Demonstration test of energy conservation of central air conditioning system at the Sapporo City Office Building

— Reduction of pump power by flow drag reduction using surfactant —

Hiromi TAKEUCHI

[Translation from *Synthesiology*, Vol.4, No.3, p.132-139 (2011)]

In recent years, the amount of carbon dioxide emission in the civilian sector has been increasing. In this experiment, the so-called Toms effect, i.e. the effect of flow drag reduction when surfactant is injected to circulating water, has been verified to reduce the transfer power of circulating water for air conditioning systems of buildings. Concerning this effect, much basic research and a few applications to buildings have been reported. There is no clear report, however, on how to add the surfactant to the circulating water in buildings constructed with complicated pipework, how the flow and heat transfer performance change after the injection of the surfactant, and how to maintain the effect for a long time. Consequently, the technology using this effect has not yet been put to practical use. This paper presents the findings of the demonstration test using the air conditioning system at the Sapporo City Office Building. Generalization of the results will hopefully lead to the spread of this technology.

Keywords **:** Surfactant, drag reduction, central heating/cooling system, energy conservation, demonstration test

1 Research objective

The amount of energy consumption is gradually increasing in the civilian sector. That is, while the energy conservation efforts are conducted in the individual devices through the introduction of the top-runner method in the private sector, the energy consumption continues to increase due to the pursuit of convenience and comfort in daily living, as well as the increased number of households. Particularly, in the business sector, energy consumption is on the rise due to the increased use of office appliances. Table 1 is the result of a statistical survey of the energy consumption structure in a business building[1]. According to this survey, the consumption is highest for lighting and power outlet at 42.4 %, followed by heating at 31.2 %. For the former, energy conservation measures are taken for the office appliances and by using LED lighting. For the latter, improvements are in progress as the inefficient refrigerators and boilers installed over 20 years ago are replaced by equipment with high coefficient of performance (COP) through the Energy Service Company (ESCO) program. While energy conservation through such replacement of hardware is effective, large initial investment is necessary. In this research, we focused on the heat transport essential in air conditioning of buildings, particularly on reducing the power needed for cold/heated water transport using circulating water.

In table 1, the percentage of power dominated by primary and secondary pumps for cold/heated water is estimated to be 2.6 % or more, and the absolute value of energy consumption is small. However, by introducing the flow drag reduction technology using surfactants, it is possible to reduce the power consumption without altering the current heat transport system. This technology is based on the phenomenon which Toms indicated in 1949 that the flow drag could be reduced by tens of percent in the presence of surfactants[2], and the basic researches and installations to air conditioning systems of buildings have been done in Japan. However, there is hardly any publication of the data. The method of injecting the surfactant, the phenomena that occur, the daily maintenance, as well as how much energy savings was achieved and the lifespan of the surfactant have not been disclosed, and this method is not widely used.

The objective of this research is to measure the energy conservation effect of the flow drag reduction technology,

Table 1. Energy consumption structure in a business building[1]

Category of energy use			Main energy consuming device
Item	Sub-item	Percentage (%)	
Heat source	Heat source itself	26.0	Refrigerator, water cooler/heater, boiler, etc.
	Supplementary motor	5.2	Cooling water pump, cooling tower, cold/heated water primary pump, etc.
Heat transport	Water transport	2.6	Cold/heated water secondary pump
	Air transport	9.4	Air conditioner, fan coil unit, etc.
Hot water supply	Heat source itself	0.8	Boiler, circulation pump, electric water heater, etc.
Lighting, power outlet	Lighting	21.3	Lighting equipment
	Power outlet	21.1	Office appliance, etc.
Motor	Ventilation	5.0	Garage fan, etc.
	Water supply and drainage	0.8	Pumping-up pump, etc.
	Elevator	2.8	Elevator, escalator, etc.
Others	Others	5.1	Transformer loss, store motor, etc.

Chemical Materials Evaluation and Research Base, AIST Tsukuba Central 5-2, 1-1-1 Higashi, Tsukuba 305-8565, Japan
E-mail: h-takeuchi@cereba.or.jp

Original manuscript received October 29, 2010, Revisions received August 22, 2011, Accepted August 24, 2011

and to consider how much it can contribute to the energy conservation in air conditioning systems of buildings. Therefore, we collaborated with the City of Sapporo and applied this technology to the cooling/heating water circulation system of the office building, conducted a demonstration test for energy savings, and attempted to diffuse this technology further by publishing the results.

In this paper, we look at the technology that was introduced in only a limited number of facilities because the research stopped at the basic phase or because the data was not disclosed even though the effectiveness was demonstrated. We gathered specialists of the component fields of the technology, and these specialists assumed their respective roles according to the technology integration scenario. The demonstration test was conducted in the Sapporo City Office Building that was in full operation. The results will be discussed here.

2 Scenario

First, the Toms effect will be briefly explained. In 1949, Toms showed that it was possible to reduce the pressure loss of the turbulent flow in a pipe by adding a small amount, about 5 to 10 ppm, of long-chained polymer to the water flowing inside the pipe[2]. The effect is temporary since the polymer structure is destroyed by the shear force of the flow and the structure is not reconstructed. On the other hand, when a surfactant is used instead of the polymer, the micellar structure formed is repeatedly reconstructed and the effect is sustained. As shown in Fig. 1, with the increased concentration of the surfactant, the monomers aggregate to form a spherical and then rod-like micelle. When these rod-shaped micelles form a three-dimensional micelle network structure, the turbulence of the flow is inhibited and the flow drag is reduced. Fig. 2 shows the velocity vector distribution of the channel flow[3]. Fig. 2a shows the case of water only, and Fig. 2b shows the case when the surfactant is added. By adding the surfactant, the irregular eddies in the flow disappear, and regular flow is achieved. This structure is broken in areas such as pumps, valves, elbows, or any parts where the flow path is greatly disturbed, but is reconstructed in relatively straight sections of the pipe, and contributes to the reduction of flow drag. When cooling and heating large buildings by circulating cold or hot water, large amount of electric power must be used to operate the water circulation pump. To drastically reduce this energy, it is effective to apply the Toms effect where the flow drag is decreased by injecting the surfactant in the circulating water. The principle of energy conservation using this method is as follows: the circulating water that surpasses the rated flow can flow through when the flow drag is reduced by adding the surfactant; the revolution of the circulation pump is lowered using the inverter to regain the rated flow; and the power consumption of the pump decreases, thus achieving energy conservations.

As shown in Fig. 3, one of the elemental technologies is to design and create an agent to see which type of surfactant matches this purpose. Another element is to clarify what kind of fluid dynamics and heat transfer occur in the water with added agent in the circulation channel and make explicit the energy conservation effect. Also, it is necessary to study the long-term stability of the added surfactant, the duration of the energy saving effect, and the maintenance procedure to operate and sustain this energy conservation technology.

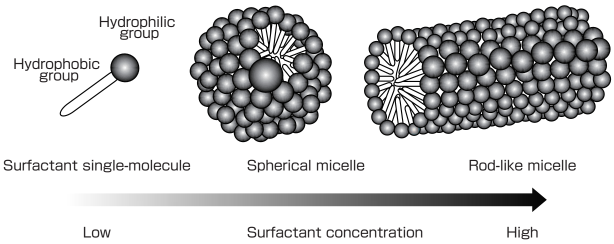

Fig.1 Changes in micelle formation due to concentration change

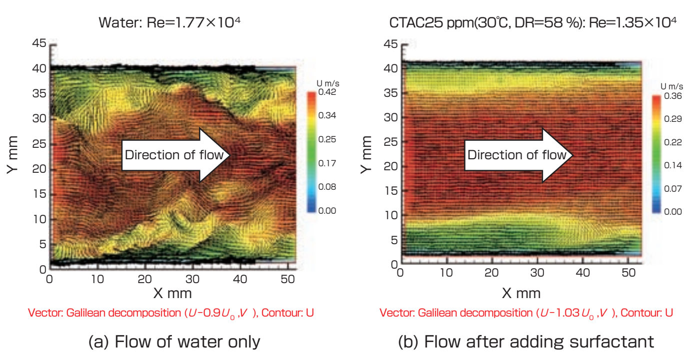

Fig. 2 Changes in flow due to micelle network

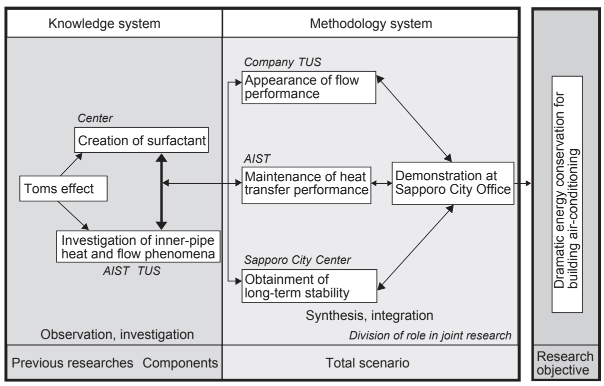

Fig. 3 Scenario for energy savings using surfactant in air conditioning of buildings

In Japan, several basic researches have been conducted for the flow drag reduction technology, various agents were developed, and their fluid dynamic properties were studied. There were over 120 cases of use of agents in building circulation water. However, since they were conducted by private companies, the technical information is undisclosed, the accumulation of technology pertaining to flow, heat transfer, and long-term stability as well as energy conservation effects are lacking, and this technology has not spread widely. In this research, specialists took the role to integrate the elemental technologies for studying the occurrence of flow performance by agent addition, evaluation of the energy conservation effect, maintenance of heat transfer property, and long-term stability of the agent. Then, a demonstration test was conducted at a public facility to generalize the results, and attempts were made to enhance energy conservations in air conditioning of buildings.

3 Development of the elemental technologies

The development of the flow drag reducing agent was conducted by the Yamaguchi University, the Shunan Regional Industry Promotion Center, and four companies in 1992, as part of an industry-academia-government collaboration, and a product was realized in 1995. The main components were: oleyl bis-hydroxyethyl methyl ammonium chloride, a surfactant; sodium salicylate, a counterion agent that promotes the formation of three-dimensional micelle network; rust inhibitor; and others[4] (hereinafter, this will be called the agent). In the Eco Energy Urban Project of the Ministry of Economy, Trade and Industry, the research mainly on the development of surfactant was conducted as an industry-academia-government collaboration for three years starting in 1997, and two research institutes under the Agency of Advanced Industrial Science and Technology also participated. For one year and a half from 1998, the project for the use of the agent in regional cooling/heating system was conducted as a NEDO project. Through these activities, detailed experiments were conducted at research institutes, and trials were done in actual buildings mainly by private companies.

The installation of the agent commercialized by the Yamaguchi Prefecture to the air conditioning of buildings had been done to some extent, but it was far from becoming wide spread. In 2002, the research group for the realization of “smooth water” was established. Specialists of industry-academia-government of this technology convened to discuss how to grow this technology into a practical product, and the need for demonstration tests was indicated[5].

The factors that affect the flow performance include the diameter of the pipes, length of the straight sections of the pipes, flow rate, water temperature, agent concentration, water quality and so on. In general, the pipes on site are very complicated, and it is not rare that the pipe arrangements are quite different from the initial plumbing diagram due to several repairs and renovations that have been done. Also, older sites tend to be without flow meters or thermometers, and this is a major inhibition in energy conservation management, let alone conducting tests. In many cases, it is difficult to utilize on site the flow performance data that was obtained at research institutes. For the maintenance of heat transfer performance, while it is reported that the agent reduces the heat transfer as well as flow drag in laboratory scale tests[6], such phenomenon has not been reported in the actual installation, and this difference must be solved. In addition, there is no disclosed data on the long-term stability or lifespan of the agent, and this is one of the priority issues for the on-site concentration management.

4 Air conditioning system of the Sapporo City Office Building

Based on this scenario, it was necessary to conduct a demonstration of the integrated elemental technologies by actually injecting the agent to the water circulation system to see how much reduction of flow drag will be obtained, whether there will be any reduction in heat transfer performance, and whether long-term stable effect can be sustained. Since the data publication after the test was necessary, we decided to conduct the demonstration test in the cooling/heating water circulation system of the Sapporo City Office Building, a public facility, rather than a private one. This was possible as AIST and the City of Sapporo had signed a basic agreement and memorandum for the efficient use of energy. It was stated therein that: the City of Sapporo would provide test sites free of charge to AIST; AIST could install test equipment in such sites to conduct experiments; and the results obtained would be shared. Figure 4 shows the exterior photograph of the office building. The building was

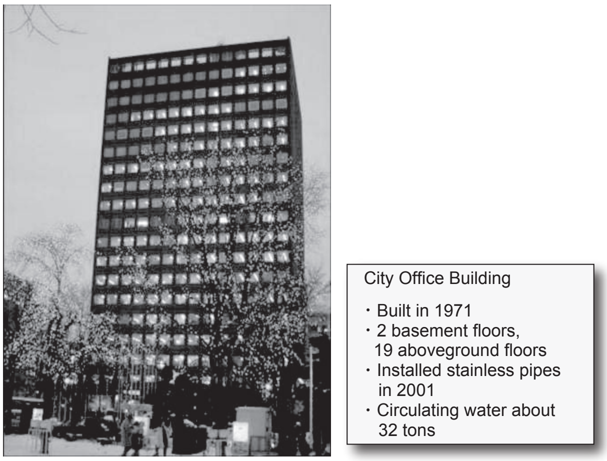

Fig. 4 Exterior of the Sapporo City Office Building

completed in 1971. It has two-tier basement, 19 aboveground floors, and a total floor area of 42,000 m^2. It is designated as a "type 2 designated energy management factory"[Note] .Figure 5 shows the cooling/heating water circulation system of the building. The circulating water is ejected from the 37 kW circulating pumps installed in the machine room on the 2nd basement for summer and winter. The water is sent to the expansion tank on the 19th floor via four 5.5 kW and one 3.7 kW or a total of five booster pumps located in the air conditioning equipment room on the 8th floor, and it is returned to the 2nd basement. The water circulated is 32 tons.

Individual air conditioning is not installed in each room. Since the test involved using the system common to the office building that would be used for daily work, it was impossible to operate or shutdown the system for the purpose of this test. Due to this situation, unlike the test in the lab, it was difficult to freely change the parameters, and the experiment had to stop immediately in times of emergency and the original condition restored. Therefore, five parties became in charge of their respective roles: Shunan Regional Industry Promotion Center, which had been involved in the development of the agent and therefore had full knowledge of the agent property, had experience in various cases as it was involved in the injection at several facilities; AIST and Tokyo University of Science (TUS) which had the abilities to conduct basic research as well as to project or clarify the transitional changes of flow and heat transfer phenomena of the circulating water after agent injection; Fujiwara Environmental Sciences Institute Ltd. which had expertise in measurements of flow rate, temperature and electric energy in a cooling/heating system composed of complex pipes; and Sapporo City Office which had mechanical and electrical engineers who were knowledgeable of the entire system and would engage in maintenance and management after the injection.

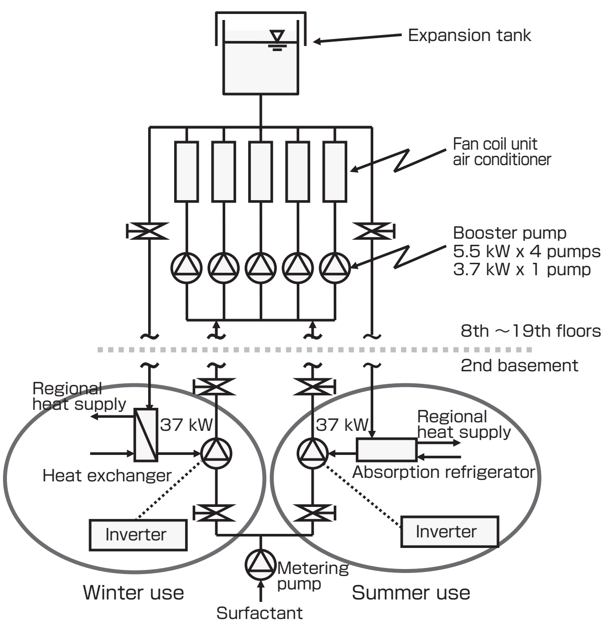

Fig. 5 Diagram of the cooling/heating system water circulation of the Sapporo City Office

5 Preparation of the demonstration test

5.1 Basic understanding of the flow property

The agent showed flow drag reduction effect at 5~65 °C, so it could be used continuously throughout the summer period when cold water was circulated and in the winter period when heated water was used. However, there was a temperature dependency of the flow drag reduction effect, and it was necessary to study the values from 7 °C to 45 °C that was the actual usage range. It was also useful to understand the effect of the rust inhibitor used concurrently on the reduction effect. These were measured using the water circulation experiment apparatus of the Tokyo University of Science. The test section had channel length of 1 m and internal diameter of 10.7 mm. The agent concentration was varied between 3000~6000 ppm, to measure the flow rate dependency of the flow drag reduction effect[7].

In using the surfactant on site, there were cases when it could not be used due to bubbling. For example, the expansion tank might be open to the atmosphere and air might be regularly introduced in some areas. For the identification of complexities in the channel, the staff of the control room of the City Office in charge of the daily system maintenance did a preliminary check of the problem areas.

The power consumption of the pump and the flow rate in each pump channel were measured before the agent injection. Portable transit time ultrasound flow meter was used for flow rate measurement, and the feeder power recorder was used to measure the power.

5.2 Inverter installation

As the flow drag decreased by agent injection, the amount of circulating water would surpass the rated flow. By decreasing the revolution of the circulation pump using the inverter, this would be brought back to the rated flow. As a result, the power consumption of the pump would decrease, and energy savings would become possible. Therefore, the installation of an inverter was necessary for this technology. From the results of the preliminary flow property tests and flow rate measurement, it could be determined that sufficient circulation would be obtained after the agent injection even when the operation of the five booster pumps on the 8th floor is stopped. The inverters were installed in each of the 37 kW winter and summer circulation pumps. The harmonics outflow current that might affect other devices was measured, but it was found that countermeasures were unnecessary.

5.3 Water quality adjustment

When 1000 ppm of the agent was added and stirred with the sampled circulating water, cotton-like precipitate was formed. This was thought to be a hydrate formed by the reaction between the anionic rust inhibitor in the circulating water and the cationic one that was used. Therefore, if this agent were injected in the circulating water directly, the hydrate would form and clog the narrow parts of the pipes. To prevent this, the cationic rust inhibitor was used. The circulating water was replaced the total of four times using the off-days to reduce the concentration of the anionic rust inhibitor to several tens of ppm, and the set volume of cationic rust inhibitor was added. The hydrate did not form when the readjusted circulating water and the agent were mixed.

The injection of the agent was done near the ejection point of the circulating pump on the 2nd basement. The plunger pump was used to pressure inject a certain amount of agent placed in the agent tank into the circulating water.

For the sampled circulating water, the calibration curve of the agent concentration and electric conductivity was obtained beforehand to calculate the agent concentration of the circulating water after injection. During the demonstration test, the circulating water was sampled from the 2nd basement, air conditioning equipment room on the 8th floor, and expansion tank on the 19th floor. The mixing state of the agent for the whole building was estimated from the distribution of the agent concentration.

6 Demonstration test

6.1 Appearance of the flow performance

The demonstration test for winter was conducted in November 2006. The details are described in reference[8]. The heating system of the office building started operating in early morning and was stopped at 17:30. Therefore, the actual circulating water was sampled at 9:00 when the entire circulating water system became thermally steady. The calibration curve for the electric conductivity and agent concentration was obtained from the samples. Since the agent had high viscosity, unevenness in concentration occurred in the system when it was bolus injected, and in extreme cases, the high concentration of the agent might cause clogging in the narrow channels. Therefore, the agent was initially injected at a slow speed of 10 kg/h. Then circulating water was sampled, concentration measured, and abnormalities were checked at the 8th and 19th floors. Slight bubbling was observed in the expansion tank on the 19th floor, but the amount was not problematic, and there was no further increase of the bubbles. A total of 100 kg of the agent was injected over three days. The estimated agent concentration at this point was 3000 ppm.

Table 2. Demonstrated operation condition and energy saving rate for summer and winter periods

Air conditioning mode	Agent concentration (ppm)	Set frequency (Hz)	Rated flow (L/min)	Energy conservation rate (%)
Cooling	about 3500	40	6600	47
Heating	about 5000	35	6600	65

To even out the agent concentration further throughout the system, the second injection was conducted after one week. Two days were taken to inject 80 kg of the agent, and the injection was completed when the estimated agent concentration reached 5400 ppm, which was sufficient to generate the flow drag reduction.

In the series of maneuvers described above, the inverter frequency was changed at the agent concentrations of 0 ppm, 3000 ppm, and 5000 ppm, and the values for the flow rate and power consumption of the pump were measured. It was found that 65 % of energy conservation could be achieved by setting the agent concentration to 5000 ppm and the inverter to 35 Hz to match the rated flow during the winter period.

The flow drag reduction was studied for the period of cooler use (summer period). It was found that 47 % of energy conservation could be achieved by agent concentration of 3500 ppm and inverter frequency of 40 Hz. The results of the demonstration test for the cooling and heating periods are shown in table 2. The calculated amount of saved energy for the cooling and heating periods in a year was 52,000 kWh, and this amounted to conservation of over 1 % of power usage for the entire city office building.

6.2 Maintenance of the heat transfer property

As shown in Fig. 5, for the reduction of the heat transfer performance in the heat exchanger used in the winter period, it was thought that the reduction of both the flow drag and heat transfer performance would not occur due to the great turbulence in the flow due to the complex channel of circulating water, because the high temperature steam supplied by the regional heat travelled through the heat exchanger tube while the circulating water flowed inside the shell-side separated by the segmental baffle plate.

The heat exchanger of the evaporation unit of the absorption refrigerator used during the summer period is composed of 414 U-shaped copper tubes of the length of 6 m and an inner diameter of 16 mm. The circulating water flows inside this hairpin tube, and flow drag reduction is expected to occur in the straight section. If the reduction of heat transfer performance is also occurring, the circulating water will circulate the building with insufficient cooling, and the cooling capacity of the entire building will be compromised. For the heat transfer coefficient of the tubes of the heat exchanger, the value obtained from the empirical equation[9] and the value obtained from the temperature difference measured at the inlet and outlet of the heat exchanger were compared, and the measurement value was about 13 % lower. In general, it is said that the reduction of heat transfer performance is greater than the flow drag reduction. In the test, the flow drag reduction for the entire building was 47 %, and about 13 % reduction in the heat transfer coefficient indicated that the heat transfer performance reduction in the heat exchanger tube was not that great. Also, the outlet temperature of the refrigerator remained at 11 °C, the set value for operation during summer, and it became clear that the energy conservation by flow drag reduction did not cause any problems for operation of the air conditioner.

6.3 Maintenance of long-term stability

After the injection of the agent, it is necessary to maintain the appropriate agent concentration. The primary reason why the concentration decreases is the leakage of the circulating water containing the agent. If there is small but regular leakage from the joints such as from the packing, relatively large amount of water may escape during the channel switching from summer to winter. The accumulation of air in the channel is prevented by adding freshwater, but the agent concentration may decrease and the flow drag reduction effect may be reduced in this maneuver. The total amount of freshwater added must be measured, and extra injection of the agent is necessary if significant reduction in agent concentration occurs. In case of the Sapporo City Office, there was no leakage from the joints, but there were several tons of outflow when switching the channel from the summer absorption refrigerator to winter heat exchanger. Therefore, after switching, the surfactant concentration was measured, and additional injection was done based on the measurements. With accumulated experience, measures could be taken in the switching maneuver, and the work could be accomplished with very little outflow. As a result, currently extra addition of the agent may or may not be needed. The measurement of the surfactant concentration is done twice a year after switching the cooling/heating. Although the concentration can be estimated indirectly on site from the electric conductivity of the sampled water using the calibration curve, the concentration of the agent is measured directly along with the concentrations of the iron, copper, and other substances by subcontracted analysis.

The pipes were replaced from iron to stainless in 2001 due to rusting caused by aging. However, the heat exchanger is iron and the fan coil in each room is copper, and electric corrosion may occur. About 1600 days have passed since the agent had been introduced, but the concentration of iron and copper in the circulating water is stable, and it is determined that there is no corrosion in the pipe system.

The long-term stability of the agent is expected to be affected by the interaction of the agent and the substances that were already present in the circulating water, the expiration of effectiveness due to the temperature history, and the lifespan of the agent itself. Although the instability that may occur in a short time can be seen before injection, the long-term effect must be determined from the past case studies. However, the follow-up surveys of past injections have not been disclosed. Therefore, this case in which the effect has been sustained for over 1600 days is a valuable demonstration.

For the toxicity of the agent, material safety data sheet (MSDS) has been created, and there is no problem as long as the agent is processed through the wastewater processing plant, without direct release to the rivers.

7 Effect of technology diffusion promotion

Figure 6 shows the changes in the number of inquiries to Company L, the developer of the flow drag reduction agent, after the three press releases.

The number of inquiries increased after AIST conducted a press release[10] in May for the heating period test results in February 2007. Also, the test results for the cooling period for 2008 were announced at the Sapporo City Office, but there were no significant increase in inquiries, perhaps because the releases were mainly in local newspapers. The inquiries increased dramatically when Japan Broadcasting Corporation (NHK) aired the news in January 2009[11].

The places where the surfactant was actually installed in two years are shown in Fig. 6. There were 18 cases, including 9 cases, the highest number, in private company factories, 4 airport facilities, 3 public facilities, and 2 private buildings. According to Company L, the number of installations increased clearly after the public announcement of the demonstration test by AIST. Until then, even if Company L installed the agent to a private facility and publicized the energy saving effect, it was mostly seen as an advertisement of the technology by a private company. However, the news coverage of a public research institute such as AIST demonstrating

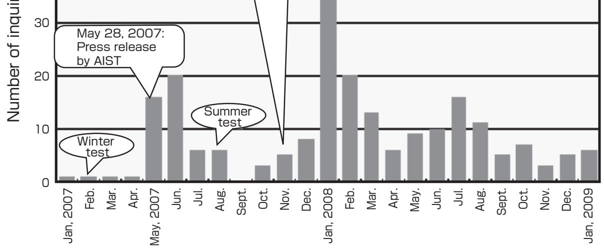

Fig. 6 Changes in the number of inquiries to Company L

Table 3. Examples of inquiries to AIST and responses

Inquirer	Question	Answer
Central government ministry	Can it be installed in the government buildings?	Since the aging of the pipes has progressed, the rust inside the pipes may be a problem. The surfactant and the rust may bond, and may inhibit the effect.
Local government	The person in charge of the facilities brought diagrams, and mentioned they wanted to do tests for the new government building that was being constructed.	Since the cooling tower is open to the atmosphere, bubbling occurs at this section, and therefore the surfactant cannot be used.
Major beverage company	We want to save energy because we need large amount of energy for cold water circulation at our plant. Also, is there any surfactant that is approved as food additive and also has flow drag reduction effect?	The person in charge visited the Sapporo City Office, and we explained the principles and MSDS. We have not done basic experiment for the flow drag reduction using food additives.
Individual home	We installed a heat exchanger in the attic 15 years ago, and get hot water from spring to autumn. Can the same effect be obtained for small pumps? Also, the heating medium has antifreeze to prevent freezing. Does the water containing surfactant have antifreeze function?	The effect can be seen even in small pumps. For example, the portable experiment apparatus used for the demonstration of Toms effect is a channel where the 18 m vinyl tube with inner diameter of 12 mm is coiled up into rings of diameter of about 30 cm, and about 30 % energy saving effect can be obtained. The pump is 150 W. The decrease of freezing point cannot be expected with 5000 ppm of this surfactant. It is necessary to check the flow drag reduction in the presence of antifreeze using the small experimental apparatus.

the efficacy of the technology was considered objective, provided practical information to offices that wished to quickly deploy energy-saving practices, and led to the increase in inquiries, and some places did actually install the technology. The nature of the inquiries was distinctly different from the usual ones that simply asked for the outline of the technology. Many of the inquirers presented the outline of the facilities in their buildings and asked about the cost, assuming actual installation.

Table 3 shows the typical questions among the 150 inquiries to AIST after the press release, and the answers. In the inquiries, there were several questions about the flow drag reduction in low temperature, including the combined use with antifreeze and ice thermal storage. Feedback from basic research such as the development of a new agent for low temperature is necessary. There were also several inquiries about the cooling system for plants that handle foods and beverages, but in most cases installation was not done since there was a possibility of circulating water leakage that might contaminate the foods. There was an inquiry from a Japanese company that had plants in Southeast Asia for use in the cooling system, but this was not done due to the problem of local concentration management.

8 Future development

Up to present, the consideration of installation to the building, the injection work, and the maintenance and inspection, as well as the manufacture and sales were done entirely by the company that developed the agent. In the future, we believe this technology will quickly diffuse if the building maintenance companies, building management companies, or design offices will conduct the preliminary check of the water quality and pipe system and the maintenance including agent injection and concentration management. From this perspective, it is probably effective to organize an annual technical experience seminar by expert lecturers to the engineers of maintenance companies.

Although the application to the regional cooling/heating system will greatly promote energy conservation, there is no clear conclusion on the issue of heat transfer performance. This is an issue that must be solved quickly through demonstration tests by the experts of the elemental technologies that comprise the system.

Acknowledgements

The demonstration test was conducted according to the basic agreement between AIST and the City of Sapporo for the effective use of energy. The joint research contract was signed among: the General Affairs Division and Environment Division, City of Sapporo; Department of Mechanical Engineering, Faculty of Science and Technology, Tokyo University of Science; Shunan Regional Industry Promotion Center; and Fujiwara Environmental Sciences Institute Ltd. We are grateful to the people in charge at these organizations for their efforts. We are also thankful to the LSP Cooperative Union which provided us technical instruction for the use of the agent, and the people of Sapporo City Office and Kitaden Co., Ltd. who provided enthusiastic technical support for the execution of the test on site and the maintenance of the system, and continues to provide maintenance work.

Notes

Note) Type 2 designated energy management factory: This is a facility in which the standard value for energy use per fiscal year is 1,500 kL to less than 3,000 kL by crude oil equivalent for fuel (heat), and 600 kWh to less than 1,200 kWh for electricity. Such facilities are required to reduce the specific energy consumption by annual average of 1 % or more.

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Author

Hiromi TAKEUCHI

Executive vice president, Chemical Material Evaluation and Research Base (CEREBA). Withdrew from the doctorate course of the Department of Chemical Engineering, Kyoto University Graduate School of Engineering in 1980. Assistant at the Department of Chemical Engineering, Kyoto University Graduate School of Engineering in 1980. Worked as planning officer, Hokkaido National Industrial Research Institute, Agency of Industrial Science and Technology and vice-director of Energy Technology Research Institute, AIST. Upon retirement, assumed current position. Specialties are flow and heat transfer. This test was conducted while at the Energy Technology Research Institute. At the same time, also conducted the cogeneration demonstration research using the supercooling heat storage in Sapporo with over ten researchers from the Energy Technology Research Institute.

Discussions with Reviewers

1 Overall

Comment (Akira Ono, AIST)

I think this study is a good example of a joint study with a local government, which is an entity with which the researchers do not regularly have contact, to diffuse the research result of the basic research to society. I also think it was difficult to conduct an experiment in an actual working building. I hope this will be referenced by many readers as a good case study of a methodology for *Type 2 Basic Research* or *Product Realization Research*.

2 Significance of the demonstration research conducted by a public research institute

Comment (Yasuo Hasegawa, Energy Technology Research Institute, AIST)

In the process of introduction and diffusion of a new energy conversion technology, there are several factors that inhibit the process, and a long time is required. This paper describes the installation procedure and energy conversion effect conducted by a public research institute for a public facility, and it is particularly valuable because it contributes to further diffusion and promotion.

I think you should present cases where the result of this demonstration led to the increase in the number of installations, and provide deeper consideration on the meaning of demonstrations conducted by a public research institute.

Answer (Hiromi Takeuchi)

The number of inquiries increased after the press release introducing the result of this demonstration, and this led to increased installations. I described the outline in chapter 7, and added considerations for the significance of the demonstration research by a public research institute.

3 Joint research with a local government

Comment (Akira Ono)

I think you should address the various factors unique to having the local government as a joint researcher, and how you solved the difficulty of conducting an experiment in a working building.

Answer (Hiromi Takeuchi)

Since any failure originating from the test was not allowed in the working building, we carefully studied the entire water circulation system and the location and performance of the component machinery. We also utilized the off-days of the office.

I did not describe some factors directly in the text since many of them do not pertain to technology, but the most difficult points were to get the people of the local government to understand the importance of this demonstration test and to obtain approval for conducting the test in the building where these people work everyday.