

**SURFACE AREA, VOLUME, MASS, AND DENSITY DISTRIBUTIONS FOR SIZED  
BIOMASS PARTICLES**

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## Surface Area, Volume, Mass, and Density Distributions for Sized Biomass Particles

### **ABSTRACT**

This semi-annual technical progress report describes work performed at Morehouse College under DOE Grant No. DE-FC26-04NT42130 during the period July 01, 2004 to December 31, 2004 which covers the first six months of the project. Presently work is in progress to characterize surface area, volume, mass, and density distributions for sized biomass particles. During this reporting period, supply requests were processed and supplies including biomass test particles (hardwood sawdust AI14546) in the size range of 100-200 microns were obtained from a cofiring pilot plant research facility owned by Southern Company, Birmingham, AL. Morehouse has completed setting up of the gravimetric technique measurement system in the heat transfer laboratory, department of physics and dual degree engineering, Morehouse College. Simultaneously, REM, our subcontractor, has completed setting up of the electrodynamic balance (EDB) measurement system to characterize shape and mass for individual biomass particles. Testing of the gravimetric system, and calibration of the cameras and imaging systems using known sizes of polystyrene particles are in progress.

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## INTRODUCTION

The term biomass refers to material of terrestrial plant origin. Hardwoods, softwoods, wheat straw, corn kernel, cassava roots, sugar cane bagasse, and coconut shells are some of the largely available agricultural biomass materials. Wood is one of the most important biomass materials that could potentially be diverted to other uses. The amount of biomass produced has been estimated to be 170 billion tons per year, of which about 70% is from forests [1]. An estimate of the amount of biomass available in the U.S. for conversion to fuels or chemicals is 2 billion tons per year [2]. The conversion of 20% of this material provides an energy equivalent of  $6.5 \times 10^{15}$  BTU, roughly 10% of the U.S. annual energy needs [1].

The political (indigenous supply) and environmental (low sulfur, no net CO<sub>2</sub>, biodegradable) benefits of using biomass will continue to provide impetus to the development of co-firing coal with biomass feed stocks. Co-firing of biomass and coal has been identified as a promising way of reducing net CO<sub>2</sub> emissions with minimum modifications in the existing technologies. In fact, some developed countries, e.g., Denmark, have already mandated the use of coal biomass blends in all coal fired boilers. Coal and biomass are certain to remain a primary source of energy for at least several decades, and this is why a great need exists to develop modern combustion systems characterized by high carbon utilization (combustion efficiency) and low emission of pollutants (SO<sub>2</sub>, NO<sub>x</sub>, N<sub>2</sub>O, air toxics, etc.). One of the most important factors affecting the performance of utility boilers is fuel type. In some cases, blending biomass with coal may solve a pollution compliance problem or an operational problem or provide an economic benefit.

Coal and biomass particles are irregular in shape. Early attempts to characterize shape relied primarily on sieve analyses to classify particle "size." This approach was subsequently augmented by microscopic measurements and sizing methods based on sedimentation rates in fluids. These methods however, give no indication of the inclination of the axes of the body with respect to three coordinates, the type of geometrical shape, the volume or the surface area [3]. Heywood [4] dealt with this issue by defining shape-dependent coefficients in his analysis of volume and surface area. These coefficients are functions of the proportions of the particle, i.e., the relative values of breadth (B), thickness (T), and length (L). These are obtained by resting the particle in its most stable position. Breadth, B, is defined as the minimal distance between two parallel tangents to the profile or outline of the particle; length, L, is defined similarly but taken at right angles to the breadth; and thickness T, is the height normal to the resting plane.

Detailed information on shape, drag, volume, density, and surface area is needed to improve our understanding of transport phenomena of irregular particles. From a fluid mechanics standpoint, a data base on various shapes of particulates would enhance the current ability to design and analyze feeder systems, cyclones, fluidized beds, and particulate separation systems. From a heat and mass transfer perspective, particle mass and shape are important considerations. In general, to simplify the analysis, heat transfer calculations are performed assuming particles to be spheres. Several studies have been published in recent years where this approach has been used and temperature measurements have been compared with model predictions [5-7]. In each of these studies, however,

large empirical corrections were required in order to match model predictions with measurements. Maloney and coworkers [5] concluded that these corrections were necessary primarily because of the shape and density, and thermal property assumptions applied in the heat transfer analysis.

Energy absorption and emission mechanisms depend on a particle's surface area whereas its temperature response depends strongly on mass ( $\rho v$ ). For irregular particles such as coal, the equivalent diameters for external surface area and volume can differ significantly [8]. Moreover, the density for these particles is found to be non-uniform [8]. Hence, in-situ measurement of particle shape and density in addition to temperature measurement would allow one to better characterize and predict the thermal transport characteristics of coal particles during devolatilization and combustion. Hurt and Mitchell [9] reported large particle-to-particle temperature variations in their combustion studies of single char particles. They concluded that particle-to-particle variations in physical properties are a leading cause of these large temperature differences. Thus, individual particles have unique surface area, volume, and density and a unified approach comprising measurements of these properties is necessary if reliable predictions of transport phenomena are to be achieved.

In pursuit of this unified approach, various experimental techniques were developed recently in the single particle laboratory at the National Energy Technology Laboratory (NETL), Morgantown. These techniques involve the use of an electrodynamic balance (EDB) to characterize particle properties. The principal advantage of this instrument is the capability of suspending a charged particle motionless at the balance's geometric center, thus facilitating particle characterization.

Using a video-based imaging system, Maloney et al. [10] developed capabilities for measuring 3-D surface areas and volumes of irregular particles. Individual particles were rotated about the EDB center axis using a set of tangentially directed gas jets. As the particle rotates, a video-based imaging system records the particle images and stores perimeter data from successive video fields. Rotation rates were measured with the aid of a second video system positioned above the balance. Surface areas and volumes were calculated by summing the surface and volume elements swept out during rotation from one video field to the next.

Maloney et al. [11] also developed capabilities for measuring drag coefficient/mass ratios ( $C_d/m$ ) for particles in the EDB. Using a high-speed diode array imaging system, they measured particle trajectories resulting from an applied stimulus. Particle  $C_d/m$  ratios were found from these trajectory measurements by means of a force balance model which matched theoretical predictions with measurements. Surface area and volume data were then used to estimate the particle drag coefficient by applying an analysis for deformed spheres derived by Brenner [12]. The particle mass was then calculated based on the measured  $C_d/m$  and the calculated drag coefficient [8].

SamPATH [13] developed a second method of characterizing the volume, external surface area, and drag equivalent diameter of an irregular particle based on conventions established by Heywood [4]. This method incorporated the same EDB measurement system and associated instruments that

were developed by Maloney et al. [10] to characterize irregular particles. In this method, irregular particles were characterized by obtaining directly the magnitudes of length, breadth, thickness, and projected areas from two view images in the planes parallel and perpendicular to the orientation of the particle during the measurement. The Cd/m ratio was also found for individual particles. This ratio was then used to obtain particle mass and density. A mean particle mass for the sample studied was obtained using a direct gravimetric method [8,13]. This method involved weighing and counting several thousand coal particles. Finally, the mean mass obtained using the EDB measurement system was validated by comparison with the results of the direct gravimetric method.

In view of the anticipated rapid development of technologies for co-feeding of coal and biomass, a great need exists for the development of a data base on the shape and density distributions of biomass particles for use in combustion models. Detailed property data including surface area, volume, mass, and density distributions for several coal samples are now available [8,13] for use in coal combustion models.

To this end, applying our experimental and analytical capabilities in the particle characterization research [5,8,10-11,13], this project seeks to characterize the shape and mass for biomass particles. Individual biomass particles will be characterized for their external surface area, volume, and drag coefficient/mass ratios. Analysis methods will be employed using shape and drag information to calculate mass and density distributions for these particles. Results of these measurements and analyses will be validated by independent mass measurements using a particle weighing and counting technique.

The specific objectives are:

- 1) Apply unique measurement systems to characterize external surface area, volume, mass, and density for a statistically significant number of individual biomass particles (20 particles) in the size range of 100 - 200  $\mu\text{m}$ .
- 2) Obtain mean mass per particle of the biomass sample tested in Objective (1) by independent mass measurements of several thousand particles using a particle weighing and counting technique.

Experiments and data analysis will be carried out to meet the project objectives. Mean mass of several thousand biomass particles obtained in Objective (2) will be used to validate the mean mass per particle obtained in Objective (1). Co-firing of biomass and coal has been identified as a promising way of reducing net CO<sub>2</sub> emissions with minimum modifications in the existing technologies. The successful accomplishment of the above objectives will provide detailed particle property data required for developing improved combustion kinetic models for technologies involving co-firing of coal and biomass feedstocks.

## EXECUTIVE SUMMARY

In this semi-annual report, the work performed under DOE Grant No. DE-FC26-04NT42130 during the period July 01, 2004 to December 31, 2004 which covers the first six months of the project is described and the major accomplishments are highlighted summarizing the most important research results.

Over the next decade there will be a renewed emphasis on co-firing biomass with coal. Co-firing of biomass and coal has been identified as a promising way of reducing net CO<sub>2</sub> emissions with minimum modifications in the existing technologies. Coal and biomass particles are irregular in shape. From a combustion perspective, particle sphere assumptions employed in most coal combustion models were found to yield significant errors (20 to 25 percent) in calculated particle volume and associated thermal mass. Even if surface area and volume differences were adequately handled in a heat transfer analysis, large uncertainties still resulted in coal particle temperature response due to particle to particle density variations. Recently, shape and density for coal particles have been characterized and detailed property data including surface area, volume, mass, and density distributions for several coal samples are now available for use in coal combustion models.

This project seeks to characterize the shape and mass for biomass particles. Individual biomass particles will be levitated in an electrodynamic balance (EDB) and their external surface area, volume, and drag coefficient/mass ( $C_d/m$ ) ratios will be characterized applying highly specialized video based and high-speed diode array imaging systems. Analysis methods will be employed using shape and drag information to calculate mass and density distributions for these particles. Results of these measurements and analyses will be validated by independent mass measurements using a particle weighing and counting technique. Experiments involving counting and weighing of several thousand biomass particles employing a microscope and a sub-milligram balance experimental system will be performed by Morehouse College in Atlanta. Experiments involving imaging systems will be performed by REM Engineering Services, our subcontractor in this project, using the EDB measurement system available at the single particle laboratory, National Energy Technology Laboratory (NETL), Morgantown. Morehouse will analyze the raw data collected in this project including that by REM. The successful accomplishment of the above goals will provide detailed particle property data required for developing improved combustion kinetic models for technologies involving co-firing of coal and biomass feedstocks.

During this reporting period, supply requests were processed and supplies including biomass test particles (hardwood sawdust AI14546) in the size range of 100-200 microns were obtained from a co-firing pilot plant research facility owned by Southern Company, Birmingham, AL. Morehouse has completed setting up of the gravimetric technique measurement system in the heat transfer laboratory, department of physics and dual degree engineering, Morehouse College. Simultaneously, REM, our subcontractor, has completed setting up of the electrodynamic balance (EDB) measurement system to characterize shape and mass for individual biomass particles. Testing of the gravimetric system, and calibration of the cameras and imaging systems using known sizes of polystyrene particles are in progress.



## **EXPERIMENTAL**

Presently work is in progress to characterize surface area, volume, mass, and density distributions for sized biomass particles. During this reporting period, Morehouse has completed setting up of the gravimetric technique in the heat transfer laboratory, Department of Physics and Dual Degree Engineering. This involved setting up a microscope, a grid surface to disperse several hundred biomass particles for counting under the microscope, and a sub-milligram balance for weighing the particles. Simultaneously, REM, our subcontractor, has completed setting up of the electrodynamic balance (EDB) measurement to characterize shape and mass for individual biomass particles. This involved installation of top, side video cameras, and imaging systems, and alignment of optics and He:Ne lasers for characterizing very small particles individually.

## **RESULTS AND DISCUSSION**

During this reporting period, supply requests were processed and supplies including biomass test particles (hardwood sawdust A114546) in the size range of 100-200 microns were obtained from a co-firing pilot plant research facility owned by Southern Company, Birmingham, AL. Setting up of the of the gravimetric technique in the heat transfer laboratory, Department of Physics and Dual Degree Engineering, Morehouse College has been completed by Morehouse as planned. Also completed was the setting up of the electrodynamic balance (EDB) measurement to characterize shape and mass for individual biomass particles by our subcontractor, REM Engineering Services.

### **Plans for the next Reporting Period**

Testing of the gravimetric system, and calibration of the cameras and imaging systems using known sizes of polystyrene particles are in progress.

### **Students Supported under this Research**

Michael D. Young, an undergraduate student in dual degree engineering, is being supported in the form of research assistantship during this reporting period.

## **CONCLUSION**

The project is progressing well. To date, setting up of the of the gravimetric measurement system in the heat transfer laboratory, Department of Physics and Dual Degree Engineering, Morehouse College has been completed by Morehouse as scheduled. Also completed was the setting up of the EDB measurement system to characterize shape and mass for individual biomass particles by our subcontractor, REM. Testing of the gravimetric system, and calibration of the cameras and imaging systems using known sizes of polystyrene particles are in progress.

## **ACKNOWLEDGMENTS**

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## REFERENCES

1. Goldstein, I. S., ACS Symposium Series No. 476, American Chemical Society, Washington, DC, pp. 332-338 (1992).
2. Goldstein, I. S., in Organic Chemicals from Biomass (Boca Raton, Ed.), CRC Press (1981).
3. Rosin, P. O., The influence of particle size in processes of fuel technology, Trans. Inst. Chem. Engrs., 15: 167 (1937).
4. Heywood, H., The scope of particle size analysis and standardization, Trans. Inst. Chem. Eng. 25:14 (1947).
5. Maloney, D. J., E. R. Monazam, S. W. Woodruff, and L. O. Lawson., Measurement and analysis of temperature histories and size changes for single carbon and coal particles during the early stages of heating and devolatilization, 1991. Combustion and Flame 84: 210-220.
6. Solomon, P. R., M. A. Serio, R. M. Carangelo, and J. R. Markham., Very rapid coal pyrolysis, 1986. Fuel 65, 182.
7. Tichenor, D. A., Mitchell, R. E., Hencken, K. R., and Niksa, S., Simultaneous in situ measurement of the size, temperature and velocity of particles in a combustion environment, Twentieth Symposium (International) on Combustion, p. 1213, The Combustion Institute, 1985.
8. Monazam, E. R. and D. J. Maloney, Characterization of mass and density distributions of sized coal fractions, Combustion and Flame, 99, 733-741, 1994.
9. Hurt, R. H. and Mitchell, R. E., On the combustion kinetics of heterogeneous char particle populations, Twenty-Fourth Symposium (International) on Combustion, p. 1233, The Combustion Institute, 1992.
10. Maloney, D. J., Lawson, L. O., Fasching, G. E., and Monazam, E. R., A novel approach for determining external surface area and volume of irregularly shaped particles, Aerosol Sci. Technol. (1994).
11. Maloney, D. J., Lawson, L. O., Fasching, G. E., and Monazam, E. R., Measurement and dynamic simulation of particle trajectories in an electrodynamic balance: characterization of particle drag coefficient/mass ratios, Rev. Sci. Instrum., 66, 6, 3615-3622, 1995.
12. Brenner, H., The Stokes resistance of a slightly deformed sphere, Chem. Eng. Sci. 19:519 (1964).
13. Sampath, R. (1994), Measurement and Prediction of Temperature Histories for Single Coal Particles Prior to and During Devolatilization, Ph.D. thesis, Department of Chemical Engineering, West Virginia University.