INVESTIGATION OF OPTICAL TECHNOLOGIES FOR MEASURING GEOTHERMAL FLUID PROPERTIES

J. K. Partin and J. R. Davidson
Idaho National Engineering and Environmental Laboratory

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Abstract

The results of an investigation evaluating the feasibility of using optical measurements for the real-time monitoring of fluid properties in geothermal process streams is described. The measurements exploit new technologies that have been developed for the telecommunications industry and include new solid state laser devices, large-bandwidth, high-sensitivity detectors and low loss optical fiber components. In particular, the potential application of improved light-emitting diode technologies for measuring the moisture content in steam and the development of a particulate characterization system based upon new, compact diode-pumped laser technologies for monitoring steam purity or mineral precipitation in fluids are presented.

Introduction

The efficiency and lifetime of steam-powered equipment are affected by the quality, or wetness, of the steam used. Steam quality is defined as the mass fraction of the total fluid mass that is in the vapor phase. Dry steam or steam of 100% quality consists solely of water vapor, while qualities less than 100% indicate that water is present in the liquid phase. In operating systems, condensate may form due to temperature drops in some part of the system. Excessive steam washing to remove particulate or reduce chloride concentrations to levels that are not damaging to equipment can also introduce moisture. Wet steam contains less useable energy than dry steam. In turbine systems, steam tends to become “wetter” as it expands. The subsequent impingement of water droplets that form, as well as entrained droplets, can initiate corrosion on turbine blades. In addition, entrained droplets often contain solids that can deposit on turbine surfaces adversely affecting the flow stream and turbine efficiency, as well as potentially causing imbalance and necessitating cleaning operations.

In brine-dominated resources, the deposition of silica and other minerals is a serious concern. The formation of silica scale in pipelines, heat exchangers, and reinjection wells places major constraints in fluid utilization in some geothermal operations, and can result in large maintenance costs for operators. Silica precipitation kinetics is generally not well understood and deposition on plant components can occur quickly without proper controls. Techniques for preventing the deposition of scale include restricting brine temperatures to above that at which silica super-saturation occurs and acidification of the brine phase to inhibit silica deposition. In other approaches, chemical inhibitors are used to sequester or complex with silica, preventing its precipitation (Thomas and Gudmundsson, 1989).

This objective of this work is to investigate the feasibility of using optical technologies for the real-time monitoring of fluid properties in geothermal plants. The application of new technologies that have been developed for the telecommunications industry, including new solid state laser devices, large-bandwidth, high-sensitivity detectors, and low loss diode technology in the design of a new generation infrared steam densitometer is reported. The feasibility of developing a particle characterization system using compact, high-performance diode-pumped laser devices is also presented. This system uses laser-induced breakdown signals to determine impurity particulate composition, size, and number density in either steam or other liquid process streams.

Steam Quality Measurements

The selective absorption of infrared radiation is a well-established technique for determining the water content of moist air. The measurement principle is based upon the fact that water vapor (steam) and liquid water exhibit strong rotational and vibrational absorption bands in the middle- and near-infrared range (Figure 1) of the electromagnetic spectrum. Typically, two wavelengths are used in the measurements: a wavelength that is strongly absorbed by water and a reference wavelength that is minimally influenced by water and steam which serves as a reference to correct for particulate or droplet scattering. The two wavelengths are chosen to be as close as possible in order to more effectively correct for scattering effects.

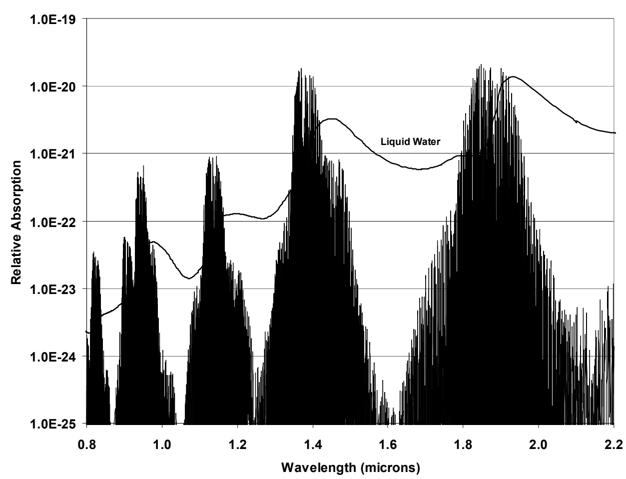

Figure 1. Near-Infrared Water Vapor and Liquid Water Absorption in Near-Infrared

While these techniques have been known for decades, they are not widely used due to the cost and complexity of the instrumentation required. In general, large-scale, Nerst glowers are needed to provide sufficient infrared radiation for the measurements, which are typically performed in regions of the electromagnetic spectrum that are not compatible with sensing over optical fibers or the use of room temperature detectors. This effort is investigating the re-engineering of these types of systems to incorporate new semiconductor emitter and detector technology that is compact, light-weight, and portable (battery operation is possible). All of these components operate at room temperature and could conceivably be packaged as devices that could be directly interfaced to steam lines and used to collect and transmit data from locations throughout the field. For the investigation five broadband light emitting diodes (LEDs), selected for their varying responses to the presence of steam and water, were procured and tested in the laboratory set-up depicted in Figure 2. (The LED wavelengths were centered at 1.0, 1.2, 1.55, 1.9 and 2.2 microns with bandpasses ranging from 0.05 to 0.15 microns.)

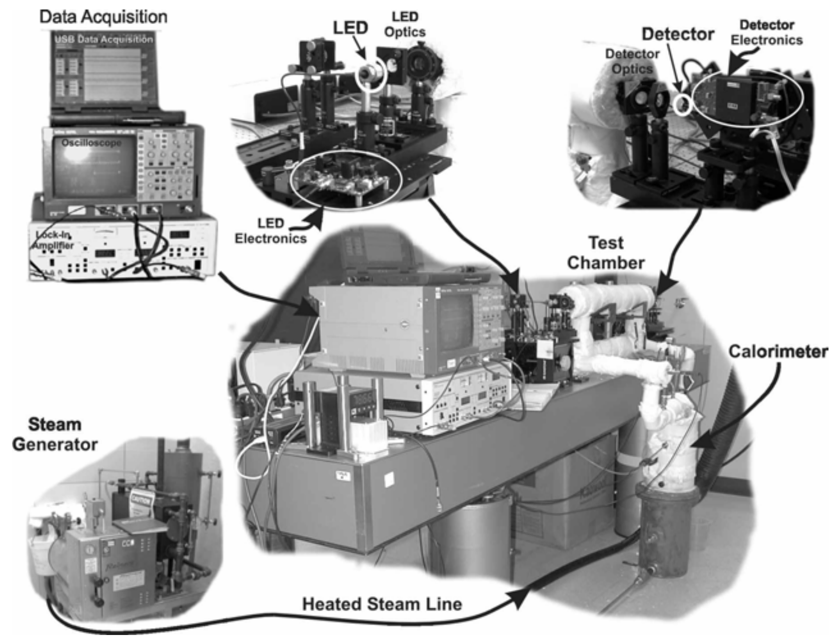

Figure 2. Steam Monitor Laboratory Set-Up

For the experiments, steam was generated using a commercial generator and propagated to a heated and insulated, one-meter sample chamber via a heated transfer hose. By controlling the heat added to the steam using the six-meter transfer hose, it was possible to control the degree of superheat available to the system. The windowed test chamber was placed in line with a throttling calorimeter in order to provide an independent measurement of quality. Measurements were performed to evaluate the intensity changes produced by the LEDs over the range of the calorimeter (~ 96-100% quality). A typical data run is presented in Figure 3. The plot

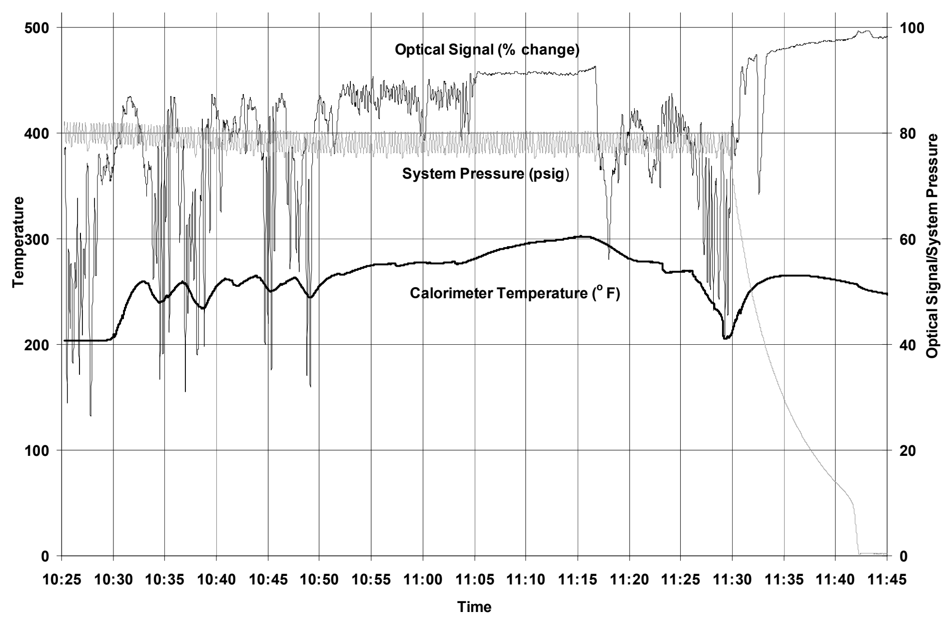

Figure 3. Change in 1.2 Micron LED Signal as a Function of Steam Moisture Content

records the optical signal change averaged over a 10 second interval, the system (line) pressure, and the calorimeter temperature. The ± 2.5 psig variation seen in the pressure is caused by the normal cycling of the steam generator.

These experiments indicated that the 1.2 micron LED was the most sensitive of the diodes tested to the presence of moisture while having a relatively low response to steam, making it the best candidate for use in an instrument for geothermal application. Referring to Figure 3, at approximately 10:30 the calorimeter temperature reads 212° F and the system pressure reads nominally 80 psig, indicating a steam quality of approximately 96%. As the line is heated up the calorimeter temperature increases, indicating a higher steam quality. Considerable modulation of the diode signal is seen to occur with small changes in steam moisture as recorded by the calorimeter temperature, indicating that a sensitive measurement of quality is possible. (Signal-to-noise analyses indicate that changes in quality on the order of 0.05% are possible over the 96-100% quality range.) The steam is dry when the calorimeter records a temperature of 280° F at approximately 11:05. At 11:17 the heated hose is deactivated, reducing the amount of heat added to the steam, and consequently decreasing the steam quality. The LED is seen to respond very rapidly to this change while the calorimeter is very slow to react. The steam generator is turned off at 11:30 and the optical signal is seen to return to approximately 100% of its original value. The 1.0 micron LED was found to be the best candidate for the reference in the instrument with no steam-induced attenuation and minimal response to moisture. A conceptual view of a field deployable system is presented in Figure 4.

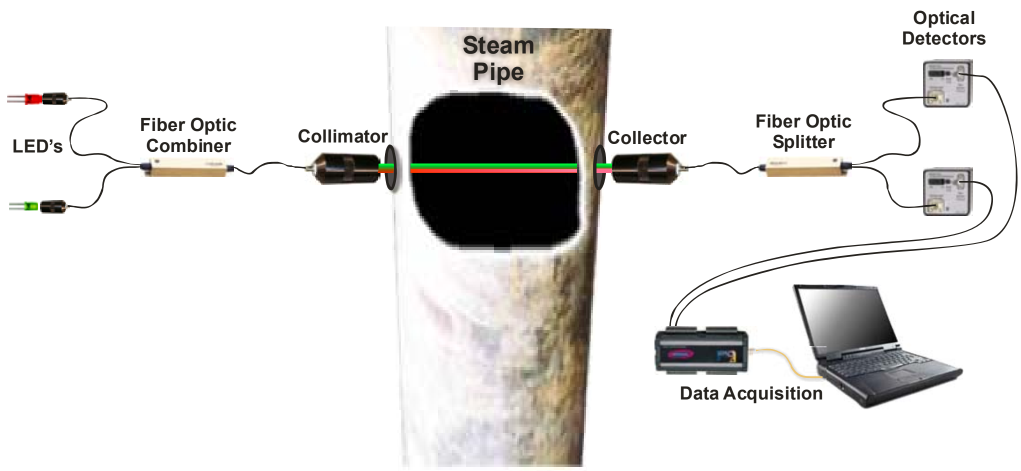

Figure 4. LED-Based Steam Densitometer Concept.

The concept presented offers several potential advantages over existing techniques. The instrumental configuration is simple, compact, and can be fiber-optically coupled to locations of interest. The data can be collected continuously and in real-time time with analyses available within seconds. Open path measurements are possible avoiding errors introduced into the measurements when sampling complicated flow regimes. The instrumentation can also operate over a wide range of moisture conditions.

Fluid Impurity Measurements

Techniques for evaluating the concentration of solids and dissolved solids found in geothermal fluids are of interest since the presence of these materials even at very low levels can cause significant damage to plant components. The principal impurities of concern are silica, iron, aluminum, and chlorides since these elements are associated with scaling and corrosion (Jung, 1995; Gallup, 1998). Currently, these measurements are performed by conductivity or trace chemistry means. Conductivity measurements are highly impacted by dissolved gases and therefore are not useful for detecting trace amounts of solids. Trace chemical techniques can be very accurate but are labor-intensive and require long time lags between sampling and analysis. Consequently, a real-time technique that is based upon the interaction of small particles with a high-energy laser pulse is under investigation (Fujimori et. al., 1992; Bundschuh et. al., 2000). When a particle is introduced into the focal volume of such a laser, as illustrated in Figure 5, the particle is vaporized and produces a luminous plasma and a pressure wave, or acoustic signal. The spectroscopic analysis of the plasma can be used to determine the elemental composition of the particle. The amplitude of the acoustic signal, as a function of the laser energy, can be used to determine the particle size. (Larger energies are required to generate breakdown of smaller particles since they are less absorptive.) The particle concentration, or number density, is then determined by measuring the number of signals as a function of laser energy.

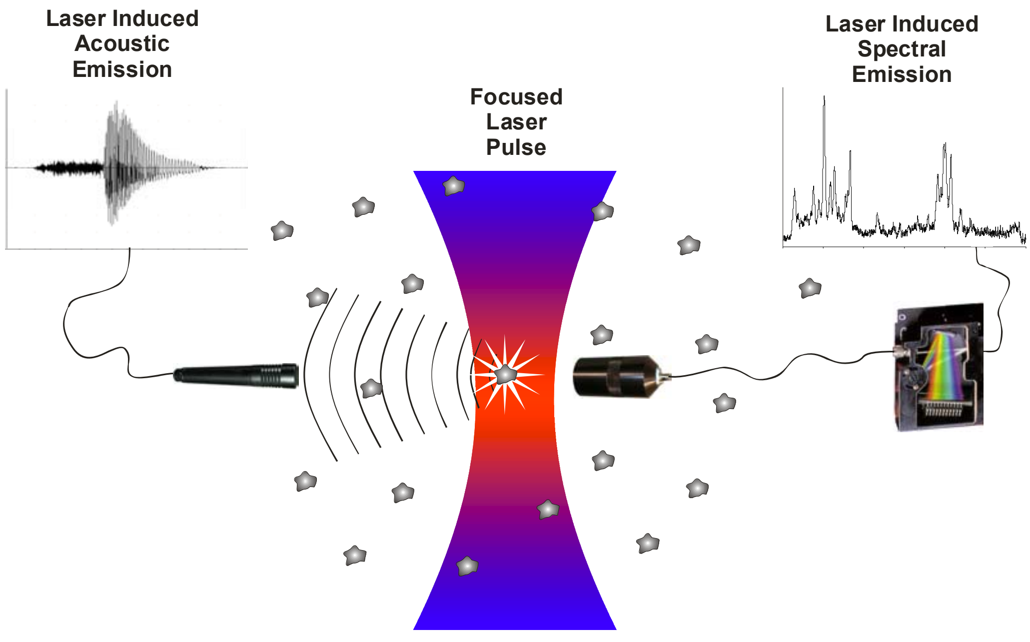

Figure 5. Application of Laser-Induced Breakdown Detection for Particulate Analysis

Spectral and acoustic signals have been successfully collected from both laboratory standards and field samples containing low-density (1 ppm by weight) suspensions of sub-micron silica, iron, and alumina particulate. An example of this data is shown in Figure 6, which presents the spectral data and acoustic data collected from a 10 ppm suspension by weight of iron oxide in nanopure water using 300 laser pulses (counts) with a repetition rate of 10 pulses per second.

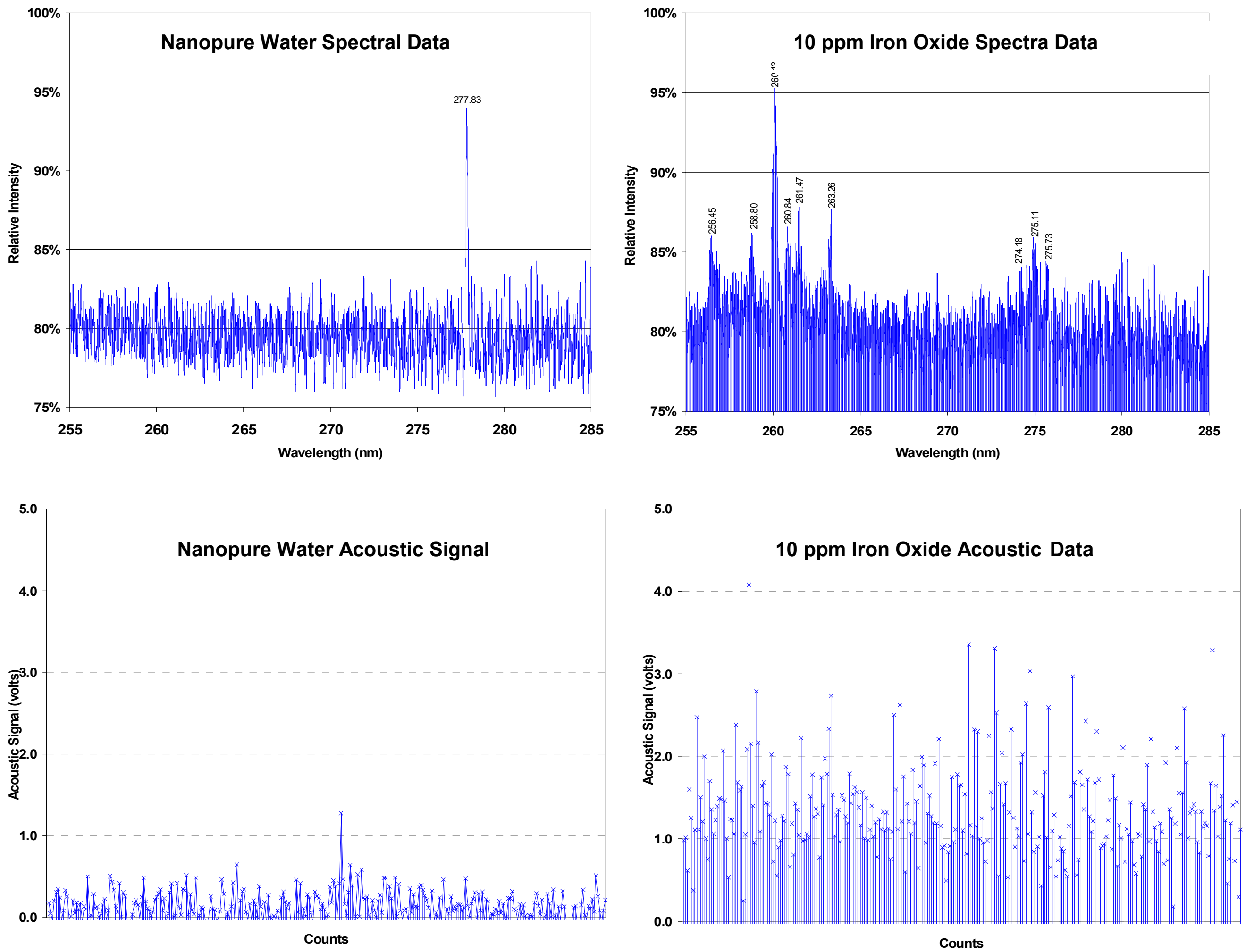

Figure 6. Laser-Induced Breakdown Detection of 10 ppm Iron Oxide In Nanopure Water

The plot illustrates some the basic premises of the detection technique. The top graphics show the emission spectra for nanopure water and iron oxide, respectively. Emission lines indicative of iron were clearly noted in the 10 ppm sample. The nanopure water also had a hit as identified in both the spectral and acoustic data plots. This is most likely due to room dust falling into the sampling curve used to collect data. In comparing the acoustic data, more signals with higher amplitudes are noted in the sample containing the iron oxide. The increased amplitude is evidence of the presence of an iron particle in the laser focus during one of the 300 counts. The number of times a high amplitude signal is detected is an indicator of the number density. (In this study the probability of detection increased from 3.7% of the laser shots to 37% of the laser shots as the concentration was increased from 1 ppm to 10 ppm.) The amplitude of the signal, correlated with laser energy is dependent, upon the size of the particle. The iron oxide used in this study had mean diameters in the 0.2 to 0.8 range. Figure 7 presents examples of spectral data collected from small diameter alumina and silica particulate with the technique.

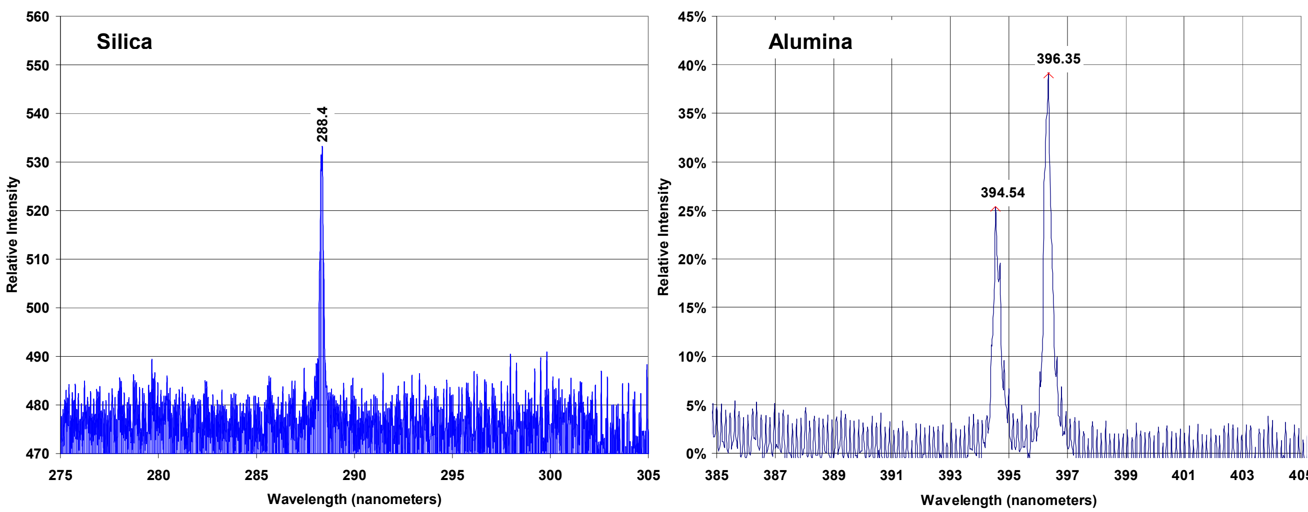

Figure 7. Laser-Induced Breakdown Spectra of Sub-Micron Diameter Silica and Alumina Particulate

The laboratory components used to collect the data are presented in Figure 8. A frequency-doubled Nd:YAG laser generates a 5-10 millijoule laser pulse that is focused into a cuvette containing the sample of interest. The focused energy causes breakdown of the particulate simultaneously generating a luminous plasma and a pressure wave. The latter is detected via small microphone pressed to one side of the sampling cell, while the plasma is imaged onto an optical fiber and transmitted to a spectrometer where it is spectrally-resolved and detected by a photodiode array detector.

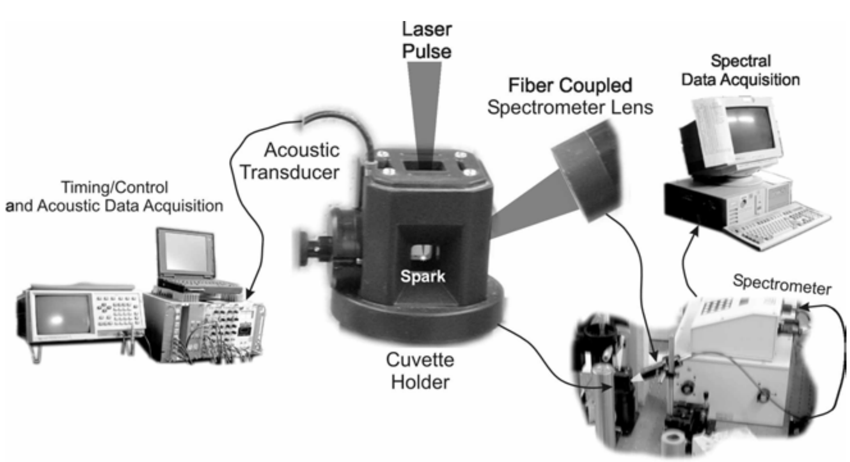

Figure 8. Laboratory Components Used In Particulate Characterization Experiments

While the instrumentation seems complex, new diode-pumped, chip lasers, silicon microphone technology, and compact spectrometers offer the possibility of packaging this type of measurement into a low-cost, fiber-coupled system for plant application. Current efforts are being directed at integrating the existing instrumentation with a remote sampling head capable of performing *in-situ* analyses so that the instrument can be deployed and evaluated in a plant environment. Potential applications include the detection of well dust, mineral precipitation, or metallic component wear.

Conclusions

Optical technologies have been investigated in the laboratory for the real-time monitoring of fluid properties in geothermal process streams. The steam quality and particulate impurity monitoring techniques have demonstrated the ability to detect gaseous and particulate species of interest within the ranges expected in geothermal applications. New laser and detector technologies, coupled with low loss optical fibers, offer the possibility of designing robust instruments capable of performing *in-situ* analyses in plant environments. Both systems are presently being redesigned and packaged for field deployment and evaluation.

Acknowledgements

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