processing the ISE outputs. The circuitry would include analog-to-digital converters measuring the ISE potentials. The circuitry would also include digital multiplexers for transmitting the potentials to a computer, which would analyze the potentials to determine the concentrations of ions of the selected species.

This work was done by Martin Buehler and Kimberly Kuhlman of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-20700, volume and number of this NASA Tech Briefs *issue, and the page number.*

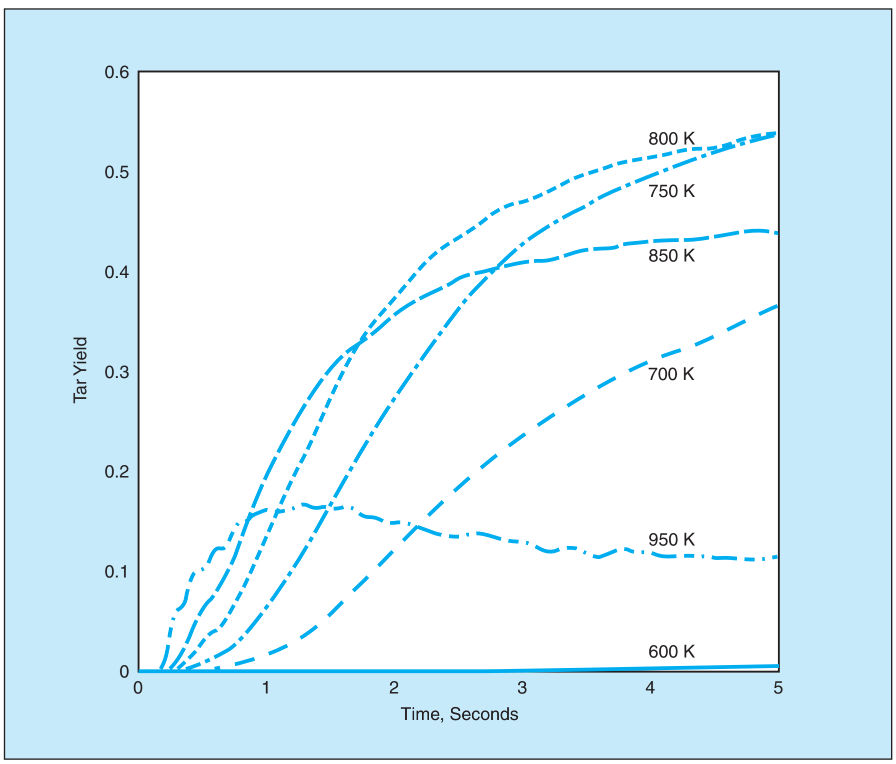
Model of Fluidized Bed Containing Reacting Solids and Gases

This model can be used to optimize designs and operating conditions.

NASA's Jet Propulsion Laboratory, Pasadena, California

A mathematical model has been developed for describing the thermofluid dynamics of a dense, chemically reacting mixture of solid particles and gases. As used here, "dense" signifies having a large volume fraction of particles, as for example in a bubbling fluidized bed. The model is intended especially for application to fluidized beds that contain mixtures of carrier gases, biomass undergoing pyrolysis, and sand. So far, the design of fluidized beds and other gas/solid industrial processing equipment has been based on empirical correlations derived from laboratory- and pilot-scale units. The present mathematical model is a product of continuing efforts to develop a computational capability for optimizing the designs of fluidized beds and related equipment on the basis of first principles. Such a capability could eliminate the need for expensive, time-consuming predesign testing.

The present model includes components in common with models described in several previous *NASA Tech Briefs* articles, including, most notably, "Model of Pyrolysis of Biomass in a Fluidized-Bed Reactor" (NPO-20708), *NASA Tech Briefs*, Vol. 25, No. 6 (June 2001), page 59; "Multiphase-Flow Model of Fluidized-Bed Pyrolysis of Biomass" (NPO-20789), *NASA Tech Briefs*, Vol. 26, No. 2 (February 2002), page 56; and "Model of a Fluidized Bed Containing a Mixture of Particles" (NPO-20937), *NASA Tech Briefs*, Vol. 26, No. 4 (April 2002), page 56. The model distinguishes among multiple particle classes on the basis of physical properties (e.g., diameter or density) and/or through thermochemical properties (e.g., chemical reactivity or nonreactivity). The formulation of the model follows a multifluid approach in which macroscopic equations for the solid phase are derived from a kinetic-like theory considering inelastic-rigid-sphere submodels in accounting for collisional transfer in high-density regions. The gas phase equations are derived using ensemble averaging.



The **Tar Yield of a Fluidized Bed** as a function of time was computed, for various temperatures of fluidizing gas, by use of the model described in the text.

Separate transport equations are constructed for each of the particle classes, providing for the separate description of the acceleration of the particles in each class, of interactions between particles in different size classes, and of the equilibration processes in which momentum and energy are exchanged among the particle classes and the carrier gas. The kinetic-like theory is based on a Gaussian approximation of the velocity distribution, assuming that spatial gradients of mean variables are small and particles are nearly elastic. Each class of particles is characterized by its own granular temperature, which represents the mean kinetic energy associated with fluctuations in the velocities of the particles. The stress tensor is augmented by a frictional-transfer submodel of stress versus strain: The separate equations of the dynamics of the various particle classes are coupled through source terms that describe such nonequilibrium processes as transfer of mass, momentum, and energy, both between particles and between gas and particles.

In one of several test cases, the model was applied to the pyrolysis of biomass particles in a laboratory fluidized bed reactor and used to compute yields of reaction products (especially tar). The results indicate that at fixed initial particle size, the temperature of the fluidizing gas is the foremost parameter that influences the tar yield and can be chosen to maximize the tar yield (see figure). The temperature of the biomass feed, the nature of the feedstock, and the fluidization velocity were all found to exert only minor effects on the tar yield.

This work was done by Josette Bellan and Danny Lathouwers of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

NPO-30163

Membrane Mirrors With Bimorph Shape Actuators

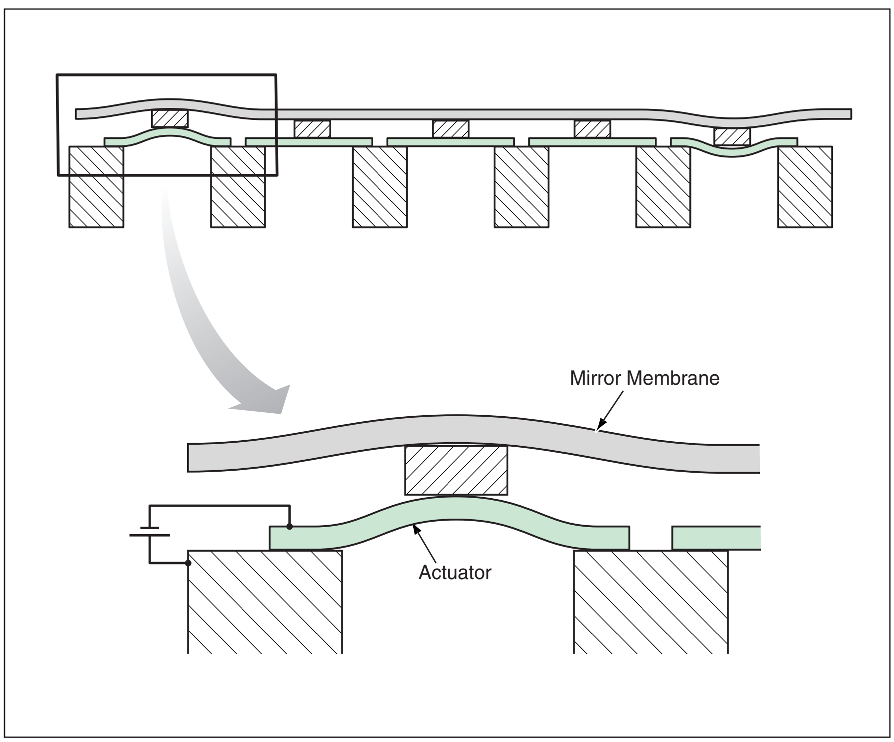
Only modest control voltages would be needed.

NASA's Jet Propulsion Laboratory, Pasadena, California

Deformable mirrors of a proposed type would be equipped with relatively-large-stroke microscopic piezoelectric actuators that would be used to maintain their reflective surfaces in precise shapes. These mirrors would be members of the class of MEMS-DM (for microelectromechanical system deformable mirror) devices, which offer potential for a precise optical control in adaptive-optics applications in such diverse fields as astronomy and vision science.

In some respects, the proposed mirrors would be similar to the ones described in "Silicon Membrane Mirrors With Electrostatic Shape Actuators" (NPO-21120) *NASA Tech Briefs*, Vol. 27, No. 1 (January 2003), page 62. Like a mirror of the type reported previously, a mirror as proposed here would include a continuous-membrane reflector attached by posts to actuators that, in turn, would be attached by posts to a rigid base (see figure). Also as before, the proposed mirror would be fabricated, in part, by use of a membrane-transfer technique. However, the actuator design would be different. Instead of the electrostatic actuators reported previously, the proposed mirror would contain bimorph-type piezoelectric actuators.

The reasons for the proposed choice of actuators are simple: In the mirror described in the cited prior article as well as in other previously reported membrane mirrors that feature piezoelectric and electrostrictive actuators, it is not possible, by use of modest actuation voltages, to obtain actuator strokes of the order of ±6 μm as needed in the intended adaptive-optics applications. The mechanical amplification inherent in the bimorph configuration would multiply the small displacements typically generated by piezoelectric devices, thereby making it possible to obtain the desired stroke magnitudes at voltages lower than would be needed to obtain the same stroke magnitudes from non-bimorph piezoelectric and electrostatic actuators.



This **Deformable Mirror** would contain bimorph actuators, which would produce relatively large strokes (≈6 μm) at modest applied potentials (≈9 V).

A voltage applied to the piezoelectric layer in a given actuator would induce a stress that would cause the actuator layer to bend and thus to pull or push on the mirror membrane. It has been estimated that an applied potential of ±9 V should be sufficient to produce an actuator stroke, and thus a local reflector displacement, of ±6 μm. Inasmuch as the actuators would be essentially capacitors from an electrical perspective, the actuators would consume power only during changes in their position settings. During maintenance of a position setting, only the supporting electronic circuitry would consume power.

This work was done by Eui-Hyeok Yang of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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