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FPC FUEL CATALYST LOADBOX TEST

BY

CENTRAL OREGON & PACIFIC RAILROAD

Report prepared
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and
FPC Technology

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EXECUTIVE SUMMARY

THE CENTRAL OREGON & PACIFIC R.R.
STATIC LOADBOX ENGINE TEST

This report summarizes the effect of Fuel Performance Catalyst (FPC™) upon engine efficiency, and exhaust smoke during static loadbox tests of one Central Oregon & Pacific RR (CORP) locomotive engine. The EMD 645 engine powers a GP 40. The engine was first tested under load at throttle notch positions 2, 4, 6, and 8 using untreated (baseline) fuel. The unit was then treated with FPC, a fuel combustion catalyst, and operated as normal for approximately 400 hours. The engine was then re-tested with FPC treated fuel, while reproducing all engine and power output conditions.

Two methods for determining fuel consumption were employed. One was a volumetric method using two FloCom™ flow transducers and transmitter to measure fuel flow to and from the engine. The second methodology measured emissions output and computed fuel flow from the products of combustion. This method is known as the carbon mass balance (CMB), and is an adaptation of the EPA standardized Federal Test Procedures, which also uses CMB for fuel consumption and engine emissions determination. Smoke density was determined using the Bacharach Smokespot method. The engine was loaded using a loadbox. CORP engine and electrical technicians collected engine and power data. A summary of the results are as follows:

(1) **Fuel consumption was reduced 1.6% to 4.8%, depending upon throttle notch, as measured with the FloCom™ transducers. The average fuel consumption reduction (improvement in engine efficiency) was 3.3% for this method.**

(2) **Fuel consumption was reduced 3.7% to 5.4%, depending upon throttle setting, as measured using the CMB method. The overall fuel consumption reduction for this engine was 4.4%.**

(3) **Exhaust smoke density was reduced 4.3% to 38.5%. Smoke density reduction averaged 13.3% for this test**. Smoke density reductions were most profound at Idle (38.5%).

(4) **Fuel consumption reductions were minimized due to an error in treatment ratio. The concentration of FPC™ catalyst in the fuel was 50% of normal treatment**. Laboratory tests, such as the AAR RP-503, have demonstrated a definite engine conditioning period after FPC fuel treatment before maximum benefit will be realized. The fuel consumption reductions seen in the CORP test on half treated fuel are approximately one half those observed previous static engine tests where the fuel was fully treated with FPC™ for the entire engine conditioning period.

These benefits are supported by several laboratory tests, including Southwest Research Institute's (SwRI) test of a 12 cylinder, 645E3B using the Association of American Railroads Recommended Practice 503 (RP-503). Other test data reviewed in this report includes the findings of the Western Australia Institute of Technology (WAIT) and several power generating operations (gensets) where specific fuel consumption tests have been possible. The last studies verify FPC is most effective when used in engines operating under conditions that more closely approach the transient duty cycle of typical field operation.

The findings of the CORP test of the FPC catalyst are also supported by findings of several loadbox tests recently conducted by several other railroads.

1.0 INTRODUCTION

During the period of May 1992 to June 1992, a rigorous test of FPC was completed by Southwest Research Institute (SwRI), San Antonio, Texas. The test program determined the effect of the fuel combustion catalyst upon fuel properties, engine wear, deposit formation, and engine performance. The test procedure was the Recommended Practice 503 (RP-503), a procedure authored and recognized by the Association of American Railroads (AAR).

The final phase of the RP-503 test program was an engine performance test on a twelve cylinder, 645E3B EMD locomotive engine. The test engine was operated under steady-state conditions at maximum horsepower output per unit of fuel consumed (brake specific fuel consumption). Brake specific fuel consumption (bsfc) was improved 1.74% by FPC treatment when compared to base diesel fuel bsfc [Ref 1].

After the completion of the RP-503, combustion experts concluded that the 1.74% improvement in bsfc would translate to **improvements several times greater in engines operated in the field due to the transient nature of actual operating conditions** [Ref 6].

Other independent laboratory studies, including the Varimax engine test conducted by the Western Australia Institute of Technology (WAIT), Perth, Western Australia, by Curtin University, also in Western Australia, and by the University of Perugia, Perugia, Italy, confirm this conclusion. Tests at varying engine speeds, loads, and injection timing, which more closely approach field conditions, agree with expert opinion.

Further, test data from over a dozen specific fuel consumption (sfc) trials of diesel power generating equipment agree with the lab studies. Diesel power generators can be tested in the field at specific loads and rpm. In these applications, it is reasonable to accurately measure fuel consumption and power output in kilowatts. And, although not subjected to severe transient operation, their application yields test results that are more representative of real world conditions, than do those from the laboratory [Ref 3].

The loadbox test conducted by Central Oregon & Pacific, using a EMD powered locomotive, is yet another example of greater FPC effectiveness in engines used and tested in the "real world". Several throttle notch positions were selected for the test, and the engine was fully loaded in an attempt to create conditions that more closely duplicate actual duty cycles. The results also agree with those of previous railroad loadbox tests and are supported by expert opinion. ***Unfortunately, the full benefit of FPC™ may not have been realized due to a gross undertreatment of the fuel, both during the engine conditioning period, and the actual treated fuel static engine tests.***

2.0 BACKGROUND

2.1 Diesel Combustion Theory

2.1.1 The Combustion Process

The four-cycle compression-ignition engine employs the conventional four strokes per power cycle of intake, compression, power, and exhaust. The two-cycle engine shortens the number of strokes of the piston by combining the power and exhaust stroke, and the intake and compression stroke.

The air inducted on the intake is either normally aspirated or forced in by the supercharger, while the fuel is injected into the cylinder near the end of the compression stroke. In most diesel engines, the combustion chamber temperature at the end of the compression stroke is approximately 600 degrees C (Celsius). This temperature is dependent upon the compression ratio and the initial air temperature.

Near the end of the compression stroke, fuel is sprayed into the combustion chamber at pressures varying from about 1,200 psi to over 30,000 psi. The injection pressure is governed by engine speed and size, and by the type of combustion chamber and injection system used [Ref 4].

With the commencement of fuel injection, the combustion process is initiated. Each charge of injected fuel experiences several phases in the reaction as follows:

(1) An ignition delay period

(2) A period of rapid combustion

(3) A period of combustion where the remainder of the fuel charge is burned as it is injected.

(4) An after burning period in which the unburned fuel may find oxygen and burn, often times referred to as the tail of combustion.

In following the combustion process and the path of fuel particles, it should be understood that after ignition has occurred, many of these steps will be proceeding at the same time, since the mixture is homogeneous [Ref 5].

2.1.2 The Delay Period

The delay consists of a physical and a chemical delay. The physical delay is required to atomize the fuel, mix it with air, vaporize it, and produce a mixture of fuel vapor and air.

During the chemical delay, preflame oxidation reactions occur in localized regions with temperature increases of 540 to 1100 degrees C. These preflame reactions are initiated by the catalytic effect of wall surfaces, high temperatures, and miscellaneous particles that form the active chain carriers prior to rapid combustion. As the local temperature increases, the fuel vapors begin to crack at an accelerating rate and produce material with high percentages of carbon, which become heated to incandescence as local ignition is initiated.

Inflammation develops quickly either by rapid and complete oxidation of the fuel and air or the oxidation of the intermediate products of the chain reactions of the fuel [Ref 5].

2.1.3 The Period of Rapid Combustion

Combustion during the period of rapid combustion is due chiefly to the burning of fuel that has had time to vaporize and mix with air during the delay period. The rate and extent of the burning during this period are closely associated with the length of the delay period and its relation to the injection process.

The relation of the delay on both the rate and extent of pressure rise during this phase is especially strong when the delay period is shorter than the injection period [Ref 5].

2.1.4 The Third Phase of Combustion

The third phase is the period from maximum pressure to the point where combustion is measurably complete.

When the delay period is longer than the injection period, the third period of combustion will involve only the fuel that has not found the necessary oxygen during the period of rapid combustion. In this case, only the mixing process limits the combustion rate. However, even when all the fuel is injected before the end of the delay period, poor injection characteristics can extend the third period well into the power or expansion stroke, causing low output and poor efficiency.

When injection timing is such that the second phase of combustion is complete before the end of injection, some portion of the fuel is injected during the third phase, and the rate of burning will be influenced by the rate of injection, as well as by the mixing rate [Ref 4].

2.1.5 The Final Phase of Combustion

The final phase or tail of combustion continues after the third phase at a diminishing rate as any remaining fuel and oxygen are each consumed. Diffusion combustion, with production and combustion of carbon particles and a high rate of heat transfer radiation characterize this last stage and the previous one. This phase occurs well down the expansion stroke, when much of the oxygen has been consumed and combustion temperatures are lower. It is at this stage that smoke and carbon monoxide emissions are formed [Ref 4].

2.1.6 The Ideal Combustion Process

The thermal efficiency of an internal combustion engine, whether spark or compression-ignition, will increase if the combustion time is reduced. Thus, more work can be extracted from the same energy input from combustion. The rate of pressure rise during the period of rapid combustion corresponding to constant volume combustion, should be as rapid as possible without exceeding a certain value.

The fuel remaining after the period of rapid pressure rise should be burned at a rate such as to hold the cylinder pressure constant, at the maximum allowable value, until all the fuel is burned.

2.1.7 The Effects of Operating Conditions on Combustion

With respect to the diesel engine, the combustion rate as well as the rate and extent of pressure rise, depends greatly on the design of the combustion chamber and the injection system. However, injection timing, engine speed, turbulence, compression ratio, fuel-air ratio, spray characteristics, fuel cetane number, and inlet temperature and pressure all effect the combustion rate or flame speed.

A detailed discussion of the impact of these operating conditions on combustion is found in Reference 4.

2.2 Possible Mode of Action of the FPC Combustion Catalyst

2.2.1 Flame Propagation

As previously mentioned, the speed with which the combustion process takes place influences the efficiency of the heat released by the chemical reaction. With greater rates of heat release, it is often possible to transfer more of the heat into useful energy.

The combustion catalyst manufactured by FPC International is a burn rate modifier. When the combustion catalyst is introduced into a liquid hydrocarbon fuel and combustion begins, the catalyst appears to form propagating centers that initiate multiple flame fronts. These propagating centers in effect increase the thermal conductivity of the fuel-air mixture, since heat transmission through it is more rapid with their presence. The effect appears to be most profound during the mixing–controlled and final phases of combustion when flame propagation is slowed or controlled by the rate at which fuel and air can mix to combustible proportions. The combustion catalyst assists in maintaining flame speed through the third and last phases of combustion.

The completeness of combustion may also be positively affected. If combustion is more complete, more energy is liberated while the flame front traverses through the fuel-air mixture. **Controlled engine tests with FPC catalyst reveal not only increased horsepower output and reduced fuel consumption, but also typically reduced unwanted gaseous and particulate exhaust emissions.**

Further, when engine operating conditions are such that flame speed is slowed, creating greater combustion time losses, the FPC fuel catalyst will recover a greater percentage of those losses. Thus, the catalyst will have a more profound effect upon engines operating in the field, than engines operating in the laboratory.

3.0 SUPPORT DATA: LABORATORY AND STATIONARY ENGINE TESTS

3.1 The AAR RP-503

In early 1992, UHI Corporation (dba. FPC International) was encouraged by several major railroads to conduct tests with FPC catalyst (FPC-1® 1/5000 ratio was used) at Southwest Research Institute (SwRI) using the Association of American Railroads (AAR), the Recommended Practice 503 (RP-503).

The RP-503 constitutes two screening tests and an engine performance trial. The screening tests include the determination of the additive effect upon fuel properties, engine deposit formation, and engine wear. The final procedure is an engine performance trial conducted in a 12 cylinder, 645E3B EMD locomotive engine.

These studies concluded that FPC catalyst had no measurable effect on the chemical properties of the fuel, nor did it detrimentally impact engine life and deposit formation. The EMD engine also showed a 1.74% improvement in bsfc at a 95% confidence level with FPC catalyst treated fuel [Ref 1].

This is a remarkable improvement given the existing efficiency of this particular engine (37.2% brake thermal efficiency and 0.354 bsfc) and the fact the test engine was run under optimum engine conditions (steady-state, notch 8, 900 rpm). Under these conditions, injection timing is the best match for maximum horsepower and lowest bsfc, and therefore, combustion time losses are minimized. Further, the engine was in like-new condition, and smoke emissions were nil.

The AAR specifies these engine test conditions since a typical locomotive engine operates 50 to 60% of the time at notch 8. However, the steady-state, maximum horsepower operating conditions tend to minimize the potential for horsepower and bsfc gains [Ref 6].

3.2 The WAIT Study

Studies by the Western Australian Institute of Technology (WAIT) have collected considerable data demonstrating the effect of the FPC catalyst on engine efficiency while operating at varying rpm, load, and injection timing. The test was designed to best illustrate the effects of the combustion catalyst. In addition, the test conditions were meant to relate the effect of the catalyst, to the most commonly altered settings and conditions encountered, during normal field operation of a heavy-duty compression-ignition engine.

The objective of the WAIT study was to analyze the effect of the combustion catalyst on engine brake power and brake specific fuel consumption. In order to considerably broaden the scope of the test program in terms of relevance to simulating true commercial and industrial operating conditions, the following parameters were introduced to be varied accordingly:

(1) Engine speed

(2) Throttle setting

(3) Fuel Injection Timing

(4) The concentration of the catalyst in the diesel fuel

The manner in which each parameter was altered is described below:

* Engine speed in all tests was varied from 1600 rpm to 2400 rpm by increments of 200 rpm.

* Throttle settings were altered alternatively from half throttle to full throttle in the majority of the tests.

* Fuel injection timing was varied from 18 degrees before top dead center (BTDC) to 42 degrees BTDC, in increments of 6 degrees, in specific tests. The standard injection timing was 30 degrees BTDC.

* The concentration of the catalyst in the diesel fuel was altered by employing three different mixing ratios.

For all tests conducted in the Varimax engine test program at WAIT, full details of which parameters were altered in each particular test are given on each page of tabulated results in APPENDIX 1.0 (The WAIT Study).

3.2.1 Conclusions from WAIT Study

The Varimax engine test program has shown quite convincingly the benefits of FPC catalyst in diesel fuel. At the highest catalyst concentration in the fuel, bsfc improvements ranged from 1.71% to 4.99%.

3.3 SPECIFIC FUEL CONSUMPTION TRIALS OF DIESEL GENERATORS

For over ten years, the FPC combustion catalyst has been subjected to field trials by dozens of professional engineers representing the interest of the company by whom they are employed. These trials have involved all types of engines under virtually every operating condition imaginable. Generally speaking, these field trials reveal FPC catalyst has greater effect upon engines in mobile equipment than stationary equipment, and high-speed engines than medium or low speed engines. These data support the laboratory data mentioned above, and the theory that the catalyst affects flame speed [Ref 3].

For the purposes of this paper, although still much like laboratory engines (operating at best power, steady-state conditions), only the details of specific fuel consumption studies in diesel generators (gensets) will be given. These tend to be the best controlled field tests available, and the only tests where the measurement of specific fuel consumption (kilowatts/liter) is practical. Further, diesel power generators are similar to diesel powered locomotives.

3.3.1 Diesel Generator Test Method

Typically, the genset is operated under steady-state conditions and fixed load on baseline fuel while the rate of fuel consumption (liters or gallons) and the power output (kilowatts) are measured. Once a reliable database has been accumulated, the fuel for the gensets is treated with FPC catalyst and the gensets operated as normal from three to five hundred hours. This is known as the preconditioning period, and is allowed due to the considerable data that indicates the catalyst first functions to remove existing engine carbon residue, therefore delaying the achievement of maximum catalyst effectiveness.

Once the engine-preconditioning period is completed, the gensets are again tested. The procedure, engine speed, and load are reproduced, with the only deviation being the baseline fuel is now treated with FPC catalyst.

All parameters affecting engine efficiency (intake air temperature, intake pressure, fuel density) are measured and corrections to power output and fuel consumption made.

Some fourteen stationary diesel gensets have been tested in this manner. Engines tested include the following makes:

(1) Blackstone EL8

(2) Caterpillar 3412

(3) Cummins VTA28G3

(4) Detroit 12V and 16V149

(5) EMD L20/645F4B

(6) Mirrlee K8 Major

(7) Ruston

(8) English Electric

3.3.2 Conclusions from Diesel Gensets, Specific Fuel Consumption Trials

Improvements in specific fuel consumption range from 3.1 to 4.8%. Greater fuel consumption reductions are observed in higher rpm gensets. Reductions in smoke density average 23% for all gensets tested [Ref 3].

4.0 THE CENTRAL OREGON & PACIFIC LOADBOX TEST

The CORP conducted studies to determine the effect of FPC™ on fuel economy and smoke emissions in a EMD powered locomotive. A loadbox was employed to load (full load) the engines. Fuel consumption was measured using a flow transducer and an exhaust gas analysis method also utilized by the US-EPA, known as the carbon mass balance (cmb). A Bacharach Smokespot Method was used to determine changes in exhaust smoke density.

The locomotive was tested for fuel consumption using the cmb method. The test was run at notches 2, 4, 6, and 8 at full load at each notch setting.

The locomotive was first tested while using untreated (baseline) number 2 diesel fuel. After the baseline tests, the fuel for the test locomotive was treated with FPC™ for approximately 500 hours. At the end of the engine-preconditioning period, the cmb test was repeated at identical load and notch settings. Engine rpm and temperature, power output and rack length were also reproduced. Performance data were corrected for fuel density and ambient conditions (air temperature and pressure).

4.1 Test Methodologies

Carbon Mass Balance

The CMB method measures the carbon containing products of the combustion process (CO_2, CO, HC) found in the exhaust, rather than directly measuring fuel flow into the engine. The CMB also makes possible the determination of FPC catalyst's effect upon smoke from the diesel engine.

The cmb uses state-of-the-art, non-dispersive infrared analysis (NDIR) and the measurement of carbon containing exhaust gases to determine fuel consumption indirectly. The method has been central to the EPA Federal Test Procedures (FTP) and Highway Fuel Economy Test (HFET) since 1974, and is internationally recognized. This method has proven to be at least as accurate as more conventional flowmeter or weigh scale methods [Ref 8].

The exhaust gas data collected during the baseline and treated fuel carbon balance tests are summarized on the attached computer printouts (Appendix 3). From these data, the volume fraction (VF) of each gas is determined and the average molecular weight (Mwt) of the exhaust gases computed. Next, the engine performance factor (pf) or the carbon mass in the exhaust is computed. The pf is finally corrected for exhaust temperature and pressure velocity (exhaust density), intake air pressure (barometric) and fuel density, yielding an engine performance factor (PF) or carbon mass flow rate corrected for total exhaust mass flow and fuel energy content.

The PFs are shown on the bottom of the computer printouts found in Appendix 3. The PF relates to the length of time required to consume a given volume of fuel, therefore a positive change in PF equates to a reduction in fuel consumption (longer time to consume same amount of fuel at the same load).

Dr. Geoffrey J. Germane, Ph.D. Mechanical Engineering, and Former Department Chair provided these formulae for UHI at Brigham Young University, as the technical approach for the cmb. Dr. Germane's resume and CMB formulas will be furnished upon request.

FloCom ™Transducers

FloCom transducers were mounted on the intake and return fuel line. The transducers measured fuel flow t o and from the test engine, and the transmitter calculated the rate of fuel consumption by determining the difference between the intake and the return signals. The FloCom and CMB readings were timed and taken at approximately the same intervals during each test sequence (Notch 2, 4, 6, and 8).

4.2 Correction for Fuel Density

Test engineers measured fuel specific gravity (density) by taking samples from the tank on the test locomotive. Only the treated fuel rate of fuel consumption is corrected for changes in fuel density (energy content). The baseline fuel density is used as the reference. The correction factor (if applicable) for fuel density is made to the treated fuel and become part of the final calculations.

The FloCom™ does not correct for fuel density. Further, the CMB instruments were calibrated using IM Protocol Gases (known gases) before each test. The FloCom™ was not calibrated for either portion of the static engine test.

4.3 Correction for Barometric Pressure.

The barometric pressure is used in the calculation of both the baseline and treated fuel consumption for the CMB test method. No barometric pressure correction could be made to the FloCom™ readings. The barometric pressure readings are found on the attached computer printouts of the exhaust emissions data.

The CMB method also corrects for the intake are temperature.

4.4 Discussion of Smoke Density

Smoke is a product of incomplete combustion, and as such, is a measure of engine efficiency. Smoke is simply unburned fuel droplets that are exhausted from the engine. Generally speaking, soot particles (pure carbon) are formed during the late stages of combustion when temperatures have fallen off and oxygen availability is limited. The FPC catalyst improves the oxidation of the fuel droplets, speeding flame front development and extracting more useful energy before the exhaust valve or port opens. More power is generated and combustion is more complete (smoke emissions are reduced).

Smoke measurements from the engine tested during the baseline and treated fuel tests were collected using the Bacharach Smokespot Method. The Bacharach method draws a specific volume of exhaust gas through a standard 5-micron filter medium. The particulate in the exhaust gas sample collects on the surface of the filter medium. The surface is darkened by the particulate according to the density of the particulate in the exhaust sample. The greater the particulate density, the darker the color. The Bacharach smoke scale ranges from 0 to 9, with 0 being a white, particulate free filter, and 9 being a completely black filter.

The smoke spot numbers are relative smoke density numbers for each engine tested and can be used to determine any change in smoke emissions when compared to FPC catalyst treated fuel. A comparison of the baseline and treated Smoke Numbers (shown in Appendix, Table 2) indicate the use of FPC catalyst created a reduction in smoke density. Smoke reductions tended to be greater at lower notch settings, particularly at idle.

The reduced engine smoking leads to less carbon or soot accumulation on injectors, valves and valve seats, piston crowns and rings, air boxes, intake ports, exhaust stacks, spark arresters, turbochargers, and other critical engine components. Less engine smoke also equates to fewer and smaller soot particles exhausting from the engine. The smaller particles have less mass and therefore, carry less heat, burning out before reaching combustible materials near the tracks. Engine component life and efficiency is also maintained much longer.

Changes in smoke density were not as great as observed in previous static engine tests of locomotive engines. This is attributable to the mixing ratio error previously mentioned, i.e., fuel received only 50% of recommended catalyst concentration.

4.5 Discussion of Power Output

Power output to the loadbox was measured in volts and amps. The amperage was reproduced during the FPC™ treated tests, but an instrument problem made it impossible to measure voltage during the treated test segment. However, electricians and engineers for CORP at the test site indicated that all engine settings were identical to the baseline and therefore, if amperage was the same, the voltage would be identical also. Therefore, power output was duplicated from test to test and notch setting to notch setting.

5.0 CONCLUSIONS

(1) As concluded by Southwest Research, under ideal engine conditions, (best power timing, engine speed, load, and at steady-state) the use of FPC catalyst in a locomotive and/or any other medium-speed diesel engine will generate a significant fuel economy improvement of no less than 1.74%.

(2) Tests conducted by another independent laboratory, the Western Australia Institute of Technology (WAIT), on a Varimax engine operated at varying rpm, injection timing, and load verify that 1.74% is a minimum, and that average fuel economy improvements under more transient conditions typically experienced in the field will be several times greater.

(3) The same WAIT study determined that fuel economy gain is increased with increasing catalyst concentration and with engine operation deviating from best power parameters, supporting the theory of the catalyst mode of action.

(4) Although engine operating conditions are less severe for stationary engines than for mobile equipment, specific fuel consumption tests in over a dozen stationary heavy duty diesel generator sets operating in the field confirm the WAIT findings. The addition of FPC catalyst to standard diesel fuel improved fuel economy approximately 4% in these studies.

(5) *The Central Oregon & Pacific* ***Carbon Mass Balance*** *loadbox test agrees with the above conclusions. Fuel consumption was reduced 3.7% to 5.4% with FPC catalyst fuel treatment and averaged 4.4%.* Additional benefits include reduced engine smoking, which will lead to reduced carbon or soot buildup on critical combustion chamber, intake and exhaust components. Smoke emissions were also reduced. **Fuel consumption and smoke emissions reductions were minimized by a error in fuel treat rate that was perpetuated throughout**

the entire engine conditioning period and the actual treated fuel static engine tests.

*(6) The Central Oregon & Pacific parallel **flow meter** test yielded improvements ranging from 1.6% to 4.8% and averaged 3.3%.* The above referenced problem of only 50% catalyst treatment level also affected this test.

(7) These data agree with the conclusions rendered by Dr. Geoffrey J. Germane, Ph.D., Mechanical Engineering and Chairman of the Department of Mechanical Engineering, Brigham Young University, in a letter to Mr. Vernon Markworth, Principal Engineer, Design and Development, Department of Engine Research, Southwest Research Institute, 6 August 1992 [Ref 6].

(8) Other combustion experts, such as Dr. G. K. Sharma, Senior Research Manager, Indian Oil Corporation, with whom the writer of this paper has discussed FPC catalyst benefits, also agree [Ref 7].

6.0 RECOMMENDATIONS

Given the considerable independent laboratory and field data collected verifying the potential for fuel savings by treating diesel fuel with FPC Catalyst. CORP can realize a significant fuel cost savings with FPC fuel treatment of 6% to 7% or more with FPC fuel treatment. Exact dollar savings will depend upon fuel cost and volume of fuel consumed, and the duty cycles of the fleet. FPCT recommends CORP commence fuel treatment with FPC as soon as possible, and begin now to recover the losses being sustained from using untreated fuel.

7.0 REFERENCES

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2. Performance Evaluation of a Ferrous Salt Combustion Catalyst Applied to Diesel Fuel by Guld

3. Ten Years of Testing by Platt

4. The Internal-Combustion Engine in Theory and Practice, Volume I by Taylor

5. The Internal-Combustion Engine in Theory and Practice, Volume II by Taylor

6. Letter to Mr. Vernon Markworth, Principal Engineer, Design and Development, Department of Engine Research, SwRI, from Dr. Geoffrey J. Germane, Chairman, Department Mechanical Engineering, Brigham Young University

7. Meeting with Dr. G. K. Sharma, Senior Research Manager, Indian Oil Co. and Mr. S. Craig Flinders, VP, Tech Services, UHI Corporation, 2 June 1994.

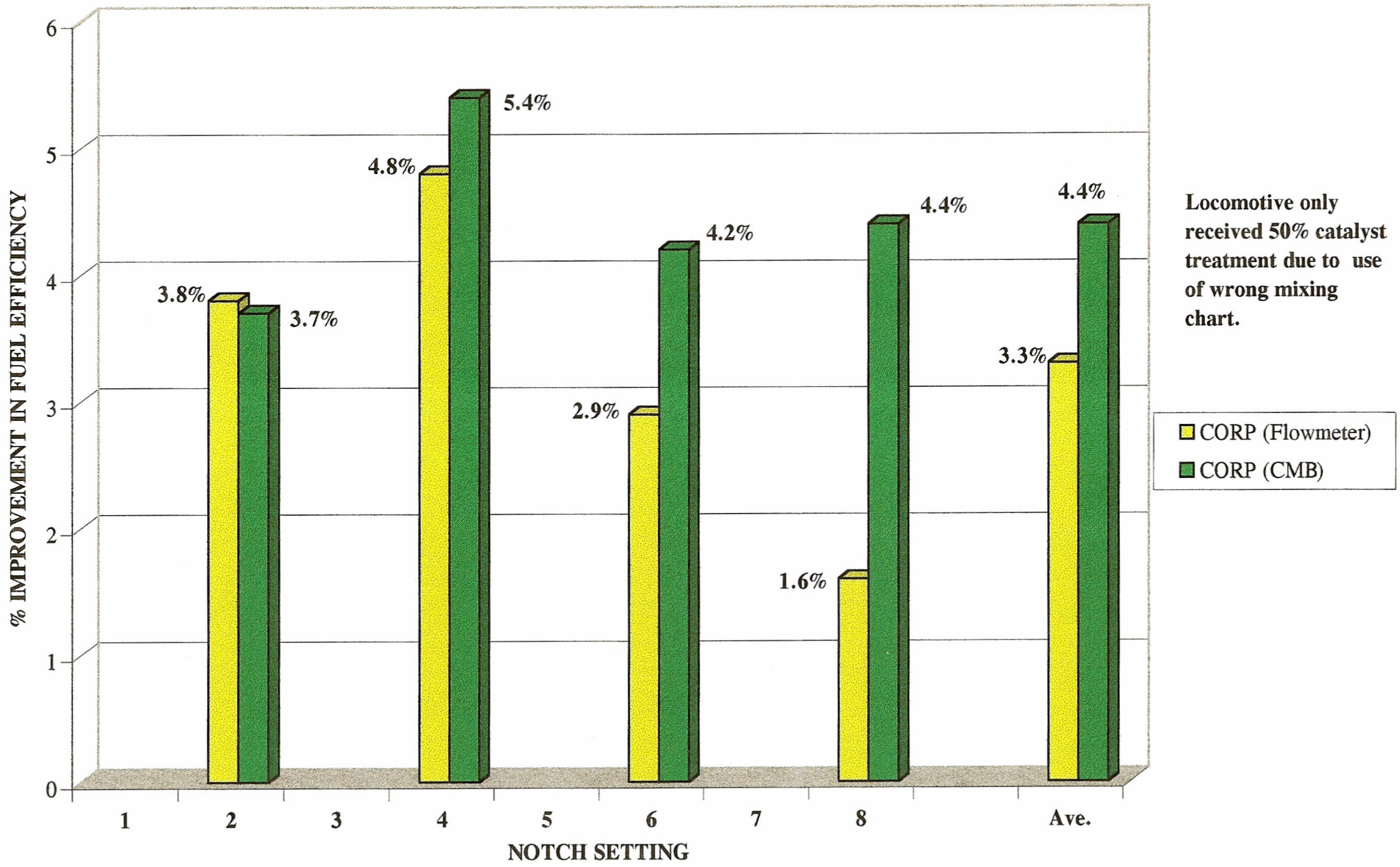
8. SAE PAPER, 75302; by Bruce Simpson, Ford Motor Company.

8.0 **APPENDIX 1**

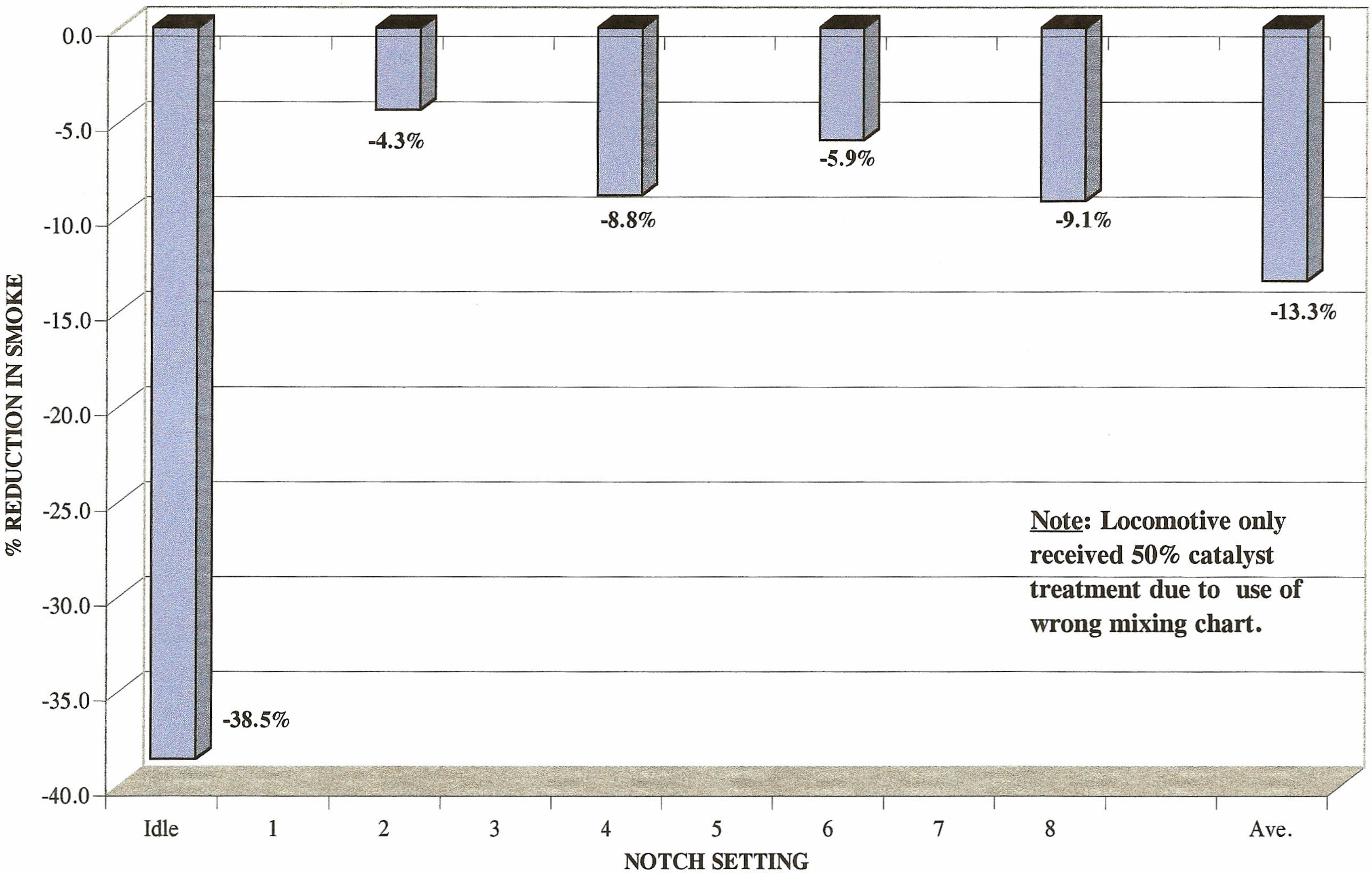
THE "WAIT" STUDY

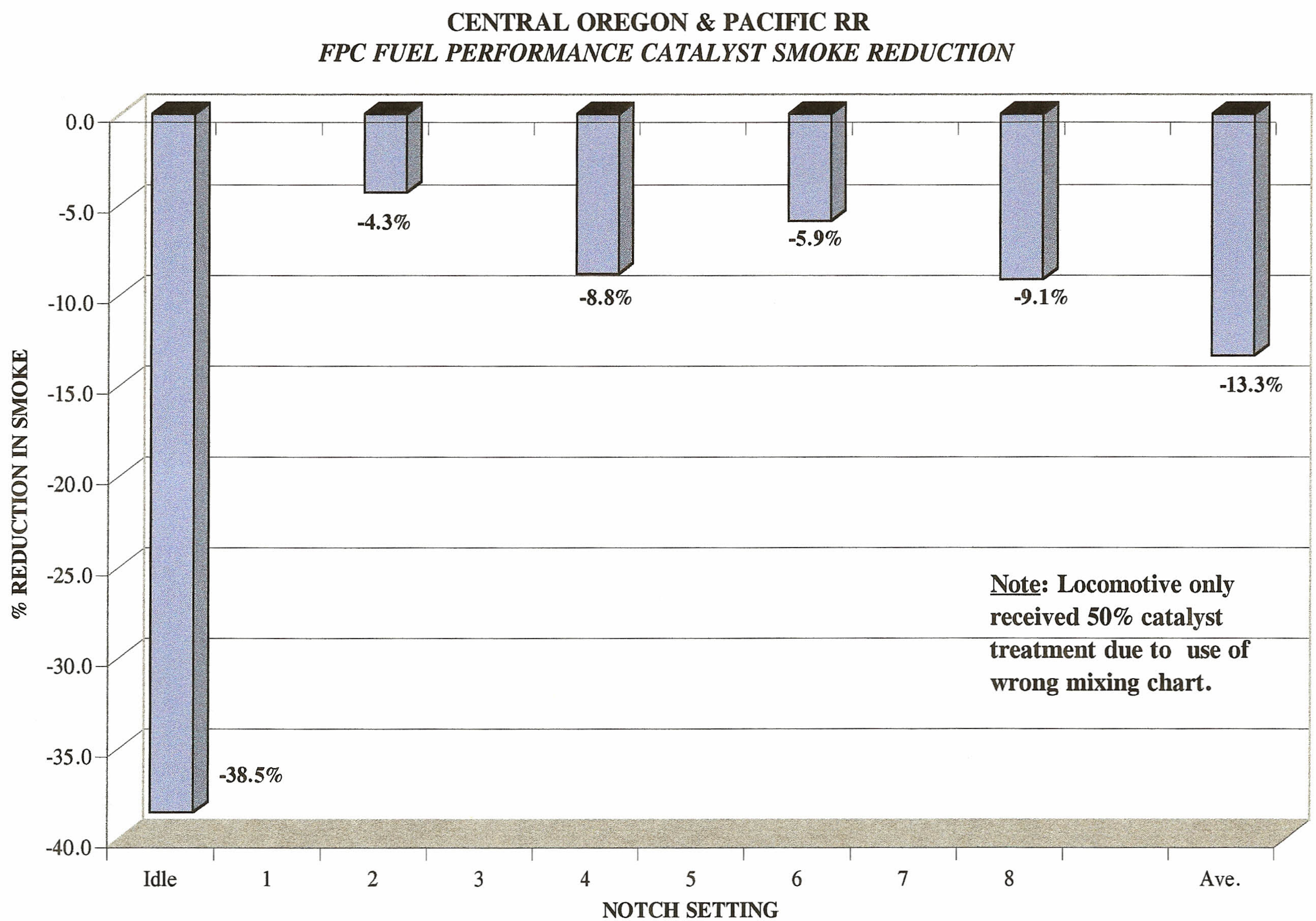
CENTRAL OREGON & PACIFIC

FPC FUEL PERFORMANCE CATALYST TEST RESULTS



CENTRAL OREGON & PACIFIC RR
FPC FUEL PERFORMANCE CATALYST SMOKE REDUCTION




CENTRAL OREGON & PACIFIC RR
FPC FUEL PERFORMANCE CATALYST SMOKE REDUCTION
% REDUCTION IN SMOKE
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-38.5%
-4.3%
-8.8%
-5.9%
-9.1%
-13.3%
Note: Locomotive only received 50% catalyst treatment due to use of wrong mixing chart.
Idle
1
2
3
4
5
6
7
8
Ave.
NOTCH SETTING

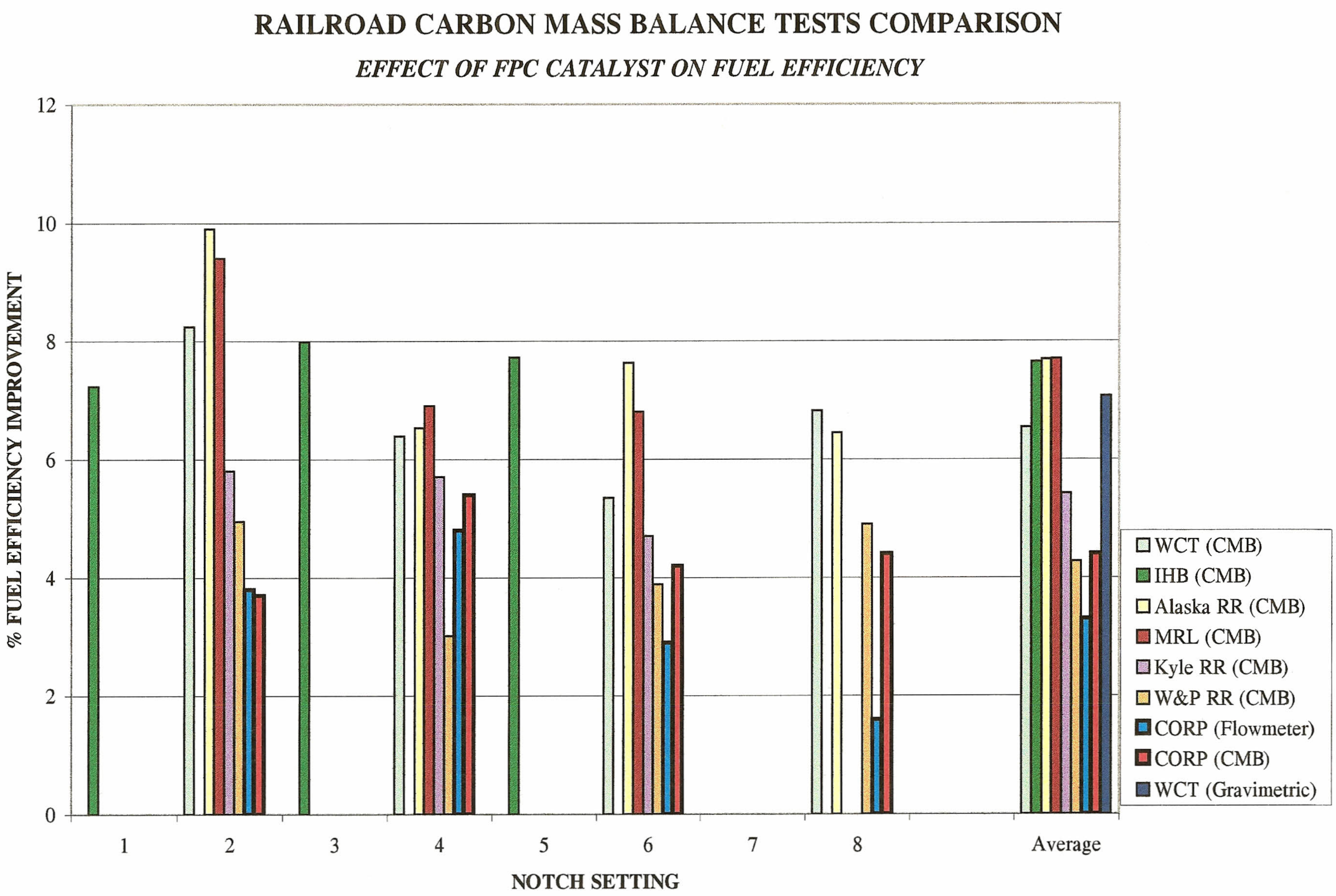
RAILROAD TESTS COMPARISON

The following charts illustrate the fuel efficiency improvements and smoke reductions achieved with the introduction of FPC™ Fuel Performance Catalyst in 7 railroads and 9 separate tests. Seven of the tests were Carbon Mass Balance, one was a flow meter test (volumetric), and one was a gravimetric test (weight).

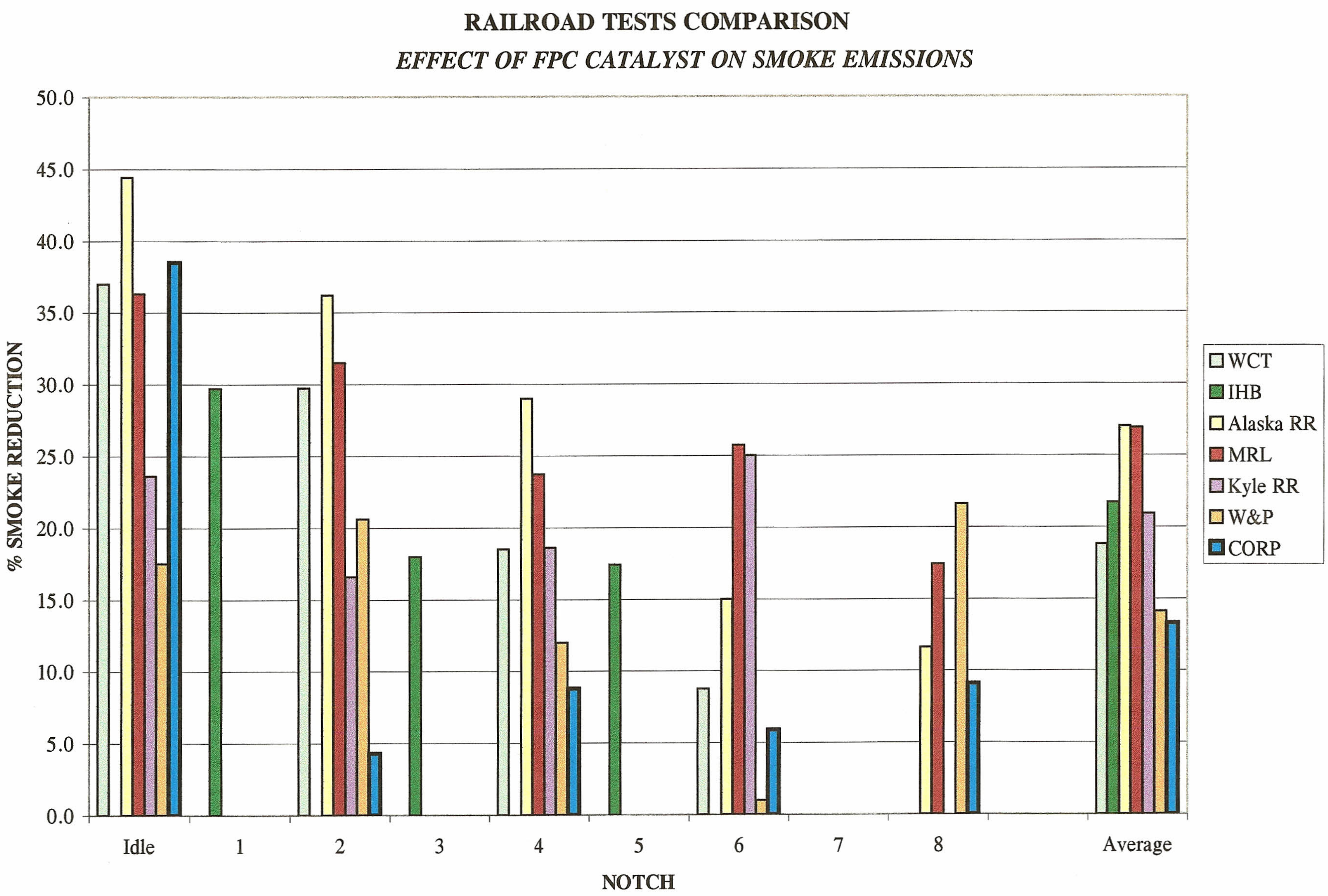
In reviewing the attached chart, it is important to note that:

1. There was a problem with the CORP test in that the FPC™ treatment was dosed at 50% of the recommended rate due to an error in the chart used to determine dose rate. The test also ran for approximately 400 hours instead of the recommended 500 hours. Therefore it is reasonable to conclude that the CORP test unit did not experience the conditioning effect that is required based on the SwRI AAR RP-503 test and the many field tests that have been conducted.
2. The Willamette & Pacific test was also somewhat short of the 500 hours of operation and the "treated test" was conducted in very stormy and wet weather. The impact on the results of the W&P test is not clear but it is safe to say the equipment did not experience the total conditioning effect and the humidity/rain may have affected the results in a way that could not be corrected in the calculations.

In summary, it is obvious from the attached charts that these two tests do not show the reduction in fuel consumption and smoke that other tests have that have met the "conditioning" period. In the case of the CORP test, the 50% dosage rate would have a significant impact in not achieving the potential results that would be expected or that have been exhibited in other tests on similar equipment.



RAILROAD CARBON MASS BALANCE TESTS COMPARISON
EFFECT OF FPC CATALYST ON FUEL EFFICIENCY
% FUEL EFFICIENCY IMPROVEMENT
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
Average
NOTCH SETTING
WCT (CMB)
IHB (CMB)
Alaska RR (CMB)
MRL (CMB)
Kyle RR (CMB)
W&P RR (CMB)
CORP (Flowmeter)
CORP (CMB)
WCT (Gravimetric)


RAILROAD TESTS COMPARISON
EFFECT OF FPC CATALYST ON SMOKE EMISSIONS
% SMOKE REDUCTION
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Idle
1
2
3
4
5
6
7
8
Average
NOTCH
WCT
IHB
Alaska RR
MRL
Kyle RR
W&P
CORP