### Title
Improved Engine Performance Through Heat Transfer Control

### Author(s)
Richard G. Murray

### Performing Organization Name and Address
College of Engineering
Oklahoma State University
Stillwater, OK 74074

### Controlling Office Name and Address
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709

### Report Date
28 July 1978

### Distribution Statement
Approved for public release; distribution unlimited.

### Abstract
The advance of technology requires engines to be more efficient, weight less, and be more reliable. Common materials used for engine parts are not designed close to their thermal limit for strength and lubrication. Additional component loading necessarily will demand a corresponding increase in component cooling. This increased cooling not only represents a thermodynamic loss that detracts from cycle efficiency but it also consumes additional engine power to operate the cooling system.
A new approach to the thermal loading problem is to apply a thin layer of a ceramic insulator to combustion chamber surfaces thereby reducing heat transfer and metallic component temperature. The following document describes the results of a test program to evaluate engine performance for engines having ceramic coatings. Both spark and compression ignition performance was examined.
IMPROVED ENGINE PERFORMANCE THROUGH HEAT TRANSFER CONTROL

FINAL REPORT. 1 Jun 76-30 Jun 78

RICHARD G. MURRAY

FOR A GRANT PERIOD FROM 1 JUNE 1976 TO 30 JUNE 1978

U. S. ARMY RESEARCH OFFICE

ARO PROJECT NO. P-14099-E
GRANT NO. DAAG29-76-G-0263

COLLEGE OF ENGINEERING
OKLAHOMA STATE UNIVERSITY

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

394931 78 05 137
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Combustion Chamber Ceramic Coated Surface Temperature</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Metallic Piston Surface Temperature</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Engine Efficiency Characteristics</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Instantaneous Heat Transfer</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>NASA Engine Test Cell</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>Multi-Cylinder Cylinder Head</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>Pistons</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>O.S.U. Engine Test Laboratory</td>
<td>15</td>
</tr>
<tr>
<td>9</td>
<td>Cylinder Parts Without Ceramic Coating</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>Cylinder Parts With Ceramic Coating</td>
<td>17</td>
</tr>
<tr>
<td>11</td>
<td>Injector Adapter Exploded View</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>Injection Spray Pattern</td>
<td>19</td>
</tr>
<tr>
<td>13</td>
<td>Engine Schematic</td>
<td>21</td>
</tr>
<tr>
<td>14</td>
<td>Hydrocarbon Measurement Apparatus</td>
<td>23</td>
</tr>
<tr>
<td>15</td>
<td>Carbon Monoxide and Backup Hydrocarbon Apparatus</td>
<td>23</td>
</tr>
<tr>
<td>16</td>
<td>Oxides of Nitrogen Measurement Apparatus</td>
<td>24</td>
</tr>
<tr>
<td>17</td>
<td>Platinum Coated Cylinder Head</td>
<td>28</td>
</tr>
<tr>
<td>18</td>
<td>Platinum Coated Piston</td>
<td>28</td>
</tr>
<tr>
<td>19</td>
<td>Cerium Coated Cylinder Head</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>Cerium Coated Piston</td>
<td>30</td>
</tr>
<tr>
<td>21</td>
<td>Indicated Power</td>
<td>32</td>
</tr>
<tr>
<td>22</td>
<td>Indicated Power</td>
<td>33</td>
</tr>
<tr>
<td>23</td>
<td>Indicated Power</td>
<td>34</td>
</tr>
<tr>
<td>24</td>
<td>Fuel Consumption</td>
<td>35</td>
</tr>
<tr>
<td>25</td>
<td>Fuel Consumption</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---</td>
<td>------------------------</td>
<td>------</td>
</tr>
<tr>
<td>26.</td>
<td>Fuel Consumption</td>
<td>37</td>
</tr>
<tr>
<td>27.</td>
<td>Ignition Delay</td>
<td>38</td>
</tr>
<tr>
<td>28.</td>
<td>Ignition Delay</td>
<td>39</td>
</tr>
<tr>
<td>29.</td>
<td>Ignition Delay</td>
<td>40</td>
</tr>
<tr>
<td>30.</td>
<td>Exhaust Gas Temperature</td>
<td>41</td>
</tr>
<tr>
<td>31.</td>
<td>Exhaust Gas Temperature</td>
<td>42</td>
</tr>
<tr>
<td>32.</td>
<td>Exhaust Gas Temperature</td>
<td>43</td>
</tr>
<tr>
<td>33.</td>
<td>Hydrocarbon Emission</td>
<td>45</td>
</tr>
<tr>
<td>34.</td>
<td>Hydrocarbon Emission</td>
<td>46</td>
</tr>
<tr>
<td>35.</td>
<td>Hydrocarbon Emission</td>
<td>47</td>
</tr>
<tr>
<td>36.</td>
<td>Carbon Monoxide Emission</td>
<td>48</td>
</tr>
<tr>
<td>37.</td>
<td>Carbon Monoxide Emission</td>
<td>49</td>
</tr>
<tr>
<td>38.</td>
<td>Carbon Monoxide Emission</td>
<td>50</td>
</tr>
<tr>
<td>39.</td>
<td>Oxides of Nitrogen Emission</td>
<td>51</td>
</tr>
<tr>
<td>40.</td>
<td>Oxides of Nitrogen Emission</td>
<td>52</td>
</tr>
<tr>
<td>41.</td>
<td>Oxides of Nitrogen Emission</td>
<td>53</td>
</tr>
<tr>
<td>42.</td>
<td>Indicated Power</td>
<td>54</td>
</tr>
<tr>
<td>43.</td>
<td>Indicated Power</td>
<td>55</td>
</tr>
<tr>
<td>44.</td>
<td>Indicated Power</td>
<td>56</td>
</tr>
<tr>
<td>45.</td>
<td>Indicated Power</td>
<td>57</td>
</tr>
<tr>
<td>46.</td>
<td>Indicated Power</td>
<td>58</td>
</tr>
<tr>
<td>47.</td>
<td>Fuel Consumption</td>
<td>60</td>
</tr>
<tr>
<td>48.</td>
<td>Fuel Consumption</td>
<td>61</td>
</tr>
<tr>
<td>49.</td>
<td>Fuel Consumption</td>
<td>62</td>
</tr>
<tr>
<td>50.</td>
<td>Fuel Consumption</td>
<td>63</td>
</tr>
<tr>
<td>51.</td>
<td>Fuel Consumption</td>
<td>64</td>
</tr>
<tr>
<td>52.</td>
<td>Ignition Delay</td>
<td>65</td>
</tr>
</tbody>
</table>
53. Ignition Delay
54. Ignition Delay
55. Ignition Delay
56. Ignition Delay
57. Exhaust Gas Temperature
58. Exhaust Gas Temperature
59. Exhaust Gas Temperature
60. Exhaust Gas Temperature
61. Exhaust Gas Temperature
62. Hydrocarbon Emission
63. Hydrocarbon Emission
64. Hydrocarbon Emission
65. Hydrocarbon Emission
66. Hydrocarbon Emission
67. Carbon Monoxide Emission
68. Carbon Monoxide Emission
69. Carbon Monoxide Emission
70. Carbon Monoxide Emission
71. Carbon Monoxide Emission
72. Oxides of Nitrogen Emission
73. Oxides of Nitrogen Emission
74. Oxides of Nitrogen Emission
75. Oxides of Nitrogen Emission
76. Oxides of Nitrogen Emission
77. Cerium Coated Piston-After Tests
INTRODUCTION

The following document is a final report for Grant Number DAAG29-76-G-0263 funded by the U.S. Army reserve office. This Project was started June 1, 1976 and had a duration of two years. In general, the scope of this Project was to investigate engine performance and emission characteristics resulting from the application of both ceramic and catalytic combustion chamber surfaces.

THEORETICAL BACKGROUND

Purpose

In general, heat engines are devices that transform a portion of high temperature heat energy into work and reject the remaining energy as a waste product at a lower temperature. Most theoretical engine cycles employ adiabatic processes for expansion and compression of the contained gases. Typical analyses for simplified reciprocating spark-ignition (S-I) and compression ignition (C-I) engines will indicate that approximately two-thirds of the energy input can be theoretically transformed into work while the remaining one-third will be rejected as waste heat. This wasted energy is contained in the exhaust products leaving the engine.

Real engines not only lose approximately one-third of the input energy in the exhaust but they also employ non adiabatic processes that waste approximately another third of the energy supplied.

Since metallic engine parts are in continuous contact with the working fluid at elevated temperature they absorb heat from the fluid and tend to increase in temperature. Structural and lubrication requirements necessitate that component temperature can be controlled to reasonable values by cooling with a heat transfer to either the cooling jacket or lubricating oil.

This heat transfer theoretically represents an energy loss from the engine.
that could otherwise partially be converted into useful work.

Since the temperature of the metallic engine components results from an intimate contact with a high temperature working fluid it is theoretically possible to control and decrease heat transfer and thus metallic temperatures by incorporating a coating of an insulating material on combustion chamber surfaces. Theoretically if the heat transfer is reduced the engine performance and efficiency should improve.

Several ceramic substances have been developed in the last few years that exhibit excellent insulating properties. These substances can be sprayed on metal surfaces by flame or plasma methods and also can be applied by a device known as a detonation gun. Some properties of various coatings and metals follow in Table 1.
### Table I

#### PHYSICAL PROPERTIES

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>THERMAL CONDUCTIVITY</th>
<th>COEFFICIENT OF EXPANSION</th>
<th>BULK DENSITY</th>
<th>SPECIFIC HEAT</th>
<th>MELTING TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BTU hr ft °F</td>
<td>in °F x 10⁻⁶</td>
<td>gm cm³</td>
<td>BTU °F</td>
<td>°F</td>
</tr>
<tr>
<td></td>
<td>(cal Sec cm C)</td>
<td>(cm cm C x 10⁻⁶)</td>
<td>(cal cm C)</td>
<td>(°C)</td>
<td></td>
</tr>
<tr>
<td>ZIRCONIUM OXIDE</td>
<td>0.67 (2.77 x 10⁻³)</td>
<td>5.4 (3.0)</td>
<td>5.2</td>
<td>0.175 (6.018)</td>
<td>4500 (2482)</td>
</tr>
<tr>
<td>ALUMINUM OXIDE</td>
<td>1.58 (0.01)</td>
<td>4.1 (2.28)</td>
<td>3.3</td>
<td>0.28 (0.028)</td>
<td>3600 (1982)</td>
</tr>
<tr>
<td>CHROME OXIDE</td>
<td>1.50 (0.01)</td>
<td>5.0 (2.78)</td>
<td>4.6</td>
<td>0.20 (0.020)</td>
<td>3000 (1649)</td>
</tr>
<tr>
<td>ALUMINUM</td>
<td>120 (0.50)</td>
<td>13.0 (7.22)</td>
<td>2.7</td>
<td>0.22 (0.022)</td>
<td>1220 (660)</td>
</tr>
<tr>
<td>CAST IRON</td>
<td>27 (0.11)</td>
<td>6.5 (3.61)</td>
<td>7.88</td>
<td>0.11 (0.011)</td>
<td>2800 (1538)</td>
</tr>
</tbody>
</table>

SOURCE: “ROKIDE CERAMIC SPRAY COATING”,
THE NORTON COMPANY, 1981.
It can therefore be stated that theoretically the application of a relatively thin layer of a ceramic insulating material should reduce heat transfer, reduce metallic structural temperature, and increase engine efficiency.

From a combustion standpoint, the elevated ceramic surface temperature in conjunction with an expected catalytic effect should assist combustion especially for lean mixtures. This factor should enhance preflame reactions and promote better engine performance on low grade fuels for C-I operation.

Finally, it is expected that decreased metallic structural temperatures should allow component redesign to reduce weight and increase reliability.

Coating Selection and Application

As previously mentioned several insulating coatings have been developed in recent years. Among these are aluminum oxide, zirconium oxide, zirconium silicate, chrome oxide, and magnesium aluminate.

To reduce heat transfer in an engine cylinder, two physical coating properties are of prime importance. First, the material must adhere to the metallic subsurface without any significant intersurface stress over a wide range of temperature. This necessitates that the coefficient of thermal expansion of the coating should be of the same order of magnitude as the base structure. Second, it should have as low a thermal conductivity as possible in order to effectively control heat transfer.

Properties of lesser importance are specific heat, compressive strength, and adherence.

Of all the coating materials investigated yttria stabilized zirconium oxide best fits the requirements for engine combustion chamber insulation. Adherence of plasma and flame sprayed zirconium oxide to cast iron and aluminum surfaces is, however, in some cases not good and coating separations will occur if proper techniques are not observed.
Before coating metallic surfaces they should be clean and free of oil. In some cases it may be necessary to preheat cast iron surfaces to expel residual oil from machining processes. To promote good bonding, it is suggested that metallic surfaces be grit blasted and given a flash coat of nickel aluminate before application of the zirconium oxide coating.

**Engine Model**

A more indepth theoretical study was performed by the author in 1976 to quantify the expected performance changes of insulated versus non-insulated engines. This study was undertaken at the National Aeronautics and Space Administration--Johnson Space Center (NASA-JSC). The outcome of this study was a computer model to predict heat transfer, engine operation parameters, and component temperatures as a function of coating conductivity and thickness.

The model utilized a modified otto cycle analysis with variable specific heats and variable polytropic exponents for compression and expansion. The quantity of exhaust residual, intake properties, compression ratio, bore, stroke, air fuel ratio, engine speed and percent of throttle could be varied. Processes considered in the model included residual gas expansion, intake, compression, combustion, expansion, blowdown, and scavenge.

Cyclic heat transfer was calculated by summation of the instantaneous heat transfer for each unit of engine rotation, (dθ) or

\[ Q = \int \dfrac{T_g - T_w}{R} \, d\theta + 2 \int \dfrac{T_g - T_o}{R} \, d\theta \]

Where \( T_g \) is the working fluid bulk temperature, \( T_w \) is the cooling water temperature, \( T_o \) is the lubricating oil temperature and \( R \) is the combined convective and conductive heat transfer resistance.

The convective resistance is controlled by the film coefficient \( (h) \) and the exposed surface area \( (A) \) which includes the circular cylinder head and
and piston surfaces as well as the variable cylindrical surface area of the
engine cylinder Θ is cyclic crankshaft rotation.

Recent work by several authorities has yielded valuable insight into
ingine combustion processes and the resulting values for the convective film
coefficient (1, 2, 3). The relationships chosen for the film coefficient in this
model are those by Woschni as follows:

\[ h = 0.035 \left( \frac{K}{B} \left( \frac{B \rho V}{\mu} \right)^{0.8} \right) \]

Where \( K \) is the thermal conductivity, \( B \) is the cylinder bore, \( \mu \) is the viscosity,
\( \rho \) is the density and \( V \) represents gas velocity as a function of mean piston speed
\( V_p \) and varies from process to process as follows:

\[ V = 2.28 V_p \] (compression and intake)
\[ V = 6.18 V_p \] (scavenge and blowdown)
\[ V = 2.28 V_p + 0.00324 \frac{V_s T_l}{P_1 V_l} \Delta P \] (combustion and scavenging)

Where \( V_s \) is instantaneous cylinder volume \( P_1, T_1, \) and \( V_1 \) are inlet closure prop-
ties and \( \Delta P \) is the difference between instantaneous pressure and unfired engine
pressure at the same crank angle. Neither combustion kinetics nor an expected
reduction in lubricating oil temperature with reduced heat transfer were accoun-
ted for in the model.

Results of this model for various coating thickness are displayed in Figures
1-3. Note that as coating thickness increases:

1. Exposed coated surface temperature increases rapidly
   for combustion and expansion,
2. Metallic piston intersurface temperature decreases and
3. Overall cyclic efficiency increases.

One important outcome of the mathematical analysis as shown in Figure 4 is that
convective resistance to heat transfer predominates throughout the cycle except
FIGURE 1
COMBUSTION CHAMBER CERAMIC COATED
SURFACE TEMPERATURE
2000 RPM
COATING THERMAL CONDUCTIVITY = 0.40 BTU
hr ft °F
= 0.002 cal
cm Sec °C

0.040" (1.2 mm)

0.020" (0.51 mm)

ZERO

TEMPERATURE °F

TEMPERATURE °C

CRANK ANGLE - DEGREE

0 100 200 300 400 500 600 700
Figure 2. Metallic Piston Surface Temperature vs. Crank Angle Degree

METALLIC PISTON SURFACE TEMPERATURE = 0.40 BTU/hr ft °F/cm sec C

0.020" (0.51 mm)
0.040" (1.2 mm)

ZERO
FIGURE 3
ENGINE EFFICIENCY CHARACTERISTICS
2000 RPM
COATING THERMAL CONDUCTIVITY = 0.40 BTU/hr ft °F
= 0.002 cm Sec °C
FIGURE 3
ENGINE EFFICIENCY CHARACTERISTICS
2000 RPM
COATING THERMAL CONDUCTIVITY = 0.40 \( \text{BTU} \frac{\text{hr ft}}{\text{hr ft}^\circ \text{F}} \)
= 0.002 \( \frac{\text{cm}}{\text{sec} \ C} \)

COATING THICKNESS - INCHES

COATING THICKNESS - MM

CYCLE THERMAL EFFICIENCY %

0

0.020

0.040

0.060
Figure 4
Instantaneous Heat Transfer
2000 RPM

- DEGREES OF CRANKSHAFT ROTATION -

- HEAT TRANSFER - JOULE -

- HEAT TRANSFER - BTU -

- NO COATING -

- 0.050" THICK COATING
  (1.3 mm) -

- RADIANS OF CRANKSHAFT ROTATION -
during combustion and early expansion where turbulence is significant. During this critical time the convective resistance is lost and the conductive resistance of an insulating coating becomes a sizeable benefit. This is also the time of high working fluid temperature where the greatest power production can be expected if heat transfer can be minimized by the insulation.

PRELIMINARY TESTING

The above theoretical expectations appeared sufficiently optimistic that a sequence of engine test were performed by NASA-JSC in which the author participated. Objectives of these tests were to identify performance changes and to establish if flame sprayed ceramic coatings could in fact endure the torturous environment of a reciprocating I-C engine combustion chamber. Figure 5 illustrates the NASA-JSC test facility with the four cylinder 153 cubic inch S-I Chevrolet test engine in place. Figure 6 and 7 portray the ceramic coated cast iron cylinder head and aluminum pistons respectively coating thicknesses were a nominal 0.51 to 0.76 mm (0.020 to 0.030 inch).

Results of the NASA-JSC tests indicated that yttria stabilized zirconium oxide would adhere to aluminum, steel, and cast iron engine parts for at least the one hundred plus hours of test operation without separation from the metallic subsurface and would not display visible degradation of the ceramic structure.

Performance observations resulting from these tests were somewhat inconclusive, some areas of operation showed slight efficiency and power improvements while others showed a small sacrifice. In general non-knocking power and efficiency was somewhat higher but combustion knock, and the resulting performance decrease appeared to be promoted by the ceramic surface.

COMPREHENSIVE TESTING

As previously stated the preliminary test at NASA-JSC proved that zirconium
Figure 5

NASA Engine Test Cell

Figure 6

Multi-Cylinder Cylinder Head
Figure 7

Pistons
oxide coatings could withstand the harsh S-I engine environment and in some cases yield a performance improvement. Based on these early tests the U.S. Army research office issued a grant to fund a two year effort at Oklahoma State University to further investigate coated engine performance. This work consisted of two phases. First to document engine performance for both S-I and C-I ceramic coated engines and second to investigate emission and performance characteristics for zirconium oxide coated engines with and without catalysts applied to the exposed ceramic, in other words, an in situ catalytic reactor.

TEST APPARATUS

The engine test laboratory used for the above test program is shown in Figure 8. Principle items of laboratory equipment for the OSU project can be divided into two categories, the engine with its associated instrumentation and the emission analysis apparatus.

Analysis Apparatus

A Cooperative Fuel Research (CFR) low speed crankcase engine was used for all tests. This engine was equipped with the split head cylinder that allowed compression ratio testing capability between 4 and 18 to one. Figures 9 and 10 show the configuration of this cylinder head and piston with and without a yttria stabilized zirconium oxide coating, respectively. Coating thickness for all tests was 0.64 mm (0.025 inch).

Note in Figure 10 that for C-I operation the spark plug has been replaced by an adapter that holds a pencil type injector for open chamber operation. This injector as well as the adaptor were designed solely for this project and are shown in Figure 11. A typical injection spray pattern is illustrated in Figure 12.
Figure 8

O.S.U. Engine Test Laboratory
Figure 9

Cylinder Parts Without Ceramic Coating
Figure 10

Cylinder Parts With Ceramic Coating
Figure 11

Injector Adaptor Exploded View
Figure 12

Injection Spray Pattern
A schematic of the engine and its associated equipment is shown in Figure 13. Combustion air was forced through an ice tower to remove excess moisture and then flowed through a laminar flow element flowmeter. Mass rate of air flow was regulated by a throttle valve preceding a surge tank that reduced pulsations for the flowmeter. For S-I operation, fuel was sprayed into the airstream and the mixture heated to standard temperature before entering the engine. S-I fuel was drawn from a graduated flask and then flowed through a rotameter for redundant flow measurement. Indolene clear (98 octane) was used as S-I fuel.

C-I fuel was also drawn from a graduated flask for a known time to establish primary flow measurement. Back up flow was determined by a micrometer controlled rack on the Bosch injection pump. A pressure transducer on the injection line produced an electric signal used to establish injection timing. Injection timing was adjustable within limits by a micrometer adjustment on the injection pump. The fuel used for C-I operation was I-H cat diesel fuel.

The engine was cooled by a boiling water jacket and lube oil temperature was controlled by an electric heater.

An AVL 14DP240C strain gauge pressure transducer and two photocells provided signals to an indicated power meter of the modified Phillips design (4). The output of this transducer was also used for oscilloscope observation of engine performance. A photographic display of pressure time (P-T), injection time, spark time, and crankshaft angular position were taken to document timing and combustion delay information.

Gas temperatures were monitored by thermocouples in the exhaust pipe and intake manifold.

Emission Apparatus

Three substances were analyzed in the exhaust of the test engine, hydro-
carbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOX). Hydrocarbon concentration was observed by flame ionization detection (FID) using a sampling apparatus illustrated in Figure 14. HC concentration was reported as parts per million carbon as related to a propane (C₃H₈) calibration gas. A non-dispersive infrared analyzer (NDIR) was used as a backup HC instrument. This same device monitored CO as illustrated in Figure 15. The sampling system and the NDIR used for NOX measurement is shown in Figure 16.

TEST PROCEDURE

Each sequence of testing was preceded by an engine tune-up that included a cylinder deglaze, installation of new piston rings, valve lapping and measurement of clearance volume for compression ratio determination. All instrumentation was given a major calibration before each test sequence and a minor calibration periodically between test runs. An engine break in was performed following each engine assembly.

S-I Tests

Before each sequence of S-I tests the fuel and ignition system performance and calibration was verified. The engine was started and brought to operational temperature on natural gas fuel to avoid combustion chamber deposits.

Engine runs were started at low values (6 to 1) of compression ratio (CR) and progressed to higher values. Initially, it was intended to secure data between 4 and 14 to one CR but low performance and violent knock necessitated a smaller CR range.

Air fuel ratios ranging from lean misfire (18 to 1) and rich misfire (14 to 1) were tested for each compression ratio.

Spark timing was adjusted to minimum advance for best torque (MBT) for each
Figure 14 Hydrocarbon Measurement Apparatus

FUEL, AIR, & CALIBRATION GASES

EXHAUST SAMPLE → FILTER → HEATED LINE → FLAME IONIZATION DETECTOR → VENT

Figure 15 Carbon Monoxide & Backup Hydrocarbon Apparatus

CALIBRATION GASES

EXHAUST SAMPLE → FILTER → NON-DISPERSIVE INFRARED ANALYZER → VENT
Figure 16 Oxides of Nitrogen Measurement Apparatus
data run. Several minutes (5 or more) of engine operation elapsed to establish equilibrium on each run before data was recorded. Ignition delay was measured as the crankshaft rotation between the spark pulse and significant cylinder pressure rise.

Before each data run all emission filters were changed, air and fuel flow rates were re-established and intake air fuel mixture temperature was adjusted to 305K (85°F).

C-I Tests

In general, C-I tests were similar to S-I tests, however, natural gas could not be used as a warm-up fuel. Compression ratios between 14 and 18 to one were investigated for air fuel ratios ranging from 19 to 34 to one. It was found that CR lower than 14 to 1 resulted in misfire and A-F richer than 19 to one produced such high concentrations of soot that emission filters were plugged in a few seconds of operation. A-F ratios leaner than 34 to one resulted in significant misfire.

C-I engine tests started at low values of CR and progressed to higher values. A-F ratios progressed from rich to lean. Inlet air temperature was regulated to 322K (120°F) for all C-I tests.

Injection timing was adjusted to MBT whenever possible, however, the maximum advance was 53 degrees and many tests had not reached best torque at the maximum advance limit.

Ignition delay was determined by measuring the difference between the injector transducer pulse and the point of significant pressure rise in the combustion chamber.

Preliminary Test

A complete set of performance data was taken during the projects first
No emission data was taken, however, since the in situ catalytic project had not been formulated. Once the second year in situ study was approved it was realized that all tests would need be rerun to include emission profiles and combustion delay. These last two items are a key indicator of how the catalyst is effecting combustion, performance, and emission.

Since test procedures and instrumentation were significantly changed after the first year and since some first year data had wide variation this data will not be included in this document.

CATALYSTS

Selection

Theoretically catalytic surfaces can be expected to influence chemical kinetics prior to, during, and following combustion. Catalysts by their nature form chemical bonds of varying degrees of stability with other atoms or groups. Although one must hope ultimately to explain the chemical behavior of a metallic catalyst in purely quantum mechanical terms, this objective still remains largely beyond reach and one is left with the construction of essentially empirical correlations (5).

It can be expected that the material of an engine combustion chamber must catalytically influence the rate and path of the reactions leading to combustion products. When aluminum and cast iron combustion chamber surfaces are replaced by yttria stabilized zirconium oxide it is reasonable to expect a change in reaction time and composition of exhaust products. An expansion of this idea would predict a further change in combustion characteristics if active catalytic substances such as platinum and cerium were introduced.

To pursue this principle a program was undertaken during the second year of the U.S. Army grant to identify the affect of various catalytic substances on
engine performance and emission. Initially, six metals (platinum, palladium, cerium, nickel, tungsten, and titanium) were selected as possible candidates. Of these, two, platinum and cerium, were applied to the zirconium oxide combustion surface and subjected to a sequence of engine tests. It was expected that these substances would yield: 1) a reduced tendency to knock, 2) a decrease in preflame chemical and physical delay time, 3) a reduction in exhaust emissions, and 4) a more favorable engine tolerance to low grade fuel (6).

Application

Metallic catalysts are not usually applied to a surface in the pure metal state. A common procedure is to dissolve a salt or metallic compound in a solvent, distribute this solution on the surface and then chemically reduce the dried film to the parent metal. This above procedure was used for both catalysts that were applied for this test.

Preparation of a platinum catalyst solution consisted of dissolving 1.2 grams of dihydrogen hexachloroplatinate IV (H₂PtCl₆·6H₂O) in 2.0 grams of distilled water. This solution was spread over the polished zirconium surfaces with a glass rod and then allowed to dry in air for 24 hours prior to a final oven drying at 422K for 12 hours.

Reduction of the dihydrogen hexachloroplatinate to platinum black was achieved by placing the surfaces in a sealed steel box and placing the box in an electric oven. Before heating, the box was purged of air by flushing with dry nitrogen for several minutes. The nitrogen in turn was forced from the box by a flow of gaseous hydrogen entering at the top and pushing nitrogen out the bottom. Hydrogen flow was controlled to 17 cubic centimeters per hour and continued throughout reduction. Reduction was completed by maintaining a 533K temperature for 24 hours. Figures 17 and 18 show the platinum surfaces after reduction.
Figure 17

Platinum Coated Cylinder Head

Figure 18

Platinum Coated Piston
The procedure for cerium application was quite similar to that for platinum. The solution was prepared with 15.1 grams of cerium (III) 2,4 pentanedionate Ce (C₅H₇O₂)₃·XH₂O in 59.1 grams of absolute alcohol. Initial hydrogen reduction temperature was 450K. This reduction was followed by a second application of solution and a final hydrogen reduction at 589K. Figure 19 illustrates the cylinder head surface after reduction with a cerium catalyst.

Production of a satisfactory surface and reduction was much more difficult with cerium than platinum. Refusal of the coating to reduce, poor adherence, and blistering were common problems. Figure 20 portrays a typical unsatisfactory cerium surface.

DATA AND ANALYSIS

Raw data was recorded manually during each engine run on computer format forms. After data acquisition all information was transferred to punch cards and processed in an IBM system 370 computer. A copy of the program is listed in the appendix.

Table 2 following tabulates all reported data, while Figures 21 through 76 display the graphical behavior of non-coated, coated, and catalytic engine performance for both S-I and C-I operation.
Figure 19

Cerium Coated Cylinder Head

Figure 20

Cerium Coated Piston
S-I Data Analysis

Figures 21 through 23 illustrate the relationship of indicated power to air fuel ratio for the various engine configurations. Note, that power in general shows a significant improvement for zirconium coated S-I engines as compared to non-coated. This trend, however, reversed at 10 to 1 CR for mid range A-F. Severe knock accounted for this power loss. The uncoated surfaces resisted knock presumably because of the lower surface temperature of the bare metal.

In opposition to expected results, a power sacrifice was observed for catalytic operation. In general, all S-I data indicated that both cerium and platinum inhibited combustion and reduced engine performance.

Indicated specific fuel consumption (ISFC) trends are portrayed in Figures 24 to 26, where as expected, the zirconium coated engine showed superiority until severe knock destroyed power output at a CR of 10.

As expected, ignition delay is much less for zirconium coated performance (see Figures 27 through 29) no doubt caused by the fuel-air mixture having contact with a hotter surface during its residence on the intake and compression strokes.

Unexpectedly, the catalytic coatings do not appear to initiate preflame reactions that reduce ignition delay.

Exhaust gas temperature (EGT) portrays the usual decline with an increase of CR as shown in Figures 30 to 32. The typical peak temperature on the lean side of stoichiometric is present, as is the increase in temperature with a reduction in heat transfer for the coated engine. Note that the combustion inhibiting phenomenon of the catalytic surfaces delays and reduces the peak EGT.

HC and CO emissions are generally similar for zirconium coated and non-coated performance while catalytic surfaces tended to produce somewhat higher
FIGURE 21  INDICATED POWER SPARK IGNITION
6–1 COMPRESSION RATIO
900 RPM

INDICATED POWER KILOWATTS

HORSEPOWER

AIR–FUEL RATIO

NON–COATED

COATED

CERIUM

PLATINUM
FIGURE 22  INDICATED POWER SPARK IGNITION
8-1 COMPRESSION RATIO
900 RPM
FIGURE 23 INDICATED POWER SPARK IGNITION
10–1 COMPRESSION RATIO
900 RPM

- NON-COATED
- PLATINUM
- CERIUM
- COATED

INDICATED POWER KILOWATTS

HORSEPOWER

AIR–FUEL RATIO
FIGURE 24 FUEL CONSUMPTION
SPARK IGNITION
6-1 COMPRESSION RATIO
900 RPM

INDICATED SPECIFIC FUEL CONSUMPTION GRAMS PER WATT HOUR

CERIUM
NON-COATED
COATED

LBS./HP-HR.

ISFC

AIR-FUEL RATIO

13 14 15 16 17 18
FIGURE 25  FUEL CONSUMPTION
SPARK IGNITION
8-1 COMPRESSION RATIO
900 RPM

- Specific fuel consumption vs. air fuel ratio for Cerium, Platinum, Non-Coated, and Coated catalysts.
- The graph illustrates the variation in fuel consumption with different air fuel ratios, showing the performance of catalysts under various conditions.
FIGURE 26  FUEL CONSUMPTION
SPARK IGNITION
10–1 COMPRESSION RATIO
900 RPM
FIGURE 27  IGNITION DELAY
SPARK IGNITION
6–1 COMPRESSION RATIO
900 RPM

IGNITION DELAY

AIR FUEL RATIO

- PLATINUM
- NON-COATED
- CERIUM
- COATED
FIGURE 28 IGNITION DELAY
SPARK IGNITION
8-1 COMPRESSION RATIO

IGNITION DELAY

PLATINUM
CERIUM
NON-COATED
COATED

AIR FUEL RATIO
FIGURE 30 EXHAUST GAS TEMPERATURE
SPARK IGNITION
6–1 COMPRESSION RATIO
900 RPM
Figure 31: Exhaust Gas Temperature
Spark Ignition
8–1 Compression Ratio
900 RPM
FIGURE 32 EXHAUST GAS TEMPERATURE
SPARK IGNITION
10–1 COMPRESSION RATIO
900 RPM
concentrations as shown in Figures 33 to 38. Again, this trend indicates that the catalytic surfaces acted as a deterrent to preflame reactions and inhibited complete combustion.

Oxides of nitrogen concentration is much the same for non-coated and catalytic performance (see Figures 39 to 41) with a large increase shown for coated operation. The expected peak concentration on the lean side of stoichiometric is found only for coated zirconium performance. The behavior of this data places some doubt on its validity even though it was repeatable and consistent. Additional tests may be justified and may point to an unexpected problem with sample handling.

C-I Data Analysis

Engine power is significantly reduced for C-I operation with zirconium or catalytic coatings as shown in Figures 42 to 46. This unexpected event could be the result of several factors, the most notable being: 1) an increased heating of the new air charge during the intake and compression strokes resulting in an increase in negative compression work, 2) a change in precombustion (catalytic) reactions at the surface that delay and inhibit combustion, and 3) an absorption of impinging fuel into the porous ceramic coating causing late and incomplete combustion.

While all of the above factors probably play a role in the poorer coated and catalytic performance, it is believed that the third is the most influential. Impingement has been a significant problem in C-I operation due to the open chamber design. The small bore cylindrical shaped combustion chamber as well as the side location of the injector produces some degree of impingement even with an improved injector hole arrangement. This impingement is far more critical on a porous ceramic surface where a portion of the fuel can be absorbed than on a smooth metal where it remains in intimate contact with the combustion
Figure 33 Hydrocarbon Emission
Spark Ignition
6-1 Compression Ratio
FIGURE 34 HYDROCARBON EMISSION
SPARK IGNITION
8-1 COMPRESSION RATIO

HYDROCARBONS PARTS PER MILLION

PLATINUM
CERIUM
NON-COATED
COATED

AIR-FUEL RATIO

0 1000 2000 3000 4000 5000 6000
13 14 15 16 17 18
FIGURE 35 HYDROCARBON EMISSION
PLATINUM SPARK IGNITION
10–1 COMPRESSION RATIO

HYDROCARBONS PARTS PER MILLION

0 1000 2000 3000 4000 5000 6000

13 14 15 16 17 18

AIR–FUEL RATIO

COATED

CERIUM

NON–COATED
FIGURE 36 CARBON MONOXIDE EMISSION
SPARK IGNITION
6-1 COMPRESSION RATIO
900 RPM

% CARBON MONOXIDE

CERIUM
NON-COATED
COATED
PLATINUM

AIR-FUEL RATIO

13 14 15 16 17 18
FIGURE 37 CARBON MONOXIDE EMISSION
SPARK IGNITION
8:1 COMPRESSION RATIO
900 RPM

- CERIUM
- NON-COATED
- PLATINUM
- COATED

% CARBON MONOXIDE

AIR-FUEL RATIO
FIGURE 38 CARBON MONOXIDE EMISSION
SPARK IGNITION
10-1 COMPRESSION RATIO
900 RPM

% CARBON MONOXIDE

AIR–FUEL RATIO

CERIUM
NON–COATED
COATED
PLATINUM
Figure 39: Oxides of Nitrogen Emission
Spark Ignition
6–1 Compression Ratio
900 RPM
FIGURE 40 OXIDES OF NITROGEN EMISSION
SPARK IGNITION
8–1 COMPRESSION RATIO
900 RPM

NITRIC OXIDE CONCENTRATION PPM

COATED

PLATINUM

CERIUM

NON-COATED

AIR–FUEL RATIO
FIGURE 41 OXIDES OF NITROGEN EMISSION
SPARK IGNITION
10–1 COMPRESSION RATIO
900 RPM
Figure 42: Indicated Power vs. Compression Ignition Ratio

- Platinum
- Non-Coated
- Cerium
- Coated
FIGURE 44. INDICATED POWER COMPRESSION IGNITION 16-1 COMPRESSION RATIO 900 RPM
Figure 45: Indicated Power to Compression Ignition 17-1 Compression Ratio 900 RPM

- Coated
- Non-Coated
- Platinum
- Cerium
Figure 46 Indicated Power
Compression Ignition
18-1 Compression Ratio
900 RPM
It seems likely that modifications in combustion chamber and injection design can promote better combustion and produce increased power. An open chamber with a central injector location or a pre-combustion chamber design should prevent impingement and combustion problems and produce the performance improvements seen in S-I operation and predicted by theory.

Figures 47 to 51 portray fuel consumption characteristics for C-I operation. The greater power output of non-coated operation produces the lowest fuel consumption that in turn correlates with the above discussion on engine output.

Compression ignition exhaust gas temperature characteristics (see Figures 57 to 61) for coated, non-coated, and catalytic performance follow expected and predictable trends with non-coated operation generally at the lowest value. This behavior would agree with and compliment the above discussion relating to delayed combustion caused by impingement and catalysts. Note, that as the A-F becomes quite lean the EGT suddenly increases dramatically. This phenomenon is explained by a weak combustion process that propagates a delayed inflammation that, in turn, exists into the exhaust valve opening interval.

Hydrocarbon emissions generally indicate that the catalytic surfaces are effective in reducing exhaust contaminants as shown in Figures 62 to 66.

This trend in conjunction with the CO emissions of Figures 67 to 71 and the EGT data indicates that the zirconium and catalytic surfaces do not prevent complete combustion they only slow down the rate, producing generally higher EGT with lower contaminant concentrations downstream at the exhaust gas sampling station.

Nitric oxide emissions (see Figures 72 to 76) are much less in C-I than in S-I operation, with catalytic exhaust still producing dramatically lower
FIGURE 49  FUEL CONSUMPTION
COMPRESSION IGNITION
16-1 COMPRESSION RATIO
900 RPM

CERIUM

COATED

PLATINUM

INDICATED SPECIFIC FUEL CONSUMPTION GM/HR

1SF. LBS/HP-HR

AIR-FUEL RATIO

19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34

.000 .100 .200 .300 .400 .500 .600 .700 .800 .900

GM/HR
FIGURE 52  IGNITION DELAY
COMPRESSION IGNITION
14-1 COMPRESSION RATIO
900 RPM

PLATINUM

CERIUM

COATED

NON-COATED

IGNITION DELAY - DEGREES

AIR-FUEL RATIO

19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

48° 47° 46° 45° 44° 43° 42° 41° 40° 39° 38° 37°
FIGURE 55
IGNITION DELAY
COMPRESSION IGNITION
17-1 COMPRESSION RATIO
900 RPM

PLATINUM

CERIUM

COATED

NON-COATED

IGNITION DELAY - DEGREES

AIR-FUEL RATIO

48° 47° 46° 45° 44° 43° 42° 41° 40° 39° 38° 37°
Figure 58: Exhaust gas temperature compression ignition 15:1 compression ratio 900 RPM.

- Cerium
- Coated
- Non-coated
- Platinum

EGT - FAHRENHEIT

1500° F
1000° F
500° F

EXHAUST GAS TEMPERATURE - KELVIN

1100°
1000°
900°
800°
700°
600°
500°

AIR-FUEL RATIO

19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
Figure 60: Exhaust Gas Temperature and Compression Ignition Temperature vs. Air-Fuel Ratio for Cerium and Platinum Coated vs. Non-Coated Catalysts at 17-to-1 Compression Ratio and 900 RPM.
FIGURE 61 EXHAUST GAS TEMPERATURE COMPRESSION IGNITION RATIO 18-1 COMPRESS 900 RPM
FIGURE 66 HYDROCARBON EMISSION COMPRESSION IGNITION 18.1 COMPRESSION RATIO 900 RPM

HYDROCARBON EMISSION - PARTS PER MILLION

CERIUM
PLATINUM
COATED
NON-COATED
FIGURE 70  CARBON MONOXIDE EMISSION
17.1 COMPRESSION IGNITION
900 RPM

% CARBON MONOXIDE

PLATINUM

CERIUM

COATED

NON-COATED

AIR-FUEL RATIO

19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
FIGURE 73  OXIDES OF NITROGEN EMISSION
COMPRESSION IGNITION
15-1  COMPRESSION RATIO
900 RPM

- NITRIC OXIDE CONCENTRATION - PPM
- AIR-FUEL RATIO

- NON-COATED
- COATED
- PLATINUM
- CERIUM
Figure 74

Oxides of Nitrogen Emission
Compression Ignition
16:1 Compression Ratio
900 RPM

Nitric Oxide Concentration - Ppm

Air-Fuel Ratio

Coated
Non-Coated
Cerium
Platinum
Figure 75: Oxides of Nitrogen Emission Compression Ignition 17:1 Compression Ratio 900 RPM
UNCLASSIFIED

IMPROVED ENGINE PERFORMANCE THROUGH HEAT TRANSFER CONTROL

JUL 78 R & MURRAY

END

DATE FILMED
11-78
emissions. Again, this data should be viewed with some question as with the S-I data. The data was reproducible and consistent, however, the large differences between different operational modes remains largely unexplained. Further examination into this phenomenon is warranted.
PROJECT PERSONNEL

Dr. Richard G. Murray served as Director for this project.

One Mechanical Engineering Master's candidate, Mr. Breene Kerr and the following undergraduate students participated in this effort.

Mark Dronberger
Barney G. Russell
Arthur Voss
John Stoeckl
Phillip May
Glen May
Steve Gardner
Jack Carter
Shane Dixon
Leon Griffin
Guy Dutton
Scott Miller

The author wishes to express his gratitude to these individuals for their exceptional efforts and their dedicated work that overcame many very difficult obstacles.

While no technical papers were written by the above students the author has submitted a draft to AUTOMOTIVE ENGINEERING magazine for possible publication. Copies of this draft have been submitted to the U.S. Army Research Office.
SUMMARY AND CONCLUSIONS

A study into thermodynamics, heat transfer and engine operational theory, indicates that thermal insulation on combustion chamber surfaces should:
1) increase engine efficiency, 2) decrease component metallic temperature thereby promoting lighter, stronger engines, and 3) increase engine tolerance to low grade fuel. The engine test program described in the preceding sections verified some of the above expectations in certain modes of operation and disproved them in others.

Additional areas of importance were: 1) the affect of catalytic surfaces within the combustion chamber, and 2) the endurance characteristics of zirconium oxide plasma sprayed coatings within an engine.

Little doubt exists as to the endurance of the zirconium oxide coatings; they can survive under severe engine conditions for extended time intervals with little or no deterioration. Figure 77 illustrates one such piston surface that survived over 100 hours of S-I and C-I operation with intermittent violent knock. The only deterioration to this surface is a slight feathering or rounding of the coating on the perimeter. No coating separations or failures occurred during this entire U.S. Army funded project. Coatings were applied to both cast iron and steel.

In general, it was determined that the placement of platinum and cerium catalytic surfaces into an engine combustion chamber inhibited or delayed combustion. While the chemical reaction tended towards completion, the rate of combustion was slowed producing poorer performance and efficiency.

Non-knocking S-I engine power and efficiency showed a significant improvement with the addition of a yttria stabilizing zirconium oxide coating to all combustion chamber surfaces.
Figure 77

Cerium Coated Piston
Zirconium coated engines encountered knock at a lower compression ratio and knocked more severely than did non-coated engines.

Compression ignition engines encountered a performance degradation with a zirconium coating; both power and efficiency were reduced significantly. This unexpected result did not agree with theory and is believed to be primarily a result of combustion chamber design rather than an outcome of the coating itself.

It is apparent from this study that ceramic surfaces offer promise in future engine technology but much research and testing is necessary before they can be fully understood and utilized.
REFERENCES


REAL IMP, IMPH, ITQ, IEFF, MHP
1 INTEGER TP, DAY, YK, HC, EXT, DEL
2 CNT INJE
3 FV = 1.053
4 I = 1
5 PRINT 4
6 PRINT 101
7 PRINT 132
8 READ IS, END=554 IN, TP, CR, IG, DEL, T, INT, EXT, DP, MHP, HC, NOX, MON, DAY
9 C = Y0
10 = 1
11 IMPP = IMPP*(1.0/.00333)
12 XNP = (3.25*3.25*3.1416*4.5*903.3/14.8*33000.)*12.1
13 IF (TP GT .4) GOTO 36
14 DIFFERENT HEAT CONTENT AND DENSITY VALUES EXIST FOR DIESEL AND SPARK
15 IGNITION FUELS
16 MV = 19100.
17 WF = FV * 1.6051
18 GOTO 37
19 CONTINUE
20 MV = 18466.
21 WF = FV * 1.8890
22 CONTINUE
23 IF (EXT EQ .0) GOTO 8
24 IF (EXT LT 500) EXT = 1000 + EXT
25 WA = DP*(11.5/4.0)*.38163*(7/60.0)
26 AF = WA / WF
27 IMPP = IMPP * XNP
28 HP = IMPP
29 ITQ = IMPP*(3.25*3.25*3.1416*4.5)/(150.8**.5)
30 EFF = (1/HP**2545.0)/MEP**3600.0/TP
31 IEF = EFF * 100.
32 BSFC = WF**3600.0/(1/HEP)
33 C CONVERT METRIC UNITS
34 BSFC = 0.6088 * BSFC
35 IMPH = 0.7457 * IMPH
36 ITQ = 1.3958 * ITQ
37 IMPP = 0.39476 * IMPP
38 EXT = 5.0*(EXT-32)/9*273
39 IF (TP EQ .1) GOTO 115
40 IF (TP EQ .2) GOTO 120
41 IF (TP EQ .3) GOTO 121
42 IF (TP EQ .4) GOTO 127
43 IF (TP EQ .5) GOTO 128
44 IF (TP EQ .6) GOTO 116
45 IF (TP EQ .7) GOTO 116
46 IF (TP EQ .8) GOTO 124
47 IF (TP EQ .9) GOTO 126
48 WRITE(6, 1081) : , CR, AF, IMPH, BSFC, IMP, ITQ, IEF, IG, DEL, EXT, HC, CO, NOX
49 GOTO 317
50 106 CONTINUE
51 WRITE(6, 1091) : , CR, AF, IMPH, BSFC, IMP, ITQ, IEF, IG, DEL, EXT, HC, CO, NOX
52 GOTO 317
53 115 WRITE(6, 1171) : , CR, AF, IMPH, BSFC, IMP, ITQ, IEF, IG, DEL, EXT, HC, CO, NOX
54 GO TO 107
55 116 WRITE(6, 1181) : , CR, AF, IMPH, BSFC, IMP, ITQ, IEF, IG, DEL, EXT, HC, CO, NOX
56 GO TO 107
57 120 WRITE(6, 1301) : , CR, AF, IMPH, BSFC, IMP, ITQ, IEF, IG, DEL, EXT, HC, CO, NOX
58 GO TO 107
<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>COMPO RATIO</th>
<th>AIR FUEL</th>
<th>I-PWP</th>
<th>ISFC</th>
<th>I-MEP</th>
<th>ITJ</th>
<th>EFF</th>
<th>ISN</th>
<th>EGT</th>
<th>HC</th>
<th>CO</th>
<th>NOX</th>
<th>TYPE</th>
<th>CATALYST</th>
</tr>
</thead>
<tbody>
<tr>
<td>2101</td>
<td>6.0</td>
<td>18.04</td>
<td>3.67</td>
<td>0.242</td>
<td>799</td>
<td>38.91</td>
<td>33.59</td>
<td>24</td>
<td>8</td>
<td>713</td>
<td>223</td>
<td>0.0</td>
<td>2580</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2102</td>
<td>6.0</td>
<td>17.04</td>
<td>3.80</td>
<td>0.247</td>
<td>828</td>
<td>45.32</td>
<td>32.88</td>
<td>26</td>
<td>10</td>
<td>727</td>
<td>725</td>
<td>0.0</td>
<td>2380</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2103</td>
<td>6.0</td>
<td>16.03</td>
<td>3.76</td>
<td>0.252</td>
<td>863</td>
<td>42.03</td>
<td>32.42</td>
<td>22</td>
<td>2</td>
<td>749</td>
<td>930</td>
<td>0.1</td>
<td>2530</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2104</td>
<td>6.0</td>
<td>15.03</td>
<td>4.08</td>
<td>0.261</td>
<td>888</td>
<td>43.24</td>
<td>31.10</td>
<td>21</td>
<td>2</td>
<td>746</td>
<td>1300</td>
<td>0.0</td>
<td>2320</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2105</td>
<td>6.0</td>
<td>14.03</td>
<td>4.16</td>
<td>0.274</td>
<td>907</td>
<td>44.15</td>
<td>29.64</td>
<td>20</td>
<td>1</td>
<td>733</td>
<td>1650</td>
<td>3.2</td>
<td>884</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2106</td>
<td>8.0</td>
<td>18.04</td>
<td>4.16</td>
<td>0.213</td>
<td>907</td>
<td>44.15</td>
<td>38.11</td>
<td>20</td>
<td>2</td>
<td>688</td>
<td>1200</td>
<td>0.0</td>
<td>2640</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2107</td>
<td>8.0</td>
<td>17.04</td>
<td>4.35</td>
<td>0.215</td>
<td>948</td>
<td>46.16</td>
<td>37.64</td>
<td>20</td>
<td>1</td>
<td>708</td>
<td>1255</td>
<td>0.1</td>
<td>2680</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2108</td>
<td>8.0</td>
<td>16.03</td>
<td>4.49</td>
<td>0.222</td>
<td>979</td>
<td>47.67</td>
<td>36.57</td>
<td>19</td>
<td>1</td>
<td>723</td>
<td>1600</td>
<td>0.2</td>
<td>2520</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2109</td>
<td>8.0</td>
<td>15.03</td>
<td>4.56</td>
<td>0.233</td>
<td>994</td>
<td>48.38</td>
<td>34.80</td>
<td>19</td>
<td>0</td>
<td>716</td>
<td>2250</td>
<td>0.2</td>
<td>2040</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2110</td>
<td>8.0</td>
<td>14.03</td>
<td>4.62</td>
<td>0.247</td>
<td>1036</td>
<td>48.98</td>
<td>32.89</td>
<td>18</td>
<td>1</td>
<td>702</td>
<td>2500</td>
<td>3.6</td>
<td>1240</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2111</td>
<td>10.0</td>
<td>18.04</td>
<td>4.42</td>
<td>0.220</td>
<td>953</td>
<td>46.97</td>
<td>40.45</td>
<td>18</td>
<td>2</td>
<td>649</td>
<td>2150</td>
<td>0.1</td>
<td>2600</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2112</td>
<td>10.0</td>
<td>17.04</td>
<td>4.04</td>
<td>0.232</td>
<td>880</td>
<td>42.86</td>
<td>34.93</td>
<td>16</td>
<td>1</td>
<td>674</td>
<td>2300</td>
<td>0.1</td>
<td>2660</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2113</td>
<td>10.0</td>
<td>16.03</td>
<td>3.92</td>
<td>0.254</td>
<td>855</td>
<td>41.63</td>
<td>31.93</td>
<td>16</td>
<td>1</td>
<td>671</td>
<td>2350</td>
<td>0.5</td>
<td>1740</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2114</td>
<td>10.0</td>
<td>15.03</td>
<td>3.07</td>
<td>0.275</td>
<td>843</td>
<td>41.02</td>
<td>29.51</td>
<td>18</td>
<td>1</td>
<td>256</td>
<td>2750</td>
<td>0.2</td>
<td>1620</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2115</td>
<td>10.0</td>
<td>14.03</td>
<td>4.06</td>
<td>0.282</td>
<td>880</td>
<td>42.84</td>
<td>28.76</td>
<td>17</td>
<td>1</td>
<td>649</td>
<td>3375</td>
<td>3.0</td>
<td>1020</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>2601</td>
<td>14.0</td>
<td>19.44</td>
<td>3.56</td>
<td>0.231</td>
<td>776</td>
<td>37.80</td>
<td>35.41</td>
<td>18</td>
<td>2</td>
<td>648</td>
<td>3850</td>
<td>2.4</td>
<td>200</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2602</td>
<td>14.0</td>
<td>24.30</td>
<td>3.47</td>
<td>0.130</td>
<td>756</td>
<td>36.79</td>
<td>43.09</td>
<td>52</td>
<td>44</td>
<td>666</td>
<td>2550</td>
<td>1.2</td>
<td>122</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2603</td>
<td>14.0</td>
<td>29.15</td>
<td>2.71</td>
<td>0.202</td>
<td>590</td>
<td>28.73</td>
<td>40.36</td>
<td>43</td>
<td>41</td>
<td>599</td>
<td>2300</td>
<td>0.2</td>
<td>480</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2604</td>
<td>14.0</td>
<td>34.02</td>
<td>0.27</td>
<td>1.756</td>
<td>58</td>
<td>2.82</td>
<td>4.63</td>
<td>44</td>
<td>42</td>
<td>933</td>
<td>1050</td>
<td>0.1</td>
<td>30</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2605</td>
<td>14.0</td>
<td>19.44</td>
<td>3.51</td>
<td>0.234</td>
<td>766</td>
<td>37.29</td>
<td>34.93</td>
<td>52</td>
<td>44</td>
<td>688</td>
<td>2995</td>
<td>2.4</td>
<td>699</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2606</td>
<td>14.0</td>
<td>24.30</td>
<td>3.16</td>
<td>0.208</td>
<td>689</td>
<td>33.56</td>
<td>39.31</td>
<td>51</td>
<td>43</td>
<td>633</td>
<td>2800</td>
<td>1.1</td>
<td>695</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2607</td>
<td>14.0</td>
<td>29.15</td>
<td>2.86</td>
<td>0.192</td>
<td>623</td>
<td>30.34</td>
<td>42.63</td>
<td>52</td>
<td>42</td>
<td>616</td>
<td>2550</td>
<td>0.5</td>
<td>758</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2608</td>
<td>14.0</td>
<td>31.59</td>
<td>1.77</td>
<td>0.286</td>
<td>385</td>
<td>18.75</td>
<td>28.54</td>
<td>44</td>
<td>42</td>
<td>1066</td>
<td>1800</td>
<td>0.3</td>
<td>350</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2609</td>
<td>14.0</td>
<td>34.02</td>
<td>0.66</td>
<td>0.706</td>
<td>145</td>
<td>7.06</td>
<td>11.57</td>
<td>40</td>
<td>43</td>
<td>960</td>
<td>1200</td>
<td>0.1</td>
<td>16</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2610</td>
<td>15.0</td>
<td>19.44</td>
<td>3.13</td>
<td>0.262</td>
<td>683</td>
<td>33.26</td>
<td>31.16</td>
<td>50</td>
<td>40</td>
<td>669</td>
<td>4100</td>
<td>2.1</td>
<td>500</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2611</td>
<td>15.0</td>
<td>24.30</td>
<td>3.23</td>
<td>0.204</td>
<td>704</td>
<td>34.27</td>
<td>40.14</td>
<td>53</td>
<td>42</td>
<td>666</td>
<td>3450</td>
<td>1.1</td>
<td>150</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>TEST</td>
<td>CATALYST</td>
<td>EFF</td>
<td>NOX</td>
<td>CO</td>
<td>CARB</td>
<td>TURB</td>
<td>FUEL</td>
<td>TYPE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.12</td>
<td>15.0</td>
<td>29.15</td>
<td>2.47</td>
<td>3.22</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.13</td>
<td>15.0</td>
<td>31.59</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.14</td>
<td>15.0</td>
<td>34.02</td>
<td>2.53</td>
<td>3.42</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.15</td>
<td>15.0</td>
<td>34.24</td>
<td>2.53</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.16</td>
<td>15.0</td>
<td>34.36</td>
<td>2.53</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.17</td>
<td>15.0</td>
<td>34.58</td>
<td>2.53</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.18</td>
<td>15.0</td>
<td>34.71</td>
<td>2.53</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.19</td>
<td>15.0</td>
<td>34.84</td>
<td>2.53</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.20</td>
<td>17.0</td>
<td>29.15</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.21</td>
<td>17.0</td>
<td>29.28</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.22</td>
<td>17.0</td>
<td>29.41</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.23</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.24</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.25</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.26</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.27</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.28</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.29</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.30</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.31</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.32</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.33</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.34</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.35</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.36</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.37</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.38</td>
<td>17.0</td>
<td>29.44</td>
<td>2.40</td>
<td>3.24</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td>0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEST NO.</td>
<td>COMPARATIVE FUEL</td>
<td>I-PAR</td>
<td>SM/HR</td>
<td>NM/HR</td>
<td>ICF</td>
<td>LTC</td>
<td>AN/LCY</td>
<td>DE K</td>
<td>NOX</td>
<td>PPM</td>
<td>HCN</td>
<td>PPM</td>
<td>CO</td>
<td>%</td>
</tr>
<tr>
<td>----------</td>
<td>------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-----</td>
<td>-----</td>
<td>--------</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>---</td>
</tr>
<tr>
<td>TEST NO.</td>
<td>COMP RATIO</td>
<td>AIR FUEL</td>
<td>I-PAR</td>
<td>ISFC</td>
<td>IMEP</td>
<td>ITQ</td>
<td>IEFF</td>
<td>IGN</td>
<td>EGT</td>
<td>HC</td>
<td>CO</td>
<td>NOX</td>
<td>TYPE</td>
<td>CATALYST</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>----------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>----</td>
<td>-----</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td>2666</td>
<td>8.0 18.04</td>
<td>3.05</td>
<td>0.233</td>
<td>839</td>
<td>40.82</td>
<td>35.24</td>
<td>23</td>
<td>8</td>
<td>659</td>
<td>1300</td>
<td>0.0</td>
<td>590</td>
<td>S-I NON COATED</td>
<td></td>
</tr>
<tr>
<td>2667</td>
<td>10.0 14.03</td>
<td>4.37</td>
<td>0.261</td>
<td>952</td>
<td>46.36</td>
<td>31.13</td>
<td>17</td>
<td>4</td>
<td>630</td>
<td>3250</td>
<td>6.0</td>
<td>50</td>
<td>S-I NON COATED</td>
<td></td>
</tr>
<tr>
<td>2668</td>
<td>10.0 15.03</td>
<td>4.42</td>
<td>0.261</td>
<td>963</td>
<td>46.87</td>
<td>33.71</td>
<td>16</td>
<td>1</td>
<td>633</td>
<td>2700</td>
<td>3.4</td>
<td>110</td>
<td>S-I NON COATED</td>
<td></td>
</tr>
<tr>
<td>2669</td>
<td>10.0 16.03</td>
<td>4.45</td>
<td>0.224</td>
<td>969</td>
<td>47.17</td>
<td>36.18</td>
<td>17</td>
<td>5</td>
<td>641</td>
<td>2300</td>
<td>1.8</td>
<td>170</td>
<td>S-I NON COATED</td>
<td></td>
</tr>
<tr>
<td>2670</td>
<td>10.0 17.04</td>
<td>4.39</td>
<td>0.214</td>
<td>957</td>
<td>46.57</td>
<td>37.97</td>
<td>18</td>
<td>4</td>
<td>646</td>
<td>2250</td>
<td>0.4</td>
<td>300</td>
<td>S-I NON COATED</td>
<td></td>
</tr>
<tr>
<td>2671</td>
<td>10.0 18.04</td>
<td>4.32</td>
<td>0.205</td>
<td>942</td>
<td>45.86</td>
<td>39.59</td>
<td>17</td>
<td>6</td>
<td>641</td>
<td>1550</td>
<td>0.0</td>
<td>310</td>
<td>S-I NON COATED</td>
<td></td>
</tr>
<tr>
<td>2672</td>
<td>6.0 14.03</td>
<td>3.72</td>
<td>0.306</td>
<td>812</td>
<td>39.51</td>
<td>26.93</td>
<td>21</td>
<td>8</td>
<td>721</td>
<td>3000</td>
<td>3.2</td>
<td>95</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2673</td>
<td>6.0 15.03</td>
<td>3.74</td>
<td>0.284</td>
<td>816</td>
<td>39.71</td>
<td>28.96</td>
<td>23</td>
<td>10</td>
<td>721</td>
<td>2550</td>
<td>2.1</td>
<td>215</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2674</td>
<td>6.0 16.03</td>
<td>3.61</td>
<td>0.276</td>
<td>787</td>
<td>38.30</td>
<td>29.38</td>
<td>26</td>
<td>13</td>
<td>727</td>
<td>2100</td>
<td>0.5</td>
<td>315</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2675</td>
<td>6.0 17.04</td>
<td>3.56</td>
<td>0.263</td>
<td>776</td>
<td>37.80</td>
<td>30.82</td>
<td>26</td>
<td>13</td>
<td>724</td>
<td>1450</td>
<td>0.1</td>
<td>390</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2676</td>
<td>6.0 18.04</td>
<td>3.42</td>
<td>0.259</td>
<td>745</td>
<td>36.28</td>
<td>31.32</td>
<td>27</td>
<td>13</td>
<td>708</td>
<td>1350</td>
<td>0.1</td>
<td>460</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2677</td>
<td>8.0 14.03</td>
<td>4.27</td>
<td>0.266</td>
<td>932</td>
<td>45.36</td>
<td>30.45</td>
<td>18</td>
<td>5</td>
<td>683</td>
<td>3900</td>
<td>4.8</td>
<td>95</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2678</td>
<td>8.0 14.99</td>
<td>4.22</td>
<td>0.253</td>
<td>919</td>
<td>44.75</td>
<td>32.11</td>
<td>20</td>
<td>4</td>
<td>694</td>
<td>3350</td>
<td>2.5</td>
<td>215</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2679</td>
<td>8.0 16.03</td>
<td>4.18</td>
<td>0.238</td>
<td>911</td>
<td>44.35</td>
<td>34.02</td>
<td>20</td>
<td>5</td>
<td>702</td>
<td>2900</td>
<td>0.9</td>
<td>355</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2680</td>
<td>8.0 17.04</td>
<td>4.04</td>
<td>0.232</td>
<td>880</td>
<td>42.84</td>
<td>34.93</td>
<td>20</td>
<td>7</td>
<td>699</td>
<td>2250</td>
<td>0.1</td>
<td>415</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2681</td>
<td>8.0 18.04</td>
<td>3.87</td>
<td>0.229</td>
<td>843</td>
<td>41.02</td>
<td>35.41</td>
<td>23</td>
<td>10</td>
<td>683</td>
<td>2000</td>
<td>0.1</td>
<td>450</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2682</td>
<td>8.0 19.04</td>
<td>3.70</td>
<td>0.227</td>
<td>805</td>
<td>39.21</td>
<td>35.72</td>
<td>21</td>
<td>9</td>
<td>669</td>
<td>2010</td>
<td>0.1</td>
<td>430</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2683</td>
<td>8.0 20.05</td>
<td>3.51</td>
<td>0.227</td>
<td>766</td>
<td>37.29</td>
<td>35.78</td>
<td>27</td>
<td>14</td>
<td>652</td>
<td>1850</td>
<td>0.1</td>
<td>700</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2684</td>
<td>8.0 21.05</td>
<td>3.24</td>
<td>0.234</td>
<td>706</td>
<td>34.37</td>
<td>34.62</td>
<td>33</td>
<td>8</td>
<td>598</td>
<td>2015</td>
<td>0.1</td>
<td>335</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2685</td>
<td>8.0 22.05</td>
<td>2.75</td>
<td>0.264</td>
<td>598</td>
<td>29.13</td>
<td>30.73</td>
<td>33</td>
<td>8</td>
<td>533</td>
<td>9999</td>
<td>99.9</td>
<td>9999</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2686</td>
<td>10.0 14.03</td>
<td>4.26</td>
<td>0.268</td>
<td>928</td>
<td>45.15</td>
<td>30.32</td>
<td>19</td>
<td>3</td>
<td>635</td>
<td>5150</td>
<td>5.4</td>
<td>105</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2687</td>
<td>10.0 15.03</td>
<td>4.37</td>
<td>0.243</td>
<td>952</td>
<td>46.36</td>
<td>33.35</td>
<td>16</td>
<td>5</td>
<td>644</td>
<td>4400</td>
<td>2.7</td>
<td>200</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2688</td>
<td>10.0 16.03</td>
<td>4.27</td>
<td>0.233</td>
<td>932</td>
<td>45.36</td>
<td>34.79</td>
<td>17</td>
<td>6</td>
<td>652</td>
<td>3500</td>
<td>1.1</td>
<td>290</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2689</td>
<td>10.0 17.04</td>
<td>4.18</td>
<td>0.224</td>
<td>911</td>
<td>44.35</td>
<td>36.17</td>
<td>18</td>
<td>8</td>
<td>655</td>
<td>3150</td>
<td>0.2</td>
<td>465</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2690</td>
<td>10.0 18.04</td>
<td>4.08</td>
<td>0.217</td>
<td>890</td>
<td>43.34</td>
<td>37.42</td>
<td>16</td>
<td>8</td>
<td>646</td>
<td>1500</td>
<td>0.7</td>
<td>620</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>2691</td>
<td>10.0 19.04</td>
<td>3.91</td>
<td>0.214</td>
<td>853</td>
<td>41.53</td>
<td>37.83</td>
<td>18</td>
<td>9</td>
<td>630</td>
<td>2250</td>
<td>0.1</td>
<td>680</td>
<td>S-I COATED PLATINUM</td>
<td></td>
</tr>
<tr>
<td>TEST NO.</td>
<td>COMP RATIO</td>
<td>AIR FUEL</td>
<td>1-PWR</td>
<td>ISFC</td>
<td>ISEP</td>
<td>ITW</td>
<td>IEFF</td>
<td>IGN</td>
<td>EGT</td>
<td>HC</td>
<td>CO</td>
<td>NOX</td>
<td>TYPE</td>
<td>CATALYST</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
<td>----------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>----</td>
<td>-----</td>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td>2692</td>
<td>14.0</td>
<td>19.44</td>
<td>3.56</td>
<td>0.231</td>
<td>776.</td>
<td>37.80</td>
<td>35.41</td>
<td>53</td>
<td>43</td>
<td>677</td>
<td>2200</td>
<td>1.8</td>
<td>100</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2693</td>
<td>14.0</td>
<td>24.30</td>
<td>3.37</td>
<td>0.195</td>
<td>735.</td>
<td>35.78</td>
<td>41.91</td>
<td>53</td>
<td>43</td>
<td>669</td>
<td>1600</td>
<td>1.2</td>
<td>115</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2694</td>
<td>14.0</td>
<td>29.15</td>
<td>2.79</td>
<td>0.106</td>
<td>609.</td>
<td>29.63</td>
<td>41.64</td>
<td>53</td>
<td>43</td>
<td>602</td>
<td>1500</td>
<td>0.3</td>
<td>130</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2695</td>
<td>14.0</td>
<td>31.59</td>
<td>2.04</td>
<td>0.248</td>
<td>445.</td>
<td>21.67</td>
<td>32.99</td>
<td>53</td>
<td>45</td>
<td>549</td>
<td>1150</td>
<td>0.2</td>
<td>100</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2696</td>
<td>14.0</td>
<td>34.02</td>
<td>3.71</td>
<td>0.659</td>
<td>155.</td>
<td>7.56</td>
<td>12.39</td>
<td>53</td>
<td>43</td>
<td>999</td>
<td>225</td>
<td>0.1</td>
<td>30</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2697</td>
<td>15.0</td>
<td>19.44</td>
<td>3.66</td>
<td>0.225</td>
<td>797.</td>
<td>38.80</td>
<td>36.35</td>
<td>53</td>
<td>41</td>
<td>256</td>
<td>2750</td>
<td>3.0</td>
<td>93</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2698</td>
<td>15.0</td>
<td>24.30</td>
<td>3.13</td>
<td>0.210</td>
<td>683.</td>
<td>33.26</td>
<td>38.95</td>
<td>53</td>
<td>41</td>
<td>666</td>
<td>2250</td>
<td>1.5</td>
<td>75</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2699</td>
<td>15.0</td>
<td>29.15</td>
<td>2.75</td>
<td>0.199</td>
<td>630.</td>
<td>29.23</td>
<td>41.07</td>
<td>53</td>
<td>41</td>
<td>633</td>
<td>1600</td>
<td>0.9</td>
<td>155</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2700</td>
<td>15.0</td>
<td>31.59</td>
<td>2.38</td>
<td>0.243</td>
<td>453.</td>
<td>22.07</td>
<td>33.60</td>
<td>53</td>
<td>43</td>
<td>544</td>
<td>1300</td>
<td>0.0</td>
<td>115</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2701</td>
<td>15.0</td>
<td>34.02</td>
<td>0.77</td>
<td>0.610</td>
<td>168.</td>
<td>8.16</td>
<td>13.39</td>
<td>53</td>
<td>43</td>
<td>999</td>
<td>625</td>
<td>0.1</td>
<td>60</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2702</td>
<td>16.0</td>
<td>19.44</td>
<td>3.54</td>
<td>0.232</td>
<td>772.</td>
<td>37.59</td>
<td>35.22</td>
<td>53</td>
<td>41</td>
<td>671</td>
<td>3100</td>
<td>2.3</td>
<td>115</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2703</td>
<td>16.0</td>
<td>24.30</td>
<td>3.19</td>
<td>0.206</td>
<td>696.</td>
<td>33.87</td>
<td>39.66</td>
<td>53</td>
<td>41</td>
<td>660</td>
<td>2100</td>
<td>1.2</td>
<td>125</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2704</td>
<td>16.0</td>
<td>29.15</td>
<td>2.66</td>
<td>0.206</td>
<td>580.</td>
<td>28.22</td>
<td>39.65</td>
<td>53</td>
<td>41</td>
<td>605</td>
<td>2150</td>
<td>0.1</td>
<td>110</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2705</td>
<td>16.0</td>
<td>31.59</td>
<td>1.86</td>
<td>0.272</td>
<td>406.</td>
<td>19.73</td>
<td>30.07</td>
<td>52</td>
<td>42</td>
<td>1077</td>
<td>1700</td>
<td>0.5</td>
<td>80</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2706</td>
<td>16.0</td>
<td>34.02</td>
<td>0.80</td>
<td>0.589</td>
<td>174.</td>
<td>8.47</td>
<td>13.88</td>
<td>53</td>
<td>41</td>
<td>988</td>
<td>700</td>
<td>0.1</td>
<td>35</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2707</td>
<td>17.0</td>
<td>19.44</td>
<td>3.37</td>
<td>0.244</td>
<td>735.</td>
<td>35.78</td>
<td>33.52</td>
<td>53</td>
<td>40</td>
<td>655</td>
<td>4500</td>
<td>2.8</td>
<td>60</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2708</td>
<td>17.0</td>
<td>24.30</td>
<td>2.75</td>
<td>0.239</td>
<td>600.</td>
<td>29.23</td>
<td>34.23</td>
<td>51</td>
<td>41</td>
<td>613</td>
<td>2500</td>
<td>1.4</td>
<td>80</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2709</td>
<td>17.0</td>
<td>29.15</td>
<td>2.04</td>
<td>0.268</td>
<td>445.</td>
<td>21.67</td>
<td>30.45</td>
<td>51</td>
<td>41</td>
<td>552</td>
<td>2100</td>
<td>1.0</td>
<td>55</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2710</td>
<td>17.0</td>
<td>31.59</td>
<td>1.16</td>
<td>0.436</td>
<td>253.</td>
<td>12.30</td>
<td>18.72</td>
<td>51</td>
<td>41</td>
<td>1010</td>
<td>880</td>
<td>0.1</td>
<td>32</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2711</td>
<td>17.0</td>
<td>34.02</td>
<td>0.09</td>
<td>0.944</td>
<td>21.</td>
<td>1.01</td>
<td>1.65</td>
<td>51</td>
<td>41</td>
<td>938</td>
<td>820</td>
<td>0.0</td>
<td>10</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2712</td>
<td>18.0</td>
<td>19.44</td>
<td>3.25</td>
<td>0.253</td>
<td>708.</td>
<td>34.47</td>
<td>32.29</td>
<td>53</td>
<td>40</td>
<td>652</td>
<td>5800</td>
<td>2.8</td>
<td>60</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2713</td>
<td>18.0</td>
<td>24.30</td>
<td>2.99</td>
<td>0.220</td>
<td>652.</td>
<td>31.75</td>
<td>37.18</td>
<td>53</td>
<td>40</td>
<td>658</td>
<td>4000</td>
<td>2.0</td>
<td>85</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2714</td>
<td>18.0</td>
<td>29.15</td>
<td>2.58</td>
<td>0.212</td>
<td>563.</td>
<td>27.42</td>
<td>38.52</td>
<td>53</td>
<td>41</td>
<td>610</td>
<td>2800</td>
<td>1.1</td>
<td>50</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2715</td>
<td>18.0</td>
<td>31.59</td>
<td>2.04</td>
<td>0.248</td>
<td>445.</td>
<td>21.67</td>
<td>32.99</td>
<td>53</td>
<td>41</td>
<td>546</td>
<td>2300</td>
<td>0.6</td>
<td>25</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2716</td>
<td>18.0</td>
<td>34.02</td>
<td>0.19</td>
<td>2.472</td>
<td>41.</td>
<td>2.02</td>
<td>3.31</td>
<td>53</td>
<td>41</td>
<td>1021</td>
<td>320</td>
<td>0.1</td>
<td>50</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2717</td>
<td>6.0</td>
<td>18.04</td>
<td>3.37</td>
<td>0.263</td>
<td>735.</td>
<td>35.78</td>
<td>30.89</td>
<td>24</td>
<td>11</td>
<td>733</td>
<td>1100</td>
<td>0.0</td>
<td>710</td>
<td>S-I COATED</td>
</tr>
<tr>
<td>TEST NO.</td>
<td>COMP RATIO</td>
<td>AIR FUEL</td>
<td>1-PWR KW</td>
<td>ISFC GM/HR</td>
<td>IMEP KPA</td>
<td>ITJ</td>
<td>IEFF</td>
<td>IGN AN DE K</td>
<td>EGT</td>
<td>HC PPM</td>
<td>CO %</td>
<td>NOX PPM</td>
<td>TYPE</td>
<td>CATALYST</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>----------</td>
<td>----------</td>
<td>------------</td>
<td>----------</td>
<td>-----</td>
<td>------</td>
<td>------------</td>
<td>-----</td>
<td>--------</td>
<td>------</td>
<td>---------</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td>2718</td>
<td>6.0</td>
<td>17.04</td>
<td>3.51</td>
<td>0.267</td>
<td>764.8</td>
<td>37.19</td>
<td>30.33</td>
<td>25.1</td>
<td>735</td>
<td>1450</td>
<td>0.2</td>
<td>590</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2719</td>
<td>6.0</td>
<td>16.03</td>
<td>3.58</td>
<td>0.278</td>
<td>781.7</td>
<td>36.00</td>
<td>29.15</td>
<td>24.4</td>
<td>730</td>
<td>2100</td>
<td>1.2</td>
<td>475</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2720</td>
<td>6.0</td>
<td>15.03</td>
<td>3.65</td>
<td>0.291</td>
<td>795.0</td>
<td>38.70</td>
<td>27.84</td>
<td>21.4</td>
<td>710</td>
<td>2700</td>
<td>3.2</td>
<td>320</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2721</td>
<td>6.0</td>
<td>14.03</td>
<td>3.69</td>
<td>0.309</td>
<td>803.3</td>
<td>39.11</td>
<td>26.26</td>
<td>23.4</td>
<td>699</td>
<td>3200</td>
<td>5.4</td>
<td>215</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2722</td>
<td>8.0</td>
<td>18.04</td>
<td>3.78</td>
<td>0.234</td>
<td>824.9</td>
<td>40.11</td>
<td>34.63</td>
<td>22.5</td>
<td>705</td>
<td>1500</td>
<td>0.0</td>
<td>730</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2723</td>
<td>8.0</td>
<td>17.04</td>
<td>3.94</td>
<td>0.238</td>
<td>859.0</td>
<td>41.83</td>
<td>34.11</td>
<td>20.5</td>
<td>721</td>
<td>2200</td>
<td>0.2</td>
<td>630</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2724</td>
<td>8.0</td>
<td>16.03</td>
<td>3.98</td>
<td>0.250</td>
<td>868.8</td>
<td>42.23</td>
<td>32.40</td>
<td>20.4</td>
<td>713</td>
<td>2700</td>
<td>2.0</td>
<td>620</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2725</td>
<td>8.0</td>
<td>15.03</td>
<td>4.01</td>
<td>0.265</td>
<td>874.9</td>
<td>42.53</td>
<td>30.60</td>
<td>17.7</td>
<td>705</td>
<td>3150</td>
<td>3.4</td>
<td>230</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2726</td>
<td>8.0</td>
<td>14.03</td>
<td>4.07</td>
<td>0.280</td>
<td>886.9</td>
<td>43.14</td>
<td>28.97</td>
<td>19.8</td>
<td>691</td>
<td>3800</td>
<td>6.1</td>
<td>80</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2727</td>
<td>10.0</td>
<td>18.04</td>
<td>4.13</td>
<td>0.214</td>
<td>901.8</td>
<td>43.84</td>
<td>37.85</td>
<td>19.7</td>
<td>674</td>
<td>2200</td>
<td>0.1</td>
<td>490</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2728</td>
<td>10.0</td>
<td>17.04</td>
<td>4.19</td>
<td>0.224</td>
<td>913.8</td>
<td>44.45</td>
<td>36.25</td>
<td>16.5</td>
<td>683</td>
<td>2750</td>
<td>0.7</td>
<td>330</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2729</td>
<td>10.0</td>
<td>16.03</td>
<td>4.19</td>
<td>0.238</td>
<td>913.8</td>
<td>44.45</td>
<td>36.10</td>
<td>16.5</td>
<td>671</td>
<td>3250</td>
<td>2.8</td>
<td>175</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2730</td>
<td>10.0</td>
<td>15.73</td>
<td>4.20</td>
<td>0.253</td>
<td>915.8</td>
<td>44.55</td>
<td>32.04</td>
<td>19.7</td>
<td>666</td>
<td>3650</td>
<td>3.8</td>
<td>120</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2731</td>
<td>10.0</td>
<td>14.03</td>
<td>4.20</td>
<td>0.271</td>
<td>915.8</td>
<td>44.55</td>
<td>29.92</td>
<td>17.7</td>
<td>660</td>
<td>4450</td>
<td>6.0</td>
<td>80</td>
<td>S-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2732</td>
<td>14.0</td>
<td>19.44</td>
<td>2.80</td>
<td>0.293</td>
<td>611.8</td>
<td>29.73</td>
<td>27.85</td>
<td>53.43</td>
<td>633</td>
<td>2800</td>
<td>2.4</td>
<td>80</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2733</td>
<td>14.0</td>
<td>24.30</td>
<td>2.66</td>
<td>0.247</td>
<td>580.8</td>
<td>28.22</td>
<td>33.05</td>
<td>53.43</td>
<td>671</td>
<td>2200</td>
<td>1.2</td>
<td>100</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2734</td>
<td>14.0</td>
<td>29.15</td>
<td>2.18</td>
<td>0.251</td>
<td>476.1</td>
<td>23.18</td>
<td>32.57</td>
<td>53.43</td>
<td>630</td>
<td>1800</td>
<td>0.5</td>
<td>110</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2735</td>
<td>14.0</td>
<td>31.59</td>
<td>1.72</td>
<td>0.294</td>
<td>375.0</td>
<td>18.24</td>
<td>27.77</td>
<td>53.45</td>
<td>571</td>
<td>1400</td>
<td>0.2</td>
<td>35</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2736</td>
<td>14.0</td>
<td>34.02</td>
<td>0.79</td>
<td>0.396</td>
<td>172.0</td>
<td>8.37</td>
<td>13.72</td>
<td>53.45</td>
<td>256</td>
<td>650</td>
<td>0.1</td>
<td>25</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2737</td>
<td>15.0</td>
<td>19.44</td>
<td>2.74</td>
<td>0.300</td>
<td>596.0</td>
<td>29.03</td>
<td>27.19</td>
<td>53.41</td>
<td>677</td>
<td>2550</td>
<td>2.8</td>
<td>90</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2738</td>
<td>15.0</td>
<td>24.30</td>
<td>2.56</td>
<td>0.256</td>
<td>559.0</td>
<td>27.21</td>
<td>31.87</td>
<td>53.42</td>
<td>655</td>
<td>1800</td>
<td>1.5</td>
<td>110</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2739</td>
<td>15.0</td>
<td>29.15</td>
<td>2.15</td>
<td>0.255</td>
<td>468.0</td>
<td>22.78</td>
<td>32.01</td>
<td>53.42</td>
<td>671</td>
<td>1700</td>
<td>0.4</td>
<td>100</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2740</td>
<td>15.0</td>
<td>31.59</td>
<td>1.61</td>
<td>0.313</td>
<td>352.0</td>
<td>17.13</td>
<td>26.08</td>
<td>53.43</td>
<td>533</td>
<td>1600</td>
<td>0.2</td>
<td>120</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2741</td>
<td>15.0</td>
<td>34.02</td>
<td>0.80</td>
<td>0.589</td>
<td>174.0</td>
<td>8.47</td>
<td>13.88</td>
<td>53.44</td>
<td>1005</td>
<td>850</td>
<td>0.1</td>
<td>85</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2742</td>
<td>16.0</td>
<td>19.44</td>
<td>2.85</td>
<td>0.288</td>
<td>621.0</td>
<td>30.24</td>
<td>28.32</td>
<td>53.42</td>
<td>671</td>
<td>2700</td>
<td>2.6</td>
<td>120</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>2743</td>
<td>16.0</td>
<td>24.30</td>
<td>2.54</td>
<td>0.259</td>
<td>553.0</td>
<td>26.91</td>
<td>31.52</td>
<td>53.42</td>
<td>644</td>
<td>1500</td>
<td>1.4</td>
<td>115</td>
<td>C-I COATED</td>
<td>CERIJM</td>
</tr>
<tr>
<td>TEST NO.</td>
<td>COMP RATIO</td>
<td>FUEL</td>
<td>I-Pwr</td>
<td>ISFC</td>
<td>IMEP</td>
<td>ITJ</td>
<td>IEFF</td>
<td>IGN</td>
<td>EGT</td>
<td>HC</td>
<td>CO</td>
<td>NOX</td>
<td>TYPE</td>
<td>CATALYST</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>-----</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>2744</td>
<td>16.0</td>
<td>29.15</td>
<td>2.59</td>
<td>0.262</td>
<td>456</td>
<td>22.17</td>
<td>31.15</td>
<td>53</td>
<td>42</td>
<td>621</td>
<td>1700</td>
<td>0.5</td>
<td>125</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2745</td>
<td>16.0</td>
<td>31.59</td>
<td>1.149</td>
<td>0.339</td>
<td>325</td>
<td>15.82</td>
<td>24.09</td>
<td>53</td>
<td>43</td>
<td>555</td>
<td>1550</td>
<td>0.2</td>
<td>100</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2746</td>
<td>16.0</td>
<td>34.02</td>
<td>0.76</td>
<td>0.618</td>
<td>166</td>
<td>8.06</td>
<td>13.22</td>
<td>53</td>
<td>44</td>
<td>1019</td>
<td>880</td>
<td>0.1</td>
<td>65</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2747</td>
<td>17.0</td>
<td>19.44</td>
<td>2.66</td>
<td>0.303</td>
<td>580</td>
<td>28.22</td>
<td>26.44</td>
<td>53</td>
<td>41</td>
<td>256</td>
<td>3750</td>
<td>2.6</td>
<td>80</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2748</td>
<td>17.0</td>
<td>24.30</td>
<td>2.33</td>
<td>0.232</td>
<td>507</td>
<td>24.69</td>
<td>28.92</td>
<td>53</td>
<td>41</td>
<td>655</td>
<td>3000</td>
<td>1.6</td>
<td>50</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2749</td>
<td>17.0</td>
<td>29.15</td>
<td>1.82</td>
<td>0.300</td>
<td>398</td>
<td>19.35</td>
<td>27.19</td>
<td>53</td>
<td>42</td>
<td>256</td>
<td>2000</td>
<td>0.7</td>
<td>90</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2750</td>
<td>17.0</td>
<td>31.59</td>
<td>1.42</td>
<td>0.355</td>
<td>311</td>
<td>15.12</td>
<td>23.02</td>
<td>53</td>
<td>42</td>
<td>533</td>
<td>1500</td>
<td>0.3</td>
<td>70</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2751</td>
<td>17.0</td>
<td>34.02</td>
<td>0.66</td>
<td>0.705</td>
<td>145</td>
<td>7.06</td>
<td>11.57</td>
<td>53</td>
<td>42</td>
<td>988</td>
<td>800</td>
<td>0.1</td>
<td>40</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2752</td>
<td>18.0</td>
<td>19.44</td>
<td>2.56</td>
<td>0.323</td>
<td>559</td>
<td>27.21</td>
<td>25.49</td>
<td>53</td>
<td>41</td>
<td>666</td>
<td>3600</td>
<td>2.5</td>
<td>70</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2753</td>
<td>18.0</td>
<td>24.30</td>
<td>2.39</td>
<td>0.275</td>
<td>522</td>
<td>25.40</td>
<td>29.75</td>
<td>53</td>
<td>41</td>
<td>644</td>
<td>2600</td>
<td>1.4</td>
<td>86</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2754</td>
<td>18.0</td>
<td>29.15</td>
<td>1.80</td>
<td>0.304</td>
<td>393</td>
<td>19.15</td>
<td>26.91</td>
<td>53</td>
<td>41</td>
<td>577</td>
<td>1750</td>
<td>0.9</td>
<td>110</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2755</td>
<td>18.0</td>
<td>31.59</td>
<td>1.28</td>
<td>0.394</td>
<td>280</td>
<td>13.61</td>
<td>20.71</td>
<td>53</td>
<td>41</td>
<td>1066</td>
<td>1400</td>
<td>0.2</td>
<td>100</td>
<td>C-I COATED</td>
</tr>
<tr>
<td>2756</td>
<td>18.0</td>
<td>34.02</td>
<td>0.28</td>
<td>1.648</td>
<td>62.</td>
<td>3.02</td>
<td>4.96</td>
<td>53</td>
<td>41</td>
<td>1013</td>
<td>900</td>
<td>0.1</td>
<td>85</td>
<td>C-I COATED</td>
</tr>
</tbody>
</table>