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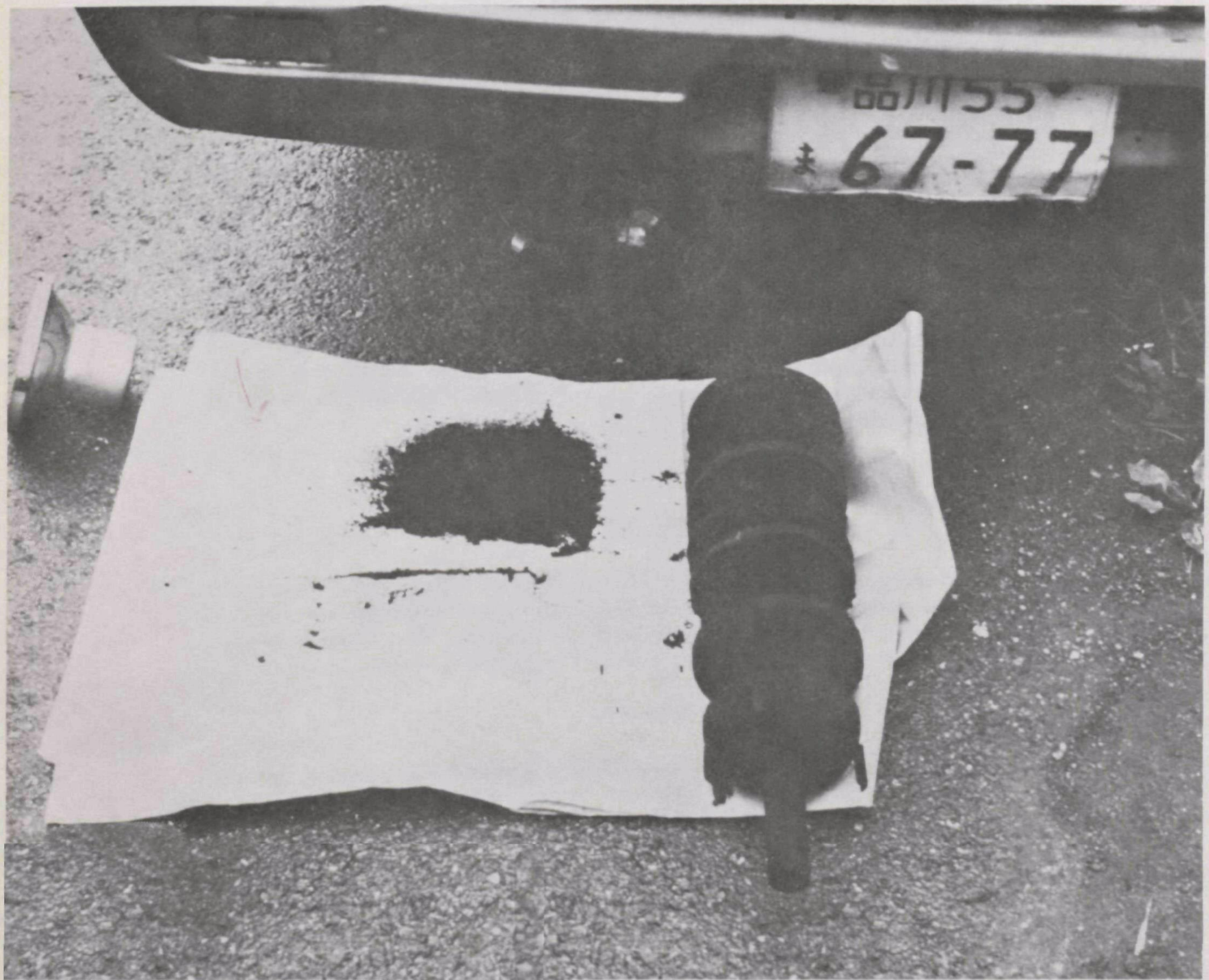
# Particulate Control Highlights: Recent Developments in Japan



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November 1979

# Particulate Control Highlights: Recent Developments in Japan

by

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Office of Research and Development
Washington, DC 20460

ABSTRACT

This report describes the results of visits in Japan to assess research and development of new particulate control technology, and to evaluate the applicability of the Aut-Ainer particulate control device to diesel engines.

New technology observed includes hooding systems for coke oven charging and pushing, fugitive emissions control in a Q-BOP furnace building, novel electrostatic precipitators (ESPs), magnetic separators, and hybrid control devices. Fugitive emissions in two iron and steel plants visited are well controlled. Fugitive emissions are prevented by road watering and process hooding. Fugitives within a large building are collected by a special lightweight ESP. Novel ESPs utilize approaches such as wide plate spacing, advanced charging systems, and water cooled collection electrodes. Magnetic separators are currently used for water pollution and are under consideration for air pollution control.

The Aut-Ainer has evolved from an experimental approach to the device development stage over several years. The device currently has limited applicability to particulate control from diesel engines. However, its basic collection characteristics seem to be based on sound principles; with a limited amount of additional development in the general area of removing the previously collected material, the device seems promising.

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## INTRODUCTION

Many problem areas in particulate control can be found in both the United States and Japan. For example, both countries are oil importers and look forward to partially solving future energy needs by burning low sulfur coal. In the United States, low sulfur coal is abundant in the western states. Use of low sulfur western coal in power plants with electrostatic precipitators designed for high sulfur coal has led to increased particulate emissions because of increased resistivity associated with fly ash from low sulfur coal. The low sulfur coal used in Japan comes from Australia. The Japanese have been anticipating problems with collection of low sulfur coal fly ash and are developing new electrostatic precipitator designs to overcome the problems. In another energy related area, both the United States and Japan increase fuel economy for transportation by using diesel engines. However, particulate emissions from diesel engines may be two orders of magnitude higher than those from gasoline engines. The increased particulate emissions would be at the worst location--in cities, near large numbers of people who would be directly exposed.

Both the United States and Japan are leading producers of iron and steel. Consequently, both face the problems of the magnitude and complexity of emissions from the iron and steel industry. While control of ducted sources has tended to improve, control of emissions from coke ovens, hot metal transfer, sinter plant fugitives, storage piles, and roads has been difficult. In Japan, new ideas in hooding and control devices are leading to the solution of some of these fugitive emission problems.

Because of the similarity of particulate control problems and the need to share technology which could provide solutions, a team of particulate control specialists, who are the authors of this report, visited Japanese companies and research organizations during May 1979. This report summarizes the information received and is intended to stimulate technology transfer. To that end, the authors will provide more detailed information upon request and have noted personnel contacted so that others may establish direct information exchange.

## CONCLUSIONS

Japanese firms concerned with controlling high resistivity particulate matter include Mitsubishi Heavy Industries Company, Hitachi, Ltd., Idemitsu Kosan Company, and Nippon Steel Corporation. A number of different approaches have been taken by these firms, including the use of prechargers, cooled collection electrodes, and increased sectionalization. Use of prechargers may not only solve high resistivity problems but also reduce costs over conventional design. The latter two options may reduce costs compared to a precipitator of equal performance but are expensive on an absolute scale.

Japanese firms concerned with controlling diesel emissions include Eikosha Company, Mitsubishi Motors Corporation, and the Japan Automobile Research Institute. The Eikosha Company has evolved a control device which consists of a primary and a secondary collector. The first agglomerates the particles and diverts them to the secondary collector. The secondary collector is a glass bag filter which may be dumped. The Japan Automobile Research Institute is experimenting with a diesel engine which uses both alcohol and diesel fuel. This reduces emissions and conserves diesel fuel. Both approaches have been tested and will reduce emissions by at least 50 percent.

Japanese firms developing or using new concepts for particulate control include Kawasaki Steel Corporation, Daido Steel Company, Hitachi, Ltd., Onoda Cement Company, and Mitsubishi Heavy Industries Company. New concepts include magnetic filtration, electric coagulation, and roof-mounted, hybrid, or wide plate spaced precipitators. Use of magnetic filtration for cleaning iron and steel waste waters lowers operating and installation costs compared to other systems. Use of wide plate spaced precipitators involves lower capital costs because of the fewer number of plates and accessories. Roof-mounted precipitators can control emissions from large shops in the iron and steel industry. This is especially important where some fugitive emissions can be contained only by the shop building itself.

## RECOMMENDATIONS

1. The applicability of Japanese techniques for fugitive particulate control in the U.S. should be surveyed.

2. Japanese approaches for diesel particulate control should be tested under EPA supervision.

3. Development of the diesel fuel/alcohol engine should be encouraged.

4. Parallel efforts in magnetic filtration should be coordinated between the two countries.

5. Improved performance of new designs for electrostatic precipitators should be verified.

6. Australian and U.S. low sulfur coal should be compared to allow interpretation of Japanese results with collection of low-sulfur-coal fly ash in the U.S.

Mitsubishi Heavy Industries Co., Ltd.
Takasago Technical Institute
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Takasago, Hyogo Pref. 676 Japan

Personnel Contacted: N. Tachibana, Manager
Y. Saito, Manager
K. Yata, Group Leader
K. Tashiro, Senior Engineer
Dr. M. Matsumoto
K. Tomimatsu

Mitsubishi Heavy Industries has research centers at Takasago, Nagasaki, and Hiroshima. Air pollution control research at the latter two deals with gaseous pollutants especially sulfur and nitrogen oxides. Research at Takasago involves noise reduction as well as particulate control for air and water. Particulate control research currently stresses electrostatic collection but may give increased attention to fabric filtration in the future. Mitsubishi personnel are concerned with the projected large imports of Australian low sulfur coal for power plant combustion. Consequently, filtration with acrylic bags at 120°C is under consideration for fly ash collection. Recently completed or active projects include:

1. Electric Coagulation - Pictures were taken at the inlet and outlet of an electrostatic precipitator to determine coagulation of hydrocarbon particles. At present most electrostatic precipitators are used on heavy oil fired power plants where resultant fly ash may form stable agglomerates.

2. Acoustic Coagulation - The general phenomenon and the Braxton device in particular were studied. Either as a sole collector or as a conditioner for another device, this approach was concluded to be less cost effective than other approaches.

3. Precipitator Electrode Spacing - For both cold- and hot-side applications of electrostatic precipitators, the optimum electrode spacing was determined. It was generally concluded that a spacing from 400 to 500 mm between collector electrodes was optimum in contrast to U. S. precipitator designs where 200 to 300 mm is typical.

4. Electro Filter - For this concept, the particulate is charged and collected in a high-void-fraction, deep-bed filter. The method is very effective for collection of high resistivity dusts but no satisfactory cleaning method was found.

5. High Pressure Gas/Particulate Control - At 110 to 150°C and 2-3 $kg/cm^2$, the applicability of an electrostatic precipitator was verified for blast furnace gas.

6. Vanishing Temperature - Experiments in hot-side precipitator application were conducted to eliminate back corona by increasing temperature for a variety of coal fly ash. As temperature increases, resistivity decreases and eventually back corona vanishes. (The U.S. delegation noted that this method may not predict the vanishing temperature in actual operation if residual fly ash on the collection plates is deleted of charge carriers and becomes more resistant.)

7. New Types of Electrodes and Precipitators - Where space charge is a problem, use of a newly developed electrode with long spikes and a steep V-I curve was planned. Details of the new precipitator type were not provided.

8. Development of Control for Coal Fired Boilers - Special problems are expected in collecting fly ash from low sulfur coal. Both hot-side precipitators and adapted cold-side precipitators will be tested in a plant being constructed to burn various types of coals.

Nippon Steel Corporation
Nagoya Works
#3-5 Chome Tokai-City
Aichi Pref.
Japan

Personnel Contacted: A. Sakaguchi, Asst. Manager
Y. Kojima, Section Chief

Nippon Steel has a problem with high resistivity sinter particulate when using Chilean ore ($\Omega = 10^{13}$ ohm-cm). Other ores from Australia and South Africa do not present a serious problem ($\Omega = 10^{11}$ ohm-cm). To deal with the worst case (when Chilean ore must be used), Nippon Steel has installed a novel electrostatic precipitator with horizontal compartments or "houses." Corona wires are horizontal, thin, stainless steel piano wire (0.5 mm diameter). The wires as well as the plates are wrapped. The spacing between grounded electrodes is extremely wide (1.2 m) and the operating voltage is correspondingly high (140-150 kV), with a maximum of 200 kV. The gas velocity is typical, 1.6 m/sec. The inlet sinter particulate is at a concentration of 0.5 - 0.7 g/Nm$^3$ and is reduced at the outlet to 0.02 - 0.05 g/Nm$^3$. Cost of the precipitator in 1974 was 60,000 ¥/m$^3$/min (\$300/m$^3$/min). Nippon Steel had calculated that the cost of a standard precipitator would be lower but did not feel that a conventional precipitator could handle their problem, especially when they used Chilean ore. In addition to seven installations of the novel house-type precipitator, Nippon Steel also has a precipitator with a bias-controlled pulse charging system in combination with zig-zag shaped electrodes. Experience with this system is limited: the anticipated high resistivity problem for its application did not develop and the charger is not operated in a pulse mode.

Onoda Cement Company, Ltd.
Takara Plant
Toyohashi Pref. Japan

Personnel Contacted: E. Sugo, Manager
M. Munakata

Onoda Cement Company has two installations which are of special interest: A wide-space electrostatic precipitator in successful continuous operation since 1972, and a hybrid (wet and dry) electrostatic precipitator. Onoda Cement has three rotary kilns; however, only No. 2 was in production at 1200-1250 tons/day. The wide-space precipitator is used on the clinker cooler for No. 2 (see Figures 1 and 2). The precipitator has two fields: the first with a plate-to-plate spacing of 320 mm and an average voltage of 44 kV (65 kV maximum); and the second, a spacing of 570 mm and an average voltage of 80 kV (110 kV maximum). The inlet loading to the precipitator is 4.3 g/Nm$^3$, and the outlet loading is 0.014 g/Nm$^3$ with no visible plume. Other data are shown in Table 1. The hybrid precipitator is used on the rotary kiln gas (see Figure 3). The first field is dry and second is wet. Both fields provide approximately 96 percent collection efficiency. The collection plates in the second field are washed continuously to a clarifying system which recycles water to the precipitator. Onoda Cement uses water sprays to control emissions from storage piles and conveyor belts.

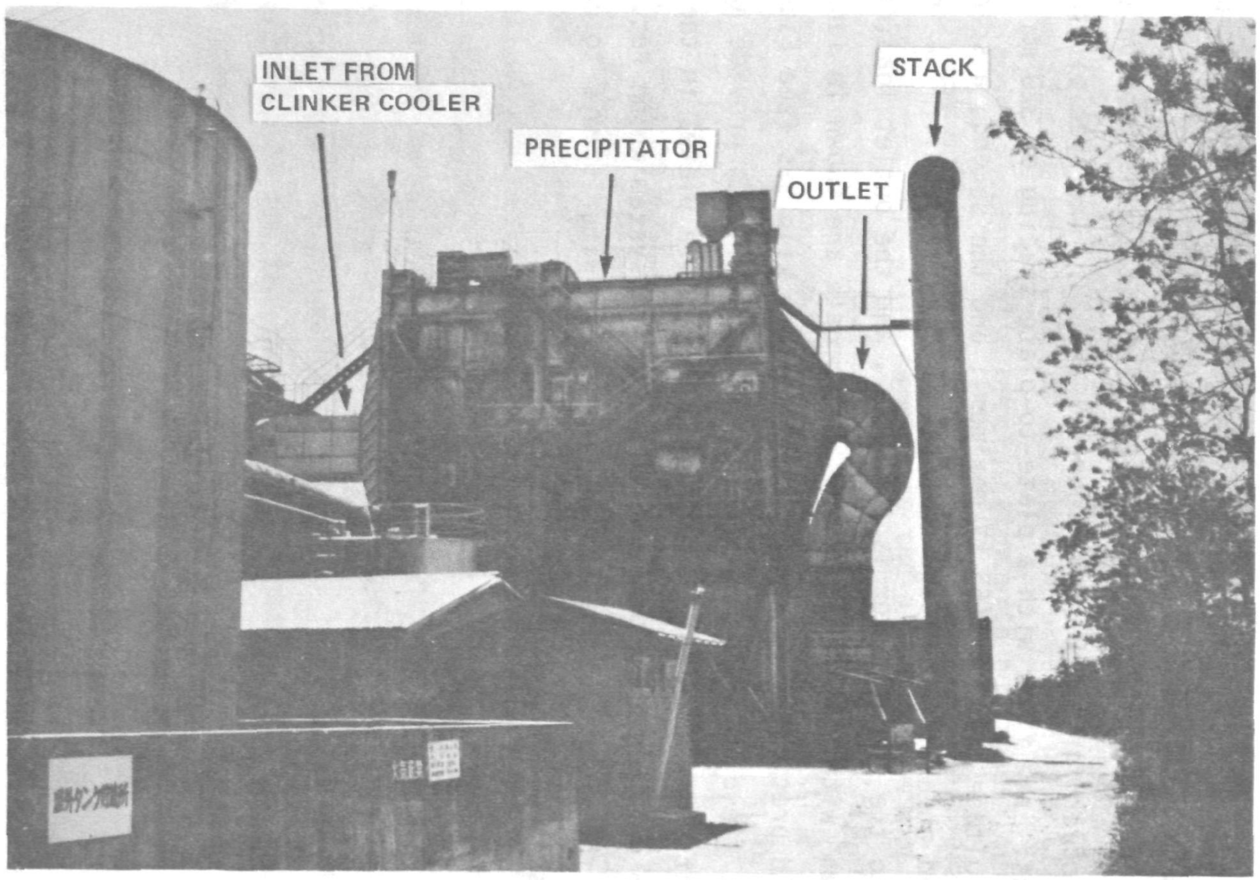


Figure 1. Wide plate spaced precipitator at Onoda Cement Company.

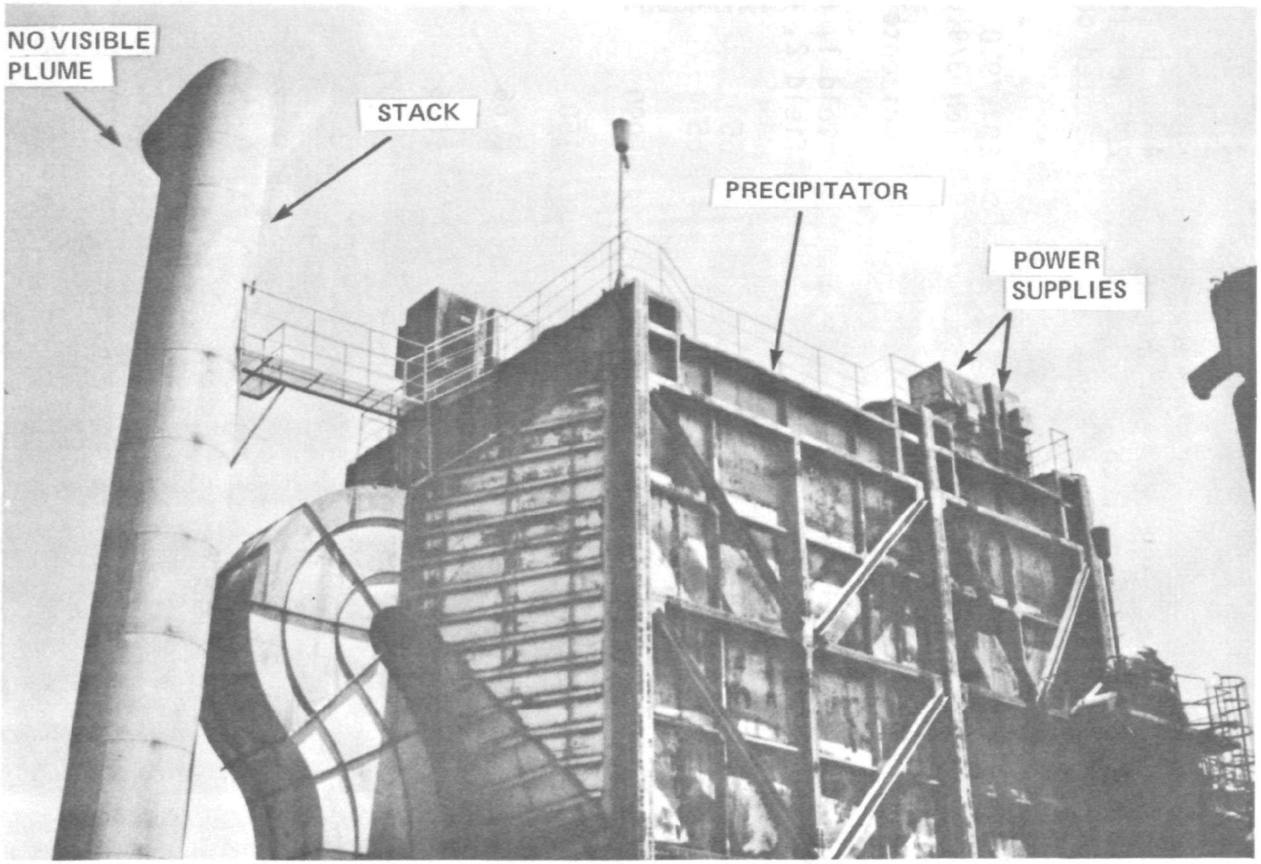


Figure 2. Stack and back side of Onoda electrostatic precipitator.

Table 1. PARAMETERS OF ONODA PRECIPITATORS

| Type | Wide Space | Hybrid |
|---|---|---|
| Number of fields | 2 | 2 |
| Discharge wire | 4 mm/SUS 27/star shaped<br>200 mm pitch<br>mounted on a frame | 4 mm/SUS 27/star shaped<br>200 mm pitch<br>mounted on a frame |
| Collecting electrode | both fields,SS541<br>field 1, 7.3 x 3.0 m<br>field 2, 7.3 x 5.0 m | - - -<br>SS41/9.0 x 5.5 m<br>STEN 3/9.0 x 2.5 m |
| Rapping (wires & plates) | horizontal | horizontal |
| Plate current, mA | 400 | field 1, 600<br>field 2, 400 |
| Design voltage, kV | field 1, 65<br>field 2, 110 | 65<br>65 |
| Gas flow rate, $m^3$/min | 2500 | 2090 |
| Temperature, °C | 150 | 150 |
| Gas velocity, m/sec | 0.56 | 0.66 |
| Inlet to field 1, g/$Nm^3$ | field 1, 4.3<br>field 2, - - | 20.5<br>0.8 |
| Outlet, g/$Nm^3$ | 0.014 | 0.03 |
| Efficiency, % | 99.7 | 99.84 |
| Year purchased | 1972 | 1973 |
| Cost, ¥ | 68,500,000 | 78,000,000 |

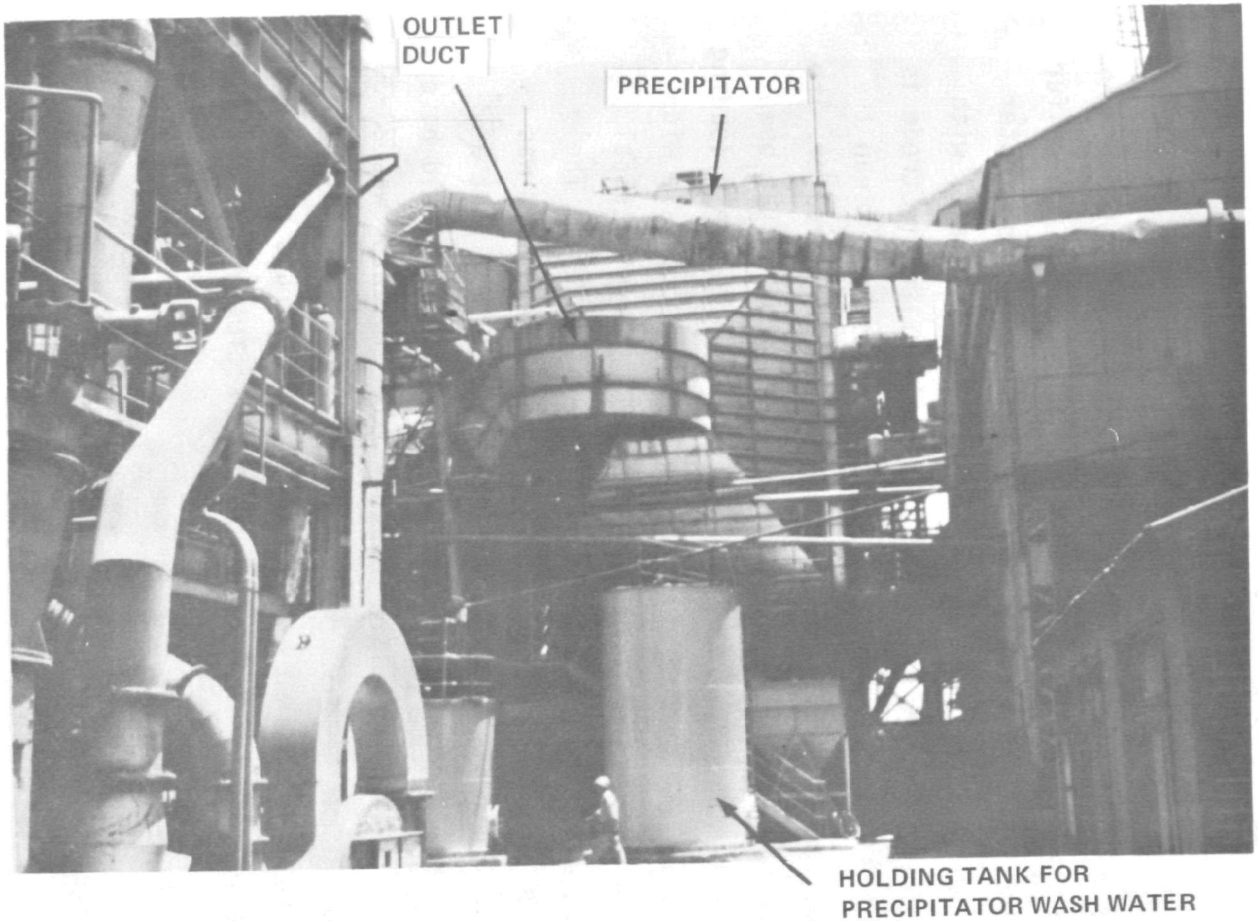


Figure 3. Hybrid precipitator at Onoda Cement Company.

Idemitsu Kosan Company, Ltd.
Chiba Refinery
Kaigan 2-1 Anesaki, Ichihara
Chiba, Japan

Personnel Contacted: K. Shiraishi, Manager
A. Iwasaki, Manager
K. Kimura
Y. Kikuchi

Chiba Refinery is using a novel electrostatic precipitator to control emissions from a fluid catalytic cracker (FCC). When low sulfur oil is treated in the FCC, resistivity at flue temperatures is greater than $10^{13}$ ohm-cm. To avoid this high resistivity, a precipitator with cooled collection electrodes was installed. The collection electrode is actually a series of 20 vertical rectangular water ducts. To clean the collecting electrode, a scraper is lowered on a chain from a roller. The scraping action reportedly works well, but some chain erosion has been noted. Total gas flow rate is 214,000 $Nm^3$/hr. Inlet particulate loading is 0.88 g/$Nm^3$, outlet 0.043 g/$Nm^3$. This precipitator also uses a wide plate spacing (700 mm) and high voltages. There are three electrical fields; voltages are 80-96, 70-84, and 63-75 kV, respectively. The plate currents are 110, 65, and 60 mA, respectively. The system was purchased in 1974 at a cost of ¥300,000,000. It was claimed that a conventional electrostatic precipitator for this application would have had to be twice as large: consequently this novel precipitator was 20-30 percent lower in cost. Further, the water heated in the precipitator is used elsewhere in the plant for an energy savings which could pay out the cost of the precipitator in a few years. The precipitator is pictured in Figures 4 and 5.

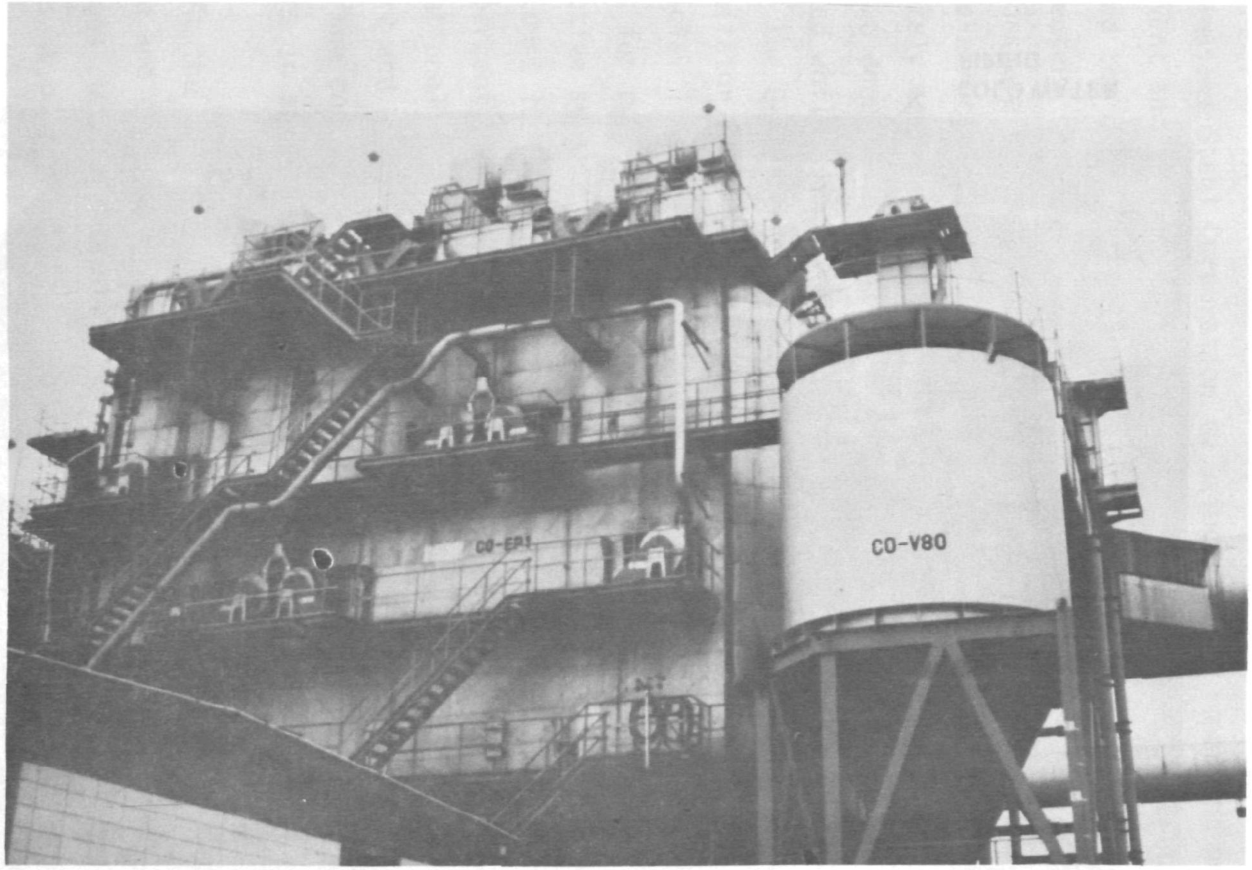


Figure 4. Cold electrode electrostatic precipitator at Idemitsu Kosan Company.

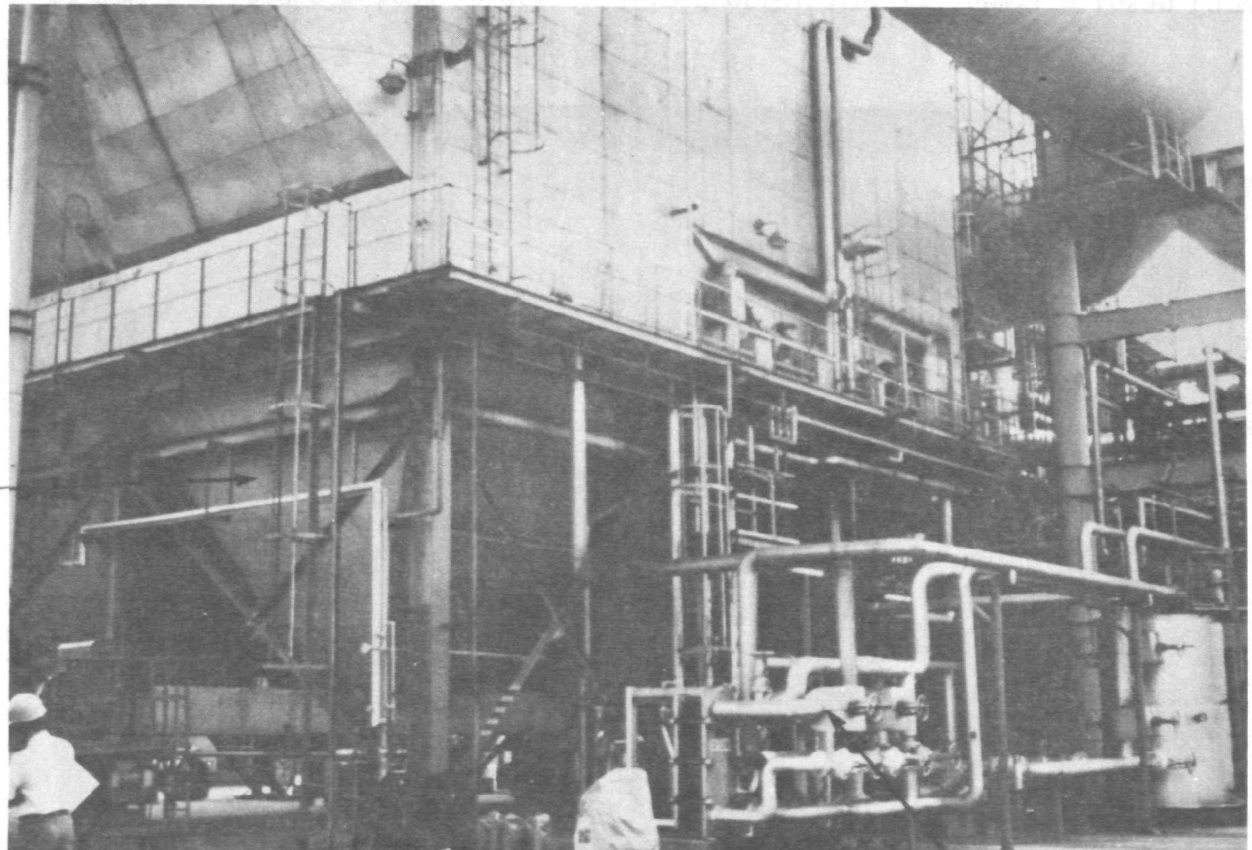


Figure 5. Cold water piping and hoppers for Idemitsu precipitator.

Kawasaki Steel Corporation
Chiba Works
1, Kawasaki-Cho Chiba City
Japan

Personnel Contacted: K. Tsutsumi, General Manager
H. Takao, Manager
T. Tanaka, Manager
K. Sakai, Sumitomo Heavy Industries

Kawasaki Steel Corporation is using several important new concepts to prevent and control fugitive emissions associated with its Q-BOP shop and the coke oven battery. Q-BOP direct emissions are controlled by a venturi scrubber with a pressure drop of 30 in. $H_2O$. Q-BOP fugitive emissions are collected by a hooding system which is evacuated to a reverse-air-cleaned baghouse rated at 18,000 $m^3$/min. The Q-BOP is completely enclosed by the hooding system except for access, at which time two doors slide away from each other to reveal the furnace. Emissions produced while the doors are open are conveyed by natural draft to the top of the Q-BOP shop (a distance of about 50 m) and through an electrostatic precipitator on the roof (see Figure 6). This precipitator is constructed of special light-weight, widely spaced plates to allow low overall weight for roof installation. Collecting electrodes are made of electric-conductive synthetic resin. The plate-to-plate spacing is 420 mm. The inlet dust loading is 0.4 g/$Nm^3$; outlet, 0.03 g/$Nm^3$; and overall efficiency, 92.5 percent. Costs for this precipitator are comparable to those for a conventional precipitator. Some expenses (such as those for structural support and ducting) are less. However, the use of water washing to clean the collecting electrodes adds an expense which balances out the savings in support and ducting.

At the coke oven battery, both charging and pushing operations are hooded and evacuated through a control device. For charging, two circular flue gas ducts are on either side of the charge car. These ducts have a series of ports which may be accessed by the charge car hooding system for any position of the charge car on the coke oven battery. When the charge car moves to a new position, the connectors from the charge car enter appropriate ports in the flue gas ducts. Charging emissions are drawn from the charge car through the ducts to a wet scrubber.

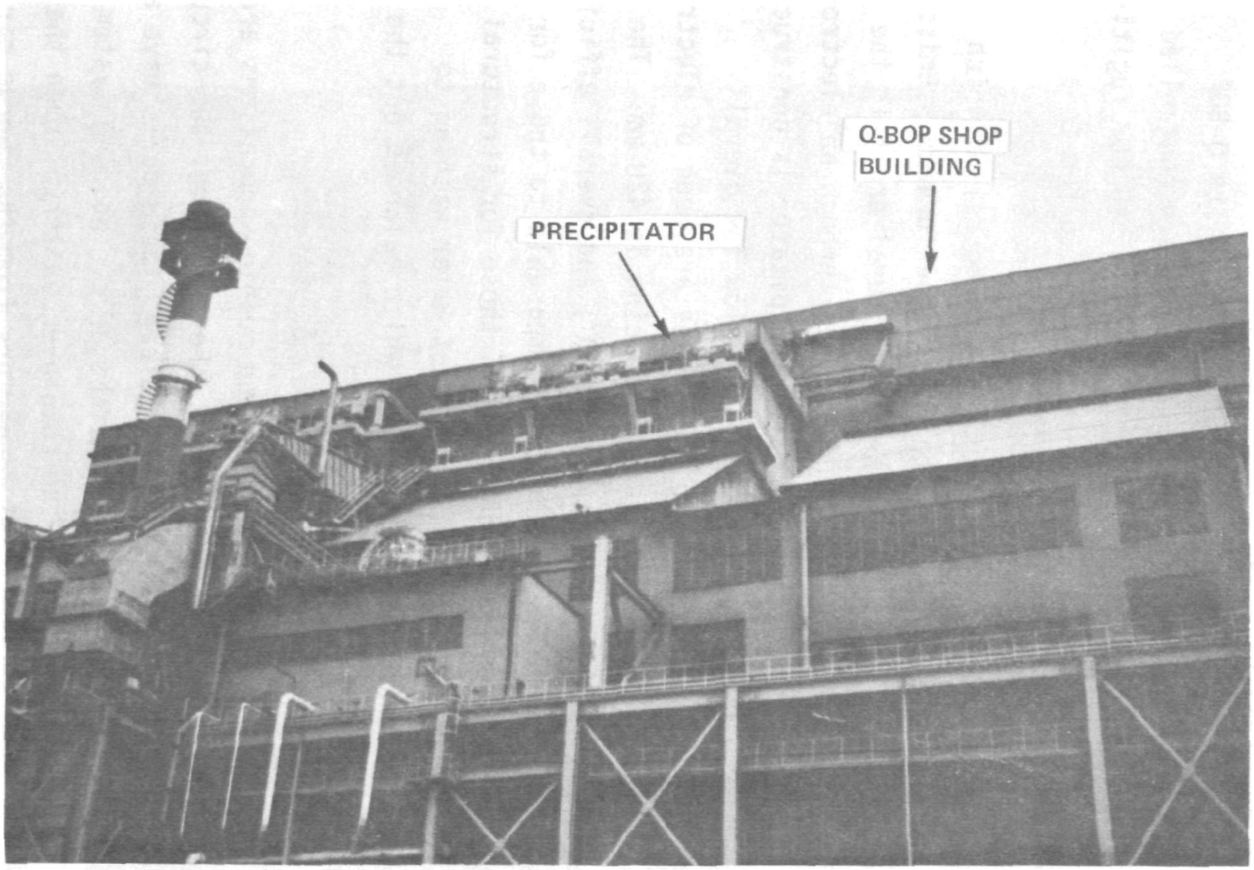


Figure 6. Roof-mounted precipitator at Kawasaki's Chiba Works.

For pushing, a movable hood (positioned above the car) catches the push. The hood connects with a large rectangular duct that extends the length of the coke oven battery. This duct also has a series of ports which allow the hood to be connected at any position. The ports are on top of the duct and are covered by metal disks which are raised magnetically for access. When the pushing hood moves to a new position, the connector from the hood covers three ports on the duct and the proper ports are opened. Pushing emissions are drawn from the hood through the duct to a wet electrostatic precipitator.

Other practices at Kawasaki Steel Corporation are worth noting. Paved roads at the plant are washed down periodically during the day. Trenches, dredged occasionally, on either side of the roads remove the washed-off particulate. This washing not only prevents fugitive dust emissions from the roads but also provides an active method for reuse or disposal of collected material. In large open areas where dust can deposit, water sprays are used to control emissions. In other open areas where it does not interfere with plant operation, trees and shrubs are planted. Besides adding to the visual quality, such plantings promote prevention and control of fugitive emissions.

Kawasaki Steel Corporation
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1, Kawasaki-Cho Chiba City
Japan

Personnel Contacted: K. Tsutsumi, General Manager
T. Tanaka, Manager
H. Takao, Manager
K. Tahara, Engineer

Kawasaki began studying the application of high-gradient magnetic filtration (HGMF) to steel mill waste waters in 1976. In coordination with Sala Far East (a division of Sala Magnetics of Cambridge, MA) and Hitachi, Ltd., Kawasaki tested a pilot unit for 6 months on several processes at their Chiba plant. Results were quite encouraging, and Kawasaki decided to install a full-scale device to treat 900 $m^3$/hr of scrubber waste water from a vacuum degasser (see Figure 7).

The production unit has been in operation for about a year (as of May 1979). It was built by Hitachi under a Sala license. It has a 2.1 m diameter canister with a field capability of 0.52 tesla at 50 kW input, but is normally operated at 0.3 tesla. Kawasaki estimates that the system cost about 50 percent more than a competitive flocculation/filtration treatment system. (See comments on cost in Hitachi visit description.) The HGMF system also requires only 20 percent of the land area of a conventional system.

Kawasaki is quite pleased with the HGMF installation. Its particulate removal is good. The filter is backflushed about once an hour with high velocity water. The only problem they have incurred is a gradual buildup of residual material on the filter which necessitates external cleaning every 6 months. They think this can be eliminated by replacing the steel wool filter with wire cloth.

Kawasaki is considering installing HGMF systems to solve other waste water problems, but have not yet studied any direct air applications.

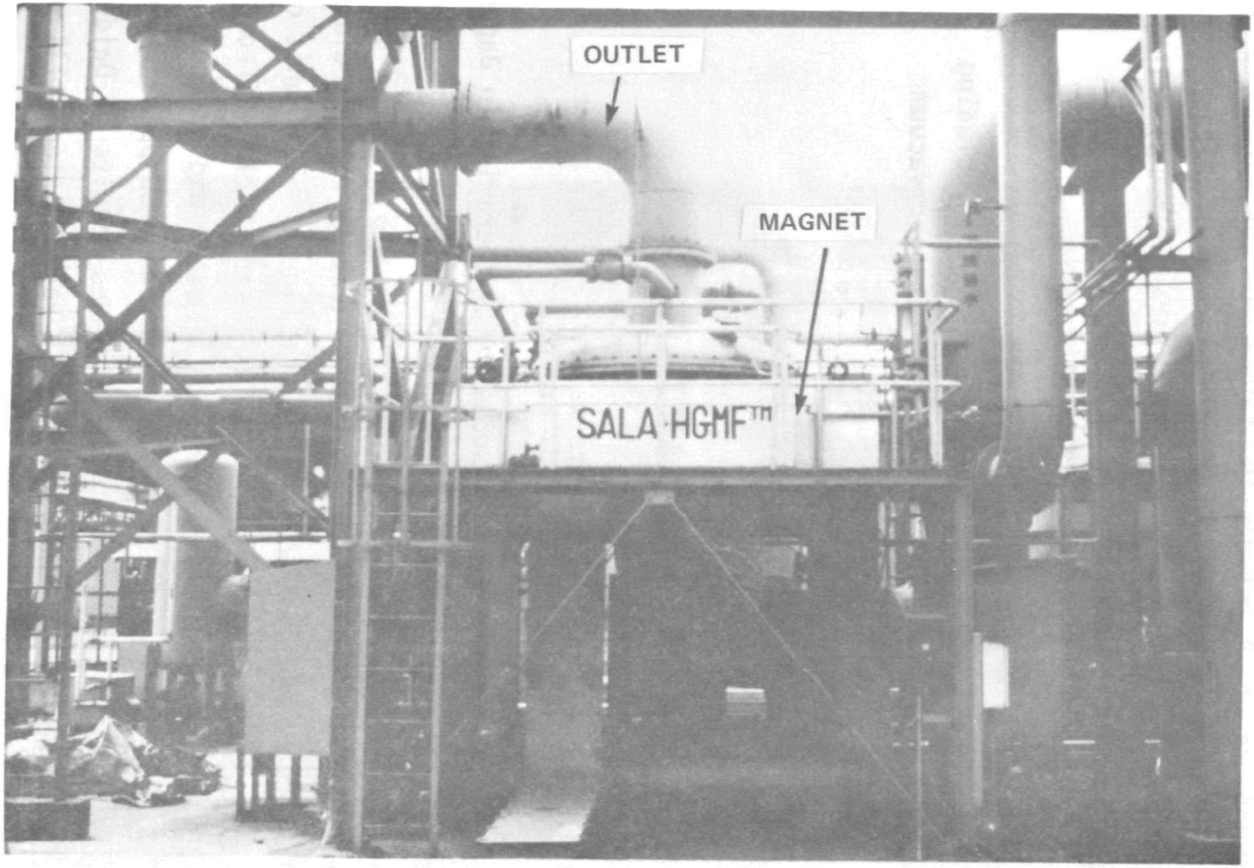


Figure 7. Magnetic filter at Kawasaki's Chiba Works

Daido Steel Company, Ltd.
Machinery Division
1, Mutsuno-Cho, Atsuta-ku
Nagoya, Japan

Personnel contacted: I. Eguchi, Director
T. Adachi, Manager
J. Yano, Engineer

Daido produces specialty steels and forged and cast products for a variety of industries. Among the activities of their Machinery Division is the manufacture of high gradient magnetic filters (HGMFs). They have tested the application of HGMF to:

1. Waste water from hot rolling mills.
2. Various other waste waters from steel mills, including scrubber effluents from oxygen converters and vacuum degassing systems.
3. Coolant in nuclear power plants.
4. Waste water from nuclear power plant.
5. Liquid sodium in fast breeder reactors.
6. Separation of iron from raw materials.
7. Other mineral processing.
8. Various other industrial waste waters.

Daido now has 10 pilot- and full-scale units operating in Japan. An example is shown in Figures 8, 9, and 10. Most of these are in use in the steel industry, processing BOF scrubber effluents, vacuum degassing waters, and rolling mill waste waters. The largest is a 1.5 m diameter unit that filters 1000 $m^3$/hr of rolling mill effluent. This unit operates at 0.3 tesla and reduces the suspended solids of the effluent from 150 to 25 ppm. They backflush with a combination of water and compressed air. The oil content of the waste water is less than 30 ppm and presents no problems to filter backflushing. Table 2 gives results of Daido's analysis of the potential for applying HGMF to various steel mill waste waters.

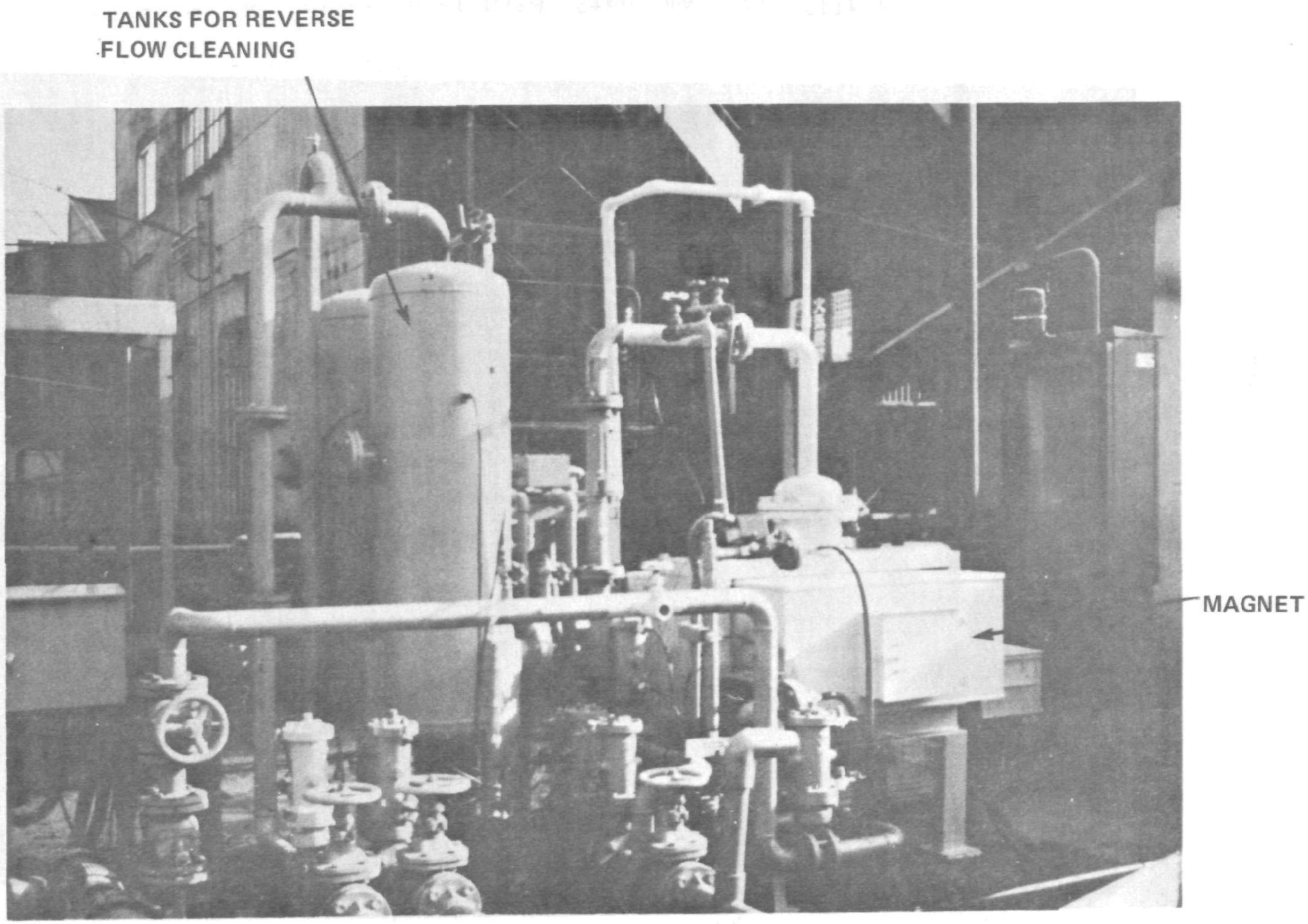


Figure 8. Magnetic filtration system at Daido Steel Company.

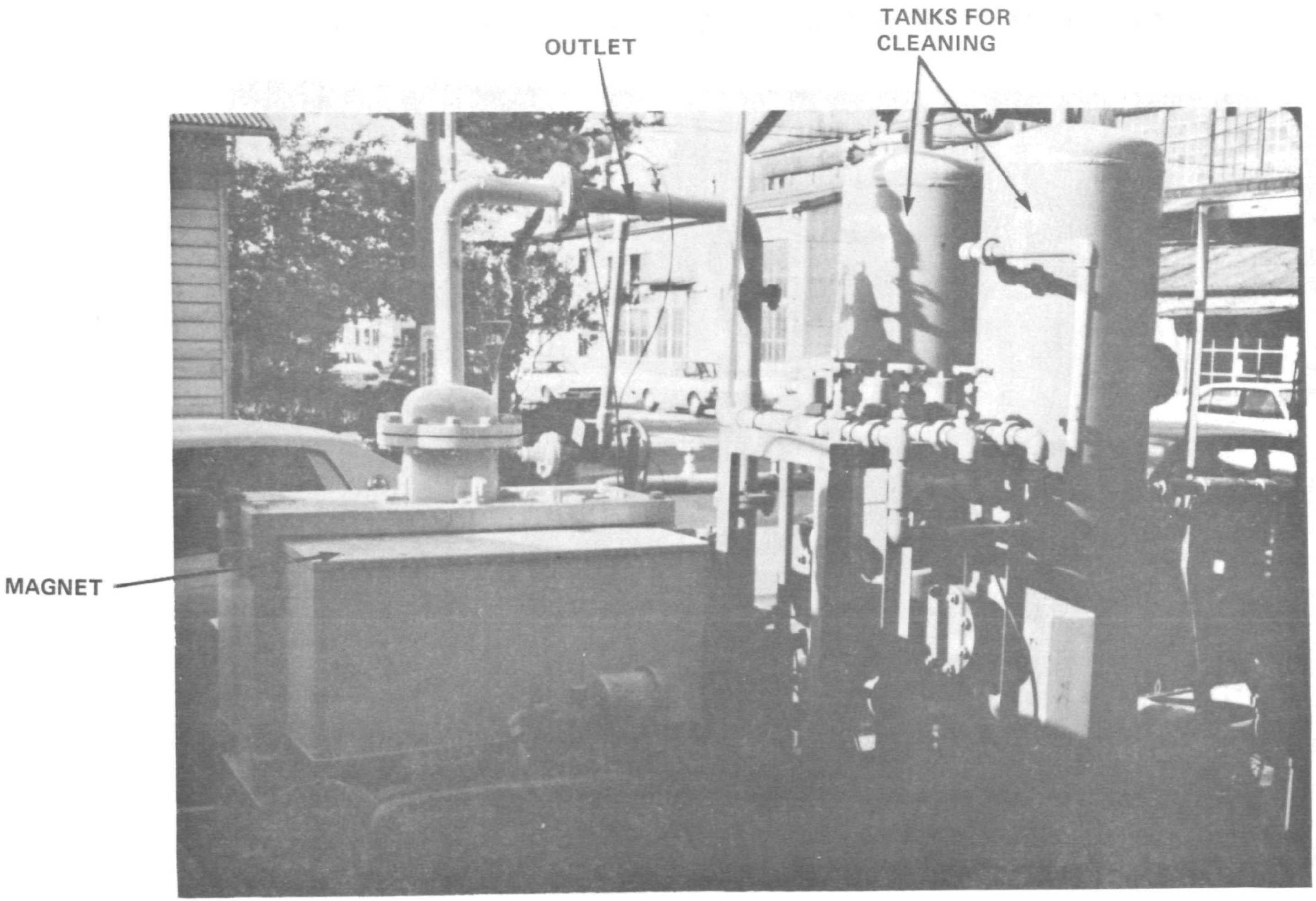


Figure 9. Close-up of Daido Steel magnetic filter.

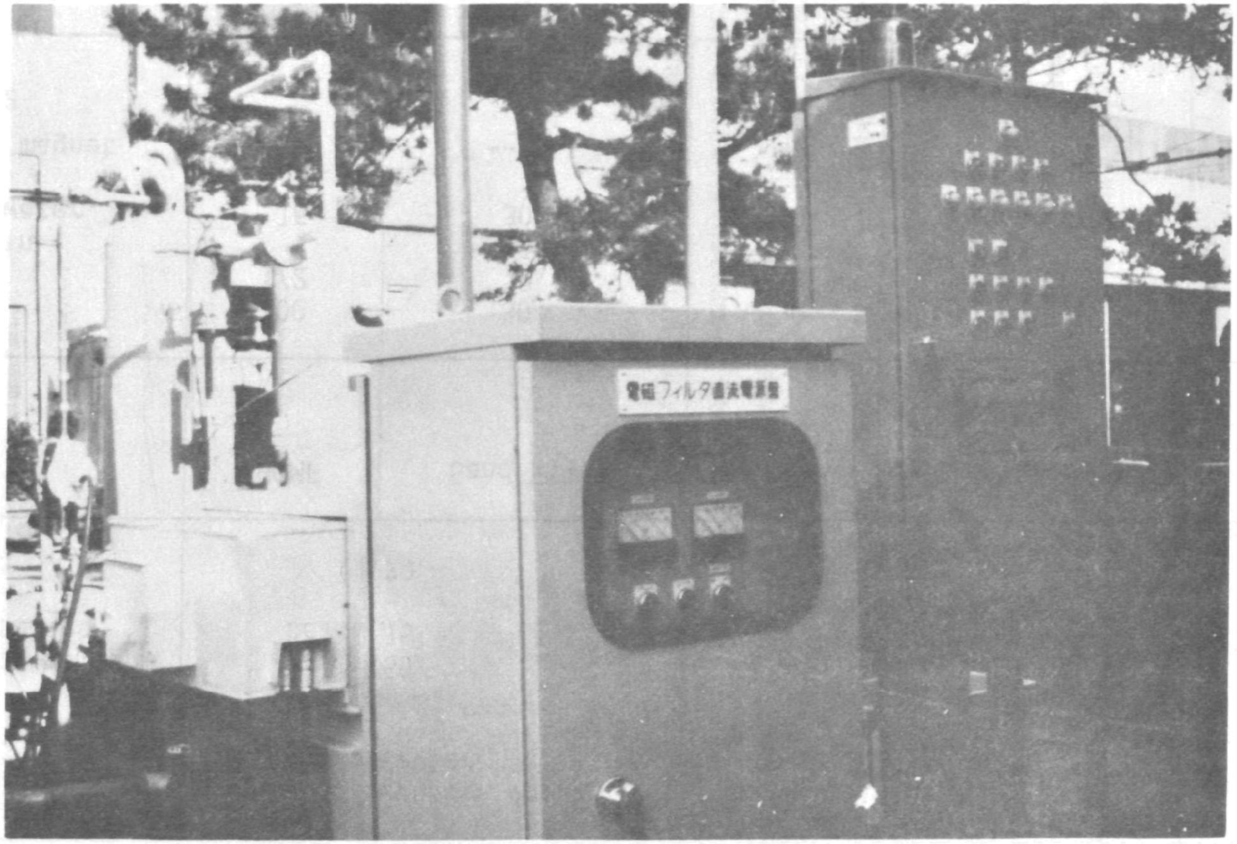

Figure 10. Power supply for Daido Steel magnetic filter.

Table 2. COMPARISON BETWEEN HGMF AND OTHER METHODS OF FILTRATION

| Classification | Class 1 (ferromagnetic fraction of suspended solids, >60%) | | Class 2 (ferromagnetic fraction of suspended solids, ∿30%) | | Class 3 (ferromagnetic fraction of suspended solids, 5-10%) | |
|---|---|---|---|---|---|---|
| Kind of waste water | From the scrubber for an oxygen converter | | From a hot rolling mill | | Cooling water of the steam ejector in vacuum degassing installation | |
| Influent suspended solids, ppm | 150 | | 150 | | 80 | |
| Desired effluent suspended solids, ppm | below 15 | | below 15 | | below 25 | |
| Influent volume, $m^3/h$ | 20 | | 1100 | | 720 | |
| Method of filtration | HGMF | Sand Filter | HGMF | Clarifier-sand filter system | HGMF | Clarifier |
| Flow rate, m/h | 200 | 30 | 600 | 40 | 200 | 2 |
| Filter run, h | 1/2 | 8 | 1/3 | 24 | 1 | continuous |
| Time of back wash, min | 1 | 15 | 2 | 15 | 4 | none |
| Volume of back wash water, $m^3$/day | 16 | 30 | 340 | 300 | 270 | none |
| Power consumption of magnet at 0.3T, kW | 5 | --- | 30 | --- | 40 | --- |
| Space requirement, $m^2$ | 4.5 | 8 | 40 | 500 | 200 | 700 |
| Running cost relative to other methods | 0.7 | 1 | 0.4 | 1 | 0.3 | 1 |
| Installation cost relative to other methods | 1.1 | 1 | 0.4 | 1 | 1.5 | 1 |

Daido has conducted feasibility studies on the application of HGMF to gas cleanup. Their preliminary conclusions are that HGMF, although not economically competitive under most conditions, might be competitive when the waste gas is hotter than 300°C or when space is limited. They alluded to some experimental work with sinter dust but revealed no test data to support these preliminary conclusions.

Daido designs its own magnets and has them made by a Japanese transformer manufacturer. They claim that their price for magnets is about half that of U.S. competitors exporting to Japan. One significant design difference is that they don't use hollow conductors in the coils, like U.S. manufacturers do. Instead Daido mounts copper fins between the insulated magnet coils and conducts the heat out to water-cooled tubes that are wrapped around the outside of the magnet coils. They claim that this design is much less expensive. They also use different grades of wire cloth (instead of steel wool) for a filter matrix. All of their systems operate cyclically.

Hitachi Research Laboratory
Hitachi, Ltd.
1-1 Saiwai-Cho, 3-Chome,
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Japan

Personnel Contacted: Y. Oguri, Deputy General Manager
H. Yamada, Senior Engineer
K. Ootsuka, Senior Researcher
A. Hino, Engineer
T. Misaka, Researcher

Hitachie built and installed Kawasaki Steel's high-gradient magnetic filter (HGMF) unit at a cost of approximately $1 million using components imported from the U. S. Since then they have produced a similar unit for Nippon Steel at about half the cost, using Japanese components and the experience they gained from their first installation. They see a very bright outlook for the application of HGMF to waste water cleanup in Japan, but have not yet studied gas applications. Table 3 gives Hitachi's analysis of optimum operating conditions for steel mill waste water application.

Table 3. SUMMARY OF APPLICATION OF HGMF FOR STEEL MILL WASTE WATERS

| | Hot Rolling Mill (scale pit overflow) | Continuous Casting (scale pit overflow) | Vacuum Degassing |
|---|---|---|---|
| **Influent suspended solids** | | | |
| a) Concentration, mg/ℓ | 100 - 150 | 150 - 200 | 80 - 100 |
| b) Elemental components | | | |
| Fe, % | 60 | 50 | 5 - 10 |
| Mn, % | -- | 0.2 | 20 - 30 |
| c) Size distribution, m | 20 - 100 | 40 - 150 | 5 - 20 |
| **Optimum operations conditions** | | | |
| a) Flow velocity, m/hr | 500 | 700 | 150 - 250 |
| b) Magnetic flux density, tesla | 0.3 - 0.5 | 0.1 | 0.5 |
| c) Feed time, min/cycle | 60 | 60 | 60 |
| d) Duty cycle, % | 95 | 95 | 95 |
| **Effluent suspended solids** | | | |
| a) Concentration, mg/ℓ | 20 | 5 | 20 - 25 |

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Y. Nonogaki, Graduate Student
H. Nakatani, Graduate Student
M. Washizu, Graduate Student

Prior to visiting Japan, EPA had developed a list of questions for the developer of the Aut-Ainer, Eikosha Company, Ltd. These were submitted to Masuda to allow ample time for Eikosha to respond. There was also a general discussion of the Aut-Ainer with Masuda.

The initial discussion of the Aut-Ainer was followed by an information exchange: reviews of current research projects in Masuda's department and several EPA projects.

Masuda is continuing work with a three-electrode system involving pulsed power supplies (Boxer, Charger). He uses a biased DC supply with a superimposed 1.5 kHz oscillation to provide corona. This maintains a reasonably high electric field with a controlled current density to prevent the development of reverse ionization (back corona).

Masuda is also continuing work to identify the various modes of reverse ionization and conditions required for the initiation of back corona.

The research activities are a continuation of those listed in the EPA report, "Electrostatic Precipitator Technology Assessment: Visits in Japan, November 1977," EPA-600/7-78-110 (NTIS No. PB 298389), June 1978.

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K. Aoi and other Eikosha personnel reviewed the development of the Aut-Ainer automotive particulate control device. They reviewed its development. They then responded to questions that EPA had presented to them earlier.

The Aut-Ainer is approximately the size of an automotive muffler. It consists of expansion chambers followed by collection regions filled with metal wool. It is cooled by outside air flowing through a central pipe to contribute to condensation.

Twenty-six questions were answered: the first 9 from EPA's Andrew W. Kaupert (Ann Arbor, MI); the next 17 from Southern Research Institute and EPA's Particulate Technology Branch (IERL-RTP).

Question 1: What data does the developer have, displaying particulate data under transient conditions?

Response: The Aut-Ainer has been tested under transient conditions but only on gasoline engines. These tests were conducted by Nisson Motors in road and chassis dynamometer tests. The car used was a Nisson Model P-510 with a regular leaded gasoline engine (Model 8D-252) at idling speed: 10 degrees B.T.D.C./600 rpm and CO = 3.5 percent. Collection efficiency was determined by weighing the Aut-Ainer and a five-stage absolute filter. The driving cycle consisted of an acceleration to lap speed (chosen between 50 and 105 km/hr) and two decelerations--accelerations between lap speed and 30 km/hr and the final deceleration to stop. Several designs of the Aut-Ainer were tested: in general all provided 70 percent collection efficiency for the tests which lasted as long as nearly 7,000 km.

Question 2. Does any particulate data exist using the proposed particulate test procedure for LDV?

Response: All data available is as described in the response to Question 1.

Question 3. What transient procedure was used to develop transient particulate data, if any?

Response: As already noted, no transient procedure has been used to test the performance on a diesel engine. The driving cycle (called "A" DURATION MODE) was used in the leaded gasoline engine tests.

Question 4. Is the concept amenable to heavy-duty engine applications?

Response: There are no apparent limitations which would restrict application of this concept to light duty vehicles. The developer feels strongly that it can be applied to heavy duty engines and is designing a unit for an 11-ton truck.

Question 5. What have the developers done to improve the short period of time between cleanings?

Response: The developer feels that the most recent design can go 6,000 km between cleanings and expects that this can be increased to 10,000 km. Most early designs allowed for collection only within a single muffler sized unit which would fill up in 1,000 - 2,000 km. The latest design does not utilize ultimate collection within this single unit but instead diverts some of the exhaust gas and most of the particles to a secondary collection chamber. The system then consists of the primary collection chamber, a diversion device at the end of the primary collector, and a secondary collector. The primary collector is a three-stage throttle plate and packing design which has been tested in many different configurations.

The simplest configuration (disk throttle plates inside a cylindrical collector body) seems to work as well as any and is the configuration of choice. The diversion devices tested are a cyclone and a screen with reverse air blowback. The concept is that particles collected in the primary collector will be agglomerated. As the agglomerates grow, they will break off from the collection packing and approach the diversion device. Since these are large agglomerates, they are easily diverted by a cyclone or caught on a screen. If they are on the screen, they are cleaned off and blown to the secondary collector by a rotating reverse air jet. In either case, agglomerates leaving the primary collector are diverted to the secondary collector. The secondary collector used by the developer was a fiber glass bag inside a drum. This provided a large storage volume and could be made larger on a large truck. However, for a light duty vehicle where space is very limited, the secondary collector should be redesigned. The secondary collector may be made small if it is to be designed for extremely easy emptying. Possibilities are a hopper (which dumps) or a bin (which may be removed or replaced in one motion). Hence, this concept is not to increase the distance between cleaning but rather to increase the ease of cleaning.

Question 6: Can a device be made available for testing at EPA, Ann Arbor, on any of the vehicles mentioned in the January 4th memo?

Response: A device can be made available and the price is from $1,250 to $2,500 depending on the type. Prices quoted are for hand manufactured items and do not reflect mass production costs. In order to supply a device, the developer must know the gas flow rate, muffler size, and exhaust pipe diameter.

Question 7: What are the developer's future plans for this concept?

Response: The developer claims to have already spent $7 million on independent experimentation and testing. Consequently, the developer is hoping to work in the future more closely with a potential user of the technology. The form of the work would be determined by the user's needs.

Question 8: What is the approximate cost of the device and are any critical or scarce materials necessary for fabrication?

Response: The developer estimates actual production costs at ¥5,000 ($25) for a production rate of 10,000 per month. The sale price might be as high as ¥20,000 ($100). Primary construction material is 18-8 stainless steel. No critical or scarce materials are necessary for fabrication.

Question 9: Of all the different constructions and cleaning arrangements proposed in your paper, what is the preferred or most effective method of collection?

Response: The preferred arrangement is as described in the Question 5 response: a muffler-sized device, which is the primary collector, followed by a cyclone and a secondary collection device. The secondary collector can be optimized either to provide large extra storage of collected particulate or to provide ease of particulate removal from the vehicle as stored.

(NOTE: The above questions were submitted by EPA's Andrew W. Kaupert (Ann Arbor, MI). The following questions were developed by EPA's Particulate Technology Branch (IERL-RTP) and Southern Research Institute.)

Question 10: What is the practicality of methods to divert the previously collected material to a collection device?

Response: The fabric filter or cyclone collection method can be used more effectively if either an auxiliary pump or pressure restriction is added in the outlet circuit.

Question 11: What is the frequency of expansion hole plugging in the device?

Response: There is no evidence of plugging.

Question 12. What is the approximate back pressure of the device?

Response: About 12 inches W.C. under heavy load.

Question 13. What data are available about the degradation in performance with miles of operation?

Response: Mitsubishi is expected to develop this data. In general, degradation in performance appears with a back pressure of about 0.25 atmospheres.

Question 14. What is the expected lifetime of the device?

Response: Similar to that of an automotive muffler.

Question 15. What is the approximate size of the device?

Response: Comparable to a muffler.

Question 16. What data are available on the collection efficiency for hydrocarbons?

Response: No quantitative data are available.

Question 17. Are sample analyses available for particulates, liquids, and gases for both new and high mileage conditions?

Response: Samples can be made available. Gas analyses will be made in Japan. Liquid and particulate samples can be shipped to U.S.

Question 18. What is the surface area to volume of the collection media?

Response: The material exhibits a porosity of about 97 percent.

Question 19. Does the manufacturer think that all the condensation occurs in the expansion chamber?

Response: No data are available other than temperature. Measurements indicate that significant cooling occurs across the perforated plates.

Question 20. How does fuel economy compare with and without the Aut-Ainer operating at a collection efficiency of about 70 percent?

Response: The manufacturer thinks there is no difference in fuel consumption.

Question 21. Has the Aut-Ainer efficiency been checked as a function of temperature?

Response: Efficiency was stated to be higher at low temperatures; that is, of course, consistent with condensation.

Question 22. Has the filter material packing density been varied?

Response: It has changed over a small range but no definitive study has been performed.

Question 23. What information is available on collection efficiency as a function of particle size?

Response: None, Mitsubishi will attempt to obtain some data.

Question 24. What data are available on the chemical composition of materials for both the inlet and outlet?

Response: No data for diesel applications.

Question 25. What collection temperature was used for the samples from the gasoline application?

Response: The samples were collected at near ambient temperatures.

Question 26. What additional information is available on the system that recirculates the collected material through the engine?

Response: This system was used only on the gasoline engine. A truck and automobile, both equipped with diesel engines, were road-tested on a drive from Tokyo to Harone. The major test, on a 2-1/2 ton truck, started with a clean Aut-Ainer using three stages of packing and a reverse air cleaned backup screen. It was stopped for inspection after about 60 km. The device had collected quite a bit of material on the filter but only a small amount in the fabric filter in a bypass line (see Figures 11-13). However, the fundamental collection seemed to be functioning. After the inspection, the Aut-Ainer was bypassed and visual observation of the exhaust emissions could be compared with and without operation. Although there was no remarkable change in the exhaust appearance, a change was visually detectable.


Figure 11. Opening Aut-Ainer after road test.

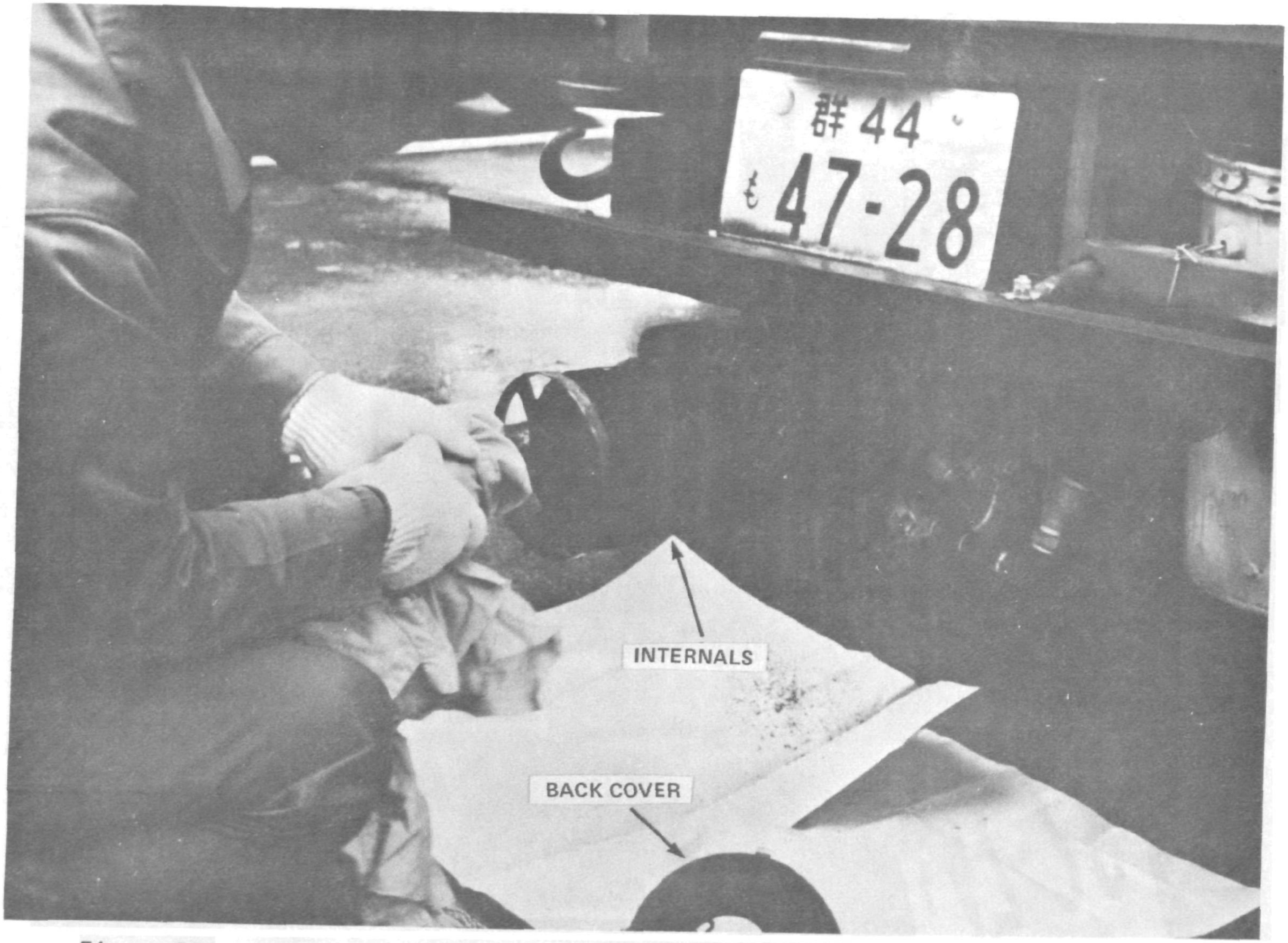


Figure 12. Removing internals from Aut-Ainer collector.


Figure 13. Throttle plates and mesh packing.

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At Mitsubishi Motor Company's test laboratories in Tokyo, tests of an Aut-Ainer had just started operating on a heavy-duty diesel engine mounted on an engine dynamometer (see Figures 14-16). This particulate device was similar to that installed on a diesel truck except that it was equipped with a cyclone collector instead of a screen collector to divert a side stream. The Aut-Ainer being tested was a three-stage, throttle plate and packing design with a cyclone at the end to divert agglomerated particles and a side stream of exhaust gas to a filter. The source of particles was half the output from a Mitsubishi V-8, Model 8DC8A (direct injection) with a displacement of 14,806 cc. The engine was run on an engine dynamometer at engine speeds of 1000 and 2200 rpm and loads of 91.3 - 101.6 kg-m. Collection efficiency was measured with a Bosch smoke density meter. Greatest emissions were at low speed, high load for a reading of 5.5 which was reduced to 2.9 by the Aut-Ainer. Using a correlation between smoke number and concentration supplied by Mitsubishi, collection efficiencies were generally around 50 percent. Volume of gas treated was 112 to 249 cfm and the pressure drop ranged from 9 to 35 mm Hg.

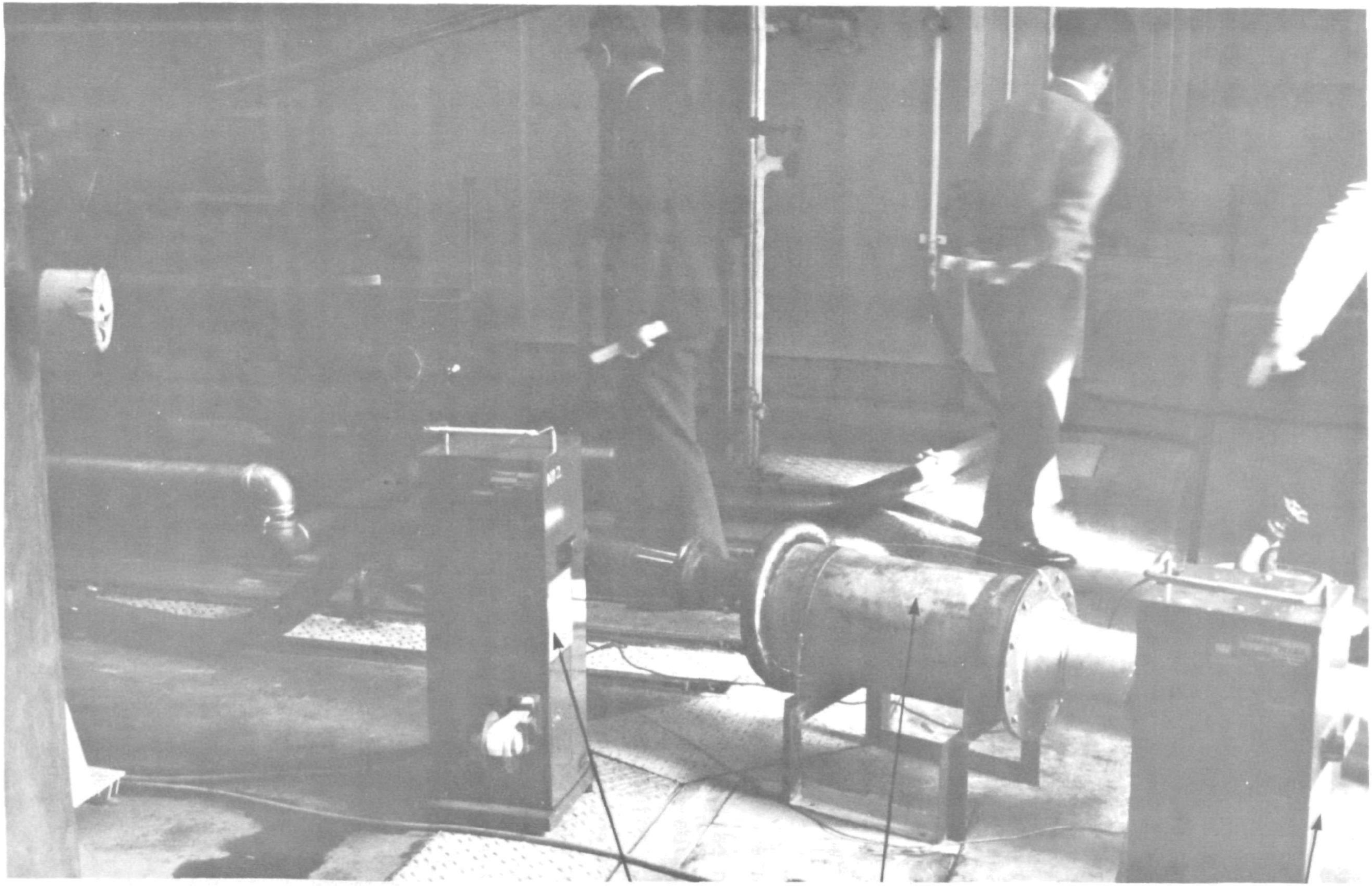


Figure 14. Experimental setup at Mitsubishi Motors.

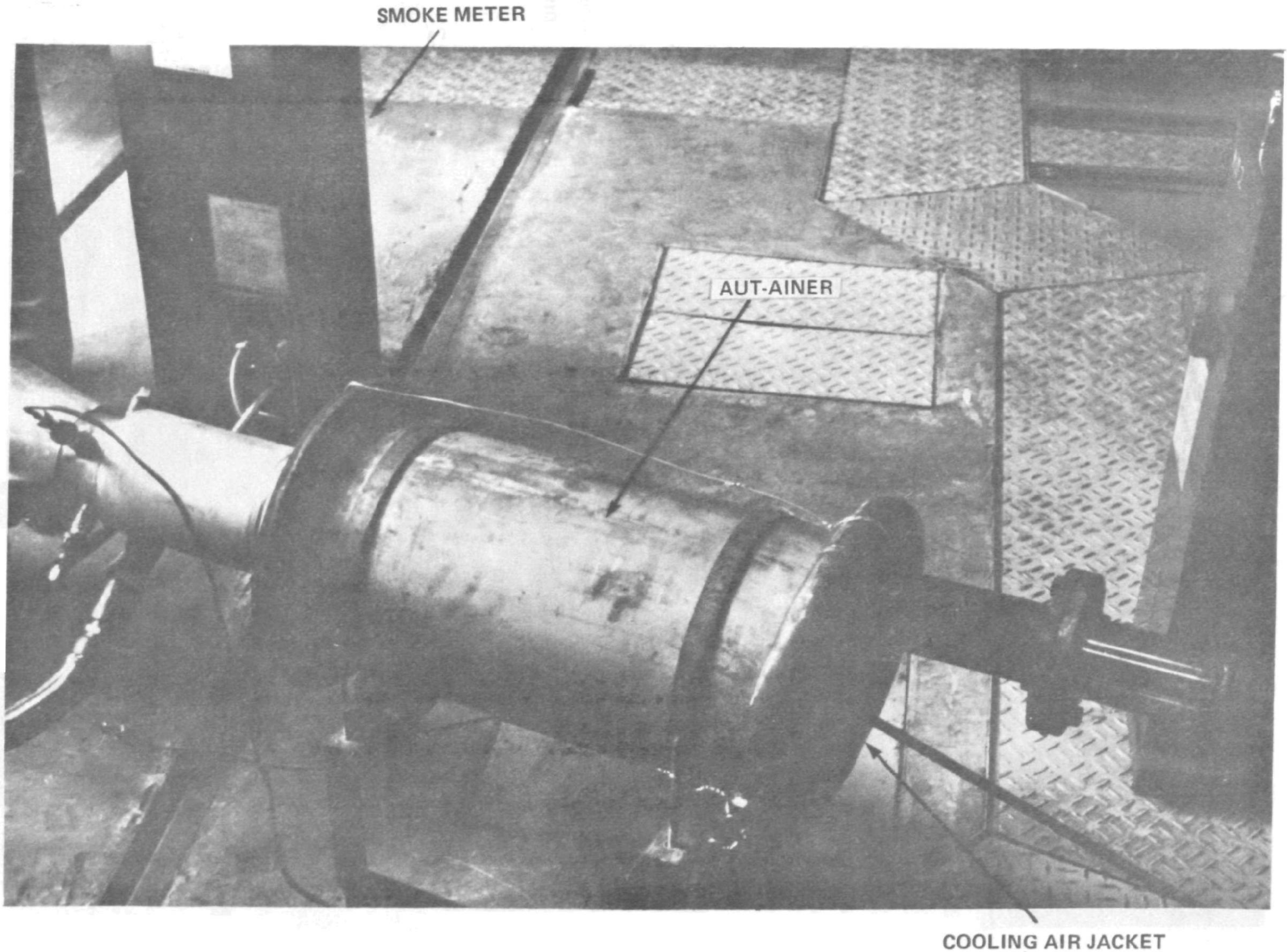


Figure 15. Close-up of Aut-Ainer.

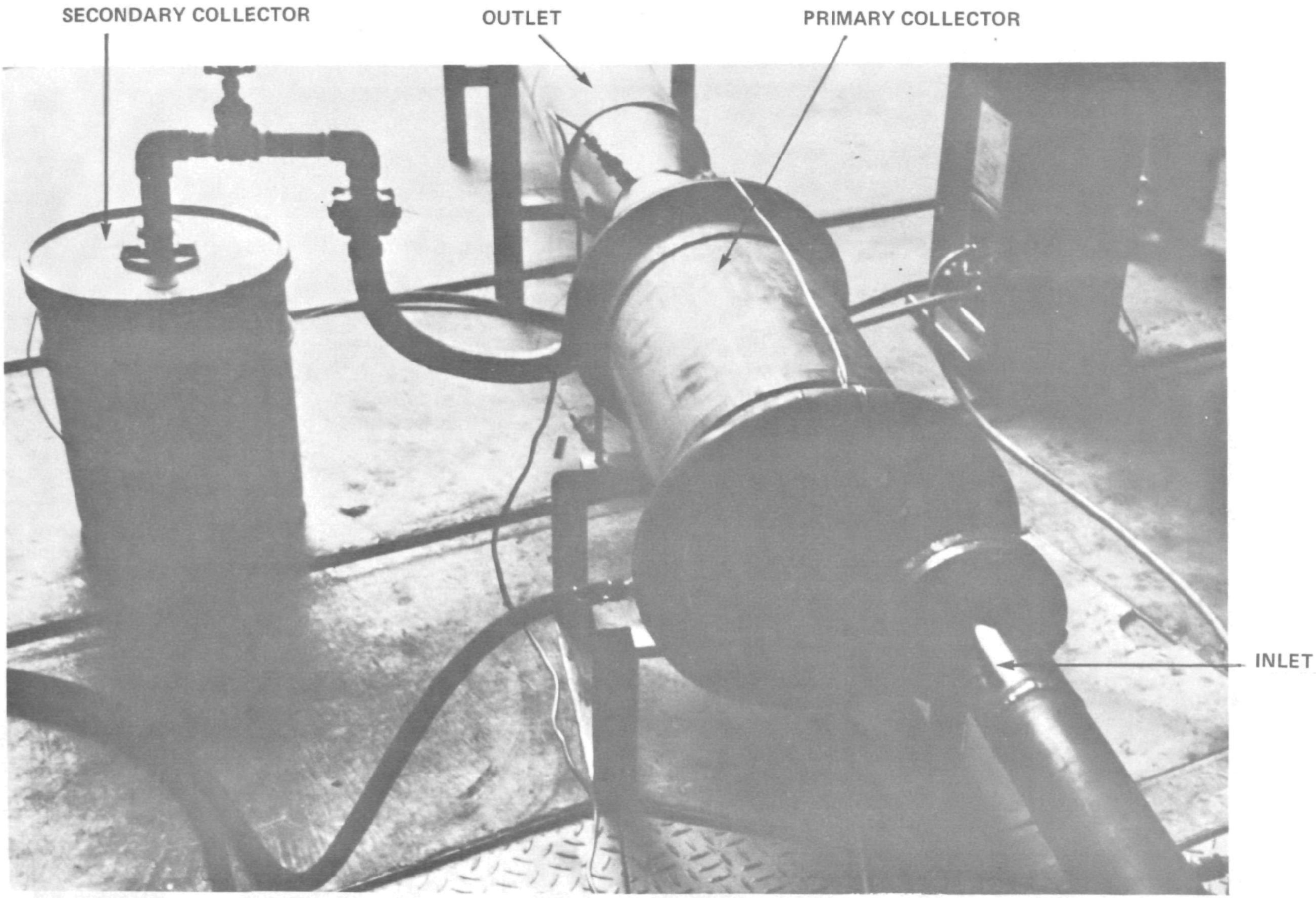


Figure 16. View of primary and secondary collectors.

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Japan Automotive Research Institute (JARI), an independent non-profit automotive research center, provided information on a number of research programs. Of particular interest was a study of burning alcohol in a diesel engine. In the engine, equipped with dual injectors, diesel fuel was injected first. Alcohol was injected after ignition. JARI claims that up to 75 percent of the energy can be supplied from alcohol in an engine with a compression ratio of 20:1.

JARI is initiating studies in which rats are exposed to a variety of automotive emissions. Both behavioral and biological effects are being investigated. JARI hopes to expand the studies to include bacteria.

## TECHNICAL REPORT DATA

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15. SUPPLEMENTARY NOTES IERL-RTP Author Drehmel's Mail Drop is 61; his phone is 919/541-2925. Related reports include EPA-600/8-77-020a through -020c, and EPA-600/8-78-005a through -005d.

16. ABSTRACT The report describes results of visits to Japan to assess research and development of new particulate control technology, and to evaluate the applicability of the Aut-Ainer particulate control device to diesel engines. New technology observed includes hooding systems for coke oven charging and pushing, fugitive emissions control in a Q-BOP furnace building, novel electrostatic precipitators (ESPs), magnetic separators, and hybrid control devices. Fugitive emissions are well controlled in two iron and steel plants visited. Fugitive emissions are prevented by road watering and process hooding. Fugitives in a large building are collected by a special lightweight ESP. Novel ESPs utilize approaches such as wide plate spacing, advanced charging systems, and water cooled collection electrodes. Magnetic separators are currently used for water pollution control and are under consideration for air pollution control. The Aut-Ainer device has evolved from an experimental approach to the device development stage over several years. The device currently has limited applicability to particulate control from diesel engines; however, its basic collection characteristics seem to be based on sound principles. With limited additional development in the general area of removing the previously collected material, the device appears promising.

17. KEY WORDS AND DOCUMENT ANALYSIS

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|---|---|---|---|---|
| Pollution | Electrostatic Precipitators | Pollution Control | 13B | |
| Dust | Electromagnetism | Stationary Sources | 11G | 13I |
| Diesel Engines | Wetting | Japan | 21G | 20C |
| Iron and Steel Industry | | Particulate | | |
| | | Aut-Ainer Device | 11F | |
| Coking | | Fugitive Emissions | 13H | |
| Leakage | | Q-BOP | 14B | |

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