VIROFLOW™ TECHNOLOGY POWER PLANT WASTEWATER TREATMENT

TECHNICAL PAPER

View of Cooling Towers.

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INTRODUCTION

The process of generating electricity can produce a variety of wastewater types that have the potential to release pollutants into surface waters, such as rivers, streams and lakes, when discharged. These wastewaters can originate from the following power plant processes:

- Blowdown from flue gas desulfurisation;
- Once-through cooling water;
- Cooling tower blowdown;
- Boiler blowdown;
- Metal and boiler cleaning waste, and;
- De-mineraliser regenerants.

The purpose of this Technical Paper is to present a general overview of water consumption and wastewater generation in standard power plant operations and to introduce Virotec Global Solutions' unique ViroFlow™ Technology, using the safe and environmentally friendly ElectroBind™ reagent, to effectively and efficiently treat heavy metals contaminated flue gas desulfurisation (FGD) blowdown wastewater, which is generated from power plants throughout the world. This Technical Paper also provides four case study examples of applications of ViroFlow™ Technology in USA and Australia; three projects are related to treating FGD blowdown water and one independent study related to the treatment of actual flue gas.

BACKGROUND

Currently, fossil fuel-based power plants consume vast quantities of water for a range of purposes, including fuel (i.e., coal) preparation, power augmentation, emissions control and so-called "cycle makeup" purposes. At the same time, significant quantities of locally-sourced water are becoming more difficult to procure as water consumption outstrips the pace of renewal at many power plants.

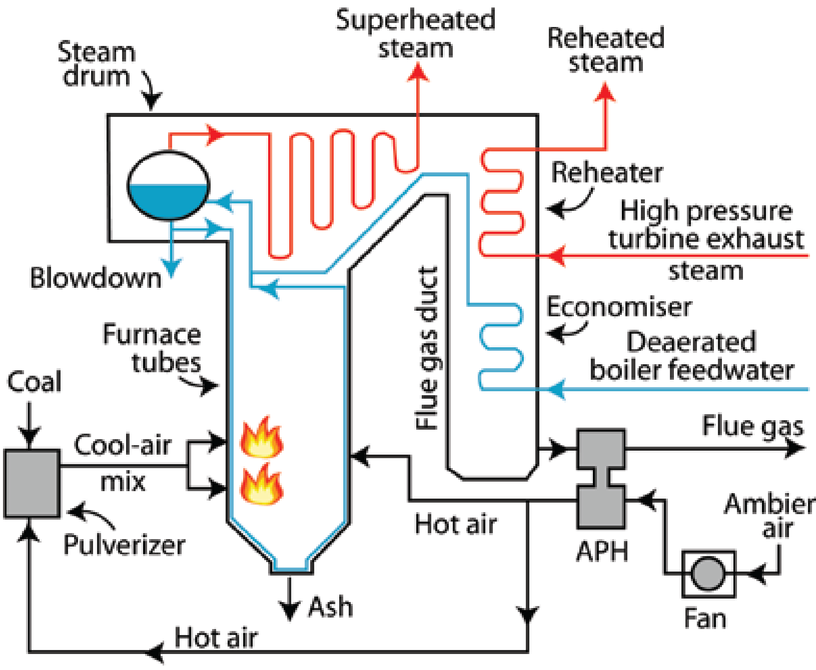
A conventional coal-fired power plant produces electricity by burning coal in a steam generator that heats water to produce high pressure and high temperature steam. The steam flows through a series of steam turbines, which spin an electrical generator to produce electricity. The exhaust steam from the turbines is cooled, condensed back into water, and returned to the steam generator to start the process over.

For most coal-fired power plants, coal is prepared for use by first crushing the delivered coal into pieces less than 5 cm in size. The crushed coal is then transported from the storage yard to inplant storage silos by conveyor belts. In plants that burn pulverized coal, coal from the storage silos is fed into pulverisers that grind the crushed coal into a fine powder and mix it with primary combustion air, which transports the pulverized coal to the steam generator furnace.

A 500 MW coal-fired power plant will have, for example, about six pulverisers, five of which will supply the steam generator at full load with about 225 metric tons of coal per hour. In plants that do not burn pulverised coal, the crushed coal may be directly fed into cyclone burners, a specific kind of combustor that can efficiently burn larger pieces of coal. In plants fuelled with slurried coal, the slurry is fed directly to the pulverisers and then mixed with air and fed to the steam generator. The slurry wastewater is separated and removed during pulverizing of the coal.

The feedwater used in a steam generator consists of recirculated condensate water and so-called "make-up" water. Because the metallic materials it comes into contact with are subject to corrosion at high temperatures and pressures, the make-up water is highly purified in a system of water softeners and ion exchange de-mineralisers. The make-up water in a 500 MW plant, for example, amounts to about 75 litres per minute, which is used to offset the losses from steam leaks in the system and blowdown from the steam drum.

The condensate and feedwater system begins with the water condensate being pumped out of the low pressure turbine exhaust steam condenser (commonly referred to as a "surface condenser"). The condensate water flowrate in a 500 MW coal-fired power plant is about 23,000 litres per minute.



Note: APH is the air preheater

Figure 1: Simplified diagram of a conventional coal-fired steam generator.

The feedwater, plus make-up water, flows through feedwater heaters heated with steam extracted from the steam turbines. Typically, the total feedwater also flows through a de-aerator that removes dissolved air from the water, further purifying and reducing its corrosivity. In the de-aerator, water may be dosed with hydrazine, a chemical that scavenges the remaining oxygen in the water to below 5.0 parts per billion (ppb); it is also dosed with pH control agents such as ammonia or morpholine to keep the residual acidity low and thus non-corrosive.

A coal-fired electrical plant

As shown in Figure 1, a conventional coal-fired steam generator is a rectangular furnace about 15 metres wide and 40 metres tall. Its walls are made of insulated steel with a web of high pressure steel boiler tubes attached to the inner surface of the walls. The de-aerated boiler feedwater enters the economiser where it is preheated by the hot combustion flue gases and then flows into the boiler steam drum at the top of the furnace. Water from that drum circulates through the boiler tubes in the furnace walls using the density difference between water in the steam drum and the steam-water mixture in the boiler tubes.

Pulverised coal is air-blown into the furnace from fuel nozzles at the four corners and it rapidly burns, forming a large fireball at the centre. The thermal radiation of the fireball heats the water that circulates through the boiler tubes mounted on the furnace walls. As the water circulates, it absorbs heat and partially changes into steam at about 362 °C and at a pressure of 190 bar (19 MPa). In the boiler steam drum, the steam is separated from the circulating water. The steam then flows through superheat tubes that hang in the hottest part of the combustion flue gases path as it exits the furnace. Here the steam is superheated to about 40 °C before being routed into the high pressure steam turbine.

The staged series of steam turbines includes a high pressure turbine, an intermediate pressure turbine and two low pressure turbines. As steam moves through the system, it loses pressure and thermal energy and expands in volume, which requires increasing turbine diameter and longer turbine blades at each succeeding stage. The entire rotating mass may weigh over 180 metric tons and be 30 metres long. It is so heavy and the internal clearances are so close that it must be kept turning slowly at 3 rpm when shut down so that the shaft will not thermally bow even slightly and become bound.

Superheated steam from the steam generator flows through a control valve into the high pressure turbine. The control valve regulates the steam flow in accordance with the power output needed from the plant. The exhaust steam from the high pressure turbine returns to the steam generator's reheating tubes where it is reheated back to 540 °C before it flows into the intermediate pressure turbine. The exhaust steam from the intermediate pressure turbine flows directly into the two low pressure turbines and the exhaust steam from the low pressure turbines flows into the surface condenser. A small fraction of steam from the turbines is used to heat the de-aerator and/or the boiler feedwater pre-heater(s). The turbine-driven electrical generator contains a stationary stator and a spinning rotor. In operation, it generates up to 21,000 amperes at 24,000 volts of three-phase alternating current (about 500 MW).

The exhaust steam from the low pressure turbines is condensed into water in a water-cooled surface condenser. The condensed water is commonly referred to as condensate. The surface condenser operates at an absolute pressure of about 35 to 40 mmHg, which maximizes the overall power plant efficiency. The surface condenser is usually a shell and tube heat exchanger. Cooling water circulates through the tubes in the condenser's shell and the low pressure exhaust steam is cooled and condensed by flowing over the tubes as shown in the adjacent diagram.

Typically the cooling water causes the steam to condense at a temperature of about 35 °C. A lower condensing temperature results in a higher vacuum at the exhaust of the low pressure turbine and a higher overall plant efficiency. The limiting factor in providing a low condensing temperature is the temperature of the cooling water and that, in turn, is limited by the prevailing average climatic conditions at the power plant's location.

The condensate from the bottom of the surface condenser is pumped back to the de-aerator to be reused as feedwater. The heat absorbed by the circulating cooling water in the condenser tubes must also be removed to maintain a constant cooling water supply temperature. This is done by pumping the warm water from the condenser through either natural draft, forced draft or induced draft cooling towers (as seen in the images to the right) that reduce the temperature of the water by about 11-17 °C and expel the low-temperature waste heat to the atmosphere. The circulation flow rate of the cooling water in a 500 MW unit is about 14.2 m3/s (225,000 US gallons per minute) at full load.

Some older power plants use river water or lake water as cooling water. In these installations, the water is filtered to remove debris and aquatic life from the water before it passes through the condenser tubes.

The condenser tubes may become internally fouled during operation by bacteria or algae in the cooling water or by mineral scaling, all of which inhibit heat transfer and reduce the condenser efficiency. In an enclosed system, the cooling water can be treated with biocidal chemicals to inhibit growth of bacteria and algae and with other chemicals to inhibit scaling. Many plants include an automatic cleaning system that circulates sponge rubber balls through the tubes to scrub them clean without the need to take the system off-line. Hot water flushes may also be used to thermally shock aquatic life build-up on the inner walls of the condenser tubes.

Aerial view of a coal-fired plant.

The cooling water used to condense the steam in the condenser returns to its source without having been changed other than having been warmed. If the water returns to a local water body (rather than a circulating cooling tower), it is mixed with cool raw water to lower its temperature and prevent thermal shock to aquatic biota when discharged into that body of water.

WATER CONSUMPTION

The electricity industry is second only to agriculture as the largest domestic user of water, accounting for 39% of all freshwater withdrawals in the nation, of which 71% is used in fossil fuelbased electricity generation. Power plants have to compete with other industrial customers, agricultural interests, and households for this limited commodity. The availability of water for use in electric power generation is limited in many parts of the United States and is an important factor in obtaining site permits for new plant construction. Difficulty or the inability to obtain necessary water permits can lead to delayed or abandoned projects. Also, it is often the case that additional infrastructure is required to provide a suitable supply, adding cost and environmental impact. In areas that do not have an adequate water source, power plant construction is not even considered, even though these locations are ideal in other respects.

To offset the observed escalating consumption rates of water, new systems have been devised that can recover a substantial portion of the water vapour present in a flue gas stream. The water recovered by this system is of a quality similar to that of a reverse osmosis (RO) system outlet. This water can be used for various plant needs or can receive minimal treatment so it can be used as direct cycle makeup.

Power plants burning fossil fuels have in the past been designed to generate electricity at the least cost under circumstances of abundant coal and natural gas resources and adequate supplies of water for plant cooling. Future power plant design will increasingly need to be designed and operated to conserve both fuel and water. Water is becoming scarce and expensive in many parts of the United States including California, where there is already a strong economic incentive to reduce the net cooling water requirements of power plant cooling steams, turbine condensers and scrubbing stack gases.

FLUE GAS DESULFURISATION

A detailed explanation of flue gas desulfurisation (FGD) systems and the current methods for treating FGD have been outlined by Elliot and Hertenstein (2007).

Some plants have introduced so-called "flue gas water recovery" projects, which are designed to recover water from combustion flue gases in order to reduce the net water requirements of power plants burning fossil fuels.

The decrease in allowable emission levels for sulfur dioxide from power plants has sparked an interest in flue gas desulfurisation systems, or scrubbers. Although water requirements for scrubbing are a fraction of those needed for cooling purposes, FGD units require a significant amount of water to produce and handle the various process streams (including, limestone slurrying and scrubber sludge handling and treatment). The make-up water requirements for the FGD process at a 550 MW, subcritical coal-fired power plant are about 570 gallons/minute (or 2,600 litres per minutes) versus about 9,500 gpm for cooling water make-up.

Flue gas scrubbing can be accomplished with either dry or wet systems. Wet scrubbers entrain the flue gas in a water spray, capturing sulfur dioxide and other pollutants, which are then removed by creating an alkaline slurry using lime. Dry scrubbing injects the alkaline particles directly into the flue gas stream, obviating the need for water, but the more limited contact between reactants in the absence of water results in lower pollutant removal efficiencies.

Arsenic (As), selenium (Se) and mercury (Hg) in the flue gas exists as both elemental and oxidized vapour as well as either heavy metal that has reacted with the fly ash. The removal of the fly ash removes the heavy metal that has reacted with the fly ash, resulting in 10-30% removal for bituminous coals but less than 10% for sub-bituminous coals and lignite. The oxidized heavy metal vapour left in the flue gas after the fly ash removal is effectively removed by wet FGD scrubbing, resulting in 40-60% total heavy metal removal for bituminous coals but less than 30-40% total heavy metals removal for sub-bituminous coals and lignite.

Faced with new evidence that utilities across the USA are dumping toxic sludge into waterways, the Environmental Protection Agency (EPA) is moving to impose new restrictions on the level of contaminants power plants can discharge. Plants in Florida, Pennsylvania and several other states have flushed wastewater with levels of selenium and other toxins that far exceed the EPA's freshwater and saltwater standards aimed at protecting aquatic life, according to data the agency has collected over the past few years.

While selenium can be beneficial in tiny amounts, elevated levels damage not only fish but also birds and people who consume contaminated fish. But the reason more selenium and metals such as arsenic are now entering U.S. waterways is because the federal government has pressed utilities to install pollution-control "scrubbing" technology that captures contaminants headed for smokestacks and stores them as coal ash or sludge. The EPA estimates that these two types of coal combustion residue often kept in outdoor pools or flushed into nearby rivers and streams amount to roughly 130,000 tons per year and will climb to an estimated 175,000 tons per year by 2015.

The federal government is focused on selenium in fish tissue because, as with arsenic and mercury, contamination accumulates rapidly in the animals' bodies and becomes more potent. Consumption of contaminated fish can trigger a range of effects in birds and humans. Birds that eat seleniumcontaminated fish experience effects such as deformation of their beaks and jaws and problems producing viable eggs, while humans can suffer neurological damage as well as hair and nail loss.

However, one of the most dangerous toxins generated from power plants is mercury. In addition to mercury being present in the wastewater from the FGD blowdown process, mercury from coalfired power plants is released into the air through the exhaust system when coal is burned. The primary exposure for humans occurs when vaporous mercury falls to the earth and runs into our lakes, rivers, and streams and contaminates the fishes. Humans can be contaminated when they eat these fish and shellfish. In 2004, 47 states and territories had fish consumption advisories for mercury for at least some of their waters.

Mercury is a developmental toxin, primarily affecting fetal development. In unborn children, it can cause brain damage, mental retardation, blindness, and many other problems. Infants are also exposed to these dangers through contaminated breast milk. While the dangers of mercury are most often associated with women and children, eating fish high in mercury has also been found to put middle-aged men at a greater risk for coronary heart disease.

VIROFLOW™ TECHNOLOGY CASE STUDIES

Virotec Global Solutions has applied its ViroFLow™ Technology to the treatment of both flue gas scrubbing and FGD blowdown water at several power plants in North America and Australia. The names and technical details of these power plants are commercially sensitive and confidential, however, Virotec is able to report the results observed from such applications.

CASE STUDY 1: FLUE GAS SCRUBBING, CALIFORNIA, USA

In 2003, a study of the possible use of ElectroBind™ reagent to treat flue gasses was initiated by the stack emissions gas treatment testing facility of the U.S. EPA Office of Research and Development, to determine whether ElectroBind reagent could remove potentially acid forming gasses (e.g., sulphur dioxide), mercury vapour and/or any other volatile contaminants.

The study began as an investigation of the possible use of ElectroBind™ reagent to prevent the escape of potentially acid-forming gasses. The results showed that while ElectroBind™ reagent was not entirely successful in treating acid-forming gasses in FGD, it did simultaneously remove substantial quantities of mercury vapour, which was not an outcome that could be achieved by alternative treatments used to remove potentially acid forming gasses. Initial results of this study are presented in Table 1.

TABLE 1: MERCURY REMOVAL FROM FLUE GASSES USING ELECTROBIND™ REAGENT

Temperature (°C)	Mercury Removed (µg/L)	Mercury Removal (%)	Mercury Captured (µg/L)	Mercury Captured (%)	Mercury Oxidised (%)
40	58.6	97.0	25.4	42.1	54.9
80	35.2	58.2	25.0	41.4	16.7
140	50.8	84.1	12.4	20.6	63.5

The analytical equipment used in this study only measures vapour phase elemental mercury but misses any mercury that has been oxidized to the Hg^{2}+ state (likely as $HgCl_2$). However, because the facility knows the amount of mercury injected into the FGD-ElectroBind™[v] vapour chamber, the amount of elemental mercury which comes out of the chamber and the amount and percentage captured, the facility can determine the exact amount of mercury oxidized by difference; the Hg mass balance will therefore be: Hg(total in) = Hg(elemental out) + Hg(captured) + Hg(ionic out).

As a result, it is now possible to use the expression “Hg removal” rather than “Hg capture” or “Hg adsorption”, because solids analyses indicate that both the binding/capturing of heavy metals in gasses as well as the catalytic oxidation of heavy metals in gasses are taking place as a result of the injection of ElectroBind™ into FGD gasses.

The U.S. EPA Office of Research and Development noted that the 40°C case is special because they had to remove water but, using ElectroBind™ reagent, they were able to remove 97% of the mercury (42% by the adsorption of elemental mercury onto the solids and 55% oxidized). At 80°C they had about 60% removal with only 17% due to oxidation, whereas at 140°C the removal efficiency had risen to 84% and about 64% of this removal involved oxidation.

These observations led the U.S. EPA Office of Research and Development to conclude that there must be two competing mercury removal mechanisms involved in the removal and binding process when ElectroBind™ was used; a) physisorption that is more favourable at lower temperatures, and b) catalysed oxidation of Hg (elemental) to Hg^{2+}, which is favoured at higher temperatures.

CASE STUDY 2: FLUE GAS DESULFURISATION BLOWDOWN WATER, SOUTH CAROLINA, USA

At a power plant in South Carolina, ViroFlow™ Technology was applied to FGD blowdown wastewater. The primary focus of the application was to treat the arsenic (As) contamination in the FGD blowdown wastewater, as is the case with most power plants in the U.S.

The wastewater discharge from the power plant had the following discharge limits imposed by the EPA:

TABLE 2: TREATMENT TARGETS FOR CONTAMINANTS IN SOUTH CAROLINA POWER PLANT FGD BLOWDOWN WASTEWATER (ALL MEASURES IN UG/L).

Parameter	Treatment Target
As	1.0
Cr	1.0
Fe	1.5

Retention lagoon.

TABLE 3: UNTREATED AND TREATED SOUTH CAROLINA POWER PLANT WASTEWATER TREATMENT RESULTS USING VIROFLOW™ TECHNOLOGY (ALL MEASURES IN UG/L).

Parameter	As	Cr	Fe
Untreated FGD Blowdown Wastewater	200	5.16	21.60
FGD Blowdown Wasterwater After ViroFlow™ Technology Treatment #1	0.25	0.44	6.29
FGD Blowdown Wasterwater After ViroFlow™ Technology Treatment #1	0.31	0.54	6.60

From the data presented in Table 3, it can be seen that treatments #1 and #2 met all discharge limits for treated FGD blowdown wastewater prior to discharge into the nearby river.

CASE STUDY 3: FLUE GAS DESULFURISATION BLOWDOWN WATER, NORTH CAROLINA, USA

At a power plant in North Carolina, ViroFlow™ Technology was applied to FGD blowdown wastewater. The plant had to meet stringent treatment targets, as presented in Table 4.

TABLE 4: TREATMENT TARGET FOR CONTAMINANTS IN NORTH CAROLINA POWER PLANT FGD BLOWDOWN WASTEWATER (ALL MEASURES IN UG/L).

Parameter	Treatment Target
pH	7.0-8.0
Ag	0.06
As	10
Cd	2.0
Cu	7.0
Hg	0.01
Pb	25
Sb	5.6
Se	5.0
Tl	0.24
Zn	50

The power plant had extremely stringent controls for Se, because the levels of Se in the coal used at the plant were extremely high and because the EPA had identified that Se toxicity was a potential problem in the wetlands where the FGD blowdown wastewater was being discharged. Specifically, the EPA had identified that Se toxicology in minnows (small indigenous fish) whose habitat in the adjacent wetlands was a potential downstream pollution threat.

Waste Rock Drum Trials at Gilt Edge Mine, USA

TABLE 5: UNTREATED AND TREATED NORTH CAROLINA POWER PLANT WASTEWATER TREATMENT RESULTS USING VIROFLOW™ TECHNOLOGY (ALL MEASURES IN UG/L; BDL = BELOW DETECTION LIMITS).

Parameter	Untreated Sample	ViroFlow™ Technology Treatment #1	ViroFlow™ Technology Treatment #2	ViroFlow™ Technology Treatment #3
pH	7.0	7.2	7.4	7.2
Ag	BDL	BDL	BDL	BDL
As	130	BDL	87	BDL
Cd	2.0	BDL	1.0	BDL
Cu	23	BDL	7.0	BDL
Hg	9.0	BDL	BDL	BDL
Pb	159	BDL	BDL	BDL
Sb	8.3	BDL	5.2	BDL
Se	1,6998	690	1,235	85
Tl	1.9	BDL	0.7	BDL
Zn	42	BDL	13	BDL

While the current treatment did not meet the strict requirements for Se treatment, the primary contaminant of concern was As, as is the case with most power plants in the U.S. Arsenic levels prior to treatment with ViroFlow™ Technology were 130 μg/L, which for treatments #1 and #2 were reduced to below detection limits.

CASE STUDY 4: FLUE GAS DESULFURISATION BLOWDOWN WATER, QUEENSLAND, AUSTRALIA

Power plants in Australia also generate FGD wastewater and Virotec has been commissioned to conduct preliminary work on treating the wastewater using ViroFlow™ Technology.

The targets for such treatments are shown in Table 6.

TABLE 6: TREATMENT TARGET FOR CONTAMINANTS IN QUEENSLAND POWER PLANT FGD BLOWDOWN WASTEWATER (ALL MEASURES IN MG/L).

Parameter	Treatment Target
pH	7.0-9.0
Al	0.08
Cd	0.0004
Cu	0.0018
Fe	No limit
Ni	0.0013
Zn	0.015
TSS	200
SO_4	1,000

TABLE 7: UNTREATED AND TREATED AUSTRALIAN POWER PLANT WASTEWATER TREATMENT RESULTS USING VIROFLOW™ TECHNOLOGY (ALL MEASURES IN MG/L; BDL = BELOW DETECTION LIMITS).

Parameter	Untreated Sample	ViroFlow™ Technology Treatment #1	ViroFlow™ Technology Treatment #2	ViroFlow™ Technology Treatment #3
pH	7.2	7.9	9.6	8.9
Al	0.3	BDL	BDL	0.1
Cd	0.05	BDL	BDL	BDL
Cu	<0.005	BDL	BDL	BDL
Fe	0.04	BDL	BDL	BDL
Ni	0.02	BDL	BDL	BDL
Zn	0.04	BDL	BDL	BDL
TSS	374	265	180	13
SO_4	1,273	-	-	937

As can be seen in Table 7, the three different treatments of ViroFlow™ Technology to FGD blowdown wastewater in Australia were effective in treating all heavy metals, while treatments #2 and #3 were effective in treating TSS and SO4 to the required limits prior to discharge into the nearby river.

CONCLUSION

The process of generating electricity can generate a variety of waste wastes that include cooling and process waters that have the potential to release pollutants into surface waters when discharged. These wastewaters can originate from the following power plant processes:

- Blowdown from flue gas desulfurisation;
- Once-through cooling water;
- Cooling tower blowdown;
- Boiler blowdown;
- Metal and boiler cleaning waste, and;
- De-mineraliser regenerants.

This Technical Paper has shown that Virotec's patented ViroFlow™ Technology has proven to be extremely useful in treating flue gas desulfurisation at the scrubbing stage as well as the treatment of blowdown wastewater in a number of power plants in North America and Australia.

The Technology is easy to install and simple to implement, is easy to operate and does not require the handling or application of hazardous chemicals, and is an environmentally safe and effective way to treat heavy metal contaminated flue gas blowdown wastewater.

REFERENCES

Elliot, P & Hartenstein, H. (2007). Selective separation of mercury and other heavy metals during FGD wastewater treatment, paper presented to 2007 APC Round Table and Expo, Chattanooga, TN, July 8010, 2007.

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