SORBENTS FOR TRACE METAL REMOVAL FROM COAL-DERIVED SYNTHESIS GAS

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ABSTRACT

Gasifiers convert coal into synthesis gas feed streams that can be used in advanced power cycles to generate electricity and in the production of a wide variety of chemicals. However, the coal-derived synthesis gas contains a myriad of trace contaminants that cannot be released to the environment if the syngas is burned to generate power or may poison the catalysts used in the downstream chemical manufacturing processes. Therefore, removal of these contaminants is critical for the widespread and environmentally-friendly utilization of coal.

TDA Research Inc. (TDA) is developing a sorbent that can reduce the concentration of the trace metal contaminants (i.e., mercury, arsenic, selenium and cadmium) to less than parts per billion levels in the coal-derived synthesis gas at elevated temperatures (260°C). This paper discusses the results of our sorbent's performance for trace metal removal.

1. INTRODUCTION

U.S. Department of Energy (DOE) is working to furnish the U.S. market place with a number of advanced, highly efficient and environmentally responsible coal-based power generation systems that can overcome the economic and environmental impediments that limit full utilization of coal. Advanced power generation cycles, such as the Integrated Gasification Combined Cycle (IGCC) or coal-based fuel cell/gas turbine hybrids, are likely to replace conventional pulverized-coal combustion plants due to their higher efficiency. However, successful commercialization of these advanced technologies depends on the development of processes that eliminate the emission of contaminants in coal. Coal-derived synthesis gas contains a myriad of trace metal contaminants, including mercury, arsenic, selenium and cadmium (Table 1) that may be regulated in power plant emissions and act as poisons for catalysts used in the fuel cells and downstream chemical manufacturing processes.

Table 1. Trace metal concentrations in typical U.S. coals (Pool et al, 1998).

Coal Type	Hg (ppmv)	As (ppmv)	Se (ppmv)	Cd (ppmv)
Pittsburg	0.11	4.1	0.6	0.06
Elkhorn/Hazard	0.13	4.0	3.1	0.31
Illinois No.6	0.22	2.7	2.2	0.15
Wyodak	0.19	1.3	1.6	0.30

Mercury was identified as a hazardous air pollutant in the Title III of the 1990 Clean Air Act Amendments. The US EPA designated it as the toxic substance of greatest concern among all air toxics emitted from the power plants because of its effects on humans and wildlife, and announced that it will regulate emissions of mercury and other air toxics from coal and oil-fired electric utilities. Mercury is particularly difficult to remove from gasified coal gas because in reduced (elemental) state, it will not condense and has little affinity for most sorbents.

Although the emissions of other trace metals are not currently being regulated, due to their higher concentrations in coal gas (particularly arsenic and selenium), they are potential poisons for the catalysts used in the fuel cells (e.g, the Ni-based solid oxide fuel cell catalyst). In addition, any catalyst that is used to convert syngas into chemicals (e.g., Co or Fe-based Fischer-Tropsch catalysts or $Cu/ZnO/Al_2O_3$ used in methanol synthesis) can be poisoned by these trace metals due to the formation of "micro-fluxes" that promote the rapid sintering of active materials or the metals irreversibly chemisorbing on and blocking the active catalytic sites (Alptekin, 2002; Quinn, 2004). Arsenic and selenium form metal hydrides in low ppm levels (arsine and selenium hydride), which will remain in the gas phase at moderately high temperatures. Removal of these contaminants is critical for successful use of coal-derived synthesis gas as a feedstock in the production of chemicals and transportation fuels, and as fuels for fuel cells.

All the technologies developed to date to for the removal of these contaminants are limited to low temperatures (near ambient). It is well documented that high temperature gas cleaning processes greatly improve the efficiency of the power cycle because cold gas clean-up systems condense the steam in the synthesis gas. As a rule of thumb, this reduces the power cycle efficiency by roughly 10% on relative basis. Therefore, there is a need for sorbents that work at above the dew point of coal-derived syngas in the 300-700°F range.

1.1 Prior Work

Mercury Removal: There has been extensive work on removing mercury from hydrocarbon streams. Liquid hydrocarbons and natural gas in particular are treated to remove mercury (200 to 300 $\mu g/m^3$) with expendable absorbents. This is generally carried out to prevent mercury damage to downstream equipment (via amalgamation), to protect the purification systems (i.e., cryo-coolers) at LNG plants and to prevent its release. These hydrocarbon gases are commonly cleaned by sulfur-impregnated activated carbons. Mercury vapors react with the surface-bounded sulfur, reducing the mercury content of the gas from about 250 $\mu g/m^3$ to less than about 0.1 $\mu g/m^3$ with very high sorbent mercury absorption capacity (Markovs, 1994). Unfortunately, although the sulfur-containing sorbents bind mercury more strongly than does the activated carbon, they are still limited to temperatures below 120°C (Chao, 1984). Not only do the high temperatures reduce their affinity for mercury; at high temperatures the sulfur reacts with hydrogen and forms hydrogen sulfide, even if the coal gas H_2S partial pressure is high. In addition, at high enough temperatures the sulfur simply evaporates.

The amalgamation of mercury with noble metals such as silver and gold is well known at moderately high temperatures (Constandi, 1992). Porous silver and/or gold containing samples have been tested in the form of loosely pack wire (referred to as wool) or as thin films coated over gauzes or monoliths. However, the widespread use of gold and silver as expendable sorbents has never caught on for obvious cost reasons. The mass of these materials required per mass of trapped mercury is high, increasing the cost of the precious metal to prohibitive levels. To date, there are no reports showing that any sorbent can cost effectively remove all mercury compounds from coal gas at high temperatures. Thus, there is a clear need for sorbents that can remove mercury from coal-derived syngas at elevated temperatures.

Arsenic Removal: There are a few commercial sorbents that remove arsenic from hydrocarbon streams, including metal impregnated activated carbons. These sorbents are designed to operate

at low temperatures to remove arsine from LPG, LNG or high-pressure hydrocarbon streams to prevent condensation of arsenic in the heat exchangers and other process equipments. These sorbents remove arsenic impurities based on physical adsorption, thus similar limitations applies for the use of these materials in high temperature coal gas clean-up.

One of the best examples of the use of low temperature adsorbents is the Liquid Phase Methanol process (LPMEOH^{TM}), which utilizes coal-derived synthesis gas to produce methanol (Heydorn et al, 2003). In this process, arsenic containing species, and principally arsenic hydride (arsine, AsH_3) were a potent methanol catalyst poison. Arsenic significantly degraded the performance of the $Cu/ZnO/Al_2O_3$ methanol synthesis catalyst, causing catalyst replacement rates of 0.2 to 0.4%/day of operation in the slurry bubble column reactor. The Eastman Chemicals Company (Kingsport, TN) who owns the facility uses a low temperature commercial sorbent to remove arsenic from synthesis gas. The physical adsorbent is affordable in this particular application, because a low temperature sulfur removal system is in place that already cools the syngas. However, it is also reported that arsenic condenses in the heat exchange lines of the cooling train, and periodic removal of the arsenic condensate (an extremely toxic material that must be handled very carefully) is necessary to effectively operate the heat exchangers. Except for previous publications by our group at TDA (Alptekin 2002, Alptekin et al., 2003), there are no publications describing the performance of any sorbent in the 300-700°F range. Similarly, for selenium and cadmium removal, there is little published information at the conditions of interest.

2. EXPERIMETAL

2.1 Sorbent Preparation

During the course of the project, more than 50 different sorbent formulations were prepared using different sources of active materials, inert substrates and additives (i.e., clays, binders). We first screened these formulations according to their physical properties, including porosity, surface area, crush strength of the pellet and active material content. In the selection of proper active material and support, the material costs were also taken into consideration. Our choice of substrate materials included conventional supports such as γ-alumina, titania, silica, activated carbon and boehmite [$AlO(OH)_3$]. All these materials satisfied the criteria of being low-cost and high surface area (150 to 580 m^2/g as measured by the manufacturers). The active material precursors and inert substrates were combined using TDA's geode technology, enabling the incorporation of large quantities of active material into the final sorbent pellet, without plugging the pores of the substrate material and reducing its porosity. The best formulations with the desired physical properties were tested for their trace metal absorption capacities under simulated reaction conditions in an automated testing apparatus.

Figure 1. TDA's sorbent produced by a leading U.S. catalyst manufacturer.

The scale-up of the production of the best sorbent material was then subcontracted to a leading U.S. sorbent/catalyst manufacturer. A 30 kg batch of the material (in the form of 1/8" cylindrical pellets) was produced using commercial manufacturing equipment.

2.2 Sorbent Testing Apparatus

We used a state-of-the-art test unit to evaluate the performance of the sorbents. These units were supported with on-line gas analyzers with ppb level detection capabilities to generate breakthrough profiles for the trace metals of interest (Figure 2). These units use a 1.0 cm-OD Pyrex reactor tube that contains a frit at its mid-point to support pellets of 1-/16 to 1/32" in diameter, which is inserted into a pressure vessel. A Mellen tube furnace surrounding the reactor controls the temperature. The system pressure is controlled with a Badger pressure control valve and gas streams of CO, H_2, CO_2, and N_2 were introduced through Porter mass flow controllers. Mercury is generated using a permeation tube (VICI) immersed in a temperature-controlled mineral oil bath in a glass container, and the mercury concentration can be adjusted by increasing the temperature of the bath. The generator uses an ampule containing liquid mercury in a membrane that is permeable to mercury vapors. At higher temperatures, the permeation rate increases.

To introduce the other trace metals, we used the hydrides of these metals stored in calibrated gas cylinders. At the conditions of interest (at high hydrogen partial pressure), these metals form stable metals hydrides; arsine (AsH_3) and hydrogen selenide (H_2Se). Mixtures of these gases with hydrogen (to enable easy detection in case of a leak) are metered into the system using electronic mass flow controllers. After mixing in a manifold, the gas stream is preheated above the dew point of water to prevent condensation. The water content of the gas is then adjusted using a high pressure HPLC pump. The injection section allows complete evaporation of the liquid and ensures good mixing of the gases. After mixing, the preheated feed mixture generally enters the reactor, but it could also bypass the reactor and flow directly to an analytical system for accurate measurement of the feed gas composition. With this setup, we can generate simulated coal-derived synthesis feed streams gas and pass them over sorbents at desired rates.

Figure 2. TDA's sorbent testing apparatus.

The mercury, arsenic and selenium concentration at the outlet of the reactor bed was continuously monitored with on-line analyzers. These analyzers have a detection limit of 10 to 150 ppb on volume basis. An SRI Model 8610A gas chromatograph (GC) was used to measure concentrations of the other reaction gases (i.e., CO, H_2, CO_2). After exiting the analyzer, the effluent gas stream was scrubbed by a strong NaOH/oxidizer solution to prevent its release. The apparatus was fully automated and ran without an operator for long periods of time.

<u>Testing Procedures:</u> We carried out experiments to measure the breakthrough and saturation capacity of the sorbents. Breakthrough of the mercury, arsenic and selenium is defined as the concentration at the bed exit exceeds 5% of the inlet concentration. Pre-breakthrough capacity is a good indicator of the rate of metal removal, however, it is also important for the sorbent to continue to absorb metals long after the breakthrough. Either in a fixed-bed or moving-bed

reactor configuration, a large fraction of the sorbent bed is operated beyond breakthrough, approaching or reaching saturation. Thus, in a number of tests, we carried the tests to the point where the sorbent reached saturation. Similarly, with arsenic and selenium we carried out experiments to measure the both the breakthrough and saturation capacity of the sorbent.

In screening tests, coal-derived synthesis gas mixtures were simulated by blending certified mixtures of H_2, N_2, CO, H_2, and CO_2. Prior to each test, the mercury, arsenic or selenium analyzer was calibrated and metal concentration was measured at the reactor inlet via a reactor by-pass line. Once a stable baseline was established, the gas flow was directed through the sorbent bed. In every test, a known quantity of sorbent was placed in the reactor (either pure or diluted with inert alumina pellets) and the reactor was heated to the desired temperature under a flow of nitrogen (or helium). After the temperature stabilized, the trace metal laden gas stream was introduced into the sorbent bed.

The critical need was to demonstrate the operation of the sorbent under representative conditions (i.e., elevated temperatures and pressures). However, evaluation of sorbents at such conditions is very difficult because mercury (and to a lesser extent other metals) interact with all types of metal tubing (e.g., stainless steel). Inert materials such as Pyrex or Teflon do not adsorb mercury, however, these materials are difficult to use at the elevated temperatures and pressures (i.e., T=300°C, P=40 bar). We used a Pyrex reactor insert with internal pressure equalization and Teflon lines and fittings to deliver the feed gases to the reactor and transfer the reactor effluent to the analysis system and ensure minimal mercury absorption on the components. In selected experiments, we used gas streams containing all the major syngas components (Table 2).

Table 2. Typical gas compositions.

Components	Composition (% vol.)
Hydrogen	20-50%
Carbon Monoxide	0-10%
Carbon Dioxide	10%
Nitrogen	0-50%
Water	0-20%
Mercury	10-400 ppbw

Test Profiles: Figure 10 presents typical accelerated test profile for mercury. At the beginning of the test, the Hg concentration in the feed gas was measured (in this particular run, it averaged at approximately at 180 $\mu g/m^3$). In low pressure tests, a higher mercury concentration was used to adjust its partial pressure to that of the actual operating conditions (i.e., Hg partial pressure of the gas containing 180 $\mu g/m^3$ Hg at 1 bar is equal to that contains 18 $\mu g/m^3$ Hg at 10 bar). The gas flow was then diverted through the reactor, and tests were carried out at 260°C and near ambient pressure (3.0 psig). At first, the mercury level at the reactor exit dropped sharply due to removal by the sorbent. Mercury breakthrough occurred after 400 minutes of operation. Mercury flow was maintained for another 1,000 minutes following breakthrough to measure the saturation capacity of the sorbent. In most of the tests, we used 95% mercury removal as the criteria for stopping the test at breakthrough and calculating the absorption capacity (i.e., for a 0.18 $\mu g/m^3$ mercury inlet concentration, we used 0.009 $\mu g/m^3$ as the breakthrough point). We defined the capacity as the mass of mercury absorbed per unit mass of sorbent.

Once the mercury concentration eluding from the bed exceeds a pre-determined concentration (in most tests 10% of the inlet Hg concentration), the automated system initiated a shutdown sequence, stopping the mercury gas flow, purging all the mercury from the system with nitrogen.

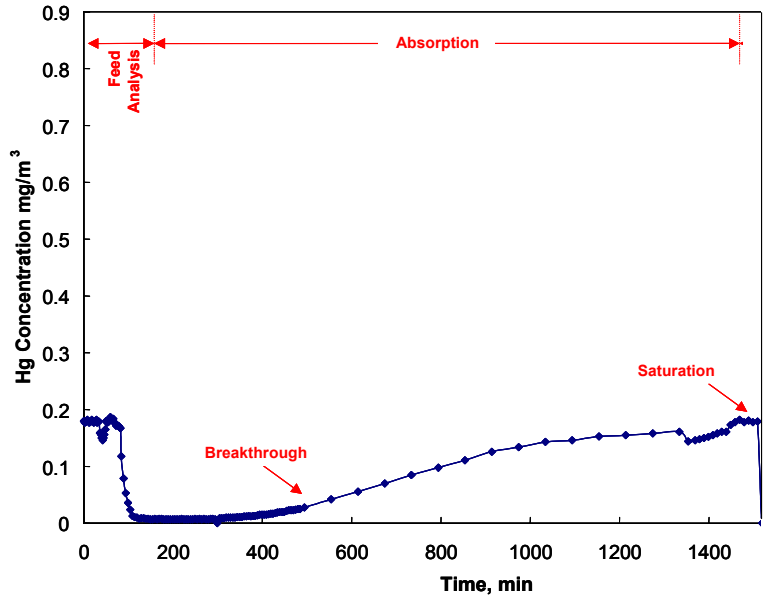

Figure 3. Typical test profile.

We also carried out similar tests with arsine at different operating conditions. Figure 4 illustrates a typical test profile for the arsine breakthrough tests. After waiting for the temperature and pressure to stabilize, we introduced flow of 2.7 ppmv arsine inlet concentration and 50% H_2/ 50% N_2. In the initial tests, we did not use any CO, H_2O, CO_2 and CH_4 in the gas mixtures to make our analytical job easier so we could focus measuring the interaction between the arsine and the sorbent. In the initial screening tests, the gas hourly space velocity (GHSV) was

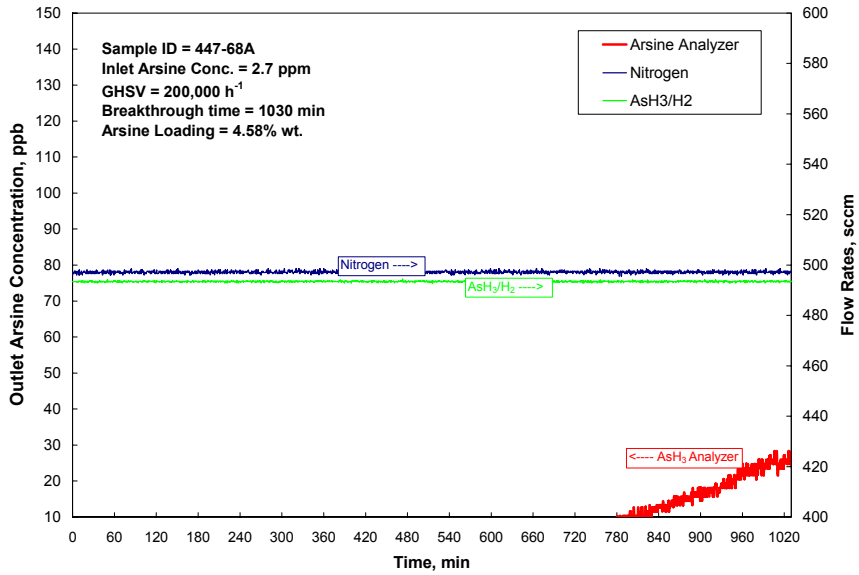

Figure 4. Arsine breakthrough curve over TDA sorbent at 230°C.

maintained at 200,000 hr^{-1}, corresponding to a contact time of 0.018 sec. We selected an extraordinarily low contact time to minimize the breakthrough time so that we could carry out these tests in a short period of time (within few days). Typical commercial expendable guard beds are run at space velocities on the order of 4,000-10,000 h^{-1}. At these conditions most of the sorbent bed is run all the way to saturation and the time between sorbent replacement approaches the sorbent capacity divided by the laoding of the contaminat (many months or several years).

Once the arsine concentration from the bed exceeds a pre-determined concentration, the samples were recovered for physical characterization and chemical analysis (i.e., elemental analysis to confirm arsenic content of the sample). The chemical analysis results and our calculations based on breakthrough are very close (± 10%). We repeated similar tests for hydrogen selenide.

3. RESULTS

3.1 Evaluation of Mercury Capacity of the Sorbent

We first tested the performance of the sorbent (scaled-up sample) for mercury removal at different temperatures. We carried out tests at 160°C, 180°C, 230°C and 260°C, which are identified as feasible depending on the type of the gasifier. At each temperature, we flowed the same simulated coal gas composition with 0.17 $\mu g/m^3$ mercury, monitored mercury breakthrough and estimated absorption capacity of the sorbent. Figure 5 shows the breakthrough profiles at these temperatures.

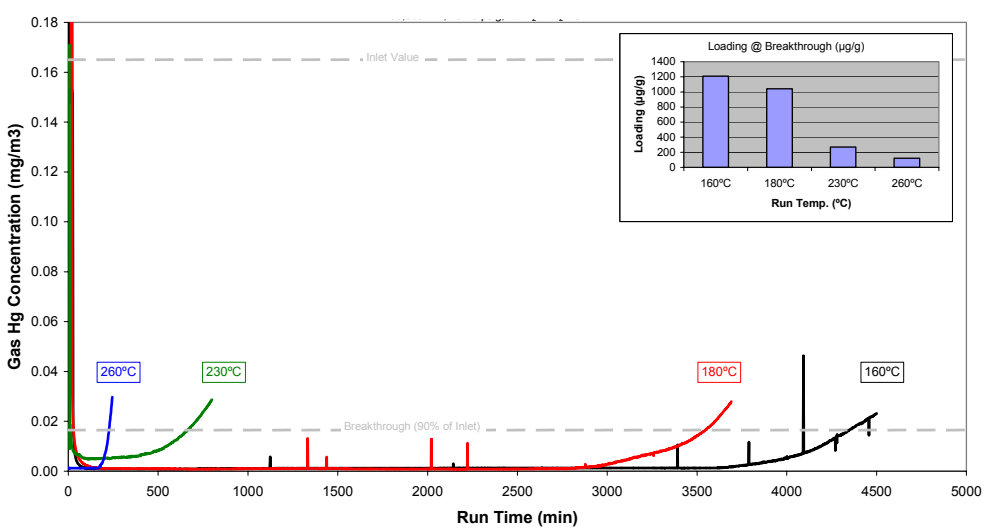

Figure 5. Hg breakthrough profiles, Hg Inlet= 0.17 $\mu g/m^3$, P= 5 psig, GHSV= 68,000 h^{-1}.

The sorbent achieved 1230, 1062, 265 and 114 µg/g Hg capacity at 160°C, 180°C, 230°C and 260°C, respectively. The trend clearly indicates that mercury absorption capacity of the sorbent is higher at lower temperatures. Although the mercury-absorbate interaction is a chemical process and the rate of a chemical reaction increases with temperature, because the equilibrium is less favorable at higher temperatures, the absorption capacity decreases at higher temperatures.

3.2 Evaluation of Arsenic Capacity of the Sorbent

In a separate set of experiments, we measured the arsenic capacity of the sorbent using simulated coal-derived syngas. In these tests, we also evaluated the impact of 20 ppmv, 800 ppmv and 4,800 ppmv of sulfur on the absorption capacity of the sorbent. These sulfur concentrations are selected to simulate conditions with: (1) upstream sulfur removal with a warm-gas desulfurization system (e.g., ZnO-based sulfur sorbent bed located upstream with no polishing step), (2) upstream sulfur removal with hot gas desulfurization (e.g., limestone addition to the gasifier) and (3) no upstream sulfur removal at all, respectively.

We first introduced 1.5 ppmv AsH_3 and 20 ppmv hydrogen sulfide (H_2S) while maintaining a GHSV of 600,000 h^{-1} at reactor temperature of 230^oC and a pressure of 350 psig. Figure 6 shows the AsH_3 and H_2S breakthrough profiles during the test. In order to increase the life of the arsine analyzer in presence of H_2S, it was operated intermittently every 2 hours, resulting a discontinuous breakthrough curve. The arsine concentration at the exit of the reactor remained below the 10 ppb detection range during the pre-breakthrough period (i.e., 100% removal of the

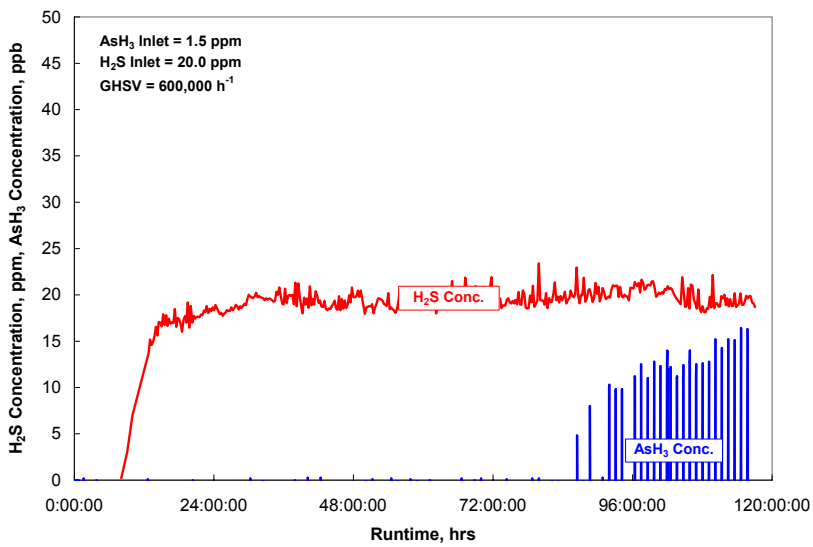

Figure 6. AsH_3 breakthrough profile in the presence of 20 ppmv H_2S in simulated coal gas. T=230^oC, P= 450 psig, AsH_3 Inlet Conc.= 1.5 ppmv.

arsenic). Such high removal efficiency is necessary to protect the catalysts used in the syngas conversion processes. We did not measure any sulfur exiting the reactor in the first 8.5 hours of the test, suggesting that sorbent also removes sulfur. This may be a valuable feature for the sorbent, which can be used to remove trace levels of sulfur remaining in the syngas, following a bulk desulfurization process. We estimated a 7.1% wt. arsenic absorption capacity for the sorbent on a pre-breakthrough basis. The arsenic absorption capacity was lower in the presence of sulfur than when sulfur-free feeds used in earlier experiments (Alptekin et al, 2002), indicating a competitive process between H_2S and AsH_3 for the same active sites.

We also investigated the effect of carbonyl sulfide (COS) on the performance of the sorbent. Typical coal gasifiers produces a CO-rich syngas that promotes formation of COS (the H_2S:COS molar ratio in typical coal-derived syngas averages at around 10). To fully assess the impact of

sulfur, we introduced equal concentrations of H_2S and COS while maintaining the total sulfur content of the gas at 20 ppmv same as in the previous experiment (basically replacing half of the H_2S with COS).

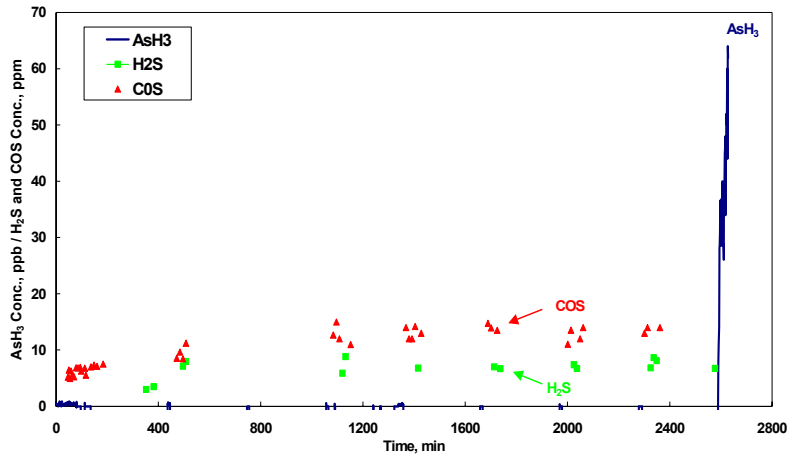

Figure 7. AsH_3 breakthrough profile in the presence of 20 ppmv H_2S in simulated coal gas T=230°C, P= 450 psig, AsH_3 Inlet Conc.= 1.5 ppm, H_2S Inlet Conc.= 10 ppmv, COS Inlet Conc. = 10 ppmv, GHSV= 1,200,000 h^{-1}.

We observed that the arsenic capacity of the sorbent increased to 10.7% wt. in the presence of 10 ppmv COS and 10 ppmv H_2S. It is speculated that the increase in capacity is due to the relatively lower affinity of the sorbent to COS. The gas profiles show that the COS breakthrough occurs almost immediately. Because the sorbent does not remove COS, its arsenic removal performance did not altered by competitive absorption of COS, which allows the sorbent to achieve a higher absorption capacity for arsenic.

Figure 8 shows the arsenic and H_2S breakthrough profiles for the sorbent at 800 ppmv H_2S inlet.

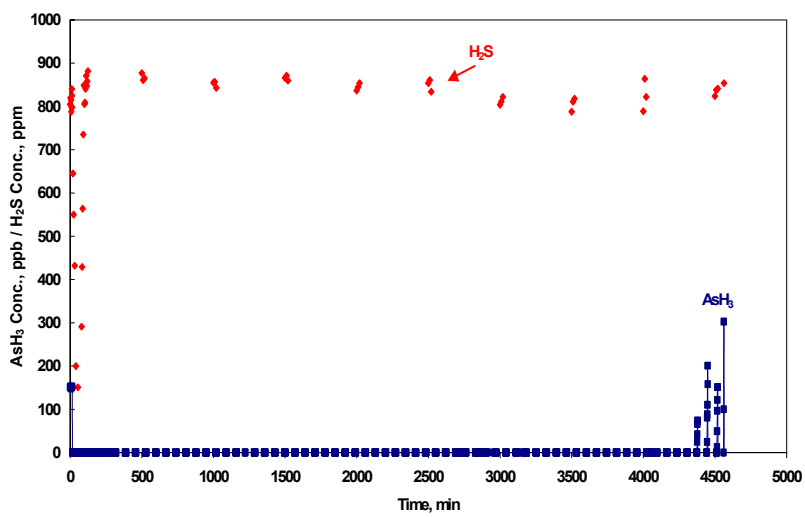

Figure 8. AsH_3 breakthrough profile in the presence of 800 ppmv H_2S in simulated coal gas T=230°C, P= 450 psig, AsH_3 Inlet Conc.= 1.5 ppm, H_2S Inlet Conc.= 800 ppmv, GHSV= 1,200,000 h^{-1}.

In the presence of 800 ppmv H_2S, TDA's sorbent had 4.1% wt. arsenic absorption capacity, simulating a condition with no upstream sulfur removal for low sulfur western coals or eastern coals with limestone addition. The capacity of the sorbent is still high enough to provide cost effective As removal in the presence of H_2S and COS.

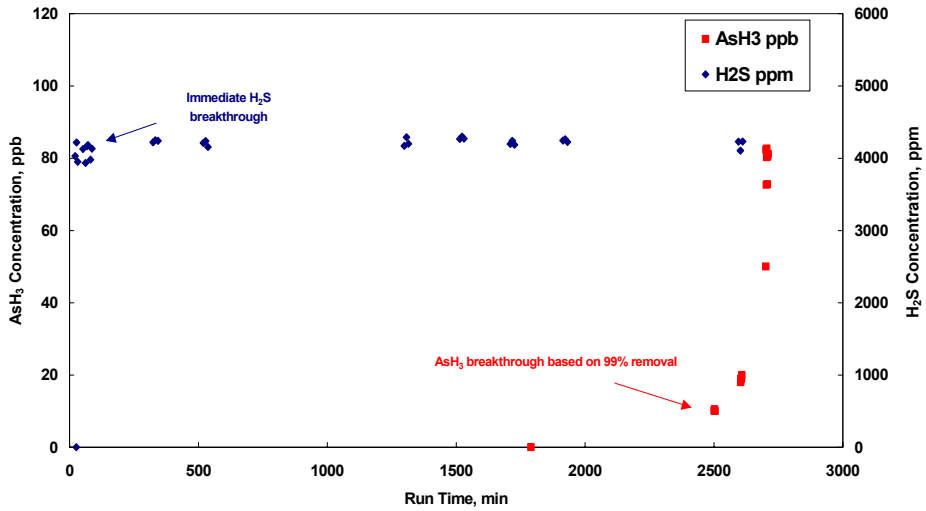

Figure 9. AsH_3 breakthrough profile in the presence of 20 ppmv H_2S in simulated coal gas T=235°C, P= 450 psig, AsH_3 Inlet Conc.= 1.5 ppm, H_2S Inlet Conc.= 4,400 ppmv, COS Inlet Conc. = 400 ppmv, GHSV= 180,000 h^{-1}.

Finally, we investigate the impact of 4,800 ppmv sulfur (4,400 ppmv H_2S and 400 ppmv COS) simulating a syngas generated by using high sulfur Eastern U.S. coals with no upstream sulfur removal. For this test, we reduced the GHSV to 180,000 h^{-1} (the gas solid contact time was still very low, on the order of 20 miliseconds). In the presence of 4,800 ppmv sulfur, TDA sorbent had 2.89% wt. arsenic absorption capacity.

3.3 Evaluation of Selenium Capacity of the Sorbent

Although arsenic has been singled out as the worst catalyst poison primarily due to its high concentration and high reactivity, coal-derived syngas contains other trace metals that must be removed to ensure a long life for the catalyst used in fuel cells or downstream chemical manufacturing processes. In particular, selenium is a present in high concentrations in some U.S. coals. We tested the performance of our best sorbent for selenium removal. As the source of selenium, we used selenium hydride (H_2Se) mixed with hydrogen. We tested the sorbent at a GHSV of 1,100,000 h^{-1} at reactor temperature of 245°C and a pressure of 350 psig in the presence of a 1.25 ppmv H_2Se/H_2 mixture (for experimental convenience, we did not simulate syngas mixture). Figure 10 shows the H_2Se breakthrough profile during the test using an on-line monitor. The sorbent's selenium absorption capacity was 24.4% on a weight basis (using dry syngas), confirmed by post-reaction chemical analysis.

3.4 Sorbent Evaluation with Multi-contaminants

We also investigated the ability of our sorbent to remove multiple trace metals in one-step. We first looked at the ability of the sorbent to remove mercury in the presence of arsenic.

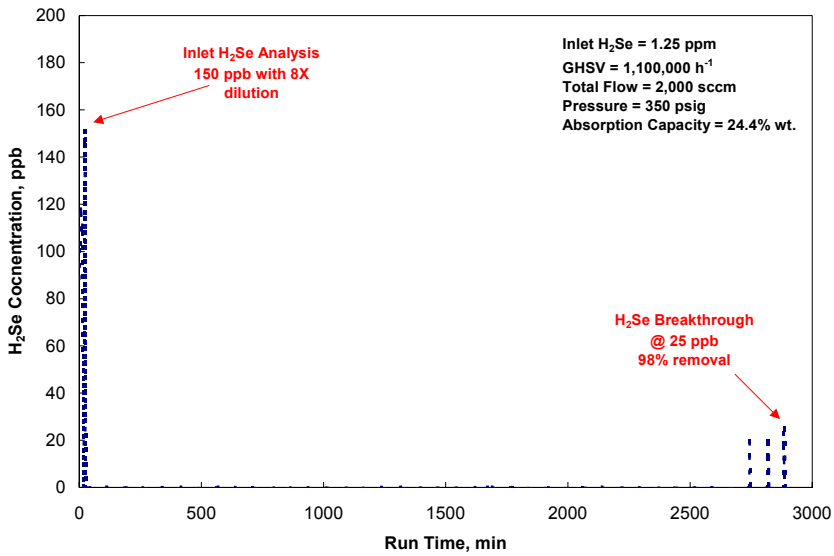

Figure 10. H_2Se breakthrough profile in the presence of under dry syngas. T=245°C, P= 350 psig, GHSV= 1,100,000 h^{-1}.

The absorption capacity of mercury is reduced (approximately 20% wt.) by presence of arsenic in the gas stream, but a stable Hg absorption was still achieved with no signs of degradation during cycling (Figure 11). The arsenic capacity of the sorbent was not fully measured because we did not observe any arsenic breakthrough in the test (because the sorbent's capacity for arsenic is far greater than it is for mercury).

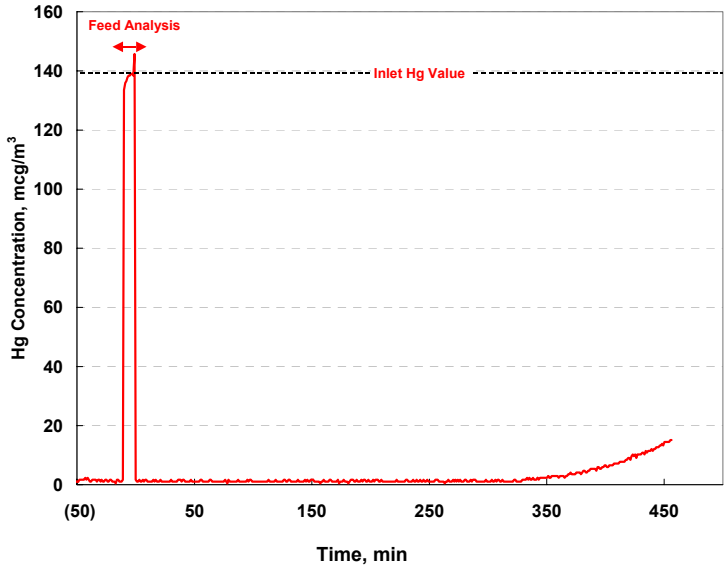

Figure 11. Hg breakthrough profile in the presence of AsH_3. T= 260°C, P= 5 psig, GHSV= 50,000 h^{-1}, Hg Inlet= 140 $\mu g/m^3$, AsH_3 Inlet= 0.75 ppmv using simulated syngas.

We also carried out an experiment in which we simulated a syngas that contains a combination of 1.25 ppmv H_2Se and 1.25 ppmv AsH_3. In this experiment, we maintained a GHSV of 1,100,000 h^{-1} at reactor temperature of 240°C and a pressure of 350 psig. Figure 12 shows the H_2Se and AsH_3 breakthrough profiles. The absorption capacities of arsine and selenium were 12.9% and 10.1% wt., respectively. The results were confirmed by post-reaction chemical analysis.

These results are also in agreement with our hypothesis on the removal mechanism for the hydrides of arsenic and selenium. The sorbent also plays two important roles in chemically stabilizing with these metals hydrides by: (1) catalyzes the decomposition of the metal hydrides into respective metal vapors and hydrogen:

$$AsH_{3(g)} = As_{(g)} + 3/2H_{2(g)}$$
$$H_2Se_{(g)}) = Se_{(g)} + H_{2(g)}$$

(2) captures and condenses the metal vapors at the surface and the pores of the sorbent, which allows such higher capacities.

$$As_{(g)} = As_{(s)} \text{ and } Se_{(g)} = Se_{(s)}$$

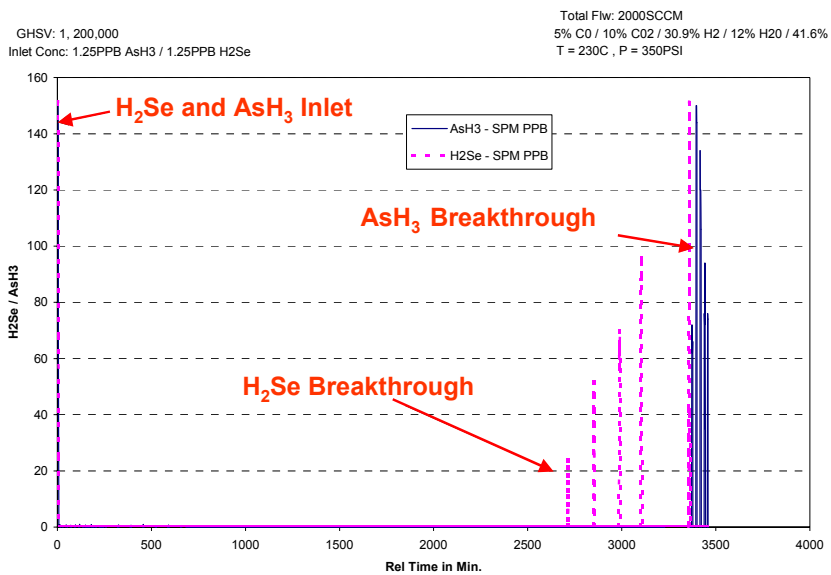

Figure 12. H_2Se and AsH_3 breakthrough profiles under representative coal gas conditions. T= 240°C.

3.5 Sorbent Stability

Following an absorption experiment, we heated the sample at 1°C/min to 500°C using a thermogravimetric analyzer (TGA). Only near 500°C did we observe a small weight change, which we believe is due to the release of arsenic. These results show that the arsenic will be removed and stabilized by the sorbent, and will not be given off under any temperature or pressure excursions, caused by any operational upsets.

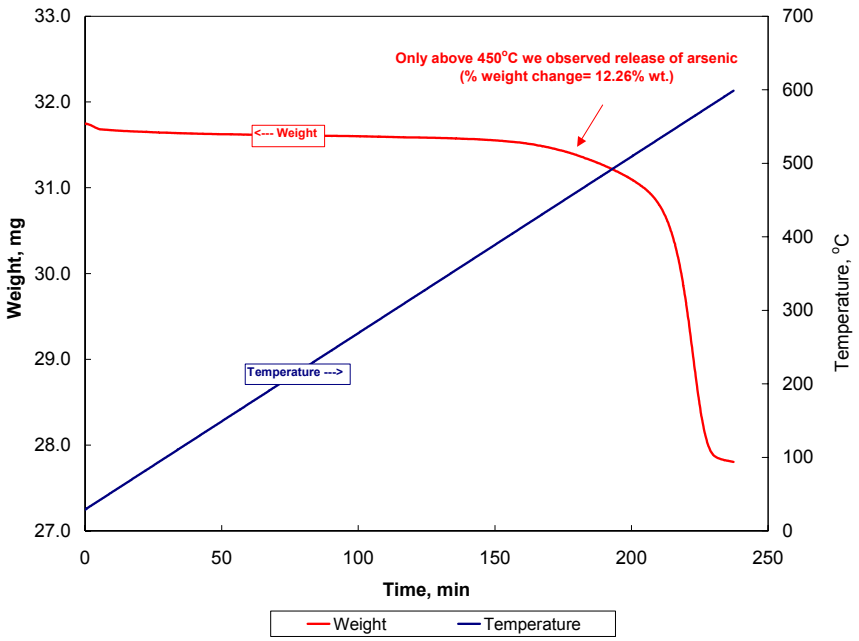

Figure 13. Temperature-programmed desorption (TPD) for the sorbent tested for combined mercury and arsenic removal.

4. CONCLUSIONS

TDA's sorbent achieves a high capacity capacity for the absorption of trace metal contaminants from coal-derived syngas at elevated temperatures (230-260°C) under simulated conditions. TDA's sorbent exhibits a high capacity for mercury absorption ranging from 114 to 1231 μg/g at temperatures ranging from 160 to 260°C. We also showed that the sorbent has a high capacity for arsenic even in the presence of high concentrations of sulfur. The capacity of the sorbent decreased from 7.1% wt. to 2.89% wt. as the sulfur content of the syngas increased from 20 ppmv to 5,000 ppmv. The sorbent achieved 24.4 % wt. capacity for selenium under simulated conditions. Finally, experiments carried out with all multiple trace metals shows that the sorbent can simultaneously remove all these contaminants from syngas in one-step.

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