bottom after the reactor reaches the desired reaction temperature, and is soaked for about 15 min. before metal vaporization begins.

The rate of vaporization is controlled by controlled heating of the heating tape surrounding the vaporization tube. The vaporization temperature is determined from theoretical calculation of SeO_2 vapor pressure data, and from the desired conc. of selenium in the reactor. The calculated weight loss (from vapor pr. data) for SeO_2 over a period of 4hrs. at 160°C is found to be substantially higher than what is experimentally observed. This can be explained by the fact that the temperature measured for the vaporization is not exactly the temperature of the SeO_2 sample kept in the pan but temperature at about 12 mm below it. Furthermore nitrogen gas circulation patterns and heat transfer resistances within the lumped sample can also explain the lower rates as observed.

For initiating the reaction, SeO_2 sample inside the vaporization tube is quickly raised to the required temperature and maintained there for a near constant rate of vaporization. Trial experimental runs indicate that for obtaining the desired vaporization rate, a temperature of 160-165°C is optimum. Since it is important to subject all the sorbents to identical conc. of selenium, the rate is kept nearly same for all the runs. Figure 4 shows the metal vaporization rates for various mineral sorbents studied, which represents satisfactory reproduction of the se concentration. Each experimental run is allowed to continue for 4 hrs. and the reaction is terminated by suddenly lowering the vaporization temperature below 125°C, which effectively stops any further selenium entrainment.

After allowing sufficient time for the furnace to cool down, sorbent sample is withdrawn from the reactor tube and dipped in 50 ml of demineralized water. The selenium content of the water is measured with a graphite-furnace atomic absorption spectroscopy (AA) after water-leaching the sample for over-night. This gives the amount of captured selenium which is water-leachable. Another 50 ml of 20% sodium acetate solution is then added to the 50 ml of water, and after 4 hrs. of dissolution in an ultra-sonic bath at 50°C, the selenium content of the solution is measured in the AA. This gives the total amount of selenium captured by the sorbent. Water leachability tests are performed in order to determine the suitability of spent sorbent for landfills

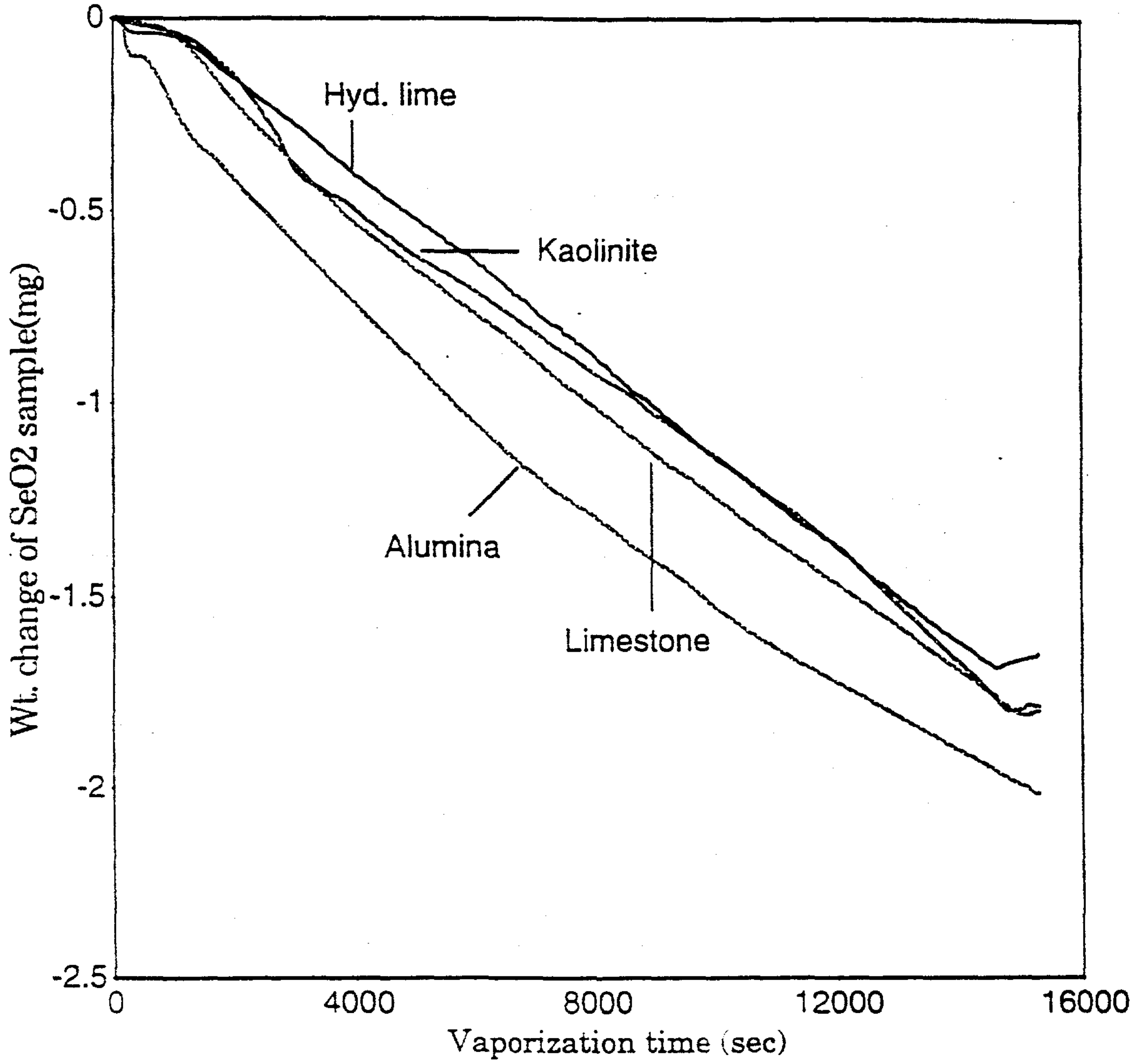

Figure 4 : SeO$_2$ vaporization rates for different sorbents studied

and also to get an idea about the amount of physically adsorbed selenium on the sorbent surface.

Separate experiments are performed to determine the exact chemical nature of the compound formed due to Se/Sorbent interaction. Under the same experimental conditions as described before sorbent is subjected to SeO_2 vapor for extended period of time (20 hours). Afterwards the sorbent sample is sent for the XRD analysis to determine the Se compound formed. Extended experimental run is necessary to have enough Se compound to give a reliable XRD analysis.

Results from the preliminary sorbent screening experiments are used to determine the most efficient sorbent for selenium capture. Further experiments are performed with this sorbent to determine the effect of temperature and Se concentration in gas phase on its Se-capture capability.

B. Results and Discussion

-Sorbent screening:

The results of the performance of the four different sorbents are presented in the form of a bar-chart in Figure 5. As can be seen from the bar-chart, $Ca(OH)_2$ is found to be the most efficient of all the sorbents tested, followed by $CaCO_3$, kaolinite and alumina. As both $Ca(OH)_2$ and $CaCO_3$ are relatively efficient for selenium capture as compared to other sorbents tested, and most of the captured Se is not leachable by water, it probably indicates that CaO reacts with SeO_2 in an oxidizing atmosphere to produce $CaSeO_3$ or $CaSeO_4$, similar to its reaction with SO_2 for production of sulfite or sulfate. Furthermore, since neither $CaSeO_3$ nor $CaSeO_4$ is water soluble the low concentration of Se in the aqueous solution obtained after water leaching would indicate the presence of these compounds.

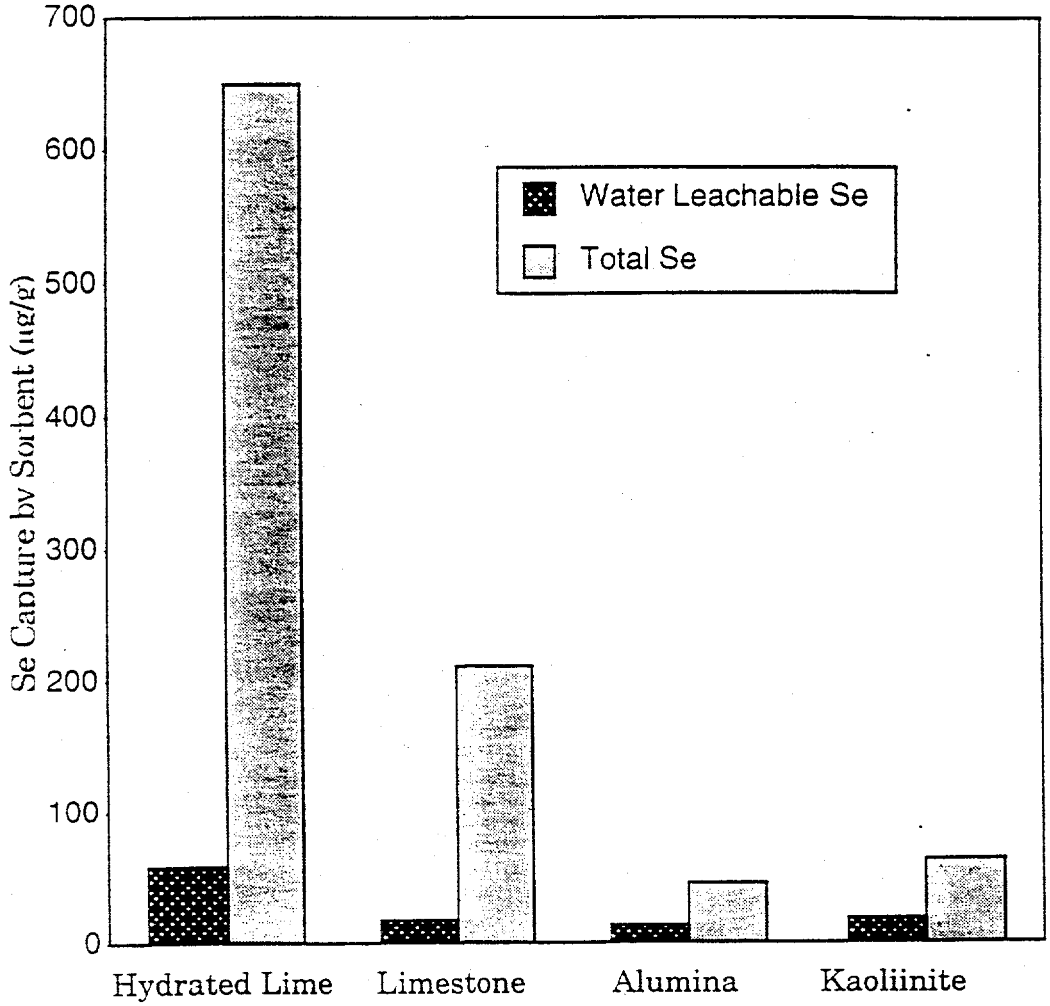

Figure 5: Total Se and water leachable Se captured by different sorbents at 900^0 C

- X-ray Diffraction analysis of $Ca(OH)_2$:

Formation of a chemical compound due to Se/sorbent interaction is confirmed by X-ray diffraction analysis done on the reacted sample to identify the product compound, which showed the presence of $CaSeO_4$, as shown in Figure 6. Se capture by $Ca(OH)_2$ for extended experiment run is compared with the Se captured during 4hrs run and is shown in Figure 7. Extended experimental runs were carried out to check for the "sorption capacity" of $Ca(OH)_2$. It was expected that a prolonged exposure would increase the total Se captured by $Ca(OH)_2$. Also, to get a reliable XRD result, it is important that the chemical species be present in a significant amount in the sample analyzed.

The formation of $CaSeO_4$ by SeO_2/CaO would require the presence of oxygen. Experiments were performed in an inert atmosphere of nitrogen, in the absence of oxygen and the requirement of oxygen to form $CaSeO_4$ was confirmed by the results of XRD analysis on the sorbent samples which were obtained from these experimental runs. These sorbent samples were subjected to same SeO_2 vapor concentration in the differential reactor but only in the absence of oxygen. XRD analysis on these samples showed absence of any selenites or selanates.

-Effect of temperature on Se Capture by $Ca(OH)_2$:

Since hydrated lime showed impressive selenium capture in these preliminary experiments, its sorption capacity is further tested at two other different temperatures (800°C and 1000°C) and Se concentration of 8ppm. Results of those experiments are illustrated in Figure 8. As the temperature is increased from 800°C to 1000°C, the water leachable part of the total Se captured decreases, probably indicating that the water leachable Se is physically adsorbed SeO_2 on the sorbent surface. Furthermore, the decrease in total Se captured with increase in

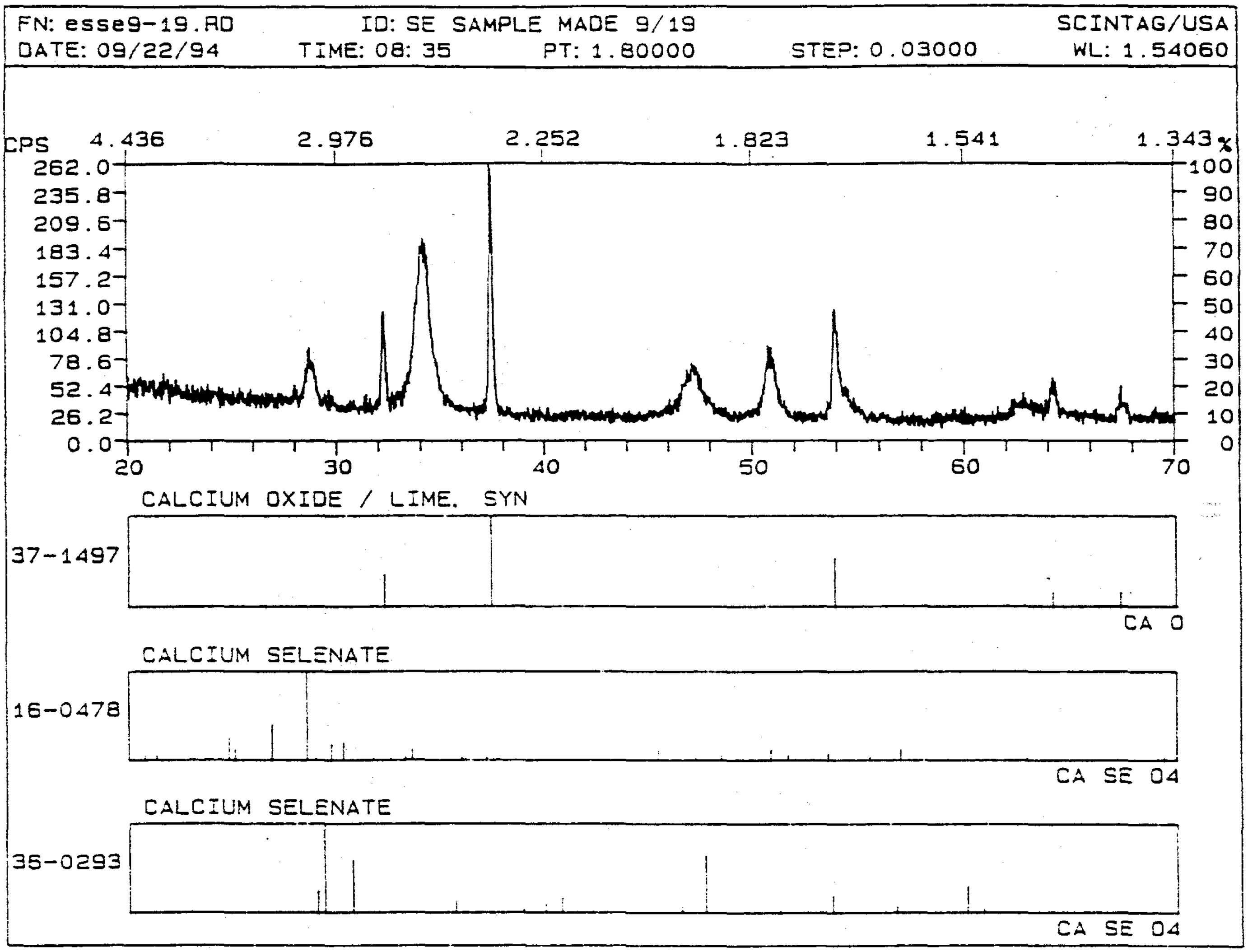

Figure 6: X-ray Diffraction Analysis of Partially Reacted $Ca(OH)_2$ Showing the Presence of $CaSeO_4$.

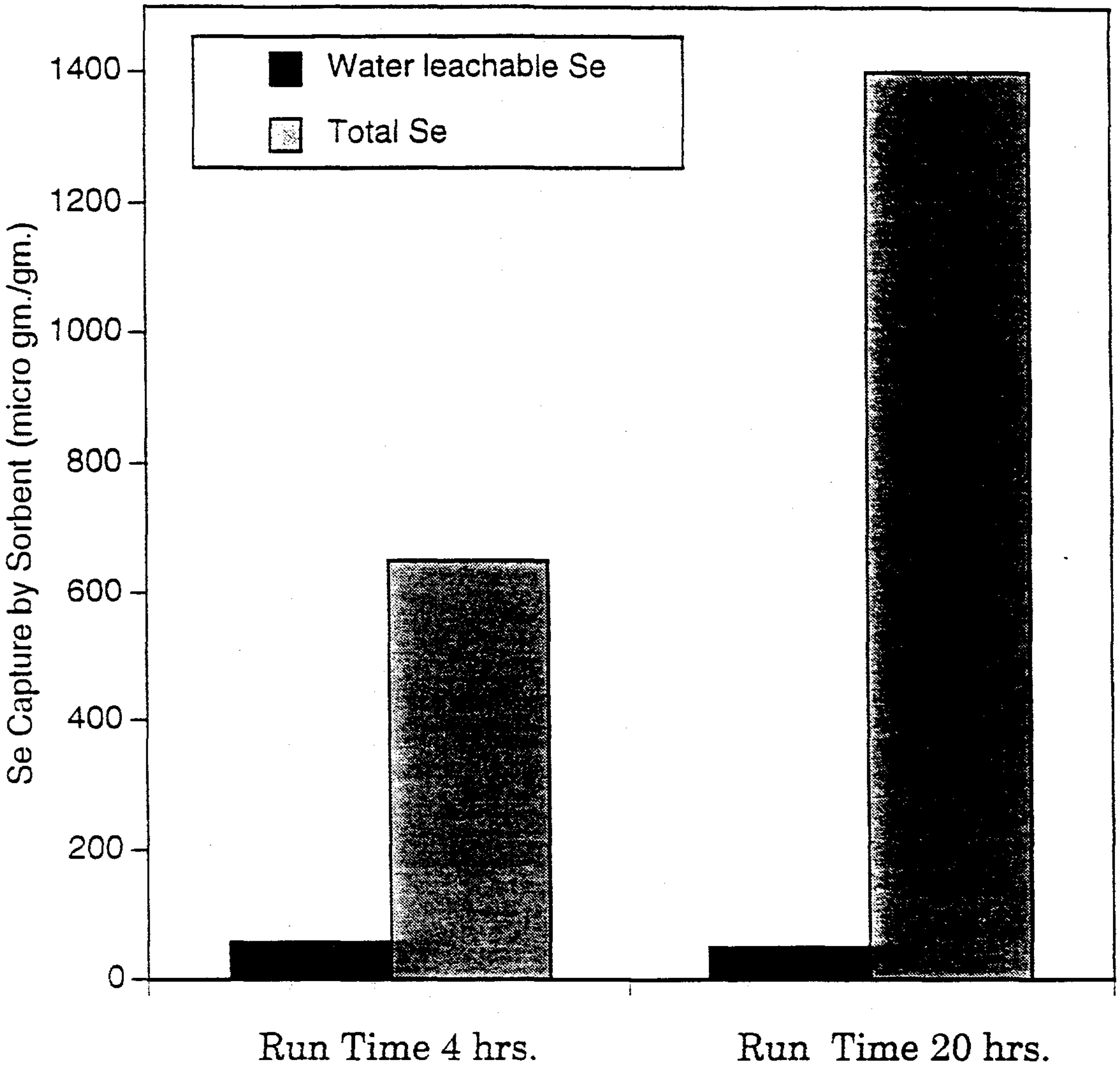

Figure 7. Total Se and Water leachable Se captured by $Ca(OH)_2$ at 900°C for Different Run Times

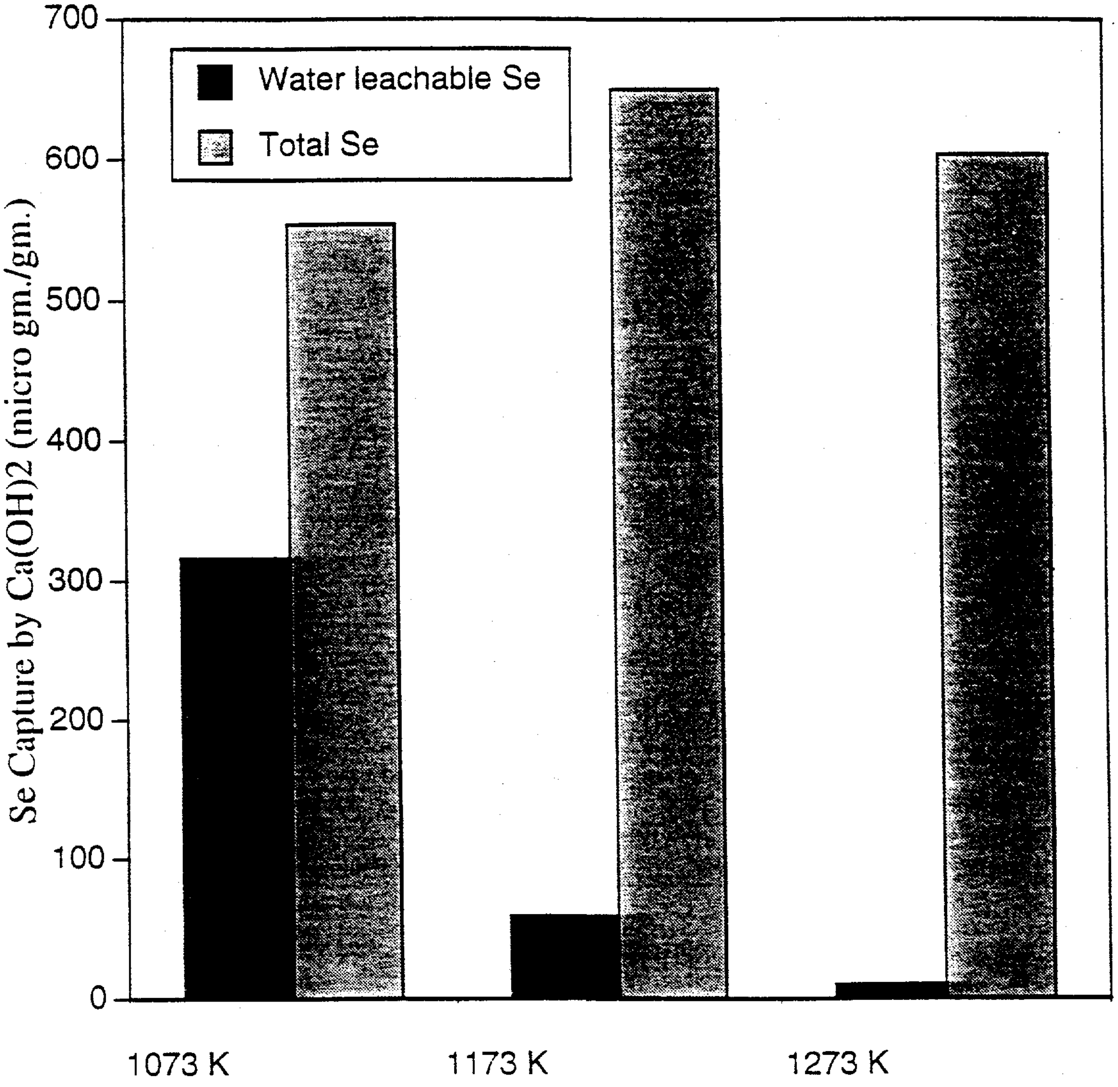

Figure 8: Total Se and Water leachable Se captured by $Ca(OH)_2$ at at three different temperatures.

temperature from 900°C to 1000°C can be explained on the basis of loss in surface area at high temperature due to sintering, or from the dissociation temperature of the reaction product. However more investigation into the reaction phenomenon is needed. Similar temperature effects are shown at a higher Se concentration of 25 ppm, as shown in Figure 9.

-Effect of Se Concentration in gas phase on Se Capture by $Ca(OH)_2$:

Effect of selenium vapor concentration in the gas phase on the overall capture of selenium by $Ca(OH)_2$, at 1173 K, is shown in Figure 10. It can be seen from there that with increased gas phase Se concentration the overall capture increases. The increase in water leachable Se is also significant. As the gas phase concentration is increased from 8 to 25 ppm, the water leachable part of total Se captured increases, further indicating that the water leachable Se is physically adsorbed SeO_2 on the sorbent surface. Similar results are obtained at a lower temperature of 1073 K and are shown in Figure 11.

Overall combined effect of higher concentration and lower temperature is to increase the water leachable part of the total Se captured. This observation is consistent with the characteristics shown by physically adsorbed species. Higher temperatures and lower concentrations of Se in gas phase tend to decreases physically adsorbed and water leachable part of the total Se Captured.

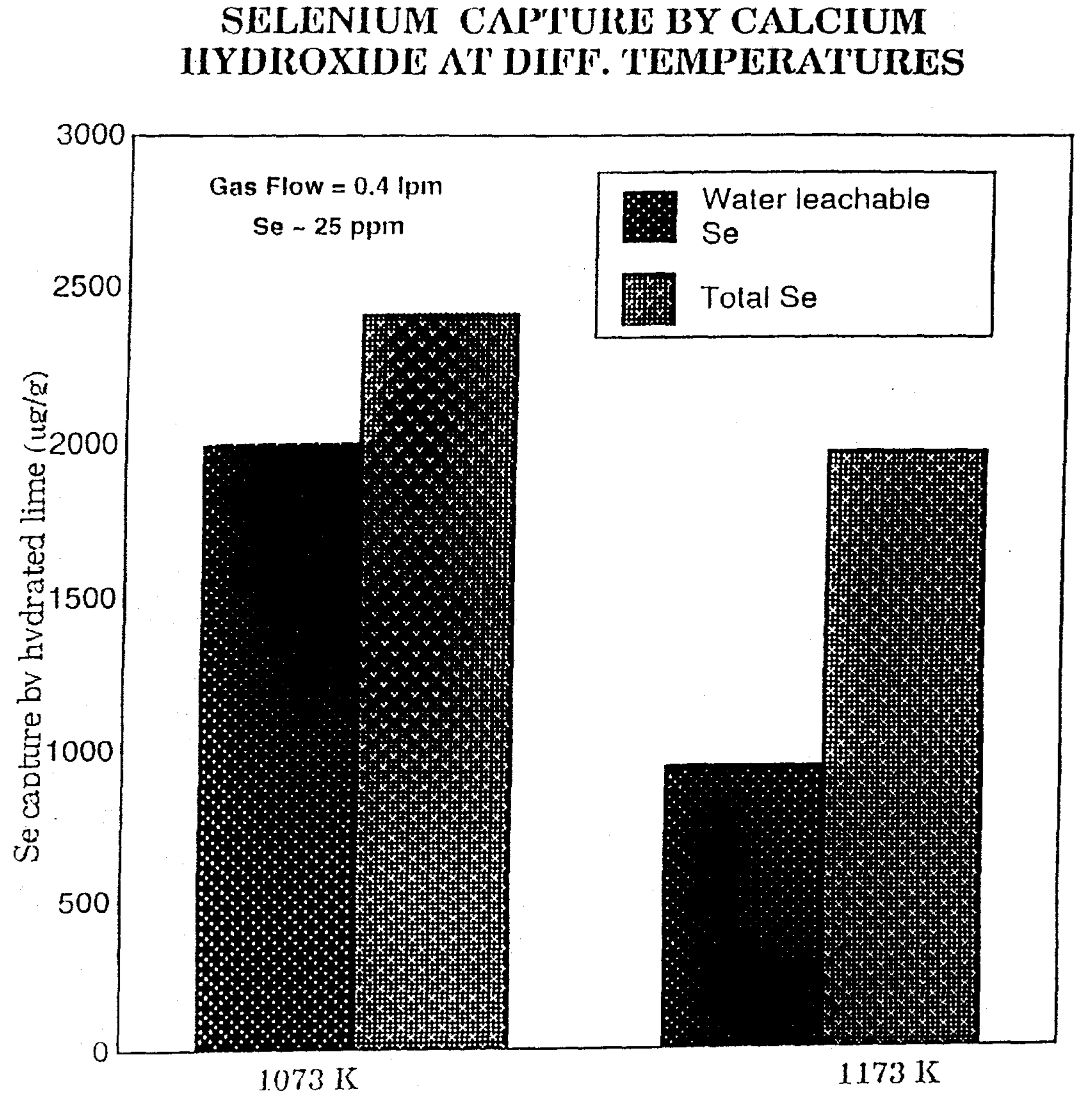

Figure 9: Total Se and water leachable Se captured by ca(OH)$_2$ at different temperatures (se conc. 25 ppm).

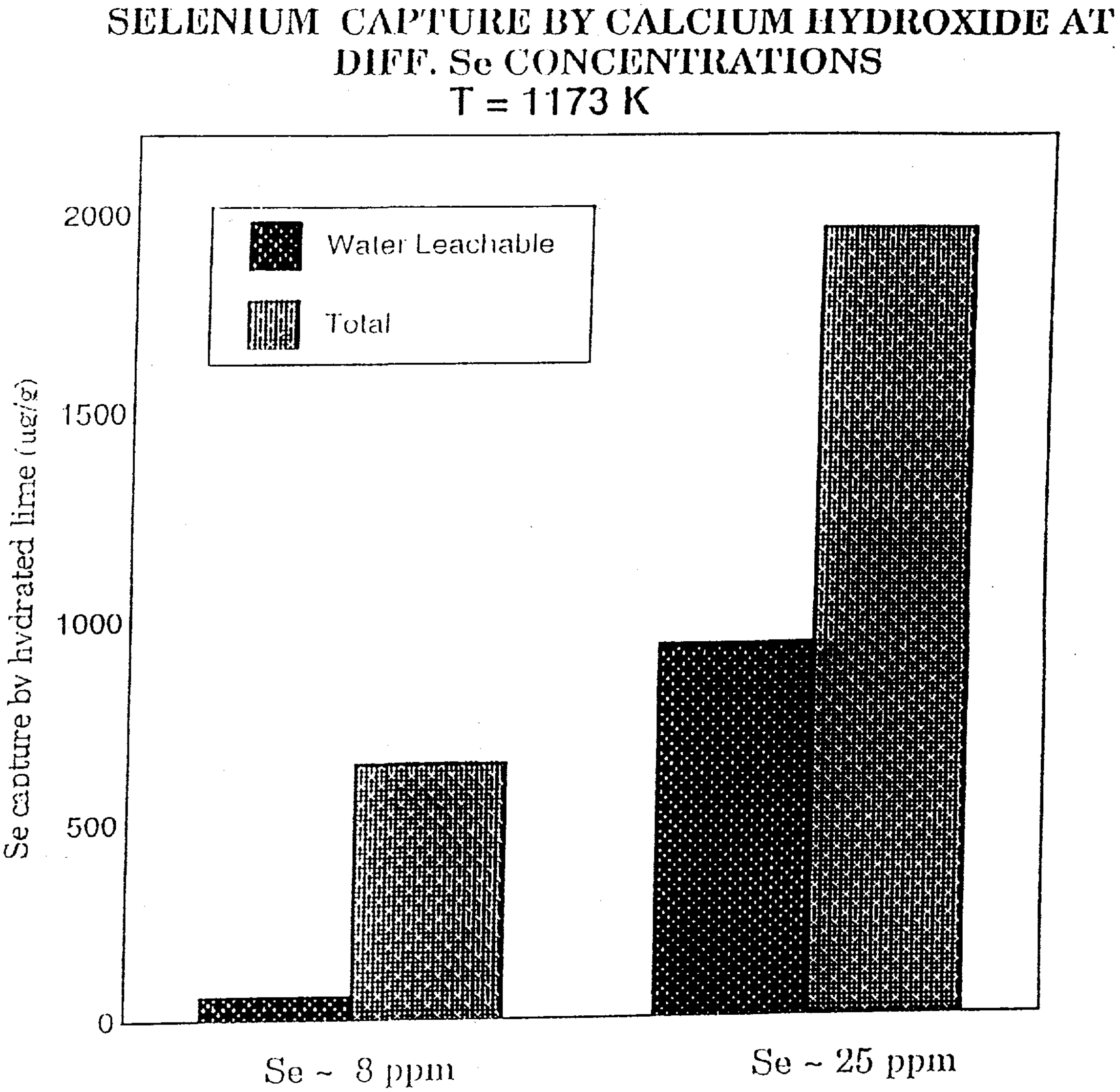

Figure 10: Total Se and water leachable Se captured by ca(OH)$_2$ at two different Se gas-phase concentrations, at 1173 K.

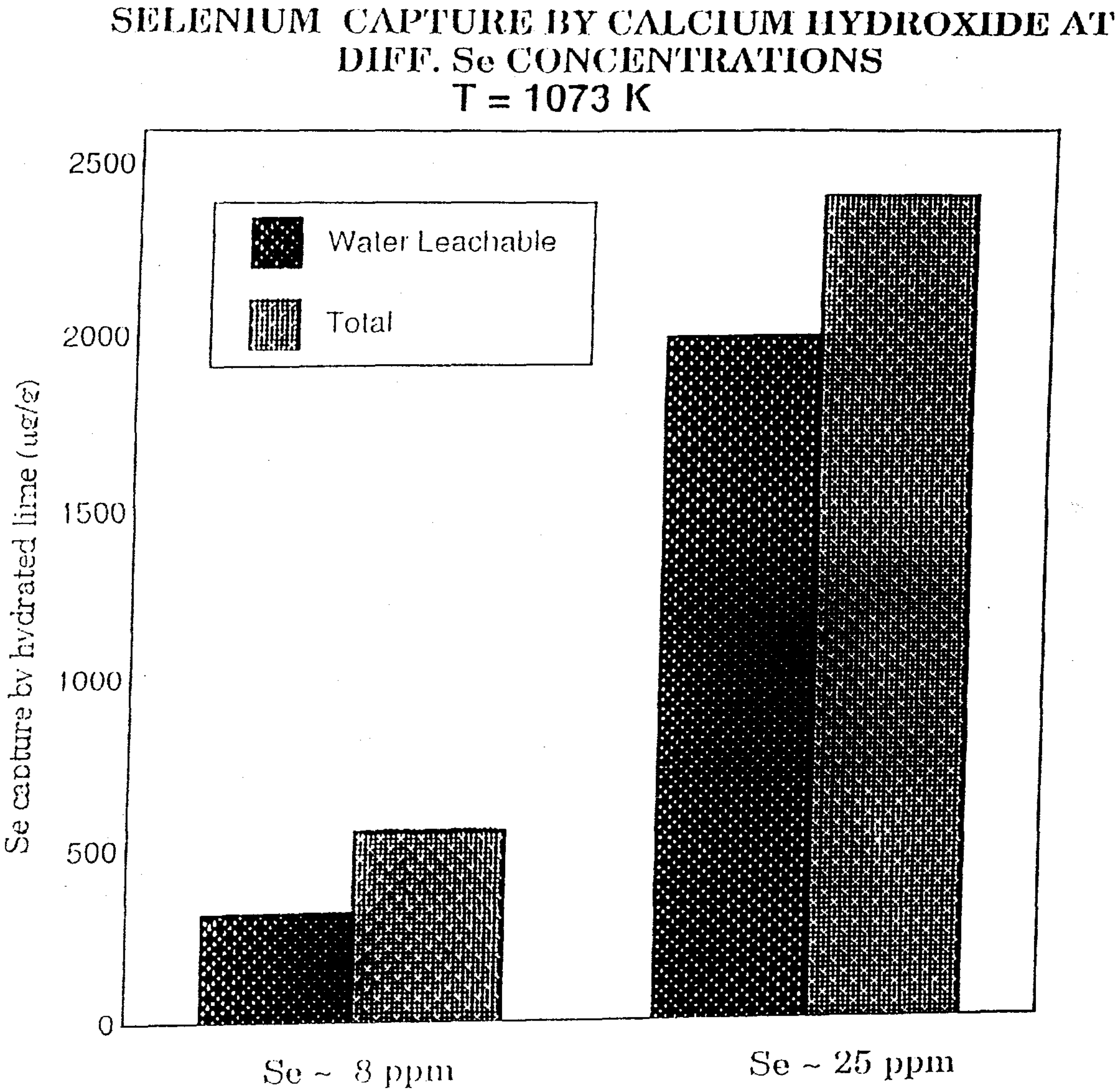

Figure 11: Total Se and water leachable Se captured by ca$(OH)_2$ at two different Se gas-phase concentrations, at 1073 K.

V. CONCLUDING REMARKS

The major accomplishments of the first year of this project are as follows:

The differential reactor system was designed and set-up to perform sorbent screening experiments. Four different sorbents were tested for their Se capturing effectiveness. It was found that $Ca(OH)_2$, of all the sorbents tested, was most effective. This result is consistent with the results obtained by other researchers (Raghunathan and Gullett).

Experiments to determine the effects of temperature and Se-vapor phase concentration on Se-capture capability of $Ca(OH)_2$ were also carried out. Results of these experiments indicate a maximum in selenium capture at a temperature of about 900°C. An increase in Se-vapor phase concentration seem to increase the Se-capture by $Ca(OH)_2$.

Mechanistic understanding of trace metal/sorbent interaction is rather limited. It is proposed that an adsorption/surface reaction mechanism can be used to explain the overall interaction. To confirm the proposed hypothesis leaching experiments were performed. Sorbent samples were subjected to water leaching to determine the physically adsorbed species. Determination of Chemical compound formed, as a result of Se/ Sorbent interaction, was made by performing X-ray diffraction analysis of the sorbent. With $Ca(OH)_2$ as the sorbent, the formation of $CaSeO_4$ was confirmed by this analysis.

Thermodynamic studies were carried out to determine the possible Se Speciation in the flue gas environment. The results of this study indicate the possibility of Se existing in oxide forms in the required temperature window (800° to 1000°C).

Results, as obtained from the differential reactor study, would form the basis for the second phase of this project. Currently work is underway to design an entrained flow reactor system in which Se/sorbent interaction in entrained flow conditions would be studied in order to determine the feasibility of developing an upper-furnace sorbent injection technique for Se removal. A few more sorbents, such as Bauxite and Silica, would be studied in differential reactor system to determine their Se-capture capability. Further insight into the trace metal/sorbent interaction would be obtained from more extensive experimentation and by the use of more sophisticated post-reaction analysis using techniques, such as "XPS" and "Auger-spectroscopy".

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