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A White Paper
Important Planning Considerations for Engine and/or Vehicle Emission Testing
Objectives Including Fuel Economy and Power Performance Measurements

Introduction:

Engine and vehicle emission testing is an expensive and time-consuming activity. It requires several million dollars of sensitive equipment and experienced test technicians to be conducted in a manner acceptable to the client and to government agencies such as EPA, TCEQ (Texas) and the California Air Resources Board (CARB). Accordingly, it is necessary that the client consult with the appropriate government agencies and the Olson-EcoLogic engineering staff to select the specific test protocol to achieve the client's objectives.

The purpose of this White Paper is to address the multitude of test protocols that are used by various government agencies to both certify new model vehicles and engines and to verify emission reduction strategies for in-use vehicles or engines.

Background:

All emission standards are set by the EPA. These standards typically become more stringent over time requiring continual upgrades and new technology. These changing standards are the market drivers for new emission control strategies and solutions.

The applicable emission standards are based on engine applications, which are in turn based on typical use patterns for the application of interest.

For example:

The new engine certification protocol and emission standards for heavy-duty diesel engines in off-road applications are quite different than the test protocols and standards for the same engine designed for on-road applications.

Small off-road engine equipment (called S.O.R.E.) is tested and certified by steady state protocols on an engine dynamometer, while the same engine in an ATV or

motorcycle must be tested using a transient cycle test protocol on a chassis dynamometer.

Automobiles and light duty trucks are originally certified as new vehicles on a chassis dynamometer over a transient cycle test protocol intended to simulate actual on-road use.

In the development of engines, vehicles and emission control products, many R&D testing variants are used to optimize results and better understand the factors that influence and affect performance. But, ultimately the products must be proof-tested by the standard test protocol for the specific product of interest.

The two categories of major interest are:

1. Original certification of new engine and vehicle products.

2. Verification of emission reductions for retrofit of products on in-use engines and vehicles, or for the provision of alternative fuels that can result in lower emissions

Nationwide there are various programs, many of which are funded by State or Federal agencies, that provide the impetus and market opportunity for retrofit products that significantly reduce the emissions from in-use engine applications. Some of these programs finance the required testing for retrofit devices and others for alternative fuel configurations. The impetus for this testing is the extensive market applications that result from government-mandated requirements.

Most of these programs do not require fuel consumption savings as part of the proof-testing obligation. However, it is obvious that the client using the solution will always be interested in the fuel savings.

The objective of this white paper is to assist a new client in the proper test protocol selection for obtaining the maximum benefit from his testing expense. This is normally comparative testing without and then with the client product demonstrated on selected engines under specified test protocols. These test protocols are normally required by government agencies.

The Official Test Protocols and Implications for Emission Reductions:

1. Heavy-duty engines for off-road stationary applications. These tests involve steady-state engine dynamometer testing over different modes of operation. These modes range from full load, rated speed to idle testing conditions.

2. Heavy-duty engines for off-road mobile applications. These tests involve testing with a non-road transient cycle (NRTC) conducted from a hot-start after stabilizing the engine.

3. Heavy-duty engines for on-road applications. These tests involve engine dynamometer transient cycle testing over a 20- minute variable load and variable speed testing cycle. One test cycle is done from a cold start, followed by at least three of the same cycles with a fully warmed up engine.

4. Automobiles and light duty trucks for on-road applications. These tests involve chassis dynamometer testing over a transient test cycle that has simulates interurban driving and highway driving. This complete test cycle officially begins from a cold start after the vehicle has soaked indoors overnight under controlled conditions. It is conducted using a chassis dynamometer with a special 48 inch chassis roll.

5. Small engines for off-road applications. These are usually tested by steady-state operation over specified load and speed modes. The number of modes and the specified loads depend on the intended engine application. The exception to this is if the engine application is for all terrain vehicles (ATVs), motorcycles or engine powered scooters where the testing is done over a transient cycle on the chassis dynamometer.

It is important to understand that emission results are quite different from test protocol to test protocol. It has been demonstrated conclusively that a product that reduces emissions when tested by one protocol cannot be expected to be as effective in another protocol.

Therefore, it is necessary to select the target market for a given product before specifying the protocol for proof-testing. Conversely, it is important to understand the mechanism and strategy for the reduction of candidate emissions. The test protocol selected may not favor the strategy or product of interest.

> For example: Oxides of nitrogen (NOx) are generated in the combustion cycle under high temperature conditions as is particulate matter (both are engine emissions that must be reduced). Unfortunately, mechanisms to reduce NOx by lowering combustion temperatures tend to increase the particulate matter generated during combustion and vice versa.

The Importance of Testing Products Using Official Test Protocols:

The emission testing of candidate retrofit products and alternative fuels or lubricants nearly always involves comparison testing with and without the product installed or used in a selected representative engine.

Typically, a significant amount of data has been previously obtained by standard official testing protocols, it is ultimately used for comparison and significantly enhances the credibility of new data obtained by the same protocol and testing procedures.

Previous data obtained by special procedures is usually not considered very seriously by the government agencies that will be certifying or verifying the new product emission reduction performance. Additionally, when data are obtained by official testing protocols at reputable and officially recognized labs, government agencies are more likely to accept the data as part of a subsequent verification objective for the client.

Frequently, data not obtained by official test protocols can provide misleading results since so many variables can affect the ultimate product performance. Additionally, such data may influenced improper consideration of important variables.

> For example: Because a product in non-test use creates more power or reduces visible smoke, does not mean that it will subsequently reduce the engine exhaust emissions.

All comparison testing for candidate retrofit products is measured over the exact same speed and load conditions as the baseline data without the product. This may result in better fuel economy or other benefits with use of the product, but not necessarily reduced emissions, and as previously mentioned, no credit is given for fuel economy improvements.

Use of the Proper Testing Protocol:

For comparison testing with and without the product, the client should always select the test protocol that is used to officially certify or verify engines in the client's target market.

> For example: What works on heavy-duty engines may be worthless for automobiles or small engines and vice versa. The testing protocols are entirely different and the required emission standards are different for different applications. If the client is conducting emission testing to certify new engines then he has no option except to test by the official test protocol for that engine application.

The Statistical Basis for Comparative Differences:

It is important to know the statistical significance of absolute measurements and differences in comparative measurements for engine emission work. EPA, TCEQ and CARB all expect data to be analyzed with 95% confidence levels.

Accordingly, it is pertinent to design the testing experiment with enough replication to assure the expected differences caused by the product are real at the 95% confidence level. This can result in a very large number of tests if the expected differences are small.

For example:
EPA and CARB may require a minimum of 42 transient cycle tests (21 tests with the baseline and 21 tests with the alternative fuel) when testing alternative fuel configurations since differences of 25% are typical. This testing expense alone can cost in excess of $150,000.

CARB specifies at least 85% reduction in PM as the minimum effectiveness for on-road retrofit verification testing. Since this is a much larger number, they only require the average of triplicate data sets for the baseline and again for the product testing. Triplicate data sets are considered to be the bare minimum number of tests to average for practically any emission testing.

A single emission comparison test can usually be expected to repeat within +/- 5%. The average of triplicate tests can be expected to be within +/- 2%. In a gross sense, if the product is not expected to demonstrate at least 5% improvement in any emission variable the experiment design will require a significantly larger number of tests. If 25% or more improvement is expected from the product, triplicate data comparisons to the baseline fuel will likely be adequate at the 95% confidence level.

Costs and Time Schedule:

Emission testing expenses include several factors.

For engine testing on engine dynamometers there is an engine installation and set-up charge, usually on the order of $3,500 plus the basic engine cost. Transient cycle emission tests cost $3,500-$4,500 each and the final engineering report costs on the order of $1,000. The total cost for one evaluation then is on the order of $25,000-$30,000 for transient cycle comparative testing using triplicate data sets with a client supplied engine.

Steady-state engine dynamometer testing (for off-road engine applications) is about 10% less. A typical time schedule once an engine is installed is about one week of testing for

either transient cycle testing or steady-state testing. There is often a backlog of two to three months after receipt of the required advance payment creating an additional scheduling problem.

For chassis dynamometer testing the cost is considerably less. The work can usually be scheduled to start within a few days. A typical comparative test project using triplicate tests with and without the product can be completed within a couple of days. Normally, the client supplies the test vehicle. The cost is on the order of $10,000 complete.

However, the same considerations for data accuracy and numbers of replicate tests apply as in engine dynamometer testing. Certification testing of new engine models or new vehicles involves the requirement to accumulate hours of durability testing in addition to several emission tests per model. This work ranges in price from $12,000 to $30,000 per model depending on the engine size and other EPA/CARB specified requirements. This program can require several weeks for completion once the new model engines have been received.

Miscellaneous Considerations:

There are a variety of factors, as summarized above, that should dictate the test design for a most cost-effective emission testing program.

> The first consideration should be identification of the optimum market focus for the particular product of interest. Since there are so many different protocols with a wide range in testing costs.
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> Secondly, there should be a good technical understanding of why the product can be effective in reducing engine emissions with no deleterious effects.
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> Finally, there needs to be a conscientious business plan justifying the emission testing expense.

Olson-EcoLogic has tested scores of devices and emission reduction solutions. It has been our experience that despite some incredible client claims based on “other testing” and a variety of strange beliefs most products don’t work anywhere near the level represented. By actual results, less than 10% of the devices provide any benefit whatsoever. This low success ratio is caused by ignoring one or all three of the above considerations.

Olson-EcoLogic is an independent testing lab. We provide emission testing of a client’s products. We do not do any product development or provide any recommendations for effective emission control systems.

We strongly recommend that any product ultimately intended for acceptance by EPA, CARB, TCEQ or any government agency begin by having a conference with the respective agency and submitting a preliminary application for their consideration. These agencies will critique the product, describe the testing requirements and suggest appropriate labs for conducting the testing if such testing is justified.