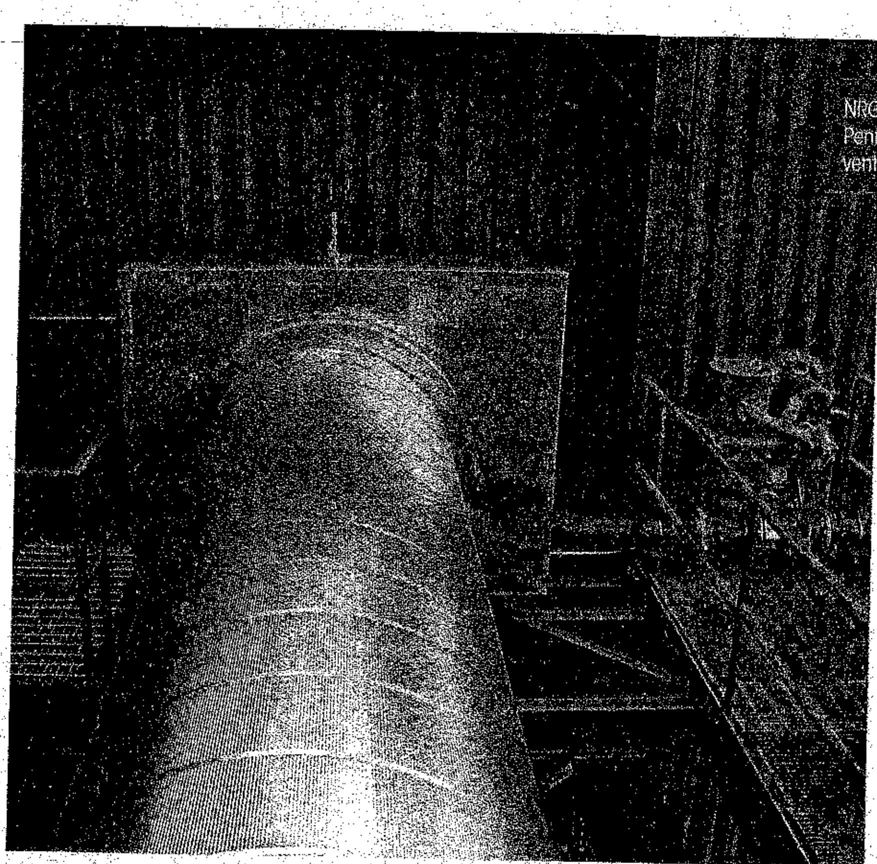

NRG Energy RICE NESHAP installation at Harrisburg, Penn., showing catalyst housing (left) and crankcase ventilation system (right).

Engineering Design for RICE NESHAP Compliance

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In February 2010, the U. S. Environmental Protection Agency (EPA) issued a new national emission standard for hazardous air pollutants (HAPs) that affected existing stationary diesel, dual-fuel and gas engines.

This regulation, known as Reciprocating Internal Combustion Engine National Emission Standard for Hazardous Air Pollutants (RICE NESHAP) was finalized in January 2013, but the original compliance dates have not changed. Diesel and dual-fuel compression ignition (CI) engines must comply by May 3, 2013 and natural gas spark ignited (SI) engines must comply by Oct. 19, 2013.

The EPA estimates that over 900,000 CI engines and over 335,000 SI engines will be affected.

This includes engines located in both major and area sources of air toxics emissions.

The compliance requirements vary and are based on engine size, use of engine, type of engine and source.

Although the regulation affects an estimated 900,000 existing compression ignited or diesel engines, almost 90 percent of these engines will only be required to meet best maintenance practices. However, a significant number of diesel and dual-fuel engines will require the addition of emissions control catalyst to meet the HAPs limits required by the RICE NESHAP regulation.

Since the EPA has chosen carbon monoxide (CO) as a surrogate for the principal hazardous air pollutant formaldehyde, this article focuses on a project to reduce CO emissions from diesel and dual-fuel engines.

In order to comply with the latest RICE NESHAP Standards, the equipment installation requirements for nonemergency diesel and dual-fuel engines greater than 500 horsepower typically include the following:

- Catalyst housing with an oxidization catalyst
- CPMS (continuous parametric monitoring system)
- Crankcase ventilation system
- Use of ultra-low-sulfur-diesel (ULSD) fuel
- Engine hour meter
- Limitations on engine start-up time
- Performance tests to demonstrate engine emission compliance

Operators of stationary engines affected by RICE NESHAP who are not in compliance by the deadline dates can be fined on a daily basis.

A one-year compliance extension can be requested, but the request must be made at least 120 days before the compliance due dates.

BACKGROUND: NRG APPLICATION

NRG Energy, a leading power generation company, operates a 12 MW peaking plant near Harrisburg, Penn. and needed to reduce the CO emissions in order to comply with the RICE NESHAP regulation.

During 2012, NRG worked with RPA Engineering (RPA), a leading, full-service engineering firm based in Wyomissing, Pa. to specify, design and install an oxidation catalyst and associated equipment to meet RICE NESHAP requirements.

Engine operation

The NRG Energy Center Paxton peaking plant is comprised of two Cooper-Bessemer LSVB-20-GDT CI engines that were installed in 1986. Each engine is rated at 8656 bhp and generates 6 MW of electricity.

The catalyst used for the engines was a combination of Platinum Group Metals on a stainless steel metal monolith, with the catalyst blocks arranged in a single layer and the weight of each block limited to 50 pounds.

NRG can operate these engines on full diesel fuel for a limited amount of hours, or dual-fuel (which is comprised of approximately 95 percent natural gas and 5 percent pilot diesel oil).

The engines are started on diesel fuel and are switched over to dual-fuel operation at approximately one-third load.

NRG operates the engines on dual-fuel because of the current cost advantages of natural gas, but NRG also has the capability to operate on diesel fuel only should this be desired.

The Cooper-Bessemer engines at NRG had been previously modified to substantially reduce the emissions of NOx in the engine exhaust compared to an unmodified dual-fuel engine.

Engine No. 1 is equipped with an AMPS System and Engine No. 2 is equipped with a Cooper Clean Burn System.

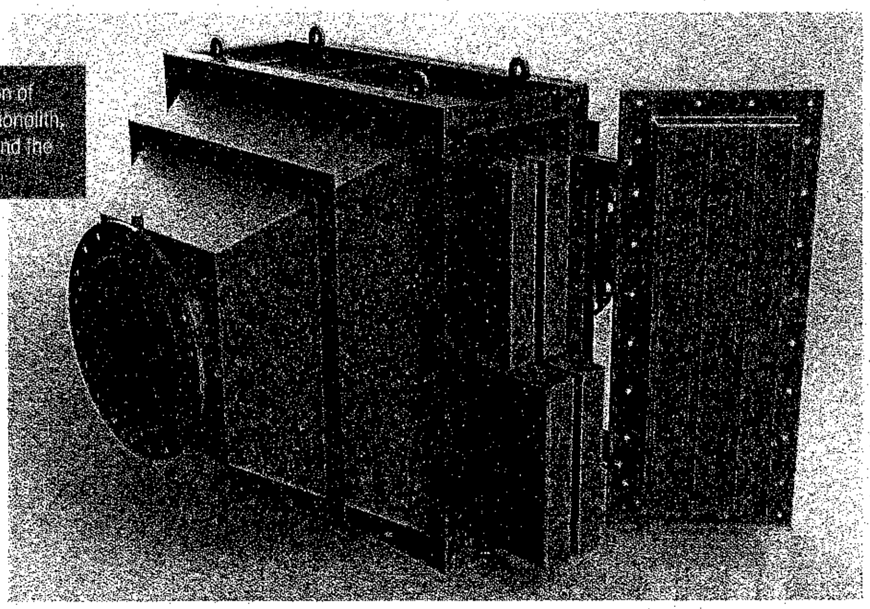
Operators not in compliance with RICE NESHAP can be fined daily.

RICE NESHAP requires that engine's time spent at idle be minimized and that the engine startup be limited to a period needed for appropriate and safe loading of the engine, not to exceed 30 minutes, after which time the non-startup emission limitations apply.

SCOPE REQUIREMENTS FOR NRG ENERGY PAXTON PLANT

Oxidation catalyst

The oxidation catalyst systems installed at NRG were furnished by Johnson Matthey Stationary Emissions Control LLC and designed to meet the RICE NESHAP emissions limit for CO emissions. For CI engines larger than 500 HP at either area sources or major sources, this limit is either an absolute emission



limit of 23 ppmvd CO at 15 percent O_2 or a 70 percent reduction of CO emissions.

The catalyst that was used for each engine was a combination of Platinum Group Metals (PGM) on a stainless steel metal monolith. The monolith was supplied in block-sized modules, and these blocks were inserted in carbon steel housings, with one housing for each of the two engines. The catalyst blocks were arranged in a single layer, with the weight of each block being limited to 50 pounds to facilitate installation and removal from the catalyst housing.

Each of the catalyst housings was equipped with a hinged door to provide access to the catalyst blocks from an adjacent walkway. The housings were installed outside of the generator building and were externally insulated to reduce heat loss. Each of the housings included spare catalyst tracks for future use should environmental regulations become more stringent. The catalyst tracks are designed to float within the housing to compensate for thermal expansion and to seal the catalyst modules to prevent exhaust gas from bypassing the catalyst.

The engine exhaust flow rates, temperatures and emissions were measured in previous exhaust stack testing, and these values were used as the design basis for this project. Although the current CO emission values were not available, the oxidation catalyst will convert CO to carbon dioxide (CO_2) by the design reduction efficiency based on the proper selection of the catalyst's gas hourly space velocity regardless of the amount of CO in the engine exhaust.

According to the RICE NESHAP Rule, the minimum and maximum temperature limits for lean burn CI engines is 450°F and 1350°F, respectively. The minimum temperature is required for the catalyzed reaction to occur; the upper temperature limit avoids thermal sintering of the catalyst. The measured exhaust temperatures of these engines from the previous testing were typically within the limits of the Rule at 500°F to 750°F from start-up to full load operation.

Continuous parametric monitoring system (CPMS):

The RICE NESHAP Rule requires the catalyst inlet temperature (as based on a four-hour rolling average) to be documented and maintained within the minimum and maximum operating temperature limitations noted above. The Rule also requires that the pressure drop across the catalyst be measured once per month to demonstrate that it is maintained within a +/- 2-inch w.c. tolerance (as measured during the initial performance test). NRG collects and stores the data with a Johnson Matthey HapGuard Continuous Parametric Monitoring System.

CPMS data readings are acquired at least every five minutes. The CPMS calculates and stores a one-hour and four-hour rolling average of temperature and differential pressure data for a minimum of 12 months. The CPMS will initiate an alarm signal when temperature or pressure readings and calculations exceed the limits set by the operator. The operator has the provision to define alarm set points and unit identification during the system commissioning.

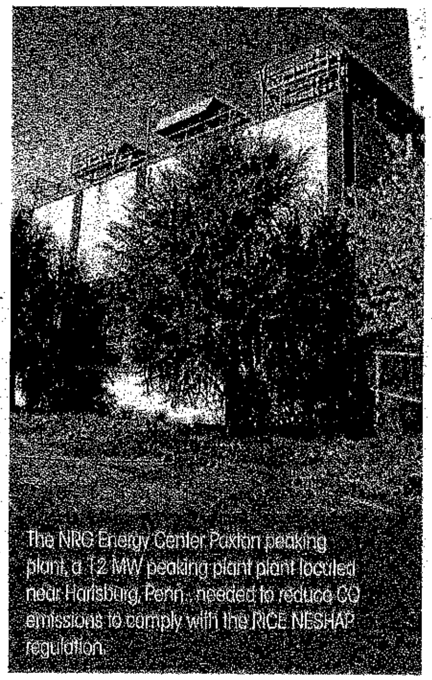
There is a dedicated, programmable CPMS for each engine's catalytic converter, which is installed in a NEMA 4 enclosure near the catalyst housing for each engine. The CPMS is programmable from a keypad on the front panel display. Real time catalyst inlet temperature and differential pressure are displayed on the front panel display. The CPMS communicates acquired data, calculated data and monthly reports to NRG's plant computer by Ethernet connection.

Crankcase ventilation system:

RICE NESHAP specifically requires that each diesel engine must have a crankcase ventilation system to capture the hazardous blow-by emissions vented from the crankcase during operation. These emissions consist of oil mist, metals and other particulate emissions.

Open or closed systems are accepted under the standard; however, most operators are installing open systems to prevent the ingestion of raw blow-by into the engine turbocharger or exhaust. While the EPA does not specifically mandate an efficiency level, best practices dictate that all visible emissions are eliminated from the crankcase vent.

This is only possible with a high efficiency filter and not with the traditional wire mesh.



The NRG Energy Center Paxton peaking plant, a 12 MW peaking plant plant located near Harrisburg, Penn., needed to reduce CO emissions to comply with the RICE NESHAP regulation.

In the case of NRG, Solberg Manufacturing Inc. designed and delivered a high-efficiency, open crankcase ventilation system to capture the vented hazardous blow-by emissions from each of the two existing Cooper-Bessemer engines. The Solberg system includes an internal air/oil separator cartridge with an efficiency of 99.97 percent for 0.3 micron particles and oil mist. This is packaged with a vacuum source, custom piping and a valve to allow NRG to maintain the natural crankcase pressure of the engine. The oily emissions are pulled through the cartridge, and the entrained oil is coalesced and collected at the bottom of the canister. The collected oil is recovered through a drain port and is scavenged to a waste oil tank inside the building. The result is clean air and no visible emissions vented from the crankcase to atmosphere.

Additional requirements

The engines were already equipped with non-resettable hour meters, and they were not required to be added to the NRG installation to meet compliance requirements. NRG was required to use ultra-low-sulfur-diesel fuel as part of the installation of the catalytic oxidation system.

CHALLENGES

The RICE NESHAP installation at the NRG Energy Paxton Plant presented several major, but not uncommon, challenges to the project team. The team worked together to overcome these challenges as described below.

Space limitations

The configuration of the existing engine installation did not leave much room for the installation of the catalyst housing or the crankcase ventilation system in an accessible location. The exhaust system for each engine included an existing, but out-of-service, heat recovery steam generator (HRSG) and an exhaust silencer.

Catalyst location options

Initially, NRG and RPA considered three options for the catalyst location. The most open area in the existing installation was the 36-inch diameter exhaust pipe between the HRSG and the silencer. One problem with this location was that it would require platform modifications to provide access to the catalyst. Another problem was that replacement of the existing HRSG with a new operating unit would cause catalyst inlet temperatures too low for catalytic oxidation.

NRG and RPA also considered a location inside the generator building between the expansion joint and the HRSG inlet. This location would have required new platforms for access and modifications to the building structure.

The third option, which required more initial cost to implement, was to remove the existing out-of-service HRSG and place the catalyst housing in a location just outside the generator building wall.

NRG and RPA determined that the existing platform could be easily modified to provide access to the new catalyst housings and also determined that there was sufficient space to allow the installation of a new HRSG, if needed.

After careful deliberation, NRG proceeded with the third option. Due to the fact that space needed to be maintained for a possible future HRSG, the allowable length that the catalyst housing took up in the exhaust duct was more limited.

Crankcase ventilation location options

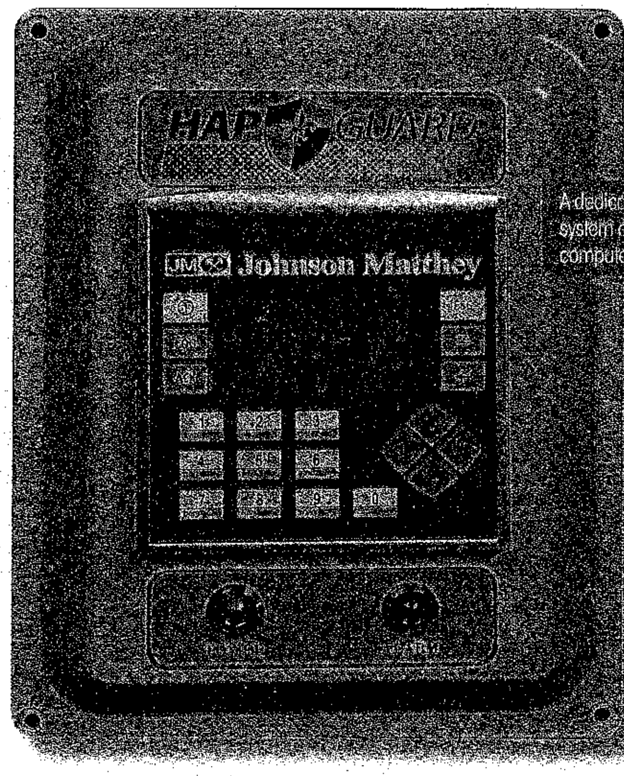
Another concern was determining a location for the crankcase ventilation system. The engine crankcase is vented through a six-inch pipe to a location just outside the generator building. A separate two-inch cylinder head vent pipe joins the main six-inch crankcase vent pipe at a location just above the engine. The high elevation at which the crankcase vent pipe ran inside the building made it difficult to select a location that would provide operator access for system maintenance and adjustment.

The decision to remove the existing HRSG contributed to finding an accessible location for the crankcase ventilation system outside the generator building on the existing platform. The Solberg crankcase ventilation system also was able to be customized to meet installation requirements, and the units were mirror images of each other.

Other factors

The selected location of the catalyst immediately downstream of an existing metal bellows expansion joint raised concerns about the resultant force that would be imposed on the catalyst housing. Johnson Matthey performed a finite element analysis to verify that this force would not lead to excessive stress in the catalyst housing during operation.

The longer run of exhaust pipe created by the removal of the existing HRSG led to greater thermal expansion in the exhaust pipe between the catalyst housing and the silencer. This was resolved by adding a new fabric expansion joint designed to compensate for four inches of thermal expansion.



A dedicated continuous parametric monitoring system communicates information to the plant's computer using an Ethernet connection.

SYSTEM PRESSURE LIMITATIONS

Catalyst pressure drop

Another concern with the catalyst housing design was the maximum pressure drop across the catalyst that could be allowed before affecting engine performance. The NRG Cooper-Bessemer LSVB-GDT-20T engine has a maximum allowable backpressure of 20-inches w.c. Most of this pressure allowance was already used up by the existing components in the engine exhaust pipe.

In order to determine the maximum pressure drop that could be allowed for the catalyst, RPA Engineering modeled the engine exhaust system and ran several different exhaust flow conditions to determine the maximum allowable design pressure drop for clean catalyst. The pressure drop allowance also needed to compensate for "dirty" conditions.

The standard catalyst housing design used by Johnson Matthey was customized after computational fluid dynamic modeling indicted that uniform flow across the catalyst face could be achieved with minimal inlet and outlet transitions between the exhaust pipe and the catalyst housing. The compactness of the catalyst housing combined with the relatively stringent allowable pressure drop limitation resulted in a unique housing configuration that fit within the existing exhaust system design.

Crankcase Pressure Requirement

The NRG Cooper-Bessemer engines are designed to operate with a slightly positive crankcase pressure to reduce the possibility of an explosion. This impacted the design of the required crankcase ventilation system.

The Solberg recirculation system incorporates a regenerative blower to create suction to overcome the differential pressure created by the oil saturated filter element. However, the systems integrated piping will recirculate the exhaust air from the blower back to the inlet of the crankcase ventilation system. The result is an equilibrium state in which the natural engine crankcase pressure is maintained. A manual control valve was included to restrict the recirculation air over time and produce a slight vacuum, if necessary, to overcome eventual leaks through worn engine seals. The NRG operators monitor crankcase pressure on a regular basis. Due to the concern with an upset condition leading to the possibility of negative pressure in the engine crankcase, a pressure switch was installed on the engine that would alarm in case of a low positive pressure in the engine crankcase.

SYSTEM START-UP

The RICE NESHAP equipment was installed at the NRG Energy Paxton Plant in the fall of 2012. The RICE NESHAP systems for each engine were started up in November 2012 by representatives of Johnson Matthey and Solberg Manufacturing. During start-up the crankcase ventilation system functioned as intended and there was no visible discharge from the crankcase ventilation vent pipe.

Sample analysis for CO emissions using a Testo 350 portable gas analyzer were taken at 58 percent load, 67 percent load, 83 percent load and 100 percent load with Engine No. 1 operating on dual fuel. As expected, the untreated CO emissions at the engine outlet were the highest at the lower engine loads. Untreated CO emissions decreased as the engine load increased. The measured CO conversion efficiency recorded the highest CO conversion rate of 97percent at the lower engine load, which then leveled off at 95 percent CO conversion efficiency at full load. During the sample testing, CO emissions at the outlet of the catalyst had reached a plateau at an absolute value of approximately 25 ppm, regardless of the CO concentration at the inlet of the catalyst.

CONCLUSION

The new RICE NESHAP regulation has placed a significant requirement on existing CI engines to reduce HAPs. Using CO as a surrogate for HAPs, the RICE NESHAP regulation required the NRG engines to reduce CO emissions by at least 70 percent or to a level of 23 ppmvd at 15 percent O_2. NRG installed a precious metal-based catalytic converter system to comply with these emission limits. Emissions testing with a lower span CO cell to measure the CO conversion at low CO concentrations showed that these emission limits were achieved. The addition of the crankcase ventilation filters removed all visible emissions at the crankcase vent pipe while enabling the engines to operate at the desired crankcase pressure of 0.4 to 0.5-inches w.c. While the installation presented some challenges, the equipment was successfully installed through a cooperative effort among all members of the team. pe