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New Spark Plug Electrode Discovery Improves Combustion

Atlanta, GA (September 10, 1999) - An improved method of igniting gasoline will provide measurable benefits in automotive engines, including reduced fuel consumption, a reduction in harmful emissions and an increase in power.

Combustion researchers at Pyrotek, Inc. are using standard spark plug components combined with a unique discharge electrode to increase combustion pressures in otherwise unchanged engines.

A side benefit to this new technology is a marked reduction in carbon deposits due to the more complete combustion. This carbon reduction reduces long-term emissions and aids in extending engine component life.

Pyrotek's research has been corroborated by studies done in conjunction with professors from leading universities, confirming that the combustion process is more completely accomplished with the new electrode design "The improved combustion effects of the Pyrotek electrode were consistently measured" states Dr. Sam Shelton of the Mechanical Engineering School at the Georgia Institute of Technology, "There is a statistically measurable increase in power and a reduction in fuel usage when compared to standard electrode designs. It provides a better means of igniting fuel at the most basic level"

The Pyrotek electrode was created for automotive use where it exhibits a improvement in power and a reduction in fuel usage, with a resulting reduction in harmful emissions. However, due to its parallel strong performance in small engines, it has been included in the most recent EPA rules governing off-road emissions. This applies to lawn mowers, blowers, edgers, farm equipment and marine engines which account for 10% of the pollution sources in U.S. The EPA considers the Pyrotek electrode to be a supplemental technology in the ongoing effort to reduce spark ignition engine emissions.

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The electrode has been incorporated into traditional spark plug components to ease its implementation into engine manufacturers' assembly lines. A spin-off of this strategy is that the electrode becomes available to all engines that use spark plugs, both new and already in-use.

"In side-by-side durability tests, the Pyrotek electrode reduced hydrocarbon emissions by 42 percent when compared to a standard spark plug design," said Norman Garrett, Director of Engineering for Pyrotek. "Carbon monoxide emissions were cut by 59 percent in specific EPA-prescribed tests."

The relative low cost of the technology and its ability to retrofit existing engines makes the development especially timely. Each state in the nation has programs to reduce total emission inventories. While newer model automobiles and small engines are producing less emissions, of greater concern are the millions of engines already in use. The Pyrotek electrode is being considered by various state agencies as a means of "cleaning up" engines already in use at a reasonable or no net cost to the consumer, once fuel savings are accounted for.

The technology is patented with additional patents pending. It is currently being tested by various engine manufacturers with positive results. The initial production run is being engineered for a product roll-out as early as Spring of 2000. The target retail price is slated to be lower than current premium spark plug offerings from major manufacturers despite the increased performance of the new design.

The new electrode was developed by a Georgia Tech graduate, Norman H. Garrett III. He is better known as the concept engineer for the Mazda Miata automobile during his tenure at Mazda's design studio in Southern California. Since leaving Mazda, Garrett has focused his engineering efforts on combustion research.

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PYROTEK TECHNOLOGY'S IMPACT ON TWO STROKE SMALL ENGINE EMISSIONS
January 5, 2000

SUMMARY
Testing has been performed at the Engine Research Labs of Michigan State University to determine the effect of the Pyrotek electrode on two stroke engines. This new testing combined with earlier research by the MSU lab and others has verified that the new technology represented by the Pyrotek electrode creates a significant, measurable, and repeatable combustion effect with a simple change in spark plug ground electrode geometry. Improved power output, reduced fuel usage, reduced emissions, and reduced carbon deposits are some of the byproducts of using the new electrode design in both four and two stroke engines.

To study the specific contributions the Pyrotek electrode might make on small two stroke engines, various tests were performed. Using the EPA 40 CFR90 test protocol, certification tests were run on engines from four separate engine manufacturers. Additionally, durability tests were run on various engines using an EPA-suggested protocol to study the effect of usage on spark plug durability.

The data show a repeatable trend with the Pyrotek electrode:

- Reduced hydrocarbon (HC) output
- Reduced carbon monoxide (CO) emissions
- Improved power output
- Reduced fuel consumption
- All of the above occur at zero hours and after in-use hour accumulation
- An extended life when compared to current spark plug designs

STUDY #1:
A two stroke Phase 1 chainsaw motor from a major manufacturer (Brand "A") was tested with a new spark plug and the same spark plug with the ground electrode converted to the Pyrotek design. This was a new engine with zero hours.

BRAND "A"	STD. ELECTRODE	PYROTEK	DELTA
Power, kW	0.55	0.57	3.6%
BSFC, g/kW-hr	1502.9	1408.5	6.3%
HC, g/kW-hr	381.4	328.3	16.2%
CO, g/kW-hr	1175.0	1084.0	8.4%

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The emission data shows that the standard design spark plug emits 16% more HC and 8% more CO than the Pyrotek design. Power and brake-specific fuel consumption were also positively affected by the Pyrotek technology. This engine ran at air fuel ratios of 12.5 to 1, typical of small two stroke engines.

STUDY #2:
For more careful study of the Pyrotek electrode's effect on in-use durability, a matched pair of two stroke Phase 1 chain saw engines from a major supplier (Brand "B") were run at the MSU labs. The engines were aged using a protocol suggested by the EPA. Each engine was tested after zero, twenty-five, fifty, and seventy-five hours of use accumulation. The engines were aged in a controlled lab held to the CFR90 ambient condition standards throughout the test and were running at the typical air fuel ratios of 12.5:1.

The loads were introduced to the engines using a small engine dynamometer. Data was recorded in controlled conditions to reduce test variability. Each engine was run at idle for 30 seconds, then at full throttle and load for 30 seconds, then the cycle was repeated for fifty minutes. A ten minute cool-down period was conducted before beginning another 50 minute use-cycle. This test cycle has proved to be very useful in aging both the engine and ignition components in a real-world model.

At zero hours, an initial A-B test of the Pyrotek electrode versus the standard design showed a strong reduction in carbon monoxide.

0 HOURS	STD. ELECTRODE	PYROTEK	DELTA
HC, g/kW-hr	165.5	166	-
CO, g/kW-hr	310	268	13.5%

Observations over various durability tests show that an initial reduction in CO leads to a long term reduction in HC emissions due to reduced carbon build up on internal engine components. To this end, the matched pair of engines were set up, initialized to confirm proper operation, then aged per the EPA suggested protocol. Each respective spark plug was kept in its assigned engine to allow observation of the total system aging including carbon build up (switching plugs between engines would erase any carbon deposit accumulations due to electrode configuration).

After twenty-five hours of aging, the standard spark plug began to show signs of deterioration. The data points themselves differ from the zero hour numbers due to humidity drifts between the two test dates (yet within the CFR90 ambient limits).

Relative to each electrode design, however, the data is accurate since testing was conducted in a single test period for both engines.

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25 HOURS	STD. ELECTRODE	PYROTEK	DELTA
HC, g/kW-hr	158	136	16.2%
CO, g/kW-hr	260	193	34.7%

The CO gap grew as age was accumulated on the engine. The HC emissions began to fall off for the standard design spark plug as the electrode exhibits typical wear patterns.

After fifty hours of aging, the data shows a strong fall-off in the standard spark plug's ability to promote complete combustion (no other mechanical wear trends were observed in either engine).

50 HOURS	STD. ELECTRODE	PYROTEK	DELTA
HC, g/kW-hr	178	125	42.4%
CO, g/kW-hr	342	215	59.2%

The standard spark plug design produced 42% more hydrocarbon emissions and 59% more carbon monoxide under identical test conditions. In addition, at the 50 hour mark power was 12% less and brake specific fuel consumption was 7% worse with the standard spark plug design as compared to the Pyrotek technology.

To this point in the test procedure, the engines had been carefully handled and undisturbed to prevent mechanical deviations of the emissions output. At the conclusion of the 50 hour aging, both engines were disassembled for inspection. Upon disassembly of the matched pair of aged engines, there was a notable reduction in carbon deposits and piston-head damage in the Pyrotek-equipped engine.

The engines were reassembled and mothballed for eight months (simulating off-season storage by a consumer) and brought out for more testing. Interest arose in continuing the durability studies on these engines, so they were set up again for CFR 90 emission testing and hour accumulation, acknowledging the fact that the emission levels would have been affected by the disassembly and inspection process.

The engine that had its hours accumulated on the standard spark plug design was re-tested for emissions, then a new Pyrotek spark plug was installed to see the affect of retrofitting a Pyrotek

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into a used engine, in this case after 50 hours of in-use aging.

RETROFIT STUDY	STD. ELECTRODE	PYROTEK	DELTA
HC, g/kW-hr	155	147.4	4.9%
CO, g/kW-hr	393	294	25.2%

The Pyrotek electrode repeated its earlier reduction in carbon monoxide and made a statistically measurable difference in hydrocarbon emissions. Since the standard electrode engine had accumulated heavy carbon deposits, it is expected that running this engine with the Pyrotek electrode in place would lead to greater HC reductions once the carbon was consumed and ejected.

As before with the initial 25 hour data, comparisons between tests run on different dates are not readily comparable due to ambient condition drifts within the allowed ranges. However, the data presented here in each table for each case is recorded during a singular test session and is relative electrode-to-electrode as presented.

The engines were run to 75 hours to further study the effects of aging on the ignition components. Unfortunately, the engine fitted with the standard spark plug was not able
to complete the test due to a mechanical failure, but relevant data was collected on the Pyrotek-equipped engine at the 75 hour mark.

75 HOURS	STD. ELECTRODE @ 50 hours	PYROTEK @ 75 hours	DELTA
HC, g/kW-hr	155	142.8	9.0%
CO, g/kW-hr	393	339	16.0%

When compared to where the standard engine was at 50 hours of aging after eight months of rest, the Pyrotek engine at 75 hours shows a 9% difference in hydrocarbon emissions and 16% in carbon monoxide output. While we are comparing across test dates in this example, the data shows the trend of the Pyrotek electrode as it ages past the 50 hour mark.

This test was run with the same Pyrotek spark plug throughout the 75 hour age accumulation. While the standard spark plug design showed significant deterioration in HC and CO output as well as reduced power and increased fuel usage at the 50 hour mark, the Pyrotek electrode design showed negligible signs of deterioration even at the 75 hour aging point, retaining the system integrity of the engine's performance.

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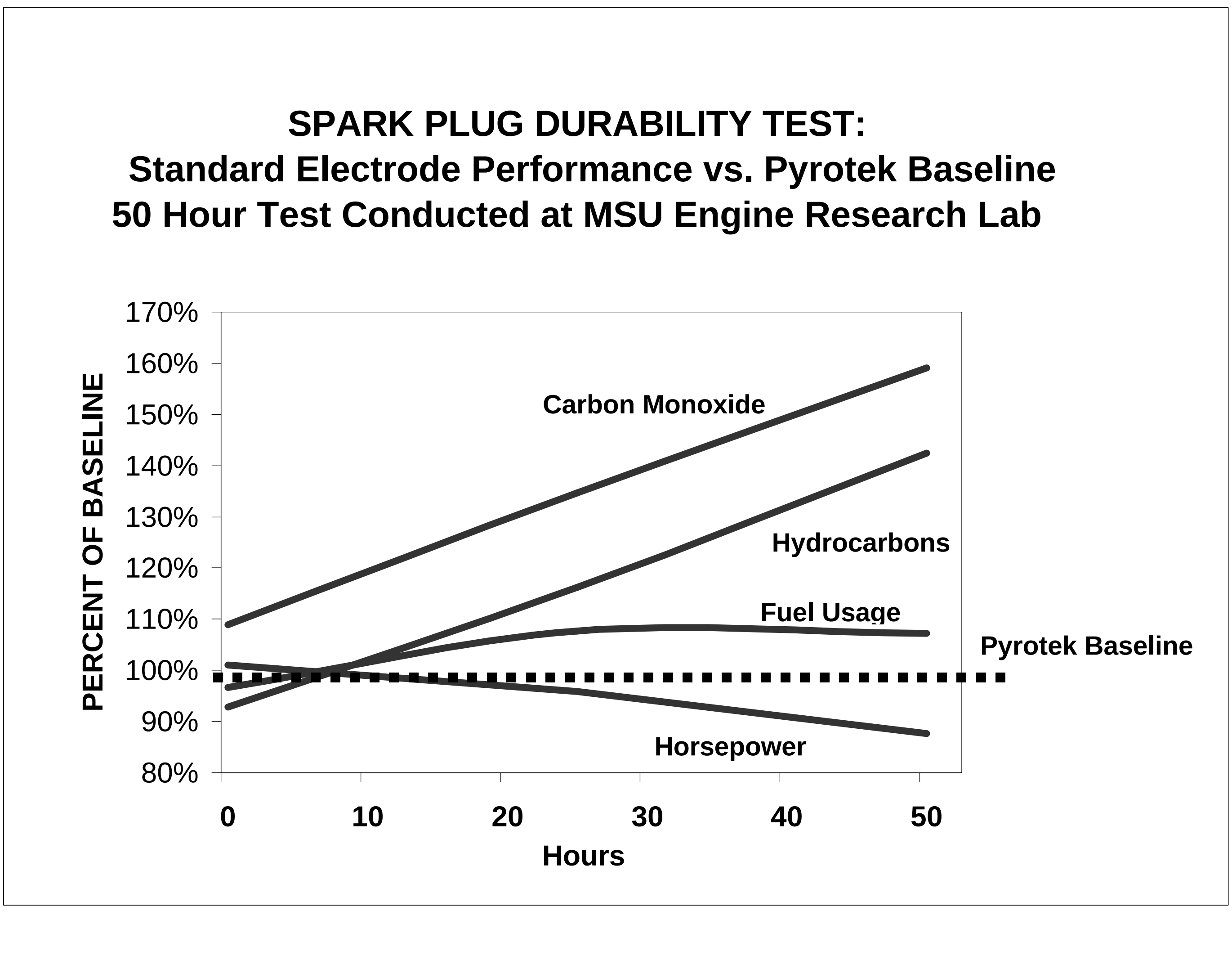
While the standard electrode design was still able to promote minimal combustion for engine operation, it was far less than optimum combustion as far as emissions and power output is concerned. This is an emerging trend across these studies - functional operation is not a strict enough criteria to judge a spark plug's effectiveness by.

In relative terms, an engine can still function with an aged spark plug but have become a relative "gross polluter" due to the spark plug's degradation. This raises concerns in that most consumers do not replace spark plugs until they fail. However, their useful, effective life is actually much shorter with degradation starting at the 25 hour mark according to these data. The Pyrotek technology offsets this trend with negligible deterioration at least up to the 75 hour mark.



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STUDY #3:
To further study the Pyrotek technology's affect on modern two strokes, the cleanest-known units were acquired from an Asian manufacturer (Brand "C"). A pair of C.A.R.B. Tier II Certified engines were tested using the 40 CFR 90 protocol at the MSU labs. These engines incorporated special porting features and one-way catalytic converters to reduce emission output.

Due to the successful test procedure developed during Study #2, each spark plug design was kept undisturbed in its assigned engine from zero hours. Baseline emission data were collected for both electrode designs in their respectively assigned engines.

BRAND "C"	STD. ELECTRODE	PYROTEK	DELTA
Power, kW	0.93	1.05	12.9%
BSFC, g/kW-hr	704.8	662.3	6.4%
HC, g/kW-hr	78.0	70.5	10.6%
CO, g/kW-hr	544.0	494.0	10.1%

When both engines and catalytic converters were new, and a comparison between two engines and their catalytic converters might be most reliable, the use of the Pyrotek spark plug led to a reduction in HC and CO emission and in improved power and fuel economy, exhibiting the measurable combustion effect of the Pyrotek electrode.

STUDY #4:
A fourth manufacturer was contacted for further studies on advanced two stroke engines. A pair of Phase II engines from a leading European small engine manufacturer (Brand "D") were collected and prepared for testing at the MSU labs. These engines use special port timing and catalytic converters to reduce emission output.

Because of the catalytic converter's function of converting unburnt hydrocarbons into carbon monoxide, data was collected with dummy catalysts in place. This was done to gain a more accurate view of the Pyrotek effect without the masking effect of the catalytic converter.

Baseline emission data were collected for both electrode designs in and A-B test in one engine before hour accumulation began. The results are as follows:

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BRAND "D"	STD. ELECTRODE	PYROTEK	DELTA
Power, kW	0.58	0.62	6.5%
BSFC, g/kW-hr	719.8	631.7	13.9%
HC, g/kW-hr	165.8	149.3	11.1%
CO, g/kW-hr	204.0	204.0	-

Again, each category was improved by the installation of a Pyrotek electrode-equipped spark plug. Hydrocarbon and carbon monoxide emissions were reduced, power was improved and fuel consumption was lessened. The standard electrode could not promote the same level of combustion that the Pyrotek electrode demonstrates in this engine.

To study the Pyrotek electrode's effect on emission downstream of a catalyst, zero hour measurements were taken in an A-B test with the catalytic converter installed. The data shows the HC output is equalized by the catalytic converter, but in CO emissions the

Pyrotek electrode yields a 19% benefit. As cited in Study #2 and previous tests, improvements in CO are a precursor to long-term HC reductions.

0 HOURS w/CAT	STD. ELECTRODE	PYROTEK	DELTA
HC, g/kW-hr	98.7	98.3	-
CO, g/kW-hr	94	79	19%

To further study these advanced engines, the aging protocol used in Study #2 was incorporated. The differing electrode designs were assign to their respective engines and hours were accumulated. Twenty-five hours of the durability cycle were accumulated on the matched pair of engines and data recorded with the catalysts installed.

25 HOURS	STD. ELECTRODE	PYROTEK	DELTA
HC, g/kW-hr	132.1	114.7	13.2%
CO, g/kW-hr	373.0	68.0	81.8%

The Pyrotek technology reduced hydrocarbon emissions by similar amounts to earlier two stroke tests. It is interesting to note that even after 25 hours of age accumulation the Pyrotek electrode emits 13.5% less hydrocarbons than the standard electrode engine did when new. The prediction that an initial CO reduction would lead to an in-use reduction in HC output was borne out in the 25 hour data.

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For a closer look at the ignition durability of the engines at the twenty-five hour mark, tests were run with dummy catalytic converters. The data recorded were as follows:

25 HOURS NO CATALYST	STD. ELECTRODE	PYROTEK	DELTA
HC, g/kW-hr	162.7	146	10.3%
CO, g/kW-hr	461.0	102	77.9%

Consistent reductions in HC and CO are evident through the use of the Pyrotek electrode when measuring the unaltered exhaust gases.

Supporting this tie-in between the Pyrotek electrode and the optimization of a two stroke catalytic converter is the data comparing the zero hour Pyrotek emissions and the 25 hour data points for the same engine.

Engine #1 w/o CAT	0 Hr Pyrotek	25 Hr Pyrotek	DELTA
HC, g/kW-hr	149.3	146	2.3%
CO, g/kW-hr	206	102	50.5%

Measuring the unaltered exhaust components without after-treatment shows that the Pyrotek plug reduces CO output over 25 hours by 50%.
It has been proposed that two stroke catalysts could be optimized in light of the HC and CO modifications offered by the Pyrotek technology. Feeding lower levels of HC and CO into the converter positively affects longevity and conversion efficiency, or offers the possibility of improving the total reduction through the conversion process. It may also be possible to use a smaller, less expensive catalyst once the Pyrotek contribution is utilized.

An observation that came out of the 25 hour data is the reduction in the catalyst's ability to successfully convert HC as shown in the following data:

Engine #1	0 Hr Pyrotek	25 Hr Pyrotek	DELTA
HC with Catalyst	98.3	114.7	16.7%
HC without Catalyst	149.3	146	-2.3%

The "without Catalyst" data shows the engine itself is stable in HC output, but the "with Catalyst" data shows the deterioration of the catalyst's ability to convert HC successfully. Just as earlier data shows standard components beginning to deteriorate at the 25 hour point, the catalytic converter's efficiency in this study fell off by 16.7% over the same usage period.

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Even after 25 hours of age accumulation, the Pyrotek technology emits 13.6% less HC and 50.5% less CO than the standard spark plug design did at zero hours. Presumably, the composition of the catalytic converter could then be optimized to provide more balanced benefits in HC and CO when using the Pyrotek technology.

CONCLUSION

The Pyrotek technology has consistently exhibited an ability to promote more complete combustion in a variety of two stroke engines. The improved combustion results in reduced emission, improved power, a reduction in fuel usage, and a reduction in carbon deposits. The positive effects of the Pyrotek technology has been demonstrated in engines ranging from older Phase 1 models (representing the existing population) to the most advanced low-emission units that meet the 2000 California standards. The Pyrotek contribution is additive to the new two stroke technologies.

The core benefits are believed to come from the faster flame front produced by the Pyrotek electrode-initiated flame kernel. This leads to higher turbulences within the expanding gases, in quicker completion of the combustion process, higher peak pressures (which have been measured), more aggressive exhaust gas flow, higher exhaust gas temperatures (also measured) and improved scavenging dynamics. It should be noted that a faster flame front would dictate different exhaust port timing, offering the possibility of further optimization that could be done with careful study using the Pyrotek electrode in a specific engine.

The low-cost implementation of the Pyrotek electrode into current new engine production can assist engine manufacturers in meeting the new Phase II standards for two stroke engine emissions with the following observations:

- An immediate average 12.7% reduction in HC emissions in new engines is achievable with by upgrading to the low cost Pyrotek design
- Pyrotek has a long term emission reduction integrity demonstrated to the 75 hour mark representing an extended life when compared to current spark plug designs
- Standard spark plug designs may be inadequate to reach the proposed 50 hour in-use requirement or a 2 year emissions warranty
- For advanced two strokes incorporating catalytic converters, the Pyrotek technology reduces the HC and CO load going into the converter, extending converter life and increasing converter efficiency
- It may be possible to optimize a catalytic converter to take advantage of the specific HC and CO outputs of a Pyrotek-equipped engine.

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- It may be possible to use the Pyrotek technology's HC reduction to reduce the need for higher efficiency catalysts, reducing the converter's capacity, load, and heat output and the converters cost.
- In-use carbon deposits are reduced leading to long term HC integrity and promoting longer engine component durability including catalysts.
- The Pyrotek technology is complementary to, and provides additional emission reduction beyond what can be achieved with the technologies which prompted re-proposal of the second phase of non-road engine SI emission standards.

In addition to the benefits to new engines, the positive effect the Pyrotek technology has as a low-cost retrofit device can greatly affect current efforts to reduce the emission inventories emitted by the existing population of two stroke engines nationwide.