TESTING AND OPERATING RESULTS OF THE KNX™ TECHNOLOGY AT THE MONTANA-DAKOTA UTILITIES CO. LEWIS & CLARK STATION

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ABSTRACT

The Montana-Dakota Utilities Co. (MDU) Lewis & Clark (L&C) Station is a 45 MW gross electric power generating station located in Sidney, Montana. The L&C station has a sub-critical, pulverized coal (PC) fired boiler burning more than 300,000 tons of northern lignite fuel per year from the near-by Savage Mine. The plant has been recently modified with KNX™ technology to provide 100% mercury oxidation (bromination) in the combustion gas. This oxidation is achieved by pre-combustion $CaBr_2$-addition to the coal which improves the co-benefit mercury capture in the existing air pollution control (APC) system which includes a multi-clone particulate collector and a flooded disc wet scrubber.

The KNX™ technology mercury capture modifications were tested in 2008 without activated carbon injection (ACI) and later with non-brominated ACI.

The successful combination of pre-combustion bromide-addition and non-brominated ACI - upstream of the air pre-heater has been in commercial operation and in compliance with the Montana Mercury Emission Standards since January 1, 2010.

This paper will present test data used to validate the selection of KNX™ technology for mercury emission control along with commercial operating snapshots from 2011 and long term data from January 1, 2010 through August 31, 2011 demonstrating the KNX™ technology's capability to maintain emission compliance.

INTRODUCTION

The Montana-Dakota Utilities Co. (MDU) Lewis & Clark Station is a 45 MW gross electric power generating station located in Sidney, Montana. Figure 1 is a photograph of the L&C Station which has a tangentially fired pulverized coal boiler (from 1958), burning more than 300,000 tons of lignite coal per year. This fuel is supplied from the nearby Savage Mine which is owned and operated by the Westmoreland Savage Corporation. The boiler operates a low NO_x firing system and is equipped with a multi-clone for ash collection. A flooded disc scrubber was added in December 1975 for additional particulate control. The current APC system captures >99% of the boiler particulate emissions and reduces SO_2 emissions by >45% using only ash alkalinity and some supplemental lime. Table 1 is a simple station summary.

Figure 1 - Lewis & Clark Electric Generating Station.

Table 1 - L&C Station Data.

Capacity (MW_e Gross)	45
Coal type	100% Savage lignite
Coal Feeders	3
NO_x control	LNCFS™ Level I
Ash Capture	Multi-Clone
SO_2 /Particulate control	Research-Cottrell flooded disc scrubber
Air Heater	One Ljungstrom
Ash utilization	Beneficially used or Landfilled

Recent modifications have been installed at the L&C station to remove mercury from the flue gas. These modifications have been in commercial operation since January 2010 to comply with Montana's mercury control rule.

The Montana legislation states that utilities, beginning January 1, 2010, or at commencement of commercial operation, whichever is later, must limit mercury emissions from the mercury-emitting generating unit to an emission rate equal to or less than:

(i) 1.5 pounds of mercury per trillion Btu (lb Hg/TBtu), calculated as a rolling 12-month average, for mercury emitting generating units that combust lignite; or

(ii) 0.9 pounds of mercury per trillion Btu (lb Hg/TBtu), calculated as a rolling 12-month average, for all other mercury-emitting generating units.

The MDU L&C Station firing northern lignite coal is in compliance with the 1.5 lb Hg/TBtu emission limit.

KNX™ TECHNOLOGY

The KNX™ technology uses a bromine containing compound as a coal additive - such as sodium bromide or calcium bromide as a dry salt or in an aqueous solution. The aqueous bromide used for the test campaign was 52% by weight $CaBr_2$. The solution was applied to the coal prior to combustion by spraying the desired flow rate onto the coal while it passed through the coal feeders. Figure 2 illustrates the general flow diagram for the

KNX™ technology testing at the MDU L&C Station.

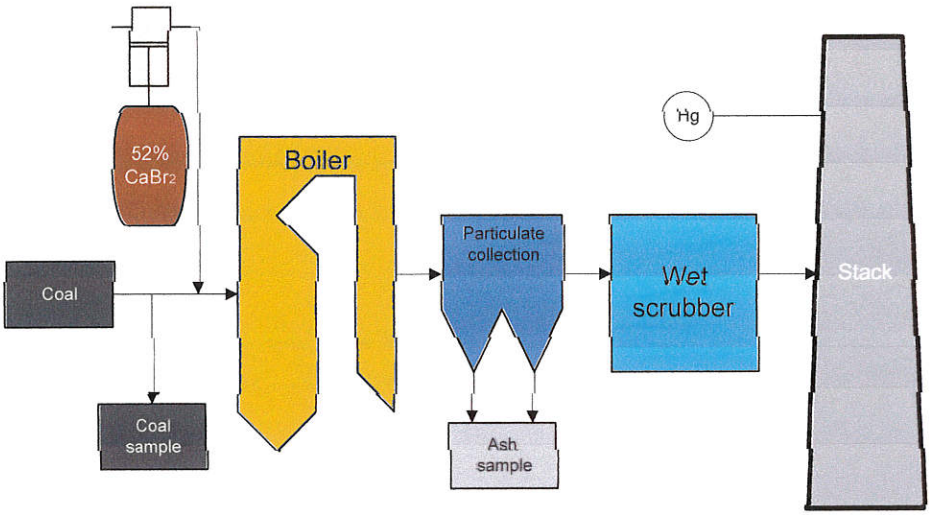

Figure 2 – MDU L&C Station KNX™ Demonstration (without ACI) General Schematic.

During the tests in June 2008 only two out of three operating feeders were supplied with the bromide solution. In the commercial application of the KNX™ technology since January 2010 all operating feeders are supplied with the bromide solution.

The presence of bromine during combustion increases the amount of mercury oxidation from the elemental form Hg^0 to the oxidized form $HgBr_2$ due to the reaction of mercury and bromine:

$$Hg + Br_2 \Rightarrow HgBr_2$$

Oxidized mercury (in this case $HgBr_2$) is highly water-soluble and generally (but not always) captured in the wet scrubber, depending on scrubber design and coal ingredients (as sulfur). $HgBr_2$ can also be adsorbed on unburned carbon (UBC) particles in fly ash and collected in particulate control devices. In contrast, elemental mercury (Hg^0) is almost water-insoluble and cannot be captured as easily as oxidized mercury. Elemental mercury (Hg^0) is highly volatile (high vapor pressure) and generally escapes capture at typical flue gas cleaning (FGC) operating temperatures.

KNX™ TECHNOLOGY TESTING

Alstom's licensed KNX™ technology was tested at the L&C Station in June of 2008.

A Thermo Scientific Mercury Freedom™ continuous mercury monitoring (CMM) system was installed prior to testing. The CMM system successfully passed RATA testing approximately two weeks before the KNX™ test campaign began and remained in continuous operation through the test period. A temporary KNX™ technology injection system was installed for the test program, with the general layout shown schematically in *Figure 2*.

The test system in 2008 consisted of a 55 gallon drum of 52% $CaBr_2$ aqueous solution, and 2 operating metering pumps mounted on a custom built skid near coal Feeders 1 & 2, which are immediately upstream of their respective pulverizer mill. 1/2" flexible PVC tubing from each pump discharge was connected to a custom built injection lance mounted in the feeder. Figure 3 shows the pump arrangement where 2 pumps are connected and the third pump is a disconnected spare. Figure 4 shows the injector set up at a coal feeder and Figure 5 shows the barrel/dolly configuration.

Figure 3 – $CaBr_2$ Injection Pumps on Skid.

The injection pumps were powered by 120V plant power, and could be turned off locally in case of feeder stoppage, boiler trip, or any other operational concern. The pumps were Walchem EHE Series electronic metering pumps, model *EHE35E1-VCV*. These were diaphragm pumps with a pulse range of *1-360* strokes/minute, and a maximum flow rate of 8.5 gallons/hour. This performance envelope offered a linear output profile over the entire range of flows anticipated for this test demonstration. Furthermore, flow could be closely regulated and easily adjusted to meet specific test objectives.

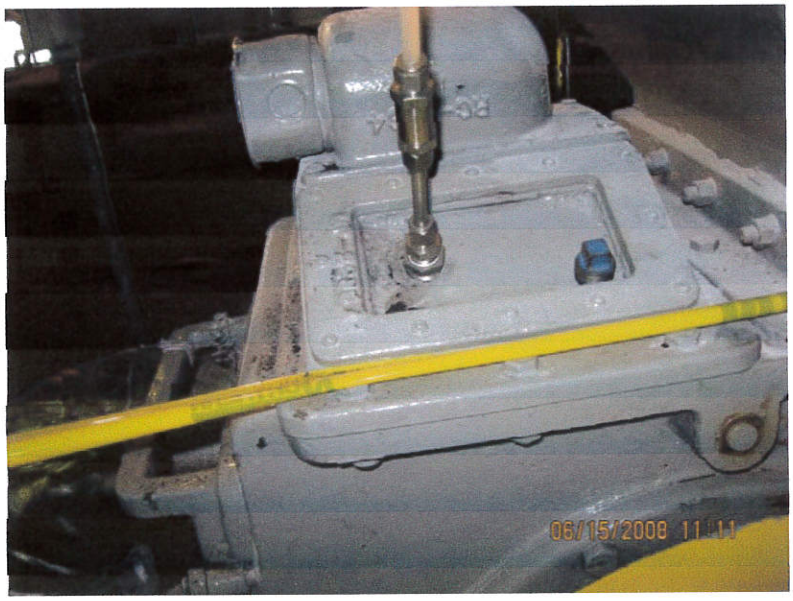

Figure 4 – Injection Location on Feeder.

Figure 5 – $CaBr_2$ Barrel and Dolly.

Based on the mercury content of the fired coal (see Table 2 below) and plant design (no high dust SCR catalyst bed), the initial target injection rates of the 52% $CaBr_2$ solution were determined to be 50, 100, and 150 ppm by weight equivalent Br per all coal.

Table 2 – L&C Station Representative Coal Properties.

Proximate Analysis	As Received
Total Moisture (%)	21.3 (±.8)
Ash (%)	10.7 (±.8)
HHV (Btu/lb, dry)	10,300(±75)
Hg (μg/g dry coal)	0.081 (±.017)
Hg (lb/TBtu)	9.970 (±2.113)

It should be noted that the total feed of the bromide solution was supplied to only two (of the three) feeders during the test period in 2008. Therefore the pre-distribution of bromide was not optimal during these tests. However, since commercial operation beginning in January 2010, all three or all operating feeders are supplied equally with $CaBr_2$.

Prior to testing, the flow rates for all pumps were calibrated using the $CaBr_2$ solution itself and an inline calibration column.

Coal samples were taken from the feeders prior to the pulverizer mills, and just upstream of the KNX™ technology injection points.

Mercury concentrations were monitored using the stack CMM. Gas analysis data such as NO_x, and SO_2 have been obtained from the plant data collection system, as well as actual power output, fuel feed rates, and other critical operating parameters.

Baseline testing was carried out prior to June 11, 2008. Parametric testing of the system with pre-combustion bromide addition (but without ACI) occurred during June 14-15.

Observation of the stack mercury results indicated that higher dosages of $CaBr_2$ than originally planned might

further reduce stack mercury levels. Therefore, actual injection rates were increased above the initially targeted levels, see discussion further down.

KNX™ TECHNOLOGY - TESTING RESULTS IN 2008 (WITHOUT ACI)

The coal fired at the MDU L&C Station during testing was 100% northern lignite from the Westmoreland Savage mine. Table 2 lists the average coal properties determined by analysis of the coal samples taken during the test campaign. The average mercury content in the samples analyzed was 0.081 μg/g on a dry basis. The range between minimum and maximum mercury contents was fairly narrow, with the exception of the first day of testing, for which the mercury content of 0.111 μg/g was higher than for the rest of the test period.

The initial test on June 11, 2008, with $CaBr_2$ injection ranging from 76-150 ppm per coal demonstrated a rapid drop in stack mercury emissions. This reconfirmed the results already known from other power stations applying the KNX™ technology. The response time was quite short but the Hg^T levels only dropped approximately 20% from the average baseline value of 11.8 μg/Nm^3. Compared to other applications of the KNX™ technology, the observed effect was too small which indicates that there was a lack of good pre-distribution of the bromide solution caused by the use of two injection points.

As shown in Figure 6 the internal mixing of the burner strands within the tangentially-fired boiler is fairly limited. Therefore it was decided later to supply all three feeders with the bromide solution.

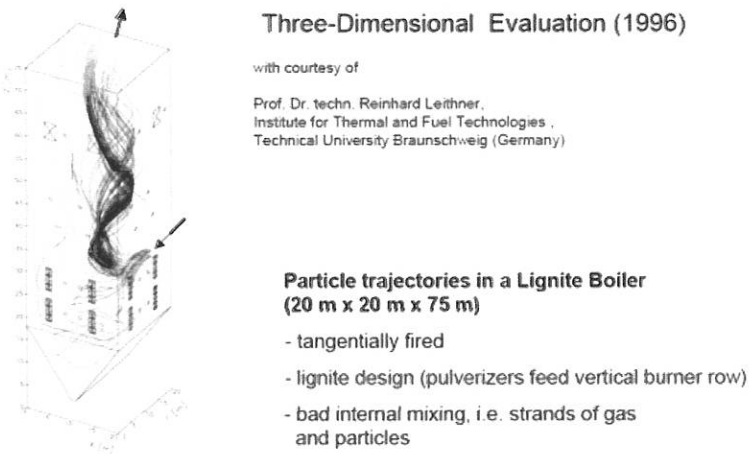

Figure 6 – Danger of insufficient bromide pre-distribution (Vosteen Consulting).

Figure 7 below illustrates the KNX™ technology effects during tests 3 through 6. Equipment problems delayed $CaBr_2$ injection testing until 18:45 on June 14, 2008 (Test 3). During this time, the measured Hg^T levels consistently trended downward from approximately 9 to 6 μg/Nm^3.

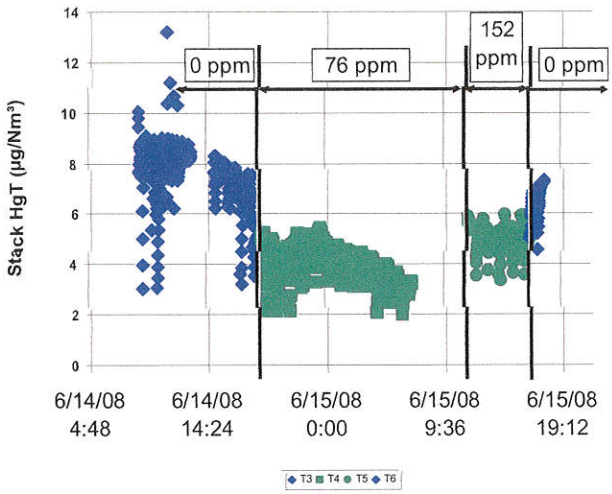

Figure 7 - Hg^T Stack Measurements, Tests 3 – 6.

$CaBr_2$ injection at 76 ppm began at 18:45 (Test 4). Again, a noticeable downward trend in mercury concentration was noted, from approximately 5.5 to 3.5 µg/Nm^3. At 11:30 on June 15, the $CaBr_2$ injection rate was increased to 152 ppm (Test 5). Interestingly, at this higher injection rate, the Hg^T levels were generally higher than for Test 4, ranging from 4-6 µg/Nm^3. Operational changes to the flooded disc scrubber may have contributed to this effect.

For a short time on June 15 (from 16:30 through 17:30), $CaBr_2$ injection was inadvertently cut off (Test 6). As can be seen, a rapid upward spike in Hg^T values occurred during this time.

Figure 8 below illustrates the KNX^{TM} technology effects during tests 7 through 10. At 17:30, the $CaBr_2$ injection was re-started at a feed rate of 114 ppm (Test 7). A rapid downward trend in Hg^T is observed during this period but stabilizes around 5.5 µg/Nm^3.

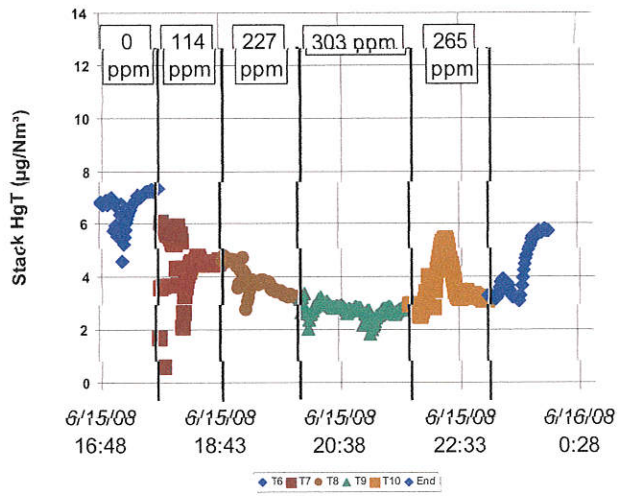

Figure 8 - Hg^T Stack Measurements, Tests 7 – 10.

$CaBr_2$ injection was increased to 227 ppm at 18:45 (Test 8). A noticeable downward trend is again apparent, with Hg^T ranging from high of 5.5 μg/Nm^3 at the beginning and a low of 3.5 μg/Nm^3 at the end of the test.

Test 9 at an injection rate of $CaBr_2$ for 303 ppm showed the lowest stack Hg^T values exhibited during the entire test campaign. The Hg^T ranging from 3.5 to 2.8 μg/Nm^3. Test 10 at an injection rate of $CaBr_2$ for 265 ppm saw a slight increase in Hg^T from Test 9, ranging from 3.0 to 3.6 μg/Nm^3. $CaBr_2$ injection was stopped at 23:00 June 15, 2008.

As shown above, mercury capture increases with increasing $CaBr_2$ injection rates within a short period of time. This testing however applied more $CaBr_2$ than elsewhere, and achieved mercury capture rates which were lower than expected.

It is suspected that the effect of wet scrubber elemental mercury (Hg^0) re-emissions played a role in increasing the stack total mercury (Hg^T) levels. This well known re-emission phenomena however was not studied in greater detail. Clearly, the pre-distribution of the bromide solution had to be optimized by supplying all three feeders equally instead of only two.

With pre-combustion bromide addition a significant reduction in overall stack mercury emissions was demonstrated. However, MDU's ultimate goal of 90% total mercury capture from coal pile to stack was not achieved.

KNX™ TECHNOLOGY WITH ACI - COMMERCIAL APPLICATION RESULTS IN 2010 AND 2011

Based on the data from the initial tests and subsequent testing with limited activated carbon injection a commercial license between Alstom and MDU's L&C Station for KNX™ technology was completed in 2009. Figure 9 below illustrates the commercial operation of KNX™ technology and ACI at MDU's L&C Station.

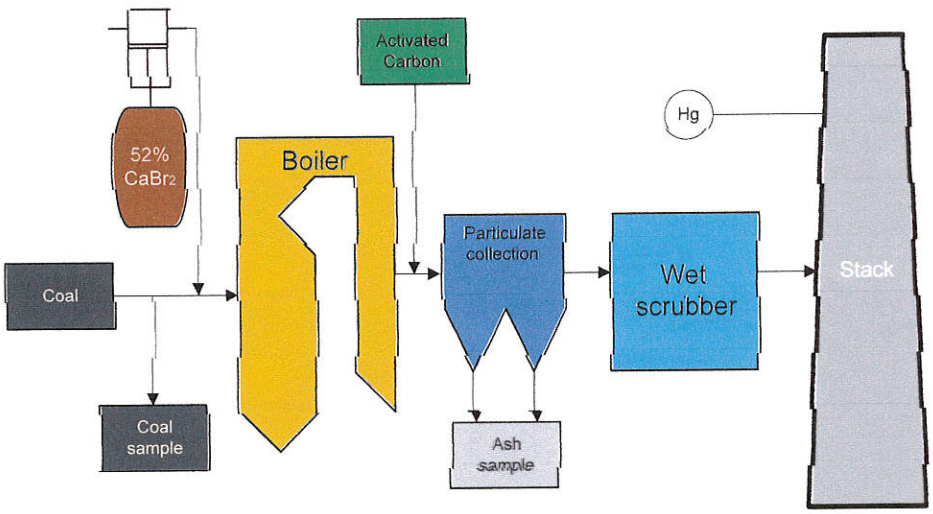

Figure 9 – Commercial KNX™ Technology with ACI.

Commercial operation of KNX™ with limited activated carbon injection (ACI) began January 1, 2010. $CaBr_2$ solution is added at all three feeders and normal, non-brominated activated carbon (Darco Hg) is injected upstream of the air pre-heater.

It will be shown below that the total stack mercury (Hg^T) at the L&C Station has been in compliance with the Montana Mercury Emission Rule from the very beginning of 2010.

The following trend charts illustrate a typical week of operation regarding stack mercury emission control. Figures 10, 11 and 12 below illustrate the daily operational mercury emission control performance as a function of load, $CaBr_2$ feed and non-brominated ACI for the period July 1, 2011 to July 7, 2011.

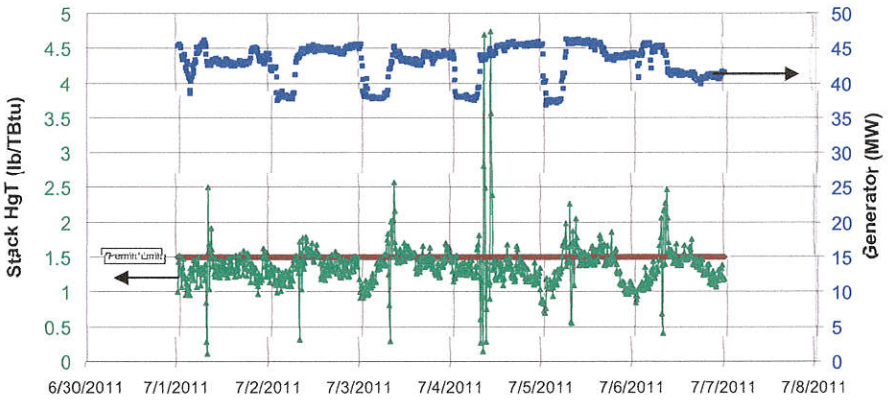

Figure 10 – Hg^T Emission vs. Generator Load.

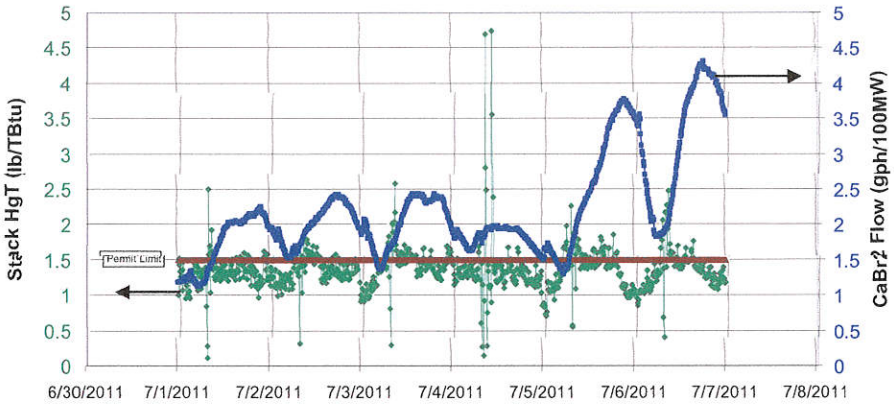

Figure 11 – $CaBr_2$ injection rate performance.

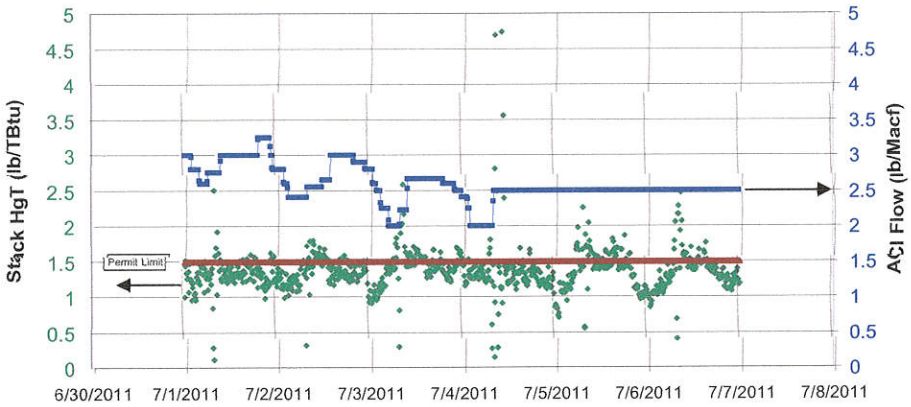

Figure 12 – Activated Carbon injection rate performance.

Figure 10 illustrates the effect of operating load. Figure 11 is the CaBr2 injection rate normalized to generator output and Figure 12 is the ACI rate normalized to flue gas flow. These figures show that the controls for Hg emissions at the L&C Station can reliably maintain the permit conditions with variable load and coal Hg content. The $CaBr_2$ feed is currently manually adjusted by the operator, in response to mercury emission levels. The current AC consumption is maintained relatively constant at a moderate injection rate of 2 - 3 lb/Macf.

Table 3 below provides a summary of the mercury control operations at the L&C Station for 2010 and 2011.

Table 3 – L&C Hg Emission Control Operating Results.

2010 Month	**$CaBr_2$ (Gal/MWnet)x100**	**ACI (lb/MWnet)**	**Stack Hg^T (lb/TBtu)**
January	3.317	0.685	1.256
February	2.755	0.729	1.331
March	3.483	0.720	1.532
April	2.333	0.698	1.387
May	3.392	0.913	1.28
June	3.179	0.962	1.339
July	3.940	0.955	1.323
August	4.605	1.050	1.517
September	2.005	0.867	1.248
October	2.859	0.723	1.296
November	3.752	0.803	1.318
December	3.393	0.736	1.28
2011			
January	2.780	0.790	1.393
February	2.120	0.655	1.325
March	1.792	0.812	1.272
April	1.781	0.807	1.204
May	2.648	1.325	1.597
June	1.980	0.850	1.276
July	3.237	0.954	1.423
August	3.239	1.079	1.346

Figures 13 and Figure 14 below illustrate the consumables and the stack Hg emission summary beginning in January of 2010.

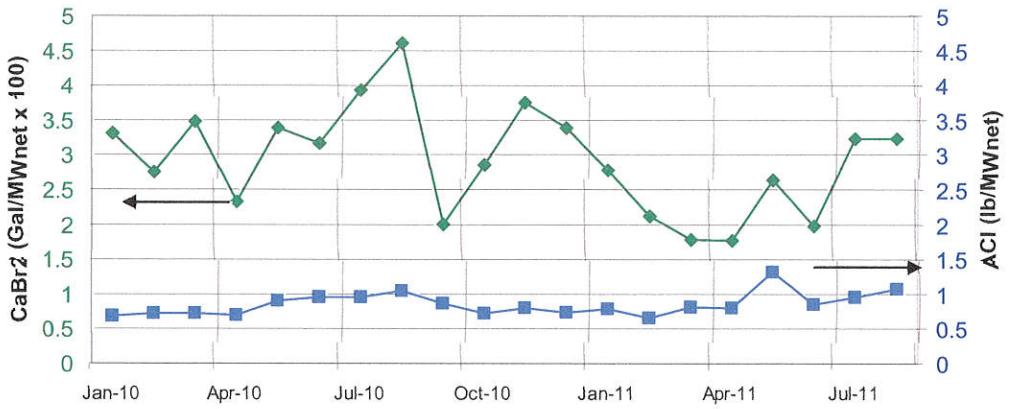

Figure 13 – $CaBr_2$ and AC Consumption Summary.

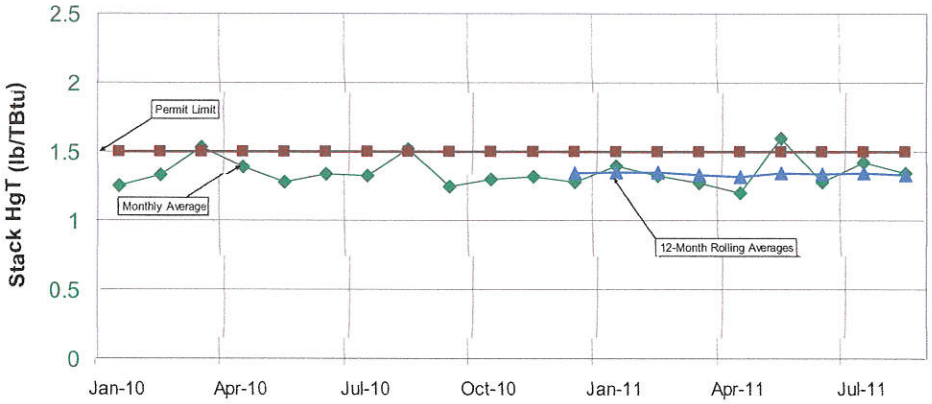

Figure 14 – L&C Station Hg Emission Compliance Summary.

CONCLUSIONS

- The KNX™ technology has been successfully operated for over 1 year.
- The effectiveness of $CaBr_2$ and its rapid response to fuel Hg variations has been demonstrated.
- The combination of pre-combustion $CaBr_2$ addition and normal non-brominated activated carbon injection (ACI) reliably controls Hg emissions with variable load and fuel Hg content.

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