

# **“PROCESS PARTICLE COUNTER (PPC) SENSOR/CONTROLLER FOR OPTIMIZING POWER RECOVERY EXPANDER AND GAS TURBINE PERFORMANCE**

## **APPLICATIONS NOTE FOR MEASUREMENTS AT THE ENTRANCE AND EXIT OF A THIRD STAGE SEPARATOR**

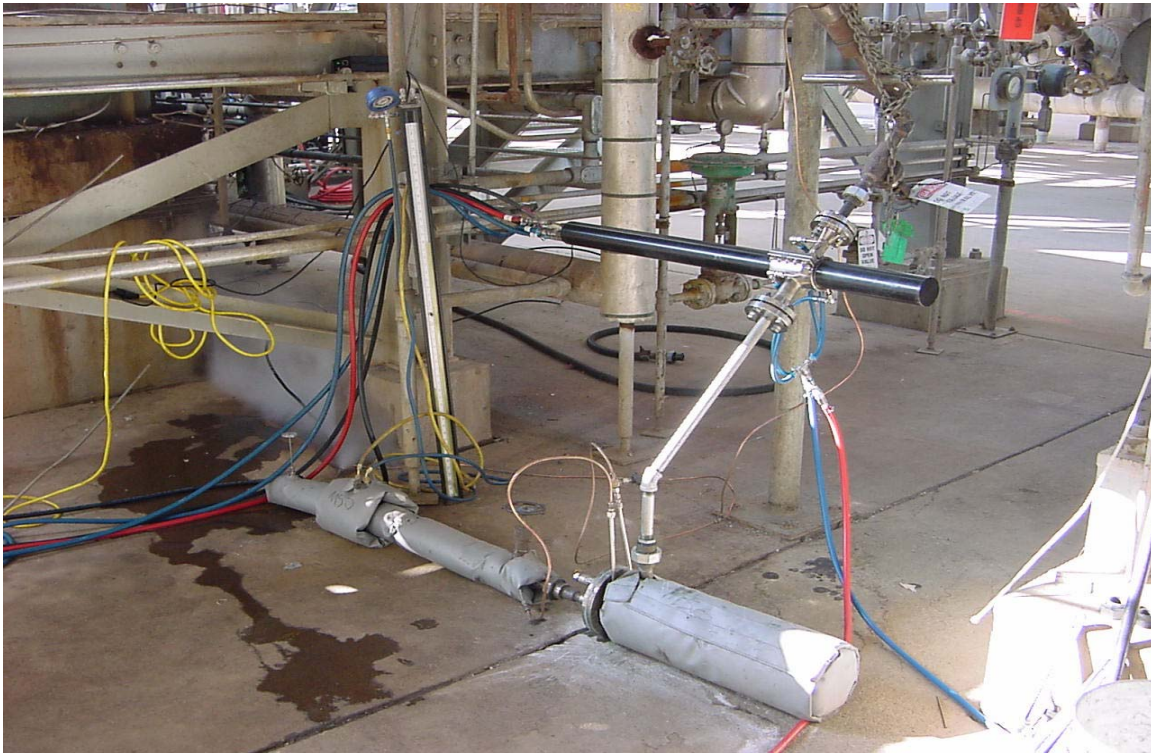
**INTRODUCTION:** Process Metrix LLC, (PMC) has developed a real-time laser-optical process particle counter/sizer (PPC) as a short term or automated long-term sensor and control system for dust monitoring of expanders/gas turbines and process stacks. This note summarizes results obtained in two series of tests at a petroleum refinery in February and July of 2002. These measurements were obtained at the entrances of the third stage separator (TSS inlet) and expander (TSS outlet) respectively. We used a prototype PPC instrument to obtain these measurements, confirming the ability of the PPC concept to accurately measure under normal system gas flow conditions (T=1200F, 47 psia). This measurement series also confirmed the required operating parameters for the fixed alignment PPC that is currently being designed.

### **DESCRIPTION OF THE INSTRUMENT AND EXPERIMENTAL SETUP**

**INSTRUMENTATION:** PMC used our research PPC instrument design, which measures over the nominal size range of 0.3 to 100 microns, at number concentrations approaching  $10^6$  particles per  $\text{cm}^3$ . The normal 1.25” by 3.5” rectangular “flow window” opening was modified by using an external water-cooled clamshell arrangement to accept the 0.75” dia. extraction flow line provided at the refinery. For the majority of measurements, the PPC was inserted in the normal line used by the refinery for mass sampling measurements, as shown in the photograph of Figure 1. The instrument was calibrated with our standard glass reticle (RS-2), and total mass balances were verified using a cement powder in our laboratory wind tunnel.

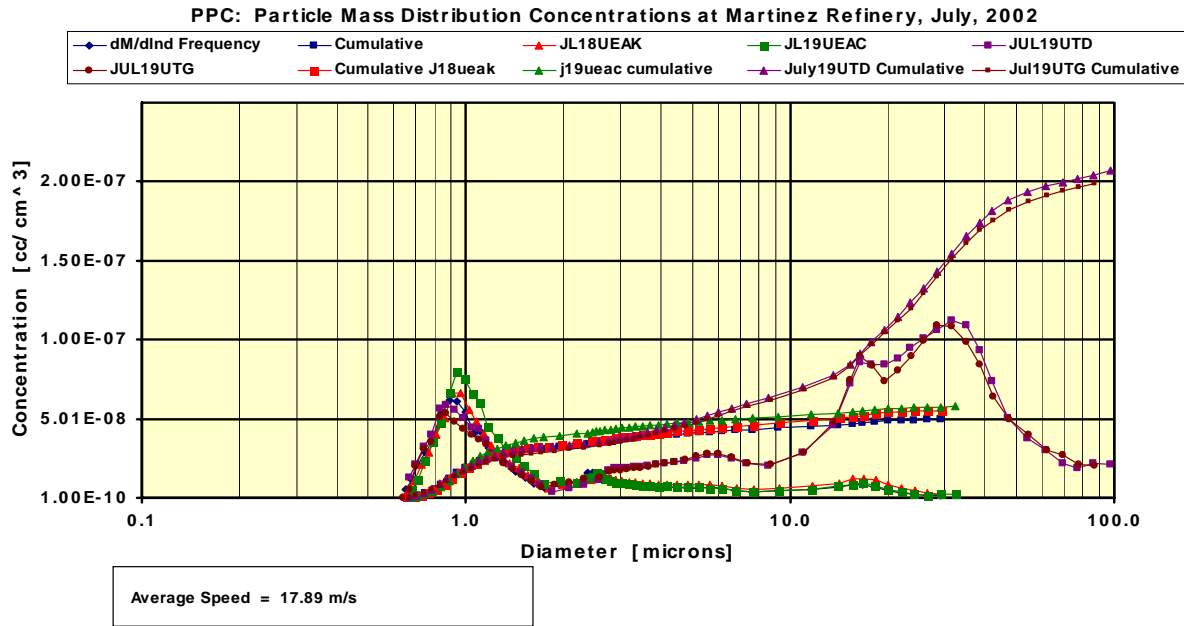
**SETUP:** Following safety training, and completion of the standard mass sample measurements by the refinery, PMC set up the PPC in less than an hour after finding the proper connection hardware for water-cooling and air purge connections.

**MEASUREMENTS:** After preliminary measurements to determine appropriate instrument settings, we settled on sample times of approximately three minutes to obtain several million particle size measurements for the entire instrument range of 0.3 to 100 microns. Real time display of the results is available in 3 minutes following each measurement. Particle velocities are also obtained by measuring the particle pulse width as the particle traverses a known laser beam diameter. With these measurements we are able to obtain the detailed size distribution and absolute concentration at actual flow conditions in the probe. We monitored the temperature and pressure conditions at the flow window, allowing determination of absolute particle loadings in the system flow or at NTP conditions for comparison with independent measurements of particle loading. For the July measurements, a throttling valve was placed downstream of the PPC, so that measurement pressures were similar to that of the primary flow (40 psia), with temperatures of approximately 700F.

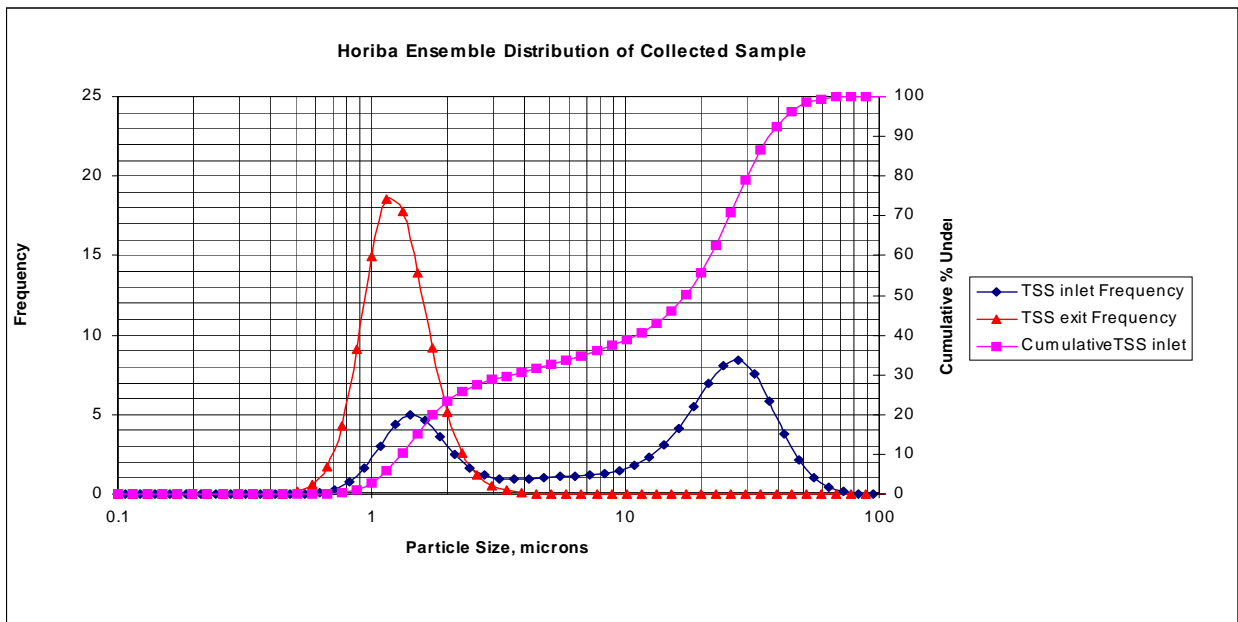


**FIGURE 1. PHOTOGRAPH OF PMC PPC AND MASS SAMPLING POT USING STANDARD SAMPLING PORTS AT THE ENTRANCE AND EXIT OF THE TSS.**

**EXPERIMENTAL RESULTS:** Figure 2 shows the July PPC results overlaid for representative upstream and downstream conditions of the TSS. The bold solid lines show representative average frequency distributions (and cumulatives with same colors) at the TSS inlet and outlet at nominally iso-kinetic sampling conditions. The July results are essentially identical to the February measurements. Figure 3 shows Horiba ensemble diffraction measurements (provided by the refiner) of a representative collected sample, giving the inlet and outlet distributions of the TSS. Note that the Horiba measurements are normalized measurements, and do not give the absolute particle concentration. Nevertheless, the two independent measurements show good agreement for the sizes of the distribution bi-modal peaks, at 1 and 28 microns respectively. The TSS essentially removes the larger end of the distribution, with little impact on the nominally one micron peak. This is consistent with the design cut-point of the TSS, which is approximately three microns. Note that the PPC shows more detail than the Horiba results (which show no particles above 3 microns) for the 10% of the mass that is above the TSS cut-point, providing more detailed information about the critical larger particles entering the expander.



**FIGURE 2. PPC FREQUENCY AND CUMULATIVE SIZE DISTRIBUTION RESULTS (NOT NORMALIZED) FOR COMPARISON WITH HORIBA INSTRUMENT RESULTS OF FIGURE 3. CONCENTRATION UNITS ARE VOLUME OF SOLIDS PER VOLUME OF GAS AT MEASURED TEMPERATURE AND PRESSURE.**



**FIGURE 3. MEASUREMENTS (BY HORIBA, ENSEMBLE DIFFRACTION) OF COLLECTED SAMPLES AT THE TSS INLET AND OUTLET.**

**MASS CONCENTRATIONS:** The next level of comparison is to determine the absolute total mass measured by the sample collection system compared with the equivalent integrated mass obtained by the PPC. This requires that we know the particle envelope density for direct mass comparison along with the gas density, determined by the temperature and pressure measurements at the probe. Incorporating this information, Table 1 summarizes the comparisons of the average total mass and ratios of the mass, upstream/downstream of the TSS. The ratios of the two techniques are within 5%, although the PPC total mass results average about 25% higher than the method 5 filter measurements. The variances of the filter measurements range from 5-15%, and the variances of the PPC results are on the order of 5%. We believe the envelope density characterization is within 5%, based on a liquid displacement measurement, which does not penetrate the pore structure of the catalyst substrate. These uncertainties do not close the entire measurement value gap (approximately 15-20% additional difference), so there are probably systematic errors in the size, particle shape, cross-section, and velocity measurements of the PPC. There could also be some systematic transport losses in the method 5 filter measurements. Nevertheless, these results show promising comparisons between an optical method and the traditional method 5.

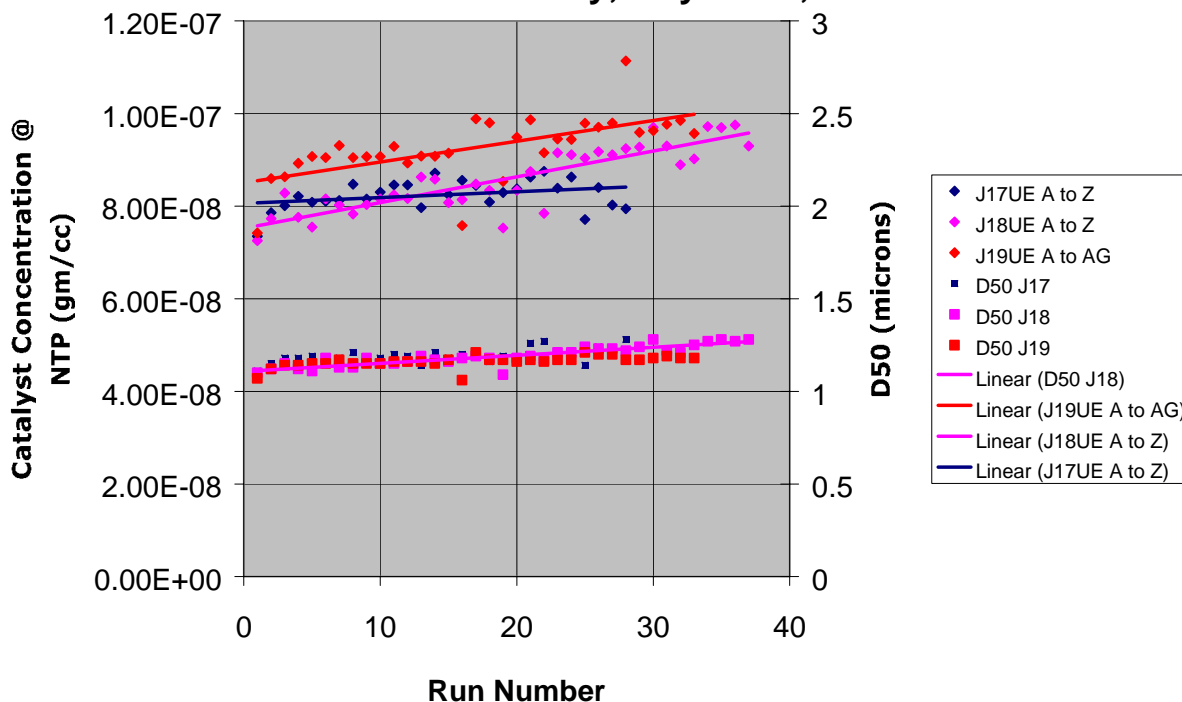
**TABLE 1. COMPARISON OF ABSOLUTE MASS CONCENTRATIONS**

Test Condition	PPC Temp (R)	PPC Pressure (psia)	Duct Velocity (m/s)	Iso-Kinetic Equivalent Velocity at PPC (m/s)	PPC Mass Loading (mg/Nm <sup>3</sup> )	Ratio of PPC inlet to outlet mass	Filter Mass Loading (mg/Nm <sup>3</sup> )	Ratio of Filter inlet to outlet mass
TSS Inlet	1165	42.5	39.6	8	300	3.29	232	3.13
TSS Outlet	1170	39.2	50	23	91		74	

Measurement Conditions and Total mass at PPC Flow Cell, July 17-19, 2002  
 Measured Particle Envelope Density = 2.00 gm/cm<sup>3</sup>

Figure 4 shows the important capability of the PPC to measure essentially continuously, providing time variation information downstream of the TSS. A complete size distribution and mass loading was obtained at approximately 6 minute intervals over a period of 4 hours. For the comparable period, two filter measurements were taken at the beginning and end of this 4 hour period, showing similar increases (25-30%) in total mass for the days of July 18, 19. For July 17, there was essentially no change in the mass loading measured by the PPC or the filter collector.

### Concentration and D50 Upstream of Expander, Martinez Refinery, July 17-19, 2002



**FIGURE 4. VARIATION OF CATALYST LOADING AND PARTICLE SIZE AS A FUNCTION OF RUN NUMBER OVER A PERIOD OF APPROXIMATELY 4 HOURS.**

#### MEASUREMENT SUMMARY

1. Size distribution measurements with the PPC are in good agreement with independent measurements of mass samples both upstream and downstream of the TSS.
2. Absolute total mass measurement comparisons are within 25% of each other for both TSS inlet and outlet measurements and ratios of inlet/outlet are within 5%. Outside of random variations, remaining differences in mass closure are most likely due to systematic errors of the PPC and Method 5.
3. More recently (Spring 2004), we have discovered small calibration errors for the larger particle sizes, which would tend to oversize particles with increasing error for larger particles. This error has now been corrected. We have also determined that using the dry bulk density is more representative of the “optical” density than liquid displacement density. Both of these corrections will bring the Method 5 and PPC results in closer agreement.

**FIXED ALIGNMENT PPC:** Since 2002, the PPC instrument has been completely updated with new, faster, and more accurate (temperature corrected) electronics, Windows real time software, and a fixed alignment optical system. The flow window design includes the option for an in situ measurement (for low pressure systems) or for a sampling system approach for high

pressure/temperature applications. The new design is process compatible for continuous operation without operator intervention (after initial installation and startup).

**ACKNOWLEDGEMENTS:** The PPC technology is based on over 25 years of research development, coupled with commercial sales of 45 research-type instruments for the coal-fired power generation industry. This work has been funded by 6 previous research contracts through DOE, EPA, and DOD.

**FUTURE APPLICATIONS DEVELOPMENT WORK:** Process Metrix currently has 3 phase II SBIR R&D projects worth over \$1.9M for continuing applications of the PPC. One project funded by DOE is for application to high pressure (20 bar), high temperature (1100F) gasifier measurements. Two other projects (funded by the Navy and Air Force) are directed at measuring real time soot particle emissions (>50 nm particles) from military gas turbines, and will use the PPC in combination with a new light scattering technique developed by PMC.

PMC has collaborated with a number of industrial organizations for development and application of the PPC, including Weyerhaeuser Corporation, International Paper Co., Dresser-Rand Corporation, Shell Global Solutions (US), and Southern Company.

**FURTHER INFORMATION:** For more details on the feasibility of PPC measurements in your process, please contact:

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The principals of PMC have successfully developed and sold two other particle sizing instrument technologies, including the Insitec, now manufactured by Malvern Instruments for continuous process control in industrial powder milling applications, including cements. More than 600 in-process Insitec instruments have been sold over the past 10 years, with a sales volume exceeding \$40M. PMC has also commercialized a new in-line particle counting instrument (for Inficon Corp.) for semi-conductor manufacturing. The PMC website provides further details on other process instrumentation developments of our laser contouring system for the steel industry based on lidar technology. PMC has over 45 man-years of experience in developing and applying real-time optical instrumentation for harsh industrial environments.