A New Way to Measure Octane: Lab & Process with CVCC Autoignition Technology

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ABSTRACT

PAC has developed a new Constant Volume Combustion Chamber (CVCC) analyzer for the measurement of octane through autoignition. The analyzer determines both Research Octane Number (RON) and Motor Octane Number (MON) with excellent correlation to ASTM engine methods D2699 and D2700, while offering superior repeatability and reproducibility. This technology has been implemented in both laboratory and process analyzers, ensuring consistency across applications. Development work is currently underway toward establishing an ASTM standard method.

The CVCC approach enables easier operation and delivers a significant reduction in octane giveaway, providing measurable value for modern refinery operations.

1. INTRODUCTION

Octane number remains one of the most critical quality parameters in gasoline production, directly influencing engine performance, regulatory compliance, and refinery profitability. Since the introduction of the Cooperative Fuel Research (CFR) engine methods in 1929, ASTM D2699 (Research Octane Number) and ASTM D2700 (Motor Octane Number) have served as the global reference standards for octane measurement. Despite their proven credibility, CFR engines impose substantial operational burdens, including high capital and operating costs, significant space and infrastructure requirements, dependence on highly skilled operators, and limited sample throughput.

In parallel, spectroscopy-based techniques such as Fourier Transform Infrared (FTIR) and Near-Infrared (NIR) analysis have gained adoption for screening and process monitoring applications. While these techniques offer speed and ease of use, they rely on multivariate calibration models and correlations that can drift over time as crude slates, blendstocks, and fuel compositions change. As a result, such methods are often unsuitable for final product release or high-confidence blending optimization.

Increasing market volatility, wider crude variability, higher ethanol blending rates, and tighter refinery margins have amplified the economic consequences of octane measurement uncertainty. To mitigate the risk of producing off-specification gasoline, refiners frequently adopt conservative blending strategies that result in systematic octane giveaway. Even small margins of excess octane can translate into multi-million-dollar annual losses at a single refinery.

This paper introduces a Constant Volume Combustion Chamber (CVCC)–based approach to octane measurement that provides a direct, combustion-based determination of RON and MON without reliance on predictive models. The technology is designed to deliver Knock Engine-equivalent credibility with improved precision, automation, and operational simplicity. Furthermore, the same analytical principle has been implemented in both laboratory and online process analyzers, enabling consistent octane measurement across the gasoline value chain.

2. BACKGROUND AND MOTIVATION

2.1 Limitations of Conventional Octane Engines

The knock engine remains the benchmark for octane determination due to its direct measurement of knock behavior under standardized operating conditions. However, practical limitations restrict its effectiveness in modern refinery environments. Engine-based testing requires frequent calibration with primary reference fuels, ongoing mechanical maintenance, and dedicated operator expertise. Measurement throughput is inherently limited, making routine component testing and rapid feedback for blending decisions impractical.

Additionally, many refineries operate aging CFR fleets that date back several decades. Maintaining these systems presents increasing challenges related to spare parts availability, safety, noise exposure, water consumption, and staffing continuity. These factors collectively increase operational risk and cost.

2.2 Challenges with Correlation-Based Techniques

Spectroscopic methods infer octane values through statistical correlations between spectral features and reference data sets. While effective within trained fuel domains, these techniques are sensitive to changes in fuel composition, oxygenate content, and additive chemistry. Maintaining robust calibration models often requires specialized chemometric expertise and frequent updates, which are not consistently performed in operational settings.

As a result, correlation-based techniques are typically applied as screening tools rather than authoritative measurements for product certification or economic optimization. Misalignment between laboratory reference methods and online or screening measurements further contributes to conservative blending practices.

2.3 Need for a Modern Combustion-Based Alternative

An ideal alternative to the knock engine would preserve the fundamental combustion-based measurement of knock resistance while addressing the operational shortcomings of engine systems. Such a solution must provide high repeatability and reproducibility, support automation, reduce operator dependency, and integrate seamlessly into both laboratory and process environments. The CVCC approach described in this paper has been developed to meet these requirements.

3. CONSTANT VOLUME COMBUSTION CHAMBER PRINCIPLE

3.1 Measurement Concept

The Constant Volume Combustion Chamber method determines octane number by characterizing the autoignition behavior of a fuel sample under tightly controlled thermodynamic conditions. A fixed-volume chamber is heated and pressurized to predefined conditions and charged with combustion air of controlled oxygen concentration. A precisely metered quantity of fuel is then injected into the chamber.

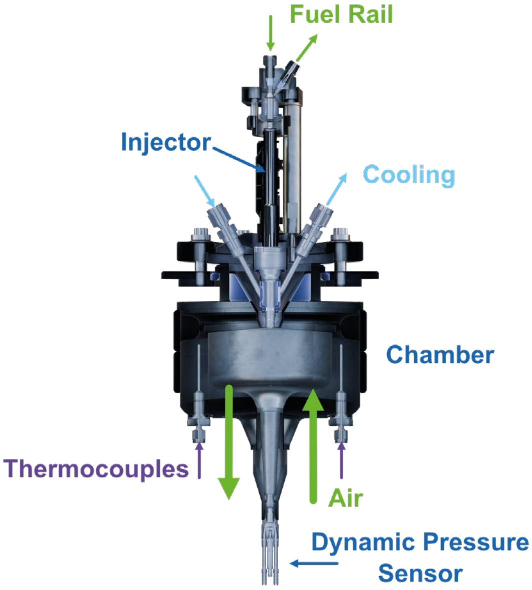

FIGURE 1. CVCC analytic system for measuring Octane

Following injection, the fuel undergoes autoignition after a short ignition delay. The resulting combustion event generates a characteristic pressure-time profile. Key features of this pressure response—including ignition delay, rate of pressure rise, and peak pressure—are extracted and mathematically related to octane number through established correlations against ASTM D2699 and D2700 reference samples.

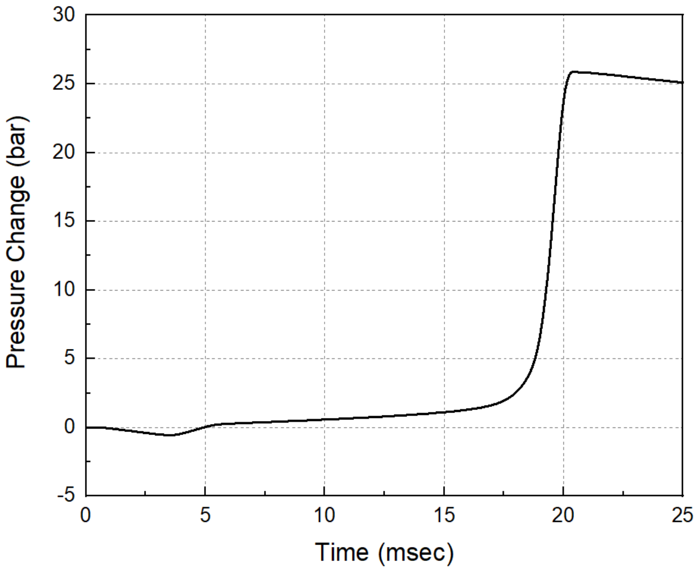

FIGURE 2. Combustion Curve showing pressure changing over

3.2 RON and MON Determination

Research Octane Number and Motor Octane Number are determined using distinct chamber conditions that reflect the differing severity of the two standardized test methods. RON is measured under lower pressure conditions, while MON is measured at higher pressure to reflect the different octane sensitivity. Both values are obtained from the same physical measurement system, enabling consistent determination of RON, MON, and Anti-Knock Index (AKI).

Using the pressure curve in figure 2, several points from the curve as well as the first and third order differentials are used in the formula to calculate the Octane number. By using several parameters in the equation, variation in sample vapor pressure and ethanol content on the combustion curve can be calculated out. Each RON measure contains several cycles of autoignition events, which are averaged for the final results, as seen in the overlapping pressure profiles in figure 3. After that a series of autoignition events are done at a higher pressure to find the MON value. The time for measurement is <1hour for the lab analyser and approximately 10mins for the process unit. As this is a Beta stage the timings may change upon release of the product.

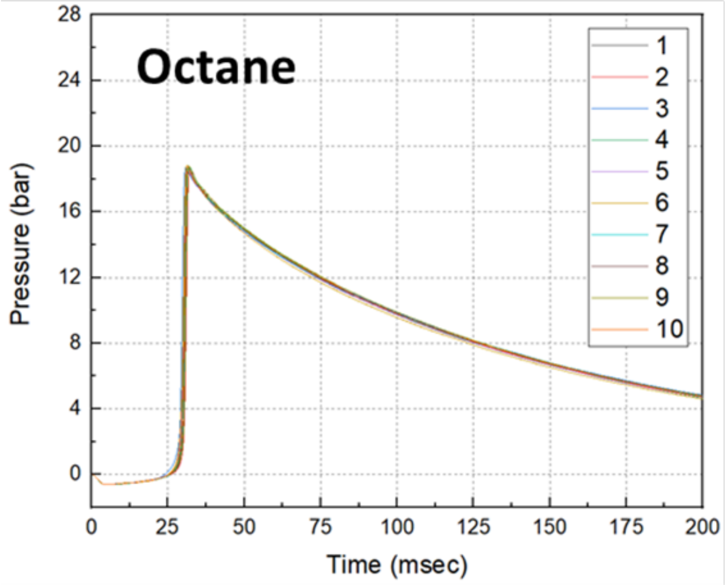

FIGURE 3. Overlapping Combustion Curve showing pressure changing

3.3 Derived Octane Reporting

Because the CVCC method correlates measured combustion behavior to established engine reference methods, reported results are expressed as derived RON (DRON) and derived MON (DMON). This nomenclature is consistent with ASTM practice for alternative test methods and clearly distinguishes the measurement approach while preserving traceability to the reference standards.

It i important to note that this is not a model. It is an equation that is valid for any sample 65-113 Ron 60-113 MON and ethanol content up to 100%, while also independent of vapor pressure. There is no requirement for rebuilding the equation.

4. INSTRUMENTATION AND IMPLEMENTATION

4.1 Laboratory Analyzer Configuration

FIGURE 4. Lab Analyzer

The laboratory CVCC analyzer is designed as a bench-scale analytical instrument suitable for routine operation in refinery and third-party laboratories. The system incorporates an automated 40-position autosampler, enabling unattended batch analysis of multiple samples. Integrated control software manages test sequencing, data acquisition, quality control checks, and result reporting.

The elimination of mechanical engine components significantly reduces maintenance requirements. Operation does not require specialized engine operators, allowing broader deployment across laboratory shifts, while reducing dependency on scarce technical expertise.

4.2 Process Analyzer Configuration

FIGURE 5. Process Analyzer

The same CVCC measurement principle has been implemented in an online process analyzer for continuous or semi-continuous octane monitoring. This configuration enables real-time or near-real-time measurement of blend components and finished gasoline streams. Alignment between laboratory and process analyzers ensures that both environments share a common measurement basis, minimizing discrepancies and simplifying validation.

5. PERFORMANCE CHARACTERISTICS

5.1 Correlation to ASTM Reference Methods

Extensive development testing has demonstrated strong correlation between CVCC-derived octane values and ASTM D2699 and D2700 engine results across a wide range of gasoline samples and blendstocks.

Figure six and seven shows the correlation between different sample, standard gasolines with and without ethanol, Europe and USA sample programs such as FAM, ASTM and primary reference fuels, PRF, TSF samples. To note this is results from our beta systems and the results may change by the time of product release

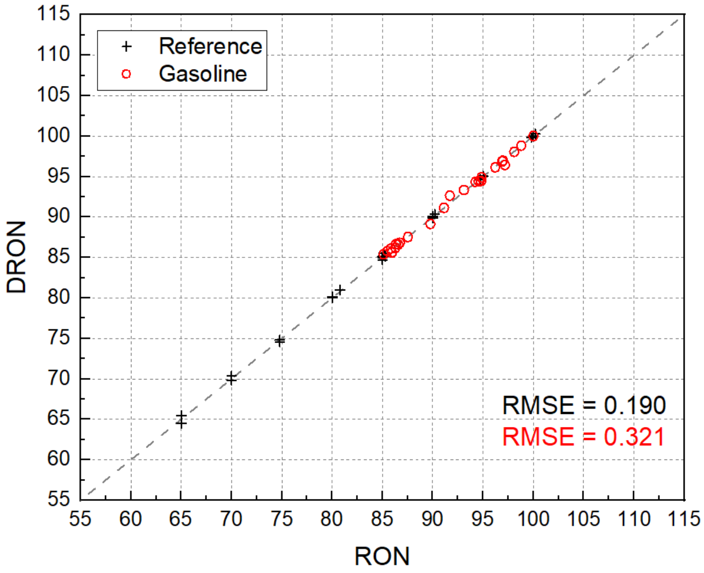

FIGURE 6. Correlation to D2699 for a series of gasoline

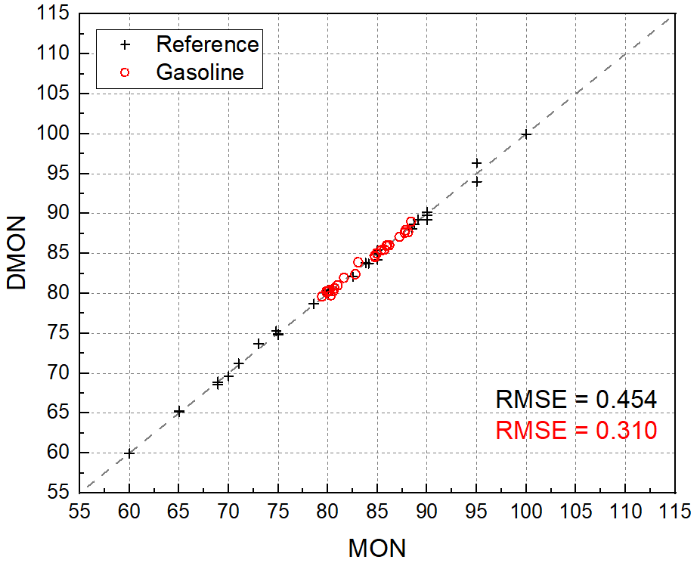

FIGURE 7. Correlation to D2699 for a series of gasoline

5.2 Repeatability and Reproducibility

The controlled combustion environment and automated operation of the CVCC system yield repeatability and reproducibility that exceed those typically achieved with engine. Figure 6 shows such repeatability three samples for RON and MON. To note this is results from our beta systems and the results may change by the time of product release

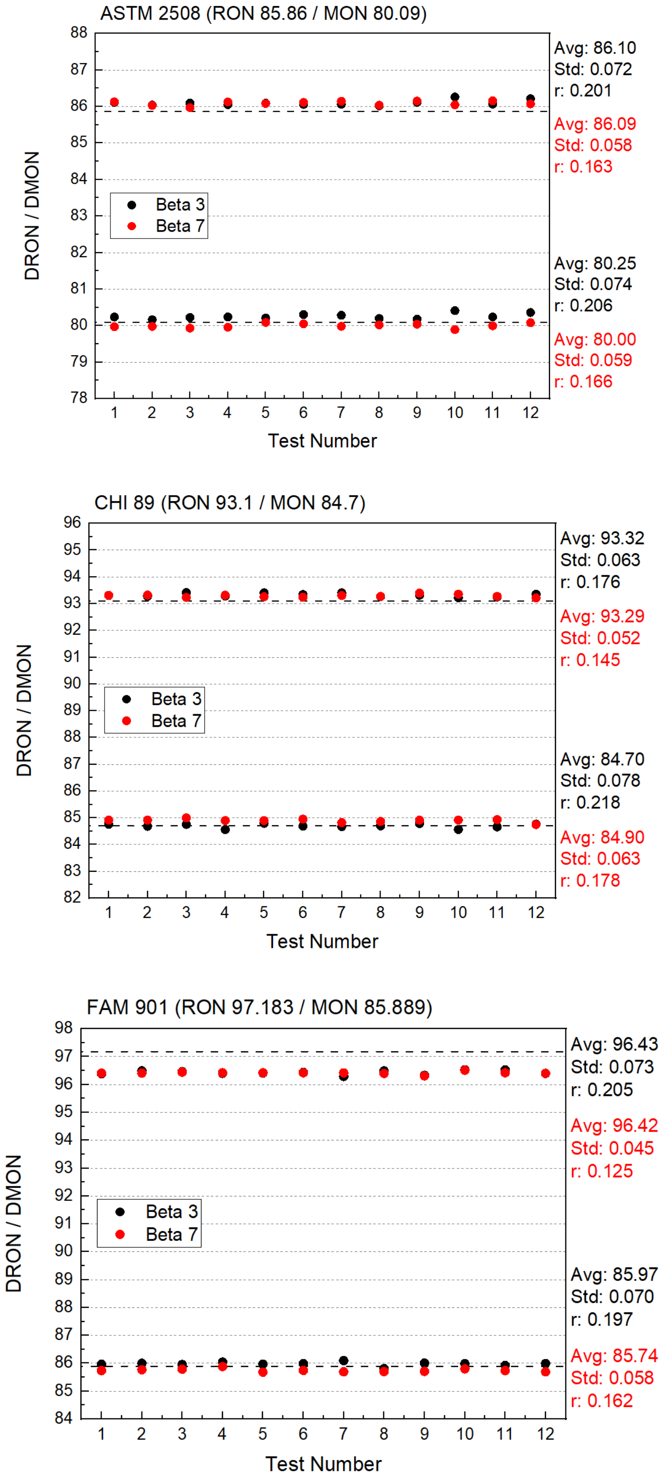

FIGURE 6. Repeatability of three different samples

6. ECONOMIC IMPACT AND OCTANE GIVEAWAY REDUCTION

Measurement uncertainty directly influences blending strategy. When octane data are perceived as noisy or inconsistent, refiners compensate by blending above specification to avoid non-compliance risk. The improved precision of the CVCC method enables tighter control of blending targets, reducing systematic octane giveaway.

For a representative medium-to-large refinery, even a reduction of 0.1 octane number in blending margin can correspond to several million dollars in annual value recovery. By enabling confident blending closer to specification, the CVCC analyzer delivers tangible economic benefits in addition to operational improvements.

7. ASTM STANDARDIZATION STATUS

Development activities are currently underway to establish an ASTM standard method for CVCC-based octane measurement. This work includes interlaboratory studies, method validation, and engagement with relevant ASTM committees. Standardization is a critical step toward broad industry adoption and regulatory acceptance, enabling the CVCC method to be referenced alongside existing engine-based standards.

8. DISCUSSION

The CVCC approach represents an evolution in octane measurement that preserves the fundamental combustion-based assessment of knock resistance while addressing the operational limitations of traditional engine methods. By providing a common measurement framework for laboratory and process applications, the technology supports a unified approach to octane management across the refinery.

The combination of improved precision, automation, and reduced maintenance burden positions the CVCC analyzer as a practical alternative for both replacement of aging knock Engine infrastructure and expansion of octane measurement into new applications such as component optimization and online blending control.

9. CONCLUSIONS

A Constant Volume Combustion Chamber–based analyzer has been developed for direct measurement of gasoline octane number through controlled autoignition. The method provides derived RON and MON values with strong correlation to ASTM D2699 and D2700 while offering superior repeatability, reproducibility, and operational simplicity. Implementation in both laboratory and process analyzers ensures consistency across applications.

By reducing measurement uncertainty, the CVCC approach enables refiners to minimize octane giveaway and capture significant economic value. Ongoing ASTM standardization efforts are expected to further support industry adoption of this combustion-based alternative to conventional octane engines.

10. REFERENCES

1. ASTM International, ASTM D2699 – Standard Test Method for Research Octane Number of Spark-Ignition Engine Fuel.
2. ASTM International, ASTM D2700 – Standard Test Method for Motor Octane Number of Spark-Ignition Engine Fuel.

11. ACKNOWLEDGMENTS

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