A Supplement to the April 2004 Issue of Energy-Tech Magazine

ENERGY-TECH

COGENERATION

CONTINENTAL
CONTROLS
CORPORATION

Air-Fuel Ratio Control

Ross Fisher

Air-Fuel Ratio Control for Rich & Lean Burn Gas Engi

By Ross Fisher

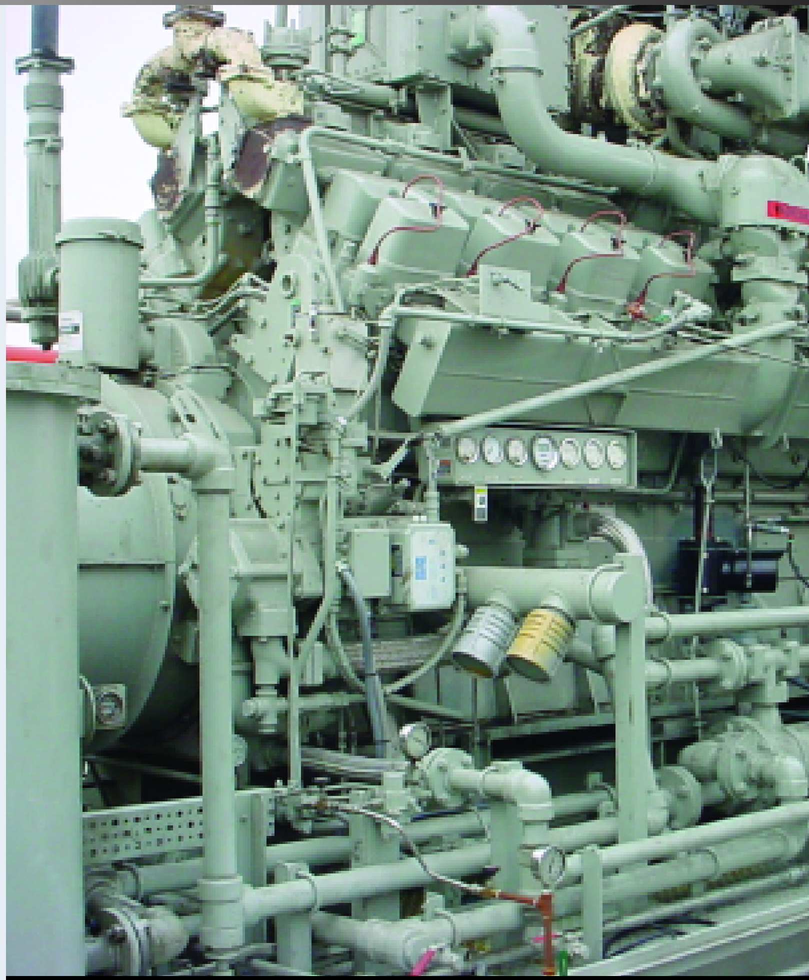
Years ago, before exhaust emissions were a concern, the natural gas engines used mainly by the natural gas industry were designed to run with excess air. The air-fuel ratio controllers were mechanical devices that were not very accurate and sometimes not even used. These engines ran very well with 5% to 20% excess air. The air-fuel ratio would often vary with load and as long as the engines would carry the load and didn't detonate or misfire, people were happy.

Later when exhaust emissions became important, it was discovered that these engines were running with very high NO_X levels, sometimes at the peak of the NO_X curve. Two strategies evolved to reduce the NO_X while containing the CO and unburned hydrocarbons.

The first strategy is Stoichiometric or Rich-Burn combustion, and the second is called Lean-Burn Combustion.

Figure 1 is representative of the Cylinder Pressure on the vertical (Y axis) and the ratio of actual air-fuel ratio divided by the stoichiometric air-fuel ratio on the horizontal (X axis). (The graph is not to scale and does not represent any particular engine.)

The Excess Air Ratio on the X-axis is referred to as Lambda. Stoichiometric air-fuel ratio is 1.0 in Figure 1. Rich-burn operation is to the left of the stoichiometric point and Lean-burn operation is any ratio to the right of the stoichiometric point. As can be seen in Figure 1, the Excess Air Ratio—Lambda—needs to be much higher than 1.0 to reduce the NO_X significantly. Operation in the detonation or knock region and the incomplete combustion region must be avoided. In the graph, it shows the engine can be operated at a higher load or BMEP, without detonating, when operating with a large amount of excess air. The higher BMEP means more horsepower is available, and the engine will be a little more efficient because of the higher cylinder pressure.



Waukesha VHP 9390 GSI Rich Burn Engine. Phot

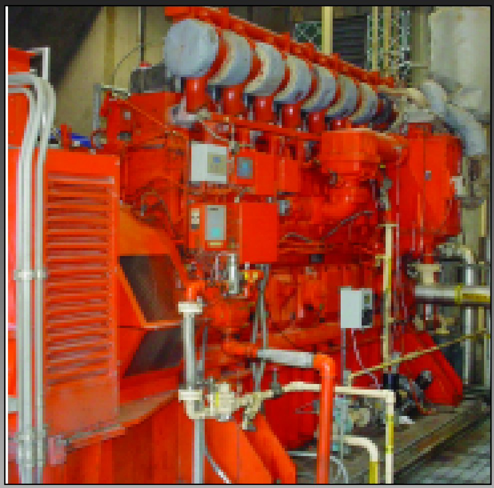
Rich-Burn Combustion

The first method, and easiest to implement, was to operate the engines at a stoichiometric fuel mixture. This is also referred to as "rich-burn" operation. A stoichiometric mixture is the chemically correct fuel mixture for combustion, with near zero oxygen left over in the exhaust. This method of operation is suitable for a three-way catalytic converter. The mixture must be precisely controlled in order for the reaction in the catalytic converter to oxidize the CO to CO_2 and reduce the NO and NO_2 to N_2 and O_2, and not have undesirable products left over.

Rich-Burn Oxygen Sensor

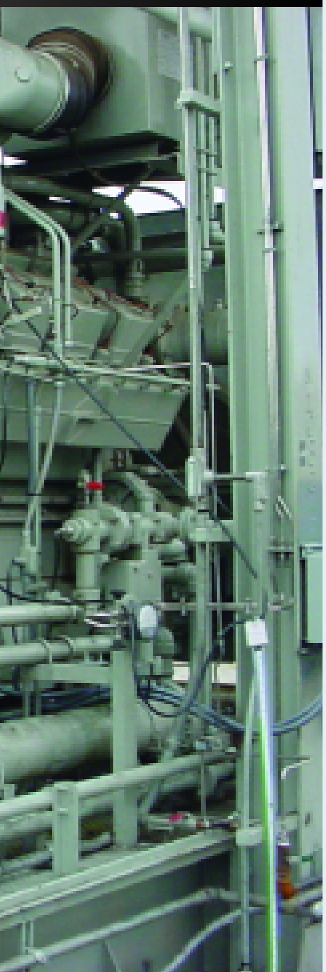
In order to achieve the precision in the control of the mixture required for the catalyst, an O_2 sensor is placed in the exhaust before the catalytic converter. The output of the O_2 sensor is fed back to the control device to close the loop on the amount of oxygen in the exhaust. The mixture is controlled to maintain a very small oxygen content, less than 0.02% in the exhaust, as indicated by the voltage produced by the O_2 sensor. This indicates that the combustion process is consuming nearly all of the oxygen. If a higher oxygen content is indicated, the engine is running too lean, while a lower oxygen content indicates the mixture is too rich.

One of the benefits of engines running in a Rich-Burn mode with a catalytic converter is they operate with very small quantities of NO_X and CO in the exhaust. At the discharge of the catalytic converter, NO_X in the range of a few parts per million is achievable. The disadvantage of this method of operation is the engine cannot generate as much power as it would in the Lean-Burn



Lean Burn Application – 8 Cylinder Waukesha AT running on 500BTU digester gas. Photo courtesy of Continental Controls.

Continental Controls ECV display. Photo courtesy of C nes



o courtesy of Continental Controls.

/ 5 Air Fuel Control and optional
Continental Controls.

mode because with less airflow, the engine runs hotter.

Rich-Burn Control Techniques

Several methods have been used to control the air fuel mixture of gaseous fuel and air. The methods used involve the use of a gas carburetor or mixing device and a pressure regulator. It is not possible for these old systems to comply with the current requirements at all load conditions because the carburetors were designed to run with a richer mixture at full load than at light loads, and the pressure regulators operate with "droop" which means the regulated pressure changes a little with change in load. The old method will not provide the accuracy required to maintain the chemically correct mixture required. The O_2 sensor was developed to provide the required accuracy.

Most techniques used to modify the fuel mixture based on the output of the O_2 sensor fall into three categories:

1. **Operating with the pressure regulator set to run at the lean limit and adding in a supplemental fuel flow through a small valve.** The fuel added is modulated by a controller that uses an O_2 sensor to maintain the correct mixture. The system has a limited range of operation and will not accommodate changes in the heating value of the gas as required in some applications. Also, because the system is already at the lean limit, if either the load is reduced dramatically or the heating value of the gas increases, the system will not be able to maintain compliance.
2. **Operating with the pressure regulator set at a high pressure and using a motorized restrictor in series with the fuel line to the carburetor to reduce the flow.** This system also has a limited range of operation. Since there is little pressure drop across the restrictor when the fuel flow is low, it is ineffective when starting the engine or running without load.
3. **Operating with a bias pressure applied to the backside of the pressure regulator, which is controlled by an electronic circuit and a current to pressure (I to P) transmitter.** The problem associated with this system is that it does not respond immediately when the load changes, it must wait until the O_2 sensor responds and it has to deal with the lag of the I to P transmitter.

Lean-Burn Combustion

The second strategy for reducing emissions is to run the engine with as much excess air as possible. The limiting factors

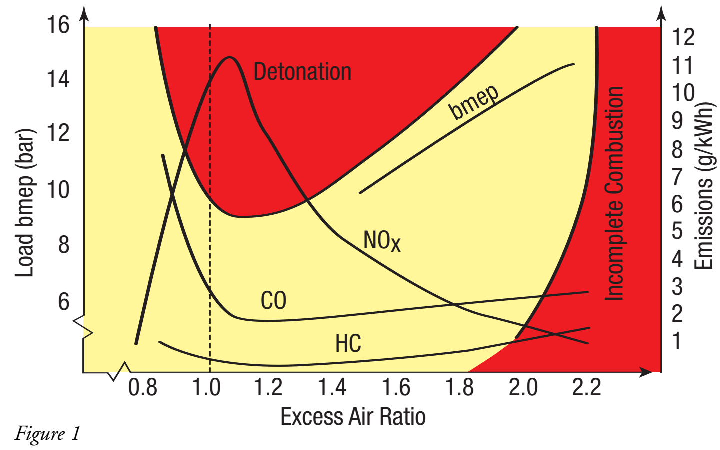


Figure 1

are usually the ability to ignite the lean gas mixture and get complete combustion. The reason this reduces the NO_X is because the temperature of combustion is lower due to the excess air. If a power cylinder has more air compressed into it, the specific heat of the air charge in the cylinder is higher, which means it can absorb the same quantity of heat with less temperature rise. The reduction in temperature causes a reduction in the oxidation of the nitrogen. Engines running with large amounts of excess air can achieve levels of NO_X below 1 Gram / HP*HR without a catalytic converter. A selective catalytic converter can be used to reduce the NO_X level further, but has the disadvantage of requiring the injection of urea or ammonia.

Lean-Burn Oxygen Sensor

The oxygen sensor used for Lean Burn engines, unlike the sensor used with Rich Burn, indicate a very wide range of oxygen in the exhaust and are often referred to as Lambda sensors. Where Lambda is the air-fuel ratio the engine is running at, divided by the stoichiometric air-fuel ratio (as shown in Figure 1).

Benefits of Lean-Burn

Engines running in the Lean-Burn mode offer several important advantages. The advantages include: more power available, engine runs cooler, a little better efficiency, and may not require a catalytic converter depending on the air quality requirements.

Lean-Burn Control Techniques

There are two basic approaches used to control the fuel-air mixture used.

The first utilizes a Lambda sensor (wide range O_2 sensor) in the exhaust and controls the mixture based on the measurement of oxygen in the exhaust.

The second method is called "mapping the engine," and is based on determining the fuel pressure required to maintain the lean mixture at all load levels. Then, the air fuel controller will adjust the fuel injection pressure as a function of the load on the engine in accordance with the map. Variations in the heating value or temperature of the fuel gas will cause the map to change.

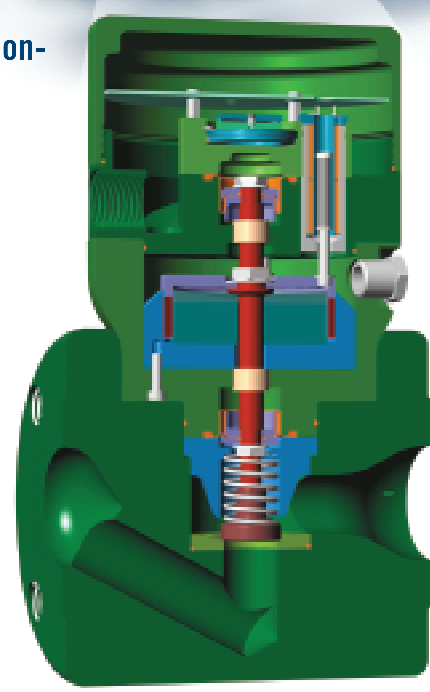
Ross Fisher is the president of Continental Controls Corporation. He has been involved in developing gas engine and gas turbine fuel control products for more than 25 years.

Meet tomorrow's emission control standards today.

When used with a Catalytic Reduction System, Continental Controls' ECV5 will provide the lowest achievable emissions from a natural gas engine. The ECV5 minimizes emissions by precisely controlling injection pressure with a bias from an O2 sensor.

Maintain continuous emissions compliance even with changes in load or speed.

While other valves can optimize fuel mixture at specific loads and speeds, when either are changed, they can't maintain emissions compliance.



ECV5

Patent pending.

Simply the best available.

When used with a catalytic converter, the ECV5 minimizes NOx, CO & HC emissions. The ECV5 normally eliminates the need for a separate low pressure regulator. The ECV5 is easily installed. Compare it to other systems on the market and you'll agree it's the best available control technology.

Make the ECV5 part of every natural gas engine package.

Call us or visit www.continentalcontrols.com for more information.

CONTINENTAL CONTROLS CORPORATION

8845 Rehco Road, San Diego, CA 92121 Tel 858/453-9880 Fax 858/453-5078 www.continentalcontrols.com mail@continentalcontrols.com