

# ENERGY

INVESTIGATION ON DURABILITY AND REACTIVITY OF  
PROMISING METAL OXIDE SORBENTS DURING SULFIDATION  
AND REGENERATION

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Technical Progress Report for the Period  
July 1 to September 30, 1996

By  
K. C. Kwon

November 1996

Work Performed Under Contract no DE-FG21-94MC31206

For  
U.S. Department of Energy  
Morgantown Energy Technology Center  
Morgantown, West Virginia

By  
Tuskegee University  
Tuskegee, Alabama

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## SCHEDULE AND MILESTONES

	FY 1994-1995												FY 1995-1996														
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S			
Procurements of Materials and Equipment	██████████																										
Fabrication of a Micro Batch Reactor					██████████																						
Development of Analytical Procedures for Concentrations of Sulfur compounds					██																						
Development of Experimental Procedures for Sulfidation Reaction of Fresh Metal Oxide Sorbents					████████████████████████████████████																						
Formulation of Durable Metal Oxide Sorbents with High-Sulfur Removal Capacity												██															
Reaction Kinetics on Sulfidation of Metal Oxide Sorbents												██															
Reaction Kinetics on Regeneration of Sulfur-loaded Metal Oxide Sorbents																		██									
Development of an Intraparticle Diffusivity Model for Sulfidation of Metal Oxide Sorbents												████████████████															
Delineation of Effects of Hydrogen Partial Pressures and Moisture Amounts on Sulfidation of Metal Oxide Sorbents												██															
Equilibrium Absorption of Hydrogen Sulfide into Metal Oxide Sorbents												██															
Development of a Micro Differential Reactor												██															

## EXECUTIVE SUMMARY

The main objectives of this research project during this quarter are to formulate metal oxide sorbents using various ingredients as well as formulation conditions, and test reactivity of formulated metal oxide sorbents with hydrogen sulfide for 120 seconds at 550°C, and develop a formula of a sorbent suitable for the removal of hydrogen sulfide from hot coal gases.

## INTRODUCTION

Metal oxide sorbents were formulated with zinc oxide as an active sorbent ingredient, and titanium oxide as a supporting metal oxide. Various additives such as Al, Ce, Zr, Cu, Co, Ni, Mn, Cr and Ca were utilized to enhance sulfur-removal capacity of formulated metal oxide sorbents. This mixture was extruded 1-mm cylindrical rods. The formulated metal oxide sorbents were calcined for 0.5 - 4 hours at 860 - 920°C. The fresh formulated metal oxide sorbents in the form of 1-mm cylindrical rod were crushed to obtain 100- 200 mesh particles, and were reacted with simulated coal gases containing hydrogen sulfide in the 35 cm<sup>3</sup> 316 stainless steel batch reactor for 120 seconds at 550°C. Concentrations of hydrogen sulfide were analyzed with a gas chromatograph to evaluate reactivity of formulated metal oxide sorbents with H<sub>2</sub>S.

## RESULTS AND DISCUSSION

Research activities and efforts of this research project were concentrated on formulating various metal oxide sorbents with various additives under various formulation conditions, and conducting experiments on initial reactivity of formulated sorbents with hydrogen sulfide.

Experiments on reactivity of formulated metal oxide sorbents with wet hydrogen sulfide contained in a simulated coal gas mixture were carried out for 120 seconds at 550°C (see Table 1) to evaluate reactivity of formulated sorbents with hydrogen sulfide. A typical simulated coal gas mixture consists of 9107-ppm hydrogen sulfide (0.005 g; 1 wt %), 0.085-g water (15.84 wt %), 0.0029-g hydrogen (0.58 wt %), and 0.4046-g nitrogen (81.34 wt%).

Table 1. Experimental conditions for the reaction of hydrogen sulfide with formulated metal oxide sorbents in the presence of moisture, nitrogen and hydrogen.

Reactor Volume, cm <sup>3</sup> :	35
Temperature, °C:	550
Reaction Time, s:	120
Particle Size, mesh	100 - 200
Amount of Sorbent, g	0.05
Initial Partial Pressure of Hydrogen at 25°C, psia:	14.7
Initial Amount of Water, g:	0.085
Initial Concentration of H <sub>2</sub> S, ppm	8700
Initial Partial Pressure of Nitrogen at 25°C, psia:	150
Initial Total Pressure of Reaction Mixture at 25°C, psia:	164.7

Metal oxide sorbents were formulated with various additives to enhance their reactivity with hydrogen sulfide contained in simulated coal gas mixtures (see Tables 2 through 7). Reactivity of formulated metal oxide sorbents was compared by reacting sorbents with initial 8700-ppm hydrogen sulfide for 120 seconds at 550°C (see Figures 1 through 5).

The metal oxide sorbents TU-61 through TU-95B shown in Tables 2 through 7 were formulated with zirconium oxide and kaolin binders.



Table 2. Formulation of various TU sorbents.

Sorbents	TU-57	TU-58	TU-59	TU-60	TU-61	TU-62	TU-63	TU-64	TU-65	TU-66	TU-67	TU-68
Amounts of Ingredients (gram) and Formulation Conditions												
ZnO		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Zinc Peroxide	2.6976											
TiO <sub>2</sub>	2	2	2	2	2	2	2	2	2	2	2	2
Corn Starch	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Zirconium Oxide			0.05		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Aluminum Oxide												
Calcium Carbonate	0.05	0.05		0.05								
Bentonite	0.15	0.15	0.15									
Kaolin				0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Cobalt Oxide												
Molybdeum Oxide												
Nickel Oxide								0.015				
Cuprous Oxide	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015		0.015	0.015	
Ferrous Oxide						0.015					0.015	0.015
Ferrous Hydroxide		0.015					0.015					
Manganese Oxide									0.015	0.015	0.015	0.015
Chromous Oxide	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Cerium Oxide												
0.5 w% H <sub>2</sub> O <sub>2</sub>												
1 w% H <sub>2</sub> O <sub>2</sub>		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2 w% H <sub>2</sub> O <sub>2</sub>												
5 w% H <sub>2</sub> O <sub>2</sub>	0.5											
Calcination Temperature, °C	860	860	860	860	860	860	860	860	860	860	860	860
Calcination Duration, hr	2	2	2	2	2	2	2	2	2	2	2	2
H <sub>2</sub> S, ppm at 2-min reaction	2366	4590	4969	4362	5351	5272	4904	5206	5166	4546	5308	5294
	2337	4566	4913	4708	5358	5228	5192	4925	5243	4994	5425	5410
	2404	4627	5352	4484	5457	5133	4918	5165	4886	4617	6018	5027
	2363				5397	5392	5220	4840	5146		5968	5198
											5449	

Table 3. Formulation of various TU sorbents.

Sorbents	TU-69	TU-70	TU-71A	TU-71B	TU-71C	TU-71D	TU-72	TU-73	TU-74	TU-75	TU-76	TU-77
Amounts of Ingredients (gram) and Formulation Conditions												
ZnO	1.7	0.5	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Zinc Peroxide		1.35										
TiO <sub>2</sub>	2	2	2	2	2	2	2	2	2	2	2	2
Corn Starch	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Zirconium Oxide	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Aluminum Oxide												
Calcium Carbonate												
Bentonite												
Kaolin	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Cobalt Oxide												
Molybdeum Oxide												
Nickel Oxide	0.015											
Cuprous Oxide		0.015	0.015	0.015	0.015	0.015		0.015				
Ferrous Oxide		0.015	0.015	0.015	0.015	0.015				0.015		
Ferrous Hydroxide												
Manganese Oxide	0.015										0.015	
Chromous Oxide	0.015	0.015	0.015	0.015	0.015	0.015			0.015			
Cerium Oxide												0.015
0.5 w% H <sub>2</sub> O <sub>2</sub>												
1 w% H <sub>2</sub> O <sub>2</sub>	1.5		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2 w% H <sub>2</sub> O <sub>2</sub>												
5 w% H <sub>2</sub> O <sub>2</sub>		0.5										
Calcination Temperature, °C	860	860	860	880	900	920	860	860	860	860	860	860
Calcination Duration, hr	2	2	2	2	2	2	2	2	2	2	2	2
H <sub>2</sub> S, ppm at 2-min reaction												
	5345	4672	5310	6157	5436	5824	4804	4819	5002	5347	5257	5085
	5403	4587	5190	6044	6449	5364	4827	4246	4663	5191	5051	4837
	5429		5086	6196	5735	5514	4438	4438	4687	5291	5161	4998
	5430		5260	6053	6187	5593	4787	4336	4609	5085	5077	4677
				6262		5437				5157	5214	4848

Table 4. Formulation of various TU sorbents.

Sorbents	TU-78	TU-79	TU-80	TU-81	TU-82	TU-83	TU-84A	TU-84B	TU-84C	TU-84D	TU-85	TU-86
Amounts of Ingredients (gram) and Formulation Conditions												
ZnO	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Zinc Peroxide												
TiO <sub>2</sub>	2	2	2	2	2	2	2	2	2	2	2	2
Corn Starch	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Zirconium Oxide	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Aluminum Oxide												
Calcium Carbonate												
Bentonite												
Kaolin	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Cobalt Oxide		0.015		0.015	0.015		0.015	0.015	0.015	0.015	0.015	0.015
Molybdeum Oxide			0.015									
Nickel Oxide	0.015					0.015						
Cuprous Oxide				0.015							0.015	
Ferrous Oxide												
Ferrous Hydroxide												
Manganese Oxide												
Chromous Oxide												0.015
Cerium Oxide												
0.5 w% H <sub>2</sub> O <sub>2</sub>												
1 w% H <sub>2</sub> O <sub>2</sub>	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2 w% H <sub>2</sub> O <sub>2</sub>												
5 w% H <sub>2</sub> O <sub>2</sub>												
Calcination Temperature, °C	860	860	860	860	860	860	860	860	860	860	860	860
Calcination Duration, hr	2	2	2	2	2	2	3	4	2	1	1	1
H <sub>2</sub> S, ppm at 2-min reaction	4497	4082	6185	5384	4975	5157	5357	5577	4597	4334	4389	5817
	4672	4197	5876	5332	4830	5036	5436	5466	4280	4249	4280	5924
	4739	4299	5867	5360	4948	5121	5120	5179	4508	4189	4052	5830
	4333	4197	5640	5217	4838	4762	5118	5593	3975	4034	3964	5835
	4420	4239	5294	5291	5137	5279	5291	5247	4537	4351	4147	5736

Table 5. Formulation of various TU sorbents.

	TU-87	TU-88	TU-89	TU-90	TU-91	TU-92	TU-93	TU-89	TU-85	TU-92	TU-89	TU-91
Amounts of Ingredients (gram) and Formulation Conditions												
ZnO	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Zinc Peroxide												
TiO <sub>2</sub>	2	2	2	2	2	2	2	2	2	2	2	2
Corn Starch	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Zirconium Oxide	0.05	0.05	0.05	0.05	0.05	0.05		0.05	0.05	0.05	0.05	0.05
Aluminum Oxide							0.05					
Calcium Carbonate												
Bentonite												
Kaolin	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Cobalt Oxide	0.015	0.015	0.015	0.015	0.015			0.015	0.015		0.015	0.015
Molybdeum Oxide	0.015											
Nickel Oxide		0.015										
Cuprous Oxide					0.015	0.015			0.015	0.015		0.015
Ferrous Oxide												
Ferrous Hydroxide												
Manganese Oxide			0.015					0.015			0.015	
Chromous Oxide												
Cerium Oxide				0.015	0.015							0.015
0.5 w% H <sub>2</sub> O <sub>2</sub>												
1 w% H <sub>2</sub> O <sub>2</sub>	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2 w% H <sub>2</sub> O <sub>2</sub>												
5 w% H <sub>2</sub> O <sub>2</sub>												
Calcination Temperature, °C	860	860	860	860	860	860	860	860	860	860	860	860
Calcination Duration, hr	1	1	1	1	1	1	1	1	1	1	1	1
H <sub>2</sub> S, ppm at 2-min reaction	6337	5120	4267	4722	5354	5798	4974	5011	4337	5366	4983	4176
	6530	5159	3655	4368	5127	5652	4915	5092	4388	5195	4987	4222
	6211	5102	4151	4305	5062	5767	5135	4966	4299	5545	4956	4221
	6631	5253	3692	4835	5088	5769	5036	5079	4378	5446	4995	4083
	6158	5070	3725	4673	5215	5855	4937	4933	4404	5281		

Table 6. Formulation of various TU sorbents.

Sorbents	TU-81	TU-86	TU-93	TU-73	TU-84C	T-94A	T-95A	T-95B	T-95C	T-94B	T-94C	T-94D
Amounts of Ingredients (gram) and Formulation Conditions												
ZnO	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Zinc Peroxide												
TiO <sub>2</sub>	2	2	2	2	2	2	2	2	2	2	2	2
Corn Starch	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Zirconium Oxide	0.05	0.05		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Aluminum Oxide			0.05									
Calcium Carbonate												
Bentonite												
Kaolin	0.15	0.15	0.15	0.15	0.15							
Cobalt Oxide	0.015	0.015			0.015							
Molybdeum Oxide												
Nickel Oxide												
Cuprous Oxide	0.015			0.015		0.015				0.015	0.015	0.015
Ferrous Oxide												
Ferrous Hydroxide												
Manganese Oxide												
Chromous Oxide		0.015										
Cerium Oxide												
0.5 w% H <sub>2</sub> O <sub>2</sub>												
1 w% H <sub>2</sub> O <sub>2</sub>	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2 w% H <sub>2</sub> O <sub>2</sub>												
5 w% H <sub>2</sub> O <sub>2</sub>												
Calcination Temperature, °C	860	860	860	860	860	860	860	860	860	860	860	860
Calcination Duration, hr	2	1	1	2	2	0.5	0.5	1	2	1	2	3
H <sub>2</sub> S, ppm at 2-min reaction	5145	4155	5158	4393	4967	4701	3979	4675	4928	5460	4993	4788
	5084	4046	5257	4359	4843	4635	3981	4754	4682	5304	5005	4724
	4932	3952	5198	4460	4941	4726	3920	4847	4784	5270	5031	4702
	5109	3961	5022	4458	5018	4661	3836	4692	4704	5228	4984	4685
	5092	4010	5161	4408	5036	4704	3912	4698	4477	5346	5072	4787

Table 7. Formulation of various TU sorbents.

Sorbents	TU-95D	TU-95A	TU-96A	TU-96B
Amounts of Ingredients (gram) and Formulation Conditions				
ZnO	1.7	1.7	1.7	1.7
Zinc Peroxide				
TiO <sub>2</sub>	2	2	2	2
Corn Starch	0.05	0.05	0.05	0.05
Zirconium Oxide	0.05	0.05	0.05	0.05
Aluminum Oxide				
Calcium Carbonate				
Bentonite				
Kaolin	0.15	0.15	0.15	0.15
Cobalt Oxide			0.015	0.015
Molybdeum Oxide				
Nickel Oxide				
Cuprous Oxide				
Ferrous Oxide				
Ferrous Hydroxide				
Manganese Oxide				
Chromous Oxide				
Cerium Oxide				
0.5 w% H <sub>2</sub> O <sub>2</sub>				
1 w% H <sub>2</sub> O <sub>2</sub>	1.5	1.5	1.5	1.5
2 w% H <sub>2</sub> O <sub>2</sub>				
5 w% H <sub>2</sub> O <sub>2</sub>				
Calcination Temperature, °C	860	860	860	860
Calcination Duration, hr	3	0.5	1	0.5
H <sub>2</sub> S, ppm at 2-min reaction				
	4702	5235	5611	4053
	4594	5181	5624	4092
	4685	5260	5642	4036
	4787	5397	5649	4115
		5287	5532	4175

Table 8. Effects of Binders on durability of sorbents formulated with Cu and Cr additives.

Sorbent	Recovery, %	Additive, g		Binders, g			
		Cu	Cr	Calcium Carbonate	Bentonite	Zirconium Oxide	Kaolin
TU-54A	90.00	0.020	0.020	0.05	0.15		
TU-55B	85.27	0.015	0.015	0.05	0.15		
TU-54B	86.82	0.020	0.020	0.05	0.15		
TU-60	100.40	0.015	0.015	0.05			0.15
TU-61	100.20	0.015	0.015			0.05	0.15

Table 9. Effects of calcination durations on durability of sorbents calcined at 860°C.

Sorbent	Calcination Time, min	Recovery, %	Additive, 0.015 g	Sorbent	Calcination Time, min	Recovery, %	Additive, 0.015 g
95A	0.5	77	none	94B	1	97	Cu
95A	0.5	80	none	94B	1	97	Cu
95A	0.5	83	none	94C	2	98	Cu
95A	0.5	88	none	94C	2	100	Cu
95B	1	102	none	94D	3	98	Cu
95B	1	101	none	96B	0.5	97	Co
95B	1	104	none	96A	1	103	Co
95C	2	102	none	96A	1	103	Co
95D	3	101	none	84D	1	105	Co
94A	0.5	80	Cu	84C	2	101	Co
94B	1	96	Cu	84A	3	100	Co

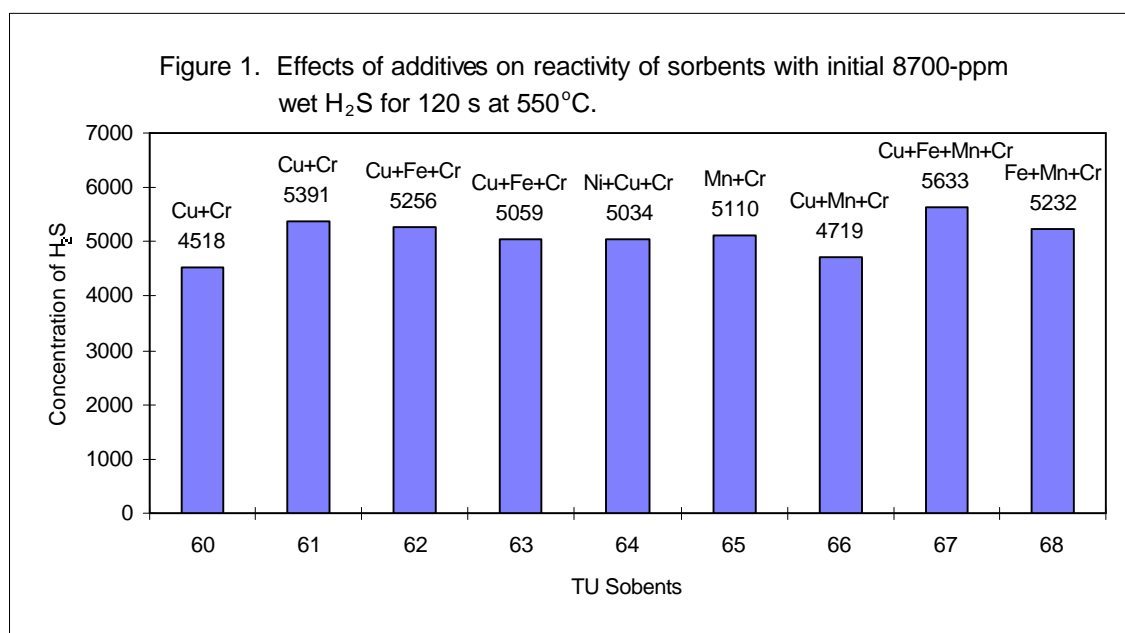
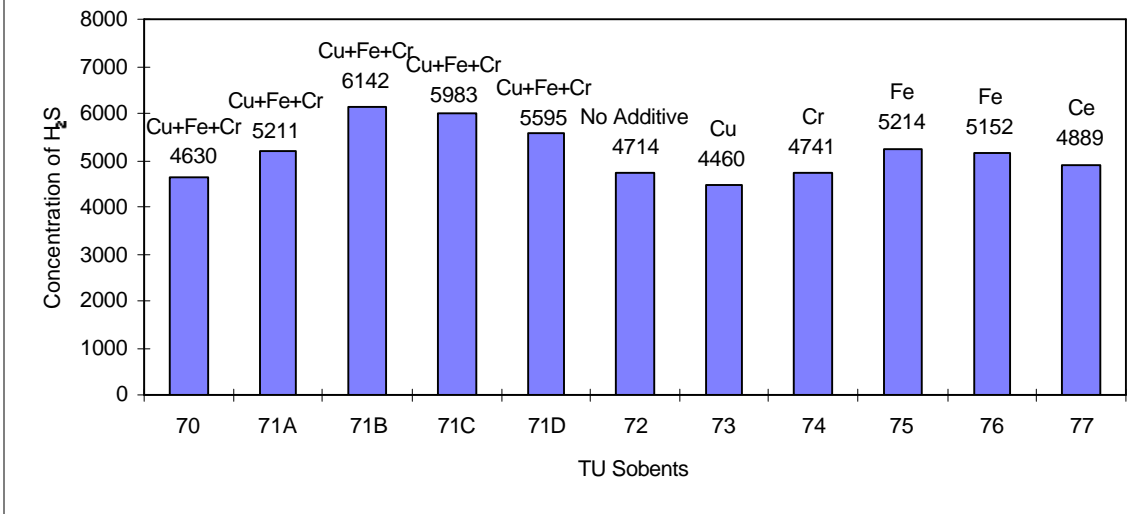
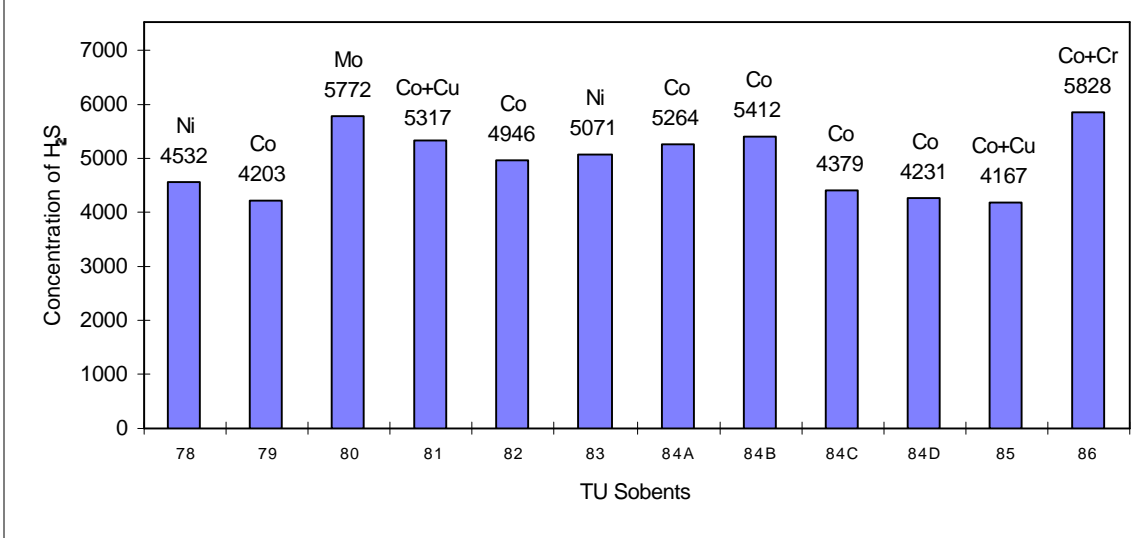


Figure 2. Effects of additives on reactivity of sorbents with initial 8700-ppm wet H<sub>2</sub>S for 120 s at 550°C.



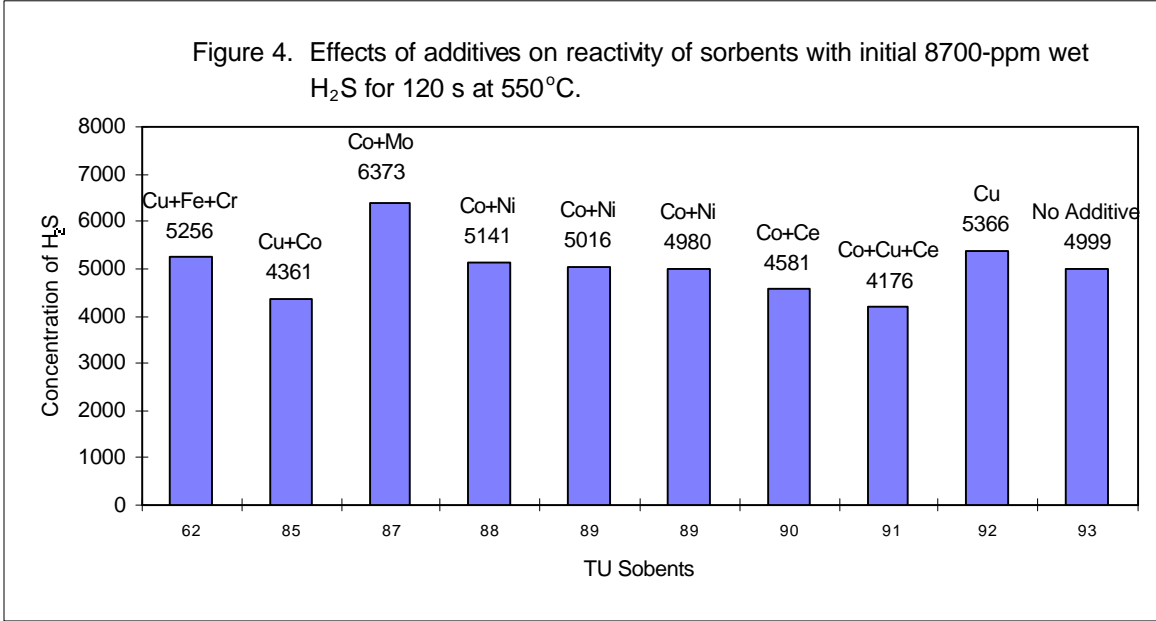
The concentration of H<sub>2</sub>S was reduced from initial 8700 ppm to 4518 ppm in the reaction with TU-60 sorbent (see Figure 1) formulated with Cu and Cr additives. The concentrations of H<sub>2</sub>S was reduced from initial 8700 ppm to 4460 ppm in the reaction with TU-73 sorbent (see Figure 2) formulated with Cu additive. The concentrations of H<sub>2</sub>S was reduced from initial 8700 ppm to 4169 ppm in the reaction with TU-85 sorbent (see Figure 3) formulated with Cu and Co additives.

Figure 3. Effects of additives on reactivity of sorbents with initial 8700-ppm wet H<sub>2</sub>S for 120 s at 550°C.

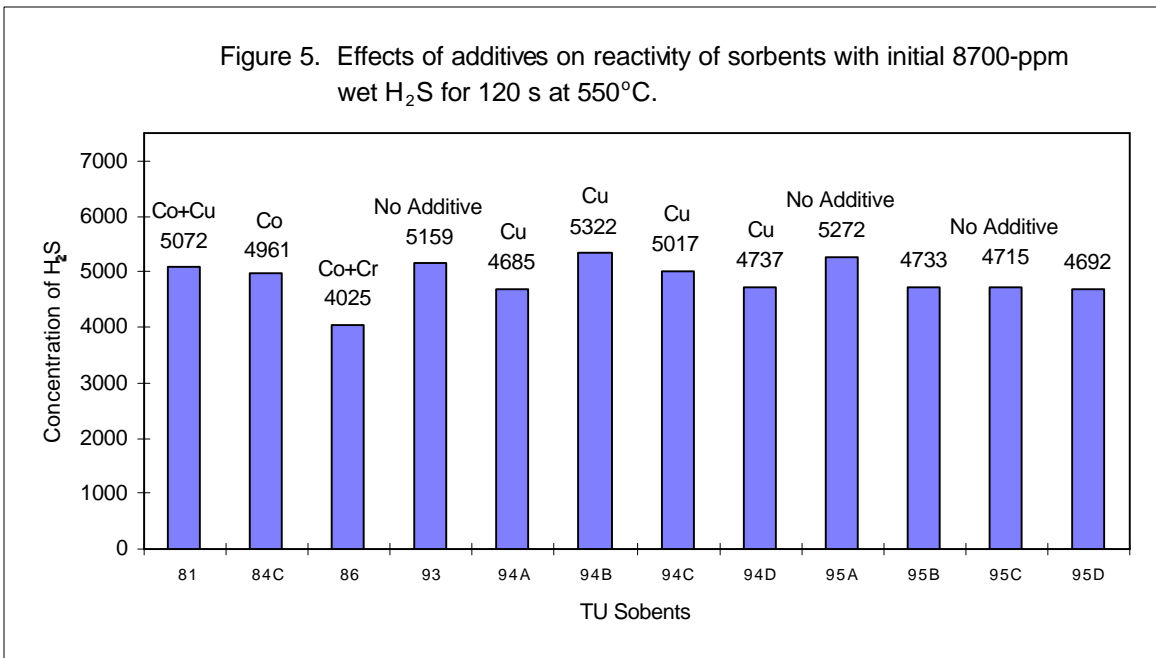




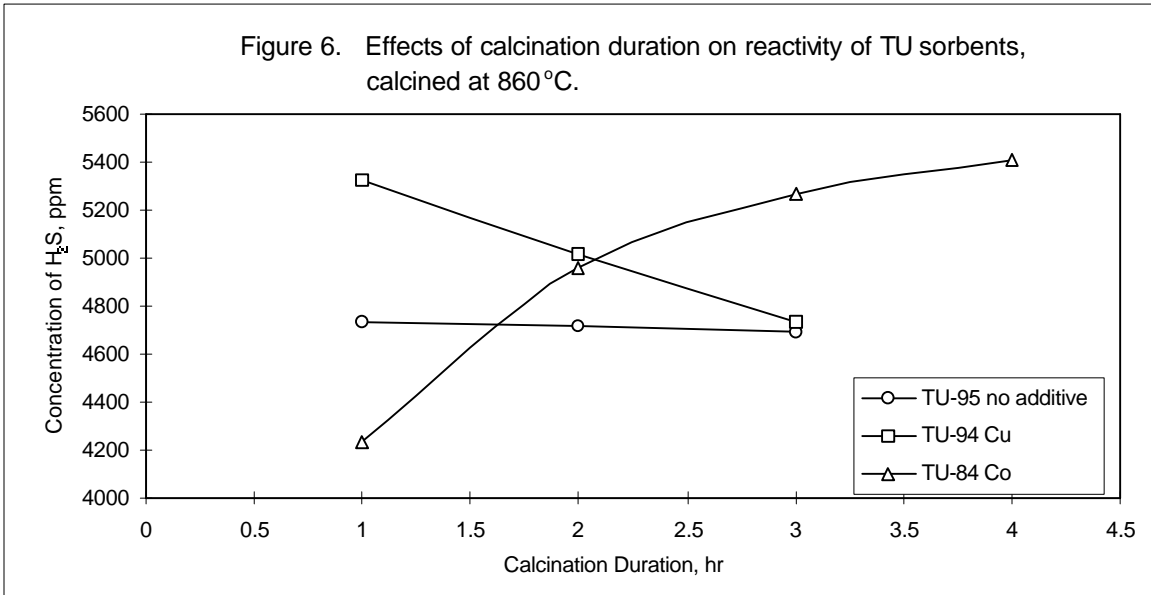
The concentration of H<sub>2</sub>S was reduced from initial 8700 ppm to 4999 ppm in the reaction with TU-93 sorbent (see Figure 4) formulated without additive. The additive Cu appears to enhance reactivity of the above-mentioned formulated sorbents in comparison with TU-93 sorbent formulated without additive.



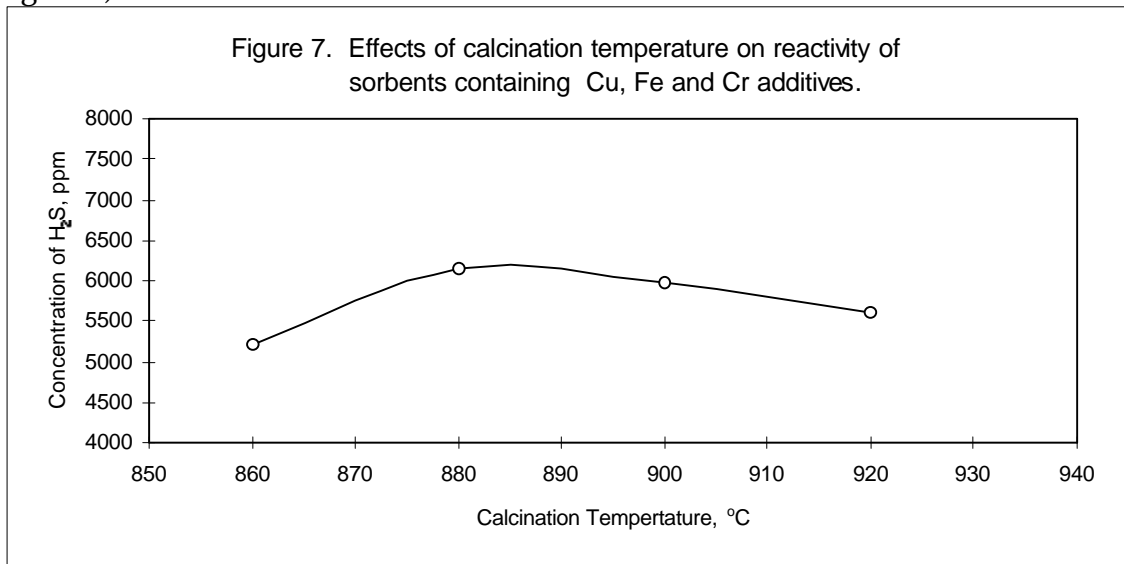
The concentration of H<sub>2</sub>S was reduced from initial 8700 ppm to 4203 ppm in the reaction with TU-79 sorbent (see Figure 3) formulated with Co additive. The concentration of H<sub>2</sub>S was reduced from initial 8700 ppm to 4231 ppm in the reaction with TU-84D sorbent (see Figure 3) formulated with Co additive.



The concentration of H<sub>2</sub>S was reduced from initial 8700 ppm to 4581 ppm in the reaction with TU-90 sorbent (see Figure 4) formulated with Co and Ce additives. The concentration of H<sub>2</sub>S was reduced from initial 8700 ppm to 4025 ppm in the reaction with TU-86 sorbent (see Figure 5) formulated with Co and Cr additives. The concentration of H<sub>2</sub>S was reduced from initial 8700 ppm to 5159 ppm in the reaction with TU-93 sorbent (see Figure 5) formulated without additive. The additive Co appears to enhance reactivity of the above-mentioned formulated sorbents in comparison with the TU-93 sorbent formulated without additive.



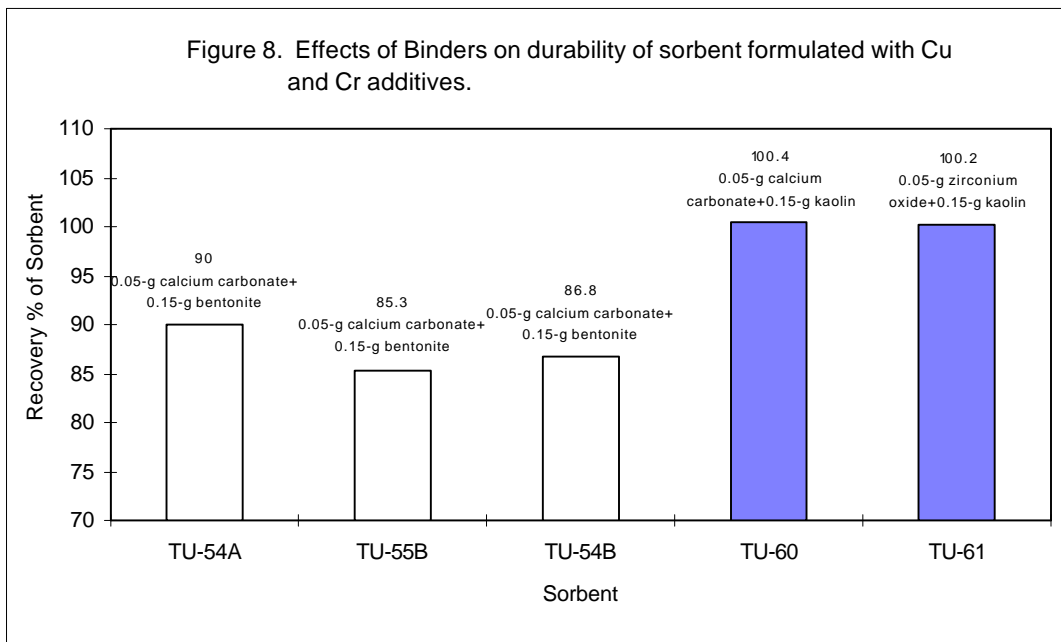
A series of metal oxide sorbents such as TU-84A, TU-84B, TU-84C and TU-84D (see Table 4) were formulated with 0.015-g cobalt additive, and calcined for various calcination durations at 860°C. The reactivity of the sorbents formulated with Co additive in the reaction with H<sub>2</sub>S decreases with increased calcination durations (see Figure 6).



A series of metal oxide sorbents such as TU-95B, TU-95C and TU-95D (see Table 6) were formulated without additive, and calcined for various calcination durations at 860°C. The reactivity of the sorbents formulated without additive in the reaction with H<sub>2</sub>S appears to be independent of calcination durations (see Figure 6).

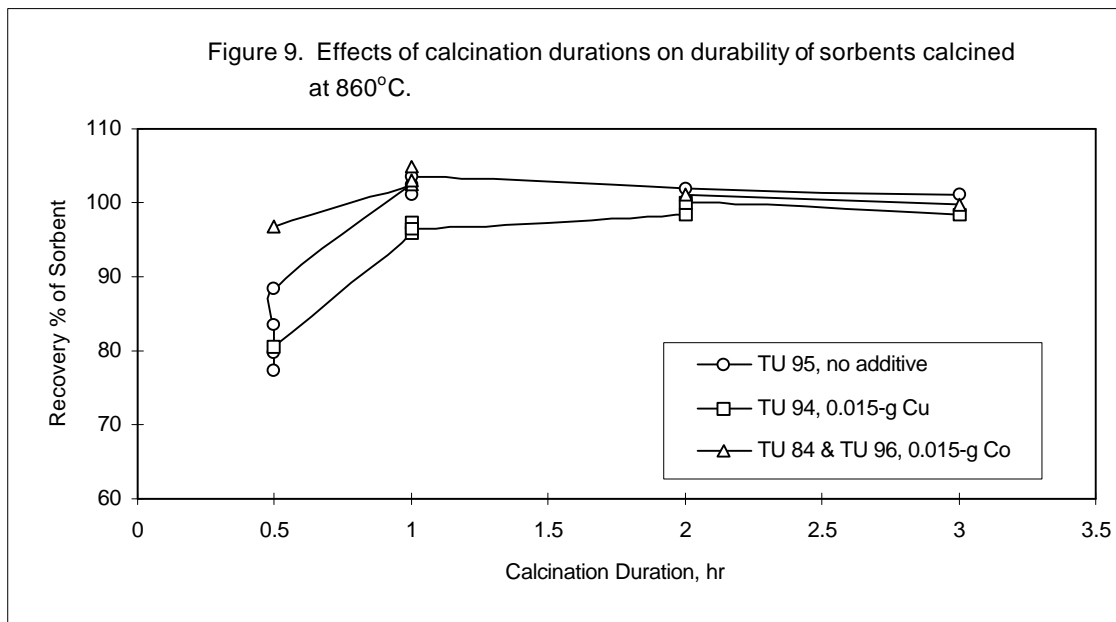
A series of metal oxide sorbents such as TU-94B, TU-94C and TU-94D (see Table 6) were formulated with copper additive, and calcined for various calcination durations at 860°C. The reactivity of the sorbents formulated with Cu additive in the reaction with H<sub>2</sub>S appears to increase with calcination durations (see Figure 6). These data may suggest effects of calcination durations on reactivity of sorbents with wet hot hydrogen sulfide are dependent on chosen additives.

A series of metal oxide sorbents such as TU-71A, TU-71B, TU-71C and TU-71D (see Table 3) were formulated with 0.015-g Cu, 0.015-g Fe, and 0.015-g Cr additives, and calcined for 2 hours at various temperatures. The reactivity of the sorbents appears to decrease with increased calcination temperatures for the calcination temperature range of 860°C - 880°C, while the reactivity of the sorbents appears to increase with increased calcination temperatures for the calcination temperature range of 880°C - 920°C (see Figure 7).



The sorbents such as TU-54A, TU-55B, and TU-54B were formulated with Cu and Cr additives, and calcium carbonate and bentonite binders (see Table 8). The sorbent TU-60 was formulated with Cu and Cr additives, and calcium carbonate and kaolin binders. The sorbent TU-61 was formulated with Cu and Cr additives, and zirconium oxide and kaolin binders (see Table 8). These sorbents were calcined for 2 hours at 860 - 880°C. These 0.05-g fresh sorbents were reacted with the initial 8700-ppm H<sub>2</sub>S and the initial 14.7-psia hydrogen in the presence of 0.085-g moisture for 120 min at 550°C.

During the runs, the batch reactor containing 0.05-g fresh sorbent was stirred horizontally 50 times per min. After the run, a gas sample was drawn for the analysis of H<sub>2</sub>S concentrations, the reactor were purged with 150-psig nitrogen, the sorbent reacted with H<sub>2</sub>S was recovered and weighed, and then the recovery percentage was obtained (see Table 8). The recovery percentages of the sorbents such as TU-54A, TU-55B, and TU-54B were 90, 85, and 87, respectively, whereas the recovery percentages of the sorbents such as TU-60, and TU-61 were 100.4 and 100.2, respectively (see Figure 8). These data may suggest that durability of formulated sorbents appears to improve with kaolin binder in comparison with bentonite binder.



The TU-95 sorbents (see Table 9 and Figure 9) were formulated without additive, and calcined for 0.5 - 3 hours at 860°C. The recovery percentages of the TU-95A sorbent calcined for 0.5 hour are 77 - 88, whereas the recovery percentages of the sorbents such as TU-95B, TU-95C and TU-95D, calcined for 1 - 3 hours, are 101- 104. The TU-94 sorbents (see Table 9 and Figure 9) were formulated with Cu additive, and calcined for 0.5 - 3 hours at 860°C. The recovery percentage of the TU-94A sorbent calcined for 0.5 hour is 80, whereas the recovery percentages of the sorbents such as TU-94B, TU-94C and TU-94D, calcined for 1 - 3 hours, are 96 - 100.

The TU-96 sorbents and TU-84 sorbents (see Table 9 and Figure 9) were formulated with Co additive, and calcined for 0.5 - 3 hours at 860°C. The recovery percentage of the TU-96B sorbent calcined for 0.5 hour is 97, whereas the recovery percentages of the sorbents such as TU-96A, TU-84A, TU-84C and TU-84D, calcined for 1 - 3 hours, are 100 - 105. These observations may indicate that durability of formulated sorbents appears to improve with increased calcination durations.

## CONCLUSION

The additives Cu and Co appear to enhance reactivity of sorbents in the reaction with wet hot hydrogen sulfide at 550°C. Durability of formulated sorbents appears to improve with kaolin binder in comparison with bentonite binder. Durability of formulated sorbents appears to improve with increased calcination durations. Reactivity of sorbents formulated with Co additive appears to decrease with increased calcination durations at the calcination temperature of 860°C. Reactivity of sorbents formulated with Cu additive appears to increase with calcination durations. Reactivity of sorbents formulated without additive appears to be independent of calcination durations.

## PRESENTATION

A research paper, entitled “Reactivity of Promising Metal Oxide Sorbents for Removal of Hydrogen Sulfide from Hot Coal Gases”, was scheduled to be presented for the Session 110-Reactive Separation Processes I at 3:35 PM, November 13, 1996, the 1996 Annual AIChE Meeting, Chicago, November 10 -15, 1996. Our paper was replaced with the paper 110d, entitled “ Development of New Packings for Catalytic Distillation” by Ishida.

A research paper, entitled “Formulation of Metal Oxide Sorbents for Removal of Wet Hydrogen Sulfide”, was accepted for presentation at the 1997 Spring National AIChE Meeting, Houston, March 9 - 13, 1997.

A research paper, entitled “Reactivity of Metal Oxide Sorbents for Removal of Wet Hydrogen Sulfide at High Temperatures”, was submitted for presentation at the Fifth Annual HBCU/Private Sector-Energy Research and Development Technology Transfer Symposium, Baton Rouge, Louisiana, March 4-5, 1997

## PLANS ON FUTURE EXPERIMENTS

Various metal oxide sorbents will be formulated with various additives under various formulation conditions in order to search for a formula of a durable sorbent with high-sulfur-absorbing capacity.