Applications for Micro Chemical and Thermal Systems

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Prepared for presentation at IMRET 5, May 27-30, 2001

Abstract

Pacific Northwest National Laboratory (PNNL) is developing a variety of applications using Micro Chemical and Thermal Systems (MICRO-CATS). The products represent a decade of research and development by PNNL in miniature systems. Miniature devices include fuel vaporizers, fuel processors, fuel cells, heat pumps, heaters, power generators, heat exchangers, and chemical processing units. The sponsors for their development include the Office of Transportation (OTT) in the U.S. Department of Energy (DOE), National Aeronautics and Space Administration (NASA), Department of Defense (Army), the Defense Advanced Research Projects Administration (DARPA) and others. OTT wants to have fuel cells in automobiles. DARPA needs miniature heating, cooling and power generation units for soldiers in the field. NASA wants miniature chemical plants to produce oxygen, fuel, and other things from the resources available in outer space. For these microtechnology users, the status of current development and the promise for future applications of miniature systems are shown.

Pacific Northwest National Laboratory

Pacific Northwest National Laboratory (PNNL) is a pioneer in developing Micro-Chemical and Thermal Systems (MICRO-CATS™). The range of research, development, and products are illustrated on our MICRO-CATS web site (http://www.pnl.gov/microcats) and shown in Figure 1.

Figure 1. MICRO-CATS Web Page

Microtech-Based Applications

The potential exists for every chemical engineering unit operation to be miniaturized. When thermal and chemical systems are miniaturized, their overall efficiency and productivity improve. PNNL uses miniaturization to develop products with the following inherent microtech advantages:

- Lightweight and compact
- Rapid heat and mass transport
- Extremely precise control of process conditions
- High performance (i.e., high throughput per unit hardware volume)
- Cost economies through mass production
- Available for distributed or mobile applications
- Short lead times for development and deployment.

Just as rapid advances in microelectronics have revolutionized computers, appliances, communication systems, and many other devices, PNNL's efforts in creating MICRO-CATS seek to revolutionize heat exchangers, heat pumps, combustors, gas absorbers, solvent extractors, fuel processors, and many other devices. These lightweight, compact, high-performance systems can work in many applications in transportation, buildings, military, environmental restoration, space exploration, carbon management, and industrial chemical processing.

PNNL's patented "sheet architecture" [U.S. Patent No. 5,611,214 (issued March 18, 1997) and U.S. Patent No. 5,811,062 (issued September 22, 1998)] provides a format for mass production of chemical and thermal systems. In addition to the "sheet architecture," PNNL has pioneered microfabrication methods for microdevices. We make microdevices with a variety of fabrication methods using copper, aluminum, stainless steel, high-temperature alloys, plastics, and ceramic materials. With all of our clients we stress that "Microtechnology doesn't work for us until it works for you."

Microthermal Systems Applications

Microthermal systems focus on devices such as heat exchangers and heat pumps. Using its "sheet architecture" and microfabrication capabilities, PNNL crafts novel microthermal systems. Two examples of this strategy won R&D 100 Awards: the Compact Microchannel Fuel Vaporizer and the Microheater. Both of these products target applications that give the microtech-based devices considerable market advantages.

The compact microchannel fuel vaporizer (CMFV) (Figure 2) is a breakthrough in miniaturizing process technology and a key component of a microchannel fuel processor that will enable fuel cell-powered vehicles. Fuel cells are a high-efficiency, low-emission alternative to the internal combustion engine and run on hydrogen. Currently, no infrastructure exists to deliver either gaseous or liquid hydrogen to fuel cell-powered automobiles, but a gasoline-distribution infrastructure does exist. The CMFV can vaporize the requisite amount of gasoline needed to power a 50-kWe fuel cell and is small enough (0.3-L) for portable or automotive applications.

The Microheater (Figure 3) is a microscale combustion system (the palm-size combustion unit weighs less than 0.2 kg [5 oz]). It can provide heat for portable personal heating/cooling devices, indoor heating devices such as baseboard heaters, in-line water heaters, and fuel cell systems. It is 10 times smaller and lighter than conventional combustors. The Microheater can produce 30 W of thermal energy per square

Figure 2. CMFV

Figure 3. Microheater

centimeter of external combustor area. One module can power a personal, portable heater for eight hours on little fuel or provide instantaneous in-line water heating; an array of modules will heat a house efficiently and reduce ducting and zoning thermal energy losses by 45%. This technology is the first application of enhanced microscale heat and energy mass-transfer to a combustion process.

Micro Chemical Systems Applications

Micro chemical systems focus on such devices as reactors and chemical separations. Miniaturization of chemical processes increases the process intensity. Examples of PNNL's use of microreaction technology include fuel processor development for the U.S. Department of Energy (DOE), man-portable power development for the Army, milliwatt power development for DARPA, and propellant processing for NASA.

Microtechnology is being used to develop a compact hydrogen generator for fuel cells that can generate 50 kW-electric for automotive use. This effort, funded by DOE's Office of Transportation Technology, is now demonstrating high performance in compact units. Over the past year, the project has concentrated most of its effort on demonstrating an overall microchannel steam reforming system, including four microchannel steam reformers and more than 24 microchannel heat exchangers, which, as a system, are intended to provide both high energy-efficiencies and high power densities. Work is also under way on other microchannel components that may ultimately find value within an automotive fuel processing system or within distributed power systems.

PNNL is developing a man-portable power system that will continuously provide 10 to 100 watts of base-load electric power for weeks or months using a microtechnology-based fuel processor. This lightweight, compact system is suitable for long-duration missions. In the fuel processor, hydrogen for the fuel cell is produced from liquid hydrocarbon fuel. The fuel processor consists of a primary fuel-reforming reactor (endothermic), a water-gas shift reactor (exothermic), and a method of removing carbon monoxide. The power generation module consists of liquid hydrocarbon fuel storage, a microchannel fuel processor, and a microscale fuel cell. A lithium polymer battery could be included in the system for startup and peak power.

Under a program for the Defense Advanced Research Projects Agency (DARPA), Battelle, Pacific Northwest Division (Battelle) and Case Western Reserve University (CWRU) are developing and demonstrating an integrated fuel cell and fuel processor for microscale (10- to 500-mWe) power generation. The system includes a microscale fuel processor, which produces hydrogen from liquid fuels such as methanol, butane, JP-8, or diesel; and a microscale fuel cell that will use the hydrogen as fuel to produce electric power. This alternative power source has many potential advantages over batteries for operating wireless electronic devices (e.g., microsensors and microelectromechanical systems), especially in terms of energy and power densities. This technology broadens the possibilities for using self-sustaining devices in remote or difficult-to-access locations. In this application, the fuel from storage is mixed with air and water in a fuel processor system that operates at 600° to 700°C for butane and 250° to 550°C for methanol. The overall power system is composed of several subsystems: fuel storage, fuel processor, synthesis gas treatment (optional), and fuel cell, along with associated peripherals such as pumps and control valves. The fuel processor contains a reforming reactor, combustion reactor, and heat exchangers. Heat generated in the combustion reactor is transferred to the endothermic reforming reactor to produce the H_2-containing synthesis gas. The synthesis gas may be processed directly in the fuel cell or treated to minimize the CO concentration, depending on the type of fuel cell. The fuel cell converts H_2 and O_2 (from air) to electrical power and water.

The NASA In Situ Resource Utilization (ISRU) program plans to include chemical processes for converting the carbon dioxide and possibly water from the environment on Mars into propellants, oxygen, and other useful chemicals. The use of such indigenous resources significantly reduces the size and weight of the payloads that need to be lifted off from Earth. The in situ propellant production involves collecting and pressurizing the atmospheric carbon dioxide, conversion reactions, chemical separations, heat exchangers, and cryogenic storage. PNNL's systems study demonstrated that microtechnology could provide significant size, weight, and energy-efficiency gains. In this system, energy management is very important. First of all, energy is a scarce resource. Secondly, heat rejection is a problem because the low-pressure atmosphere makes convective heat transfer ineffective. Mictrotechnology-based systems are attractive because processing fluids in microchannels can change the governing physics dramatically. The gravitational forces are secondary to surface, interfacial, and hydrodynamic forces. Therefore, microscale technology very naturally overcomes the challenges and limitations of operating in reduced gravity and micro gravity environments.

Revolutionary Science and Technology

Nanotechnology will have a significant impact on microscale technology of the future (see Figure 4). Nanotechnology is changing fundamentally the way materials and devices will be produced. With the ability to build things atom-by-atom and molecule-by-molecule, there will be new classes of structural materials.

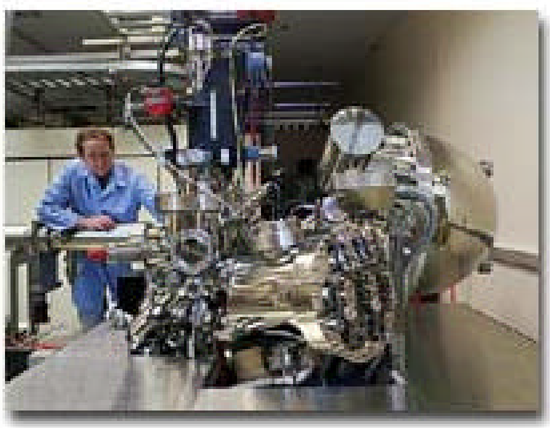

Figure 4. Molecular Beam Epitaxy

PNNL is spearheading R&D in nanoscience and nanotechnology, especially in the areas of nanomaterials and nanobiology. The PNNL NANO website (http://www.pnl.gov/nano) tells how revolutionary new materials with enhanced surface properties will greatly improve microscale devices and systems. PNNL is in the business of discovering fundamental phenomena and applying this knowledge to the development of commercial products. Nanotechnology will enable products to be lighter, stronger, smarter, cheaper, cleaner, and more precise. All of these advances will provide many benefits to future microscale systems. PNNL seeks to make revolutionary strides in putting nanotechnology to work for the benefit of humankind.

Acknowledgment

Pacific Northwest National Laboratory is operated by Battelle for the U.S. Department of Energy under Contract DE AC06-76RLO1830.