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Process Optimization Guidance (POG and iPOG) for Mercury **Emissions** Control

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ABSTRACT: This paper introduces two new tools to quickly identify and assess a broad range of Hg emissions controls for utility gas cleaning systems worldwide. The Process Optimization Guidance (POG) document summarizes the available options for mercury control at most coal-fired power plants, covering everything from efficiency improvements and fuel switching through co-benefit effects (maximizing Hg capture in existing pollution control systems) to Hg-specific sorbent and oxidation technologies. The POG includes a "decision tree" concept that helps the reader determine the potential compliance strategies for particular coal-fired gas cleaning systems. The Interactive Process Optimization Guidance (iPOG) is a user-friendly software package that formalizes the "decision tree" concept in the POG document. It accurately estimates Hg removals and emissions rates for broad ranges of coal quality, the most common configurations for furnace firing and flue gas cleaning, and Hg controls, both inherent and external. Two case studies presented in this paper show its utility in addressing "What if...?" scenarios, in which the impact of adding Hg controls to existing cleaning systems can be quickly and conveniently evaluated. The iPOG supports compliance strategies based on coal cleaning and blending, stronger inherent Hg removal in new air pollution control units for NO_x and SO_x control, and dedicated external Hg controls, such as activated carbon injection (ACI) and halogen addition. This flexibility is compounded by minimal input data requirements and extremely fast execution times. This makes the iPOG useful for those who are new to the technicalities within the issue of Hg control, such as policy makers or even operators in developed countries or countries with economies in transition. Relative novices can "play" with the iPOG, selecting generic coals and simple plant design options, and then discover just how much simple changes in coal characteristics or plant operation may affect emissions. Being based on statistical regressions of an American Hg field test database and streamlined input data requirements, iPOG cannot possibly resolve differences among different Hg control strategies within the measurement uncertainties or depict the distinctive features of particular gas cleaning systems. Such limitations are especially pronounced whenever SO_3 adsorption interferes with Hg removal via ACI and also when distinctive selective catalytic reduction (SCR) design specifications strongly affect Hg⁰ oxidation along a SCR catalyst monolith. Whereas the Hg removals for such situations are accurately predicted by previously reported reaction mechanisms, they are beyond the current scope of iPOG. However, the iPOG is fully capable of estimating Hg emissions from a preferred control scenario ahead of expert analysis.

INTRODUCTION

In February 2009, the Governing Council of the United Nations Environment Programme (UNEP) agreed on the need to develop a global legally binding instrument on mercury. The negotiation of the text of the instrument, likely to be known as the Minamata Convention, is to be completed by 2013. To maximize the information available during negotiations, the Governing Council requested to "continue and enhance" the work of the UNEP Global Mercury Partnership. The partnership is regarded as one of the main mechanisms for the delivery of immediate actions on mercury during the negotiation of the global mercury convention.¹ The partnership currently has seven identified priorities for action (or partnership areas) that are reflective of the major source categories. One of these is the Coal Partnership. Because the behavior and control of mercury at coal-fired plants is complex, it is likely that developed countries and those with economies in transition will find it a significant challenge to act swiftly on mercury reduction strategies without expert guidance. In response to this, the Coal Partnership has produced the Process Optimization Guidance document, known as the POG. The POG summarizes practices capable of providing reduction of mercury emissions from coal-fired power plants. The POG is a tool to help determine the approaches to control mercury emissions for individual coal-fired power plants, allowing for a preliminary selection of a mercury control strategy. The Interactive Process Optimization Guidance (iPOG) has been developed to allow users to investigate mercury behavior in coal combustion by changing parameters in a specially designed interactive computer model.

Both the POG and the iPOG are distributed as free tools for interested parties to help determine the most appropriate technologies for mercury control from coal combustion systems on a case by case basis.

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Figure 1. "Decision tree" diagram detail: (A) "SNCR/no NO_x control" branch and (B) "SCR" branch.

POG

The POG is intended to help users (plant operators, governments, policy makers, and any other interested parties) in evaluating potential opportunities to achieve multi-pollutant emission reductions, such as SO_2 , NO_x , PM, and mercury emissions, including improved energy efficiency. The POG focuses on providing guidance on how to optimize plant performance and existing pollutant controls to achieve the cobenefits of reduced mercury emissions. However, the POG also includes information on mercury-specific control options, such as sorbent injection and oxidation strategies. The POG briefly

covers issues, such as mercury in ash and other residues, and how these should be handled. Because of the transient nature of such information and the rate at which the market is evolving, the POG does not include information of the costs of mercury control other than in a comparative manner (i.e., "high" versus "low" cost options).

To include specific experience in selected countries, workshops on the POG have been held in Russia, China, and South Africa and the document has been translated into Russian and Mandarin. The POG is available for free download from the UNEP Coal Partnership website.² As part of the POG, the "decision tree" concept was developed summarizing the decision processes used to determine the most appropriate methods of mercury control on a case-by-case/plant-by-plant basis depending upon the NO_{xy} PM, and SO_2 controls. This flow diagram is split into two in panels A and B of Figure 1 representing the branches with and without selective catalytic reduction (SCR).

The flow diagram is not diagnostic or prescriptive but rather aims to help the user focus on only those sections of the report that are relevant to their specific situation; i.e., those plants that already have SO_2 and NO_x control systems are recommended to concentrate on oxidant techniques, whereas those plants with more basic pollution control systems in place have potentially more options to consider, including fuel switching, upgrading pollution control systems, and combined multipollutant control technologies, in addition to oxidant- and sorbent-based systems.

IPOG

The iPOG is a user-friendly software package that formalizes the "decision tree" concept in the POG document. Although the iPOG is not designed to provide a prescriptive determination of which control option is most appropriate at any particular plant, it does estimate the performance for various Hg control strategies and thereby focuses the user on only those options that are most relevant. The iPOG estimates Hg emissions rates from full-scale utility gas cleaning systems fired with any coal or coal blend, given a few coal properties, the gas cleaning configuration, selected firing and gas cleaning conditions, and an assortment of Hg control technologies. All of the most common gas cleaning configurations are implemented, and users can assess Hg emissions reductions by coal pretreatment and blending, the co-benefits to Hg capture from existing pollution control equipment for NO_x, PM, and/or SO₂, and Hg-specific control technologies, such as halogen addition with or without activated carbon injection (ACI) with untreated or brominated sorbents. Licensed commercial Hg control technologies, such as TOXECON-I and TOXECON-II and bromine addition, can also be examined. In addition, users can input coal properties from any geographical location in ranks from lignite to anthracite, alone or in blends of up to three components. The most common configurations and Hg control options are implemented as default selections in the iPOG, so that entry-level users can easily navigate toward the results. Experienced users can analyze advanced control configurations with their own detailed specifications. The estimated Hg emissions are primarily based on engineering correlations of the Hg field test database from American utilities, supplemented with predictions from Niksa Energy Associates LLC's (NEA) detailed Hg transformation mechanisms, as explained later.

Because the simulations are cheap and fast, iPOG is a good tool to address "What if...?" questions regarding variations in fuel quality, cleaning configurations, operating conditions, and external Hg controls. The iPOG delivers quantitative answers to all of these types of questions in no more than a few seconds of execution time. The iPOG does not estimate the costs for the various compliance options. However, it nevertheless supports financial management strategies to minimize the costs of regulatory compliance by accurately estimating how much Hg can be removed for a broad range of inherent and external controls. When costs are associated with their Hg control scenarios, users will be in a position to identify the least cost control options at the levels of individual plants as well as regional utility operations.

SCOPE OF THE CALCULATION SEQUENCE

Any calculation sequence to forecast Hg emissions using the iPOG proceeds through an intuitive sequence of up to seven interactive windows that resemble the screens in the Integrated Environmental Control Model.³ The screens accept all required input specifications and present the estimated Hg speciation, the Hg collection efficiency for each air pollution control device (APCD), and the stack emissions. The gas cleaning configuration can be cold-side electrostatic precipitator (ESPc) only, fabric (or baghouse) filter (FF) only, hot-side electrostatic precipitator (ESPc) only, SCR + ESPc, SCR + FF, SCR + wet PM, ESPc + wet flue gas desulfurization (WFGD), SCR + ESPc + WFGD, SCR + wet PM + WFGD, spray dryer absorber (SDA) + FF, SDA + ESPc, and SCR + SDA + FF. ESPc and/or FF in series can be configured for ACI between two PM control devices (TOXECON-I) or within an ESPc (TOXECON-II).

The allowable types of Hg control are collected in Table 1 and compared to the options included in the POG decision tree, as

Table 1. Mercury Control Options in POG and iPOG

POG	iPOG
coal treatment	coal treatment
co-benefits for Hg oxidation/capture	co-benefits for Hg oxidation/capture
Hg ⁰ oxidation additives	Hg ⁰ oxidation additives
untreated ACI	untreated ACI
treated/enhanced ACI	treated/enhanced ACI
untreated non-carbon sorbents	
lime injection	
ESP tuning	
oxidants for wet PM	
WFGD additives	

follows: (a) Coal treatment covers the elimination of pyrite and its associated Hg via both washing and float-and-sink separations. (b) Cobenefits for Hg oxidation and capture include in-flight oxidation and sorption of elemental Hg (Hg⁰) and oxidized Hg (Hg²⁺) on suspended unburned carbon (UBC) along ductwork, Hg⁰ oxidation along SCR catalysts, collection of particulate Hg (HgP) on UBC in ESPs, oxidation of Hg⁰ and collection of HgP on FFs, and retention of Hg²⁺ in scrubbing solutions in WFGD (without Hg⁰ re-emission). These Hg transformations may occur in any of the supported gas cleaning configurations. (c) Hg oxidation additives cover sprays of bromides and chlorides on the coal feed, as well as in-duct injections of Cl and Br vapors. (d) ACI can be implemented with both untreated and brominated carbons upstream of the air preheater (APH) and any particulate control device (PCD) and also within an electrostatic precipitator (ESP).

POG covers the following options that are not supported in iPOG: (1) non-carbon Hg sorbents, such as amended silicates, (2) ACI with lime co-injection in SDAs, (3) lime injection downstream of SDAs, (4) additives to promote Hg⁰ oxidation in wet PMs and WFGDs, and (5) ESP tuning to enhance HgP capture. These controls cannot yet be supported in iPOG because the field test databases that cover broad ranges of fuel quality and cleaning configuration have not yet been reported. As more data on these approaches becomes available, they can be implemented.

Once a user specifies the cleaning configuration and Hg controls, if any, he or she then enters more detailed specifications on the cleaning conditions. Users new to Hg control technologies may use default specifications on coal rank and typical additive levels and ACI concentrations. Experienced users will enter the more detailed input specifications in Table 2. Single coals or coal blends with up to three blend components can be selected from any geographical location under any coal rank from lignite to anthracite. The listed coal

Table 2. Input Data Requirements

coal properties	rank, moisture, ash, S, HHV, Cl, Hg, and blend percentages
furnace conditions	rating, load, gross efficiency, firing configuration, loss-on- ignition (LOI), economizer $O_{2^{j}}$ and bottom ash (as a percentage of total ash)
gas cleaning configuration	flow diagram from the furnace exit to stack, including all APCDs and Hg controls
SCR	economizer NO concentration and NO reduction efficiency
ESP, FF, and wet PM	PM collection efficiency
WFGD and SDA	SO ₂ capture efficiency
sorbent injection	conventional or brominated sorbent, injection position, and concentration
agent injection	weight percentage halogen, injection position, and concentration

properties are used to estimate a flue gas composition. Under the best of circumstances, these properties should be reported for every day of Hg speciation measurements whenever iPOG estimates are compared to field test data. The iPOG covers the most common furnace firing configurations, including wall-, T-, and cyclone-fired furnaces. Stokeror grate-fired furnaces and fluidized-bed combustors are not supported.

Furnace conditions are also required to estimate a flue gas composition and also to determine a flue gas flow rate. Given a furnace rating, a load profile during the tests, a higher heating value (HHV) of the fuel, and an O_2 concentration at the economizer, the gas flow rate and composition may be estimated on the basis of a specified gross thermal efficiency, which has a default value of 32%. The partitioning of coal ash into bottom ash and fly ash is also important because LOI is expressed as a percentage of the retained fly ash only. A NO concentration at the economizer must be provided whenever a SCR is present, along with the NO reduction efficiency. Only the overall PM collection efficiency must be specified, and these generally exceed 98%. Similarly, only the overall SO₂ capture efficiency of a WFGD must be specified. For both ACI and halogen additions, a chemical composition and the injection rate and position must be

As seen in Figure 2, the calculation results comprise all Hg mass flows, Hg removals at all APCDs, and the Hg stack speciation and emissions for the selected gas cleaning and Hg control configuration. The mass flow rates of Hg in all input and exit streams appear along with the removals in individual APCDs along the gas cleaning system. For the test case shown in Figure 2 for chloride addition to the coal and ACI upstream of the ESPc, users can parametrically vary the halogen and/or sorbent loadings and change the injection locations in a series of case studies to identify the best performance from this Hg control configuration.

ESTIMATION ALGORITHMS

In the literature, Hg speciation and removal in utility gas cleaning systems have been estimated by statistical regressions of field test data, detailed chemical reaction mechanisms validated with field test data,⁴ or some combination of the two.⁵ Whereas the predictions from some chemical reaction mechanisms are generally accurate to within the measurement uncertainties,⁴ reaction mechanisms must be supported by very thorough descriptions of the APCDs and cleaning conditions. Some of this information is proprietary, and some is not readily available, even to plant operators. Because the iPOG was designed to be used by non-technical policy analysts as well as emissions control specialists, the input requirements were kept to an absolute minimum, to deliver meaningful estimates for representative plant configurations rather than plant-specific predictions. This choice precludes any calculation sequence based on reaction mechanisms; therefore, the estimation algorithms in the iPOG are a series of APCD-specific regressions.

The database underlying the regressions was compiled primarily from the phase I and II U.S. Department of Energy (DOE)/National Energy Technology Laboratory (NETL) Mercury Control Technology Field Testing Program.⁶ Phase



Figure 2. iPOG screenshot showing Hg emissions estimates for an ESPc only system with Cl addition and untreated ACI.

I characterized inherent Hg capture by testing at plants firing bituminous coals with SCRs and/or flue gas desulfurization (FGD) units in addition to ESPc. Phase II emphasized low-rank coals with ESPc only cleaning configurations supplemented by ACI.

Efforts in the past to describe Hg transformation and capture using statistical regressions based on the Information Collection Request (ICR) database of the U.S. Environmental Protection Agency (EPA) yielded poor quantitative performance.⁷⁻¹⁰ These regressions are not statistically significant,⁸ except for systems with SDAs, because of errors and omissions in the ICR database and inadequacies in the regression functions, among many other reasons.

We developed regressions to circumvent the two primary flaws in previous applications, which are (1) inherent discrepancies among measured values because of random variations in the gas cleaning conditions and (2) no database covers the entire range of coal quality and cleaning conditions for every gas cleaning configuration and Hg control option. To address these issues, we first qualified the reported Hg speciation components and Hg removals for consistency within $\pm 15\%$ of the total Hg inventory across all sampling locations at each test site, as explained elsewhere.⁴ Only qualified test data were used in the regressions. Then, the field test database was supplemented with predictions from the MercuRator software of NEA to bridge any major gaps in coal quality and cleaning conditions for each of the subject APCDs. MercuRator predictions were previously validated with the entire phase I and II NETL database within the measurement uncertainties, as well as with numerous other data sets from various utility companies. Formal evaluations with over 150 tests have already been reported.^{4,11,12} On the basis of the satisfactory quantitative performance, we used MercuRator predictions to fill the gaps in the available measurements, particularly for wet PM and ACI into ESPh. The qualified database was then streamlined to exclude measurements and predictions that represent atypical APCD temperatures, flue gas residence times, etc., to minimize the impact of such unregulated variations.

The primary variables in the statistical regressions were selected to account for the most important parameters in the reaction mechanisms in MercuRator. They are the flue gas halogen concentration (Cl or Br), fly ash LOI, fly ash loading in the flue gas, specific surface area of the UBC, and ACI concentration. Product terms of the flue gas halogen level with the fly ash loading, UBC surface area, and ACI concentration were also included in applicable regressions. For systems with SCR, the NO concentration and the reduction efficiency were included. For systems with FGD, the regression variables were the fraction of Hg^{2+} estimated for the FGD inlet and the SO_2 capture efficiency. The correlation coefficients for the Hg removals in the different APCDs and for the extents of Hg⁰ oxidation across SCRs are presented in Table 3. For the three types of PCDs in the first three rows, the regressions account for variations in halogen levels because of both inherent coal Cl variations and the addition of external halogenation agents, along with fly ash loading, LOI, and UBC surface area. These correlation coefficients vary between 0.81 and 0.97. The comparable regressions for ACI into ESPc and FFs have coefficients from 0.83 to 0.93. The generally higher correlation coefficients for FFs versus ESPs suggests that random variations in the cleaning conditions are less consequential in FFs than in ESPs, probably because of the much greater contact areas between flue gas and the accumulated UBC in FF filter cakes.

Table 3. Correlation Coefficients for iPOG Estimates with the NETL Database

APCD	R^2
ESPc	0.83
FF	0.97
ESPh	0.81
ACI + ESPc	0.83
ACI + FF	0.93
SCR ^a	0.76
$WFGD^{b}$	0.83

^{*a*}Hg⁰ oxidation and not removal across the SCR. ^{*b*}WFGD Hg removal given the level of Hg²⁺ at the WFGD inlet.

Correlation coefficients for wet PM and ESPh with ACI addition are omitted because no qualified measurements for these units were available in the database; therefore, these regressions are entirely based on MercuRator predictions.

The regression for SCRs is for Hg⁰ oxidation and not Hg capture. It accounts for flue gas concentrations of NO and halogens, both Cl and Br, and the NO reduction efficiency across the SCR. The correlation coefficient for SCRs is 0.76, which is lower than the other control devices because Hg oxidation across SCRs also depends upon the monolith type, the channel shape and size, and the catalyst porosity distribution and formulation. Whereas these aspects of the SCR design have been quantitatively related to the Hg^0 oxidation performance,^{13,14} none of them factors into the iPOG estimates because they can be proprietary and are not readily available. Because Hg capture in WFGDs is primarily determined by the level of Hg^{2+} entering the system and many factors upstream of the WFGD affect the inlet Hg²⁺ level, we resolved WFGD retention, per se, by developing the WFGD regression from measured Hg^{2+} levels at the WFGD inlet. The correlation coefficient of 0.83 therefore represents the agreement between measured and predicted Hg capture in the WFGD alone, without contributions from uncertainties in Hg²⁺ predictions upstream of the WFGD. This regression also does not represent Hg⁰ re-emission from WFGDs, as occurs infrequently and intermittently in some full-scale WFGDs.¹⁵

COMPARISON OF IPOG ESTIMATES WITH FIELD TEST DATA

The iPOG was developed to provide indicative results for populations of gas cleaning systems that describe "typical" cleaning conditions rather than plant-specific values. The supported cleaning configurations can be broadly classified as PCD only, PCD + FGD, SCR + PCD, and SCR + PCD + FGD. Each configuration can also be supplemented with external Hg controls from coal pretreatment, halogen addition, and/or ACI. The two most important variables affecting inherent Hg capture, coal Cl and fly ash LOI, can also be varied across the complete domain of commercial operation. iPOG results for all of these variations are compared to selected field test data in Table 4. The tolerances reported for the predictions provide the bounds of predicted values for a particular test case but do not represent the statistical accuracy of the predictions.

Wherever possible, tests with halogen addition and/or ACI were included for each cleaning configuration to extend the inherent variations in coal Cl and LOI. By necessity, the measurements behind these ranges came from different plants, which admit into these comparison variations in several other factors because of inherent differences among plant design and

Table 4. Comparisons of Hg Removals from iPOG to Selected Field Test Data

coal	test label	furnace	HCl (ppmv)	LOI (wt %)	halogen (ppmw)	ACI (lb/MMacf)	measured (%)	iPOG estimate (%)
				E	SPc Only			
bit	EES3U14	Т	90	5.9			29.6	21.3 ± 3.2
bit	YAU2BL2	Т	19	9.0			31.8	38.6 ± 5.8
bit	YAU2252	Т	20	15.0		4.2	71.6	65.0 ± 9.8
sub-bit	EES1U25	cyclone	4	15.0			62.2	65.3 ± 9.8
sub-bit	PPU2BL2	Т	6	0.3			7.6	10.5 ± 1.6
sub-bit	PPU2L8	Т	6	0.3		4	56.8	47.8 ± 7.2
lig	MRYU2P3	cyclone	3	0.3	800 ^a		10.5	10.8 ± 1.6
lig	MRYU2P4	cyclone	3	0.3	800 ^a	0.5	16.2	16.4 ± 2.5
sub-bit	MEU2SE5	Т	5	1.5	190 ^b		51.6	9.5 ± 1.4
sub-bit	MEU2SE6	Т	5	1.5	190 ^b	2.9	69.3	41.8 ± 6.3
sub-bit	MEU2LH1	Т	5	1.9		3 ^c	94.8	95.0 ± 14.3
				ТО	XECON-I			
sub-bit	PIU789P03	wall	6	0.7		1.0	70.4	66.7 ± 10.0
sub-bit	PIU789P23	wall	6	0.7		2.0	92	80.7 ± 12.1
				TO	XECON-II			
sub-bit	INU2PHG3	Т	6	0.45		1.0	39	33.1 ± 5.0
sub-bit	INU2PHG5	Т	6	0.45		6.0	65	57.9 ± 8.7
				ESP	c + WFGD			
bit	CON4U12	wall	92	4.5			85.2	79.1 ± 11.9
blend	MOUBL3	wall	3	0.2			24.6	45.1 ± 6.8
blend	MOUCL1	wall	3	0.2	600 ^a		51.7	68.9 ± 10.3
lig	MRYU2P4	cyclone	3	0.3	800 ^a	0.5	45.4	38.6 ± 5.8
lig	MRYU2P8	cyclone	3	0.3	70^{b}	0.5	57.6	49.6 ± 7.4
				SC	R + ESPc			
bit	EES6U13	Т	85	3.5			1.7	16.4 ± 2.5
bit	EES8U13	Т	40	2			8.0	7.6 ± 1.1
sub-bit	MLRU4B4	wall	6	0.25			23.4	10.1 ± 1.5
sub-bit	MLRU4BR	wall	6	0.25	50 ^b		22.5	9.3 ± 1.4
				SCR + 1	ESPc + WFGD			
bit	EES2U21	wall	40	0.75			88.0	81.8 ± 12.3
bit	EES2U22	wall	130	0.85			88.9	88.4 ± 13.3
'CaCl ₂ . ^b C	CaBr ₂ . ^c Brominat	ed ACI.						

operation. Whereas these inadvertent variations can significantly affect Hg capture, they cannot affect the iPOG results. Consequently, the forthcoming comparisons to field test data are intended to demonstrate that the iPOG results can accurately depict the trends for variations in halogen levels, LOI, and ACI concentration, subject to the inevitable uncertainties that come into play whenever iPOG estimates are compared to the field test data from various plants.

The test cases for the ESPc only configuration cover lignite, sub-bituminous, and bituminous coals in T-fired and cyclone furnaces, with and without Cl/Br addition and with and without untreated and brominated ACI. The first three tests labeled EES3U14, YAU2BL2, and YAU2252 depict large variations in coal Cl, LOI, and ACI concentrations to cover the entire commercial ranges of Cl and carbon surface areas. The measured Hg removals for the three cases of 30, 33, and 72% compare well to the iPOG estimates of 21, 39, and 65%, respectively. The next three tests represent sub-bituminous coals with very low Cl but a large range of carbon surface area because of large LOI variations of 15 and 0.3 wt % and a substantial ACI concentration. Even with very little Cl, ACI increased the Hg capture from approximately 8 (PPU2BL2) to 57% (PPU2L8), which is clearly evident in the iPOG estimates. The inherent capture with 15% inherent LOI (EES1U25) is even greater and also apparent in the iPOG estimate, even though cyclone furnaces give lower fly ash loadings and lower

LOI surface areas than T-fired furnaces. The next two cases, MRYU2P3 and MRYU2P4, represent very high Cl and carbon surface areas from a lignite coal fired in a cyclone furnace with $CaCl_2$ added on coal and, in one case, ACI at a low concentration of untreated carbon. As expected, the Hg removals as HgP are low both with and without ACI, and the iPOG estimates accurately depict the enhanced capture with ACI.

The final three measurements under the ESP only configuration are for the same T-fired furnace firing a subbituminous coal with the addition of Br as CaBr₂ and with untreated and brominated ACI. Whereas the measurements show significant levels of Hg capture because of CaBr₂ addition and CaBr₂ addition with untreated ACI at 2.9 lb/MMacf, the iPOG estimates are 30-40% lower. The estimated 9.5% Hg capture in MEU2SE5 is similar to the low Hg capture estimated for MRYU2P3 with the addition of 800 as-received (ar) ppmw CaCl₂. Because Br addition does not increase HgP in field tests,¹⁶ the high capture in MEU2SE5 without ACI points to either a measurement error or some atypical condition at this location. With Br addition and untreated ACI (MEU2SE6), the estimate is closer to the measured Hg removal, and the remaining discrepancy should probably be attributed to the very large discrepancy in the baseline case with only Br addition. In contrast, the near-complete Hg capture in the saturation limit for brominated ACI is accurately estimated for case MEU2LH1. Because iPOG does not have any userspecified calibration factors, discrepancies in a baseline case will tend to propagate through case studies with added Hg controls, as illustrated in this case study.

Two more PM only configurations in Table 4 represent the licensed Hg control technologies of TOXECON-I and TOXECON-II, whereby ACI is positioned between an ESPc and a FF and within the fields of an ESPc, respectively. In the TOXECON-I tests, the measured Hg removals increased from 70 to 92% as the ACI concentration was increased from 1 to 2 lb/MMacf. The enhancement is also apparent in the iPOG estimates, albeit in terms of Hg removals that are too low by up to 11% (but within the uncertainties on the estimates in both cases). Most of the Hg capture in these cases was due to HgP capture in the FF filter cake, which is typically estimated more accurately than for other PM controls (cf. the very high correlation coefficient in Table 2). In the TOXECON-II tests, the measured Hg removals increased from 39 to 65% as the ACI concentration was increased from 1 to 6 lb/MMacf. This enhancement is also apparent in the iPOG estimates, which grew from 33 to 58% for the greater ACI concentration. Note that the iPOG estimates accurately depict the better performance of TOXECON-I compared to TOXECON-II, insofar as even a much greater ACI concentration in TOXECON-II could not achieve the performance of TOXECON-I with the same Cl levels, because FFs are the most effective collectors of HgP, by far.

The cases for an ESPc + WFGD cleaning configuration cover lignite and bituminous coals and bituminous/sub-bituminous blends for wall-fired and cyclone boilers with external Cl/Br addition and ACI. This configuration removes HgP in the ESPc and Hg²⁺ in the WFGD. The iPOG estimates accurately depict how judicious applications of Cl and Br addition and ACI can enhance Hg removals with lignite (MRYU2P4 and MRYU2P8) into the realm of removals normally seen with bituminous coals (CON4U12). The estimates also accurately depict the enhanced removal with the blend because of Cl addition (MOUCL1), although the large discrepancy for the baseline removal (MOUBL3) has again propagated into the case with an external Hg control. The accurate estimates for the total Hg removals were not due to fortuitous compensation of erroneous removals for the ESPc and WFGD. Test MRYU2P4 appears in both the ESPc only configuration and the ESPc + WFGD configuration with the distinction that the measured Hg removal in the former case refers to the ESPc removal only,

data were obtained at different furnaces and provide yet another illustration of the significance of plant-specific factors. Without a baseline calibration protocol, iPOG can only depict the established tendency for greater removals for progressively greater Cl and LOI levels. For the pair of sub-bituminous cases, iPOG correctly predicts no enhancement for Br addition, because Br addition does not enhance the production of HgP, the form of Hg removed in an ESPc. However, both estimates are low by almost 15%.

The NETL field test database on the SCR + ESPc + WFGD configuration covers only furnaces fired with bituminous coals because low-rank coals tend to have low coal S; therefore, plants firing low-rank coals typically do not require both SCR and FGD for NO_x and SO₂ emissions compliance in the U.S.A. Despite the large variations in the Cl levels of the two test cases from the same plant in Table 4, the measured Hg removals were the same and the estimates increased by less than 10% for the greater Cl level and slightly greater LOI (EES2U22). This behavior is a consequence of a saturation in the impact of Cl variations on Hg removals that changes from a direct proportionality at low Cl levels to an insensitivity to Cl variations at high levels. That transition usually occurs around 25 ppm Cl in flue gas; therefore, both cases in Table 4 were within the saturation region.

To summarize, we note that the iPOG estimates correctly rank order the Hg removals for the different gas cleaning configurations. For typical cleaning conditions, the iPOG predicts the lowest levels of inherent Hg capture for the ESPc only and the SCR + ESPc configurations, albeit with very substantial enhancements for halogen addition and ACI provided that the Cl levels and carbon surface areas are reasonably balanced. Successively higher removals are predicted for the ESPc + WFGD and SCR + ESPc + WFGD configurations. The iPOG estimates also show that the only PM only cleaning configuration that can match the performance of an SCR + ESPc + WFGD is TOXECON-I.

PARAMETRIC CASE STUDIES

While the evaluations in Table 4 demonstrate the performance of iPOG across broad domains of coal quality, cleaning configurations, and Hg controls, the case studies in this section exploit that performance to examine representative "What if...?" questions.

Case 1. Rank order the Hg removals for coal blending, halogen addition, and/or ACI in an ESPc only configuration

预览已结束, 完整报告链接和二维码如下:



https://www.yunbaogao.cn/report/index/report?reportId=5 15657