

electron doner, in the case of chloride giving it 18 total electrons to give a total charge of -1, and in the case of bromide giving it 36 total electrons to give a total charge of -1. Halogen atoms do not donate electrons to other atoms, because this would result in a halogen atom losing an electron to have 6 electrons in its outer shell, an unstable configuration according to the octet rule. In the case of an elemental halogen, which exists as a diatomic molecule, instead of donating electrons to one another, each halogen atom shares one of its electrons in the outer shell with the other halogen atom via overlapping electron orbitals in a covalent bond, allowing each halogen atom to have a filled octet while the diatomic molecule remains neutrally charged. Therefore, a halogen atom does not donate electrons to another halogen atom to form a halide, and a diatomic halogen molecule never includes a halide; Br₂ is not and does not include Br⁻, and Cl₂ is not and does not include Cl⁻.

19. As described in the paper “Effect of HBr formation on mercury oxidation via CaBr₂ addition to coal during combustion”, Y. Yang et al., RSC Adv., 2016, 6, 59009-59015 (“Yang”), in a bench-scale simulated coal-fired power plant, CaBr₂ was added in various concentrations to three different types of coal that were combusted and the concentration of HBr and Br₂ in the released combustion gases were analyzed by quantitative gas analysis mass spectrometry. See, Yang at Sections 2.1-2.2. Section 3.4 states at page 59012 bridging to page 59013 that “[t]he results confirmed the generation of HBr in coal-fired flue gas due to the CaBr₂ additive in coal, but Br₂ was not detected.” Near the end of Section 3.4 at page 59013 Yang states that “[t]he HBr concentration in flue gas increased with increasing amounts of CaBr₂ additive....” At the top of the right column on page 59013, Yang proposes the following formula for the generation of HBr from CaBr₂: $\text{CaBr}_2 + \text{H}_2\text{O} \rightarrow \text{CaO} + \text{HBr}$, stating at page 59013 from the left column bridging to the right column that the water is generated by hydrogen-containing organisms in coal during combustion via $\text{C}_n\text{H}_m\text{OH} + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{CO}_2$.

20. As described in the paper “Mercury control evaluation of calcium bromide injection into a PRB-fired furnace with an SCR”, M. Berry, Proceedings of the Air

Quality VI Conference, Arlington, VA, 2007 ("Berry"), a CaBr_2 was injected at various concentrations into the furnace of a full-scale coal-fired power plant and the concentration of HBr in the released combustion gases were analyzed at the ESP inlet and at the ESP outlet. Berry found that HBr content increased with increasing calcium bromide injection. See, Berry at page 5, top two paragraphs and Figure 3.

21. As described in the book "Coal Combustion Products (CCPs) Characteristics, Utilization, and Beneficiation", T. Robl et al., Woodhead Publishing, 2017, ("Robl"), at page 91, last full paragraph and last partial paragraph:

As described previously, eastern coals with a higher chlorine content produce mostly oxidized mercury in their flue gases, while western coals, such as PRB coals, that have a low chlorine content tend to produce mostly elemental mercury. ...

Halogen salts such as calcium chloride (CaCl_2), calcium bromide (CaBr_2), or potassium iodide (KI) can be added to the coal as a means of supplementing the coal chlorine content. Salts added with the coal or injected into the furnace decompose at furnace temperatures to form vapor-phase acids (HCl , hydrogen bromide (HBr), or hydrogen iodide (HI)) in the flue gas.

22. Typical temperatures in a coal-combustion furnace range from 2,400-4,200 °F, with internal flame temperatures reaching 4,000-4,200 °F or higher. Table 1 lists select halide salt boiling points. Coal-combustion furnace temperatures are higher than the boiling points of halide salts such as NaBr and CaBr_2 . Thus, the conditions and environment inside the furnace/boiler are adequate for boiling of halide salts (whether in a solid state, in a liquid solution, or as part of the coal) to form gaseous molecules.

Table 1. Common Halide Salt Boiling Points.¹

Compound	Boiling point, °F
NaBr	2,534
NaCl	2,669
NaI	2,379
CaCl ₂	3,516
CaBr ₂	3,299
CaI	2,012
NH ₄ Br	745
NH ₄ Cl	640
NH ₄ I	761

23. The FactSage program (see, <http://www.factsage.com/>) is one of the largest fully integrated database computing systems for chemical thermodynamics calculations. The FactSage program is a series of information, database, calculation, and manipulation modules that access databases containing properties of materials. The FactSage program can calculate the conditions for multiphase, multicomponent equilibria, with a wide variety of tabular and graphical output modes, under a large range of constraints. Equilibrium calculations performed by the FactSage program can be used to determine equilibrium molecular decomposition states as a function of temperature. These thermodynamic models can be used to predict the chemical species that will be present to react with other molecules present in the flue gas at the same time, such as radicals, ionic compounds, elemental forms of chemical elements, and the like. FactSage was used to calculate equilibrium concentrations of materials present for a 100 g solid NaBr sample in a coal-combustion furnace as a function of temperature, shown in Figure 1. Figure 1 clearly shows the rapid emergence of gaseous NaBr molecules once the NaBr boiling point of 2,530 °F is reached. At temperatures of around 3,000 °F, nearly all the solid NaBr has been converted to gas phase NaBr molecules. As the gas phase NaBr molecules are brought to temperatures beyond 3,000 °F, dissociation into gaseous sodium atoms and bromine atoms occurs.

¹ Lide, D.R., 1995, CRC handbook of chemistry and physics: a ready-reference book of chemical and physical data, CRC press.

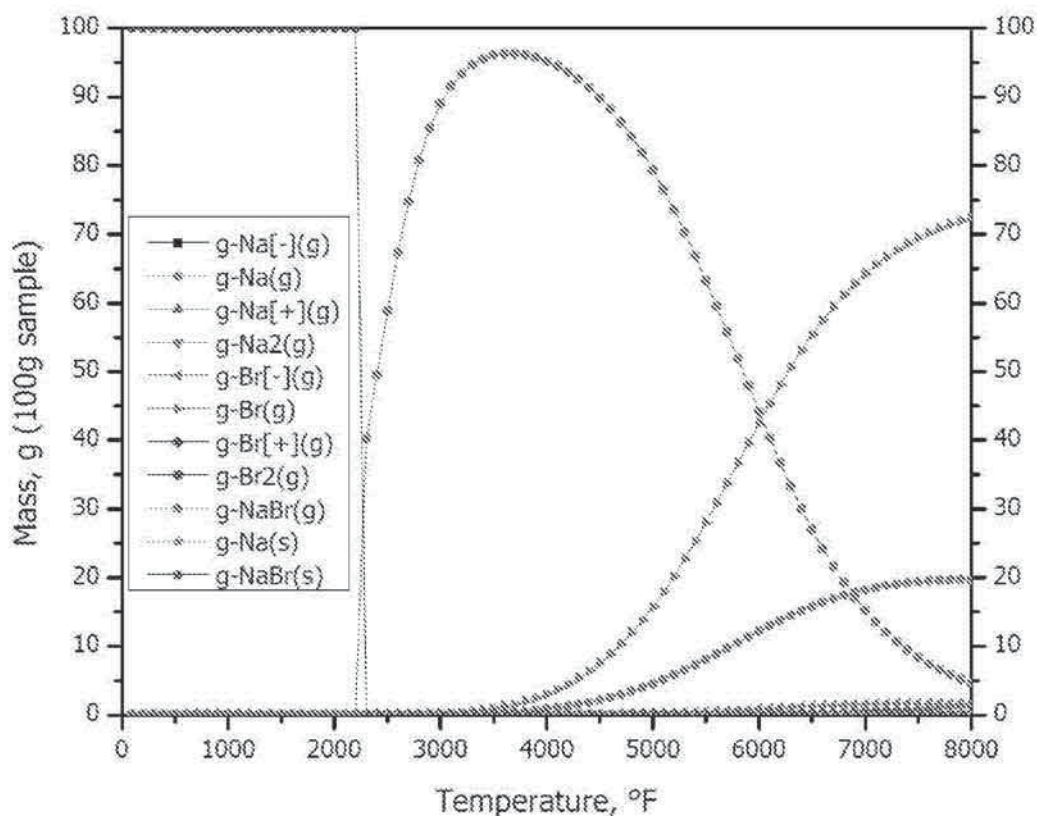


Figure 1. NaBr FactSage equilibrium calculation.

24. Not shown in Figure 1, the gaseous NaBr reacts with water molecules in the flue gas to form HBr, via $\text{NaBr} + \text{H}_2\text{O} \rightarrow \text{NaOH} + \text{HBr}$, see, Yang and discussion thereof at item 19 herein. The HBr is then available to react with Hg^0 released by the coal and with activated carbon sorbent that has been introduced further downstream into the flue gas.

25. The effect of chlorides in coal on flue gas HCl content has been studied much more than the effect of bromides on coal on flue gas HBr content, due in part to federal HCl emission regulations. Chlorides, like bromides, also exhibit a similar transformation to hydrogen chloride in coal combustion flue gas, see, Robl and discussion thereof at item 21 herein. Hydrogen chloride, as an acid gas, is one of the emission categories that the EPA regulates through the Mercury Air Toxics Standards (MATS)². The MATS includes specific HCl limits that power plants must comply with by performing quarterly EPA

² <https://www.epa.gov/mats>

Method 26(A)³ stack sampling to verify compliance. Inorganic and organically bound chlorides in the coal are volatilized and decomposed in the furnace and form HCl in the flue gas.

26. As shown in the report "Pilot- and full-scale demonstration of advanced mercury control technologies for lignite-fired power plants", S. Benson et al., Energy & Environmental Research Center, Final report, U.S. Department of Energy, National Energy Technology Laboratory, February 2005 ("Benson 1"), at figure 31 on page 37, addition of NaCl to lignite coal in a pilot-scale coal combustion system caused an increased HCl concentration in the flue gas. The HCl concentration in the flue gas increased with increased amounts of NaCl on the coal. Benson 1 shows at figure 36 on page 41 that addition of CaCl_2 to the coal caused increased HCl concentration in the flue gas. The HCl concentration in the flue gas increased with increasing amounts of CaCl_2 on the coal. Figures 31 and 36 of Benson 1 are reproduced below.

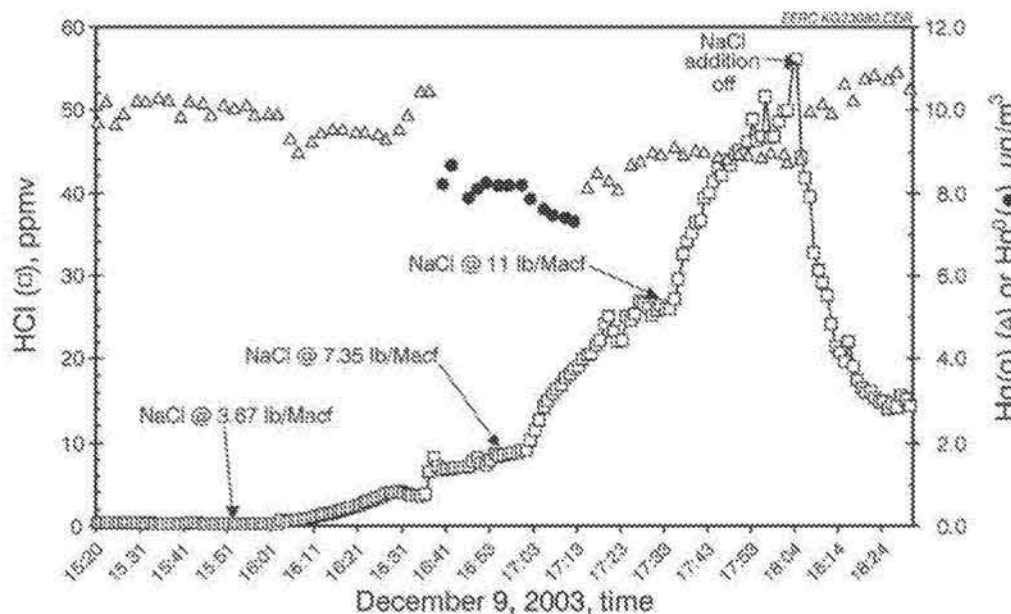


Figure 31. Temporal variations in SDA inlet HCl and FF outlet Hg(g) and Hg^0 concentrations as NaCl was added to the Center lignite coal.

³ <https://www.epa.gov/emc/method-26a-hydrogen-halide-and-halogen-isokinetic-method>

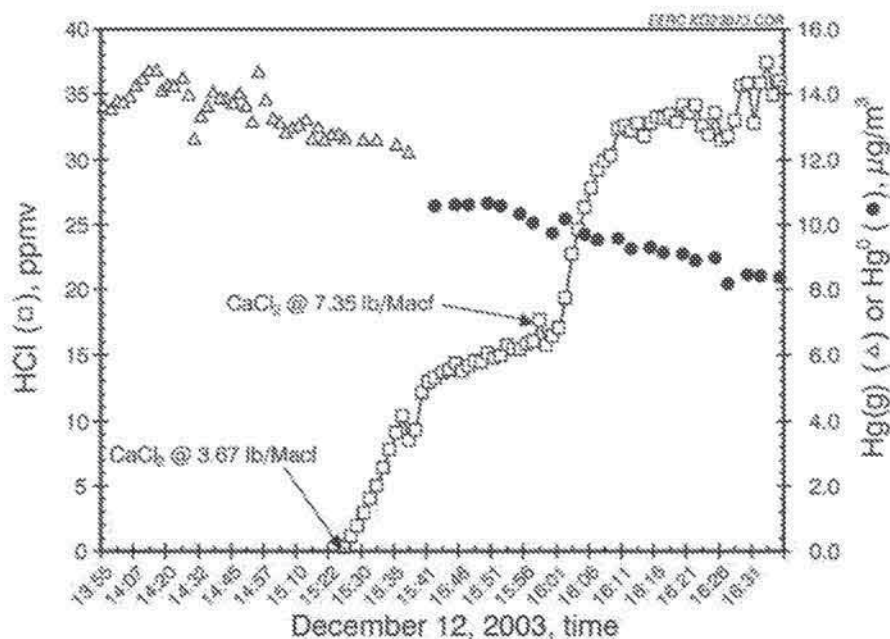


Figure 36. Temporal variations in SDA inlet HCl and FF outlet Hg(g) and Hg⁰ concentrations during CaCl₂ additions to the Center lignite coal.

27. As shown in the report “JV Task 73—Mercury control technologies for electric utilities burning subbituminous coals”, S. Benson et al., Energy and Environmental Research Center, Draft final report, June 2005 (“Benson 2”), at figure 11-11 at page 48, addition of CaCl₂ to subbituminous coal in a pilot-scale coal combustion system caused an increased HCl concentration in the flue gas. The HCl concentration in the flue gas increased with increased amounts of CaCl₂ on the coal. Figure 11-11 of Benson 2 is reproduced below.

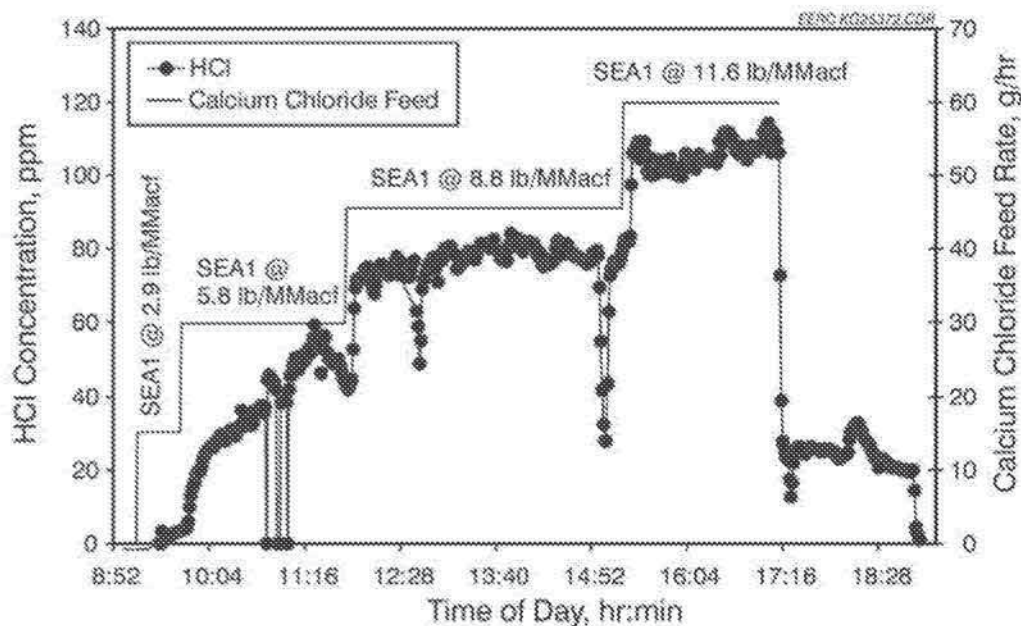


Figure 11-11. Temporal variations in ESP outlet HCl concentrations and SEA1 (CaCl_2) addition rates.

28. As shown by items 19-27 herein, in a coal-fired power plant, placing halide salts on the coal or in the combustion chamber results in formation of gaseous halide salt in the flue gas and formation of the respective hydrogen halide in the flue gas. Placing bromide salts such as NaBr or CaBr_2 on the coal or in the combustion chamber results in formation of gaseous NaBr or CaBr_2 in the flue gas, as well as formation of HBr in the flue gas. Likewise, placing chloride salts such as NaCl or CaCl_2 on coal or in the combustion chamber results in formation gaseous NaCl or CaCl_2 in the flue gas, as well as the formation of HCl in the flue gas.

29. Wikipedia defines "salt" as "...an ionic compound that can be formed by the neutralization reaction of an acid and a base. Salts are composed of related numbers of cations (positively charged ions) and anions (negative ions) so that the product is electrically neutral (without a net charge). These component ions can be inorganic, such as chloride (Cl^-), or organic, such as acetate (CH_3CO_2^-); and can be monatomic, such as

fluoride (F^-), or polyatomic, such as sulfate (SO_4^{2-}).” See,

[https://en.wikipedia.org/wiki/Salt_\(chemistry\)](https://en.wikipedia.org/wiki/Salt_(chemistry)).

30. Dictionary.com defines “bromide” as “Wikipedia defines “NaBr” as “a salt of hydrobromic acid consisting of two elements, one of which is bromine, as sodium bromide, NaBr.” See, <https://www.dictionary.com/browse/bromide>.

31. Dictionary.com defines “salt” as “a Wikipedia defines “NaCl” as “a crystalline compound, sodium chloride, NaCl, occurring as a mineral, a constituent of seawater, etc., and used for seasoning food, as a preservative, etc.” See, <https://www.dictionary.com/browse/salt?s=t>.

32. Sigma-Aldrich has an online products page entitled “Sodium Salts” that includes sodium bromide and sodium chloride. See, <https://www.sigmaaldrich.com/materials-science/material-science-products.html?TablePage=19295381>.

33. As shown by items 29-32 herein, NaBr is a salt that includes Na^+ ions and Br^- ions. NaCl is a salt that includes Na^+ ions and Cl^- ions. $CaBr_2$ is a salt that includes Ca^{2+} ions and Br^- ions. $CaCl_2$ is a salt that includes Ca^{2+} ions and Cl^- ions.

34. We further declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by a fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application and/or any patent issued thereon.

Dated: March 20, 2019

By: / John Pavlish /

John Pavlish

Dated: March 15, 2019

By: / Nicholas Lentz /

Nicholas Lentz

A/N 15/978,760

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s): Edwin S. Olson et al.

Examiner: AMBER ROSE ORLANDO

Application No.: 15/978,760

Group Art Unit: 1776

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Title: SORBENTS FOR THE OXIDATION AND REMOVAL OF MERCURY

DECLARATION UNDER 37 C.F.R. § 1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION B

I, John Pavlish, declare and say as follows:

1. I have been the Chief Technology Officer and Senior Vice President of Midwest Energy Emissions Corporation since November 16, 2014. Prior to this, I served as an Executive Consultant Advisor to Midwest Energy Emissions Corporation. Prior to joining Midwest Energy Emissions Corporation, I was a Senior Research Advisor and the Director of the Center for Air Toxic Metals Program at the Energy & Environmental Research Center in Grand Forks, North Dakota. I have over 25 years of mercury-related experience and am regarded as an international expert on the topic of mercury. My primary areas of interest and expertise include research, technical consultation and development of mercury control technologies, in particular, for coal combustion and gasification systems. I am an inventor of a number of patented mercury control technologies and have years of experience in development and testing of these technologies for commercial applications. Over the last 15 years, I have spent much time evaluating the efficacy of a number of different mercury control technologies/approaches and their cost competitiveness in the commercial market. I also have years of power plant experience and have worked for an engineering/consulting company, Black & Veatch, where I served as Unit Leader/System Engineer. I am a professional engineer, a member of the American Society of Mechanical Engineers, and a member of the Air & Waste Management Association (AWMA). I serve on numerous professional and

technical committees and am a U.S. Representative on the Mercury Emissions from Coal International Experts Working Group on Reducing Emissions from Coal and a member of the United Nations Environment Programme Global Mercury Partnership, Reduction of Mercury Releases from Coal Combustion. I have published over 200 papers, articles, and reports on various mercury-related topics and issues.

2. U.S. patent publication no. 2004/0003716 ("Nelson") describes treatment of activated carbon outside the flue gas with hydrogen bromide (HBr), and describes testing to measure the percent mercury removal when the treated activated carbon was injected into either simulated or actual flue gas at various injection rates. Specifically, Nelson performed experiments in Example 5 (paragraphs [0082]-[0085]) and 7 (paragraphs [0089]-[0092]), and provides the data in FIG. 14 and FIG. 15.

3. In Example 5, Nelson treated Norit DARCO® FGD with gaseous HBr, and tested its use by injecting the HBr-treated sorbent into a simulated coal-fired flue-gas stream in a pilot-scale test system. Nelson's FIG. 14 shows data for one activated carbon sample treated with HBr. The activated carbon had 10 wt% HBr, and at a sorbent injection rate of about 3.7 lb/MMacf gave a mercury removal of about 82%.

4. In Example 7, Nelson treated Norit DARCO® FGD with gaseous HBr, and tested its use in a coal-fired power plant by injecting the treated sorbent into the flue gas prior to the electrostatic precipitator (ESP). Nelson's FIG. 15 shows data for two activated carbon samples treated with HBr. The two activated carbon samples contained 9 wt% HBr. The data in FIG. 15 for the two HBr-treated sorbents show that at a sorbent injection rate of about 2.2 lb/MMacf, 45% of the mercury was removed, and at a sobent injection rate of about 4.2 lb/MMacf, 62% of the mercury was removed.

5. The percent mercury removal, and the percent mercury removal per 1 wt% HBr additive on the sorbent, versus the sorbent injection rate for Nelson's HBr-treated activated carbon formed in Nelson's Examples 5 and 7 is given in the table below. The

percent mercury removal per 1 wt% HBr was calculated as the percent mercury removal divided by the HBr wt% on the sorbent. The units "lb/MMacf" are pounds of sorbent per 1 million actual cubic feet of flue gas.

Sample	Additive	Sorbent Description	Sorbent Injection Rate (lb/MMacf)	HBr wt% on Sorbent	%Hg Removal	%Hg Removal per 1 wt% HBr on Sorbent
N1	HBr outside flue gas	Norit DARCO [®] FGD	3.7	10	82	8.2
N2	HBr outside flue gas	Norit DARCO [®] FGD	2.2	9	45	5.0
N3	HBr outside flue gas	Norit DARCO [®] FGD	4.2	9	62	6.8

6. A bromine-treated activated carbon was prepared by exposing activated carbon (Norit DARCO[®] Hg, an activated carbon that a Norit Americas technical representative told me was rebranded for mercury control applications and was previously referred to as Norit DARCO[®] FGD) to gaseous bromine. A cement mixer was used to expose the activated carbon to the bromine gas. Tumbling vanes produced a dispersion of the activated carbon within the barrel. A cover was fit over the opening to keep the activated carbon dispersion inside the barrel. In the center of the lid, a small hole was drilled, and a tube extended to the center of the barrel. The tube was attached to a source of bromine vapor (Br₂) in dry nitrogen via a swivel so that the tube in the barrel would rotate and the tube to the source would be stationary. A charge of 1 to 5 kg of the activated carbon was weighed and transferred to the barrel. The weight of bromine transferred to the barrel was equal to 5 weight % of the amount of activated carbon.

7. An HCl-treated activated carbon was prepared by exposing activated carbon (Norit DARCO[®] Hg) to gaseous HCl. The carbon was weighed and added to a flask which was attached to a rotary apparatus. A hard-plastic tube was inserted into the

condenser end of the apparatus for introduction of the HCl/nitrogen gas mix. This extended to the center of the flask. HCl from a cylinder was run through a flow meter and mixed with a low flow of nitrogen in a T-tube attached to the inlet tube. The flow rate was set to provide 5 wt % HCl over 15 minutes exposure. The flask was slowly rotated in the apparatus at room temperature so that the carbon turned over but did not exit the flask. After the exposure period, the HCl flow was stopped and the HCl-treated activated carbon was removed.

8. A pilot-scale 550,000-Btu/hr pulverized coal (pc)-fired test unit was used to combust subbituminous coal and test mercury control using various sorbents. The coal combustion flue gas exiting the pilot unit was cooled down to a nominal temperature of 149°C (300°F) and then was introduced into a single wire tubular ESP unit. Activated carbon sorbents were fed with a K-Tron dual-screw feeder upstream of the ESP. The feeder was calibrated prior to the start of each carbon injection test. No scrubber was used. Before Hg control testing began, a baseline condition was established with the pilot-scale unit, and flue gas mercury content was measured before each test as about 6-10 $\mu\text{g}/\text{m}^3$. The flue gas HCl concentration, with no additives on the coal, as calculated by the chlorine measured in the coal, was 2-5 ppm. Percent mercury removal was then measured for the activated carbon alone (untreated), the activated carbon treated with Br_2 outside the flue gas described herein at item 6 as per the Nelson procedure, and with sodium bromide (NaBr) or sodium chloride (NaCl) added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas.

9. The results of the pilot-scale test with untreated activated carbon and with the activated carbon treated with Br_2 outside the flue gas described herein at item 6 are given in the table below.

Sample	Additive	Sorbent Description	Sorbent Injection Rate (lb/MMacf)	Br ₂ wt% on Sorbent	%Hg Removal
1	None	Norit DARCO [®] Hg	0.7	0	31.4
2	None	Norit DARCO [®] Hg	1.6	0	45.9
3	None	Norit DARCO [®] Hg	3.7	0	56.6
4	None	Norit DARCO [®] Hg	9.2	0	61.2
5	None	Norit DARCO [®] Hg	25.7	0	62.5
6	Br ₂ outside flue gas	Norit DARCO [®] Hg	0.7	5	49.5
7	Br ₂ outside flue gas	Norit DARCO [®] Hg	1.1	5	54.9
8	Br ₂ outside flue gas	Norit DARCO [®] Hg	1.6	5	62.2
9	Br ₂ outside flue gas	Norit DARCO [®] Hg	3.7	5	78.1

10. The results from the pilot-scale test with sorbent enhancement additives (SEAs) NaBr or NaCl added to coal along with injection of untreated activated carbon into the flue gas, and with the activated carbon treated with HCl outside the flue gas described at item 7, are given in the table below. The bromide (Br⁻) or chloride (Cl⁻) injection rate was calculated as the SEA injection rate times the fraction of the additive (based on molecular weight) that is Br⁻ or Cl⁻; for Br⁻, $\text{Br}^-/\text{NaBr} = 79.904/(79.904+22.9898) = 0.7766$; for Cl⁻, $\text{Cl}^-/\text{NaCl} = 35.453/(35.453+22.9898) = 0.6066$. The HBr or hydrogen chloride (HCl) equivalent injection rate was calculated as the Br⁻ or Cl⁻ injection rate times the molecular weight ratio of HBr/Br⁻ or of HCl/Cl⁻; for HBr/Br⁻, this is $(1.00794+79.904)/79.904 = 1.013$; for HCl/Cl⁻, this is $(1.00794+35.453)/35.453 = 1.028$. The equivalent HBr or HCl wt% on sorbent was calculated as the HBr or HCl injection rate divided by the sum of the sorbent injection rate and the HBr or HCl injection rate (e.g., 100% of the HBr or HCl was assumed to react with the sorbent). The percent mercury removal per 1 wt% HBr or HCl was calculated as the percent mercury removal divided by the HBr wt% or HCl wt% on sorbent.

DECLARATION UNDER 37 C.F.R. § 1.132

Application Number: 15/978,760

Filing Date: May 14, 2018

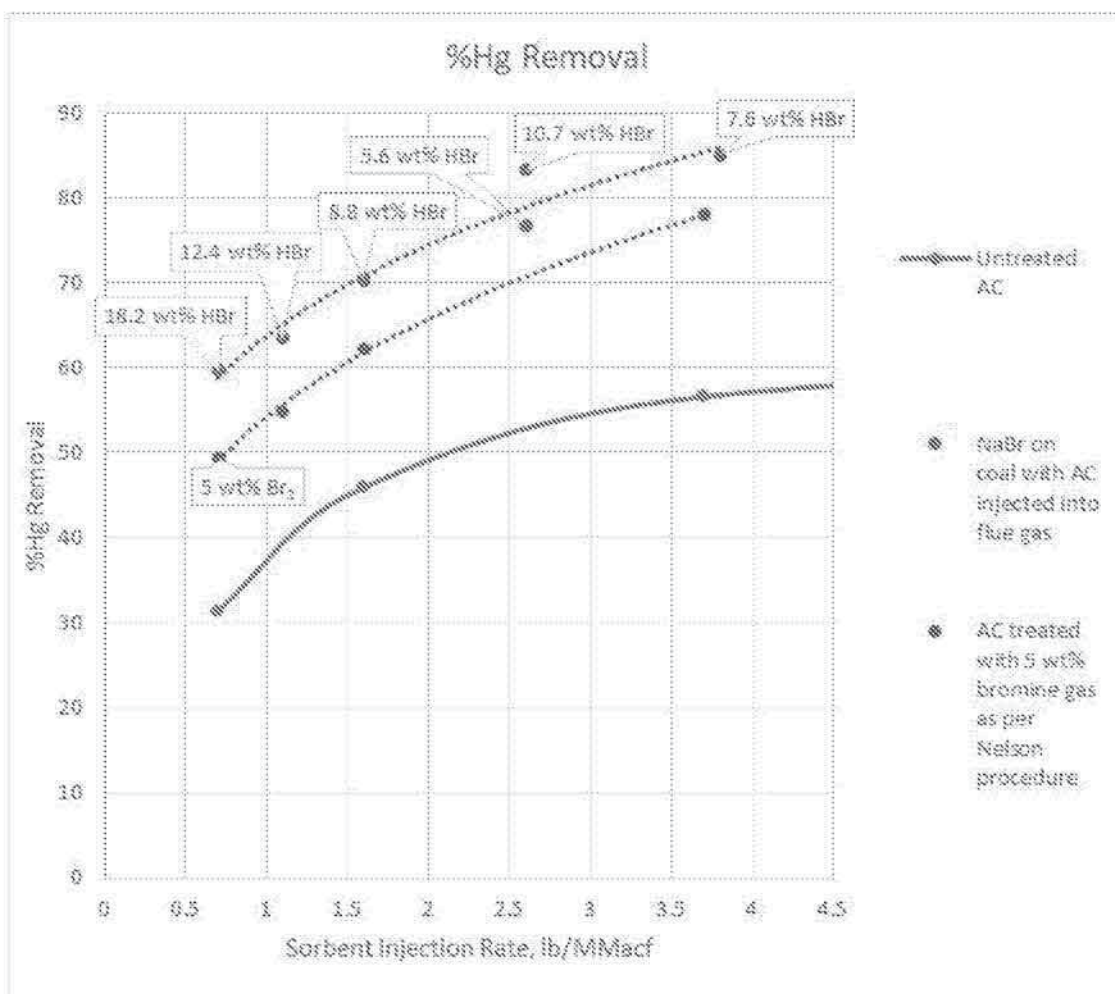
Title: SORBENTS FOR THE OXIDATION AND REMOVAL OF MERCURY

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Dkt: 4820.007US4

Sample	Additive	Additive injection rate (lb/MMacf)	Sorbent description	Sorbent injection rate (lb/MMacf)	Br or Cl ⁻ injection rate (lb/MMacf)	HBr or HCl equivalent injection rate (lb/MMacf)	Equivalent HBr or HCl wt% on sorbent	%Hg removal	%Hg removal per 1 wt% HCl or HBr on sorbent	Milligrams HBr or HCl/MMacf per 1% Hg Removal
13	NaBr on coal	0.2	Norit DARCO® Hg	0.7	0.16	0.16	18.2	59.8	3.3	1211
14	NaBr on coal	0.2	Norit DARCO® Hg	1.1	0.16	0.16	12.4	63.6	5.1	1139
15	NaBr on coal	0.2	Norit DARCO® Hg	1.6	0.16	0.16	8.8	70.4	18.0	1029
16	NaBr on coal	0.2	Norit DARCO® Hg	2.6	0.16	0.16	5.6	76.7	13.6	944
17	NaBr on coal	0.4	Norit DARCO® Hg	2.6	0.31	0.31	10.7	83.3	7.8	1739
18	NaBr on coal	0.4	Norit DARCO® Hg	3.8	0.31	0.31	7.6	85.1	11.3	1702
19	NaCl on coal	2.4	Norit DARCO® Hg	0.7	1.46	1.50	67.5	60.6	0.9	11202
20	NaCl on coal	3.4	Norit DARCO® Hg	0.7	2.06	2.12	74.7	61.2	0.8	15714
21	NaCl on coal	4.9	Norit DARCO® Hg	0.7	2.97	3.06	80.9	57.8	0.7	23979
22	NaCl on coal	4.9	Norit DARCO® Hg	1.1	2.97	3.06	73.0	67.4	0.9	20564
23	NaCl on coal	4.9	Norit DARCO® Hg	1.6	2.97	3.06	65.0	69.6	1.1	19914
24	NaCl on coal	6.9	Norit DARCO® Hg	1.6	4.19	4.30	72.3	71.2	1.0	27412
25	HCl outside flue gas	0	Norit DARCO® Hg	0.7	0.04	0.04	5.0	27.9	5.6	569
26	HCl outside flue gas	0	Norit DARCO® Hg	1.6	0.08	0.08	5.0	34.2	6.8	1061
27	HCl outside flue gas	0	Norit DARCO® Hg	2.6	0.13	0.13	5.0	35.1	7.0	1680
28	HCl outside flue gas	0	Norit DARCO® Hg	4.9	0.24	0.25	5.0	40.3	8.1	2757
29	HCl outside flue gas	0	Norit DARCO® Hg	7.7	0.37	0.39	5.0	43.9	8.8	3978
30	HCl outside flue gas	0	Norit DARCO® Hg	15.5	0.75	0.78	5.0	52.9	10.6	6645

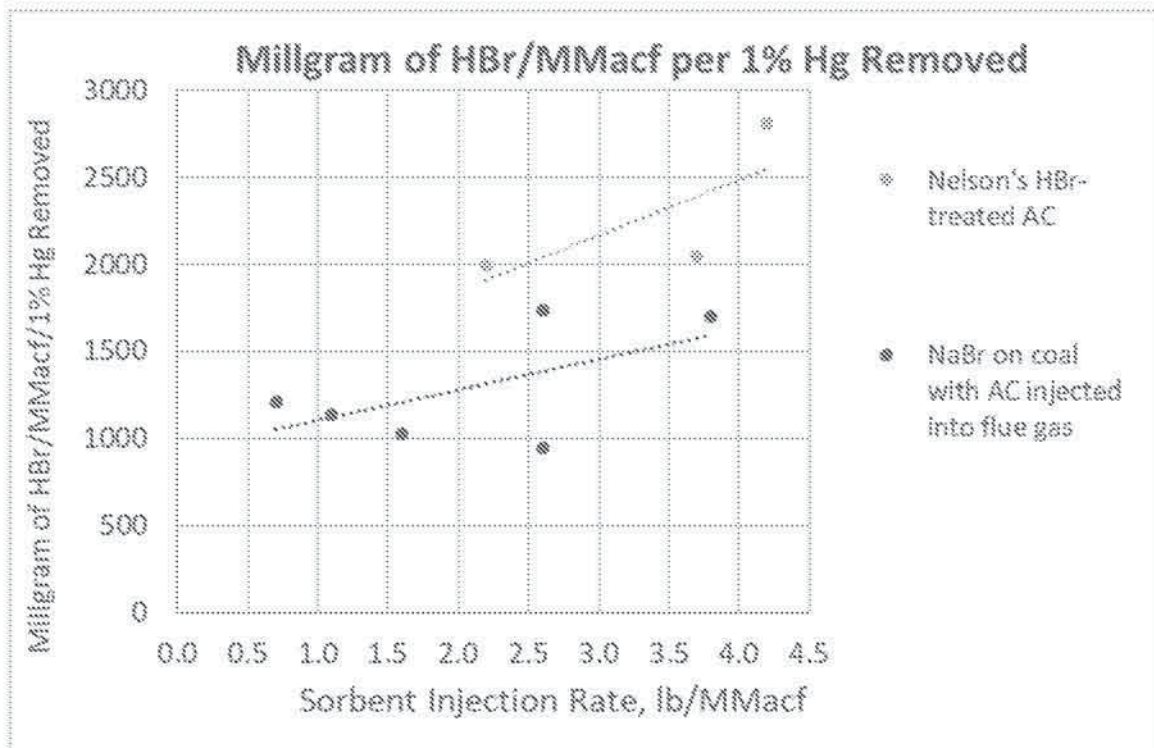
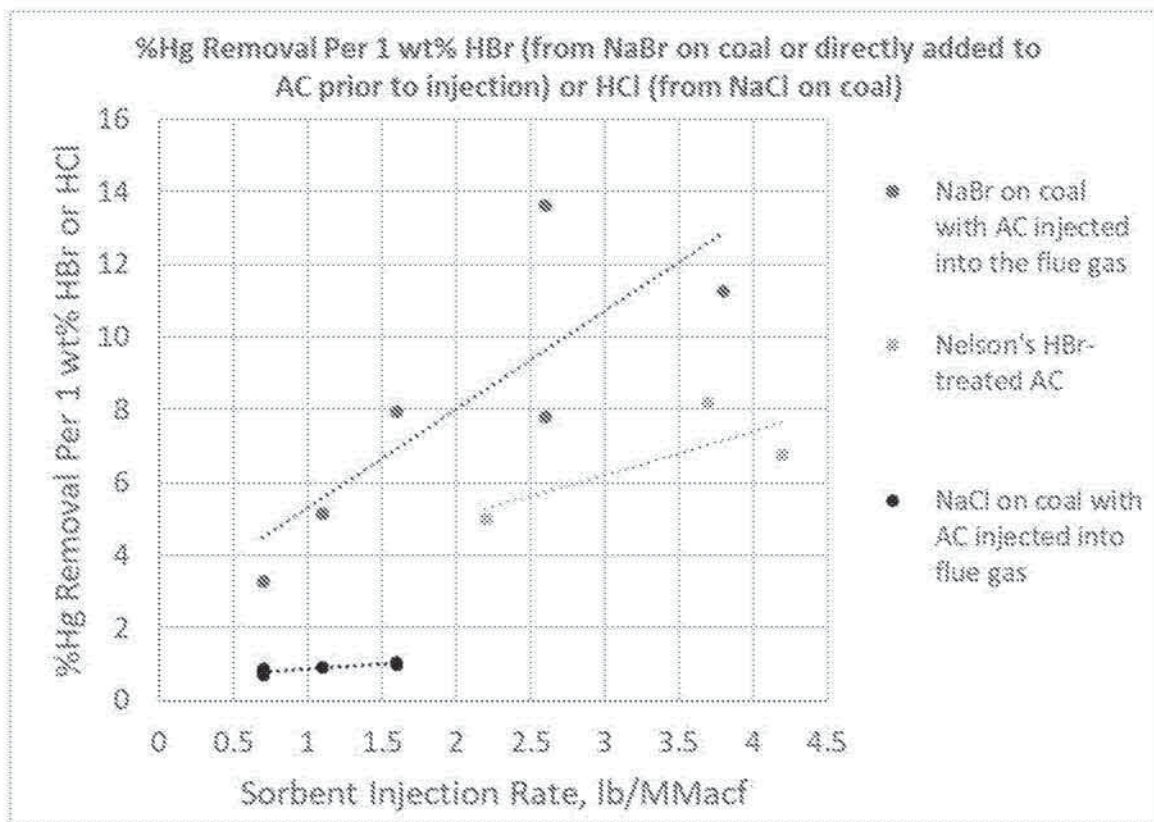
11. The following plot shows the percent mercury removal versus the sorbent injection rate for the activated carbon alone (untreated), the activated carbon treated with Br_2 outside the flue gas described herein at item 6 as per the Nelson procedure, and for NaBr added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas. All of the data in the following plot is taken from the data in the tables at item 9 and 10, which was produced using the same pilot-scale setup described at item 8.



12. The data in the plot above show that the NaBr added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas (in-flight promotion with Br) provided a higher percent of mercury removal at all tested sorbent

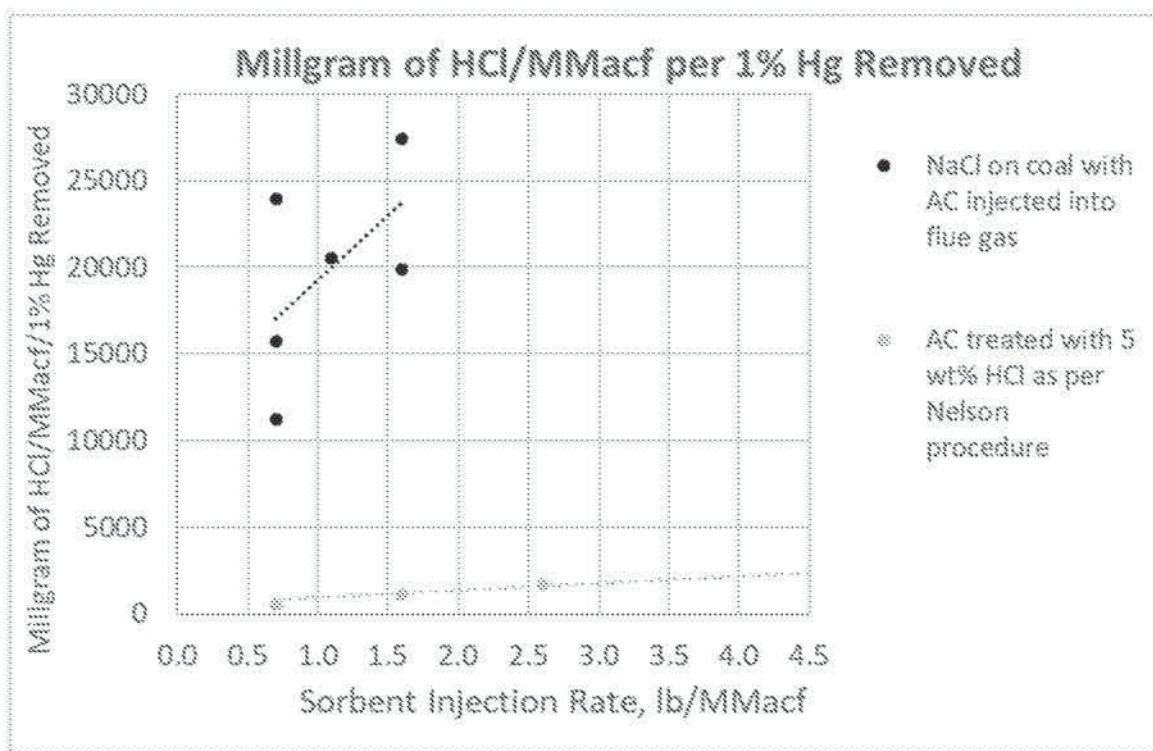
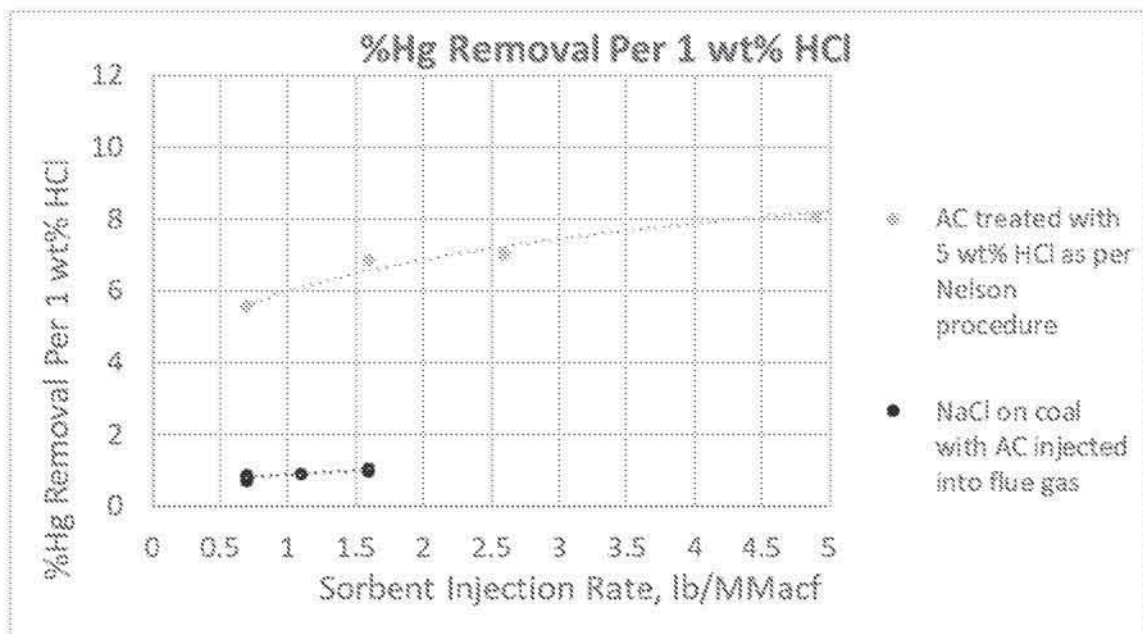
injection rates as compared to the activated carbon alone (untreated) and compared to the activated carbon treated with Br_2 outside the flue gas described herein at item 6 as per the Nelson procedure. With NaBr added to the coal and activated carbon injected into the flue gas, there was a significant reduction in the amount of sorbent required to achieve similar mercury removal compared to the activated carbon treated with Br_2 outside the flue gas. For example, to achieve 70% mercury removal, 2.5 lb/MMacf of Br_2 -treated carbon was required, as compared to 1.6 lb/MMacf with NaBr added to the coal and activated carbon injected into the flue gas; an additional $(2.5-1.6/1.6)*100\%$ or 56% treated sorbent was required to achieve the same level of mercury removal.

13. The following first plot shows the percent mercury removal per 1 wt% HBr or HCl versus the sorbent injection rate with NaBr or NaCl added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas, and for Nelson's activated carbon treated with HBr outside the flue gas. The following second plot shows the milligrams of HBr/MMacf per 1% mercury removal versus the sorbent injection rate with NaBr added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas, and for Nelson's activated carbon treated with HBr outside the flue gas; NaCl added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas was omitted from this plot because the values for the milligrams of HCl/MMacf per 1% mercury removal were so high (about 10,000 to 30,000). The data sets in the following first and second plots "NaBr on coal with AC injected into the flue gas" and "NaCl on coal with AC injected into flue gas" are taken from the data in table at item 10, which was produced using the same pilot-scale setup described at item 8. The data set in the following first and second plots "Nelson's HBr-treated AC" is taken from the table at item 5, which is from Nelson's experimental setup.



14. The data in the first plot above show that the NaBr added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas provided a significantly higher (about 2x) percent mercury removal per 1 wt% HBr at all tested sorbent injection rates as compared to Nelson's activated carbon treated with HBr outside the flue gas. Further, the data show that NaBr added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas provided a significantly higher (about 6-8x) percent mercury removal per 1 wt% HBr or HCl at all tested sorbent injection rates compared to the NaCl added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas. The data in the second plot above shows that NaBr added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas provided a significantly lower milligrams of HBr/MMacf per 1% mercury removal at all tested sorbent injection rates as compared to Nelson's activated carbon treated with HBr outside the flue gas, indicating more efficient (approximately 2x) use of HBr for mercury removal during in-flight promotion of activated carbon than treatment of activated carbon outside the flue gas.

15. The following first plot shows the percent mercury removal per 1 wt% HCl versus the sorbent injection rate for NaCl added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas, and for the activated carbon treated with HCl outside the flue gas described herein at item 7 as per the Nelson procedure. The following second plot shows the milligrams of HCl/MMacf per 1% mercury removal versus the sorbent injection rate with NaCl added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas, and for the activated carbon treated with HCl outside the flue gas described herein at item 7 as per the Nelson procedure. The data sets in the following first and second plots are taken from the data in table at item 10, which was produced using the same pilot-scale setup described at item 8.



16. The data in the first plot above show that activated carbon treated with HCl outside the flue gas as per the Nelson procedure provided a much higher percent of mercury removal per 1 wt% HCl at all tested sorbent injection rates as compared to NaCl

added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas. The data in the second plot above show that the milligrams of HCl/MMacf per 1% mercury removal versus the sorbent injection rate with NaCl added to coal prior to introduction to the furnace with injection of untreated activated carbon into the flue gas was significantly higher as compared to the activated carbon treated with HCl outside the flue gas described herein at item 7 as per the Nelson procedure, indicating more efficient use of HCl for mercury removal by treatment of activated carbon outside the flue gas than by promotion in-flight.

17. I further declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by a fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application and/or any patent issued thereon.

Dated: March 20, 2019

By: / John Pavlish /
John Pavlish

A/N 15/978,760

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s): Edwin S. Olson et al.

Examiner: AMBER ROSE ORLANDO

Application No.: 15/978,760

Group Art Unit: 1776

Filed: May 14, 2018

Docket No.: 4820.007US4

Confirmation No.: 6432

Title: SORBENTS FOR THE OXIDATION AND REMOVAL OF MERCURY

DECLARATION UNDER 37 C.F.R. § 1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION A

I, John Pavlish, declare and say as follows:

1. I have been the Chief Technology Officer and Senior Vice President of Midwest Energy Emissions Corporation since November 16, 2014. Prior to this, I served as an Executive Consultant Advisor to Midwest Energy Emissions Corporation. Prior to joining Midwest Energy Emissions Corporation, I was a Senior Research Advisor and the Director of the Center for Air Toxic Metals Program at the Energy & Environmental Research Center in Grand Forks, North Dakota. I have over 25 years of mercury-related experience and am regarded as an international expert on the topic of mercury. My primary areas of interest and expertise include research, technical consultation and development of mercury control technologies, in particular, for coal combustion and gasification systems. I am an inventor of a number of patented mercury control technologies and have years of experience in development and testing of these technologies for commercial applications. Over the last 15 years, I have spent much time evaluating the efficacy of a number of different mercury control technologies/approaches and their cost competitiveness in the commercial market. I also have years of power plant experience and have worked for an engineering/consulting company, Black & Veatch, where I served as Unit Leader/System Engineer. I am a professional engineer, a member of the American Society of Mechanical Engineers, and a member of the Air & Waste Management Association (A&WMA). I serve on numerous professional and

technical committees and am a U.S. Representative on the Mercury Emissions from Coal International Experts Working Group on Reducing Emissions from Coal and a member of the United Nations Environment Programme Global Mercury Partnership, Reduction of Mercury Releases from Coal Combustion. I have published over 200 papers, articles, and reports on various mercury-related topics and issues.

2. Herein, when I refer to the invention I am referring to a method of separating mercury from a mercury-containing gas as described in independent claim 2 of U.S. patent application serial no. 15/978,760. All websites referenced in this document were accessed March 20, 2019.

The EPA Calls For New Mercury Removal Technology in the 1990s

3. The background story for this technology begins with the Clean Air Act Amendments of 1990. That law required the U.S. Environmental Protection Agency (EPA) to study the impact of various air pollutants, including mercury.¹ To assist in the research, in 1992, the EPA established a National Center for Excellence at the Energy & Environmental Research Center (EERC) referred to as the Center for Air Toxic Metals (CATM). It is through the EERC that my fellow co-inventors and I would eventually discover the invention claimed in U.S. patent application serial no. 15/978,760. Our research focused heavily on developing new methods for detecting, measuring, and ultimately, removing mercury from coal-fired power plant exhaust gas.

4. In 1997 and 1998, the EPA issued two reports to Congress: *Mercury Study Report to Congress* (issued December 1997)² and *Study of Hazardous Air Pollutant Emissions*

¹ Website: <https://www.epa.gov/clean-air-act-overview/1990-clean-air-act-amendment-summary-title-iii>

² United States Environmental Protection Agency, "Mercury Study Report to Congress, Volume I: Executive Summary", EPA-452/R-97-003, December 1997, <https://www.epa.gov/mercury/mercury-study-report-congress>

from *Electric Utility Steam* (issued February 1998)³. As an outcome of these studies, the EPA found a pressing need for regulation of mercury pollution from power plants.⁴ Unfortunately, it also found that no existing technologies were up to the task of significantly reducing the mercury pollution from those plants.⁵

5. With that said, the EPA did provide some indications as to promising areas for future research. For example, similar to cited reference U.S. patent no. 5,435,980 (“Felsvang”), the EPA noted a connection between the chlorine content in coal and potential ways to remove mercury.⁶ It also identified activated carbon injection as a potential control technology for mercury removal.⁷ Nonetheless, it acknowledged that much more research was needed:

Research continues on the chemistry and interactions of flue gas, fly ash, and mercury species. This fundamental research is needed at various flue gas conditions encountered across the utility industry in order to develop low cost mercury strategies for full-scale utility operation. Thus, while AC injection shows promise as a mercury control technology, more data and research are needed to understand the factors that affect mercury removal.⁸

6. In the wake of these reports, various governmental and industry organizations injected millions of dollars into basic scientific research and experimental studies in the

³ United States Environmental Protection Agency, “Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units -- Final Report to Congress”, United States Office of Air Quality EPA-453/R-98-004a, Environmental Protection Planning and Standards, February 1998, <https://www.epa.gov/mats/study-hazardous-air-pollutant-emissions-electric-utility-steam-generating-units-final-report>

⁴ On March 15, 2005, the EPA issued the Clean Air Mercury Rule to significantly reduce mercury emissions from coal-fired power plants, with a goal of reducing utility emissions of mercury from 48 tons/year to 15 tons/year, a reduction of nearly 70 percent. See, https://en.wikipedia.org/wiki/Mercury_regulation_in_the_United_States.

⁵ Footnote 3 reference at ES-19, “Regarding potential methods for reducing mercury emissions, the EPA has not identified any demonstrated add-on control technologies currently in use in the U.S. that effectively remove mercury from utility emissions.”

⁶ Footnote 3 reference at section 13, pages 37-38.

⁷ Footnote 3 reference at section 13, pages 40-41.

⁸ Footnote 3 reference at section 13, page 43, second full paragraph.

search for new mercury removal technologies.⁹ Because increased regulation of mercury emissions was expected to require significant upgrades to the country's fleet of coal-fired plants, much of the research focused on retrofit technologies that could be adopted at relatively low cost, including sorbent injection systems¹⁰.

The EPA Espouses the Conventional Wisdom in Favor of Pre-Treated Sorbents, Not In-Flight Sorbent Enhancement in the Flue Gas

7. In 2002, the EPA surveyed the state of research in this field and produced a follow-up report.¹¹ It noted that the complex chemistry of the coal combustion process was still not fully understood, but that progress had been made. It described how coals with higher halogen content (specifically, chlorine) were better able to oxidize mercury and promote its capture.¹² However, it also noted that this oxidation reaction could be inhibited by other chemicals present during combustion in the boiler.¹³ The EPA also described promising experiments being performed with halogen-treated sorbents.¹⁴

8. Notably, the EPA did not recommend in-flight sorbent enhancement in the flue gas by spraying additives on coal or injecting halogens into the boiler. Rather, it described research into methods for *pre-treating* sorbents with various additives, including chlorine, and then injecting those pre-treated sorbents downstream from the

⁹ T. D. Brown, D. N. Smith, R. A. Hargis Jr., W. J. O'Dowd, 1999, Mercury Measurement and Its Control: What We Know, Have Learned, and Need to Further Investigate, *Journal of the Air & Waste Management Association*, 49:6, 1-97, DOI: 10.1080/10473289.1999.10463841

¹⁰ Footnote 9 reference at page 80, first column.

¹¹ J. D. Kilgroe, C. B. Sedman, R. K. Srivastava, J. V. Ryan, C. W. Lee, S. A. Thorneloe, Control of Mercury Emissions from Coal-Fired Electric Utility Boilers: Interim Report, U.S. Environmental Protection Agency, Office of Research and Development, EPA-600/R-01-109, December 2001

¹² Footnote 11 reference at section 6, page 7, first full paragraph.

¹³ Footnote 11 reference at section 5, page 7, second full paragraph "It is speculated that SO₂ and water vapor may inhibit gas-phase oxidation of Hg⁰ by scavenging the chlorinating agent."

¹⁴ Footnote 11 reference at ES-8, second-to-last full paragraph, "Impregnation of carbons with sulfur, iodine, or chlorine can increase the reactivity and capacity of sorbents."

boiler.¹⁵ This approach ensured that, e.g., chlorinating agents could react with the sorbent material without being “scavenged” by other chemicals present in the boiler. This approach also ensured that the sorbent additive would have plenty of time to react with the sorbent—the EPA explained that, for many plants, injected sorbents would have only a few seconds to find and react with mercury present in the flue gas, with high and costly carbon-to-Hg ratios needed to achieve adequate mercury removal.¹⁶ This is consistent with the general understanding in the industry that sorbent additives such as halogens or halides should be mixed with sorbents *before* coming in contact with mercury-containing flue gas.

Sidney Nelson Touts Brominated Sorbent, Not In-Flight Sorbent Enhancement in the Flue Gas

9. The same year the EPA published its follow-up report,¹⁷ on April 24, 2002, Sidney Nelson filed the provisional application for the cited reference U.S. patent publication no. 2004/0003716 (“Nelson”), U.S. provisional application no. 60/377,790 (“Nelson provisional”). His application reported experiments that he had conducted using sorbents pre-treated with Br₂ and HBr. His application demonstrated that those pre-treated sorbents could outperform some commercially available sorbents, explaining exposing the activated carbon to concentrated forms of Br₂ or HBr outside the flue gas allows a relatively large quantity of the concentrated Br₂ or HBr to react with the activated carbon.¹⁸

¹⁵ Footnote 11 reference at section 5, paragraph bridging pages 33-34.

¹⁶ Footnote 11 reference at 5-33, “Activated carbon duct injection seems to be the most promising Hg control technology for coal-fired electric utility boilers equipped with ESPs. In this technology, the injected activated carbon removes Hg only while contacting the flue gas during very limited sorbent/gas contact time (<3 seconds).” Note that this section of the report refers to the reaction between pre-treated chlorinated sorbent and mercury as occurring “in-flight.” To be clear, this portion of the report describes only the use of a pre-treated sorbent, not the claimed invention.

¹⁷ Footnote 11 reference.

¹⁸ Nelson at paragraph [0043], “...it appears that in exposing PAC to concentrated bromine gas, a relatively large quantity of the bromine reacts with the carbon, forming surface compounds on the large surface-area of the carbon.”

10. Consistent with EPA teachings, Nelson did not recommend or teach adding chemicals to the flue gas or in-flight mixing of Br_2 and HBr with sorbents. Quite the contrary, he recommended that the bromine be contacted with the sorbent outside the presence of boiler gases "...for a sufficient time..." to ensure that enough bromine reacted with the sorbent.¹⁹ Treatment times for HBr - and Br_2 -treatment of activated carbon described by Nelson were on the order of several minutes (1.5-100 minutes)²⁰; in contrast, only a few seconds are available for in-flight sorbent enhancement in the flue gas (e.g., generally less than 10 seconds)¹⁶. He also identified an even further reason to avoid in-flight sorbent enhancement in the flue gas: he noted that bromine compounds are "...quite corrosive."²¹ As a result, he recommended mixing bromine and sorbent in equipment "...preferably lined with corrosion-resistant material..."²¹ such as Teflon²²—an approach that is not possible when bromine is added to coal or injected upstream from or into the boiler.

11. Despite the development of brominated sorbents and other advancements in the field, by 2003, the EPA recognized that there was still no "single best technology that can be broadly applied" for mercury capture.²³

¹⁹ Nelson at paragraphs [0023], [0028], and claim 1.

²⁰ Nelson at page 8, paragraph [0087] and the table at the top of the second column. For HBr -treated activated carbon, the adsorption rate was 1 gram of HBr absorbed per 1 kg of activated carbon per minute, or 0.1 wt% HBr absorbed per minute, meaning that to reach the 9 wt% HBr reported in the table required about 90 minutes. Note that Figure 14 reports results for 10 wt% HBr , and Figure 15 reports results for 9 wt% HBr . For Br_2 -treated activated carbon, the adsorption rate was 10 grams of Br_2 absorbed per 1 kg of activated carbon per minute, or 1 wt% Br_2 absorbed per minute, meaning that to reach the 15 wt% Br_2 reported in the table required about 15 minutes. Note that Figures 14 and 15 report results for 1.5 wt%, 5 wt%, and 15 wt% Br_2 , according to the table requiring about 1.5 to 15 minutes to form.

²¹ Nelson at paragraph [0044].

²² Nelson provisional at page 4, last paragraph.

²³ J. H. Pavlish, E. A. Sondreal, M. D. Mann, E. S. Olson, K. C. Galbreath, D. L. Laudal, S. A. Benson, "Status Review of Mercury Control Options for Coal-Fired Power Plants", Fuel Processing Technology 82 (2003) 89–165, at page 89, first paragraph.

The EPA Continues to Teach Away from In-Flight Sorbent Enhancement in the Flue Gas

12. In 2005, the EPA issued another follow-on report.²⁴ In this report, the EPA again noted the connection between chlorine content in coal and mercury capture.²⁵ It also recognized the advantages of brominated carbon sorbents.²⁶ The report also notes that halogen-containing sorbent enhancement additives have been added to coal along with injection of activated carbon sorbents into the flue gas to remove mercury.²⁷ However, despite being aware of these facts—facts that the examiner has relied on to demonstrate obviousness of the claims at issue—in the final summary the EPA does not recommend, or even mention, in-flight sorbent enhancement in the flue gas.²⁸ Although the EPA’s “key observations” for retrofitting the country’s coal plant fleet mention the use of fuel additives and the injection of activated carbon into the flue gas, the use of these technologies together is not mentioned, and in-flight enhancement of the sorbent in the flue gas is not mentioned; rather, injection of pre-treated halogenated activated carbon is emphasized.²⁹

²⁴ U.S. Environmental Protection Agency, “Control of Mercury Emissions from Coal Fired Electric Utility Boilers: An Update”, Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, Office of Research and Development, February 18, 2005

²⁵ Footnote 24 reference at page 25, third-to-last bullet point. See also, page 10, second paragraph, with regard to chloride salts on coal, noting that “Long term effects, such as corrosion, plugging, impacts on combustion equipment could not be assessed during the short-term parametric tests. Therefore, the use of coal additives offer some promise at improving mercury capture; however, they may have other impacts that need to be evaluated.”

²⁶ Footnote 24 reference at pages 18-21.

²⁷ Footnote 24 reference at page 22, second paragraph. See also, page 24, second-to-last full paragraph, “Additives used to enhance PAC performance or other sorbents that may be used, however, might cause adverse effects on plant components. The potential for such impacts would have to be evaluated through long-term field testing conducted over time periods of several months or more.”

²⁸ Footnote 24 reference at pages 30-32.

²⁹ Footnote 24 reference at pages 31-32, items 6 and 9, discussing injection of activated carbon and halogenated activated carbon, are the only items to highlight specific mercury removal levels, and fail to mention halogenated fuel additives or in-flight sorbent enhancement in the flue gas.

13. The EPA's failure to recommend the use of halogenated fuel additives in combination with injection of activated carbon into the flue gas to cause in-flight enhancement of the sorbent in the flue gas is particularly striking because my coinventors and I had already begun publishing results from initial testing of in-flight sorbent enhancement in the flue gas. The EPA acknowledged those results in their report, noting that 63% mercury removal was achieved, and specifically found that this approach is different from merely using pre-treated sorbent.²⁷ Nonetheless, despite having this initial data as a roadmap to arrive at the claimed invention, the EPA continued to espouse the conventional view in favor of pre-treated sorbents.

The Department of Energy Funds Research into In-Flight Sorbent Enhancement in the Flue Gas

14. Despite the EPA's optimism for injection of pre-treated halogenated carbon sorbents into the flue gas in the early 2000s, various research groups were pursuing alternative technologies during this time period. The EERC was one of those groups. After extensive research into methods for detecting and measuring mercury species, and some research into various sorbents, my co-inventors and I theorized that in-flight sorbent enhancement in the flue gas could provide an improvement over pre-treated sorbent.

15. The EERC obtained funding to test this theory in 2003 from the U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL) under the Office of Fossil Energy's Innovations for Existing Plants (IEP) Program.³⁰ The goal of Phases I and II of the program was development of Hg control technologies that could achieve 50 to 70% Hg capture at costs 25 to 50% less than the baseline 1999 estimate.³¹ Our initial pilot-scale tests suggested that our approach could achieve mercury removal efficiencies

³⁰ T.J. Feeley III, J. Murphy, J. Hoffmann, S. A. Renninger, A Review of DOE/NETL's Mercury Control Technology R&D Program for Coal-Fired Power Plants, April 2003.

³¹ Footnote 30 reference, page 3, second paragraph.

ranging from 50-90%. As a result, the EERC successfully obtained several multi-million-dollar awards under the program.³²

In-Flight Sorbent Enhancement in the Flue Gas Is Finally Recognized as a Critical Advancement

16. It is estimated that over \$60 million dollars was spent by the EERC on the research, development, testing, and demonstration of mercury removal from flue gas.³³ In 2008, DOE published a document highlighting the successful development and demonstration of the technology.³⁴ Some of the key advantages of the technology are highlighted as follows^{34, 35}:

- Improves mercury oxidation and enhances activated carbon reactivity, which can improve capture in downstream equipment.
- Allows use of more abundantly available supplies of activated carbon (treated activated carbons have limited supply).
- Improves mercury capture while using far less activated carbon.
- Improves mercury capture efficiencies in some instances to greater than 90% (standard ACs can be limited to around 60%).
- Allows for performance and cost optimization of SEA and activated carbon at each site.
- Minimizes ESP particulate and opacity problems by using lower amounts of activated carbon.
- Minimizes fabric filter particulate emissions and pressure drop while allowing the unit to operate at maximum load by using lower amounts of activated carbon.

³² Footnote 30 reference, page 2, second paragraph; page 5 at Table 1; page 6 at Table 2; page 7 at Table 3; page 9, first full paragraph; page 13, last paragraph; page 17, last full paragraph; paragraph bridging pages 17-18; page 18, first full paragraph; and page 19, last partial paragraph.

³³ <https://www.midwestemissions.com/>

³⁴ U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, Cooperative Research and Development, "Successes: Sorbent Enhancement Additive Technology for Mercury Control", 2008

³⁵ A. P. Jones, J. W. Hoffmann, D. N. Smith, T. J. Feeley, J. T. Murphy, "DOE/NETL's Phase II Mercury Control Technology Field Testing Program: Preliminary Economic Analysis of Activated Carbon Injection," Environ. Sci. Technol., 2007, 41 (4), pp 1365-1371. DOI: 10.1021/es0617340, January 17, 2007.

In-Flight Sorbent Enhancement in the Flue Gas Experiences Commercial Success and Is Copied by Sidney Nelson and Other Competitors

17. One of the most straightforward indications of the success of the invention comes from chemical giant Albemarle, one of the largest suppliers of bromine worldwide. In 2008, Albemarle acquired Sidney Nelson's brominated sorbent company Sorbent Technologies Corp. and the Nelson patent.³⁶ Albemarle continued to market and sell brominated carbon sorbents. Nonetheless, today, even Albemarle now sells chemicals and systems for in-flight sorbent enhancement in the flue gas.³⁷

18. In fact, even Mr. Nelson himself ultimately accepted the benefits of in-flight sorbent enhancement in the flue gas. In a post-Albemarle acquisition presentation entitled "How China Can Leapfrog the World in Mercury Emission Reduction", he noted that pre-treated sorbents were accepted in the U.S., but he recommended that Chinese operators should instead use in-flight sorbent enhancement in the flue gas.³⁸ As his basis for proposing that new approach he did not cite his own research or some commonly understood reference or theory from the 1990s or early 2000s. Rather, he relied on data collected by myself and my colleagues at the EERC and published in 2006.³⁹

19. Despite the initial success of pre-treated sorbents, in-flight sorbent enhancement in the flue gas has more recently experienced important growth in the U.S. EPA data indicates that in-flight sorbent enhancement in the flue gas is currently used by more than

³⁶ See, U.S. assignment database for U.S. patent no. 6,953,494, assigned to Sorbent Technologies Corporation on 9/18/2006, and assigned to Albemarle Corporation on 9/30/2010. See also, <http://www.chemeurope.com/en/news/85387/albemarle-corporation-acquires-sorbent-technologies-corporation.html>.

³⁷ <https://www.albemarle.com/businesses/bromine-specialties/bromine-&-derivatives/mercury-control>, at the "ADDITIVES" tab.

³⁸ https://www.dri.edu/images/stories/editors/leapfrog/techprog/IId_3_NelsonJr.pdf at slide 24.

³⁹ Footnote 38 reference at slide 20.

one-third of all plants in the U.S.,⁴⁰ and it has been recognized as one of the key technologies enabling cost effective mercury removal from coal plant exhaust.

20. I further declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by a fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application and/or any patent issued thereon.

Dated: March 20, 2019

By: John Pavlish

John Pavlish

⁴⁰ EPA Air Markets Program Data: <https://ampd.epa.gov/ampd/>. From this webpage, the “Query” tab was clicked. For programs and data sets, the program “mercury and air toxics standards (MATS)” and the data set “facility attributes” were selected, and then “next step” was clicked. For time frame, “select a range” was selected from 2019 to 2019, and then “next step” was clicked. For criteria, nothing was selected, and then “next step” was clicked. For variables, only the variables “owner”, “fuel type (primary)”, and “mercury controls” were selected, and then “next step” was clicked. The CSV file was downloaded, and then the “facility” file was opened as an Excel spreadsheet. The data was sorted to include only coal plants, column G, which totaled 606. Column H was then sorted to include only additives to enhance PAC; the total number was 70. Column H was then sorted to include only the units that had actually filled out what mercury control technology they are using, which totaled 228. Assuming that the 228 units are a random sampling of the 606 total, that number statistically represents all of the units and the distribution of different mercury control approaches. Thus, if 70 units are using coal additives with PAC and 228 units are representative of the 606, about 1/3 (e.g., $70/228 = 0.31$) of the units are using coal additives with PAC.

S/N 15/974,343

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s):	Edwin S. Olson et al.	Examiner:	Amber Orlando
Serial No.:	15/974,343	Group Art Unit:	1776
Filed:	May 8, 2018	Docket:	4820.001US9
Customer No.:	21186	Confirmation No.:	1072
Title:	SORBENTS FOR THE OXIDATION AND REMOVAL OF MERCURY		

PETITION FOR A THREE-MONTH EXTENSION OF TIME

Mail Stop RCE
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

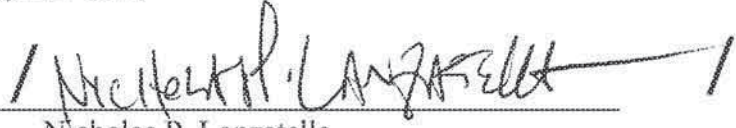
In accordance with the provision of 37 C.F.R. § 1.136(a), it is respectfully requested that a three-month extension of time be granted in which to respond to the Final Office Action mailed January 14, 2019, said period of response being extended from April 14, 2019 to July 14, 2019.

Please charge Deposit Account No. 19-0743 in the amount of \$1,400.00 to cover the required extension fee. Please charge any additional fees or credit overpayment to deposit Account No. 19-0743.

Respectfully submitted,

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Date July 10, 2019

By 
Nicholas P. Lanzatella
Reg. No. 63,803

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Use as many sheets as necessary)	<i>Complete if Known</i>	
	Application Number	15/974,343
	Filing Date	May 8, 2018
	First Named Inventor	Edwin S. Olson
	Group Art Unit	1776
	Examiner Name	Amber Orlando
Sheet 1 of 1		Attorney Docket No: 4820.001US9

US PATENT DOCUMENTS			
Examiner Initial *	USP Document Number	Publication Date	Name of Patentee or Applicant of cited Document
	US-10,343,114	7/9/2019	Olson, Edwin S, et al.
	US-20120100053A1	4/26/2012	Durham, Michael D, et al.
	US-20130157845A1	6/20/2013	Nalepa, Christopher J, et al.

FOREIGN PATENT DOCUMENTS			
Examiner Initial *	Foreign Document Number	Publication Date	Name of Patentee or Applicant of cited Document
	WO-2012030560A1	3/8/2012	Nalepa, Christopher J, et al.

OTHER DOCUMENTS – NON PATENT LITERATURE DOCUMENTS			
Examiner Initial *	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.		
	"Application Serial No. 15/382,114, Final Office Action mailed 06-21-19", 31 pgs		
	"Application Serial No. 15/589,359, Non Final Office Action mailed 06-21-19", 7 pgs		
	"Application Serial No. 15/978,760, Notice of Allowability mailed 05-30-19", 3 pgs		

EXAMINER

DATE CONSIDERED

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s):	Edwin S. Olson et al.	Examiner:	Amber Orlando
Serial No.:	15/974,343	Group Art Unit:	1776
Filed:	May 8, 2018	Docket:	4820.001US9
Customer No.:	21186	Confirmation No.:	1072
Title:	SORBENTS FOR THE OXIDATION AND REMOVAL OF MERCURY		

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

MS Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

In compliance with the duty imposed by 37 C.F.R. § 1.56, and in accordance with 37 C.F.R. §§ 1.97 *et. seq.*, the enclosed materials are brought to the attention of the Examiner for consideration in connection with the above-identified patent application. Applicant respectfully requests that this Information Disclosure Statement be entered and the documents listed on the attached PTO 1449 Form be considered by the Examiner and made of record. Pursuant to the provisions of MPEP 609, Applicant requests that a copy of the PTO 1449 Form, initialed as being considered by the Examiner, be returned to the Applicant with the next official communication.

Pursuant to 37 C.F.R. § 1.97(b), it is believed that no fee or statement is required with the Information Disclosure Statement. However, if an Office Action on the merits has been mailed after filing of the application or after the filing of the most recent RCE, the Commissioner is hereby authorized to charge the required fees to Deposit Account No. 19-0743 in order to have this Information Disclosure Statement considered.

Pursuant to 37 C.F.R. § 1.98(a)(2), copies of cited U.S. Patents and Published Applications, and Non-Published Applications identifiable by USPTO Serial Number, are no longer required to be provided to the Office. Applicant acknowledges the requirement to submit copies of foreign patent documents and non-patent literature in accordance with 37 C.F.R. § 1.98(a)(2).

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

Serial Number: 15/974,343

Filing Date: May 8, 2018

Title: SORBENTS FOR THE OXIDATION AND REMOVAL OF MERCURY

Page 2

Dkt: 4820,001US9

The Examiner is invited to contact the undersigned at the telephone number indicated if there are any questions regarding this communication.

Respectfully submitted,

SCHWEGMAN LUNDBERG & WOESSNER, P.A.

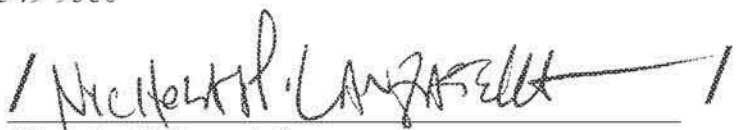
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By



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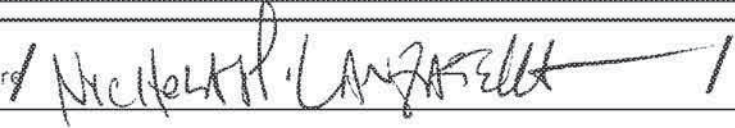
CERTIFICATION AND REQUEST FOR PRIORITIZED EXAMINATION UNDER 37 CFR 1.102(e)

(Page 1 of 1)

First Named Inventor:	Edwin S. Olson	Nonprovisional Application Number (if known):	15/974,343
Title of Invention:	SORBENTS FOR THE OXIDATION AND REMOVAL OF MERCURY	Docket No.:	4820.001US9

APPLICANT HEREBY CERTIFIES THE FOLLOWING AND REQUESTS PRIORITIZED EXAMINATION FOR THE ABOVE-IDENTIFIED APPLICATION.

1. The processing fee set forth in 37 CFR 1.17(i)(1) and the prioritized examination fee set forth in 37 CFR 1.17(c) have been filed with the request. The publication fee requirement is met because that fee, set forth in 37 CFR 1.18(d), is currently \$0. The basic filing fee, search fee, and examination fee are filed with the request or have been already been paid. I understand that any required excess claims fees or application size fee must be paid for the application.
2. I understand that the application may not contain, or be amended to contain, more than four independent claims, more than thirty total claims, or any multiple dependent claims, and that any request for an extension of time will cause an outstanding Track I request to be dismissed.
3. **Request for Continued Examination – Prioritized Examination under § 1.102(e)(2)**
 - i. A request for continued examination has been filed with, or prior to, this form.
 - ii. If the application is a utility application, this certification and request is being filed via EFS-Web.
 - iii. The application is an original nonprovisional utility application filed under 35 U.S.C. 111(a), or is a national stage entry under 35 U.S.C 371.
 - iv. This certification and request is being filed prior to the mailing of a first Office action responsive to the request for continued examination.
 - v. No prior request for continued examination has been granted prioritized examination status under 37 CFR 1.102(e)(2).

Signature 	Date July 10, 2019
Name (Print/Typed) Nicholas P. Lanzatella	Practitioner Registration Number: 63,803
Note: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. Submit multiple forms if more than one signature is required, see below*.	
*Total of <u>1</u> forms are submitted.	

REMARKS

This responds to the Final Office Action dated January 14, 2019.

No claims are presently amended. Claims 1-10, 14, and 21-26 are presently canceled, and claims 11-13 and 15-20 were canceled previously. New claims 27-55 are presently added. As a result, claims 27-55 are now pending in this application.

New claim	Prior claim or other support from published U.S. application
27	1
28	2, FIG. 11, and [0217]
29	FIG. 11 and [0217]
30	Example 10 at [0122]
31	[0077] and [0202]
32	[0069]
33	[0112]
34	[0105]
35	[0123]
36	25, [0090]
37	[0090]
38	25, [0090]
39	24
40	FIG. 2
41	22
42	23
43	24
44	[0015] and [0051]
45	14
46	[0047]
47	[0123]
48	[0217]
49	[0003]
50	[0058] and FIG. 11
51	[0109]
52	[0007], [0053], [0072], [0188], [0199]
53	[0007], [0053], [0072], [0188], [0199]
54	1
55	1, 25, [0090]

Independent claims 27, 54, and 55 recite combusting coal in a combustion chamber, to provide the mercury-containing gas, wherein the coal or the combustion chamber comprises added

Br₂, HBr, a bromide compound, or a combination thereof; injecting a sorbent comprising activated carbon into the mercury-containing gas downstream of the combustion chamber; contacting mercury in the mercury-containing gas with the sorbent; and separating the sorbent contacted with the mercury from the mercury-containing gas. As explained herein at parts I-IV, this combination of features is patentable over the cited references. Dependent claims 28-53 are directly or indirectly dependent on independent claim 27. As such, these dependent claims incorporate all the features of claim 27. Accordingly, claims 28-53 are patentable for at least the reasons given herein for patentability of independent claim 27.

37 CFR §1.132 Declarations

A 37 CFR § 1.132 declaration by John Pavlish filed with the Response of 3/20/2019 for U.S. patent application no. 15/978,760 is submitted herewith that describes objective evidence of nonobviousness ("Declaration A"). The 37 CFR § 1.132 declaration by John Pavlish submitted with the last response was revised and filed with the Response of 3/20/2019 for U.S. patent application no. 15/978,760 and is submitted herewith ("Declaration B"). A 37 CFR § 1.132 declaration by John Pavlish and Nicholas Lentz filed with the Response of 3/20/2019 for U.S. patent application no. 15/978,760 is submitted herewith that explains that Br₂ is not HBr and does not include HBr, and Cl₂ is not HCl and does not include HCl; that Br₂ is not and does not include Br[•], and Cl₂ is not and does not include Cl[•]; NaBr is a salt that includes Na⁺ ions and Br⁻ ions; and that NaCl is a salt that includes Na⁺ ions and Cl⁻ ions ("Declaration C"). A 37 CFR § 1.132 declaration by John Pavlish filed with the Response of 3/20/2019 for U.S. patent application no. 15/978,760 is submitted herewith that explains that data from Nelson's experimental setup and from the pilot-scale unit of item 8 of Declaration B are validly comparable ("Declaration D").

Summary of Arguments

Response to Examiner's Rejection under 35 USC § 103

The claims were rejected over Felsvang in view of Nelson based on the Examiner's assessment that Felsvang teaches in-flight sorbent promotion using a chlorine-based material and Nelson teaches that bromine-based materials are superior for promoting sorbents. This was,

respectfully, in error. As explained below, the Examiner has not established a *prima facie* case of obviousness.

The Cited References Do Not Provide a Motivation to Attempt In-Flight Promotion With HBr or Br⁻ Over Pre-Treatment of Sorbents

As an initial matter, while Felsvang does mention supplying chloride to coal and providing activated carbon in flue gas, Felsvang does not teach that this process promotes the activated carbon. The Examiner fails to identify any teaching in the art that exposure of activated carbon to halogen- or halide-containing flue gas (as opposed to, e.g., concentrated halogen or halide gas) would generate a promoted sorbent, as opposed to, for example, the activated carbon and the halogen or halide in the flue gas providing independent, albeit complementary, mechanisms for mercury removal. For example, a person with a cold may expect aspirin and a decongestant to work well together at reducing symptoms, but that does not mean that taking the two compounds together will cause an additional beneficial chemical reaction.

To be sure, writing a decade later, Sidney Nelson acknowledges that chlorine and bromine can be used to promote carbon sorbents in-flight in the flue gas.¹ But, as the Examiner acknowledges, the Nelson reference does not teach in-flight promotion in the flue gas as a way to create a promoted sorbent, nor does Nelson teach adding any chemical to the flue gas would improve mercury removal. Quite the contrary, Nelson describes pre-treating sorbent (i.e., outside of flue gas) as an “essential element” of his invention.² He offers specific reasons as to why pre-treatment was viewed as essential. For example, he notes that bromine species can be “quite corrosive,”³ the carbon should be “uniformly exposed to and reacted with the bromine,”⁴ the carbon should be purged of H₂O which interferes with bromination,⁵ and he describes a mixing time for HBr and activated carbon of 90 minutes or more⁶. As explained more fully below, a person of

¹ Declaration A at item 18.

² Nelson at paragraph [0040].

³ Nelson at paragraph [0044].

⁴ Nelson at paragraph [0046].

⁵ Nelson at paragraphs [0048] and [0051].

⁶ Nelson at page 8, paragraph [0087] and the table at the top of the second column. For HBr-treated activated carbon, the adsorption rate was 1 gram of HBr absorbed per 1 kg of activated carbon per minute, or 0.1 wt% HBr absorbed per minute, meaning that to reach the 9 wt% HBr reported in the table required about 90 minutes. Note that Figure 14 reports results for 10 wt% HBr, and Figure 15 reports results for 9 wt% HBr. For Br₂-treated activated carbon, the adsorption rate was 10 grams of Br₂ absorbed per 1 kg of activated carbon per minute, or 1 wt% Br₂ absorbed per

ordinary skill in the art would recognize that the combustor and flue gas ductwork are composed of corrodible metal, the concentration of halogen in the flue gas would be low, the flue gas would contain significant H₂O (e.g., 7% as per Nelson)⁷, and that in-flight mixing would allow for only several seconds of contact time between the activated carbon and the promoter rather than 90 minutes. Thus, Nelson would motivate a person of ordinary skill in the art to promote sorbents in a controlled setting outside of a flue gas, not to attempt in-flight promotion in a flue gas. At the very least, Examiner has not shown that a person of ordinary skill in the art would be motivated to modify Felsvang in view of Nelson.

Objective Evidence Confirms the Patentability of the Claims

The arguments above are reflected in the story of the claimed invention. Submitted herewith is the 37 CFR § 1.132 declaration by inventor John Pavlish that describes objective evidence of nonobviousness (“Declaration A”). Mr. Pavlish explains—with support from extensive contemporaneous documentation—how the EPA kicked off a race for the development of new mercury removal technologies. From early on though, the conventional wisdom was that sorbents should be pre-treated before injection into the flue gas. While at the Energy & Environmental Research Center (“EERC”), Mr. Pavlish and his co-inventors fought against this conventional wisdom and eventually obtained millions of dollars in federal grant money to develop the claimed invention. Their efforts were so successful that the Department of Energy specifically highlighted their work as a significant achievement. Since then, this technology has been recognized as one of the most widely adopted technologies for mercury control in the U.S.

The claimed invention has had such a significant impact on the industry, that even Sidney Nelson himself (the author of the Nelson reference) eventually touted the benefits of in-flight promotion in the flue gas with bromine. In doing so, he acknowledged that this approach differed from the conventional approach of pre-treating sorbent, and he specifically cited the work of the EERC as demonstrating the benefits of in-flight promotion in the flue gas with bromine. This objective evidence of non-obviousness further establishes the patentability of these claims. *Crocs*,

minute, meaning that to reach the 15 wt% Br₂ reported in the table required about 15 minutes. Note that Figures 14 and 15 report results for 1.5 wt%, 5 wt%, and 15 wt% Br₂, according to the table requiring about 1.5 to 15 minutes to form.

⁷ Nelson at paragraph [0079].

Inc. v. Int'l Trade Comm'n, 598 F.3d 1294, 1310 (Fed. Cir. 2010) (internal quotation marks omitted) (objective evidence “can be the most probative evidence of nonobviousness in the record, and enables the court to avert the trap of hindsight”).

What follows is a detailed description of support for the arguments above, rebuttal evidence showing that the presently claimed invention has properties that could not be predicted from any cited reference, and responses to the Examiner’s arguments.

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The Rejection of Claims Under §103

I. The Office Action rejected claims 1-3, 5-8, 14, and 21-26 under 35 U.S.C. § 103(a) over U.S. patent no. 5,435,980 ("Felsvang") in view of U.S. patent publication no. 2004/0003716 ("Nelson").

This rejection is respectfully traversed.

As explained herein at **I(A)**, a person of ordinary skill in the art would not combine Nelson and Felsvang as alleged. Part **I(B)** discusses in-flight promotion with HBr or Br⁻ in the flue gas versus treatment outside the flue gas. As explained herein at **I(B)(1)**, in-flight promotion with HBr or Br⁻ promoters is more effective for mercury removal than treating the sorbent with HBr, Br⁻, or Br₂ outside the mercury-containing gas, and as explained herein at **I(B)(2)**, there would be no way for a person of ordinary skill in the art to predict this advantage from the cited references. Part **I(C)** discusses in-flight promotion in the flue gas with HBr or Br⁻ versus HCl or Cl⁻. As explained herein at **I(C)(1)**, in-flight promotion with HBr or Br⁻ promoters is more effective for mercury removal than in-flight promotion with HCl or Cl⁻ promoters, and as explained herein at **I(C)(2)**, there would be no way for a person of ordinary skill in the art to predict this advantage from the cited references. Part **I(D)** explains that a person of ordinary skill in the art would find that treatment of activated carbon outside the flue gas with HCl as per Nelson's process actually provides more effective mercury removal per wt% HCl than treatment of activated carbon with HCl or Cl⁻ in the flue gas. As explained herein at **I(D)(1)**, even if a person of ordinary skill in the art compared the mercury removal of activated carbons promoted with HCl or Cl⁻ in the flue gas to activated carbons treated with HCl outside of the flue gas, they would not determine that in-flight promotion provides the same or better mercury removal properties per wt% HCl. Section **I(E)** discusses objective evidence of non-obviousness of the claimed invention. Sections **I(A)(3)**, **I(B)(3)**, **I(C)(3)**, and **I(D)(2)** reply to the Examiner's responses to arguments made in the Response of 12/3/2018.

I(A). A person of ordinary skill in the art would not combine Nelson and Felsvang as alleged.

As explained herein at **I(A)(1)**, Br₂ is not HBr and does not include HBr, and Cl₂ is not HCl and does not include HCl; also, Br₂ is not and does not include Br⁻, and Cl₂ is not and does not include Cl⁻. As explained herein at **I(A)(2)**, there would be no motivation for a person of ordinary skill in the art to use Nelson's HBr in place of Felsvang's HCl or Cl⁻ in Felsvang's process. Section **I(A)(3)** includes replies to the Examiner's responses to arguments in the Response of 12/3/2018.

I(A)(1). Br₂ is not HBr and does not include HBr, and Cl₂ is not HCl and does not include HCl; also, Br₂ is not and does not include Br⁻, and Cl₂ is not and does not include Cl⁻.

As explained in Declaration C at item 17, hydrogen halides are diatomic molecules including a halogen atom and a hydrogen atom; in contrast, elemental halogens are diatomic molecules including two of the same halogen atom. HBr and HCl each include a hydrogen atom and one halogen atom, while Br₂ and Cl₂ each include two halogen atoms. Hydrogen halides have different properties than elemental halogens and are therefore different compounds. HBr has a molecular weight of 80.91 g/mol, while Br₂ has a molecular weight of 159.81 g/mol; HBr has a boiling point of -67 °C, while Br₂ has a boiling point of 58.8 °C; HBr has a melting point of -87 °C, while Br₂ has a melting point of -7.2 °C. HCl has a molecular weight of 36.46 g/mol, while Cl₂ has a molecular weight of 70.91 g/mol; HCl has a boiling point of -85 °C, while Cl₂ has a boiling point of 70.91 g/mol; HCl has a melting point of -114 °C, while Cl₂ has a melting point of -101 °C. Hydrogen halides are not part of and cannot be extracted or isolated from elemental halides; rather, only via a chemical reaction that results in a chemical and structural change can hydrogen halides be formed from elemental halides. Hydrogen bromide is produced by reacting hydrogen and Br₂ at about 200-400 °C, a reaction that is typically catalyzed by platinum or asbestos. Hydrogen chloride is produced by reacting hydrogen and chlorine with one another. Therefore, elemental halogens are not hydrogen halides, and do not include hydrogen halides—Br₂ is not HBr and does not include HBr, and Cl₂ is not HCl and does not include HCl.

As explained in Declaration C at item 18, chlorine has an atomic number of 17, meaning it has 17 protons and 17 electrons, giving it an electron configuration of 1s²2s²2p⁶3s²3p⁵, having 7 electrons in its outer shell. Bromine has an atomic number of 35, meaning it has 35 protons and 35 electrons, giving it an electron configuration of 1s²2s²2p⁶3s²3p⁶3d¹⁰4s²4p⁵, also having 7 electrons in its outer shell. According to the octet rule, a halogen atom desires to fill its outer shell with 8 electrons total by gaining one electron. A halide ion is a halogen atom that has accepted an electron from an electron donor, in the case of chloride (Cl⁻) giving it 18 total electrons to give a total charge of -1, and in the case of bromide (Br⁻) giving it 36 total electrons to give a total charge of -1. Halogen atoms do not donate electrons to other atoms, because this would result in a halogen atom losing an electron to have 6 electrons in its outer shell, an unstable configuration according to the octet rule. In the case of an elemental halogen, which exists as a diatomic molecule, instead of

donating electrons to one another, each halogen atom shares one of its electrons in the outer shell with the other halogen atom via overlapping electron orbitals in a covalent bond, allowing each halogen atom to have a filled octet while the diatomic molecule remains neutrally charged.

Therefore, a halogen atom does not donate electrons to another halogen atom to form a halide, and a diatomic halogen molecule never includes a halide; Br₂ is not and does not include Br⁻, and Cl₂ is not and does not include Cl⁻.

I(A)(2). There would be no motivation for a person of ordinary skill in the art to use Nelson's HBr in place of Felsvang's HCl or Cl⁻ in Felsvang's process.

The Office Action admits that Felsvang fails to describe or suggest a halogen or halide promoter that is Br₂, HBr, or Br⁻. Nelson fails to describe or suggest in-flight promotion of activated carbon with a halide or hydrogen halide in the flue gas. The Office Action alleges that one of ordinary skill in the art would replace Felsvang's HCl or Cl⁻ with Nelson's HBr to accomplish the presently claimed method, stating that such a modification of Felsvang would be made "...to promote activated carbon (Nelson paragraphs [0017] and [0041]) so as to provide an effective carbon sorbent for mercury." (Office Action, page 4, last sentence of second full paragraph). Applicant respectfully disagrees. As explained below, a person of ordinary skill in the art would not be motivated to use Nelson's HBr in Felsvang's process, because Nelson fails to describe or suggest that HBr-treatment of activated carbon provides similar, let alone improved, mercury-removal ability as compared to HCl or Cl⁻-treatment of activated carbon.

As explained herein at **I(A)(2)(a)**, Felsvang focuses on HCl or Cl⁻ concentration in the flue gas. As explained herein at **I(A)(2)(b)**, a person of ordinary skill in the art would not combine Nelson with Felsvang as alleged because Felsvang fails to describe or suggest in-flight promotion can occur. As explained herein at **I(A)(2)(c)**, a person of ordinary skill in the art would not be motivated to use Felsvang's process with activated carbon. As explained herein at **II(A)(2)(d)**, Nelson provides no motivation to replace Felsvang's HCl or Cl⁻ treatment with Nelson's HBr treatment.

I(A)(2)(a). Felsvang focuses on HCl or Cl⁻ concentration in the flue gas.

Felsvang is directed to adding chlorine (Cl₂) or chloride (Cl⁻) materials to the coal or combustion products. Felsvang makes clear that addition of chlorine or chloride material increases the amount of chloride supplied to the flue gas, or to the drying-absorption zone, see, Abstract and col. 3, lines 40-44. Felsvang states at col. 3, line 67 bridging to col. 4, line 4: “[i]t has been experienced that the increase of the Hg-removing effect of chloride addition to the drying-absorption zone in a process treating flue gases of low chloride content is especially remarkable when activated carbon is present....” Felsvang states at col. 4, lines 51-55: “...most chloride or chlorine containing compounds will release gaseous chlorides when introduced into the combustion zone of a coal fired boiler....” Felsvang states at col. 6, lines 3-11:

If the chloride content is found to be below a certain value as defined above and in the attached claims arrangements are taken according to the invention for increasing the gas chloride content. This may be done in connection with an introduction of activated carbon which in itself also has a Hg removing effect and together with chloride addition exhibits a synergistic effect enabling an extremely efficient Hg removal.

At column 3, lines 53-55, Felsvang states that “[t]he term ‘chloride’ is intended to mean chloride ions as such or gaseous hydrogen chloride or compounds which by heating in the presence of coal forms Cl⁻ or HCl.” Thus, Felsvang gives a definition of “chloride” that includes both HCl and Cl⁻.

I(A)(2)(b). A person of ordinary skill in the art would not combine Nelson with Felsvang as alleged because they would not know or expect in-flight promotion of the activated carbon sorbent would occur.

As explained herein at I(A)(2)(b)(i), a person of ordinary skill in the art would not combine Nelson with Felsvang as alleged because Felsvang fails to describe or suggest in-flight promotion can occur. As explained herein at I(A)(2)(b)(ii), promoter concentration in flue gas is low compared to during treatment outside of flue gas. As explained herein at I(A)(2)(b)(iii), contact time between promoters in the flue gas and activated carbon is very short compared to treatment outside the flue

gas. As explained herein at **I(A)(2)(b)(iv)**, a person of ordinary skill in the art would believe that hydrogen halides in the flue gas would be consumed via corrosion or scavenging.

I(A)(2)(b)(i). A person of ordinary skill in the art would not combine Nelson with Felsvang as alleged because Felsvang fails to describe or suggest in-flight promotion can occur.

Felsvang fails to describe or suggest that any reaction occurs between activated carbon and HCl in the flue gas. Felsvang's primary focus is the enhancement of HCl or Cl⁻ concentration in the flue gas, with addition of activated carbon being optional and not required to experience the effect of the invention. At col. 6, lines 29-33, Felsvang states "...the chloride introduction may alternatively be performed separately from the introduction of activated carbon or it may be performed without using activated carbon." At col. 6, lines 8-11, Felsvang explains that, in addition to increasing the chloride content, (emphasis added) "[t]his may be done in connection with an introduction of activated carbon which in itself also has a Hg removing effect and together with chloride addition exhibits a synergistic effect enabling an extremely efficient Hg removal." Felsvang therefore describes that activated carbon removes mercury, and that increasing HCl or Cl⁻ content removes mercury, and when the two are used together they operate side-by-side, failing to describe or suggest any reaction that occurs between the HCl or Cl⁻ and the activated carbon. Only a portion of Felsvang's Example 4 demonstrates the use of activated carbon with HCl or Cl⁻, finding only a small increase in mercury-removal activity (discussed herein at **I(A)(2)(c)**), while the majority of Felsvang's Examples (1-3) are devoid of any mention of activated carbon.

In contrast, Nelson describes a chemical reaction that occurs between the halogens and the activated carbon, and disparages simple impregnation or physical adsorption of halogens onto the activated carbon, explaining at paragraphs [0017] and [0044] that physical adsorption leads to desorption from the activated carbon. Nelson explains at paragraphs [0044] and [0053] that elevated temperatures should be used during the treatment of the activated carbon with the bromine gas to minimize physical absorption and maximize chemical reaction between the bromine and the activated carbon which avoids desorption of the bromine during transport, storage, and upon injection into a hot gas stream.

A person of ordinary skill in the art would have to understand that a reaction can occur between Felsvang's HCl or Cl⁻ and the activated carbon in Felsvang's flue gas in order to

understand that Nelson's bromine-treated sorbents have any similarity to the sorbents of Felsvang. With Felsvang's failure to describe or suggest any chemical reaction between the activated carbon and the HCl or Cl^- in the flue gas, a person of ordinary skill in the art would have no idea that Nelson's hydrogen bromide could be used in place of Felsvang's HCl or Cl^- . Therefore, a person of ordinary skill in the art would not replace Felsvang's HCl or Cl^- with HBr or Br^- . Independent claims 27, 54, and 55 are patentable for at least this reason.

I(A)(2)(b)(ii). Promoter concentration in flue gas is low compared to during treatment outside of flue gas.

At paragraph [0051] Nelson gives a preference for the use of pure Br_2 or HBr to treat the activated carbon. Nelson's Examples do not mention the use of a carrier gas to dilute the halogen gases used to prepare the treated sorbents used therein.

Forming HBr or Br^- in the flue gas from bromide salts such as NaBr on coal gives a very low concentration of HBr/ Br^- in the flue gas compared to pure HBr. A person of ordinary skill in the art would believe the concentration of HBr/ Br^- in the flue gas would be too low to result in effective treatment of activated carbon injected into the flue gas, especially considering the short contact time between the HBr/ Br^- and the activated carbon as discussed herein at I(A)(2)(b)(iii).

I(A)(2)(b)(iii). Contact time between promoters in the flue gas and activated carbon is very short compared to treatment outside the flue gas.

As explained in Declaration A at item 10, Nelson states repeatedly that the bromine-containing gas is to be contacted with the activated sorbent "for a sufficient time" to increase the ability of the activated carbon to adsorb mercury. See, e.g., Abstract and paragraphs [0023] and [0028]. Nelson at page 8, paragraph [0087] and the table at the top of the second column describes contact times required to form HBr- and Br_2 -treated activated carbons. For HBr-treated activated carbon, the adsorption rate was 1 gram of HBr absorbed per 1 kg of activated carbon per minute, or 0.1 wt% HBr absorbed per minute, meaning that to reach the 9 wt% HBr reported in the table required about 90 minutes. Note that Figure 14 reports results for 10 wt% HBr, and Figure 15 reports results for 9 wt% HBr. For Br_2 -treated activated carbon, the adsorption rate was 10 grams of

Br₂ absorbed per 1 kg of activated carbon per minute, or 1 wt% Br₂ absorbed per minute, meaning that to reach the 15 wt% Br₂ reported in the table required about 15 minutes. Note that Figures 14 and 15 report results for 1.5 wt%, 5 wt%, and 15 wt% Br₂, according to the table requiring about 1.5 to 15 minutes to form. In contrast, as explained in Declaration A at item 10, contact times between a promoter in the flue gas and activated carbon injected therein are generally less than 10 seconds.

As explained in Declaration A at item 8, before the priority date of the present claims, the EPA did not recommend in-flight sorbent enhancement in the flue gas by spraying additives on coal or injecting halogens into the boiler. Rather, it described research into methods for *pre-treating* sorbents with various additives, including chlorine, and then injecting those pre-treated sorbents downstream from the boiler. This approach ensured that the sorbent additive would have plenty of time to react with the sorbent—the EPA explained that, for many plants, injected sorbents would have only a few seconds to find and react with mercury present in the flue gas, with high and costly carbon-to-Hg ratios needed to achieve adequate mercury removal.

A person of ordinary skill in the art would believe the contact time between HBr/Br⁻ in the flue gas would be too short to increase the ability of the activated carbon injected into the flue gas to adsorb mercury, especially considering the low concentration of HBr/Br⁻ in the flue gas as discussed herein at I(A)(2)(b)(ii).

I(A)(2)(b)(iv).Consumption of hydrogen halides in the flue gas via corrosion or scavenging.

As explained in Declaration A at item 10, Nelson states at paragraph [0044] that a corrosion-resistant material should line the equipment used to mix the bromine gas and the activated carbon “...because the bromine species can be quite corrosive.” Nelson states at paragraph [0051] that “[i]t is not a preferred embodiment of this invention to include water with the bromine gas vapor if this causes corrosion problems in the processing equipment that outweigh any advantages.”

As explained in Declaration A at item 8, before the priority date of the presently claimed invention, the EPA did not recommend in-flight sorbent enhancement in the flue gas by spraying additives on coal or injecting halogens into the boiler. Rather, it described research into methods for *pre-treating* sorbents with various additives, including chlorine, and then injecting those pre-treated sorbents downstream from the boiler. This approach ensured that, e.g., chlorinating agents could react with the sorbent material without being “scavenged” by other chemicals present in the boiler.

A person of ordinary skill in the art would believe that HBr in the flue gas would be consumed via corrosion of the combustion chamber and other metallic areas of the coal-combustion plant in contact with the flue gas, or via scavenging by other species present in the flue gas. As a result, a person of ordinary skill in the art would believe that an inadequate concentration of HBr would be present for reaction with activated carbon injected into the flue gas, especially considering the low concentration of HBr/Br⁻ in the flue gas as discussed herein at I(A)(2)(b)(ii), and the short contact time between the HBr/Br⁻ and the activated carbon as discussed herein at I(A)(2)(b)(iii).

I(A)(2)(c). A person of ordinary skill in the art would not be motivated to use Felsvang's process with activated carbon.

Felsvang gives no data showing that the addition of HCl or Cl⁻ additives to coal can produce enhanced HCl or Cl⁻ concentrations in the activated carbon. Felsvang includes only a single Example showing the use of activated carbon for mercury removal, Example 4, the relevant portions of which are reproduced below (col. 9, lines 21-46):

HCl concentration in the flue gas was 142 mg/Nm³. Mercury was measured in and out of the system. The following results were achieved:

Inlet μgHg/Nm ³ at 5% O ₂	Outlet μgHg/Nm ³ at 5% O ₂	% Removal
5.4	0.14	97
5.2	0.18	97
5.0	0.20	96
4.7	0.18	96

Average removal with this system is 96%.

The above process was modified by adding activated carbon through conduit 14 to the stream of flue gas in duct 4 upstream of the drying chamber. Mercury was measured in and out of the system.

The following results were achieved:

Amount of carbon mg/Nm ³	Inlet μgHg/Nm ³ at 5% O ₂	Outlet μgHg/Nm ³ at 5% O ₂	% Removal
8	4.0	0.10	98
8	4.4	<0.01	>99.8
36	6.2	0.01	99.8
36	5.6	<0.01	>99.7

Felsvang finds in Example 4 that HCl alone provided 96-97% mercury removal, while the addition of activated carbon provided 98-99.8% mercury removal, an improvement of only 1-3.8%. In contrast, Felsvang's Comparative Examples 1-3, performed with no added HCl or Cl⁻ in the flue gas and no activated carbon, had a mercury removal of 1-37%. The activated carbon in Example 4 provided scarcely any improvement, with the vast majority of mercury removal improvement occurring in the presence of HCl alone without activated carbon. An improvement of 1-3.8% does not demonstrate a synergistic effect between HCl and activated carbon, especially in view of the 60-96% improvement in mercury removal achieved by HCl alone when Example 4 is compared to Comparative Examples 1-3. One of ordinary skill in the art would know that such a small

improvement could have been caused by variability in combustion gas conditions and the accuracy of the measurements—evidence for any improvement from the use of activated carbon with the HCl in Felsvang is very weak and may not have occurred at all.

In addition, Felsvang fails to describe or suggest that in-flight promotion of activated carbon with HCl or Cl⁻ in the flue gas provides better mercury removal than treatment of activated carbon outside the flue gas with HCl. If one of ordinary skill in the art were hypothetically considering whether to use Felsvang's HCl or Cl⁻ treatment of activated carbon in the flue gas or Nelson's treatment of activated carbon outside the flue gas to remove mercury, that person would pick the process that results in the best mercury removal. As an initial matter, before considering modifying either one of the references, the person of ordinary skill would notice the extremely poor improvement (if any improvement actually occurred) caused by addition of activated carbon in Felsvang's sole Example showing the use of activated carbon (Example 4) and would question whether Felsvang's process is an efficient way to use activated carbon for mercury removal as compared to Nelson's process. If one of ordinary skill in the art were to investigate Felsvang's embodiments including activated carbon and compare the relative mercury-removal ability to that of activated carbon treated with HCl outside the flue gas, as shown herein at **I(D)**, they would find that treatment of activated carbon outside the flue gas with HCl as per Nelson's process actually provides more effective mercury removal per wt% HCl than treatment of activated carbon with HCl or Cl⁻ in the flue gas, which would lead one of ordinary skill in the art away from using Felsvang's process in the first place.

Therefore, a person of ordinary skill in the art hypothetically having Felsvang and Nelson in-hand would not select the Felsvang process to follow or modify and therefore would not be motivated to combine Felsvang and Nelson as alleged. Independent claims 27, 54, and 55 are patentable over Felsvang and Nelson for this additional reason.

I(A)(2)(d). Nelson provides no motivation to replace Felsvang's HCl or Cl⁻ treatment with Nelson's HBr treatment.

For a person of ordinary skill in the art to be motivated to replace Felsvang's HCl- or Cl⁻-treatment with treatment by another material to provide an effective activated carbon sorbent for mercury removal, that person would need to think that the material they are using to replace the HCl

or Cl^- would result in the same or better mercury-removal efficiency. However, as explained below, Nelson fails to describe or suggest that treatment of activated carbon with HBr provides the same, let alone better, mercury removal efficiency as activated carbon treated with HCl or Cl^- .

At paragraph [0017], Nelson states:

[0017] The particular advantages of using bromine, rather than iodine or iodides, or chlorine or chlorides, with activated carbons for mercury control have not been previously appreciated. Gaseous bromine and hydrogen bromide have been combined with carbon substrates before, but not to sequester mercury from hot combustion-gas streams. For example, Greinke U.S. Pat. No. 5,372,619 found that bromine-treated carbon can make a superior natural-gas storage medium. In another example, SKC Inc. sells a small tube with hydrobromic acid-treated charcoal to sample air for ethylene oxide. However, with both of these uses it is important that the adsorption targets, natural gas and ethylene oxide, be easily desorbable from the carbon, the exact opposite of what is required in a mercury vapor sequestration application. In a similar vein, in U.S. Pat. No. 6,475,461 Ohsaki describes a process for treating carbon substrates with gaseous bromine or chlorine, but then explicitly desorbs them to achieve his desired product. Seki U.S. Pat. No. 3,961,020; Yoshida and Seki et al. U.S. Pat. No. 4,174,373; and Knoblauch et al. U.S. Pat. No. 5,179,058 impregnate activated carbon with bromine to produce a catalyst for reacting nitrogen oxide with ammonia to form nitrogen and water. In this application too, the bromine of the carbon does not act as a sequestration agent, permanently tying up its target. Rather, it serves as a catalyst, taking part in a repeated series of desired chemical reactions, but not becoming permanently consumed by any of them. Perhaps it is understandable that the tenacity of carbon-bromine-mercury complexes could be overlooked.

The first sentence of paragraph [0017] refers to the "...particular advantages of using bromine..." for treatment of activated carbons for mercury control, which must mean either elemental bromine (Br_2) or the element bromine generally, and is not a specific reference to bromides (Br^-). The "...particular advantages of using bromine..." is compared to iodine (I_2),

iodides (I^-), chlorine (Cl_2), and chlorides (Cl^-), but no specific comparison is made between bromides (Br^-) and chlorides (Cl^-). However, it does not make sense for Nelson to refer to the element bromine generally while specifically distinguishing between chlorine (Cl_2) and chlorides (Cl^-), and iodine (I_2) and iodides (I^-) in the same sentence. If Nelson wanted to compare both elemental bromine (Br_2) and hydrogen bromide (HBr) to the other halides specifically disclosed in the first sentence, Nelson would have specifically distinguished between bromine (Br_2) and bromides (Br^-); therefore, "...bromine..." in the first sentence of paragraph [0017] would be interpreted as elemental bromine (Br_2), and not as the element bromine generally.

No "...particular advantages of using bromine..." are explicitly described in paragraph [0017], with the remainder of the paragraph focusing on the failure of the prior art to use bromine with activated carbon for mercury control, describing various disadvantages of other processes, such as the desorbability of Br_2 , HBr , or Cl_2 from the activated carbon, or the failure of the Br_2 or HBr to act as a mercury sequestration agent. The paragraph concludes with a statement that it is understandable that "...the tenacity of carbon-bromine-mercury complexes..." could be overlooked, which must refer to complexes including either elemental bromine (Br_2) or the element bromine generally, with no specific reference to bromide (Br^-) or complexes formed therefrom. The concluding statement of paragraph [0017] is directed toward the discussion in the bulk of paragraph [0017]—the prior art fails to use bromine with activated carbon for mercury control and therefore fails to generate carbon-bromine-mercury complexes—rather than as a statement of any relative advantage of bromine over other halogens or halides. The "...tenacity of carbon-bromine-mercury complexes..." is not specifically compared to the strength of any other complexes, such as carbon-chlorine-mercury complexes, carbon-chloride-mercury complexes, carbon-iodine-mercury complexes, or carbon-iodide-mercury complexes; therefore, at best, the "...tenacity..." of the complexes described in the last sentence of paragraph [0017] can be regarded as a general statement, rather than as a comparative one. Paragraph [0017] fails to attribute any advantage of Nelson's invention specifically to HBr or Br^- , and, moreover, fails to describe or suggest that HBr or Br^- treatment of activated carbon could provide equal, let alone better, mercury removal than HCl or Cl^- treatment of the activated carbon.

At paragraphs [0019]-[0022], Nelson states:

[0019] Accordingly, it is an object of the present invention to provide a sorbent material that can be injected into a hot mercury-containing combustion gas, so that a significant portion of the mercury is adsorbed onto the sorbent and removed from the flue gas with the combustion fly ash.

[0020] Further, it is an object of the present invention to provide a flexible, retrofittable mercury-control method that can be applied to a number of combustion gas streams and a wide range of exhaust system equipment configurations.

[0021] In addition, it is an object of the present invention to provide a mercury sorbent material that is simple and inexpensive to manufacture and use.

[0022] It is also an object of the present invention to provide a mercury sorbent material that causes the adsorbed gas-phase mercury to become essentially permanently-sequestered from future interactions with the environment.

Paragraphs [0019]-[0022] describe several general advantages of Nelson's activated carbon treatment, including the ability to remove mercury from a hot mercury-containing combustion gas, a flexible and retrofittable method that can be applied to a wide range of equipment configurations, simplicity and ease of use, and permanent sequestration of the mercury from environmental interactions. None of the advantages include equal or greater mercury-removal ability of HBr- or Br⁻-treated activated carbon as compared to HCl- or Cl⁻-treated activated carbon.

At paragraphs [0023]-[0024], similarly to what is stated in the Abstract and paragraphs [0028]-[0029], Nelson states:

The mercury sorbent is prepared by treating a carbonaceous substrate with an effective amount of a bromine-containing gas for a sufficient time to increase the ability of the carbonaceous substrate to adsorb mercury and mercury-containing compounds.

[0024] In some aspects of the invention, the bromine-containing gas comprises at least one of: elemental bromine and hydrogen bromide. In some aspects of the invention, the carbonaceous substrate comprises activated carbon.

Nelson therefore states that elemental bromine (Br_2) or hydrogen bromide (HBr) can be used to treat an activated carbon outside of a flue gas to increase the ability of the activated carbon to absorb mercury.

At paragraph [0041], Nelson states:

[0041] I have discovered that the simple act of exposing a carbonaceous material, preferably powdered activated carbon (PAC), to gaseous bromine, $\text{Br}_2(\text{g})$, or to gaseous hydrogen bromide, $\text{HBr}(\text{g})$, significantly increases the carbonaceous material's ability to remove mercury species when injected into high-temperature coal-fired flue-gas compositions. Surprisingly, gaseous bromine produces a much more effective and appropriate carbon sorbent for mercury in hot combustion gases than do iodine or iodide species, or chlorine or chloride species, in contrast to what has been taught in the prior art.

Paragraph [0041] begins by stating that gaseous bromine (defined as Br_2) or hydrogen bromide (HBr) increases the mercury absorption capacity of activated carbon. Then, paragraph [0041] goes on to explicitly state that gaseous bromine, defined as Br_2 in the prior sentence, produces a more effective mercury-absorbing carbon sorbent than iodine (I_2), iodide (I^-), chlorine (Cl_2), or chloride (Cl^-). With the precise definitions given for gaseous bromine and hydrogen bromide, and then reference only to gaseous bromine in the next sentence, Nelson makes clear that the comparison of efficacy is only with respect to elemental bromine (Br_2) and not hydrogen bromide. Like paragraph [0017], paragraph [0041] also fails to describe or suggest that hydrogen bromide treatment of activated carbons is more effective for mercury removal than HCl or Cl^- treatment of activated carbons.

At paragraph [0042], Nelson states:

[0042] The combination of carbon and gaseous bromine produces an inexpensive sorbent material that can be simply injected into the ductwork of a power plant ahead of an existing electrostatic precipitator, without the need for large volumes of sorbent, retrofitted flue-gas cooling, or extended sorption time on an additional fabric filter.

Paragraph [0042]'s reference to "gaseous bromine" refers only to elemental bromine (Br_2) due to the explicit definition given in the preceding paragraph [0041]. Paragraph [0042] expands on the advantage mentioned at paragraphs [0020]-[0021], stating that an advantage of the invention includes simple injection of the treated activated carbon sorbent into the ductwork ahead of an ESP, without the need for large volumes of sorbent, retrofitted flue-gas cooling, or extended sorption time on a filter.

At paragraph [0043], Nelson states:

[0043] While not intending to be limited by hypothesized chemistry, it appears that in exposing PAC to concentrated bromine gas, a relatively large quantity of the bromine reacts with the carbon, forming surface compounds on the large surface-area of the carbon. When the PAC is then injected into the flue gas, the elemental mercury and oxidized mercury species there appear to react with at least one form of the bromine-carbon surface compounds that were created and are held fast. When the carbon particles are removed from the flue gas along with the fly ash by the electrostatic precipitator (ESP) or fabric filter, the mercury is removed with them. The mercury sorbents are then disposed of with the fly ash. Because the mercury has been chemically adsorbed, rather than just physically adsorbed, the captured mercury appears to be very stable and does not revolatilize or leach.

Paragraph [0043] expands on the general advantage described in paragraph [0022] of permanent sequestration of the mercury from environmental interactions. The advantage is not described or suggested to include equal or greater mercury-removal ability of HBr - or Br^- -treated activated carbon as compared to HCl - or Cl^- -treated activated carbon.

At paragraph [0044], Nelson states:

[0044] Production of the new mercury sorbent materials is simple and inexpensive. The carbon material and the bromine gas need simply be contacted with each other for the advantageous mercury-reactive surface compounds to quickly form. Elemental bromine is a liquid at ambient temperature, but turns to a gas at only a modestly elevated temperature. Hydrogen bromide is a gas at even ambient temperature. Using a gas-phase carbon reactant considerably simplifies the production of the sorbent and leads to the low costs which are a requirement for a sorbent to be used as a once-through duct injectant. Any common mixing method and equipment can be used to contact the gaseous bromine species with the carbon-based substrates, although it is preferably lined with corrosion-resistant material, because the bromine species can be quite corrosive. It is also preferable that the mixing of bromine gas and carbon be done at an elevated temperature. This keeps the bromine gas in the gaseous form, but also minimizes the amount of any bromine physically-adsorbed into the pores of the carbon. Such physically adsorbed bromine is not chemically bound to the carbon lattice and can be emitted in handling, in storage, and especially, when the sorbent is injected into a hot flue gas.

Paragraph [0044] expands on the general advantage described in paragraph [0021] of simple and inexpensive generation and use of the treated activated carbon sorbent. Paragraph [0044] also describes that elevated temperature during treatment can provide an advantage of reduced physical-adsorption of the elemental bromine or the hydrogen bromide, which helps to avoid emission during handling, storage, and during injection into a hot flue gas. The advantages are not described or suggested to include equal or greater mercury-removal ability of HBr- or Br⁻-treated activated carbon as compared to HCl- or Cl⁻-treated activated carbon.

At paragraph [0047], Nelson states:

the process. An example would be a powdered activated carbon (PAC). Such a material would already have some gas-phase mercury adsorption capability which the treatment process of this invention will greatly amplify.

Nelson therefore states that the treatment process therein amplifies the mercury absorption capabilities of activated carbon. The advantage is not described or suggested to include equal or

greater mercury-removal ability of HBr- or Br⁻-treated activated carbon as compared to HCl- or Cl⁻-treated activated carbon.

At paragraph [0049], Nelson states:

[0049] A critical element in the process is that a bromine-containing gas 3 is used to treat the carbonaceous substrate. Preferably this gas comprises elemental bromine, Br₂(g), although other bromine-containing gases, such as hydrogen bromide, HBr, will also have the advantageous effect of the invention.

Nelson therefore states that elemental bromine (Br₂) or hydrogen bromide (HBr) gas can be used to treat an activated carbon outside of a flue gas. Nelson also states that use HBr to treat the activated carbon "...will also have the advantageous effect of the invention." Nelson uses the singular "...effect..." and does not state that HBr can have all of the advantageous effects of Br₂ described therein; however, which particular advantageous effect does Nelson refer to? Further, Nelson refers generally to the advantageous effect of "...the advantageous effect of the invention..." but does not state that HBr can have all the advantageous effects of elemental bromine (Br₂); rather, Nelson states that HBr, like Br₂, can have "...the advantageous effect of the invention." By "...advantageous effect of the invention..." Nelson refers to general advantages of "...the invention..." and not specifically to advantages of Br₂; therefore, advantages specifically attributed to Br₂ in Nelson would not be imputed to HBr by the last sentence of paragraph [0049].

Nelson describes several general advantages at paragraph [0019]-[0022] that are not attributed specifically to Br₂ and that could be referred to by paragraph [0049]'s general reference to "...the advantageous effect of the invention...", such as the ability to remove mercury from a hot mercury-containing combustion gas (expanded on at paragraph [0047]), a flexible and retrofittable method that can be applied to a wide range of equipment configurations (expanded on at paragraph [0042]), simplicity and ease of use (expanded on at paragraphs [0042] and [0044]), and permanent sequestration of the mercury from environmental interactions (expanded on at paragraph [0043]). Paragraphs [0044] and [0053] also describe that elevated temperature during treatment can provide an advantage of reduced physical-adsorption of the elemental bromine or the hydrogen bromide, which helps to avoid emission during handling, storage, and during injection into a hot flue gas. Paragraph [0062] states that mercury sorbents prepared according to Nelson's invention can capture