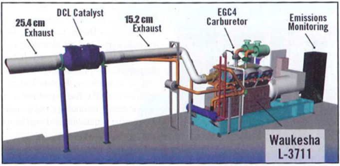
BY JOE ZWERS



Installation layout of the field test site.

A Breakthrough In Ultra-Low Emissions Technology

California companies fund research to develop emissions technology

Southern California, U.S.A., has some of the world's toughest emission standards. However, those standards don't do a bit of good if the technology doesn't exist to meet them.

That was the problem facing companies there when the South Coast Air Quality Management District (SCAQMD) passed stringent new emissions regulations. Under Engine Rule 1110.2, no new distributed generation or combined heat and power (CHP) sites were able to hit the levels required over an extended period of time. But rather than accepting that it couldn't be done, the California Energy Commission's Public Interest Energy Research (PIER) program, Southern California Gas Co. (SoCal Gas) and other parties funded a US$2.1 million research effort to find a solution.

Under the program, Continental Controls Corp. and the Gas Technology Institute (GTI) developed, tested and validated a sensing and emissions control system for reciprocating engines that not only meets new, more stringent emission standards, but can continue to operate for extended periods of time without continuous testing and intervention from a technician. That system is now available for use by companies that need to meet the California standards as well as by others who may not have the same ultra-low emissions requirements but are looking for a way to set up an automated control system to help maintain continuous compliance and simplify operations.

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Setting The Standards

Southern California has long had the reputation for having some of the worst smog in the nation. But it has also made some of the biggest strides over the last three decades in addressing its emissions challenges. There were 121 days with Stage 1 Episodes (one-hour average $O_3 \geq 0.20$ ppm) in 1977, the year the South Coast Air Quality Management District (AQMD) began, but only one Stage 1 Episode in the last dozen years. The region has also gone from non-attainment to full attainment of federal health standards for lead, nitrogen dioxide and sulfur dioxide. All of this occurred despite the area population growing since the late 1940s from 4.8 million to more than 16.9 million, and the number of motor vehicles increasing from 2.3 million to 12.1 million.

Air Quality Drivers

In March 2008 the Environmental Protection Agency (EPA) lowered the federal eight-hour ozone standard from 84 to 75 ppb. As a result of this new federal standard, additional emissions reductions for key ozone-causing pollutants will be required in many local air districts in Southern California. Both the South Coast Air Quality Management District (SCAQMD) and the San Joaquin Valley Air Pollution Control District (SJVAPCD) are currently rated "Extreme" non-attainment areas. SCAQMD models show that the NO_x inventory will have to be reduced from approximately 800 tons per day (inventory in 2008) down to about 70 tons per day by the compliance deadline of 2024. In order to meet this huge reduction, all sources of NO_x, including all stationary point sources, will have to meet far more stringent emissions levels in the future.

SCAQMD amended its engine regulation (Rule 1110.2) in February 2008. Engine applications impacted include distributed generation, water pumping, air compression, gas compression and air conditioning/refrigeration. This air district now requires all existing engines to meet Best Available Control Technology (BACT) emissions levels and requires new engines used in distributed generation to meet NO_x and CO emissions levels approximately five times less than BACT. Engine operators must also demonstrate compliance with these more stringent emissions levels by checking emissions on a weekly basis (smaller engines) or continuously (larger engines).

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The California Emission Commission field test of the Continental Controls Corp. (CCC) ultra-low emissions system utilized a Waukesha L3711 engine.

The Need For New Technology

There was one major oversight with the new Distributed Generation standards — the technology didn't exist to meet and maintain those standards on the reciprocating engines, which were central to the California Energy Commission's strategy of using CHP as a way to reduce fuel consumption and greenhouse gas emissions while improving grid resiliency. In November 2007, therefore, SoCal Gas requested a grant from PIER to develop the control technologies needed.

As SoCal Gas describes in its proposal to PIER, "Engine emissions control technology is lagging the regulatory requirement for criteria pollutants." However, since the regulation applied only to the California market, there were not cost-effective technologies for manufacturers to use to design systems to meet the requirements. The proposal continues, "Engine manufacturers are key to widespread market acceptance of CHP, but they have been unable or unwilling to provide a factory solution to California's emissions requirements or to integrate thermal systems into their CHP packages."

To address this market shortfall, SoCal Gas proposed that it split the cost of developing the new technology with PIER, covering 52% of the total funding. The two-year project would develop and demonstrate ultra-low emissions technology and an up-fit conversion kit for rich-burn engines. The conversion kits would be for engines in the 200 to 800 kW range with a cost of US$15 000 to US$40 000, depending on the size of the engine. Upon completion of the demonstration, the technology would be prepared for commercial exportation for both upgrading existing engines and for use in packaging of new engines.

Initial Laboratory Tests

PIER accepted the research proposal. SoCal Gas selected two main partners for the emissions control part of the project. Continental Controls Corp. (CCC) of San Diego, California, had recently introduced an electronic carburetor called the EGC2, which had the potential to provide greater engine control. In addition, the Gas Technology Institute (GTI) had experience with various sensor technology and it could assist in the acquisition and analysis of engine and emissions data.

CCC and GTI initially conducted laboratory tests using a 5.7 L GM engine with a DCL Inc. catalytic convertor. Three sensor technologies were evaluated: traditional narrow band heated exhaust gas oxygen (HEGO) and wide band universal exhaust gas oxygen (UEGO) sensors; combined nitrogen oxides/oxygen (NO_x/O_2) sensors for catalyst health monitoring; and a heating value/air-fuel ratio (AFR) sensor for use in "feed-forward" control of AFR, which could be used in applications such as biogas or digester gas where the heating value of the gas changes. Through real-time detection of the gas composition, the CCC controller could calculate the ideal AFR mix based on the gas composition going in — not the exhaust emissions coming out of — the engine.

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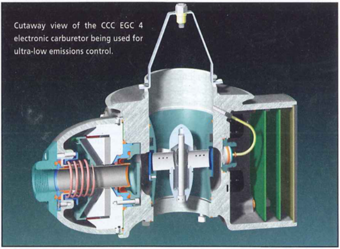

Cutaway view of the CCC EGC 4 electronic carburetor being used for ultra-low emissions control.

Reference Limits	NOx	CO	VOC	Remarks
Prior to 2009	45	2000	250	PPMv Corrected to 15% O_2
Fontana Woods SCAQMD Permit	45	250	250	PPMv Corrected to 15% O_2
SCAQMD Permit (as of 7-1-2011)	11	250	30	PPMv Corrected to 15% O_2
SCAQMD New DG Engines (with heat recovery)	3.5	16.2	14	PPMv Corrected to 15% O_2
CARB 2007 (with heat recovery)	3.5	8.1	2.8	PPMv Corrected to 15% O_2
Current Operation	<3.5	<16.2*	1.3	PPMv Corrected to 15% O_2

The permit history for the Fontana Wholesale Lumber L3711 Waukesha engine. *Occasional excursions above this limit.

The testing was designed to establish a control system that would continue to meet the CARB emissions limits over the long term, or at a minimum be able to meet and maintain the slightly higher Distributed Generation limits. Most AFR Control (AFRC) systems measure the exhaust coming out of the engine and use it to adjust the air-fuel mixture entering the engine. Sensors placed after the catalyst report whether the emissions comply with the appropriate standards. However, there is no way for the operator to tell whether a noncompliant condition is caused by the AFRC malfunctioning, by a mechanical or electrical problem with the engine (such as misfire or detonation) or by a problem with the catalyst.

After repeated tests, CCC employed dithering of the electronic gas carburetors to finally bring the emissions levels into compliance with the R1110.2 DG standards.

Real-World Results

It was now time to test the system in a real-world application. SoCal Gas identified a customer, Fontana Wholesale Lumber (FWL), as the test site. FWL treats wood with heat or chemicals to make it resistant to fire, insects and fungus. The company uses a 12-cylinder Waukesha L3711 engine with a 400 kW generator to provide power for the facility. The exhaust heat is recovered and used to dry the treated lumber or provide heat for the boiler.

For the test, CCC finished the design of a new larger electronic carburetor, the EGC 4, which along with a new DCL catalyst was installed on the engine. The exhaust and catalyst were insulated to retain as much heat as possible, both to improve the performance of the catalyst and to maximize the amount of heat available for the cogen application. A data acquisition system was set up that monitored temperatures and pressures as well as NO_x and CO emissions from more than 25 sensors and other inputs on and around the engine. The data was available for monitoring in real time and stored for later analysis.

The system worked well, but there were occasional CO excursions that couldn't be linked to changes in the load or AFRC. As dithering was integrated into the control scheme, the amount of CO excursions was greatly reduced. The system was generally meeting the SCAQMD R1110.2 standards in the short term.

But one of the objectives was to make it possible for the equipment to continue to maintain compliance for months at a time without having to be tested and adjusted by a technician. To achieve this, CCC developed a catalyst monitor system that included support via CANbus for a NO_x sensor downstream of the catalyst. By using feedback from the NO_x sensor, the system could automatically readjust the setpoint in the oxygen sensor control in the AFR. This intelligent and dynamic feedback to the AFRC represented a significant breakthrough in technology because it signifies a true closed-loop function that can automatically find and readjust the oxygen sensor setpoint to keep emissions at the lowest possible point.

With this system, the engine could operate for months without any operator intervention related to the AFR system. Occasionally, the emissions would temporarily exceed the SCAQMD R1110.2 permitted range for new Distributed Generation, but the system would quickly recover. Over time, the software algorithm continued to refine and adjust the ideal oxygen sensor setpoint and the

David Campbell of Continental Controls and John Vronay of Vronay Engineering monitor the operation of the engine via their computers.

emissions levels continued to improve. At one point, the engine and controller were not adjusted for over three months and maintained emissions compliance throughout the period.

Exporting The Technology

Extensive research in the laboratory and the field have validated that it is possible to modify existing equipment to meet the ultra-low stationary gas engine emission standards set by the SCAQMD. The FWL engine has now operated for more than 3000 hours and it is time to apply what was learned to other sites.

Key findings from the research include:

- In most cases, UEGO (wide band) sensors offer the most stable, dependable closed-loop control for stoichiometric engine controls. They have less drift and are less affected by external temperature and pressure changes than HEGO (narrow band) sensors.
- Using the GTI real-time gas quality sensor to measure the gas composition before it enters the engine could be an effective technique for biogas or other alternative fuels, although it is not currently cost effective for standard natural gas applications.
- The most significant finding was that using a NO_x sensor and software algorithm post-catalyst to provide performance feedback on the entire system, and altering the upstream control loop based on this feedback is an effective way to maintain compliance over the long term and therefore reduce the amount of operator intervention that would normally be required. This technique provides automatic adjustment for drifting sensors or aging three-way catalysts.

The data gained from this project can now be used to help other California distributed generation sites lower their emissions and improve the air quality in their area. But the lessons learned also have broad application in areas that are not subject to California's stringent rules.

A major problem with any type of emissions control system is maintaining its accuracy over time as the catalyst and sensors age. Adding the post-catalyst NO_x sensor to the control system allows continuous, automatic compliance over the long term without having an engineer on-site to measure and adjust the controls. Continuous compliance is far more cost effective than having a technician continuously running around to make adjustments just before an emissions test, and then being out of compliance most of the time.

CCC and SoCal Gas are considering additional field tests to continue testing this new control scheme on other engines and other applications to further refine and improve the technology. The system is now available from CCC for almost all makes and models of natural gas engines.

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