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NEW, LOW GAS ABSORPTION, ELECTRONIC WATER CONDENSER FOR USE IN GAS ANALYZER SAMPLE CONDITIONING SYSTEMS FEATURING THE "M CLASS" ELECTRONIC WATER CONDENSER

Tom Baldwin, Baldwin Environmental

INTRODUCTION

Electronic water condensers are an effective means of removing water in combustion waste gas streams and process samples, prior to analyzing with a gas analyzer. In recent years, electronic water condenser have found prevalent use in Continuous Emissions Monitoring Systems (CEMS). As air quality regulations have required lower emission levels for criteria pollutants (N0x, S0x, C0, Particulate), component absorption in the sample conditioning system has drawn more attention by agency personnel. Electronic condensers provide high speed water separation from the stack gas, reducing the component absorption as compared to other dewatering methods. This paper presents a new design of electronic water condensers for use in CEMS and process monitoring applications.

BASIC PRINCIPLE OF OPERATION

Electronic water condensers use Peltier effect, thermoelectric elements to move heat from on source to another. A thermoelectric cooler (TEC) is a small heat pump, which has the advantage of no moving parts. TEC's by principle of operation, also lend themselves to precise electronic temperature control. TEC's are used in various applications where space limitations and reliability are paramount, and CFC's emissions are of concern. TEC's, being totally solid state, do not require maintenance or fluid recharging. The thermoelectric element transfers heat, using direct electrical current, flowing through dissimilar element junctions. The TE operates like a reverse thermocouple. A thermocouple measures temperature by generating a millivoltage from two dissimilar metal wires, with a temperature gradient from one end of the wire to the other. The two dissimilar wires are welded at the hot end, and open for connection to a milli-voltmeter at the cold end. The difference in temperature between the hot junction and the cold junction creates a voltage linearly proportional to the hot junction temperature. A thermoelectric element works in the reverse, heat is absorbed and desorbed on the surface of a ceramic substrate. Sandwiched between two ceramic substrates are P type and N type semiconductor materials (bismuth telluride). These junctions are connected electrically in series and thermally in parallel to the ceramic surfaces.

When a positive DC voltage is applied to the n-type thermoelement, electrons pass from the p- to the n-type thermoelement, and the cold side temperature will decrease as heat is absorbed by the flowing electrons. The heat absorbed is a function of the current applied, and the number of p- and n-type junctions. The heat is transferred to the hot side of the TE ceramic surface, where it is dissipated into a heat sink or other heat transfer device.

Like conventional refrigeration, thermoelectrics obey the basic physical laws of thermodynamics. Both in principle and result, the solid state thermal electric cooling element has much in common with conventional compressor type refrigeration. In standard refrigeration units, the main components are a compressor, evaporator and condenser. The evaporator surface is where the liquid refrigerant evaporates, changes to a vapor absorbing heat energy. The compressor circulates the refrigerant gas and applies enough compression to increase the temperature above ambient level. The condenser helps discharge the absorbed heat into ambient air through a thin walled air radiator.

Thermoelectric cooling uses the same principles. The refrigerant in both liquid and vapor form is replaced by two dissimilar metal heat conductors. The cold junction (evaporator surface) becomes cold through absorption of heat energy by the electrons as they pass from one semiconductor to another, instead of energy absorption by the refrigerant gas as it changes from liquid to vapor. The compressor is replaced by a DC power source which pumps the electrons from one semiconductor to another. A heat sink replaces the conventional condenser fins, discharging the accumulated heat energy from the system through a fan powered air cooled heat sink fin.

The difference between the two refrigeration methods, thus, is a thermoelectric cooling system refrigerates without use of mechanical moving parts, except perhaps in the auxiliary sense, and without a refrigerant.

APPLICATION OF PELTIER ELEMENTS TO SAMPLE COOLER HARDWARE

HEAT SINK ASSEMBLY

The design of the heat sink is the key work element to a good thermoelectric system.

We use some terms to describe the thermoelectric sample cooler assembly. The impinger, element in contact with the sample gas, is commonly called the HEAT EXCHANGER. This heat exchanger slips into a HEAT TRANSFER BLOCK, the cold block. The heat transfer block is contacted by the thermoelectric element on the cold side, and the HEAT SINK on the hot side. A typical thermoelectric element can pump against a temperature differential from cold to hot side of 50^{o} C. Since the control set point of the cooler is 5^{o} C, the heat sink side plate can reach 55^{o} C., before problems develop.

The heat sink must be able to move heat rapidly from the thermoelectric element. This is achieved by a combination of radiator fins, and a high volume fan, moving ambient air for heat exchange. This system provides adequate heat exchange, and a compact design for the sample cooler.

IMPINGER (HEAT EXCHANGER) DESIGN

The heat exchanger is the work horse of the sample cooler. It removes water from hot, wet, dirty stack gas, with minimal gas component absorption. The heat exchanger is constructed per drawing IC0060, in the Appendix. The hot, wet, stack gas enters the exchanger from the top, and travels down through the thermally isolated center tube. The thermal isolation is achieved by a vacuum jacket around the inlet tube.

This jacket serves two purposes:

a. To keep the sample gas temperature above the dew point while the gas transits the inlet tube.
b. Minimizes the heat loss to the cold outer wall of the heat exchanger.

Once the gas reaches the bottom of the inlet tube, water condensation takes place immediately upon reaching ambient temperatures. The water nucleates into droplets, where gravity takes hold, quickly removing the droplet, with minimum gas contact. The gas, not affected by gravity, makes a 180° turn at the bottom of the tube and travels up the cold wall. This rapid separation greatly reduces the gas absorption in the water, verified by empirical test results. Further condensation of water occurs on the cold heat exchanger wall, until an exit dewpoint of 5° C. is achieved. Sample gas "superheating" occurs when it flows over the non-insulated inlet tubing. This superheating results in an exit gas temperature of 55 to 60° F. Further condensation of the remaining moisture in the sample gas is minimized by the higher sample temperature.

An optimal design for the heat exchanger calls for minimal surface area, low volume, and flexible materials of construction. The minimal surface area is required to minimize component "attenuation", (loss) in the heat exchanger, while allowing enough surface area for complete water condensation to take place. Minimal volume is required to minimize residence time, and to provide minimal pressure drops across the exchanger. Flexible materials of construction allow the application engineer a choice of materials in contact with the sample depending upon the acidic components likely to be present, the water volume to be removed, and the desired flow rate to be achieved. By constructing the heat exchanger in a variety of materials, many application design requirements can be achieved.

We have settled upon two heat exchanger options. These heat exchangers are identical to Figure IC0060, differing only in length. Empiracilly, we have found a relationship of residence time, water concentration, and gas component removal is optimal at a rule of thumb of 0.5 l/m per inch of heat exchanger length. Thus we use a 5" and a 10" heat exchanger. The rule of thumb of 0.5 l/m per inch holds true in this figure for water concentrations below 50%. TE cooler performance curves have great flexibility with the heat exchanger design. Various increasing flow rates can be achieved depending upon the inlet process load (inlet water concentration).

Thermoelectric coolers use high speed heat exchangers to make the water separation. The design of the impinger, limits the condensing, liquid water contact with the highly absorptive criteria pollutants in the exhaust gas. By coupling this high speed heat exchanger design with rapid electronic temperature control, the thermoelectric cooler reacts rapidly and directly to changing process loads, and can be sized to the application, reducing energy consumption in the sampling system. The refrigeration type condenser, on the other hand, must be oversized to the application, because it operates on a steady state control principle. By definition, it cannot rapidly react to process input loads.

SAMPLE CONDITIONER DESCRIPTION

A dry, extractive, sampling system consists of a heated probe to extract the sample from the stack or source; a heated sample line to transport the sample to the water condenser; and a sample conditioning panel where the sample is filtered, dewatered, and pumped to the gas analyzers. A typical flow diagram for a stack sampling system is attached to this paper. The sample conditioner consists of an electronic water condenser, a diaphragm gas sample pump, a peristaltic drain pump, a low micron in-line sample filter, water slip sensor, and total sample flowmeter. The components are mounted on a plate or bracket, for easy integration into a continuous gas measurement system. A typical gas analyzer sample conditioning flow diagram is given in Figure 4SHS-GCFS3/425 in the Appendix.

M CLASS SAMPLE COOLER DESIGN

To sample combustion product stack gas or exhaust from any internal combustion process, a method to remove moisture from the sample, without removing the components to be analyzed, is a must. This new, compact water condenser design is an ideal way to decrease the dew point of the combustion gases to a repeatable, stable, constant low dew point. Most gas analyzers have some interference to water vapor, and in the presence of acid gases, are subject to corrosion. By removing the moisture to a low level, and maintaining stability of the dewpoint, the gas analyzers can make a more accurate analysis on a long term, repeatable basis.

The M Class electronic water condenser lowers the incoming gas sample dewpoint to 5°C (41°F). Particulate matter is partially removed by the heat exchangers. Particulate which passes through the condenser is removed by a low micron in-line filter downstream of the condenser.

Standard thermoelectric coolers are normally supplied with the following integrated features:

- LCD display of operating temperature
- Voltage output proportional to operating temperature
- LED display of key operating characteristics:
  - Ready to sample
  - Temperature sensor failure
  - Water slipping by the cooler
  - Electronic or power failure
- Dry contact alarms for:
  - Too high operating temperature
  - Water slipping by the cooler
  - Temperature sensor failure
  - Power failure
- Sample pump On/Off control
- Heated Line Temperature Interlock
- Current output for:
  - Exit sample gas dew point temperature
  - Cooler operating temperature
  - Sample gas inlet temperature

The M Class cooler separates these standard features into optional features. Separate control boards are supplied for:

- LCD Display
- Alarm Card for:
  - Dry contact computer alarm status
  - Sample pump On/Off control
  - Heated sample line interlock
- Current output card for:
  - Exit sample gas dew point temperature
  - Cooler operating temperature
  - Sample gas inlet temperature

By making these features modular, the sample system design engineer can pick and choose the options required for the application, as well as the process loading in a single thermoelectric cooler package. These features provide a broad range of flexibility in a single enclosure. Application of an electronic water condenser to stack sampling requires thorough knowledge of the samples characteristics. The M Class water condenser is available in a number of capacities and configurations. It’s major new innovation is the ability to cover a wide range of applications and loads within the same physical package. The mounting footprint stays the same no matter what model number and load capacity is chosen. This feature makes the cooler applicable for system integrators and large company purchases. A single cooler model series covers a broad range, with common spare parts and utility connections.

GAS ABSORPTION IN THE LAMINAR HEAT EXCHANGER

Many users are interested in quantifying the criteria pollutant (absorptive gases) attenuation (losses) in thermoelectric coolers. A test apparatus was designed and constructed to investigate the losses in high speed heat exchangers (impingers) for various materials of construction.

Test Apparatus Description

a. Figure EPA-001 illustrates the test apparatus we use to evaluate heat sink design, heat exchanger performance for water removal, and gas absorption.

b. Sample gas is doped with known concentrations of water, using a positive displacement calibrated peristaltic pump.

c. Sample gas and aspirated liquid water enter a boiler where the water is vaporized. Known concentration calibration gas is injected immediately above the boiler. We found excessive losses of SO2 when we injected the calibration gas into the boiler directly.

d. A heated sample line operating at 300° F., transport the sample containing water vapor and component gases to the sample cooler.

e. Test data is logged by recording component operating temperatures, pressures, flows, dew point, gas concentrations and recovered water.

f. Test apparatus included a TECO Model 10AR NOx Analyzer, Western Research Model 922 SO2/NO/NO2 combination analyzer, ESC Model 1800 Data Logger, EGG Model 905 Chilled Mirror Dew Point Analyzer, Rikadenki strip chart recorder, and Protocol 1 calibration gases.

A Baldwin Environmental Model M325 Electronic Sample Cooler was tested for gas absorption, within its rated flow and load ranges; using stainless steel, Kynar, and glass heat exchangers.

The test apparatus was operated using Protocol 1 gases, delivered to the boiler through a Horiba S-tec capillary gas divider. Due to boiler attenuation, the calibration gas was injected into the flowing ambient air stream directly above the boiler. Thus several dilutions took place. The ambient air/water enriched stream diluted the calibration gas approximately 50%. Since this test is a relative one; IE, knowing the beginning and ending gas values without water, we are able to measure gas absorption as a function of water concentration injected, and materials of construction used.

Test Results

Figure B summarizes the test results for SO2, for stainless steel, Kynar, and glass heat exchangers. Glass appears to attenuate SO2 the least for water concentrations below 30%. It is interesting to note, that stainless steel performs quite well at water concentrations of 15% and below, where the majority of applications fall. The data for this graph is available from the author upon request. Due to time constraints, SO2 concentrations tested were at the 3-400 ppm level. Future tests will be at lower SO2 concentrations and high water volume % such as found in waste incinerator applications. We do not yet know the relationship of lower concentrations, residence time, and water concentrations. These absorption tests will assist the application engineer in choosing the correct heat exchanger materials of construction to guarantee a successful installation considering the stack gas source, water concentration, SO2 expected concentration, and system flow rate requirements.

Figure A summarizes the test results for NO2. NO was found to have negligible absorption under all conditions and materials of construction, so the test results summarize the NO2 absorption data. NO2 calibration gas was Protocol 1 grade, 2000 ppm, supplied by Scott Company. The NO2 gas was gas divided with Nitrogen to achieve the lower level test concentrations. Again, as in the SO2 test data, time constraints prevented further investigations at low NO2 levels. This data used 200-400 ppm NO2 levels for the test, concentration levels rarely found in actual practice. Our intent here was to develop a worse case scenario. Again, NO2 absorption follows the same curve shapes as SO2. Glass performs quite well at water concentrations to 50%.

SECOND TEST APPARATUS USING USA EPA ICE BATH IMPINGERS

A second test apparatus was assembled to compare gas absorptions for ice bath, impinger sampling trains to the high speed, thermoelectric condenser (impinger).

Gas Absorption Test Results for EPA Method 6, Ice Bath/Impinger Gas Sampling Train at Various Gas Concentrations and Flow Rates.

To provide a comparison of the thermoelectric cooler impinger system versus the performance of the reference Method 6 impinger train, we laboratory tested a Method 6 train.

The Method 6 train consisted of four (4) glass impinger, 500 cc volume. The first impinger was modified with a cut off inlet tube, 4" above the bottom of the impinger, the second impinger was a straight impinger, third and fourth were Smith-Greenburg impingers. Ice bath was maintained at 32° F. throughout the test sequence. The impingers were operated under the following sample conditions:

a. Flow train: Heated sample line connected directly to impinger #1. Diaphragm sample pump connected directly to impinger #4, with the remainder test apparatus as shown in Figure D.

a. Inlet sample vacuum: -1" Hg
b. Sample Pressure after sample pump: 10 psig
c. Ambient Temperature: 68° F.
d. Flow Rates: As shown
e. Inlet Sample Temperature: 300-400° F.
f. Outlet Sample Temperature: 55-60° F.

Test results are summarized in Figure C. Test results followed the classical, known absorptions for glass impinger trains. We experienced problems with the test apparatus at the higher flow rates, since the impinger train cannot maintain consistent outlet dewpoints. Outlet dewpoints increased dramatically with increased flow rates and water concentrations as expected. The test results show SO2 and NO2 absorptions up to 20% and 14% respectively. These results are certainly flawed; otherwise, every RATA or Compliance field tests would be reporting failures. Again, due to time constraints, the tests were performed only at two representative flow rates, at fairly high SO2 and NO2 concentrations, and with many systematic problems. We intend to do future testing, performed at lower concentrations, higher flow rates, and resolution of the systematic problems. Residence time did show as a factor in gas absorption. Doubling test flow rate, lowered the gas absorption by a significant 2%.

CONCLUSION

The thermoelectric cooler produced consistent outlet dewpoints, making the test easy to perform. The thermoelectric heat exchanger exhibits lower gas absorption than the Method 6 train for SO2 and NO2 concentrations of 200-400 ppm levels, based on initial test results we started for the Method 6 impinger train absorptions. Unfortunately, the Method 6 test results were incomplete, so we will follow up this paper in future with further test data at much lower SO2 and NO2 levels for both the Method 6 impinger train comparison and the thermoelectric heat exchanger. Field stack reference method testing problems have been documented for SO2 and NO2 levels of 20-40 ppm at water concentration levels of 15-30%. We intend to add more field comparison testing on actual stack tests to augment the initial findings found in our laboratory test results.

Due to very low NOx emissions required in many Air Quality Districts in the United States, particularly in the Los Angeles basin, taking into consideration the lower absorption exhibited by the thermoelectric cooler; the South Coast Air Quality Management District (SCAQMD) issued their Rule 100.1, which requires the use of a thermoelectric cooler in combination with the impinger train, for all relative accuracy and compliance testing within the district.

By integrating the low gas absorption feature of a thermoelectric cooler with its rapid load response, M Class modular design, and efficient power consumption, into a gas sample conditioning system; a flexible, reliable pollutant measurement can be made on a continuous basis with greater than 98% uptime, which will pass the most stringent of performance testing.

BEI
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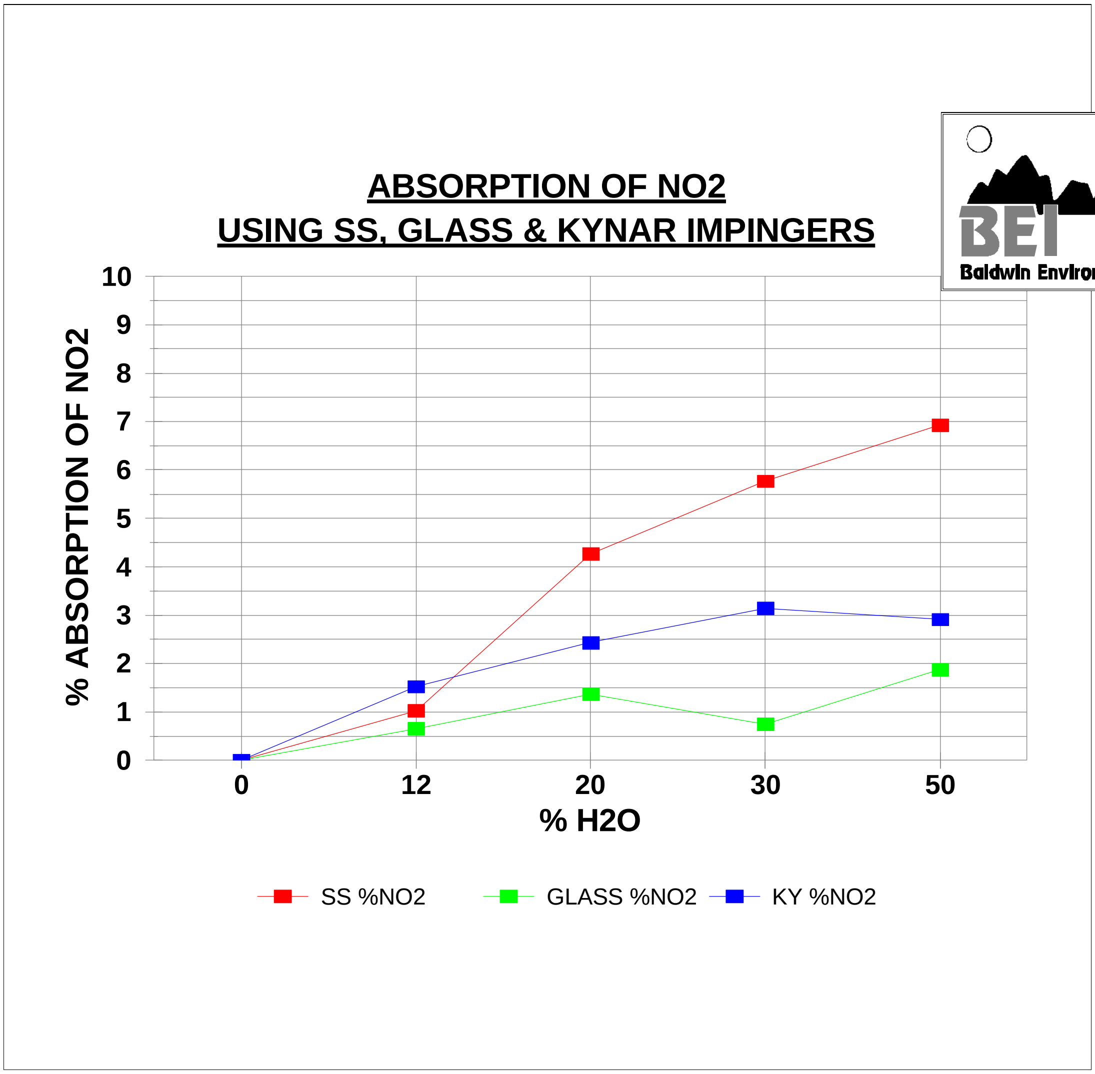

ABSORPTION OF NO2
USING SS, GLASS & KYNAR IMPINGERS

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JANUARY 24, 1999**

FIGURE A

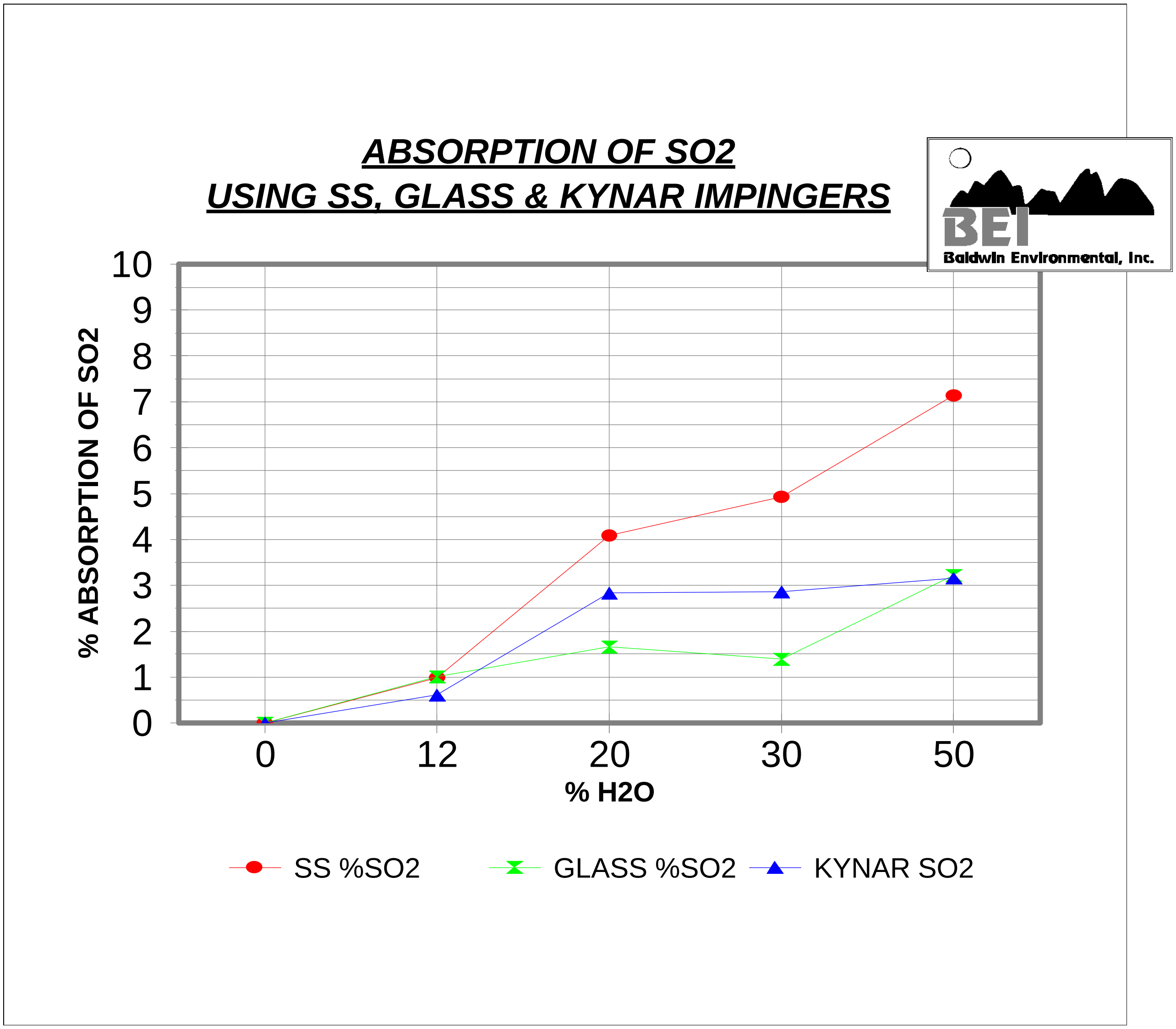

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FIGURE B

EPA METHOD 6 GLASS IMPINGER TRAIN GAS ABSORPTION TEST
JANUARY 21, 1999

TEST CONDITION	% H20	INDICATED PPM SO2	INDICATED PPM NO2	INDICATED PPM NO	CORRECTE PPM SO2	CORRECTE PPM NO2	CORRECTE PPM NO	% SO2 ABSORB.	% N02 ABSORB.	% NO ABSORB.	% H20 RESIDUAL	DEW POINT TEMP.
SAMPLE	0.0000	173.0000	475.0000	101.0000	173.0000	475.0000	101.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FLOWRATE	10.0000	166.0000	476.0000	100.0000	167.6800	475.0000	100.0000	3.0751	0.0000	0.9901	0.9220	+6
4 L/M	20.0000	156.0000	461.0000	98.1600	157.9900	466.6000	99.3000	5.7789	1.7684	0.7000	1.2800	+10.8
	30.0000	148.0000	444.6900	98.0000	149.9000	444.6900	99.2700	5.1206	4.6957	0.0302	1.2900	+11.0
	50.0000	136.1600	399.6000	97.1600	138.0700	404.7500	98.3200	7.8919	8.9815	0.9570	1.3900	+12.3
SAMPLE	0.0000	173.0000	475.0000	101.0000	173.0000	475.0000	101.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FLOWRATE	10.0000	169.0000	475.0000	101.0000	170.5700	475.0000	101.0000	1.4046	0.0000	0.0000	1.2800	+10.7
8 L/M	20.0000	160.0000	464.0000	99.8000	162.0700	470.0000	100.5000	4.9833	1.0526	0.4950	1.3400	+11.5
	30.0000	153.0000	451.0000	99.2000	154.9900	456.8900	100.4000	4.3685	2.7894	0.0995	1.3900	+12.5
	50.0000	139.0000	403.0000	98.0000	140.9500	408.6800	99.3800	9.0586	10.5518	1.0159	1.6500	+14.4

FIGURE C