Tri-Mer® Corporation
1400 Monroe St. • P.O. Box 730 • Owosso, MI 48867 • (989) 723-7838 • Fax (989) 723-7844

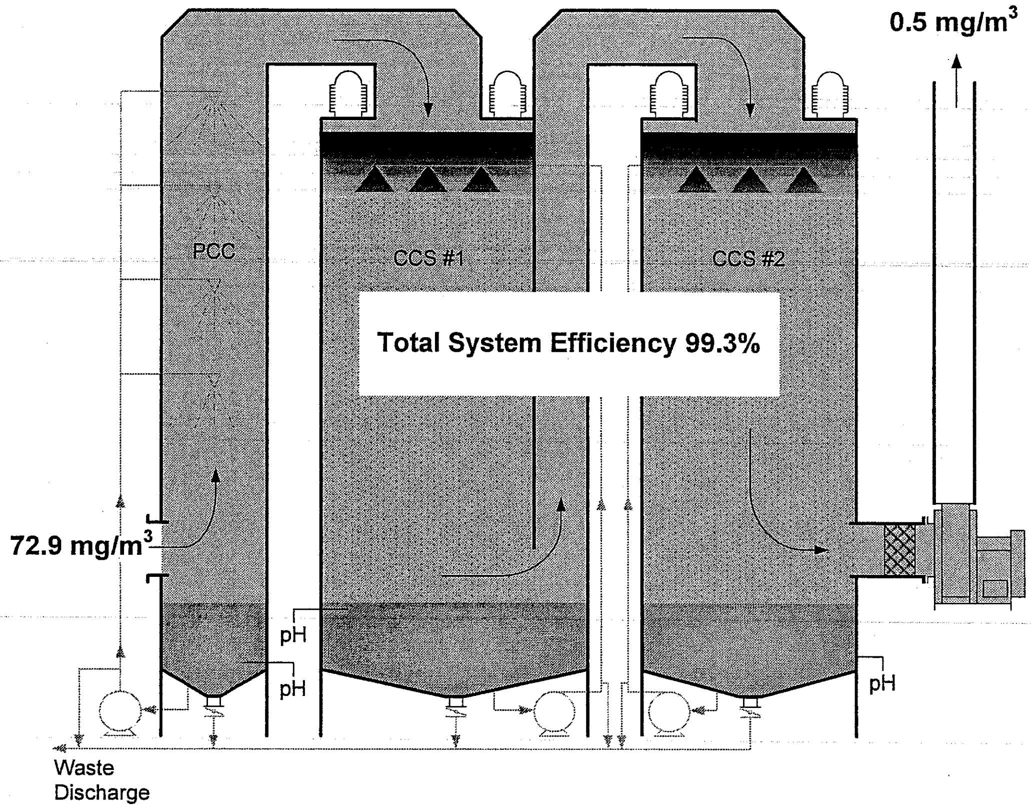
CLOUD CHAMBER SCRUBBER PERFORMANCE RESULTS

FOR DIESEL EXHAUST

Summary of Results

The following is a report of the results of testing of Tri-Mer's Cloud Chamber Scrubber technology using exhaust from diesel fuel as a source. Performance evaluation tests were recently conducted at the Tri-Mer factory to determine the removal efficiency for total particulate and condensable organics of a 2-stage Cloud Chamber Scrubber (CCS) system equipped with a Pre-conditioning Chamber (PCC) for diesel exhaust . The results of the test showed that the CCS removed total particulate matter and condensable organics in excess of 99% as shown in Figure 1. The evaluations also showed that the CCS system could operate on a continuous basis with no reductions in performance or impacts to the system that might be cause for concerns in regards to long-term commercial operations.

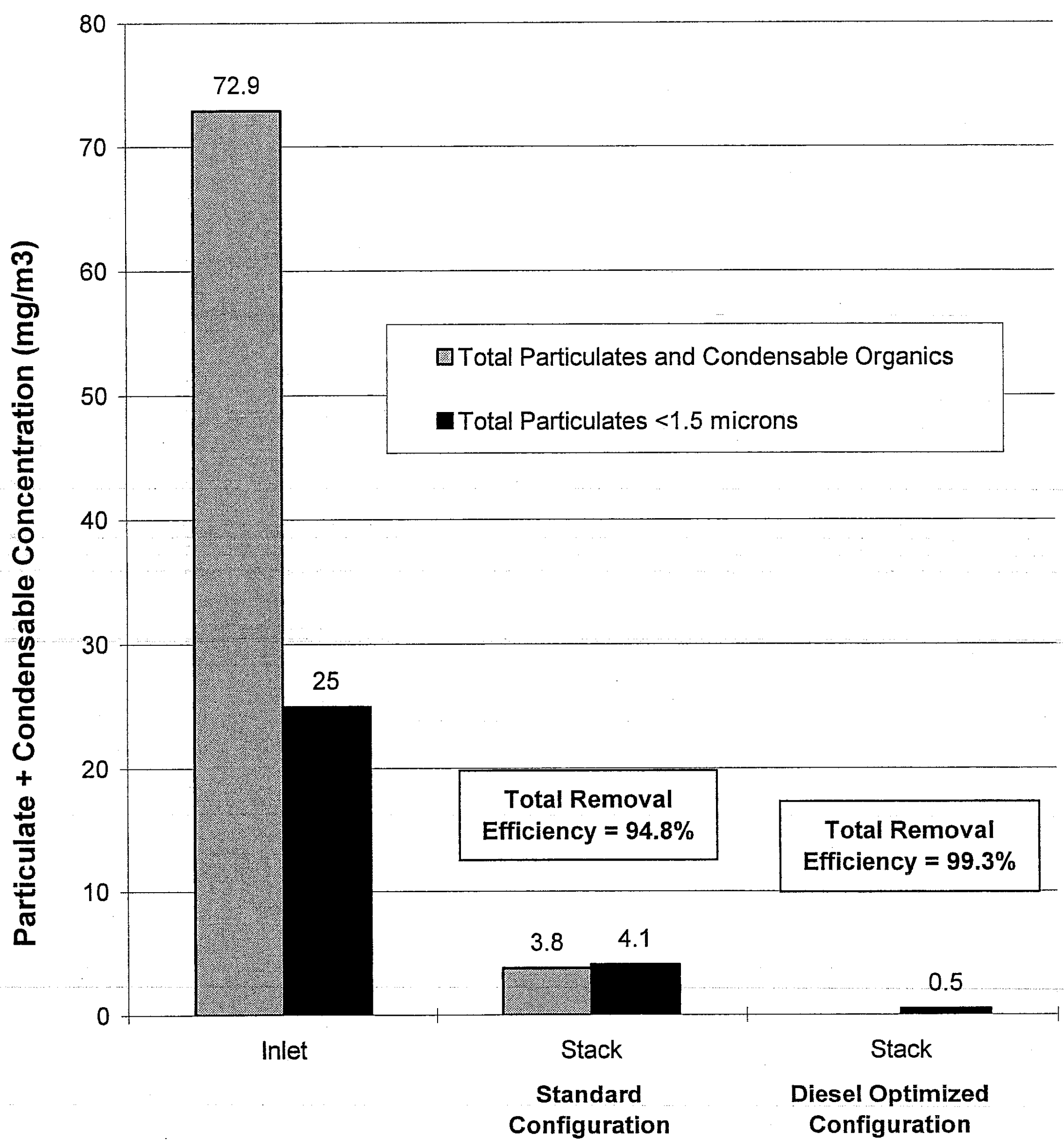
Figure 1
CCS Performance Summary – Total Particulates & Condensable Organics



For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Two different testing methods were used to determine the CCS performance performed over a two week period. The first involved the use of filters and gravimetric analysis, and determined the performance of the system for total particulates and condensable organics. The second used a continuous analyzer to determine the performance of the system for particulates that are less than 1.5 microns in size. Figure 2 is a summary of data for both evaluations and shows the performance of the system for the standard configuration and a configuration that was optimized for Diesel exhaust.

Figure 2
Diesel Exhaust Performance Data - Gravimetric & ELPI Measurements



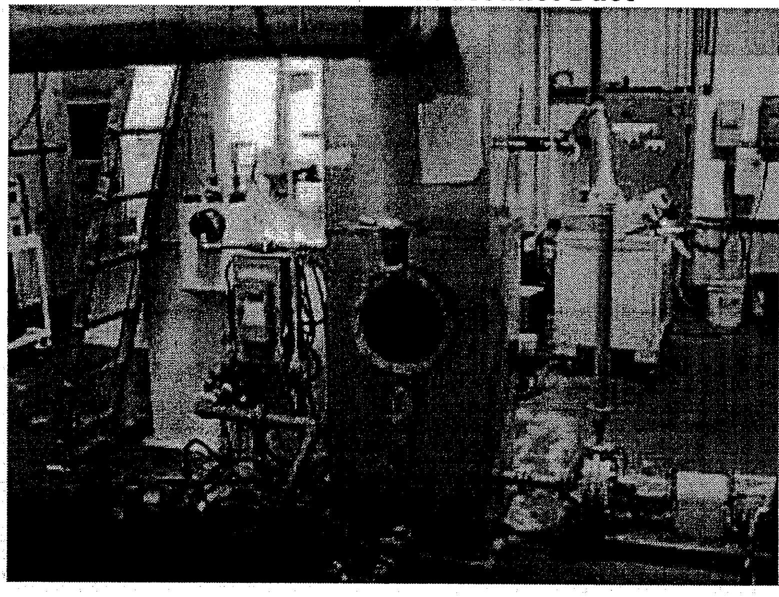
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

The evaluations were completed using a fully operational system located in Tri-Mer's engineering laboratory. Photos of the system from two different angles are shown below. This system is nominally designed for flow rates in the range 200 to 600 scfm and can accommodate sources with temperatures up to 1,100 F. A more detailed description of both testing methods and the source of diesel emissions are described below.

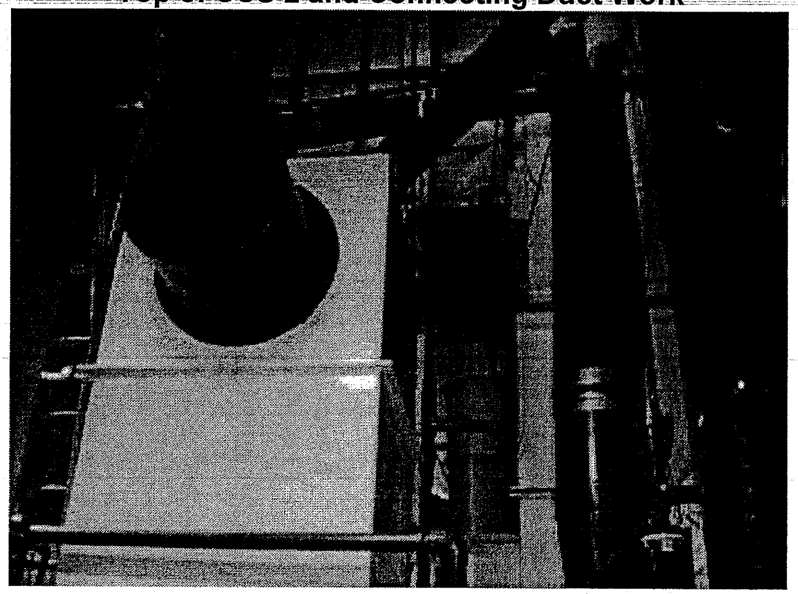
Performance measurements were made using a modified version of EPA Method 5 for total particulates and condensable organics. A Dekati Mass Monitor (DMM) manufactured by Dekati Limited of Finland was used to measure total particulates at or below 1.5 microns.

Based on the data collected and past operating experience with the CCS in other commercial applications, Tri-Mer is now able to deliver commercial CCS systems in various sizes and configurations for the treatment of diesel exhaust from stationary sources.

PPC and Diesel Exhaust Inlet Duct



Top of CCS 2 and Connecting Duct Work

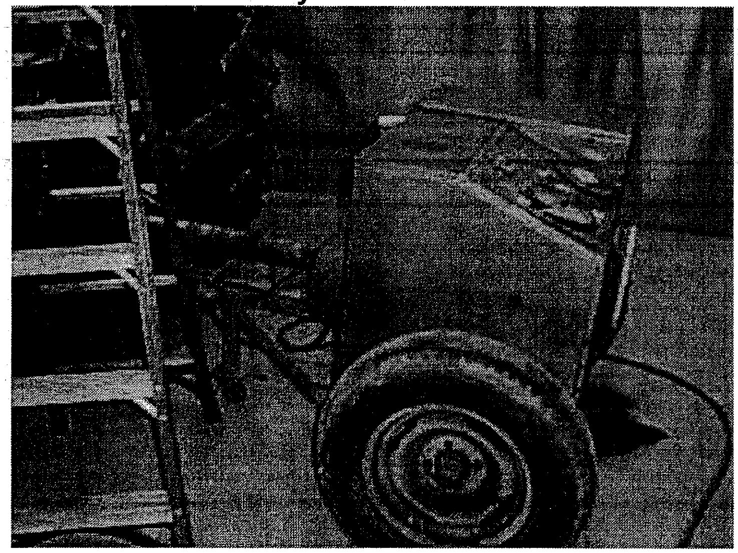


For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Diesel Exhaust Source

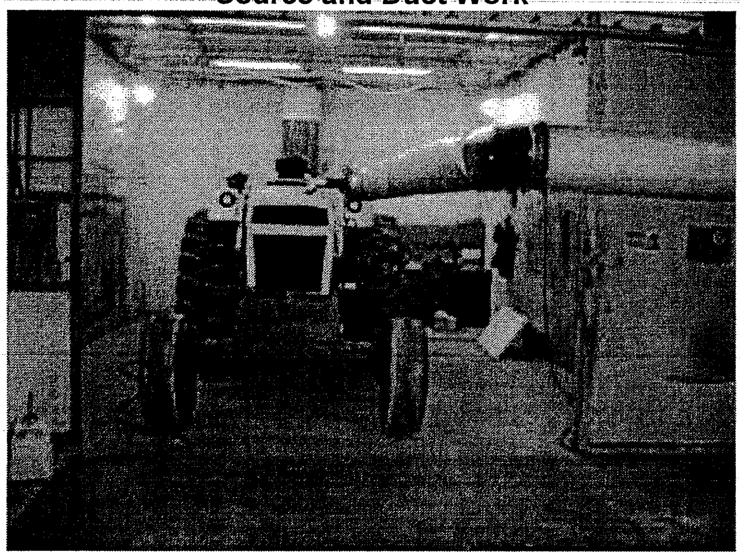
The source used to generate the diesel exhaust was a 1970 Case Agra King 1170 farm tractor coupled to a Hydrogage Model P400 dynamometer. The tractor engine was operated continuously at 2000 RPM. This produced 535 RPM at the PTO and when put under load by the dynamometer produced 67 HP. The published PTO HP for this source is 121. The source was fueled utilizing standard regular on road diesel fuel.

Dynamometer



Prior to coupling the source to the CCS flow characteristics were determined in 240" of 6" steel duct. Under load the source produced 599 acfm at 618°F at 120" from the exhaust manifold flowing at 3186 fpm. The source was then coupled to the CCS via 60'-0" of 12" steel duct which produced a gas flow of 763 fpm or 12.716 fps which provided 4.7 seconds of aging prior to entering the inlet of the CCS. Also, a normal occurrence was cooling of the gas stream to a steady 357°F at the inlet of the PCC during testing.

Source and Duct Work



For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Following temperature stabilization at the PCC inlet several operating parameters of the CCS also reached a steady operating condition as described below.

- After 40 minutes of re-circulating the PCC sump reached and maintained a steady liquid temperature of 120°F.
- The initial CCS sump temperature was 70°F and rose to 80°F after 40 minutes.
- After 2 hours of operation the PCC sump temperature had held at a constant 120°F.
- After 2 hours of operation the CCS1 sump temperature had stabilized at a constant 116°F.
- After 2 hours of operation the CCS2 sump temperature had stabilized at a constant 102°F.
- All other parameters such as re-circulation flow rate, nozzle pressure, and gas flow remained constant throughout the test.
- Fuel consumption averaged 27.8 lbs/hr.

Some noticeable changes did occur to the system over the duration of the test and are listed below.

- Sump conductivity in the CCS increased from a baseline control water sample measured at 807 μS (microsiemens) at 23.3°C to 994 μS at 39.0°C.

CCS System Configuration and Theory of Operation

Based on advances in electrofluidics, Cloud Chamber technology treats submicron particulate matter (including condensable gases) with a high degree of efficiency—typically greater than 99%—while simultaneously removing soluble gases traditionally treated with a wet scrubber. Similar to the way that a thunderstorm clears haze from the atmosphere, Cloud Chamber technology uses charged water droplets to remove very fine particles from pollution sources.

With its broad treatment capabilities, the Cloud Chamber is an effective and cost effective air pollution control solution for any industrial exhaust application that produces submicron particles. Cloud Chamber technology can also be integrated into ventilation systems, providing increased air purity for delicate industrial processes and protection from airborne molecular contamination (AMC) and from biological and chemical agents.

CCS technology works by passing the contaminated gas stream through a chamber that contains a carefully generated atmosphere of high-density charged water droplets (the scrubbing "cloud"). Inside an operating cloud chamber system, billions of charged droplets move rapidly, changing direction randomly. When a particle and a droplet pass within 20 microns of each other, electrical forces cause mutual attraction, with the less massive particle being pulled towards the droplet. Each individual water droplet therefore becomes a particle collector.

These droplets actively collect particles as they move downward through the chamber, eventually "raining" into a collecting sump at the bottom of the system. Captured particles are removed as a low volume slurry from the bottom of the sump. Water from the top of the sump is recirculated, recharged, and returned to the Cloud Generation Module at the top of the chamber.

Since the charged droplets act as the particle collectors, there is no need for fibrous filters, collector plates, venturi throats, layered pads, bags, or cartridges.

Several factors influence the effectiveness of a Cloud Chamber system. These factors include droplet size, droplet charge, particle size, particle charge, particle retention time, and electric

For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

field effect. For each application, a computer simulation can be run to analyze these factors, along with inlet loading and information on any gases to be treated. The results from this simulation are used to determine the ideal system setup, in terms of recirculation flow, gas-to-cloud contact time, charge rate, and chamber size. Fine tuning of some of these parameters then occurs during the start-up phase of actual operation.

Cloud Chamber systems are made up of some or all of the following components, depending on the application and required performance.

Preconditioning Chamber (PCC): The preconditioning chamber uses a coarse spray of water to cool the incoming gas stream, provide an initial stage of gas scrubbing, remove coarse particles (larger than 10 microns), and cause very small particles to agglomerate into particles larger than 0.1 micron.

Cloud Generation Module(s) (CGM): The Cloud Generation Module generates billions of charged water droplets. This module is located in the top section of the CCS unit, drawing a maximum of 10 watts per 1000 cfm.

Cloud Generation Chamber (CGC): The Cloud Generation Chamber works in conjunction with the Cloud Generation Module, acting as the containment vessel where the scrubbing cloud forms. The contact time between the exhaust stream and the cloud in the Chamber determines the efficiency of scrubber operation; the longer the contact time, the higher the efficiency. Each droplet in the Cloud Generation Chamber is capable of collecting thousands of submicron particles as it passes through the chamber. When a droplet has collected enough tiny particles that its charge has been neutralized, it coagulates with other droplets and falls into the sump. The liquid in the sump is re-circulated to the Cloud Generation Module, where new charged droplets are continuously formed.

Mist Eliminator: The mist eliminator removes excess moisture from the gas stream before it exits the system. It is a simple chevron mist eliminator, similar to those found on conventional wet scrubbers. The mist eliminator provides 99.5% droplet removal efficiency on water droplets 15 microns in size.

A schematic of a typical air pollution control system is shown in Figure 3. It illustrates the treatment steps as the gas stream flows through the system.

The contaminated air stream enters the Preconditioning Chamber (PCC) counter flow to a cascade of water. The PCC cools the gas stream, performs the first stage of gas stream scrubbing and conditioning, removes particles larger than 10 microns, and causes the finest particles to agglomerate.

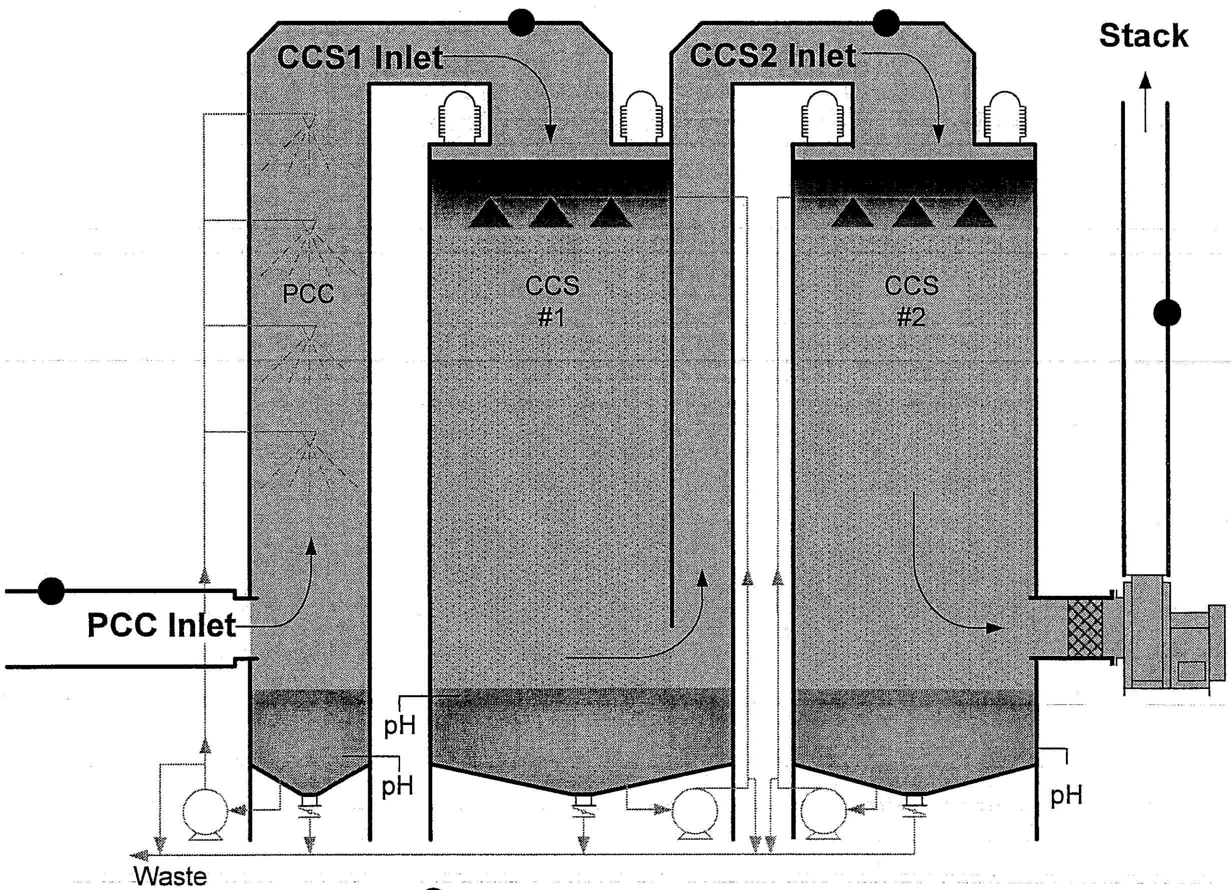
From the PCC, the gas stream enters the Cloud Generation Chamber (CGC), mixing with the cloud of very small, positively charged water droplets. Neutral and negatively charged particles are electrically attracted to the droplets. As the droplets gather negatively charged particles, they become neutral, coagulate, and fall to the sump at bottom of the chamber.

At the same time, the charged cloud scrubs any soluble gases. The cloud acts on the same principle as a wet scrubber, but with as much as <u>100 times the surface area per unit volume than a packed bed</u>, it is much more efficient than a conventional wet scrubber.

For applications requiring a higher level of particle removal, the Cloud Chamber System is fitted with another Cloud Generation Chamber, which creates a negatively charged cloud. Positively charged particles are electrically attracted to the droplets. Because the large majority of particles are electrically neutral and removed in the first chamber, this second chamber is generally not used. Scrubbed gas exits the second CGC and passes through a mist eliminator prior to leaving the system.

For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 3
CCS System – Sampling Locations



Testing Results – Total Particulates and Condensable Organics

Tests to determine the efficiency of the CCS for control of total particulates and condensable organics were conducted on April 1 and 2, 2005. These tests consisted of simultaneously extracting gas from various locations on the CCS system as shown in Figure 3. A log of the samples collected along with the operating conditions of the system during each of the sample collection runs is shown in Table 1. The definition of the table headings are listed below.

- Run # — Corresponds to the Run# shown in Table 2.
- Inlet — Location from which the sample was collected – see Figure 3.
- Outlet — Location from which a simultaneous to the "Inlet" sample was collected – see Figure 3.
- Segments — Defines which portions of the CCS were operating during the test run. The segments are defined at the bottom of Table 1.
- Notes — Identifies any unusual circumstances associated with the run.
- Sump T — Temperature of the sump water for the indicated segment.
- Recirc P — Pressure of the recirculation water for the indicated segment.
- Gas F — Exhaust flow through the CCS system.

- Recirc Flow rate of the recirculation water through the indicated segment.
- Gas T Temperature of the exhaust gas at the indicated segment as either wet bulb or dry bulb.

The sample gas was pulled through a non heated 47 mm PTFE absolute filter which collected both particulates of all size ranges and condensable organics. The volume of gas was totalized and corrected to standard conditions using a vacuum pump and electronic mass flow controller (MFC). The mass of the filters was determined before and after sample collection using an analytical balance with a sensitivity of 0.1 mg. The samples were stabilized for weighing by oven drying and desiccation. The mass of particulate collected was combined with the sample volume to calculate the mass emissions as mg/Nm3. The results of these calculations are shown in Table 2.

The results of each sample collected at various locations along the gas flow path of the CCS, from the inlet to the stack, are shown in Figure 4. The average for the multiple runs is also shown and these values are shown in the Figure 5. These averages were used to calculate the removal efficiency between each of the system stages and are shown in Figure 6. The data was collected when the system was operating in a dual standard configuration and subsequent data collection using a DMM has allowed the optimization of the system for diesel exhaust which is significantly more efficient. The DMM data is shown in the next section and indicates that the overall efficiency of the CCS system for particulate matter and condensable organics is greater than 99%.

Testing Results – Particulates <1.5 microns

On April 12, 2005 performance measurements of the CCS system were collected using a DMM provided and operated by Dukati. The instrument was operated continuously during the day and data was collected while operating the system in a variety of different configurations. The data was logged and the resulting plots are shown in Figures 7 and 8. The various important operating conditions are annotated on these plots.

A summary of the data collected at various locations along the CCS system is shown in Figure 9 along with the removal efficiencies for each of the various stages. This data is for a system that is optimized for diesel exhaust. The average values for particulate concentrations measured by the DMM are shown in Figure 10.

Testing Results – SO2

During April and May of 2005 a pilot test of the CCS technology is being conducted on the exhaust of a glass melting furnace. This exhaust contains significant amounts of both SO_2 and sodium sulfate particulates. The pilot unit is very similar to the unit being used for diesel testing in design and construction, however is sized for twice the flow. The primary difference in operation between the two systems is in the addition of sodium carbonate to both the PCC and CCS sumps to maintain a pH of approximately 8 in the glass furnace pilot. The Sodium carbonate reacts with the SO_2 to form sodium sulfite, but NaOH can also be used for this purpose and would most likely be the chemical of choice for diesel applications.

Part of this test has involved the continuous monitoring of both the inlet and outlet of the CCS pilot unit for SO_2. To date the monitoring has shown the CCS to be very effective at controlling

For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

SO_2 emissions under a variety of conditions including a single CCS chamber and low liquid to gas ratios. Figure 11 shows eight hours of continuous monitoring data for SO_2 and also shows the calculated removal efficiencies.

Testing Results – Solids Collection

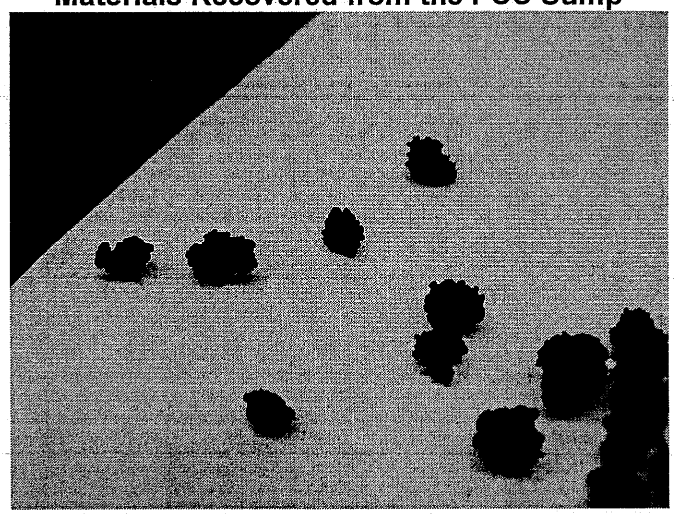
In the case of diesel exhaust most of the emissions are not water soluble with the exception of SO_2 and NO_2. The particulates and condensable organics will be emulsified in the scrubbing liquid of the CCS and will be collected for removal from the system in a number of different mechanisms as described below.

- Accumulation in the sump of the PCC for which an example of these materials are shown in the photo below. In addition to these "globs" of grease (condensable organics) and carbon, the PCC also accumulates emulsified carbon and grease. These materials will be removed from the PCC by overflowing gravity drain to a sluicing filter before re-circulation and by blowdown to waste storage.

- Accumulation in the sump of the CCS for which an example of these materials are shown in the photo below. Unlike the PCC, these materials were collected in a bag filter that was on the recirculation line of the CCS. This filter effectively removed a significant portion of the emulsified carbon and grease. In commercial units these materials will be removed from the CCS by overflowing gravity drain to a sluicing filter before re-circulation and by blowdown to waste storage.

The use of a sluicing filter in the commercial systems will produce a liquid waste that may require further reduction of oil and grease content prior to discharge to the POTW and a separate sludge that is high in organic content. This sludge will need to be handled and disposed of as a hazardous waste. The volume of sludge will be equal to the amount of particulate and condensable material removed by the CCS.

Materials Recovered from the PCC Sump



For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Materials Recovered from the CCS Re-circulation Filter Bag

The efficiency of sludge removal during the testing of the system using the DMM was determined by drying and weighing the bag device that was filtering the recirculation water in CCS 1 and CCS 2. This particular filter bag was from Loeffler Filtration and sized to capture 100 micron particulate. A new bag was inserted in a Hayward double-length basket strainer prior to the start of the test.

Upon completion of the testing bag was removed from the filter housing and dried. The bag was not weighed before inserting it, therefore the average base weights from three unused bags was used for the base line weight. Using the recirculation readings from the liquid flow meters in the CCS system it was estimated that 11,232 gallons passed through the bag during the test.

Bag weight after test	304 grams
Sample bag average weight –	203 grams
Sample bag 1 – 206.82 grams	
Sample bag 2 – 210.21 grams	
Sample bag 3 – 193.01 grams	
Total collected material weight –	101 grams

This material represents 5.5 hours of continuous operation at an average CCS removal efficiency of 95%. With a flow rate of 266 scfm through the system and a total particulate load to the CCS chambers of 49.9 mg/m3 the total particulate mass transferred to the CCS liquid would be 111 grams. This compares very favorable with the 101 grams that was collected in the filter. These results indicate that a high level of sludge removal can be accomplished by filtration.

For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Table 1 – Gravimetric Sampling – Sample Log

Run #	Inlet	Outlet	Segments	Notes	Segment A (PCC)					Segment B (CCS1)					Segment C (CCS2)					Stack	
													inlet Gas T					Inlet Gas T		Gas T	
					Sump T	Recirc P	Gas F	Recirc F	Gas T	Sump T	Recirc P	Recirc F	Dry	Wet	Sump T	Recirc P	Recirc F	Dry	Wet	Dry	Wet
					F	*psi*	*scfm*	*gpm*	*F*	*F*	*psi*	*gpm*	*F*	*F*	*F*	*psi*	*gpm*	*F*	*F*	*F*	*F*
1	CCS2	Stack	A+C	1	122	30	266	160	362	98	52		126.0	124.9	98	66	48	106.4	105.6		
2	CCS2	Stack	A+C	1	124	30	266	160	355	103	52		120.0		105	66	48				
3	CCS1	Stack	A+B+C		124	30	266	160	358	105	52		118.0		105	66	48				
4	CCS1	CCS1	A+B		122	30	266	160	355	105	52		118.0		105	66	48				
5	CCS 2	Stack	A+B+C+D	3	122	30	266	160	354	105	52		124.8	124.9	105	66	48	105.9	105.0	108.0	107.1
6	PCC	NA	A		120	30	266	160	361												
7	PCC	NA	A		120	30	266	160	358	All data was static from Run 5											
8	PCC	NA	A		122	30	266	160	362												
9	CCS2	Stack	A+B+C		122	30	266	160	356	75	52		120		75	66	48				
10	CCS2	Stack	A+C	1	123	30	266	160	359	82-98	52		120		82-98	66	48				
11	PCC	NA	A		122	30	266	160	362	102	52		120		102	66	48				
12	CCS2	Stack	A+B+C	2	122	30	266	160	356	104	52		120		104	66	48				

Segment A = PCC
Segment B = CCS 1 w/ horizontal grid
Segment C = CCS 2 w/ vertical grid
Segment D = Pre-charger

Notes
1 - Water was flowing in CCS 1 during this test, but the charge voltage was off.
2 - 4 oz of surfactant was added to the CCS sump.
3 - The charge on the grid was very unstable and arcing.

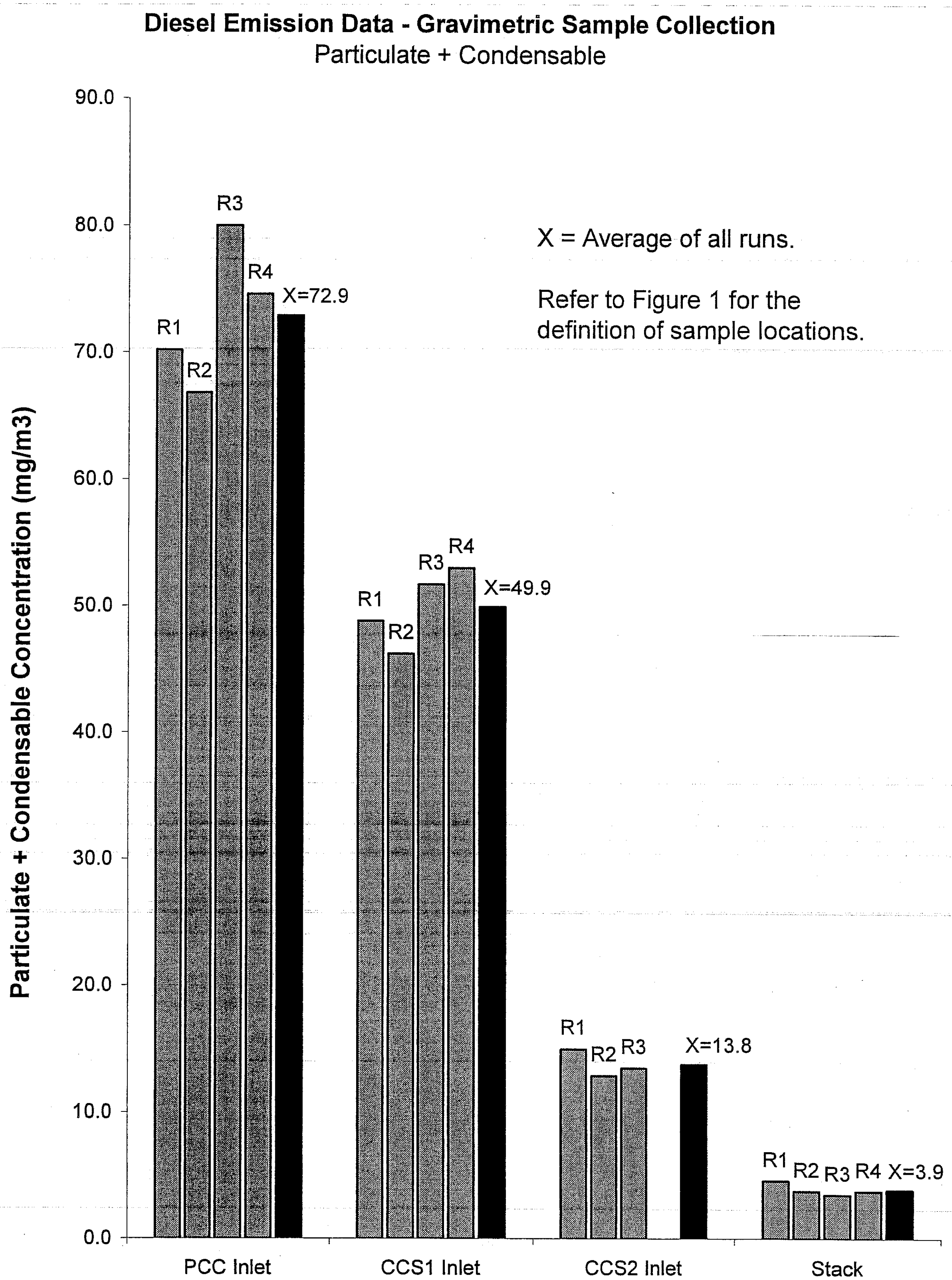
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Table 2 – Gravimetric Sampling – Mass Calculations

Run #	Date	Time	Filter Number	Mass Initial mg	Final 1 mg	Final 2 mg	Total mg	Volume liters	Conc mg/m3	Conc g/scf	DRE %
1 IN	4/1/2005	15:40	12	115.9	121.9		6.0	123.0	48.8	0.021	69
1 OUT	4/1/2005	15:40	13	109.8	111.7		1.9	126.4	15.0	0.007	
2 IN	4/1/2005	17:03	10	106.6	112		5.4	116.9	46.2	0.020	72
2 OUT	4/1/2005	17:03	14	106.6	108.2		1.6	123.7	12.9	0.006	
3 IN	4/1/2005	18:30	13A	118.4	122.4		4.0	77.4	51.7	0.023	91
3 OUT	4/1/2005	18:30	11	108	109.3		0.6	130.4	4.6	0.002	
4 IN	4/1/2005	19:57	18	87.9	92.3		4.4	83.0	53.0	0.023	53
4 OUT	4/1/2005	19:57	20	88.1	91.1		3.0	121.4	24.7	0.011	
5IN	4/1/2005	21:46	22	87.8	90.2		2.4	119.7	20.1	0.009	81
5OUT	4/1/2005	21:46	16	84.4	85.8		0.5	131.8	3.8	0.002	
6 IN	4/2/2005	9:58	15	197.5	198		2.3	32.8	70.2	0.031	
7 IN	4/2/2005	10:19	17	85.2	87.4		2.2	32.9	66.8	0.029	
8 IN	4/2/2005	10:46	19	88.0	90.5		2.5	31.3	80.0	0.035	
9IN	4/2/2005	11:22	21	86.5	88.2		1.7	125.0	13.6	0.006	74
9OUT	4/2/2005	11:22	24	86.9	87.5		0.6	170.0	3.5	0.002	
10IN	4/2/2005	13:52	27	81.3	86.1		4.8	116.3	41.3	0.018	67
10OUT	4/2/2005	13:52	24	83.9	85.3		1.7	126.0	13.5	0.006	
11IN	4/2/2005	14:08	26	88.5	90.8		2.3	30.8	74.6	0.033	
12IN	4/2/2005	14:42	23	81.5	86.9		5.4	120.3	44.9	0.020	91
12OUT	4/2/2005	14:42	28	82.5	83		0.5	130.0	3.8	0.002	

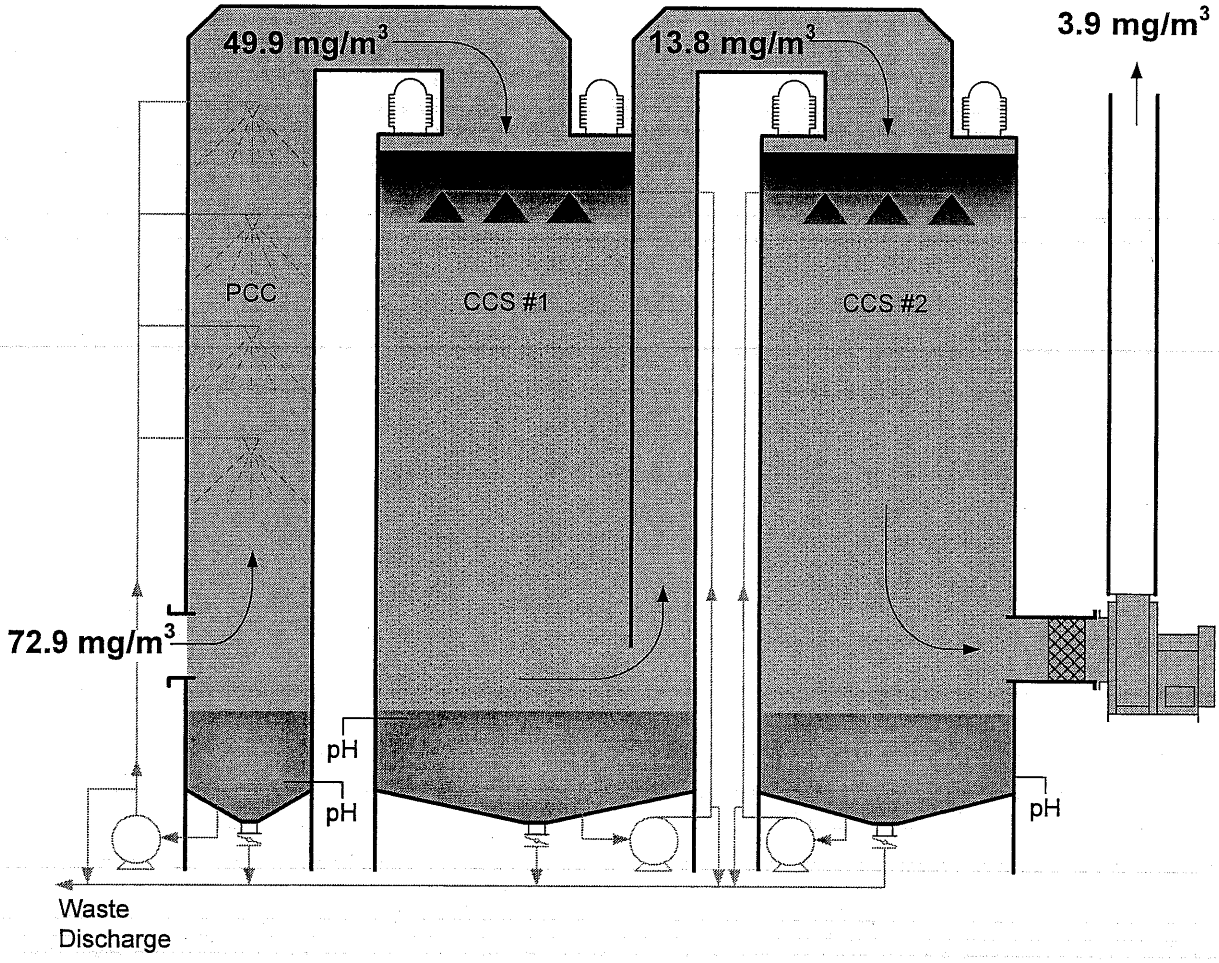
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 4



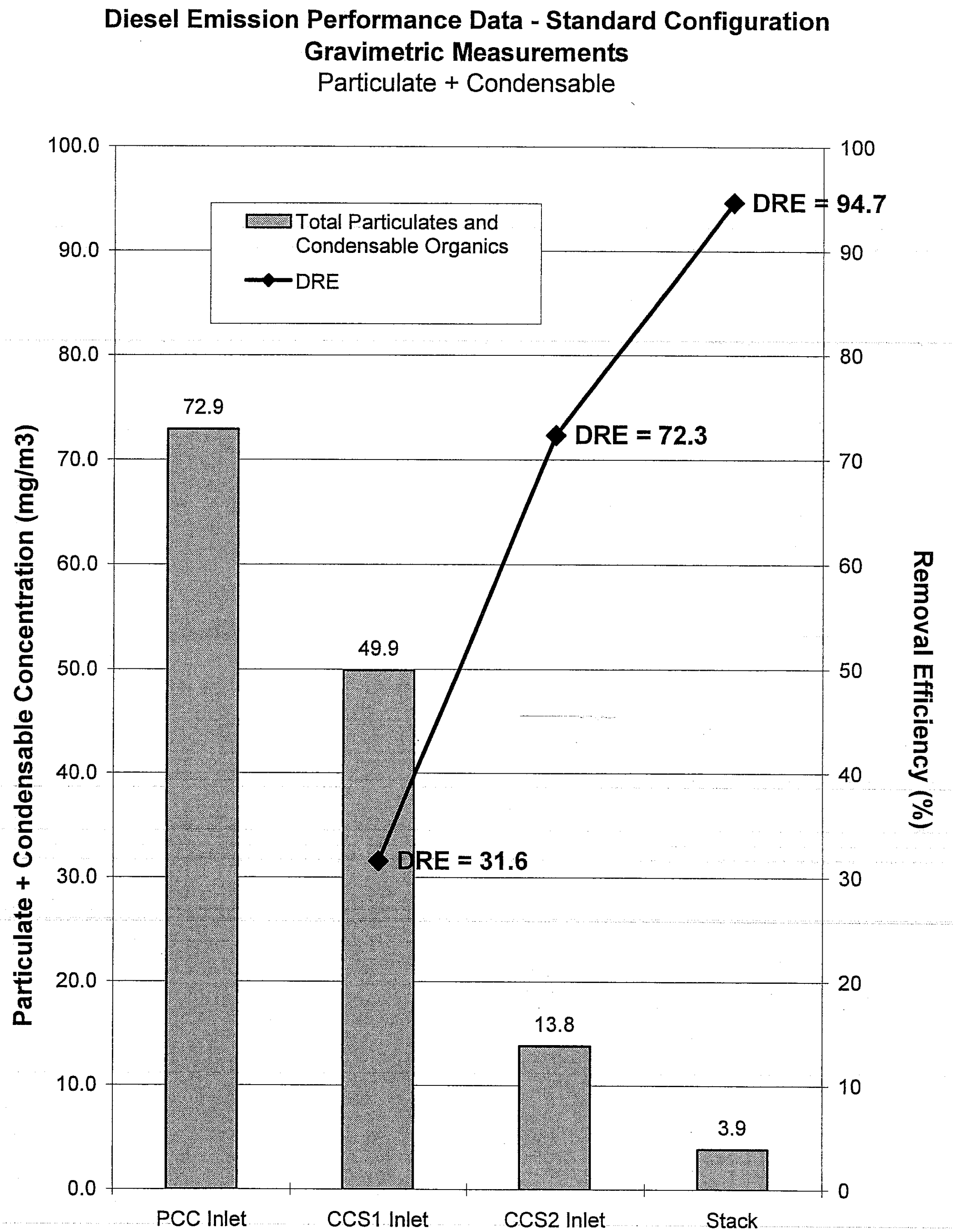
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 5
CCS Performance Summary – Total Particulates & Condensables



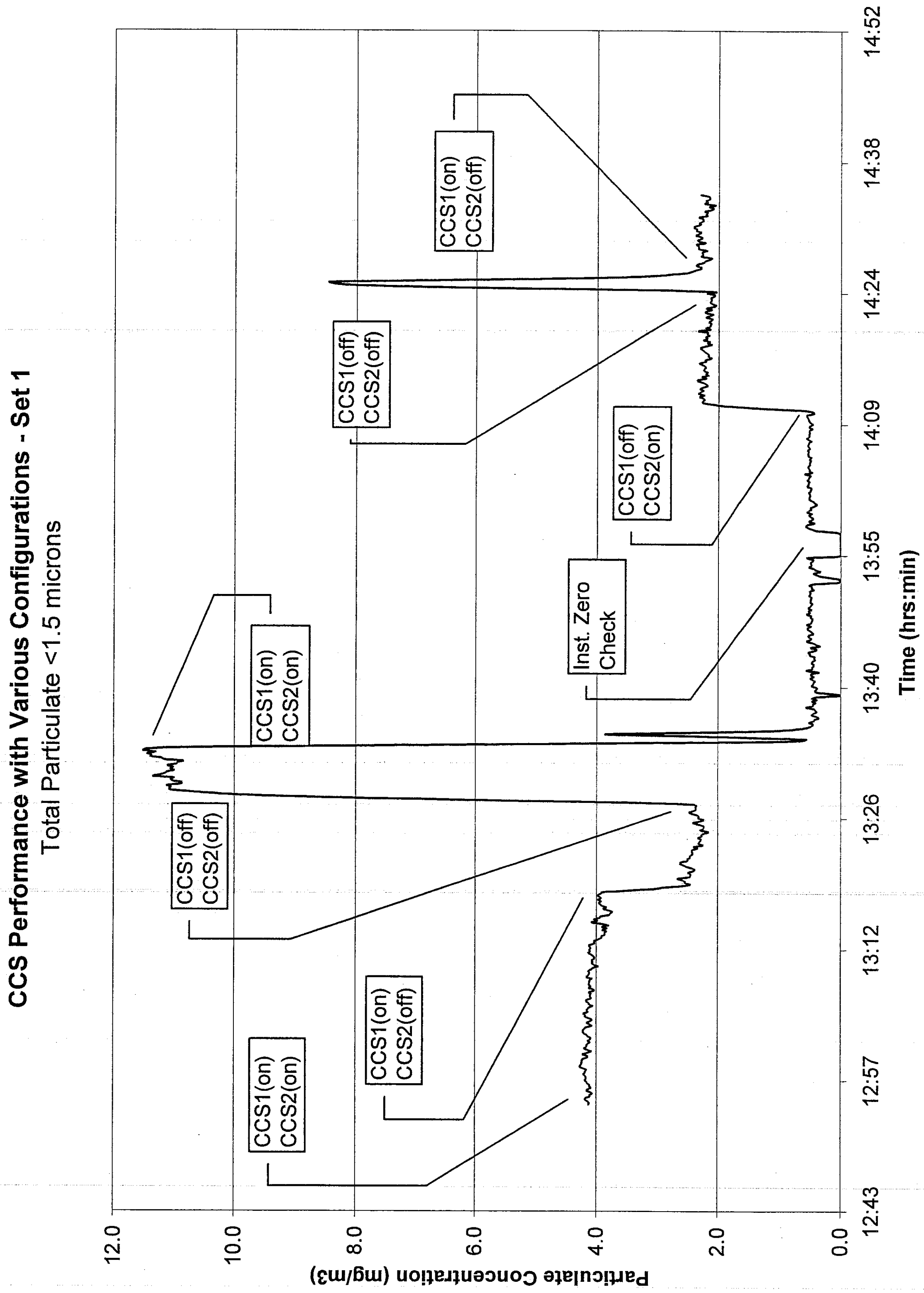
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 6



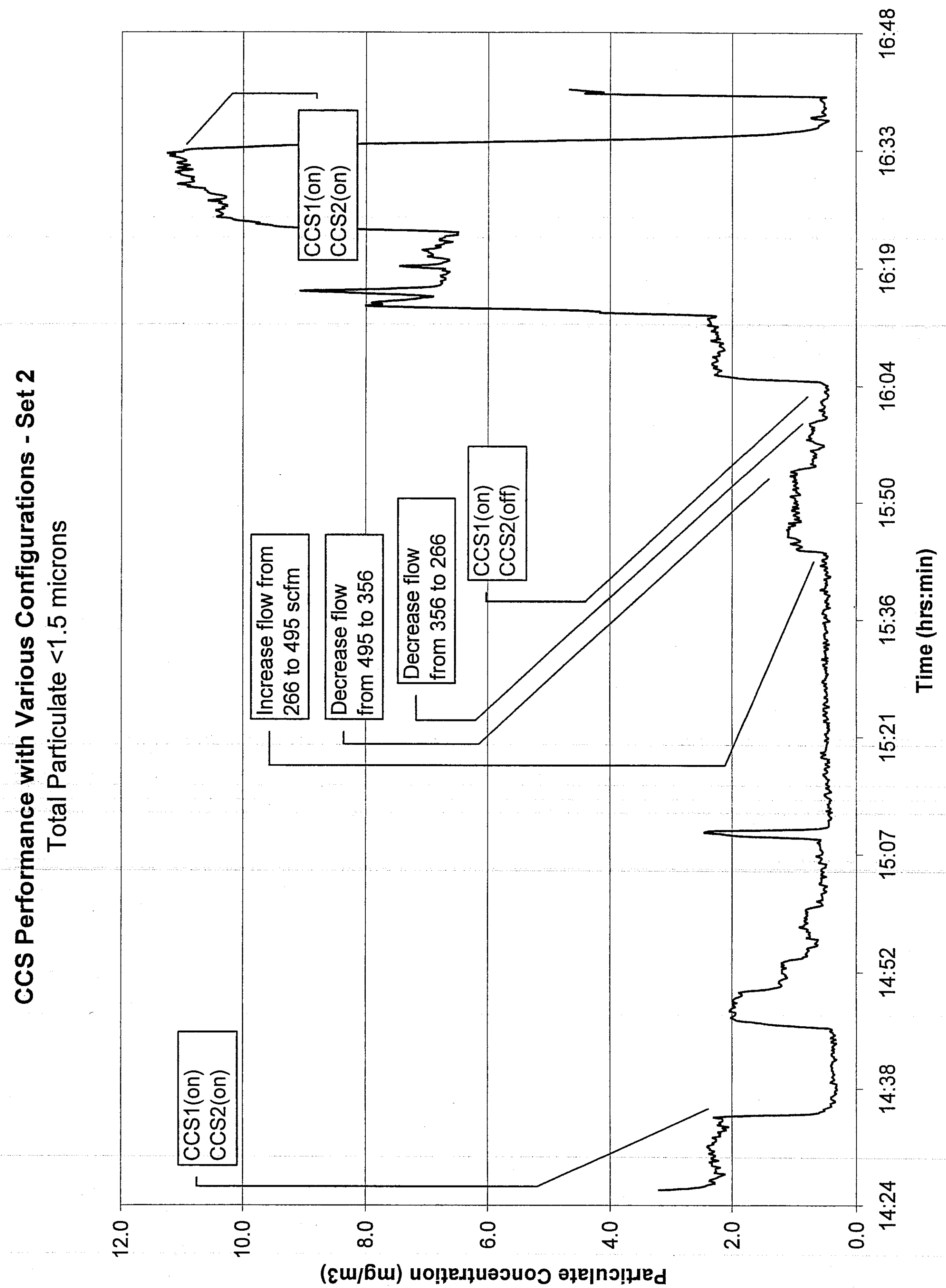
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 7



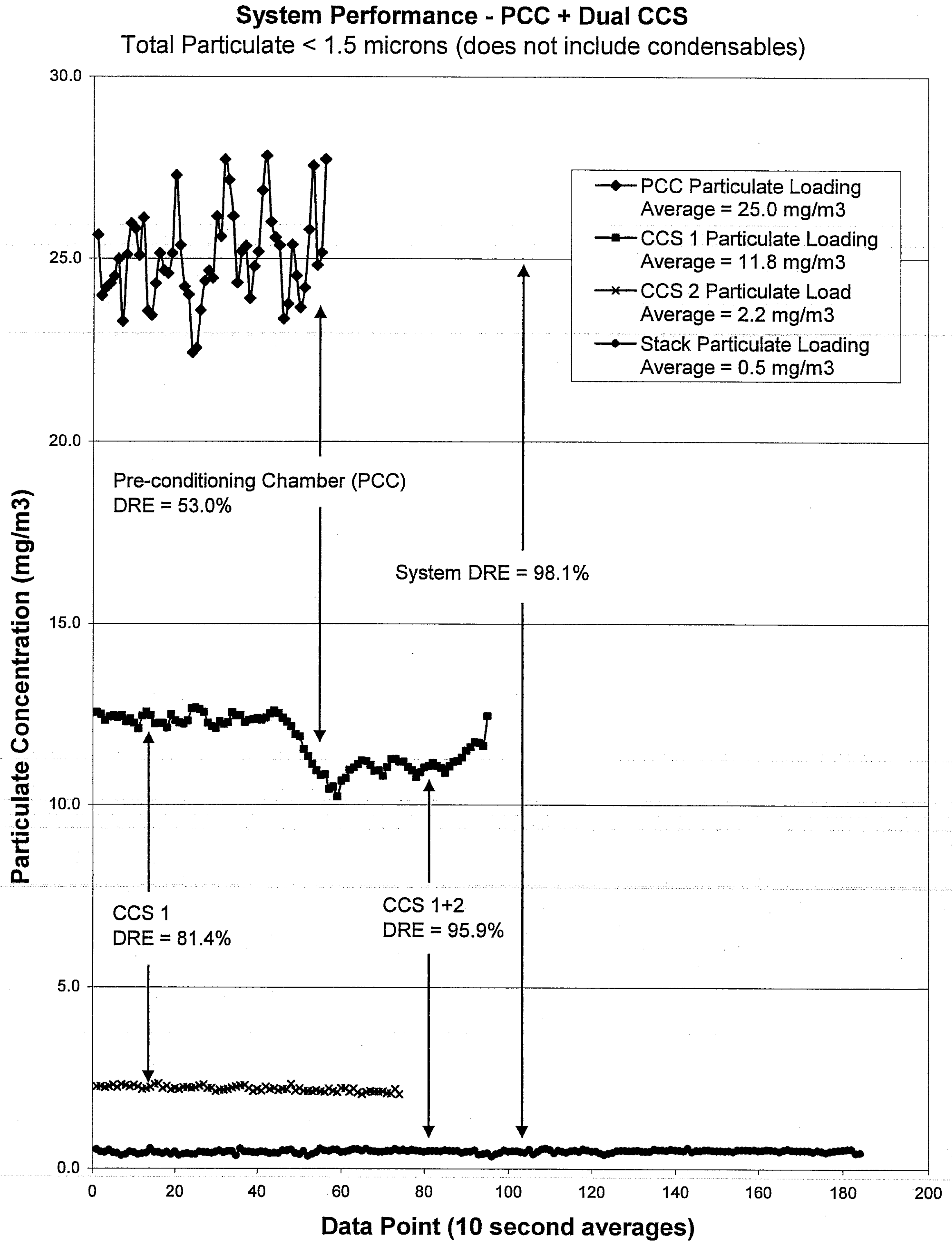
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 8



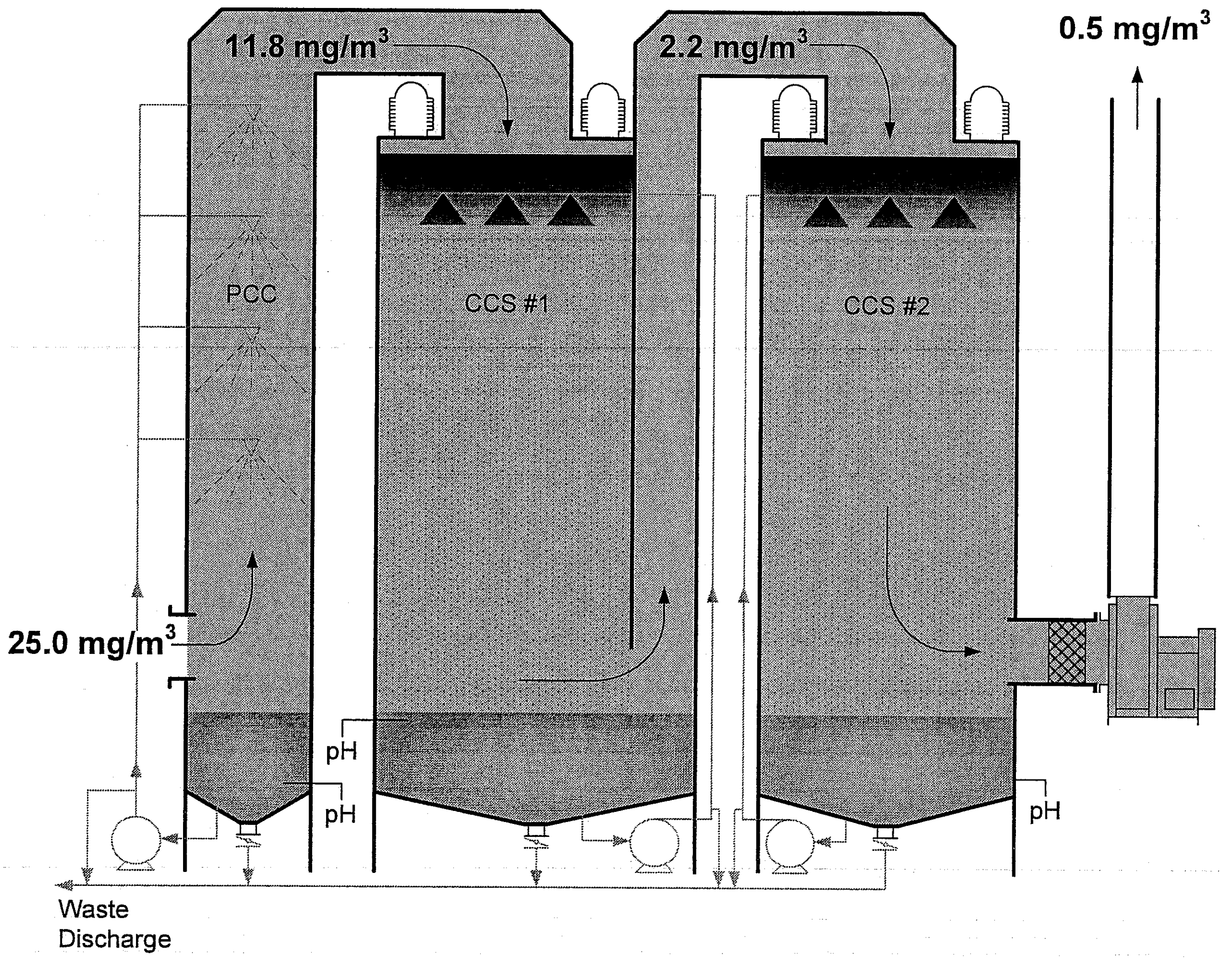
For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 9



For Information Contact:
Rod Gravley - CCS Product Manager - 541-602-2690

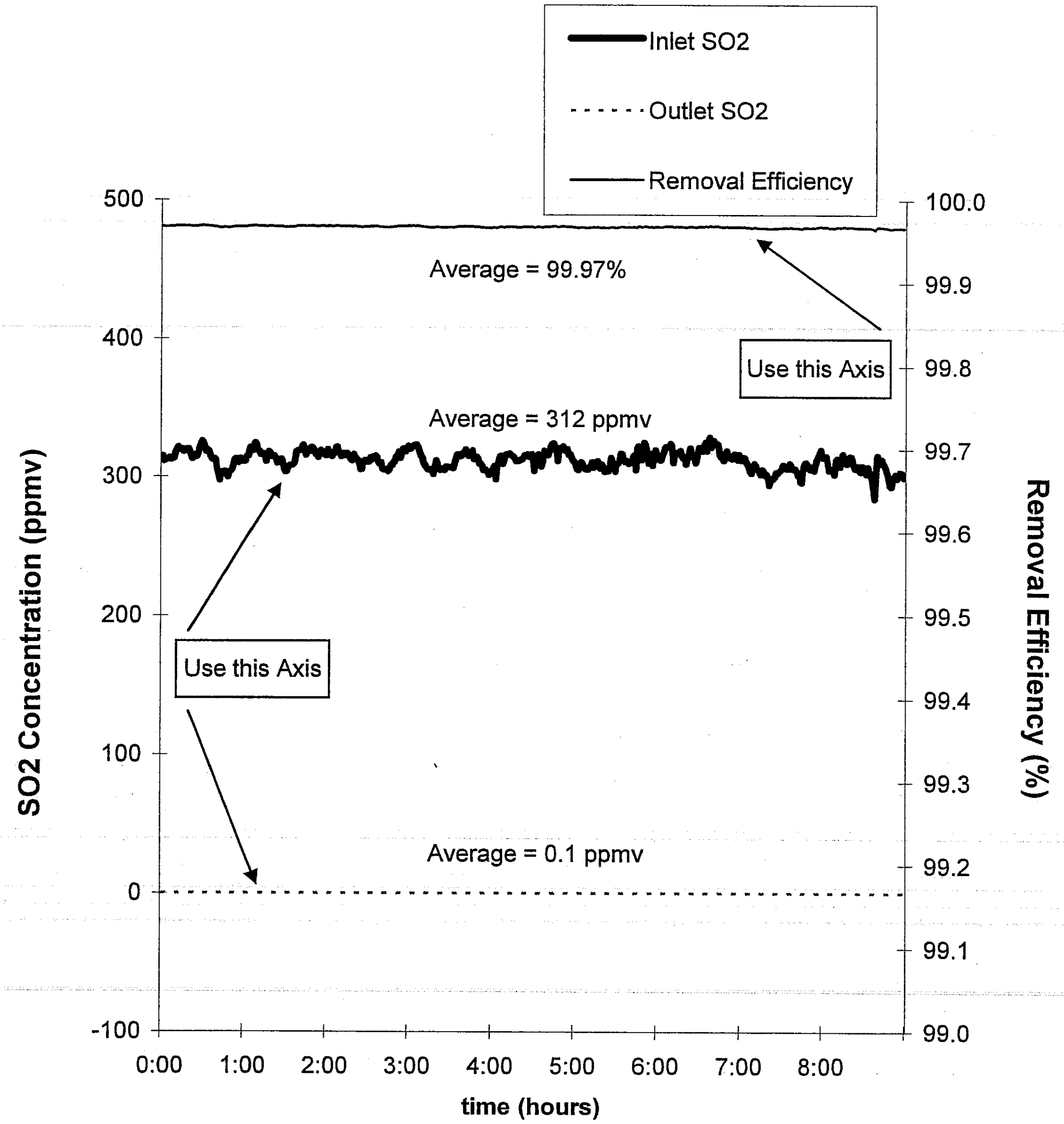
Figure 10
CCS Performance Summary – Particulates <1.5 microns



For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690

Figure 11

CCS Performance Data - Glass Melting Furnace - SO_2



For Information Contact:
Rod Gravley - CCS Product Manager - 541·602·2690