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Environmentally Friendly Manufacturing Systems

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●Vol. 74/Mar. 1996 Mitsubishi Electric **ADVANCE**

Environmentally Friendly Manufacturing Systems

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The cover for our special edition on environmentally friendly manufacturing systems is a collage of some of the products and technologies introduced in the following pages. Recent award-winning advances bring benefits that serve both modern buildings like the Landmark Tower Yokohama and rare butterflies in tropical rain forests.

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OVERVIEW

Environmental Preservation & Manufacturing Systems

*by Takashi Mitsuhashi**

Mitsubishi Electric Corporation and its associated group of companies, including affiliates and subsidiaries in over 30 nations, are currently introducing and implementing a variety of measures to ensure that all manufacturing systems are fully consistent with the requirements of environmental protection.

The main thrust of corporate environmental policy is to ensure conformity with the international environmental standards being advocated by the International Standardization Organization (ISO) based on international agreement and cooperation. An environmental management system has already been created that covers all group companies and is being implemented at each and every manufacturing site. Another important thrust is the performing of environmental-impact assessments for all products. The concept of "design for environment (DFE)" has already been applied to all home electrical appliances, and is currently being applied to other product groups. In this area, we have been cooperating with Daimler-Benz since 1994, with the result that innovative concepts are being applied to the entire production system, from materials procurement to the disposal of scrapped products. Again, in 1995, research and development throughout the organization underwent major revision, integrating and expanding environmentally related fundamental research and development. This has enabled us to enter new environmentally oriented areas of business and to create a structure geared towards greater contributions to the "recycling society" of tomorrow.

Mitsubishi Electric's corporate slogan is "Technology for Life," and the corporation is committed to a leadership role in the cooperation and international solidarity essential to ensure an enriched—rather than an impoverished—environment for the six billion inhabitants of the world in the 21st century. As the world becomes ever more information oriented, our highest priority will be on establishing manufacturing systems that take proper account of the environment. ❑

**Takashi Mitsuhashi (Managing Director) is with Corporate Engineering, Manufacturing & Information Systems.*

Mitsubishi Electric's Commitment to Global Environmental Problems

*by Dr. Toshio Ito and Eiki Jidai**

It is incumbent on enterprise, as a whole, to minimize the waste streams generated by manufacturing processes. Wastes and inefficiencies are costly to manufacturers for the same reasons that they exacerbate global environmental problems.

We must first recognize that supply and demand economics which exclude recycling issues are fundamentally flawed. It is mistaken to consider a transaction completed when a product is sold and consumed, as though the used product somehow disappears from the face of the earth. The resources consumed during manufacture, the packaging materials and the discarded merchandise all continue to affect the environment as well as the activities of living organisms.

To incorporate environmental considerations into our economic framework will require that corporations cooperate with government and nongovernmental organizations worldwide.

With manufacturing operations in more than 30 countries, Mitsubishi Electric has an especially important obligation to promote global environmental protection efforts. In 1991, Mitsubishi Electric adopted a global environmental charter and established clear targets to guide activities of some 110,000 employees in about 100 corporate organizations worldwide toward sustainable manufacturing practices.

Measures to Avoid Ozone Depletion

It is imperative that the release of ozone-depleting compounds be halted as soon as possible so that stratospheric ozone can continue its life-sustaining function of shielding living organisms from ultraviolet radiation. Mitsubishi Electric formed a committee on eliminating use of ozone-depleting chemicals, and initiated a company-wide technological development effort that has ended in-house use of these compounds in 1995, four years ahead of the schedule speci-

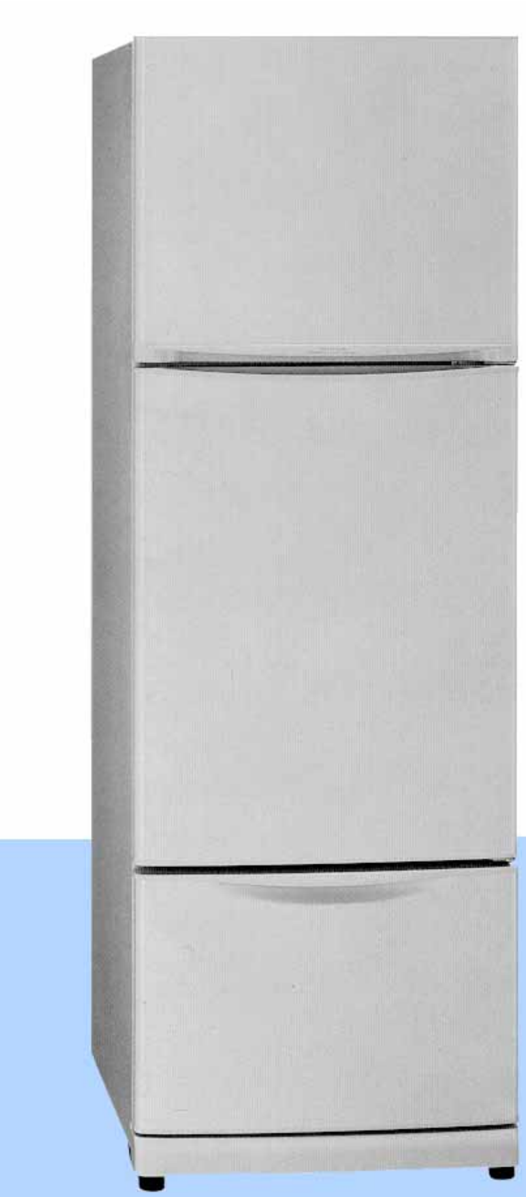
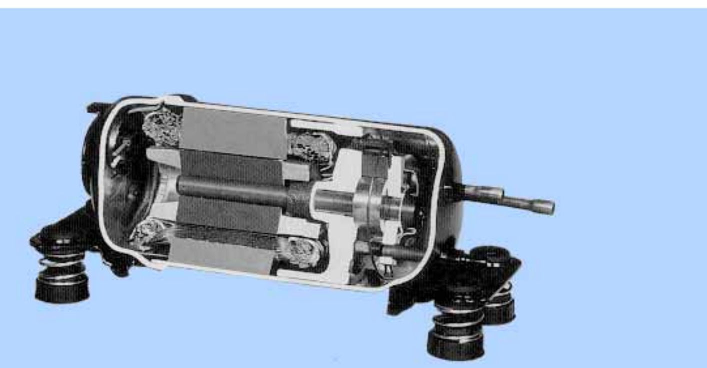



Fig. 1 A CFC-free refrigerator and a cut-away view of the rotary compressor it uses.

Dr. Toshio Ito (Senior Managing Director) is with Corporate Research & Development and Eiki Jidai with the Environmental Protection Department.

fied by the Montreal Protocol. The following sections detail some of the steps we have taken.

CFC-Free Refrigerators

Two chlorofluorocarbons (CFCs) designated for phasing out under the Montreal Protocol were widely used in refrigerator manufacture—CFC-12 as a refrigerant and CFC-11 as a foaming agent for thermal insulation. Mitsubishi Electric has already developed technologies using the approved alternatives, HFC-134a and HCFC-141b. Sale of refrigerators using these compounds began late in 1993. Ozone-friendly refrigerators in popular sizes over 400 liters were launched the next spring. By June 1995, the corporation's entire product line had made the transition to CFC-free technologies.

In an important technological coup, Mitsubishi Electric became the first company to mass-produce refrigeration equipment using a rotary compressor with HFC-134a refrigerant and a non-soluble lubricant. Fig. 1 shows a cut-away view of this compressor. The U.S. Environmental Protection Agency awarded the corporation the 1994 EPA Stratospheric Ozone Protection Award for this contribution to worldwide environmental preservation (Fig. 2).

Manufacturing Processes Free of Ozone-Depleting Materials

Due to their outstanding solvent properties, the manufacturing industry had used CFCs and trichloroethane (TCE) extensively in a wide variety of manufacturing processes. Within Mitsubishi Electric, these solvents had been relied on heavily in semiconductor production and machine parts manufacture. The corporation has now modified its manufacturing processes to either use alternative solvents or eliminate solvent washing requirements completely.

Fig. 2 The EPA Stratospheric Ozone Protection Award.

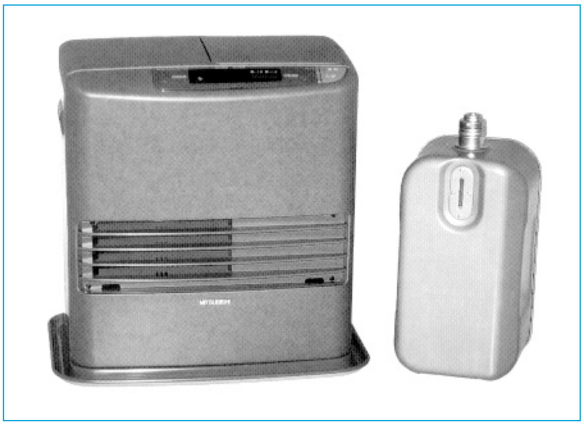


Fig. 3 Kerosene fan heater and tank formed from lubricant-coated steel sheet.

A typical example is the tanks Mitsubishi Electric produces for its free-standing oil heaters. A TCE wash is generally required to remove cutting oil used to facilitate the forming process. The corporation has eliminated the oil and washing requirements by using a lubricant-coated steel sheet (Fig. 3). The process reduces the waste stream, lowers manufacturing costs and saves space on the factory floor. As this example shows, environmental protection requires interventions at both process and design levels.

Measures to Avoid Environmental Pollution

Environmental pollution results when human activities exceed the earth's natural self-cleansing functions. Mitsubishi Electric has succeeded in reducing its waste stream by 30% since 1991 by adopting new recycling technologies and installing incinerators at its factory sites. Further reductions in the waste will require careful planning in the design and manufacture of each product.

Mitsubishi Electric has already begun analyzing the environmental impact of new products—a procedure called life-cycle assessment—for which in-house standards have been developed. Products are designed with their ultimate disposal in mind: they must be easily disassembled, and the mass and volume of both product and packaging reduced. In September 1994, Mitsubishi Electric and the Daimler Benz Group began joint development of product design tools that will facilitate disassembly.

Many of Mitsubishi Electric's products have been designed to satisfy product assessment requirements. Motor and compressor components are designed for easy disassembly. Air- conditioners use fewer electrical components, and heat-exchanger mass and volume have been reduced by 30%. Recyclable plastics are now used to manufacture washing machine bases, refrigerator evaporation trays, television rear panels, vacuum cleaner components and the ducting for free-standing oil heaters.

Packing materials use wood and styrofoam more sparingly, and styrofoam recycling technology is being developed. Styrofoam packaging materials for TVs now include 50% recycled content (Fig. 4).

Measures to Reduce the Greenhouse Effect

Higher concentrations of carbon dioxide (CO_2) in the atmosphere cause a greenhouse effect and may be responsible for climatic disturbances.

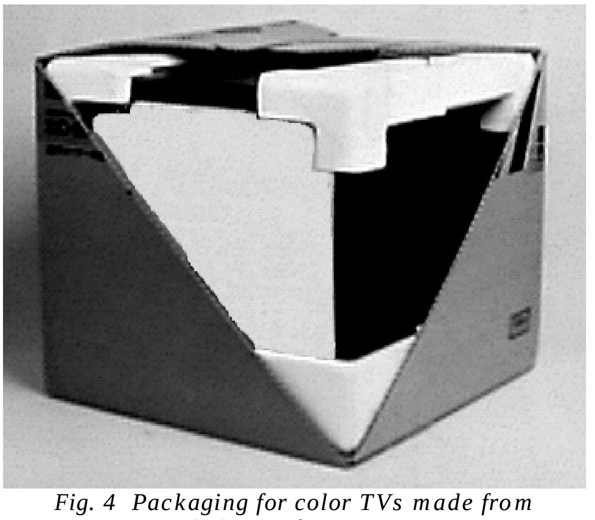


Fig. 4 Packaging for color TVs made from recycled styrofoam.

The solution is to reduce CO_2 production by consuming less energy.

All sectors of Japanese industry are working to achieve the government's target of stabilizing the per-person CO_2 emissions at the 1990 level by the year 2000. Mitsubishi Electric factories are taking steps to reduce the power consumption of boilers and air-conditioning systems for clean-room facilities. The construction industry is designing energy-saving technologies for apartment and office buildings that will also contribute to reduced greenhouse emissions.

Energy savings in stand-alone electronic products and systems requires a reduction in power and fuel consumed in manufacture, operation and disposal. This is something Mitsubishi Electric has worked on since the 1973 oil crisis. Fig. 5 shows year-on-year improvement in the energy-efficiency of Mitsubishi-built refrigerators. Improvements in compressor design and insulation efficiency have lowered power consumption, while better control electronics and sensors have made it possible to develop new, more energy-efficient refrigeration cycles. Similar energy savings can be seen in Mitsubishi Electric's air-conditioners and most other current products.

Measures to Preserve Greenery

Protecting verdant open spaces is vital to sustaining natural cycles since plants and trees

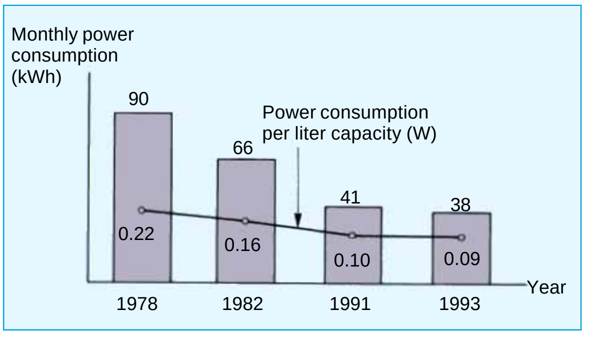


Fig. 5. The increasing efficiency of Mitsubishi refrigerators. (Figures based on 428-liter models.)

Fig. 6 Landmark Tower Yokohama.

consume CO_2 and liberate oxygen in the process of using solar energy to produce starch. The development of rural and suburban open spaces should be restricted. Mitsubishi Electric believes that high-rise development in built-up urban areas is the most suitable means of accommodating society's needs for additional residential and industrial floor space. The corporation is devoting considerable resources toward development of elevator, escalator and air-conditioning technology for high-rise buildings. The 70-story, 286m Landmark Tower Yokohama building showcases the corporation's latest offerings, including a high-speed passenger elevator that reaches speeds of 760m/min (Fig. 6).

Monitoring the Environment

Mitsubishi Electric has developed an earth observation satellite with a highly accurate radar system that can monitor environmental conditions on the earth's surface under all weather conditions. Mitsubishi Electric is supplying an even more sophisticated radar system for use in ADEOS, an advanced earth observation satellite scheduled for launch in 1996. With the radar, ADEOS will be able to see pollution on the land and ocean surfaces, and measure depletion of the ozone layer. We expect it to make a large contribution to global environmental protection.

Establishing an Environmental Management System

Many enterprises in Japan are setting up in-house environmental monitoring and management organizations that operate independently of their manufacturing activities. Companies have established in-house environmental standards, trained inspectors and are conducting environmental audits on a regular basis. Multinational corporations are targeting the same standards of environmental protection at their offshore manufacturing facilities that they adhere to at domestic plants.

Mitsubishi Electric is taking similar steps. The corporation has issued company-wide environmental regulations and is taking a comprehensive and organized approach toward environmental management. Corporate regulations have been updated with organizational changes and a new system of checks and balances to promote transparent management practices.

Routine Operations

Mitsubishi Electric is also promoting environmentally friendly activities in day-to-day work. These goals include high-yield, zero-defect production, high productivity, efficient use of energy, reduction of inventory levels, and a clean and well-organized workplace.

We believe that this level of employee commitment at Mitsubishi Electric companies and affiliates worldwide is essential to avoiding environmental accidents. It will also contribute to smaller waste streams and higher levels of recycling both at the workplace and in society as a whole.

Joint Activities with Other Corporations

Many manufacturing companies already evaluate environmental impact during the design of new products, and the International Standard-

Fig. 7 A model of Japan Earth Resources Satellite.

ization Organization (ISO) is investigating standards for life-cycle assessment. To be effective, such measures will obviously need to be implemented at an industry-wide and global level.

Last year, Japan's Ministry of International Trade and Industry used life-cycle assessment data from companies in 15 industries to formulate goals for future manufacturing environments. We can anticipate greater international cooperation on environmental issues between companies in similar industrial sectors, as well as increasing cooperation between diverse industries.

Cooperation Between Local and Central Governments, Industries and Consumers

A citizens' mandate is needed to fairly distribute the costs of environmental protection. Industries as well as governments have an obligation to inform consumers regarding these issues.

Beginning in March 1994, Japanese manufacturers were formally obligated to collect and where possible recycle large appliances including televisions with screen sizes of 25 inches and above and refrigerators with capacities over 250 liters. This replaced an inconsistent hodgepodge of local directives.

For manufacturers to establish a national used-appliance collection system, central government must lead the nation to a consensus on environmental policy satisfactory to consumers, manufacturers and local government. The nation is currently debating policies such as restricting use of paper wastes in landfills, compulsory manufacturer recovery and disposal of used appliances, and recovery of CFCs from used refrigerators and air-conditioners. In November 1994, the Electrical Appliance Manufacturers Association set up a discarded appliance reprocessing center to support local-

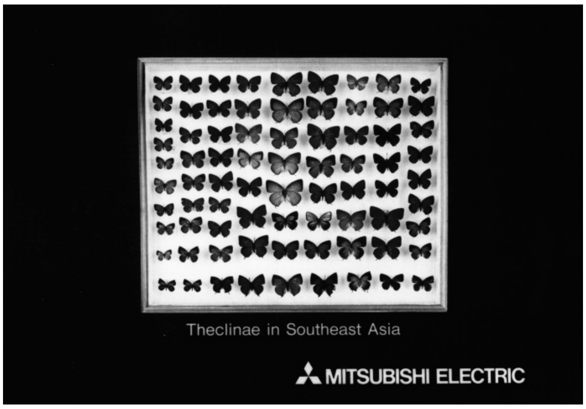


Fig. 8 A photo of the Theclinae *species found in the Malay Peninsula.*

government efforts to recover used appliances. We feel that cooperative efforts of this kind will encourage manufacturers to take the lead in developing the technologies suitable to address these issues.

Important characteristics of environmental problems are that they transcend national borders, and they develop over a long period of time from the interaction of a multitude of factors. Actions we take now will bring visible effects in the 21st century. This is why every sector of industry must make environmental plans at least five to ten years in advance. Companies must question whether their practices are sustainable, and make medium- to long-range improvement plans. Economic constraints should not limit corporate investment in R&D, new technologies and public education aimed at protecting the environment, since this is an investment in the future of humanity.

One of the authors travels regularly to the tropical jungles of Southeast Asia to observe the many species of butterflies. Southeast Asia, South America and Africa are treasure troves of butterfly species. The Malay Peninsula alone has twice as many species as the entire Eurasian continent north of the Himalayas. A favorite of this author is the genus *Theclinae* (Fig. 8), which are colored in iridescent purples and greens. The gossamer construction that gives butterflies their beauty also makes them a sensitive indicator of global environmental health. The yearly decline we observe in their numbers signals us that current environmental issues are serious and demand our immediate attention. ❑

Satellite Technology for Environmental Observation

*by Tsutomu Iwahashi and Hirokazu Tanaka**

Over the past half century, we have witnessed large-scale changes in the earth's environment—desertification, decimation of tropical rainforests, acid rain, depletion of the ozone layer and increased emission of greenhouse gases. Images and numerical data provided by remote-sensing satellites help researchers to better understand these phenomena. This report addresses the state of the art in this environmentally important technology.

Introduction to Remote-Sensing Technology

Earth observation satellites are placed in relatively low orbits below 1,000km. The orbit is designed to allow the satellite to scan the earth's entire surface over periods of days to weeks.

Surface phenomena are imaged using radiation in the visible spectrum, the near or thermal infrared region, or the microwave (radar) band. This radiation may be emitted, reflected or scattered by the surface under observation.

The concentration of various substances in the atmosphere is measured by using specific wavelengths at which these substances absorb radiation. The concentration of ozone, for example, is measured using wavelengths in the ultraviolet and far-infrared bands.

Using data collected by various sensors, researchers can monitor the state of surface vegetation, distribution of water and its dynamics, the composition of the atmosphere, and the occurrence of volcanic eruptions (Fig. 1).

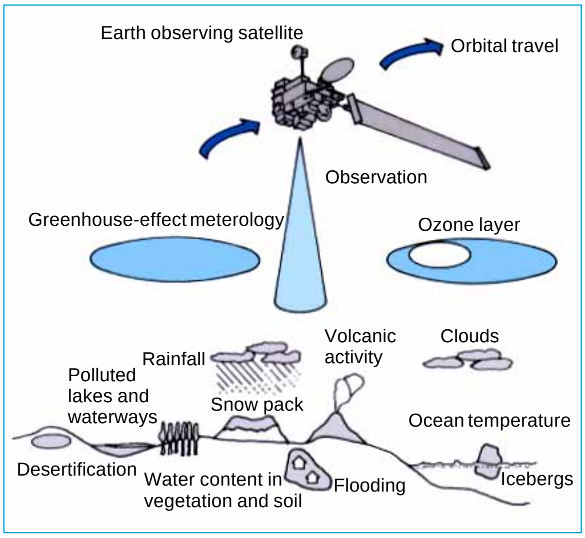


Fig. 1 The basic concepts of remote-sensing satellite technology.

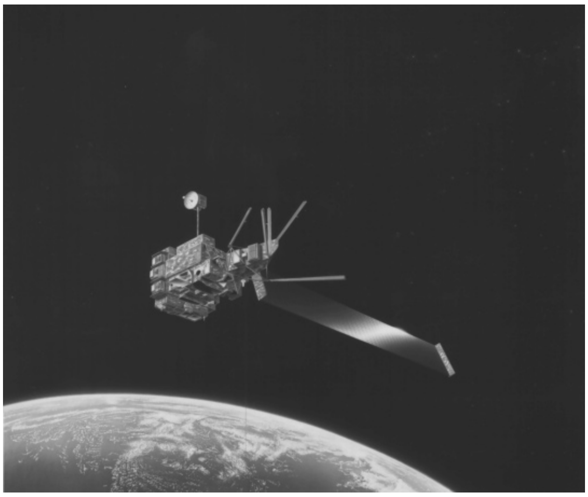


Fig. 2 Illustration of ADEOS (Courtesy of NASDA).

The ADEOS Satellite

Japan's National Space Development Agency (NASDA) contracted Mitsubishi Electric as system integrator for NASDA's Advanced Earth Observation Satellite (ADEOS, Fig. 2). The corporation is overseeing the entire development of the satellite, which is planned for launch in 1996. ADEOS is designed specifically to collect environmental data that will be made available to researchers worldwide.

Remote-Sensing Instruments

The following sections introduce remote-sensing instruments developed by Mitsubishi Electric for ADEOS and other satellites.

ADVANCED VISIBLE AND NEAR-INFRARED RADIOMETER (AVNIR). AVNIR has high-resolution passive optical sensors that can monitor the state of vegetation and other ground cover, and the color of coastal waters. These sensors can resolve features as small as 8m in panchromatic mode and 16m in the multiband mode. AVNIR's pointing mechanism can direct the sensors as far as ±40° left and right to scan a designated 80km swath (Fig. 3).

**Tsutomu Iwahashi and Hirokazu Tanaka are with the Kamakura Works.*

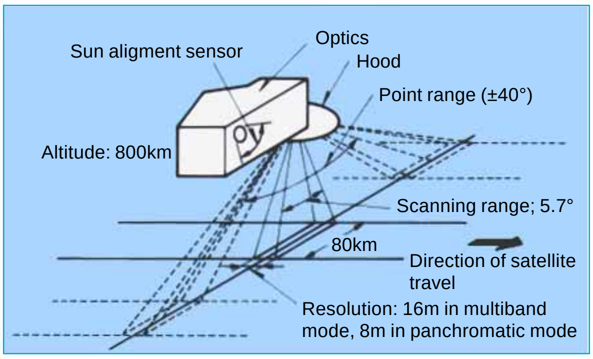


Fig. 3 Scanning geometry of the AVNIR sensor.

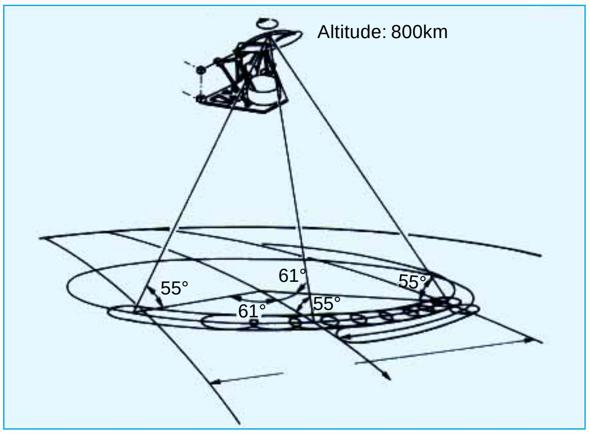


Fig. 4 Conical scanning geometry of the AMSR sensor.

ADVANCED MICROWAVE SCANNING RADIOMETER (AMSR). Under development for ADEOS-II's launch in 1999, AMSR uses a passive sensor that detects thermal emissions from land or ocean surfaces in the microwave band. The data it collects can be applied to monitor a wide variety of phenomena, including ocean surface temperature and salt concentration, icebergs, oil slicks, water vapor content and precipitation. Fig. 4 shows the scanning geometry.

SYNTHETIC APERTURE RADAR (SAR). This active electromagnetic sensing technology derives precise images from the coherence of radio signals reflected by the ground. A recent subject of world attention is the ability to generate topographic data by combining holographic data collected for the same area from two separate orbits. SAR has the advantage of functioning irrespective of weather and daylight conditions. Fig. 5 shows a photograph of the SAR antenna carried by Japan Earth Resources Satellite 1 (JERS-1).

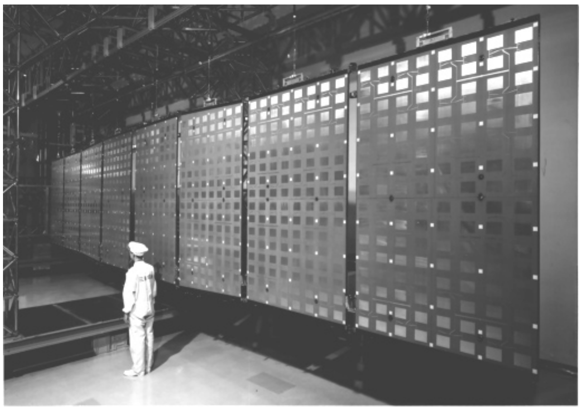


Fig. 5 The SAR antenna for JERS-1.

Data Processing

NASDA's Earth Observation Center collects, stores and processes remote-sensing data beamed down by satellites. The data needs to be "massaged" to compensate for various forms of distortion that arise due to the wobbling of the satellite, sensor idiosyncrasies and other factors. Once these errors are adjusted, numerical data can be used to monitor changes over time or converted to images. Sometimes, satellite data is combined with other geographical data or maps to produce special-purpose images. Figs. 6 and 7 show the region around Mt. Pinatubo before and after its recent eruption, showing the destructive effect on vegetation caused by lava flows and cinders. The photos were taken by MESSR, a near-infrared radiometer carried on Marine Observation Satellite 1 (MOS-1).

Several factors have brought about an enormous increase in the volume of remote-sensing data available for processing: sensor resolution is increasing, new satellites are capable of carrying multiple sensors and geostationary satellites are being used to relay data so that signals can be monitored even when the satellites move outside the line-of-sight of available earth stations. At the same time, dramatic

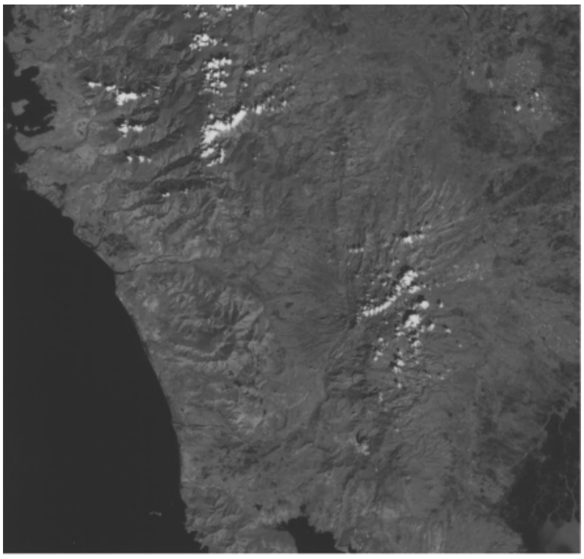


Fig. 6 The Mt. Pinatubo region in November 1989 (Courtesy of NASDA).

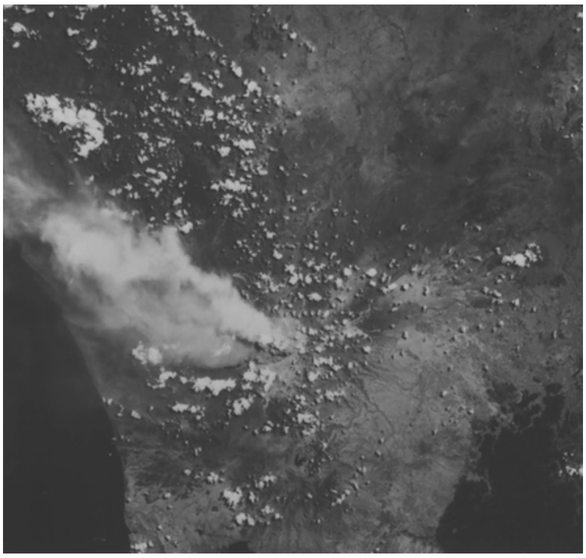


Fig. 7 The Mt. Pinatubo region in July 1990 (Courtesy of NASDA).

advances in computing power have made it possible to move the processing from mainframes to workstations—which is now the general practice even in large data-processing centers. These developments suggest that amateurs and students will have much wider acccess to satellite remote-sensing data in the future.

Table 1 Plans for Development of Remote-Sensing Satellite Systems for Environmental Observation

Sensors	
	Wider range of spectra
	Special-purpose sensors for specific wavebands
	More all-weather sensors
	Improved spatial resolution
Observation	
	More frequent observations
	Realtime observation using multiple satellites
	Long-term monitoring program for greenhouse gases
	Forecasting of short-term and local phenomena
	Ocean pollutant monitoring for oil and suspended solids
	Use of multiple sensors in combination
Data	
	Frequent distribution of realtime data
	Information resources to support regional planning
	Earth stations for rural municipalities to support local monitoring applications
	Regular telecasts of global atmospheric, forestry and water vapor data

Table 1 lists priorities for the future deployment of remote-sensing systems, their use in earth observation and their application to real-world problems.

There is still much to be learned about current environmental problems, and international environmental monitoring and protection organizations will surely be needed to solve them. Mitsubishi Electric's involvement in the further development of satellite remote-sensing technologies will continue to contribute to a better understanding of our planet and its environment. ❑

Ventilation and Air-Conditioning System Design for the New Astram Metro Line in Hiroshima

*by Shigenobu Horita, Tsutomu Kayama and Toshifumi Nakamura**

Integrated design of subway station ventilation, air-conditioning and emergency equipment offers the greatest performance and safety with the minimum construction and operating costs. This article describes the use of simulation technology in the design of ventilation, air-conditioning and emergency equipment for underground stations in a new rapid-transit system in Hiroshima.

Underground Environment of Rapid-Transit System and its Simulation by Computer

The new Astram metro line runs 18.4km from Koiki Park on the northwest to the city center where the last three stations, Hondori, Kenchomae and Shirokita, are underground. The train makes 21 stops, and the travel time from terminal to terminal is 37 minutes. The line is the first operational new-generation rapid-transit system in Japan to employ underground stations, and the first to use an enclosed platform with screened doorways, which lowers air-conditioning costs and improves safety.

The underground environment consists of tunnels, stations, trains and surrounding underground passages, each having unique properties of airflow, power dissipation, thermal transfer and thermal storage. These elements can interact in unexpected ways, and must be understood if we are to design efficient ventilation and cooling systems. This knowledge is also essential to plan for emergencies such as an underground fire when exhaust fans must extract smoke and fumes from the platform and the stopped train.

Computer simulations of airflow and thermal effects offer engineers a way to model and predict system behavior under various circumstances. Mitsubishi Electric used the proven Subway Environmental Simulation (SES) software developed by the U.S. Department of Transportation to assist the design of emergency equipment and operational procedures for these situations.

To use SES, we first represent the tunnels, platforms, stairways and passages as a network of pipes through which pressurized air can flow. Calculations can then be made as to how such factors as forced-air ventilation, winds caused by the passage of trains, heat dissipation by trains, temperature, humidity and the thermal transmission of walls affect each other and the station environment. Finally, how the various

Table 1 Simulation of Emergency Ventilation Systems for Underground Rapid-Transit Facilities

Purpose	Evaluation item	Location	Conditions	Simulation
Design ventilation equipment and establish procedures for routine and emergency operation	Static ventilation	Tunnels, stations	Routine	Calculate airflows in tunnels and stations with ventilation fans operating
		Platforms, stairways	Track fire	Calculate airflows at platform and stairways with train on fire at platform and emergency exhaust fans running
		Tunnels	Tunnel fire	Calculate airflows in tunnels with a train on fire stopped in a tunnel and emergency exhaust fans running
	Dynamic ventilation	Tunnels, stations	Routine	Calculate changing airflows and velocities in tunnels and stations under normal train operation schedule with ventilation fans operating
Design ventilation equipment	Temperature and humidity	Tunnels, stations	Routine	Calculate station and tunnel temperatures and humidities under normal train operation schedule with station air-conditioning and ventilation fans operating
Design air-conditioning equipment	Air-conditioning load	Stations	Summer	Calculate cooling loads required to maintain a specific temperature in tunnels and stations under normal train operation schedule with station air-conditioning and ventilation fans operating
Design airflow paths for station building and cooling tower	Train wind	Station exits, platform stairways, ends of platforms	Two trains arrive, or leave, simultaneously	Calculate the strongest winds that occur when two trains arrive or leave a station simultaneously

**Shigenobu Horita and Toshifumi Nakamura are with the Nagasaki Works and Tsutomu Kayama is with the Transportation Systems Marketing Division.*

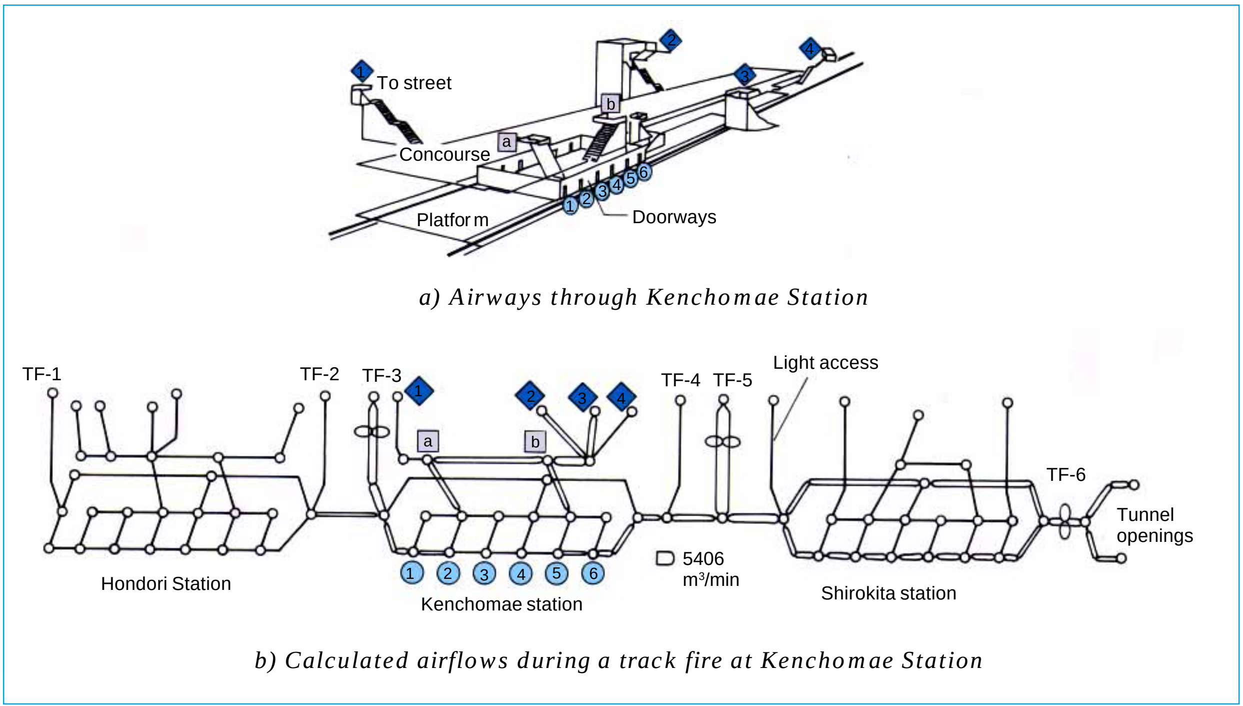


Fig. 1 Modeling and simulation.

number of trains, and ventilation and cooling rates affect airflow volumes, velocities, temperatures and humidity can be determined. Table 1 lists categories of emergency equipment and the content of simulation operations.

The Design of Emergency Ventilation Equipment

Fig. 1 shows a ventilation network model used to determine the airflows at Kenchomae Station. The model includes the two adjoining stations and the tunnels that link them together.

We designed the exhaust fans to operate in seven emergency ventilation modes, each intended to clear smoke from a specific area. We then simulated their operation to determine the equilibrium airflow volumes and velocities. We also performed three-dimensional computational fluid dynamics (CFD) of specific locations and made measurements on small-scale models to determine the airflow resistance of the platform doorways and evaluate the pressure effects of the exhaust fans.

The thickness and the direction of the arrows in Fig. 1b indicate the magnitude and direction of the airflows predicted with a train stopped at Kenchomae Station and fans TF-3, TF-5 and TF-6 operating.

We used simulations to verify that all seven emergency ventilation modes would create the required airflows and that the exhaust fans provide adequate capacity.

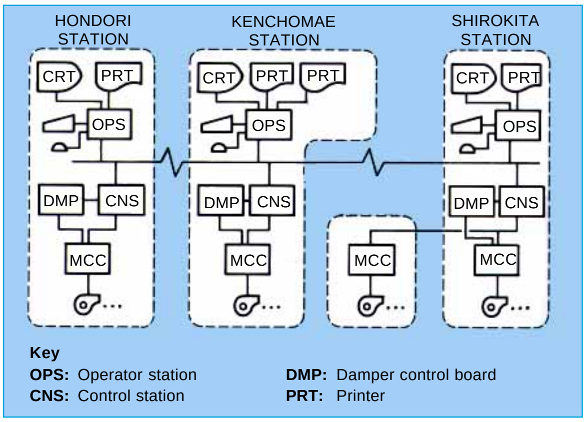


Fig. 2 The configuration of the environmental control system.

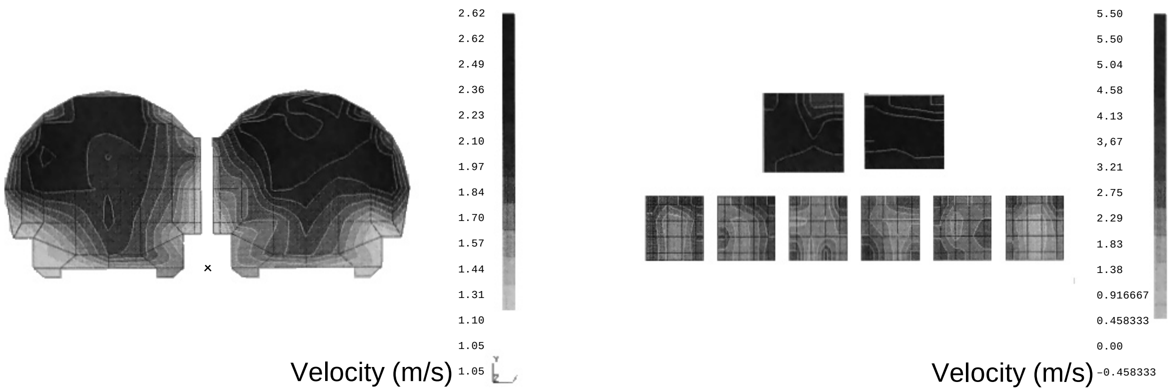
Environmental Control System

We set up environmental control centers for each station to control routine operation of the air-conditioning and ventilation equipment, and to activate the emergency ventilation modes. We also set up a remote control center that can operate the equipment at all three stations in emergency conditions.

Optical-fiber cables link the stations together and join the control stations to the damper control panels. Electrical wiring joins the control stations to the motor-control centers. This layout was chosen to provide generous information capacity and connectivity with minimum wiring requirements.

Ventilation Capacity Verification Tests

We measured the various airflow velocities in all seven smoke-ventilation modes, using a previously qualified hot-wire anemometer (M6611).



a) In the Kenchomae-to-Shirokita tunnel during a tunnel fire

b) Through the platform doors during a train fire at Kenchomae Station platform.

Fig. 3 Measured airflow velocities at various cross sections.

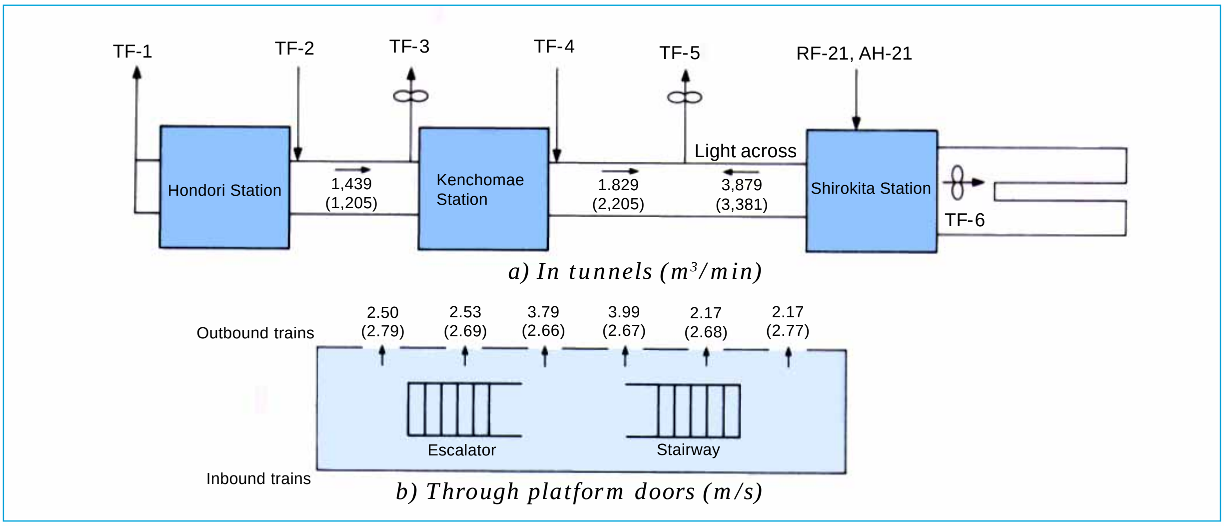


Fig. 4 A comparison of measured and calculated airflow velocity values for a train fire at the Kenchomae Station platform (calculated values in parentheses).

Smoke was used to determine the flow directions. We measured airflow at 50 to 60 points at every tunnel cross section, and at 16 points over the platform door openings. Ten readings were sampled at each point, one per second, and the average value recorded. These measures were integrated over the effective cross section to obtain the inflow volume across boundaries.

Using these values, we predicted airflow behavior under several scenarios. Fig. 3a shows the predicted air velocities across the tunnel between Kenchomae and Shirokita in the event of a tunnel fire. Fig. 3b shows the air velocities at the platform door openings and platform stairways should a fire occur on the tracks in front of the platform at Kenchomae Station, and Fig. 4 contrasts the air velocities in the tunnel and at the platform doors under these conditions with average values. The large amount of air leakage predicted at Hondori Station is borne out by actual measurements.

We then performed airflow measurements under all the emergency ventilation modes and verified adequate airflow to remove smoke from the facility. Finally, we conducted a full-scale smoke test. We stopped a train at Kenchomae platform, opened the train and platform doors, started a smoke plume from the train toward the platform, and set the ventilation mode for a track fire. The exhaust fans quickly drew smoke from the platform through the space between the train and platform doors into the train landing area and out through the exhaust vents.

A fire has the potential to turn an underground station into a death trap. Now that the technology to simulate a station's airflows exists, this risk can be greatly reduced by designing a ventilation system that exhausts smoke away from passenger hallways and exits. ❑

Environmental Assessment of Gas-Insulated Power-Distribution Transformers

*by Kiyoshi Sakai and Satoru Hoshino**

With growing public awareness of global environmental problems, manufacturers need to be especially conscious of the environmental consequences of their products. This article describes the environmental, safety and cost incentives for use of gas-insulated power-distribution transformers, and considers their environmental impact through the entire product life cycle.

Product Safety

The windings of power-distribution transformers are insulated and cooled in one of three ways:

Oil-immersed transformers use paper-wrapped windings immersed in mineral oil, which serves as both the insulation and cooling medium. Although inexpensive and widely used, these transformers are undesirable in high-rise buildings and densely populated urban areas because of the high fire risks that accompany the use of transformer oil.

Gas-insulated transformers use polyethylene terephthalate (PET) film to insulate the windings, which are placed in a sealed tank filled with SF_6 gas that cools the windings and protects them from moisture and dust. In contrast with transformer oil, SF_6 gas is extremely safe. It is highly inert, and has been given a Group 6 UL safety rating, which puts it in the same high-safety class as nitrogen gas. Its safety has been verified in other tests as well. (1)

Encapsulated-winding transformers use plastic to surround the windings, which are also air cooled. The fire danger is low, and no tank is required, making encapsulated transformers smaller than either oil or SF_6 gas-insulated types. However the windings are somewhat exposed, and gradually deteriorate due to exposure to air, moisture and other environmental factors.

Maintenance

Maintaining substation performance is essential in urban contexts where power consumption is heavy. Hong Kong Electric reported that the maintenance costs of gas-insulated transformers were dramatically lower than those of oil-immersed transformers (Fig. 1), leading them to replace all obsolete transformers with gas-insulated types.

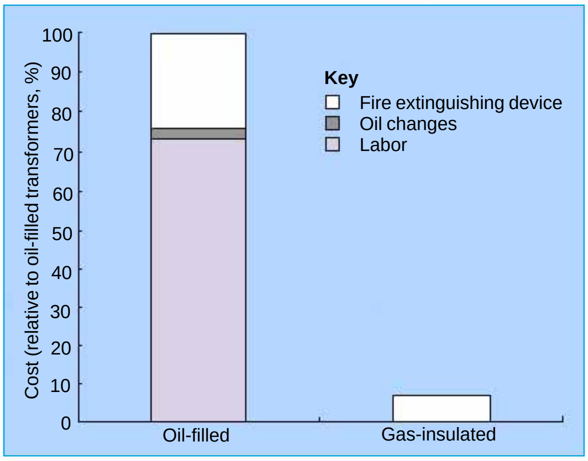


Fig. 1 Comparative maintenance costs.

Transformer oil must be periodically filtered and exchanged because it degrades over time, losing its insulating qualities. Fire-extinguishing equipment must also be maintained. SF_6, on the other hand, does not degrade (2) and protects the insulation system from environmental factors that might reduce performance. Maintenance is practically non-existent in comparison.

Gas-insulated transformers turn out to be cheaper than oil-immersed transformers when maintenance costs are factored in.

Recycling

Power-distribution transformers have a high recycling value because they can be easily disassembled and their chief constituents, which are high-purity steel, aluminum and copper, can be recycled indefinitely.

Gas-insulated transformers are far more easily recycled than oil-immersed types. SF_6 gas can be reused and PET film recycled into containers, carpets and other products, allowing fully 96% of the natural resources in gas-insulated transformers to be recycled after decomissioning. The oil and paper insulation of oil-immersed transformers cannot be reused, which lowers the reuse ratio to only 71%.

Fig. 2 lists the materials and reuse ratios of these two types of transformer. Fig. 3 shows

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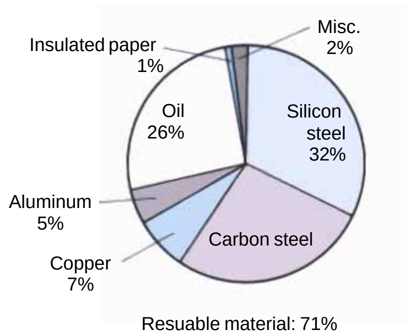
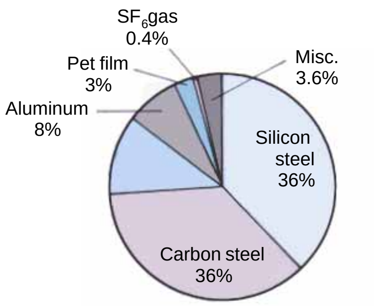


a) Oil-immersed transformers



b) Gas-insulated transformers

c) Material purity

Material	Element	Purity (%)
Silicon steel	Fe	98.5
Carbon steel	Fe	99.0
Copper	Cu	99.9
Aluminun	Al	99.7

Fig. 2 Transformer composition.

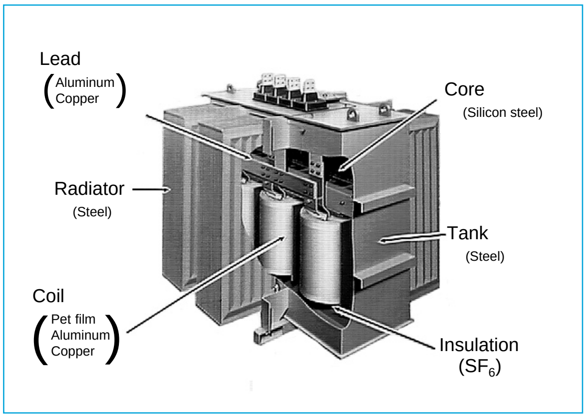


Fig. 3 Construction of an SF_6-insulated distribution transformer.

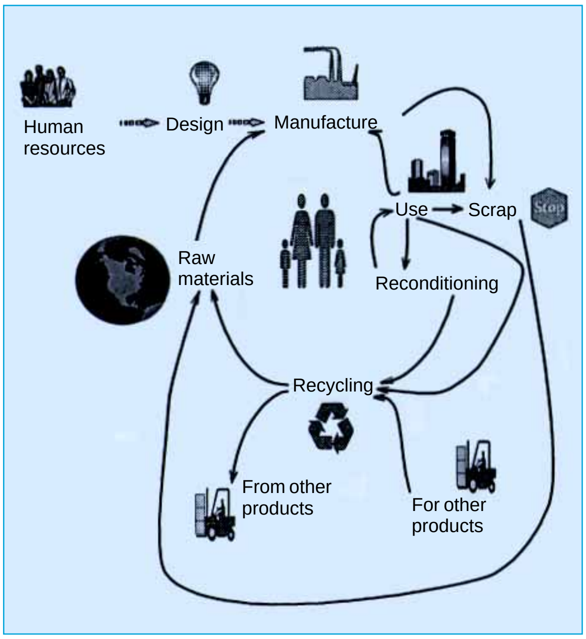


Fig. 4 Resource flows over transformer product life.

the relatively simple construction of gas-insulated transformers, which assists in their recycling. The main components are the core, the windings and the tank.

Environmental Impact

Fig. 4 shows the resource flows involved in transformer manufacture, use and decommissioning. Almost all of the components of obsolete products are recycled or reused.

Another facet of the environmental impact is the energy cost. Table 1 shows the energy consumption calculated for the manufacture and operation of 1,500kVA oil-immersed and gas-insulated distribution transformers. The figures are based on conversions of 3.72×10^7 J/l for fuel oil, 3.88×10^7 J/l for crude oil and 9.22×10^6 J/kWh for electrical energy. The table shows that although gas-insulated transformers require more energy to fabricate and assemble, they are actually cheaper in the long run due to their lower operating losses.

Table 1 Estimated Energy Cost Over Entire Life Cycle of 1,500kVA Power-Distribution Transformers
(billions of Joules)

Type	Manufacturing energy cost			Operating energy cost*
	Materials refining	Forming and assembly	Total	
Oil-filled	107	16	123	16,700
Gas-insulated	190	13	203	11,100

*The operating costs assume 20-year operation.

Factoring this into the comparison gives gas-insulated transformers even greater cost and energy advantages.

In addition to a well-earned reputation for safety and reliability, gas-insulated transformers offer advantages of easy recycling, low environmental impact and lifetime costs well below those of common oil-immersed transformers. ❑

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2. "The Use of Sulfur Hexafloride (SF_6) in High-Voltage Switchgear and Control Gear." IEC/TC and SC 17A, 1994.

The Application of Sound-Absorbent Plastic to Acoustic Paneling

*by Katsuhisa Ootsuta and Dr. Shuichi Tani**

Mitsubishi Electric has developed a durable high-performance acoustic panel using a special sound-absorbent plastic acoustic-insulation material formed by subjecting thermoplastic resin beads to heat and pressure. The plastic is incorporated into a module that enhances its sound-deadening properties. Rugged, weather-resistant design and excellent longevity make the paneling suited to both indoor and outdoor use.

Features of the Sound-Absorbent Plastic

Conventional acoustic paneling loses its ability to absorb sound as its fibers absorb moisture, and the binder degrades under ultraviolet exposure. Fiberglass-based paneling sheds glass fibers and the filling compacts over time. The sound-absorbent plastic we developed is immune to these problems, can be formed in any desired shape and manufactured in any color. The forming process does not compromise the basic noncombustibility and weather resistance of the raw plastic. Finally, use of a known composition facilities later recycling.

Panel Construction

Fig. 1 shows the basic sound-absorbing structure, which consists of a layer of the new acoustic insulation material, a dead-air space and rear plate to prevent sound leakage. The acoustic insulation is formed using plastic granules 0.5~2.0mm in size, and is denser toward the front and more porous toward the back.

The maximum absorption frequency is determined by the acoustic mass of the insulation layer and the thickness of the air space, which we can predict by analyzing an electrical circuit. The insulation layer can be treated as resistance and inductance in series, and dead-air space as capacitance. Together, the elements form a series resonator.

By forming an insulation layer that nearly matches the acoustic impedance of air, it is possible to achieve a sound-absorption rate close to 100% at the resonant frequency. The acoustic resistance and characteristic acoustic impedance of the insulation layer can be controlled by adjusting its porosity during manufacture.

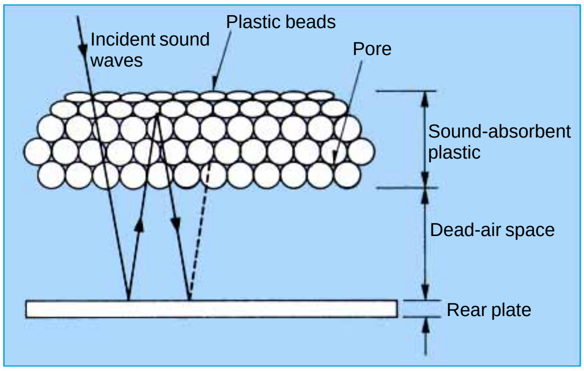

Fig. 1 Sound-absorbing structure.

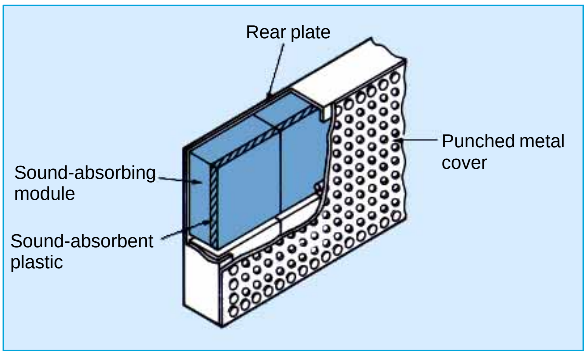

Fig. 2 Panel construction.

Fig. 2 shows the basic construction of the acoustic panel. It consists of a rear supporting plate that prevents sound leakage and a layer of the sound-absorbent plastic insulation separated by a lattice that maintains the dead-air space and sets up smaller sound-absorption cells. The front surface of the sound-absorbent plastic is covered with a protective punched metal sheet.

The lattice period was chosen to keep the cells smaller than a half-wavelength at the central absorption frequency. This restriction ensures that the phase of the sound front arriving at each cell is approximately uniform, which leads to better resonator excitation.

Sound Absorption Performance

Fig. 3 shows a simple module that forms a resonator. The thickness of the dead-air space controls the maximum absorption frequency. Additions to this basic lower-frequency module make it possible to cover a wider spectrum of frequencies.

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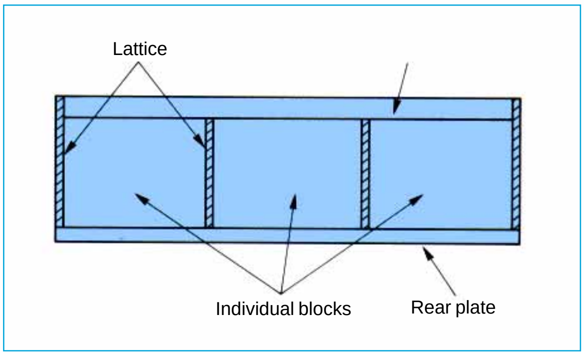

Fig. 3 A simple sound-absorbent panel.

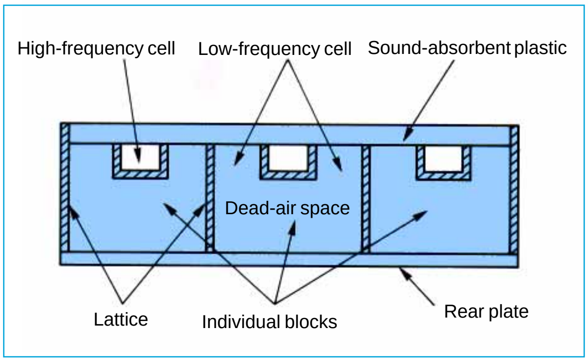

Fig. 4 A compound sound-absorbent panel.

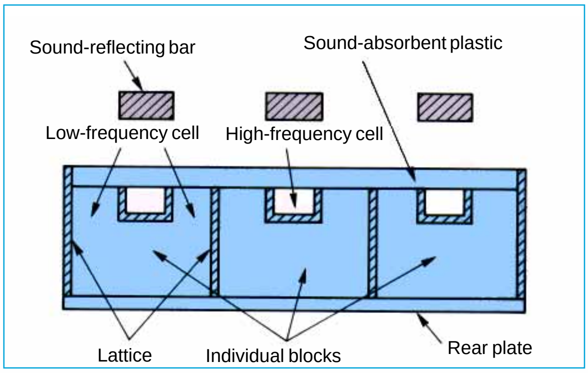

Fig. 5 A compound sound-absorbent panel with sound-reflecting bars.

Fig. 4 shows a compound module with both high- and low-frequency sound-absorbent structures. As with the low-frequency cells, the air-space thickness of the high-frequency cells determines the frequency of maximum energy absorption. These cells have a large frontal area to maximize the high-frequency absorption; at

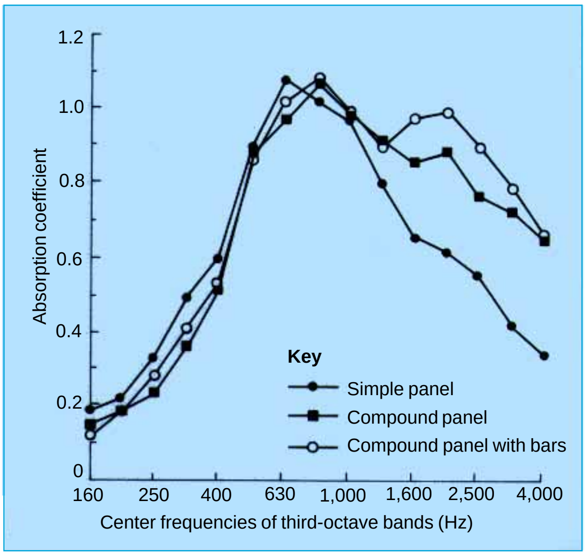

Fig. 6 Panel absorption coefficients in a reverberation room.

the same time, they allow low-frequency sound waves to diffract around behind, so that the effective area for the low-frequency cells is not diminished.

Fig. 5 shows a module with sound-reflecting bars in front that further increase the high-frequency sound-absorption efficiency. The bars are mounted in front of the high-frequency cells, and help by containing sound energy initially reflected off the cell surfaces.

Fig. 6 shows the absorption coefficients of these three types of modules measured in a reverberation room. The simple module is 50mm thick and has a single absorption peak at 800Hz. The compound module is 50mm thick and has a second absorption peak at 2,000Hz. Adding the sound reflecting bar, creating a total thickness of 70mm, results in nearly uniform absorption between 600 and 2,000Hz.

Weather Resistance

We used accelerated artificial exposure tests and thermal cycling to verify the sound-absorbent plastic's weather resistance. The exposure test was made using a carbon-arc lamp to simulate solar radiation over a period of 2,000 hours. Thermal cycling between –18 and +18°C was

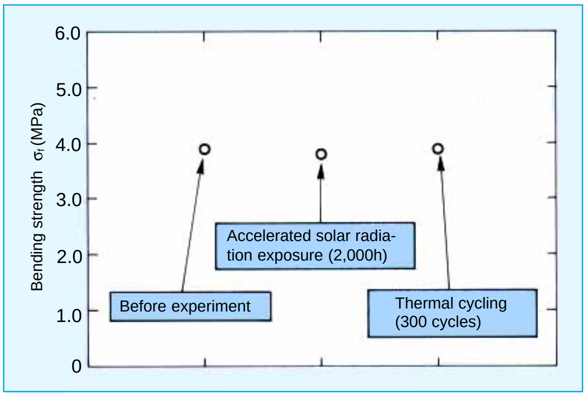

Fig. 7 Bending strength at 20°C after exposure and thermal cycling.

conducted for a few weeks with one cycle lasting 3.75 hours. The sound-absorbent plastic was also immersed in a bath and frozen and thawed 300 times.

Fig. 7 shows the bending strength of the sound-absorbent plastic after thermal cycling and exposure tests, showing that neither test had much effect on the plastic's physical properties, although the exposure test did cause some surface discoloration. Freezing and thawing also caused no damage.

This high-tech replacement for conventional acoustic panels offers better sound-deadening performance, together with durability sufficient to last the life of a building. ❑

A Highly Sensitive Atmospheric NO_X Sensor

*by Dr. Yoshio Hanazato, and Saori Kimura**

Mitsubishi Electric Corporation is developing sensors that can detect atmospheric oxides of nitrogen (NO_X) in concentrations at the parts-per-billion (ppb) level. Studies of gas-sensitive films and NO_X adsorption/desorption mechanisms led to development of a surface acoustic-wave device with a chromium tetraphenylporphyrin film that selectively detects NO_X concentrations in the ppb to tens of ppb range. This article reports on the aforementioned sensors, their operating principles and response characteristics.

Background

Oxides of nitrogen from auto exhausts are a major source of atmospheric pollution in urban areas. Health considerations require that we begin to monitor indoor and outdoor NO_X pollution and take necessary measures to reduce unsafe concentrations through ventilation, filtering or catalytic breakdown. Highly sensitive, highly selective NO_X measuring instruments suitable for automated use will make it practical to implement monitoring on a wider scale.

Current NO_X sensors offer only parts-per-million (ppm) sensitivity, which limits their use to fixed pollution sources such as industrial smokestacks and incinerators where the NO_X concentration is high. Sensors for general atmospheric monitoring and having sensitivities in the ppb range are under development, but commercial products are not yet available.

NO_X Adsorption and Desorption on Metal Porphyrin Thin Films

Sensitivity and selectivity of gas sensors is determined by the adsorption/desorption characteristics of the sensor material with respect to the molecules of the intended gas. Understanding the adsorption/desorption mechanism is therefore essential to the development of highly sensitive and selective sensors. It is known that organic semiconductors such as metal-porphyrin and metal-phthalocyanine compounds exhibit high sensitivity and selectivity toward acid gases such as NO_2, but the mechanisms are still poorly understood. The authors conducted studies on the NO_2 adsorption/desorption behavior of metal tetraphenylporphyrins (MTPPs) and ultimately chose them for developing gas-sensitive films.[1]

Through this work, we learned that the adsorption/desorption characteristics of MTTPs depend strongly on the material's redox potential and surface morphology, with a lower redox potential corresponding to faster adsorption and desorption. Because of their rough surface, chromium tetraphenylporphyrin (CrTTP) thin films show faster adsorption and desorption than would be expected on the basis of redox potential alone, suggesting that surface morphology considerations are of great importance as well. We ultimately selected CrTTP as the detector material for an experimental sensor due to the excellent stability, reproducibility and amplitude of its NO_2 adsorption/desorption response. To convert these adsorption effects to electrical signals, we chose to use piezoelectric surface acoustic-wave resonator (SAW) devices, which offer high sensitivity while being suited to mass production.

Sensor Operating Principles

The oscillation frequency of piezoelectric devices such as SAW resonators and quartz crystals mainly depends on the change in mass, and therefore is affected by the mass of adsorbed gas molecules. The relationship between change in mass and change of frequency in the piezoelectric devices is given by:

$$\Delta f = -Cfo^2(\Delta m/A) \quad \text{(Eq. 1)}$$

where Δf is the change of frequency in Hz, Δm the change in mass in grams, and A is the active area of the SAW resonator in cm^2. The constant (C) for an ST-cut quartz substrate is 1.3×10^{-6} cm^2s/g (SAW resonator), which would correspond to a 1Hz change in the frequency of an 80MHz SAW resonator with gas adsorption of $0.12ng/cm^2$.

NO_X Sensor Construction

Fig. 1 shows the construction of a NO_X sensor based on a SAW resonator. Two 78.8MHz SAW devices are formed side-by-side on a single sub-

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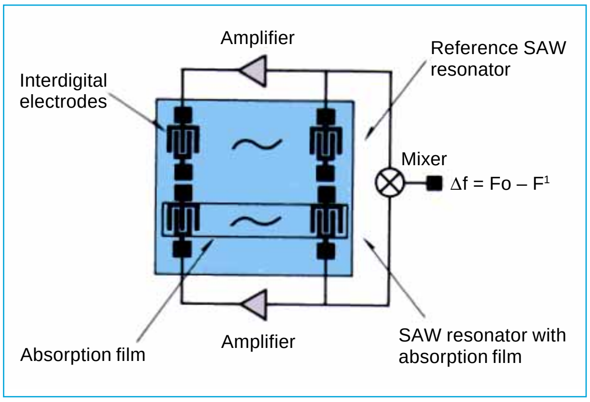

Fig. 1 Schematic diagram.

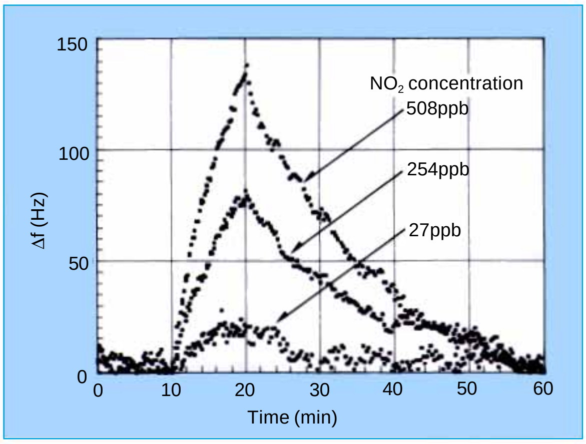

Fig. 2 Response curves (exposure to No_2 shown between arrows).

strate. One is coated with a thin, vapor-deposited CrTPP layer, and serves as the NO_X detector; the other, uncoated, serves as a frequency reference for comparison. The sensor measures 23 x 18mm, and provides outputs for measuring the frequency difference. The sensor surfaces are kept at an operating temperature of 120~130°C.

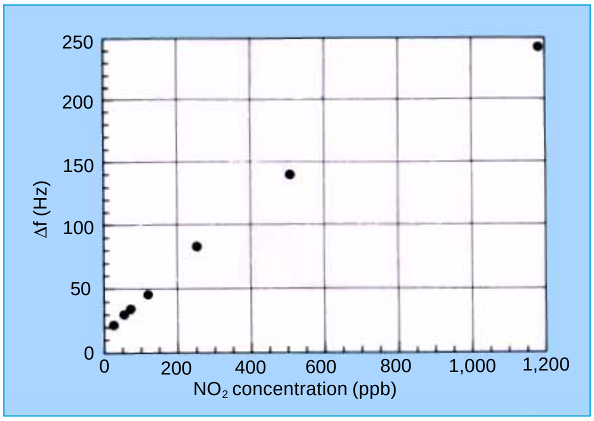

Fig. 3 Calibration curve

Sensor Response Characteristics

Fig. 2 shows the sensor response curves associated with a 10min exposure to NO_2 concentrations of 27, 254 and 508ppb. The vertical axis shows the magnitude of the change in frequency, and therefore shows positive values even though the actual frequency output of the SAW sensor decreases when NO_2 is introduced. The sensor returns to its baseline output approximately 40min after being returned to air without NO_2.

Fig. 3 shows a calibration curve derived from the Fig. 2 peak values, which indicates that the sensor will be useful down to at least the tens of ppb range. From Fig. 2, it is clear that ten-minutes' exposure was not long enough for the sensor to reach a steady state—about 20min would have been required. However, when using the first differential response, the peak of the response curve is received in 30~40s (Fig. 4). There is also a relation between this peak value and the NO_2 concentration, suggesting that we might be able to reduce the measurement time using differential responses.

Table 1 lists the sensor's selectivity with regard to other gases. The sensor does not respond to CO, CO_2, NO nor n-butane (a typical hydrocarbon compound utilized), although it does respond to the acid gas SO_2 with a sensitivity about an order of magnitude less than the NO_2 response. This should not present a problem in practice because petroleum refining and smoke-stack desulfurization processes keep the atmo-

Table 1 Gas Selectivity

Gas	Concentration (ppm)	Response Δf (Hz)
NO_2	0.98	242.5
NO	10.3	Not measurable
SO_2	1.1	21.6
CO	49.9	Not measurable
n-butane	50.2	Not measurable
CO_2	10,000	Not measurable

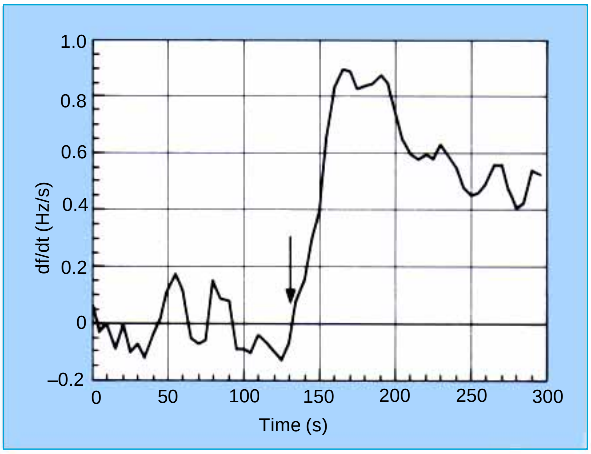

Fig. 4 Differential response curve on exposure to NO_2 at 979 ppb (arrow shows exposure start).

spheric concentration of SO_2 at relatively low levels.

These studies demonstrated that by using CrTPP film as an adsorption medium and a SAW resonator to monitor mass change it is possible to measure extremely small NO_2 concentrations of the order of 10 ppb with excellent selectivity.

Although effective, the NO_X sensors presented here had a response in the tens of minutes, whereas a faster response would be desirable for field use. The authors plan to continue their development work towards a reliable device that meets these requirements. ❑

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Advanced Ozone Water-Treatment Technology

*by Dr. Junji Hirotsuji, Yoshitaka Kawaai and Tetsuya Tamura**

Mitsubishi Electric has developed commercial ozone water-treatment technologies that can provide safe, odor-free drinking water, establish environmentally sound sewage-treatment processes and implement high-quality water reclamation systems. This article introduces advanced ozonization systems the corporation has delivered for treating drinking water and sewage, and a combined process employing ozone and hydrogen peroxide that is currently under development.

Advanced Ozonization Technology for Treatment of Drinking Water

BENEFITS. Ozone treatment of drinking water benefits water quality in several ways.

It prevents formation of trihalomethanes and other organochlorine compounds by decomposing humic acids. Humic acids react with chlorine to produce this class of substances.

It deodorizes drinking water by breaking down two major compounds that contribute to musty smell, geosmine and 2-methylisoborneol, which other processes do not remove.

Combined with activated carbon filtration, it serves to remove agricultural chemicals, wastes from high-tech industrial processes and other substances listed in water-quality regulations.

Japanese water-quality regulations require that trihalomethane, formed by the reaction of chlorine disinfectants and humic substances, be present in tap water at concentrations no higher than 100μg/l. Ozone has long been used as a decolorizing agent to decompose humic acids and other pigmented compounds, and therefore ozone removal of humic substances reduces the potential for trihalomethane formation.

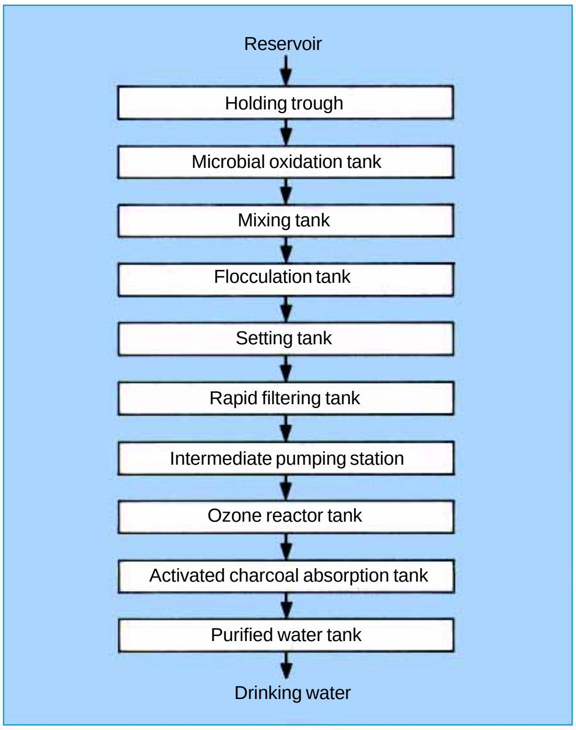

Fig. 1 The water-treatment process at the Chatan Water-Treatment Plant.

Table 1 Main Specifications of Ozone Treatment Facility at Chatan Water-Treatment Plant

Ozone reactor tank	
Construction	Reinforced concrete
No. of tanks	4 (2-stage x 2)
Capacity	194,000m^3/day
Tank dimensions	3.85 x 8.8 x 5m (W x L x D*)
Contact time	10 min. (5 min./stage)
Treatment	Diffusion with simultaneous air and water flow
Ozone generator capacities	8.1kg/h x 4
Ozone injection rate	0~4mg/l
Additional equipment	Catalytic ozone breakdown unit

*Effective depth

Activated charcoal absorption tank	
Construction	Reinforced concrete
No. of tanks	17 tanks (4 systems with 1 spare)
Capacity	219,800m^3/day
Tank dimensions	5.05 x 10.85m (W x L)
Contact time	12min
Treatment	Fixed-layer, downward-flow activated charcoal
Activated charcoal thickness	2m
Cleaning method	Blowback with air and water
Lower water collector	Porous concrete
Additional equipment	Activated charcoal supply

A WATER-TREATMENT PLANT IN OKINAWA. The corporation has already delivered 18 commercial ozone and activated carbon water-treatment systems. Here we introduce an

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ozonization facility delivered to the Chatan Water-Treatment Plant of the Okinawa Prefecture Enterprise Bureau.

The plant processes up to 194,000m^3 of water per day, concluding with ozonization and active charcoal filtration. Conventional treatment was judged incapable of satisfying water quality requirements because the rivers used as a water source were polluted with domestic wastewater, and the required chlorination would have resulted in excessive trihalomethane formation.

We designed the ozonization system to limit trihalomethanes at the consumers' faucet to 60µg/l and chloroform to 30µg/l, based on Japanese Ministry of Health and Welfare regulations, which limits trihalomethane-forming potential to less than 100µg/l, and WHO water-quality guidelines.

Table 1 lists the facility specifications. Four air-fed glass-tube silent-discharge ozone generators are used, each with an ozone production capacity of 8.1kg/hr. The water is ozonated by mixing ozonated air and water from opposite directions in a large tank, and repeating the process in a second tank. The tanks are 3.85 x 8.8m, with a 5m water depth. The water retention time is 10min.

PERFORMANCE. Table 2 lists the water quality at each stage of treatment in the facility. The ozone treatment and activated charcoal filtering accomplish the greatest reduction in trihalomethane formation potential. These processes both contribute to lower levels of total organic carbon (TOC) and methylene blue active substances (MBAS), and reduce requirements for chlorine and potassium permanganate. The facility met the original design objectives, and has contributed to a safer and better-tasting water supply.

Ozone Processing in Sewage Treatment

BENEFITS. Ozone processing is used in sewage treatment for deodorizing, decolorizing and microbicidal effects. A portion of the treated wastewater can be reclaimed through ozone processing to feed streams and fountains, supplement rivers, and for other recreational purposes, as well as applications in the treatment facility itself.

Ozone processing can also be adopted on a larger scale to decolorize the entire outflow of sewage-treatment plants where pigmented compounds—which the activated sludge process does not remove—are present in high concentrations. Ozone is an effective decolorizing agent because it selectively attacks the double-bonds that give pigments their characteristic colors.

Chlorination byproducts such as trihalomethanes and other hazardous organochlorine compounds in treated-sewage outflows affect ecosystems and can have a negative impact on water quality if they enter water sources. Ozone is more lethal to microorganisms than chlorine without forming these substances.

Many sewage-treatment plants are expected to install ozonization facilities due to these environmental benefits.

A SEWAGE TREATMENT PLANT IN OSAKA. The corporation has delivered 16 ozonization systems for sewage treatment. Here we will introduce an installation at the Chubu Treatment Plant of the South Osaka Central Coast Sewage District.

Industrial wastewater comprises most of the plant's inflow, however it also receives highly colored fiber and food-processing plant wastes that result in discolored waters where the plant discharges its outflow to Osaka Bay—which happens to be a highly visible location near a popular beach area and the New Kansai International Airport.

The plant had used sodium hypochlorite and polyaluminum chloride decolorizing agents; however, residual chlorine from these compounds caused a variety of problems, including breakup of the activated sludge floc, equipment

Table 2 Operation Results of Chatan Water-Treatment Plant

Stage of treatment	THM-FP (µg/l)	TOC (mg/l)	MBAS (mg/l)	Chlorination requirement (mg/l)	$KMnO_4$ requirement (mg/l)
Reservoir	59	1.9	0.08	2.2	7.6
After microbial treatment	57 (3)	1.75 (8)	0.05 (38)	1.0 (55)	6.8 (11)
After settling tank	44 (25)	1.43 (25)	0.05 (38)	0.5 (77)	4.5 (41)
After filtering	41 (31)	1.28 (33)	0.04 (50)	0.4 (82)	3.7 (51)
After ozonation	24 (59)	1.25 (34)	0.01 (88)	0.1 (95)	2.6 (66)
After activated charcoal filtering	15 (75)	0.72 (62)	0.01 (88)	0.0 (100)	1.5 (80)

Note: Figures in parentheses list the cumulative removal of the substance in percent.

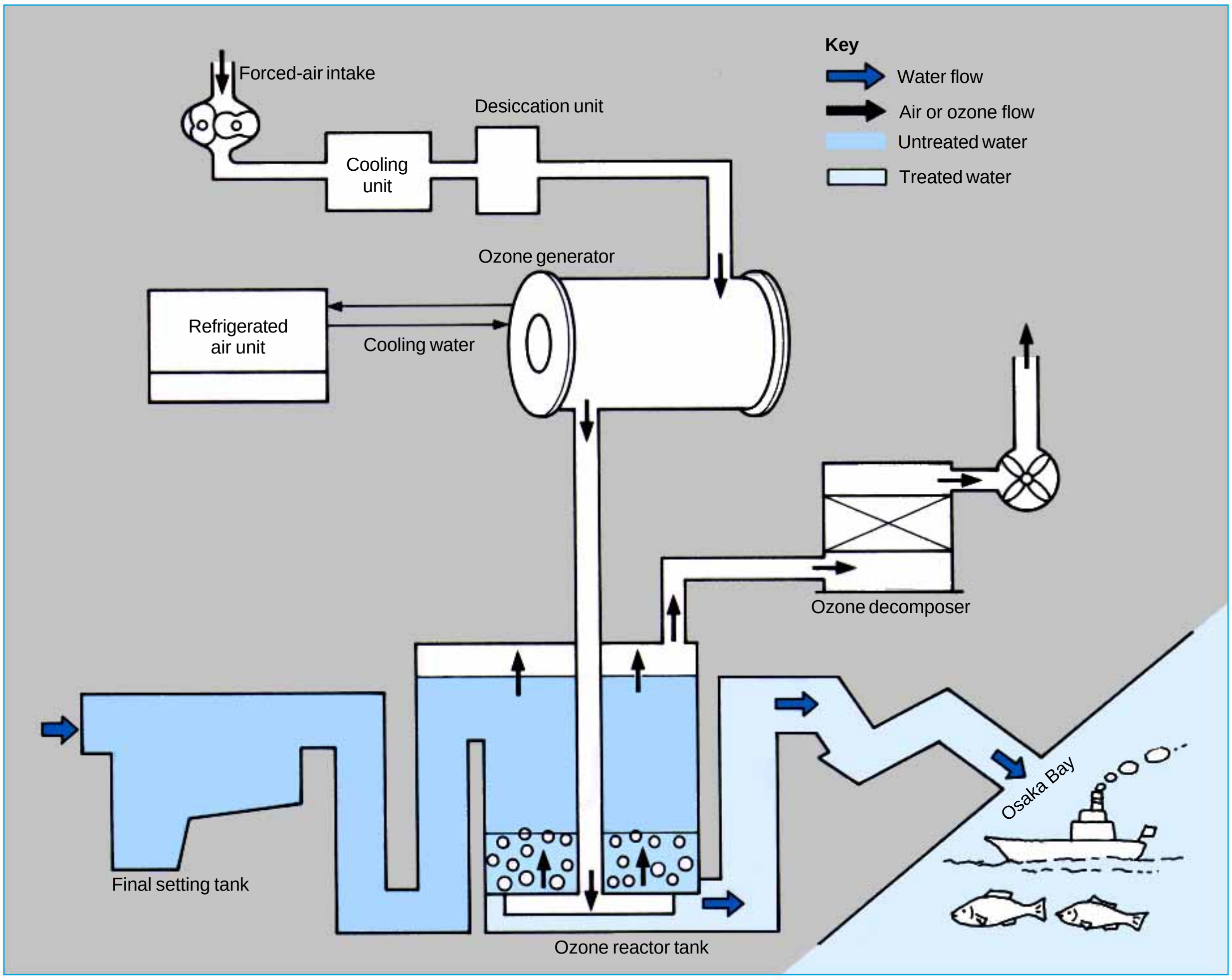


Fig. 2 The ozonation process at the Chubu Treatment Plant.

Table 3 Main Specifications of Ozone Treatment Facility at Chubu Treatment Plant

Item	Type	Number
Air blower	Roots compressor, 9.81N/cm³ (1kgf/cm³), 4.94m³/min, 22kW	6
Ozone generator	Air-fed glass-tube silent-discharge, 4kg/h (1), 5kg/h (2)	3
Ozone injector	Diffusion pipe	2
Ozone reaction tank	Reinforced concrete 2.55 x 4.5 x 4.5m (W x L x D)	2
Ozone decomposer	Activated charcoal decomposer, 200m³/h (standard state)	3

corrosion and high operating costs.

We planned an ozone decolorizing facility for the plant to alleviate these problems. The production system came online in August 1992 following extensive testing.

The ozone facility consists of an ozone generator, ozone reaction tank and catalyzer to break down residual ozone in the vented gas (Fig. 2). The facility employs one 4kg/hr ozone generator and two 5kg/hr generators, all of the air-fed glass-tube silent-discharge type. The water and ozone are mixed in two single-stage diffuser-type reactor tanks that are 2.55 x 4.5m with a 4.5m water depth. The retention time is 14.9 minutes (Table 3).

PERFORMANCE. Table 4 shows the results of the ozone decolorization treatment. Spectrophotometry was used to measure the decolorizing performance. In general the degree of coloring was measured at under 10% (practically colorless), indicating that the facility functioned as planned, although the changing composition and color degree of the effluent from the final settling tank results in some variations.

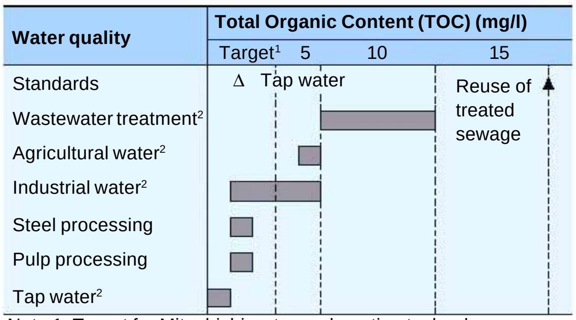
Runs 1~4 in the table show that even when the retention time (the period of contact between the water and ozone) was shortened due to large throughput, constant decolorizing performance could be achieved by boosting the ozone-injection rate. A side benefit of the process is that the chemical oxygen demand (COD) of the effluent dropped by 20~30%.

Table 4 Operation Results of Ozone Treatment Facility at Chubu Treatment Plant

Run No.	Inflow rate (m^3/h)	Reaction time (min.)	Injection rate (mg/l)	Initial water purity(%)	Final water purity(%)	Impurities reduction%	Initial COD(mg/l)	Final COD(mg/l)	COD reduction%
1	274	13.9	30.9	21.9	6.0	73	26.4	19.1	28
2	248	15.4	39.0	15.3	7.1	54	22.8	17.4	24
3	219	17.4	27.0	9.6	2.4	75	16.3	11.5	29
4	234	16.3	17.4	4.3	1.6	63	13.0	11.0	15
Avg. (1~4)	244	15.6	28.6	12.8	4.3	66	19.6	14.8	24
5	138	27.6	29.1	23.7	7.6	68	21.3	15.7	26
6	164	23.2	23.9	20.4	6.6	68	20.9	14.5	31
7	165	23.1	22.2	20.1	6.9	66	21.6	17.4	19
8	162	23.5	20.2	14.7	3.7	75	17.9	14.1	21
Avg. (5~8)	157	24.2	23.9	19.7	6.2	69	20.4	15.4	25

Note: Runs 1~4 employed two ozone generators, and runs 5~8 one ozone generator.

Table 5 Water Quality Levels and Application Requirements



Note 1: Target for Mitsubishi water-reclamation technology
Note 2: Measured values

Combined Ozone and Hydrogen Peroxide Water Reclamation Technology

BACKGROUND. Advanced wastewater treatments hold the potential to increase the water supply and reduce water pollution through extensive water reclamation. Use of reclaimed water is already on the rise, and further growth is expected.

Reclaimed wastewater needs to be sufficiently pure to serve as a source for water-supply systems or to use directly in agriculture and industry. The maximum total TOC for these applications is 2~3mg/l, which requires removal of refractory substances, such as the products of biological metabolism, and residual organic substances that remain in wastewater even after ozone treatment.

Several new processes with high oxidative potential have been studied for this purpose: high-pH ozonization, UV ozonization, and combined ozone and hydrogen peroxide treatment. At Mitsubishi Electric, we investigated combined ozone and hydrogen peroxide treatment, with the goal of achieving TOC levels of 3mg/l or lower.

The combined process is relatively simple to implement. All it requires is that we supplement a conventional ozone injection process with a small amount of hydrogen peroxide.

REACTION MECHANISM. The hydrogen peroxide reacts with ozone to produce hydroxy free radical ·OH (Eq. 1). Even more highly oxidizing than ozone, this species is capable of breaking down refractory compounds and oxidizing almost all residual organics into carbon dioxide and water.

$$O_3 + H_2O_2 \rightarrow \cdot OH + \cdot O_2H + O_2$$
$$\cdot OH + O_3 \rightarrow \cdot O_2H + O_2 \qquad \text{........(Eq. 1)}$$
$$\cdot O_2H + O_3 \rightarrow \cdot OH + O_2$$

Although the hydroxy free radical easily decomposes alcohol and other organic compounds in laboratory tests, we anticipate that inorganic ions, such as carbonate ions, present in wastewater would react with and consume much of the species. Numerous other compounds in wastewater complicate the issue, requiring further investigation.

RESEARCH AND DEVELOPMENT. Engineers in Europe and the United States are studying the varieties of wastewater, preprocessing steps to limit the ineffective consumption of hydroxy free radical, and suitable reactor vessel designs for the radical reaction. Treatment facilities using the combined process have already been set up at several water-treatment plants. Japan lags the west in the research and development of this technology, with no commercial systems implemented to date, but promising results from initial studies at Mitsubishi Electric sug-

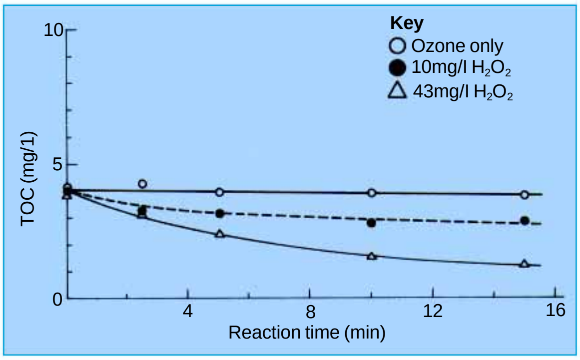


Fig. 3 TOC removal by H_2O_2/O_3 treatment after pretreatment by PAC coagulation and filtration.

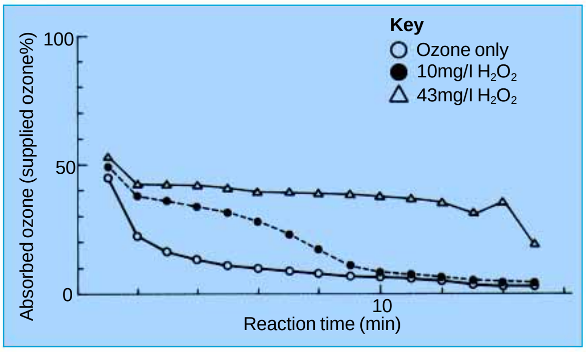


Fig. 4 Ozone absorption characteristics.

gest that this process will be suitable for future water reclamation projects.

EXPERIMENTAL RESULTS. Fig. 3 shows the results of a batch processing experiment where we subjected treated wastewater to PAC coagulation and filtration, and then used a combined ozone and hydrogen peroxide process. While ozone alone does not significantly reduce the TOC, the addition of hydrogen peroxide causes the TOC to decline to as low as 1.5mg/l.

The combined process is also more efficient: the amount of ozone consumed per TOC removed is less than that required for conventional ozonization, and the ozone absorption efficiency is higher than that with conventional ozonization.

Fig. 4 shows the results of batch experiments in water 30cm deep: absorption efficiency is 10% under conventional ozonization, while it rises to 40% with the addition of hydrogen peroxide. The absorption continues to remain high even after the reaction time has elapsed and the hydrogen peroxide has been consumed. The high absorption occurs because the dissolved ozone is quickly utilized in reactions with hydrogen peroxide and hydroxy free radical.

By supplementing existing ozonization facilities with hydrogen peroxide, we can expect to raise the absorption efficiency to 20~25% in tanks 4~5m deep, or convert processes to using compact, contact-type tanks without loss of efficiency.

In summary, the combined ozone and hydrogen peroxide treatment effectively lowers the TOC, allows construction of more compact equipment and is well suited to water-reclamation schemes.

WORK IN PROGRESS. Our current R&D is aimed at determining the best pretreatment processes and conditions, determining the optimum amount of hydrogen peroxide and its best method of introduction, and finally, the optimum ozone injection conditions.

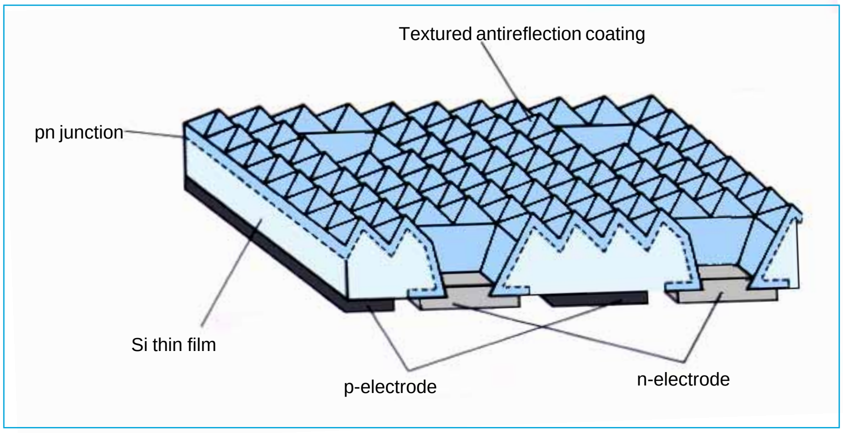
We are also conducting design studies on a practical water reclamation system. A pilot plant will enter operation by March 1996 to help determine the technology's performance under real-world conditions, and we are designing future systems that will be simple, economical to run and easy to maintain.

This R&D project was conducted in affiliation with the Public Utility System Research Project of the Engineering Advancement Association of Japan.

Water purification technology is increasingly important as we face increasing water pollution, growing urban populations and greater water demand. Mitsubishi Electric believes that its work in the field of ozonization technology for water-supply purification and sewage treatment will contribute to the health and environmental quality of future generations. ❑

New Manufacturing Process for Thin-Film Solar Cells

Mitsubishi Electric is developing a process to produce efficient and inexpensive thin-film polycrystalline silicon solar cells. The solar cell is formed on the surface of a silicon substrate, then stripped off with the aid of a special via-hole etching procedure. The process dramatically lowers the manufacturing cost because each device requires only 10% of the silicon used to manufacture a conventional device, and because the silicon substrates can be used many times. The cells have P and N electrodes on the rear surface, which boosts conversion efficiency and facilitates mass production of modules. Thin, light and flexible, the devices can be mounted in a wide variety of ways. Land, mobile and satellite applications are anticipated.



The structure of a thin-film solar cell.

Development has been supported by the New Energy and Industrial Technology Development Organization (NEDO) as a part of the New Sunshine Program under the Ministry of International Trade and Industry❑

Environment-Friendly Packaging Technologies

Fig. 1 Recycled EPS (left) and virgin product (right)l

The returnable package shown in Fig. 3 consists of two paperboard packages shipped in a single plastic box. It can be reused many times.

Low-mass packages (Fig. 4) consume fewer resources than conventional packages. The corporation designs appliances such as VCRs, air-conditioners and washing machines to be sufficiently rugged for shipping in these packages, and conducts fragility testing to ensure that the packages provide sufficient protection. ❑

Fig. 3 Returnable package for lighting fixtures.

Mitsubishi Electric has developed four environment-friendly packaging technologies that satisfy government regulations, consumer demand and in-house environmental standards.

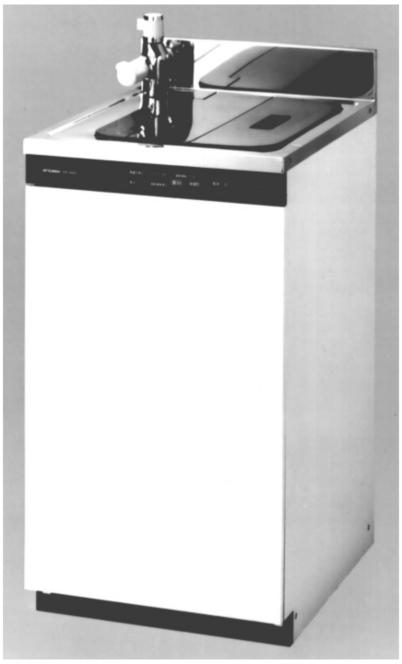
An expanded-polystyrene (EPS) recycling process enables EPS reuse in the same molding process as virgin styrofoam (Fig. 1). The used EPS is ground up, processed into uniform beads, treated with anti-static chemicals, and mixed with virgin beads prior to molding.

An all-paperboard package reduces packaging waste by substituting paperboard triangles for styrofoam blocks. The Japan Packaging Institute awarded Mitsubishi Electric a prize for the paperboard lighting fixture package shown in Fig. 2. One box houses five lighting fixtures. The paperboard is easily recycled.

Fig. 2 All-paperboard package for lighting fixtures.

Fig. 4 Low-mass paperboard package for a VCR

Cooking Washer



The Cooking Washer.

The widespread use of electrical home appliances has greatly lightened the burden of general housework. In the kitchen, however, “washing” has usually meant “washing by hand,” and rationalization of this task has long been sought. Previous dishwashers, while they were suitable for washing a number of dirty dishes at the same time, have not been able to perform the washing operations involved, for example, in cooking. Our research suggests that this kind of washing accounts for two-thirds of all washing done in the kitchen.

The Cooking Washer uses a high-speed water jet to wash away oily dirt without the use of detergents, and then uses a high-speed jet of air to remove water droplets. It is fast and flexible enough to handle all of the washing tasks in the kitchen, including those involved in cooking. It is extremely easy to operate, with a large opening for inserting dirty items into the washer, where they are immediately detected and washed. Anything that enters the washer, from dishes to cooking utensils, including pots and pans and even the ingredients to be cooked, can be quickly and easily washed. Thrifty with water and energy, the Cooking Washer is very easy on the environment. ❑

Compact Lossnay Ventilation Units

Intended for continuous use in well-sealed residences, Models VL-30SL and VL-30SL-BE serve fresh-air supply and exhaust functions using an energy-saving Lossnay heat-exchange element. The units occupy half the volume of previous models and can be easily installed to improve the ventilation in existing dwellings. They mount in a 65mm hole, the same size used for air-conditioners, and the outdoor hood uses knurled screws for attachment without tools. The fresh-air intake is fitted with a dust filter. ❑

Model VL-30SL and VL-30SL-BE Lossnay ventilation units.

The JT-16C “Jet-Towel” Hand Dryer

In recent years, devices for drying the hands—from paper or cloth towel dispensers to hot-air hand dryers—are increasingly found wherever people live and work. Paper towels have the disadvantage of using valuable natural resources, and other problems associated with these devices include waste disposal and processing, hygiene and length of time taken to completely dry the hands.

Mitsubishi “Jet-Towel” hand dryers, first introduced in *Advance* Vol.70, adopt a completely new approach to drying that solves all of these problems. Previous dryers used a flow of warm air to evaporate droplets of moisture on the hands. They therefore suffered the disadvantage of taking a long time to dry the hands (30~40s).

In contrast, the JT-16C Jet-Towel is compact, with a long useful life, and it uses a highly reliable brushless blower motor to generate a high-speed blast of air (60m/s) that literally blows away all droplets of moisture, drying the hands in a matter of only 5~10s.

Operation is completely automatic and only requires that the hands be briefly inserted in, and then withdrawn from, the device. At no time do the hands need to come into contact with any part of it. The droplets blown off the hands are collected in the drain tank under the device. The product boasts outstanding hygiene and ease of maintenance, and is expected to generate rapidly expanding sales. ❑

The Jet-Towel hand dryer, JT-16C.

Energy-Saving Ozone-Friendly Refrigerator

The 407-liter Model MR-J41B employs the world's first mass-production rotary compressor for use with environmentally acceptable HFC-134a refrigerant. The refrigerator is energy efficient, consuming 20% less power than previous models. This is achieved by use of a compressor motor control system providing high startup torque and a highly efficient control setting for when the motor reaches operating speed, and by addition of a valve that maintains the pressure difference between the high-pressure and low-pressure sides of the refrigerant circuit when the motor shuts down. In addition, a new lubrication technology reduces compressor vane wear by 50% compared with previous products, ensuring long, reliable operation. The four-compartment model comprises a refrigerator compartment on top, a two-level drawer-type freezer, and a vegetable compartment. The automatic icemaker is designed to prevent ice from picking up food odors. The control system incorporates neural-network and fuzzy-logic principles. ❑

The MR-J41B refrigerator using HFC-134a refrigerant and a rotary compressor.

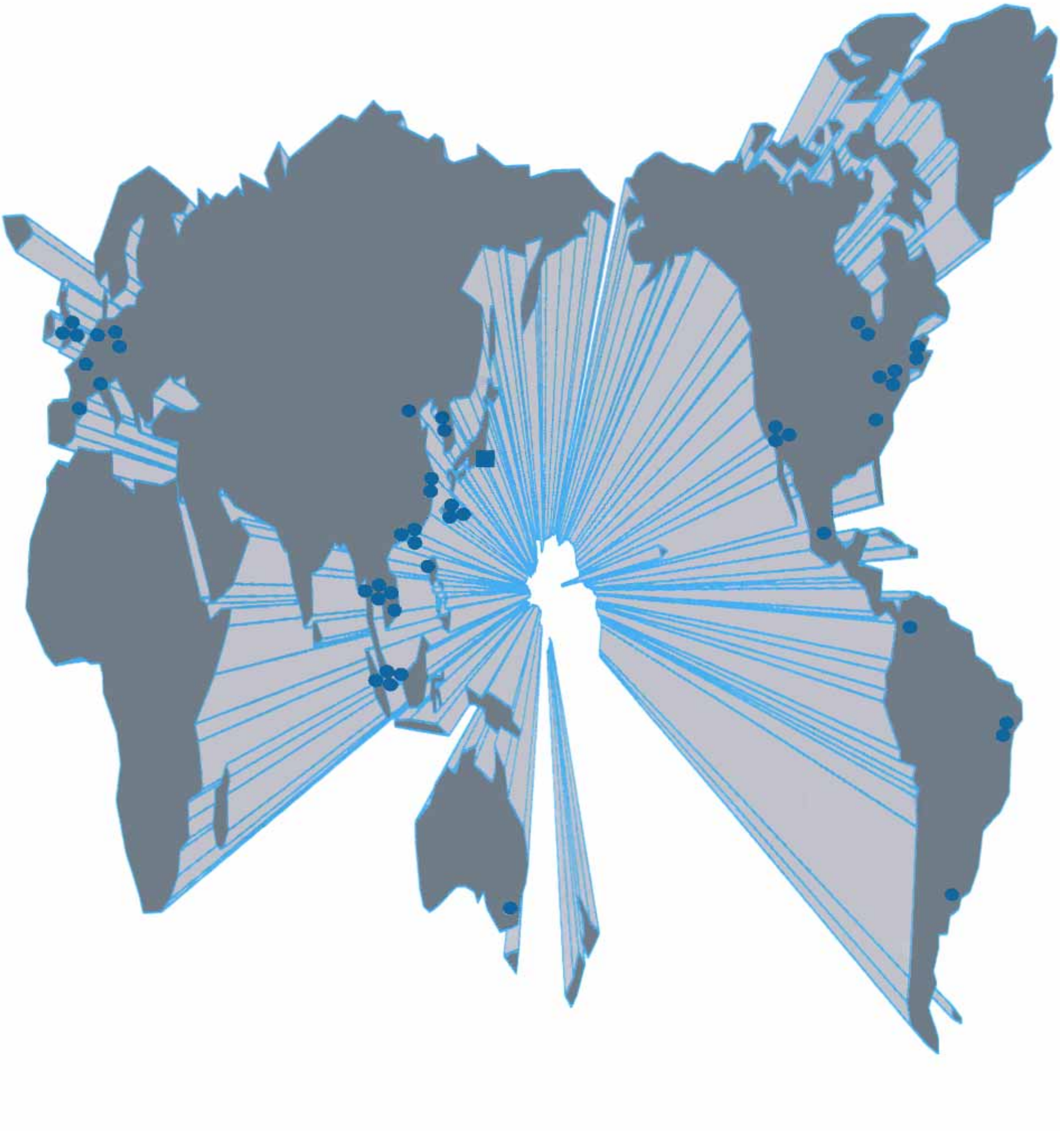
Energy Conservation Measures for Room Air-Conditioners

The front panel and remote control unit of an MSZ-FX255 room air-conditioner.

Series MSZ-FX255 room air-conditioners for 1995 consume only half the power of previous models at rated output, and are estimated to consume 40% less energy per year. Several improvements have made this possible. All models have a compressor with an energy-saving brushless DC motor that provides the same cooling power with 15% lower energy input. The area of the heat exchangers has been expanded by 50% in the indoor units and 100% in the outdoor units. The units feature larger diameter fans with a new blade design that is 35% more efficient at rated output. Additional resource savings have been achieved by reducing the component count by 25% in the indoor unit and 26% in the outdoor unit.

Consumer air-conditioners now consume more electric power per household than refrigerators in Japan. About 80% of Japanese households have at least one air-conditioner installed and 50% have two or more. Environmental and cost considerations make more energy-efficient appliances essential. ❑

SERVING THE WORLD



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