



ReACT™

(Isogo #1 and #2)

Regenerative Activated Coke Technology with No Water Consumption

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*H. James Peters
Hamon Research-Cottrell, Inc., Somerville, NJ
james.peters@hamonusa.com*

Abstract

Many issues face coal fired utilities with respect to environmental demands, some based on current and future regulations and others based on local pressures. These include increasingly stringent control of criteria pollutants, anticipated federal and state requirements for mercury and HAP control, plume visibility, disposal issues and future climate change considerations..

For western utilities water use issues play an especially prominent role.

The J-Power/Isogo repowering project replaced two vintage coal fired units, and within the same site limits, more than doubled generation capacity to 2x600MW with ultrasupercritical boilers fitted with SCR, ESPs, and advanced generation ReACT™ technology. The controls provide exceptionally low emissions from the high efficiency coal fired boiler plant, which ranks Isogo as the cleanest coal fired power plant in the world in terms of emissions intensity. Emissions levels at Isogo are at levels equivalent to natural gas fired power plants.

Regenerative Activated Coke Technology (ReACT™) is an integrated multi-pollutant control approach provides SO_x, NO_x, and Hg adsorption on activated coke with regeneration of the activated coke sorbent and has 1% of the water use of conventional WFGD.

ReACT™, which is both mature (having origins in German technology in the 1960s) and fully commercial on coal fired utilities (to 600MW scale in Japan), is available in the United States through a recent license agreement between J-Power Entech and Hamon Research-Cottrell.



J-Power Isogo

Japan’s Electric Power Development Corporation (EPDC) first negotiated pollution control permits for their 2x265MW Isogo power station with the city of Yokohama City in 1964.

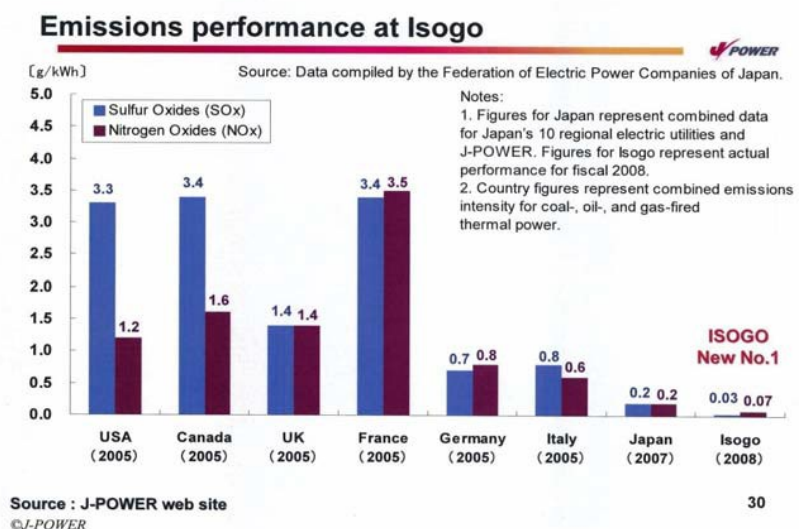
EPDC launched a number of initiatives to protect the environment, including installing the first WFGD system in Japan. After more than 30 years operation, EPDC (now J-Power) committed to replace the Isogo Thermal Power Station and negotiated with the city of Yokohama for a major repowering project, which would more than double the generation capacity at the site together with more stringent environmental controls.

J-Power’s new 2x600MW Isogo Power Station burns low-sulfur coal and incorporate high efficiency ultrasupercritical boilers, combustion NOx control, primary SCR, ESPs and ReACT™.

After more than 8 years' of operating experience at Isogo Unit #1 ReACT has achieved consistently more than 98% SO2 and 20 to 40% NOx removal efficiency (in addition to NOx control in the upstream SCR) and >>90% mercury removal. On the basis of the Isogo #1 performance, J-Power agreed to a more stringent permit level for the second unit which began commercial operation in mid 2009.

The Isogo plant has been recognized for world class performer with emissions intensity levels for SOx and NOx that are the lowest worldwide for coal fired power. Isogo typically operates in the single digit ppm concentration range for SO2 and NOx (against Unit 2 permit levels of 10ppm and

13 ppm), particulate at less than 5 mg/Nm3 (0.005 lb/mmBTU) and with well over 90% control of both elemental and oxidized forms of mercury.





The basic process concept originated with Bergbau Forschung in Germany the 1950s, saw additional development by Foster Wheeler in the 1970s in conjunction with their Resox process, and commercialization with activated coke by Mitsui Mining in the 1980s, and subsequent full commercialization by Electric Power Development Company (now J-Power) as an advanced generation multipollutant control technology for coal fired boilers.

Process development efforts in the late 1970's focused on high efficiency (98%) SO₂ removal efficiency but it was quickly recognized that ReACT also provided NO_x removal as well. The ReACT process design for SO₂ control routinely removes 20-40% NO_x as a co-benefit, and with additional NH₃ injection can be configured to achieve 50-70% NO_x removal or higher..

J-Power (EPDC) began development of ReACT as an alternative to WFGD. The key initial consideration was water requirements. In many cases, EPDC had faced serious difficulties in obtaining water from local government water agencies. In the case of the Isogo repowering at increased generation capacity increased water use was to be avoided if possible.

J-Power, subsequently fully acquired the technology from Mitsui in 2005, and in addition to their three full scale units at Takehara (1995), Isogo #1(2002) and Isogo #2 (2009), has provided units for refinery, incineration, and sinter plant applications through its subsidiary J-Power EnTech.

Since commercial operation began in 2002 at Isogo#1 and 2009 at Isogo #2 both units have shown remarkably high environmental performance. From SO₂ inlet concentration of 200-400 ppm, stack SO₂ concentration at stack outlet is typically less than 5 ppm, with SO_x removal efficiency was over 98 %. Since SCR was installed upstream as the primary control, ReACT provided an additional 20-40% NO_x control as a co-benefit to reduce NO_x concentrations to <10 ppm at the stack.

The ReACT™ process has also been successfully demonstrated for U.S. coal applications in an EPRI project hosted by Sierra Pacific Power at its North Valmy Station.

Valmy results were reported by (Dene et al, MEGA Symposium 2008) at 97.6-99.9% SO₂ removal, 25.7-48% NO_x removal, 97.1-99.6% Hg removal. The expected high levels of SO₂, NO_x, and Hg performance were readily demonstrated, consistent with commercial results at the full scale units in Japan.

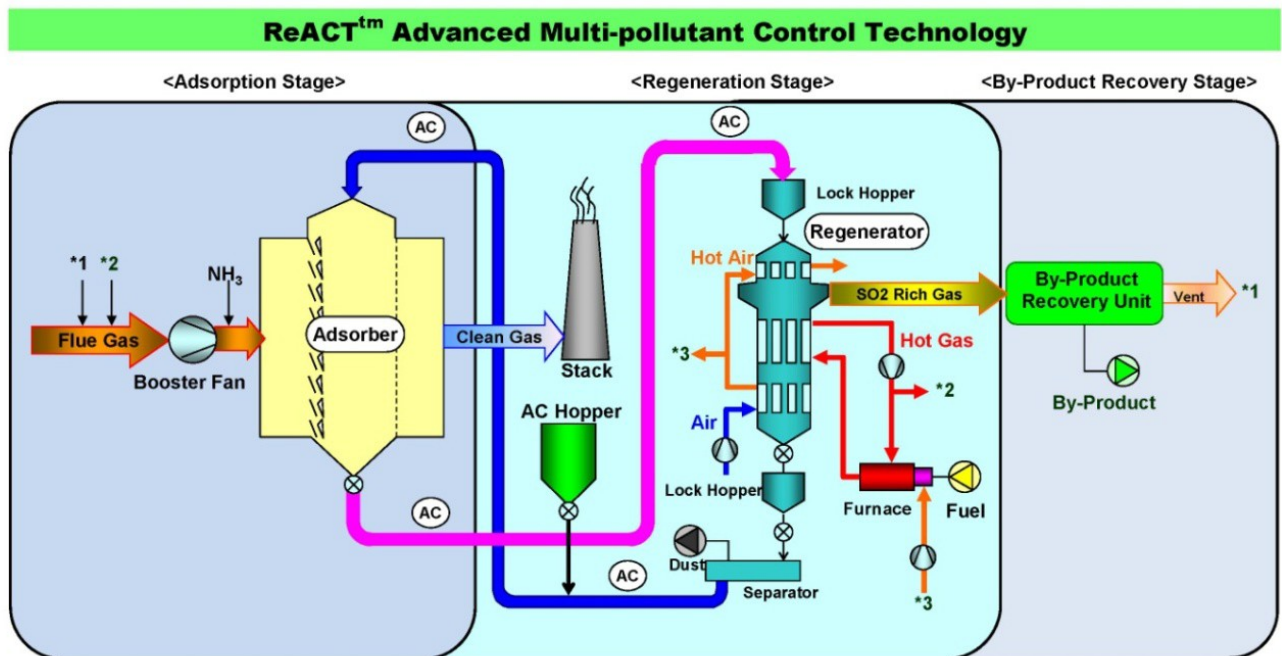
ReACT™ Process Description

The multi-pollutant control ReACT™ technology is a completely dry scrubbing system based on adsorption of SO₂, SO₃, and Hg and reduction of NO_x to N₂ on activated coke in a moving bed.

ReACT™ involves three process stages. Downstream of primary particulate control which may be an existing ESP or FF, flue gas is contacted with a slowly moving bed of activated coke fed to the top of a cross flow adsorber. Activated coke removes SO₂, SO₃, NO_x, Hg and other species through adsorption, chemisorption and catalytic reactions which are enhanced in the presence of ammonia. Particulate is also reduced across the moving bed by impaction on the coke pellets.

Pollutant laden activated coke is transferred to a thermal regeneration stage, where reactions are completed and pollutants are desorbed as a sulfur rich gas stream. The regenerated activated coke stream is cooled and fines are separated before return to the adsorber. Make-up coke in pellet form is added to replace the separated fines.

The third stage receives the sulfur rich gas stream for saleable byproduct production.



The ReACT™ process offers several benefits for utility applications, including:

- Adsorption does not consume water or lose water to waste disposal streams.
- Adsorption performance improves with lower back end flue gas temperatures.
- No steam or SO₃ plume further addresses visibility issues.
- Regeneration of sorbent greatly reduces site logistics for reagent make-up, processing and waste handling compared with other FGD processes.
- Marketable byproduct is produced.
- Primary particulate is upstream (existing), preserving beneficial use of ash.
- Mercury control is obtained at >>90% levels for both elemental and oxidized forms.
- Mercury laden disposal streams are minimized.
- Power consumption is approximately 60% of WFGD



Comparison of FGD technologies

The following table illustrates comparative water and reagent use for a nominal 250MW unit.

| Nominal 250 MW plant burning PRB | 600,000 scfm 7000 hours/year | Wet FGD | Dry FGD and CDS | ReACT |
|---|---|--|---|---|
| Stack condition | | Saturated 126F Heavy water plume | 30F approach 156F Medium water plume | Flue gas 320F No plume |
| Evaporative water consumption | gal/1000 scfm | 0.46 (115,000,000 gpy) | 0.36 (90,000,000 gpy) | 0 |
| Ash | 5.5% Ash 15,500 lb/hr flyash | 15500 lb/hr in upstream FF or ESP | 15000 lb/hr in downstream FF | 15500 lb/hr in upstream ESP |
| SO ₂ | 0.5% S 8800 BTU/lb 2750 lb/hr SO ₂ | 95% control | 85-95% control | >95% SO ₂ control and >>95% SO ₃ control 20-50% NO _x control 95% Hg control |
| Reagent preparation | | Wet grinding | Slaking | Thermal Regeneration |
| Reagent usage | | 1:1 mol:mol Ca:S removed 14500 tpy CaCO ₃ | 1.5 mol:mol Ca:S at inlet 14000 tpy CaO | Activated carbon AC make up 3000 tpy |
| Disposal | | Dewatering, impoundment, gypsum 70% solids (4,000,000 gpy) | Calcium salts mixed with flyash 2% H ₂ O residual | Fines separation ~0.4 tph Dust is wetted |

Other water use – such as cooling water for mechanical and process equipment are not considered in the table above.

Note that ReACT activated coke fines separated after regeneration are suitable for reuse as an activated carbon sorbent or may be combusted for fuel values.



Activated coke

The ReACT™ process uses activated coke in pellet form.

This material generally compares with powdered activated carbon as follows:

| | Activated Coke | Activated Carbon |
|-------------------------------------|--|---------------------------|
| Shape/Diameter | Tablet/Almond ~10 mm | Powdered |
| Specific Surface Area | 150-300 m ² /g | >1000 m ² /g |
| SO ₂ adsorption capacity | 60-120 mg/g | |
| Pore size | 10-1000 A | 10-100 A |
| Pore volume | 0.05-0.1 cc/g | 0.5-0.6 cc/g |
| Roga-Index (abrasion resistance) | 95% | 70-85% (for tablet forms) |
| Raw Material | Coal | Coal |
| Application | SO _x , NO _x , Hg removal | Hg removal |



In ReACT, granular activated coke is repeatedly recycled between the adsorption tower and the regeneration tower. The size of activated coke is gradually reduced over time from mechanical wear. Fines are separated prior to return to the adsorber. In addition, reactions in the regenerator use some carbon. Make-up activated coke replaces these losses. Operating results show that activated coke supply rate is less than 1.5% of circulating rate of activated coke according to design.

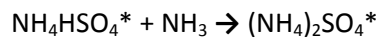
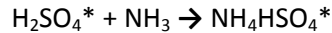
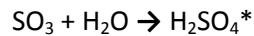
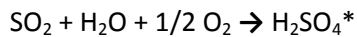
Since fines removal and other carbon losses are offset by make-up the size distribution of the activated carbon in the system reaches a stable long term distribution.



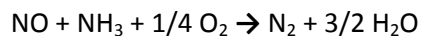
SO_x, NO_x and Hg control

The ReACT™ adsorber can be designed for 98% SO₂ control levels. Normalized gas space velocity of 300-500 hr⁻¹ and activated coke residence time of 80-120 hr are typical. Ammonia is injected into the upstream flue gas at 0.5 mol NH₃ to mol SO₂. Contacting conditions in the adsorber provide 10 seconds for the flue gas to transit the high surface area available in the moving activated coke bed.

SO₂ and SO₃ are adsorbed at high efficiency on the activated coke surfaces as sulfuric acid ammonium sulfate and ammonium bisulfate. (* denotes adsorbed species).



The catalytic effect of activated carbon also leads to reduction reactions to reduce NO_x in the presence of ammonia.



where C..R represents a surface functional site

Activated coke has a different characteristic compared to other catalysts which tend to deteriorate over time with activity loss due to aging, fouling, and contamination. Instead, the performance of the activated coke increases over time. Activity is improved thorough regeneration which exposes fresh surface and micropores through carbon reactions and increases the number of functional groups on the catalyst surface from residual sulfur, oxygen and nitrogen species.

Mercury control level in ReACT also occurs as a co-benefit from the SO₂ based adsorber design. In the ReACT adsorber, the total carbon surface area in contact with flue gas and contacting time greatly exceeds that of activated carbon injection methods practiced with ESP or FF and both elemental and oxidized forms of mercury are readily captured.

Several measurements of mercury concentration at Isogo indicate that mercury is less than 1 microgram/Nm³ as measured with Ontario Hydro Method. This represents >>90% control at Isogo. Similar tests at Valmy reported Hg control well above 95%.

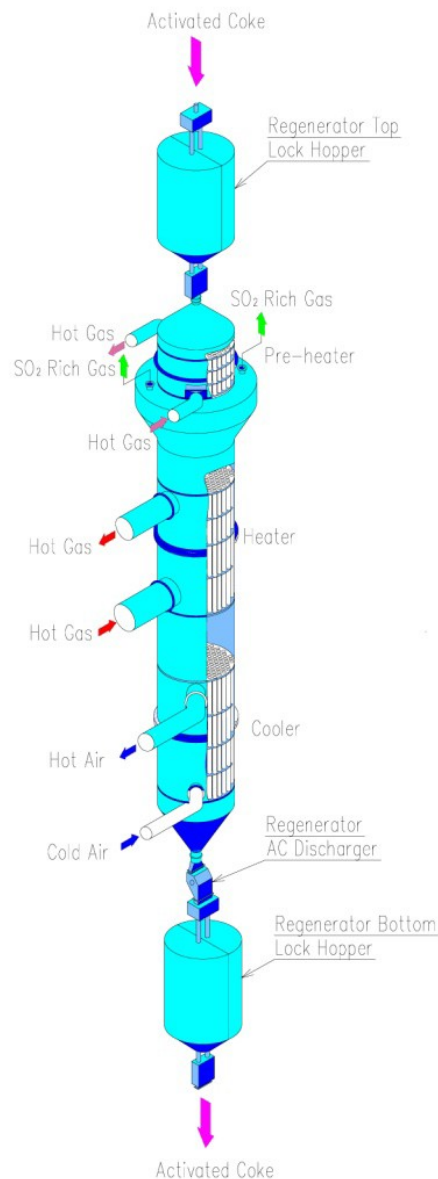
ReACT also provides significant waste volume minimization for Hg laden disposal materials.



ReACT™ Activated Coke Regeneration

Following is a schematic of a typical ReACT regenerator which thermally desorbs sulfur rich gases and prepares activated coke for return to the adsorption stage.

Activated coke at flue gas temperatures carrying adsorbed SO₂, NO_x and Hg is fed through a lock hopper to the top of the regenerator. Activated coke moves downward by gravity flow through three indirect heat exchanger sections for preheating, heating, and cooling the regenerated coke which is then discharged through a lock hopper to fines separation and then returned to the adsorber.



Non-isothermal kinetics related to thermal regeneration are illustrated for the Bergbau Forschung process in the following figure excerpted from Reference 1. The kinetics show that the thermal desorption is driven to completion by heating the activated coke to 450C.

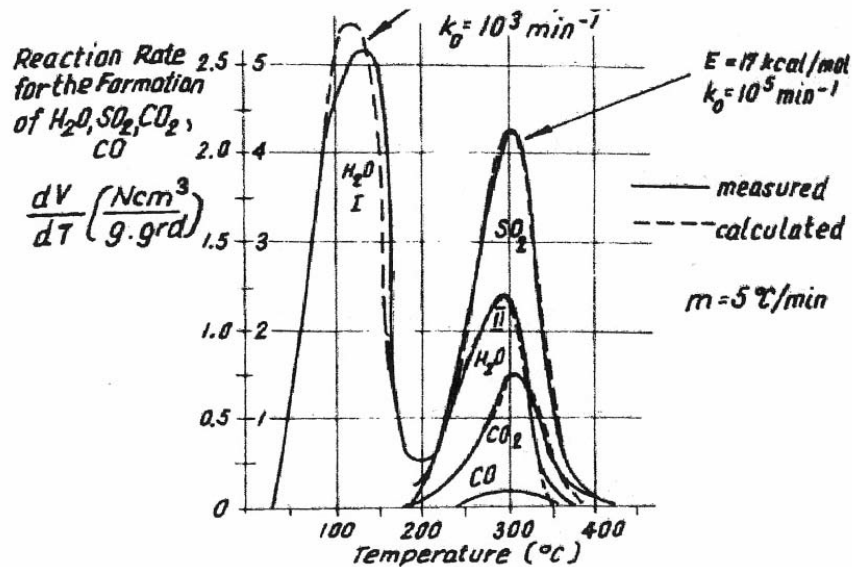
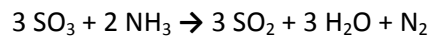
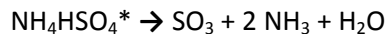


Figure 2. Nonisothermal kinetics of thermal regeneration

The design of the heat exchanger control of the shell side heating and cooling air temperatures and flows provide the required temperature and residence time profile to completely desorb gases which are generated by chemical reactions in the regenerator which decompose the adsorbed sulfur species.

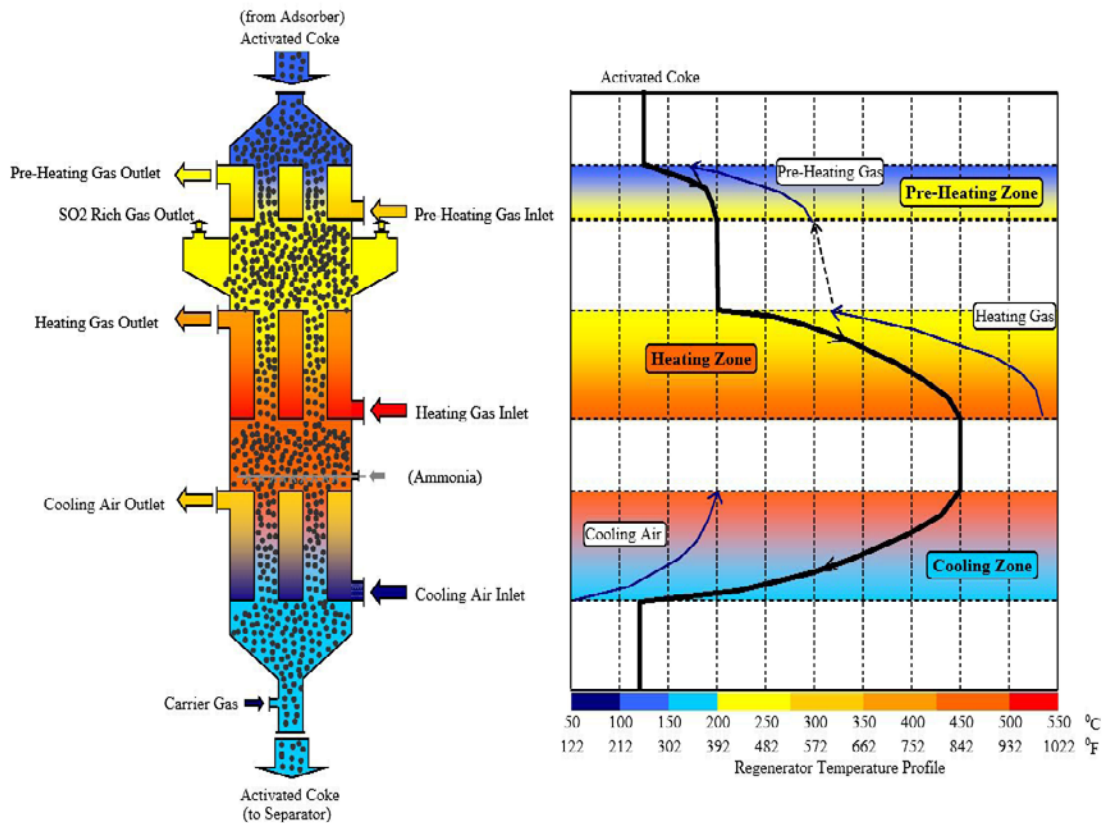


A sulfur rich gas release zone is located between the pre-heat and heating sections of the regenerator tower. The sulfur rich gas released (SO₂, N₂, CO₂, and H₂O) flows to an acid plant for production of marketable sulfuric acid.

Prior to cooling the activated coke to flue gas temperature for return to the adsorber stage, ammonia gas can be introduced to pre-condition the activated coke and provide increased NO_x control.

Mercury retention in the regenerator

In the ReACT regenerator temperature profiles and retention time at 450C allows the regeneration process for the sulfur compounds to complete in accordance with the kinetic requirements.



Mercury compounds are also thermally desorbed at >400C to the vapor phase. This temperature is reached within the heating zone and mercury desorption is complete at the bottom of the heating zone.

Mercury and other desorbed gases flow upward and counter-current to the activated coke flow and contact lower temperature coke surfaces. At the top of the heating zone, the activated coke at 200C has effectively re-adsorbed all the mercury vapors.

The mercury is effectively confined in this zone of the regenerator. Since the capacity of activated coke for mercury adsorption is quite high, the Isogo plant extracts only 100tons of AC during planned outages on 2 to 3 year intervals, or <0.1 ton/ per MW per year. Disposal is managed during a scheduled regenerator downtime (all activated coke has been cooled) by diverting the portion of activated coke that had been in the heating zone and lower SRG zone.

Mercury in the sulfuric acid byproduct at Isogo is reported at below detection limits.



Carbon make up and disposal

A comparison of the carbon make-up and disposal requirements for a typical 250 MW plant using ReACT compared to typical ACI injection for Hg control illustrates a significant point related to Hg-laden material disposal.

| | |
|----------------|--|
| Basis: | 250 MW PC boiler burning low-sulfur PRB, 75% capacity factor |
| Firing rate: | 2800 MMBTU/hr (at 11,000 BTU/kWh) |
| Flue gas flow: | ~1,000,000 acfm @ 300F |
| Flyash load: | 2 to 3 gr/acf (55,000 tons/year @ 2 gr/acf) |
| Hg load: | 5 to 10 lb/10 ¹² TBTU |

For the ReACT™ process, fresh make up activated coke replaces losses due to fines separation after regeneration and carbon consumed in regenerator reactions. Make-up for a 250MW plant is approximately 1250 tons/year (4 to 6 tons/year per MW). This mercury-free material can be burned for fuel value or may have beneficial re-use as a carbon sorbent at other sites.

For a regenerator serving a typical 250 MW coal fired boiler, the activated coke from the mercury capture zone in the regenerator is about 30 tons, and with a disposal interval of two-three years, the disposal rate would be less than 15 tons/year (<0.1 ton/MW-year).

For typical activated carbon systems, 90% mercury control requires injection of powdered activated carbon (PAC) into the flue gas at rates between 2 lb/MMacfm and 10 lb/MMacfm. The higher rates are generally associated with injection is upstream of an electrostatic precipitator, and lower rates with injection upstream of a fabric filter. Injection rates have some sensitivity to fuel type, boiler type and effects of increased SO₃ from upstream SCR.

When powdered activated carbon is injected upstream of the primary particulate control, whether it be an ESP or a fabric filter, the flyash is then contaminated with mercury laden carbon which may render otherwise saleable flyash for cement or road material into landfill waste or pose future questions as to waste disposal.

If activated carbon is injected into a secondary fabric filter placed downstream of an ESP (which may be powered back to control the PAC/ash mixture at the FF to about 10% carbon, activated carbon usage can be minimized and flyash beneficial use maintained but with additional equipment and energy requirements.



Mercury laden material for disposal

The comparison shows a dramatic reduction in the volume of Hg contaminated waste for the regenerated activated coke process and into a form where off-site recovery of metallic mercury from the activated coke is also possible, eliminating re-introduction of mercury to the environment.

| | | | | |
|--|---|--------------------------------|--------------------------------------|---|
| Basis | 250 MW, 1,000,000 acfm @ 320F, 75% capacity factor, >90% Hg control | | | |
| | Powdered Activated Carbon (PAC) | | | Activated Coke ReACT™ |
| | ESP | Primary FF | Secondary FF added downstream of ESP | Removal on two year cycle |
| Hg removed assuming coal @ 10 lb Hg/1012 BTU | 160 lb/year | 160 lb/year | 160 lb/year | >160 lb/year |
| PAC injection rate | 10 lb/106acfm | 5 lb/106acfm | 3 lb/106acfm | --- |
| Make-up carbon | 2000 ton/year activated carbon | 1000 ton/year activated carbon | 600 ton/year activated carbon | 1,250 ton/year activated coke |
| Disposal – not Hg laden | 0 | 0 | 50,000 tons/year as ash sales | 1,250 ton/year 80% coke fines, 20% flyash 41,000 ton/year as ash sales |
| Hg-laden disposal | 58,000 tons/year | 57,000 tons/year | 6,000 tons/year | 30 tons every two years |



I-Power Isogo

The Isogo repowering project which replaced 2x265 MW conventional PC boilers and pollution control (ESP, WFGD) with 2x600MW ultrasupercritical boilers and advanced pollution control represents a world class solution for clean coal. Sited in Yokohama harbor, the plant design also considered aesthetics in terms of plant appearance, including visibility at the stack.

The emissions performance cited is on a par with natural gas fired facilities and the project and the technology incorporated should be of interest for U.S. energy planning at many levels.





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