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## Development of a liquid desiccant air conditioning system using ionic liquids

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### Abstract

Liquid desiccant air-conditioners (LDAC) with heat pump can perform cooling dehumidification or heating humidification, and have high energy-saving and sterilization performance. Therefore, they are installed in hospitals, nursing homes, and food factories, where humidity control is required. However, lithium chloride (LiCl), a conventional humidity control liquid, is highly corrosive to metals, requiring the use of highly corrosion-resistant materials such for the pipes and the heat exchangers. This leads the problem that the manufacturing cost of the air conditioner increases.

Therefore, we developed an inexpensive and compact LDAC by adopting a novel ionic liquid (IL) that does not corrode the metals commonly used in air conditioners. In this study, we evaluated the metal solubility and sterilizing property of the ionic liquid. Based on the physical properties of the IL, the humidity control module was improved for the purpose of downsizing and cost reduction of the unit. Moreover, we conducted a performance evaluation of the LDAC in the environmental test room under the condition in which temperature and humidity change rapidly in short period of time to simulate the condition of sudden showers of rain in summer. Test results showed that processed air was supplied at very stable level.

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*Keywords: Liquid Desiccant Air Conditioning, Ionic Liquids, Heat pump, Dehumidification*

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### 1. Introduction

The development of an efficient air-conditioning system has become more and more important from the standpoint view of realizing a sustainable society. In hospitals and factories where temperature and humidity control throughout the year are required, gas as fuel have been used as heat sources of boilers and absorption chillers. However, there is a lot of heat loss in the boiler and the steam piping, and the energy consumption is high. LDAC is attracting attention as one of the most promising candidates to replace such inefficient air conditioning systems [1-3].

However, the present commercial LDAC uses an aqueous solution of LiCl as the humidity control liquid or desiccant. The LiCl is very caustic/corrosive to metals, in particular, iron or aluminium, both of which are popular resources of materials in the air-conditioner system; this requires expensive special corrosion-resistance pipes and heat exchangers, which causes a critical problem that the manufacturing cost of the air-conditioning system is rather high.

Ionic liquids (ILs) have gained strong interests due to their unique physical and chemical properties and their applied fields have been significantly expanding. ILs show a low volatility, unique solvation capability, and high stability and the liquids have thus been applied in various fields of electro-chemistry, organic and inorganic synthetic chemistry, catalysis, and gas absorption [4-5].

In these backgrounds, we have developed an inexpensive and compact LDAC by adopting a novel IL that does not corrode general-purpose metals such as iron and aluminium. In this study, we evaluated the metal

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solubility and the sterilizing property of the IL. Based on the physical properties of the IL, we improved the heat exchanger and the humidity controller. Moreover, we conducted a performance evaluation of the LDAC in the environmental test room under the condition in the rated dehumidification condition and the transient condition.

## 2. Outline of LDAC

Figure 1 shows an outline of LDAC in the case of dehumidification. LDAC is a device that absorbs and releases water vapor in the air by bringing the outside air into direct contact with a gas-liquid contactor wetted with a liquid humidity control liquid to adjust the humidity and temperature of the air. It consists of a processor and a regenerator. The processor plays a role of supplying the treated air to the room, and can create air of any temperature and humidity by adjusting the temperature and concentration of the humidity control liquid. Also, the temperature and concentration of the humidity control liquid can be independently controlled, and the temperature and humidity of the air can be freely set. On the other hand, the regenerator has a role of concentrating the liquid by heating the humidity control liquid, which has been diluted by absorbing the moisture in the air, and bringing it into contact with the outside air. Humidification is performed by switching between cooling and heating of a heat source such as a heat pump. Various heat sources such as heat pumps, groundwater, exhaust heat, and solar heat are used to cool or heat the liquid. In particular, the use of heat pumps that can heat and cool at the same time will improve system efficiency.

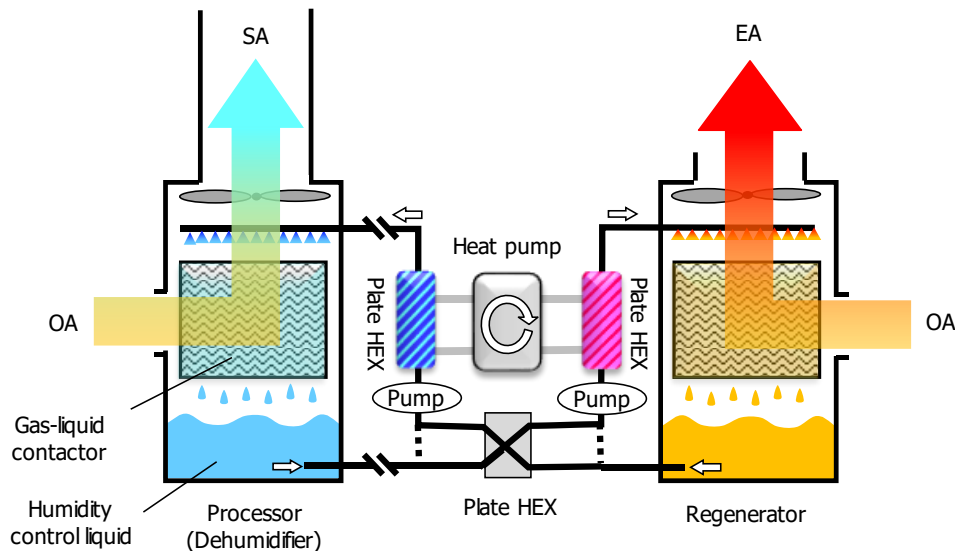


Fig.1 Outline of LDAC (Dehumidification case)

## 3. Physical properties of IL

In general, humidity control liquids are required to have high humidity control performance, inexpensive, satisfy, and high sterilization properties and so on. LiCl which is mainly used as a humidity control liquid for LDAC, satisfies such requirements, but has the problem of being highly corrosive to metals.

In this study, a novel IL developed by Evonik Industries was used as the humidity control liquid. This IL exhibits high dehumidification performance, thermal and chemical stability, low volatility, comparable heat mass transfer properties [6] and is suitable for LDAC. Table 1 shows comparison of thermophysical properties of humidity control liquid. At the same temperature and the equivalent liquid desiccant mass fraction at which the saturated vapor pressure is identical, the aqueous IL exhibits lower density and surface tension than aqueous LiCl. On the other hand, the viscosity of aqueous IL is higher than that of aqueous LiCl. In the following, the results of evaluating the level of metals dissolved into the IL and sterilization performance in comparison with LiCl are shown.

Table 1 Thermophysical properties of humidity control liquid (25°C)

	Mass fraction	Density	Viscosity	Surface tension	Thermal conductivity	Specific heat capacity
	%	kg/m <sup>3</sup>	Pa · s	N/m	W/mK	kJ/kgK
IL	0-80	1000-1150	0.001-0.03	0.072-0.039	0.607-0.271	4.2-2.2
LiCl	0-35	1000-1215	0.001-0.005	0.072-0.091	0.607-0.539	4.2-2.8

### 3.1. Level of Metal ions into the IL

Figure 2 and Fig.3 show the metal ions of stainless steel and aluminum dissolved into the IL. The test period is 3 weeks and the temperature of the solution is heated up to 70°C. The mass fraction of IL and LiCl are 80wt% and 35wt%, respectively. Saturated vapor pressure at these mass fractions is close to the value when dehumidifying the outside air in summer. The size of the metal sample is 40mm×10mm×3mm. The amount metal ions SUS and aluminum dissolved into the IL is much less than into the LiCl solution and is at a practically acceptable level. This result suggests that commonly used tubes and heat exchangers can be used, which is a great advantage in reducing the manufacturing cost of air conditioners.

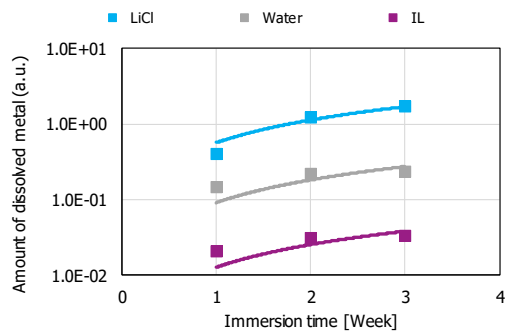


Fig.2 Amount of dissolved metal (Aluminum)

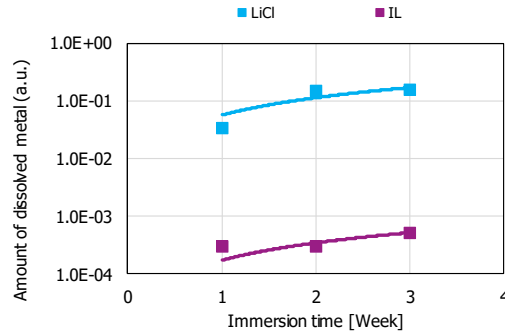


Fig.3 Amount of dissolved metal (SUS304)

### 3.2. Sterilization performance

In the COVID-19 pandemic, the air cleaning performance of air conditioners is also required as an additional factor. Therefore, we investigated the sterilization and virus inactivation performance of the IL. As an example, Fig. 4 and Fig. 5 show the results of the sterilization effect against *Legionella* and *Aspergillus niger* of the IL in comparison with LiCl solution. When each bacterium is brought into contact with the IL, it dies after 1 minute, and the sterilization performance is higher than that of LiCl.

Table 2 shows the inactivation effect of the IL on three types of viruses (*feline coronavirus*, *influenza virus*, and *feline calicivirus*). The IL was added to the liquid containing the virus cell line, and after a predetermined period of time, the amount of virus infection to the cell line was measured. In the case of the purified water for comparison, the amount of viral infection hardly changed after 60 minutes, but with the IL, the amount of viral infection decreased sharply down to the detection limit even after only 1 minute, demonstrating a remarkable viral inactivation effect.

Regarding the hazards of this IL, we conducted an acute toxicity test using mice in accordance with the OECD guidelines, and confirmed that the classification of hazards to health (GHS) is beyond the most mild class.

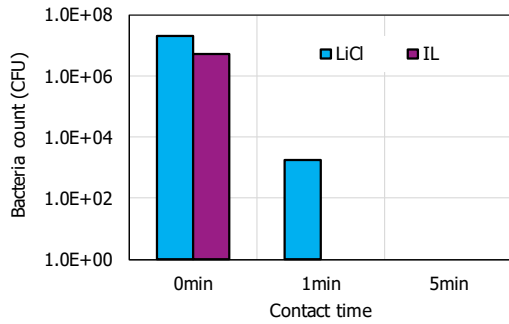


Fig. 4 Bacteria count (Legionera)

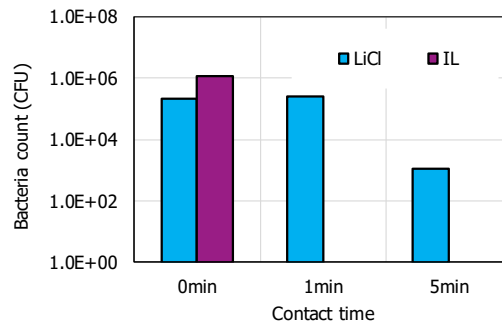


Fig.5 Bacteria count (Aspergillus niger)

Table 2 Virus inactivation performance result of ionic liquid

	value of virus infectious dose (TCID50/mL)					
	<i>feline coronavirus</i>		<i>influenza virus</i>		<i>feline calicivirus</i>	
	IL	Water	IL	Water	IL	Water
0min	1.7×10 <sup>5</sup>	1.7×10 <sup>5</sup>	1.0×10 <sup>5</sup>	1.0×10 <sup>6</sup>	2.4×10 <sup>5</sup>	2.4×10 <sup>5</sup>
1min	No count	—	No count	—	No count	—
5min	No count	—	No count	—	No count	—
60min	No count	1.1×10 <sup>5</sup>	No count	3.1×10 <sup>6</sup>	No count	2.4×10 <sup>5</sup>

#### 4. Configuration of humidity control module

In LDAC, the supply air temperature is determined by controlling the temperature of the humidity control liquid, and the air humidity is determined by controlling the concentration of the humidity control liquid. In a typical LDAC, as shown in Fig. 6, the humidity control liquid is first cooled in a plate heat exchanger and then directly contacted with the outside air in an air-liquid contactor. The temperature and humidity of the outside air are regulated by direct contact with this liquid.

In the conventional LDAC systems using LiCl, as the humidity control liquid generates heat when it absorbs moisture, the temperature gradually rises in the downstream direction of the gas-liquid contactor. Since the dehumidifying ability of the humidity control liquid decreases as the temperature rises, it is necessary to flow a large amount of the liquid in order to prevent this, and the capacity of the solution pump and the solution tank have been increased. Therefore, from the viewpoint of the cost reduction and the compactness, it was necessary to reduce the liquid flow rate and the tank size as much as possible.

In this study, as shown in Fig. 7, a sandwich structure was adopted in which tube heat exchangers and gas-liquid contactors were alternately arranged, and dehumidification was performed while cooling the humidity control liquid. As a result, it becomes possible to reduce the liquid flow rate while reducing the temperature rise of the humidity control liquid in the downstream direction. We conducted tests using the tube layout and the type of gas-liquid contactor at various conditions of parameter, determined the optimal combination, and developed a compact integrated humidity control module that combines a heat exchanger and a humidity control mechanism. As a result, the circulation flow rate (liquid volume) was reduced by 90% compared to the conventional machine, and the tank size was also greatly reduced. As showed in Table 1, the IL has lower surface tension and higher viscosity than LiCl. Therefore, it should be noted that a stable and thin liquid film is likely to be formed even at a low flow rate [7].

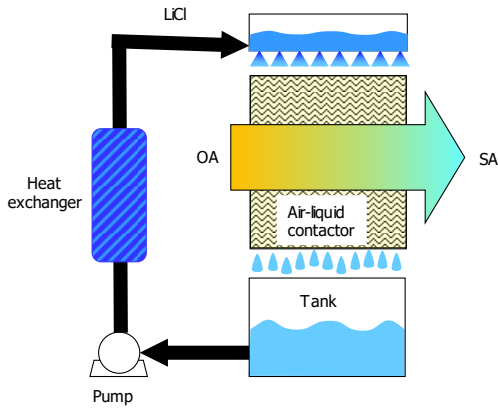


Fig.6 Conventional humidity control module

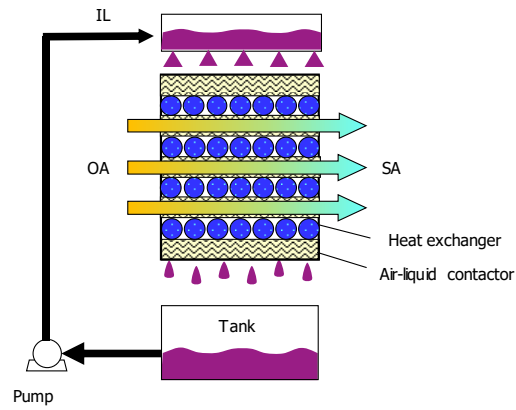


Fig.7 Developed humidity control module

### 5. Specifications

Figure 8 shows the appearance of the developed LDAC, and Table 3 shows the specifications. The processor and the regenerator have the same shape. As a heat source, not only hot and cold water from a heat pump chiller, but also hot water discharged from a factory, well water, etc. can be used. Compared to the conventional models of line-up, this unit has about 20% reduction in manufacturing cost, about 25% reduction in installation area, and about 90% reduction in the amount of humidity control liquid.

The LDAC shown in Fig. 8 has a rated air volume of 4,500 m<sup>3</sup>/h, but customers in the industrial field require a variety of processing air volumes. Therefore, as shown in Fig.9, we made it possible to customize and incorporate it inside the air handling unit (AHU) used for general air conditioning. As a result, we have been able to respond to a wide range of processing air volumes according to customer needs.



Fig.8 Outside appearance of the LDAC (processor)

Table 3 Specifications of the LDAC

Dimensions (Width × Depth × Height)	1,600×1,830×2,000
Weight (kg)	1,620
Pump power supply (W)	200
Rated dehumidification capacity (kg/h)	67.5
Rated humidification capacity (kg/h)	68.6
Rated Air flow rate (m <sup>3</sup> /h)	4,500

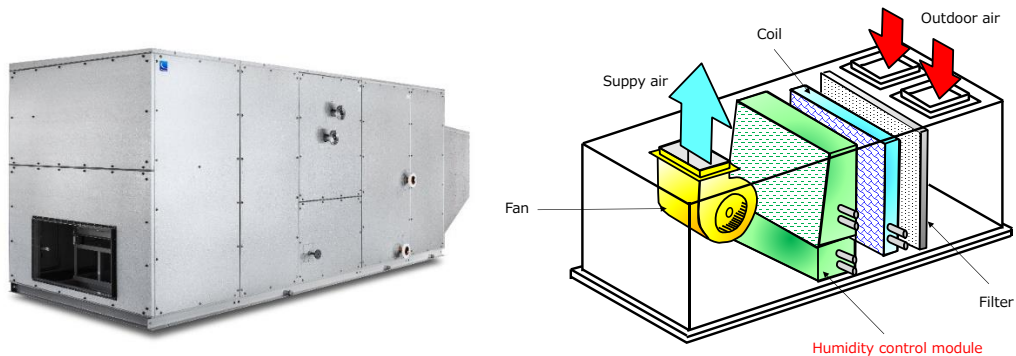


Fig.9 Outside appearance of the LDAC (AHU version)

## 6. Performance tests of the LDAC

The performance tests of the developed LDAC were conducted in the climatic environmental testing room in the research and development division of Chubu Electric Power Co., Inc. Rated humidification performance, dehumidification transient performance were measured. 100kW heat pump chiller was used as a heat source.

### 6.1. Rated dehumidification performance test

Table 4 shows the results of the rated performance test. This test was conducted under typical Japanese summer outdoor air conditions, assuming application to a commercial building. The measured value of the dehumidification capacity was close to the target value, confirming that stable performance were obtained.

Table 4 Results of rated performance test

		Target value	Measured value
Flow rate (m <sup>3</sup> /h)		4,500	4,474
Temperature of cold water (°C)		10.0	9.6
Temperature of hot water (°C)		45.0	37.8
Outdoor air	Temperature (°C)	34.3	34.3
	Humidity (g/kgDA)	19.5	19.5
Supply air	Temperature (°C)	20.0	18.4
	Humidity (g/kgDA)	7.0	6.4
Cooling Capacity (kW)		70.3	73.2
Dehumidification capacity (kg/h)		67.5	70.3

### 6.2. Dehumidification transient performance test

This test was conducted for the purpose of verifying the humidity control during sudden weather changes. In manufacturing processes such as pharmaceutical and painting processes, it is important to maintain a stable state even under drastic change in ambient conditions.

Figure 10 shows changes in temperature and humidity processed by the developed LDAC in a situation simulating the condition in which temperature and humidity change rapidly in short period of time such as sudden showers of rain in summer. By control temperature and concentration of the IL suitably, test results showed that the processed air was supplied at very stable level. The averaged temperature, humidity, and humidity ratio during the test were 26°C, 44%, and 9.2g/kgDA, respectively. The temperature change of the supply air was ±0.6 °C and the humidity change was within ±1%.

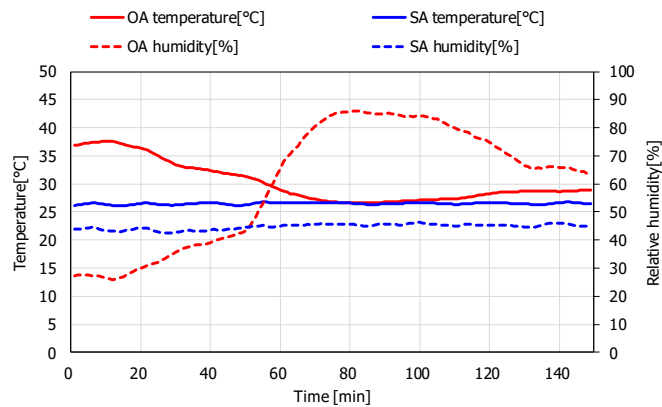


Fig.10 Supply air temperature and humidity characteristics when a shower is assumed

## 7. Primary energy consumption

Table 5 shows the result of estimating primary energy consumption and CO<sub>2</sub> emission of the conventional system and that of the developed LDAC system when the system is introduced to a hospital in Japan. The conventional system consists of a gas steam boiler and an air-cooled heat pump chiller. A substantial reduction in energy consumption of 72% and CO<sub>2</sub> emission of 49% from that of the conventional system can be expected when the new system is introduced. It is noted that although the LDAC system using LiCl considerably increases the power consumption of the pump compared to the developed system, the impact on the increase of primary energy consumption and CO<sub>2</sub> emission is not so large.

Table 5 Estimated primary energy consumption and CO<sub>2</sub> emission

	Conventional system	Developed system	Reduction rate
Primary energy consumption [GJ/year]	449	126	72% down
CO <sub>2</sub> emission [ton-CO <sub>2</sub> /year]	111	56	49% down

-Estimate condition-  
 Building: Hospital (floor area: 2,000m<sup>2</sup>)  
 Air conditioning operation: 24h/day, 365day, flow rate 10,000m<sup>3</sup>/h  
 System Efficiency: Heat pump chiller (cooling COP:4.07, heating COP:4.06), Gas boiler 70%  
 Calorific value: Electric 9.70MJ/kWh, Gas 45MJ/m<sup>3</sup>  
 CO<sub>2</sub> emission factor: Electric 0.449kg-CO<sub>2</sub>/kWh, Gas 2.29kg-CO<sub>2</sub>/m<sup>3</sup>

## 8. Summary

We have developed an inexpensive and compact LDAC by using a novel IL that does not corrode general-purpose metals. The developed LDACs were already installed in hospitals, nursing homes, offices, food supermarkets, and beer factory as energy-saving and hygienic air conditioners. The results obtained during the research and development of this system are as follows:

- The amount of SUS and aluminum dissolved in the IL is much lower than that in LiCl solution. In addition, the IL has a higher sterilization effect against bacteria and viruses than LiCl solution.
- A sandwich structure in which tube heat exchangers and gas-liquid contactors are alternately arranged was developed for the direct contact of air to liquid. Consequently, the liquid flow rate can be reduced by 90% compared to the conventional unit.
- By appropriately controlling the temperature and IL concentration, extremely stable processing air can be supplied even under conditions where the outside air conditions change rapidly.
- It is expected that the energy consumed by conventional air conditioning system such as heat pump chiller and boiler, can be reduced 72% by introducing the new system.

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