

## Integrated Arrays of Ion-Sensitive Electrodes

Electronic “tongues” would “taste” selected ions in water.

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The figure depicts an example of proposed compact water-quality sensors that would contain integrated arrays of ion-sensitive electrodes (ISEs). These sensors would serve as electronic “tongues”: they would be placed in contact with water and used to “taste” selected dissolved ions (that is, they would be used to mea-

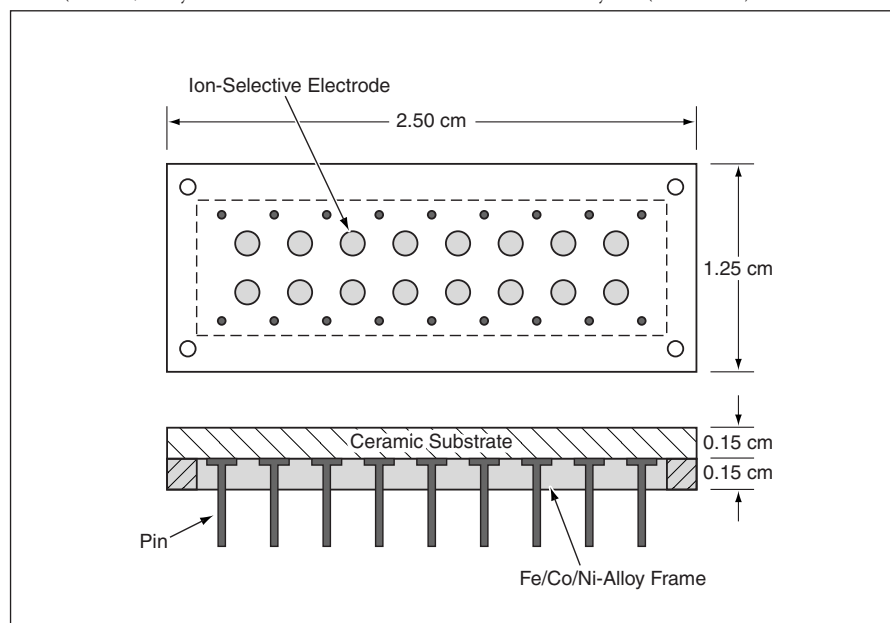
sure the concentrations of the ions). The selected ions could be any or all of a variety of organic and inorganic cations and anions that could be regarded as contaminants or analytes, depending on the specific application. In addition, some of the ISEs could be made sensitive to some neutral analytes (see table).

Discrete ISEs are commercially available, but are large, relative to the ISEs in the proposed sensors. In comparison with an array of commercial ISEs, an array of the proposed type would be about ten times as dense; in other words, one could detect a greater variety of ions by use of a sensor of a given size, or, alternatively, the sensor needed to detect a given set of ionic species could be made smaller. In addition, the proposed sensors have been conceptually designed to be amenable to mass production at relatively low cost.

In the example of the figure, the array of ISEs would be formed on a co-fired ceramic substrate strengthened by a Kovar (or equivalent) iron/nickel/cobalt-alloy frame. Each electrode would comprise a gel layer covered by a polymer layer and further covered by a protective layer. Fabrication of the array would include the following sequence of operations:

1. The gel layers of the electrodes would be deposited on the substrate by screen printing.
2. By use of an electrolytic doping apparatus, each electrode would be doped electrostatically with a selected ionophore. The basic principle of the doping process would be similar to that of electrophoresis, wherein molecular fragments migrate along a conductive gel channel under the influence of an electric field. The design and mode of operation of the apparatus would be such that the process of doping each electrode would not deplete previously doped electrodes.
3. The polymer layers of the electrodes would be deposited by screen printing in the same manner as that of the gel layers.
4. The polymer layers would be doped in the same manner as that of the gel layers.
5. The protective layers would be screen-printed over the electrodes.

The sensor would be inserted in a socket on a printed-circuit board that would contain electronic circuitry for



A Unitary Array of 16 ISEs would occupy an area of only about 3.1 cm<sup>2</sup>. An array of 16 discrete ISEs would be much larger.

<b>Inorganic Cations</b>	H <sup>+</sup> , Li <sup>+</sup> , Na <sup>+</sup> , K <sup>+</sup> , Rb <sup>+</sup> , Cs <sup>+</sup> , Be <sup>2+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup> , Sr <sup>2+</sup> , Ba <sup>2+</sup> , Mo <sup>4+</sup> , Fe <sup>3+</sup> , Cu <sup>2+</sup> , Ag <sup>+</sup> , Zn <sup>2+</sup> , Cd <sup>2+</sup> , Hg <sup>2+</sup> , Tl <sup>+</sup> , Bi <sup>3+</sup> , Pb <sup>2+</sup> , U <sup>4+</sup> , Sm <sup>3+</sup> , NH <sup>4+</sup>
<b>Inorganic Anions</b>	CO <sub>3</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup> , SCN <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , OH <sup>-</sup> , phosphate, sulfite, SO <sub>4</sub> <sup>2-</sup> , Cl <sup>-</sup> , SeO <sub>3</sub> <sup>2-</sup> , I <sup>-</sup>
<b>Organic Cations</b>	1-phenylethylamine, 1-(1-naphthyl)-ethylamine, ephedrine, norephedrine, pseudoephedrine, amphetamine, propanolol, amino acid methyl esters, α-amino-ε-caprolactam, amino acid amides, benzyl amine, alkyl amines, dopamine, mexiletine, local anesthetics (procaine, prilocaine, lidocaine, bupivacaine, lignocaine), diquat and paraquat (herbicides), tetramethyl- and tetraethylammonium, guanidine, metformin, phenformin, creatinine, protamine
<b>Organic Anions</b>	salicylate, phthalate, maleate, 2-hydroxybenzhydroxamate, nucleotides, heparin
<b>Neutral Analytes</b>	CO <sub>2</sub> , O <sub>2</sub> , NH <sub>3</sub>

These **Ions and Neutral Analytes** are ones for which ionophores have been reported and for which ISEs are expected to exhibit (1) linear responses at concentrations up to 1 M and (2) sensitivity to concentrations as low as 10<sup>-6</sup> M.

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).*

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## Model of Fluidized Bed Containing Reacting Solids and Gases

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

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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

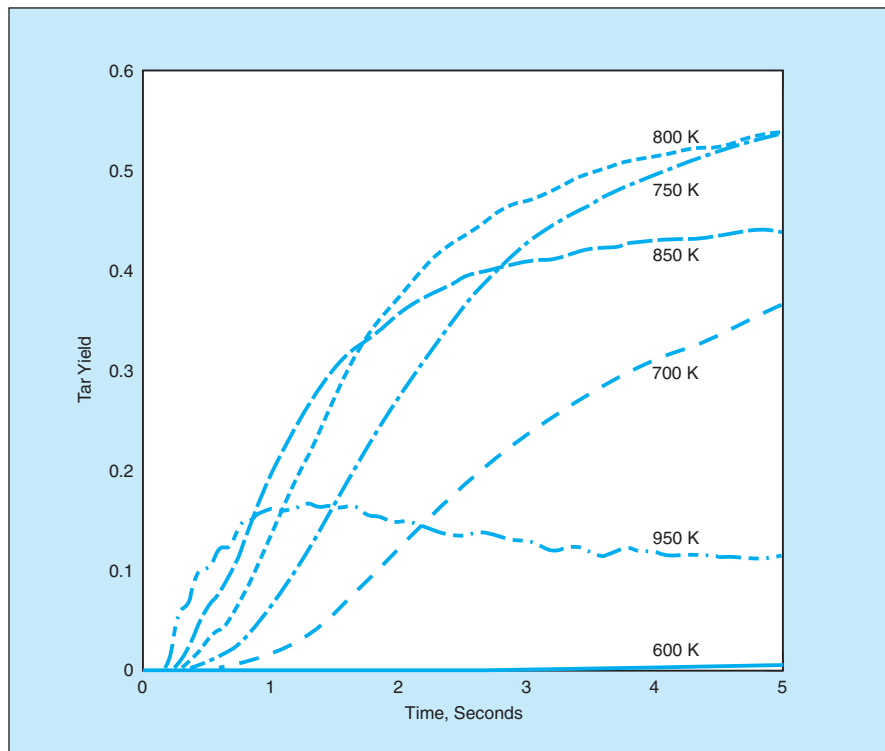
a computational capability for optimizing the designs of fluidized beds and related equipment on the basis of first principles. Such a capability could eliminate the need for expensive, time-consuming predesign testing.

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 Flu-

idized 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.

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



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.