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Development of Supersonic Vaporization Cooling System for an Air-cooled Chiller

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Abstract— This paper provides a new cooling method for the water misting cooling. Differing from traditional air-cooled water chillers, this study aims to achieve power savings and improved efficiency by improving the cooling method and power consumption index of traditional air-cooled water chillers. In order to prevent scaling issues from occurring during the atomization of oscillator operation, a filter is provided at the water inlet to reduce scale generation. Furthermore, the system uses a high-performance pollution-free HC refrigerant, combined with an atomizer at the high-pressure side (condenser), driving the mist to flow evenly along the condenser by the unit fan and condenser fan, for lowering the temperature. Since this equipment reaches the cooling demand shortly, the compressor tends to start/stop frequently; this is disadvantageous to the compressor, therefore variable-frequency will be considered to address the frequent start/stop issue so as to perfect the combination.

Index Terms-- Water Mist Cooling, Supersonic Oscillator, Variable Frequency, Air-cooled Water Chiller.

I. INTRODUCTION

The market-available water-spray type air-cooled water chiller mainly depends on water mist for cooling the system; this tends to result in rusty base frames and water accumulation around the unit. The study intends to keep-up the performance of the water-spray type air-cooled water chiller and improve its shortcomings. Based on the finding that [1] the nozzle diameter and the distance from the nozzle to the test surface will affect the critical heat flux; and [2] using three different surface areas/shapes and nozzle angles in studying the behavior of spray cooling; [3] we compared spray cooling and thin film cooling in the cooling performances on surfaces of heated steel plates, concluding that spray cooling has a better cooling effect than thin-film cooling; [4] we analyzed the effects on heat-plate behaviors using different volumes of atomization, spray angles, and nozzle-to-object distances; [5] performed spray-cooling experiments by spraying on high-temperature metal surfaces, finding that the massive flow rate of liquid significantly increases heat conductance,[6] increase the volume of atomization there will be significant increase in heat transfer, [7]in the distance 1.2m the heat transfer will increase by the amount of air, when in the 0.3m, the heat transfer is increase at the first, and then is decline later.[8]in the spray system need to care about the quality of water,[9]use the water and R-134a to research the cooling behavior of the droplets on a hot plate[10]there are three kinds of radiators to compare and analysis with air-cooled, water-cooled and evaporative cooled documents show that spraying water mist is truly an excellent cooling method, and that water mist consists of small water molecules that hardly cause a pollution issue, and it is not yet used on air-cooled water chillers. Therefore this study intends to use it on the air-cooled water chiller, and a supersonic atomizer will be used as the major cooling mechanism.

Due to shortcomings in air-cooled water chillers such as complex peripheral components, environmental pollution, and easily rusted frameworks, the study will mainly use supersonic oscillating vaporization as the main cooling method for addressing the said shortcomings. The atomized mist vaporizes easily in the air due to the small particulate diameter. When spread over a condenser with the help of a condenser fan, no water accumulation will occur. To increase efficiency, the thickness of the condenser is higher than usual, which also enables a longer retaining time for the water mist on the condenser. An additional human-machine interface is provided for observing the real time operation of the machine, as well as for remote monitoring.

The study employs variable frequency control to eliminate frequent start/stop of the compressor; it is capable of controlling the temperature as well as providing a power saving operation and allowing the supersonic atomizer system to adjust the volume of atomization in coordination with the compressor loading status. Since supersonic atomization has mostly been used in cooling electronic ships and small components, and documents show that atomization is capable of carrying away a large amount of heat via vaporization of the water mist, the study therefore intends to design an experiment platform to measure the data and verify if atomization is equally efficient as the traditional air-cooled water chiller, or even has more efficient and more energy saving.

Fig1.shows the air-cooled water chiller's main components , it is the air-cooled water chiller cycle, variable frequency control the compressor → condenser → evaporator controller (a capillary tube or an expansion valve) , as the medium of refrigerant in the system, the constant cycle to repeat the endothermic and exothermic.

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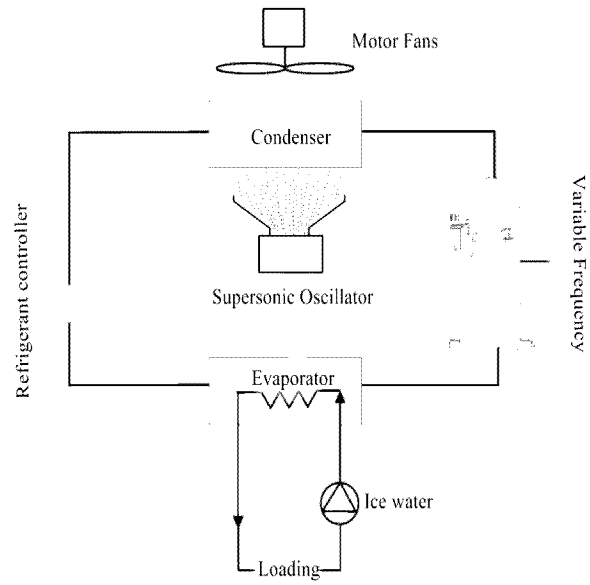

Fig.1 flow chart of air-cooled water chiller

II. DESIGN OF THE EXPERIMENT PLATFORM AND PARAMETER SET UP

A. The Experimental Equipment.

The supersonic water misting vaporization platform design is show Fig. 2 Fig.1 Design of supersonic vaporization Water Chiller; Fig.2 shows the experiment platform of Air-cooled Water Chiller, the comprising components are: 1. Fan; 2. Condenser; 3. Water spray outlet; 4. Interface/circuitry assembly, as shown in Fig.3; 5. Water pump; 6. Liquid Storage; 7. Compressor; 8. Supersonic Atomization Oscillator. Their main functions are described as follows:

1. Fan: The fan drives water mist to distribute it evenly over the condenser surface.

2. Condenser : the main function is exchanging heat to the air (heat dissipation), using the air to carry away heat from the refrigerant inside the condenser, so that the high-temperature and high-pressure gaseous refrigerant transforms into hyper-cooled high-pressure liquid refrigerant of normal temperature.

3. Man-machine interface: for viewing the current status of machine operation, including chilled water temperature, condenser temperature, operation load, etc.

4. Compressor: the heart of the system. The system uses a volute-type compressor, mainly for compressing the refrigerant to generate the high-pressure and low-pressure necessary for the refrigeration cycle: the low-pressure and low temperature gaseous refrigerant is compressed to form high-pressure and hyper-heated refrigerant vapor, which is delivered into condenser for carrying out heat-exchange.

5. Supersonic Atomization Oscillator : water is atomized by supersonic vibration into mist and spreads in the air. This is the basic cooling setup of the study.

6. Refrigerant controller: its main function is to regulate the flow rate of refrigerant entering the evaporator, so that the quantity of liquid refrigerant entering the evaporator equals the quantity of vaporized refrigerant in the evaporator. Another function is to maintain the system pressure difference between the high-pressure side and low-pressure side, so as to provide the low-pressure required in the evaporator for the liquid refrigerant to vaporize and the high-pressure required in the condenser. The unit uses capillary as the controller.

7. Evaporator: mainly for performing heat exchange of the refrigerant and water chiller system. Commonly used evaporators for water chillers are dry expansion-type and flooded-type. Structurally, heat-exchangers can be divided into shell- & pipe-types and plate-types. This unit uses a plate heat exchanger.

8. Refrigerant controller: The refrigerant controller may be divided into a manually operated expansion valve, automatic expansion valve, the temperature-sensitive expansion valve, capillary tube and float control valves, etc., and its main function is to adjust the refrigerant into the evaporator of the flow, the flow of the refrigerant liquid entering the evaporator equals refrigerant after evaporation the amount of the liquid in the evaporator. Another to maintain the pressure of the high and low side of the system , the machine is used , to achieve the required high pressure of the refrigerant liquid is evaporated in the evaporator to the desired low pressure and the refrigerant in the condenser pressure capillary.

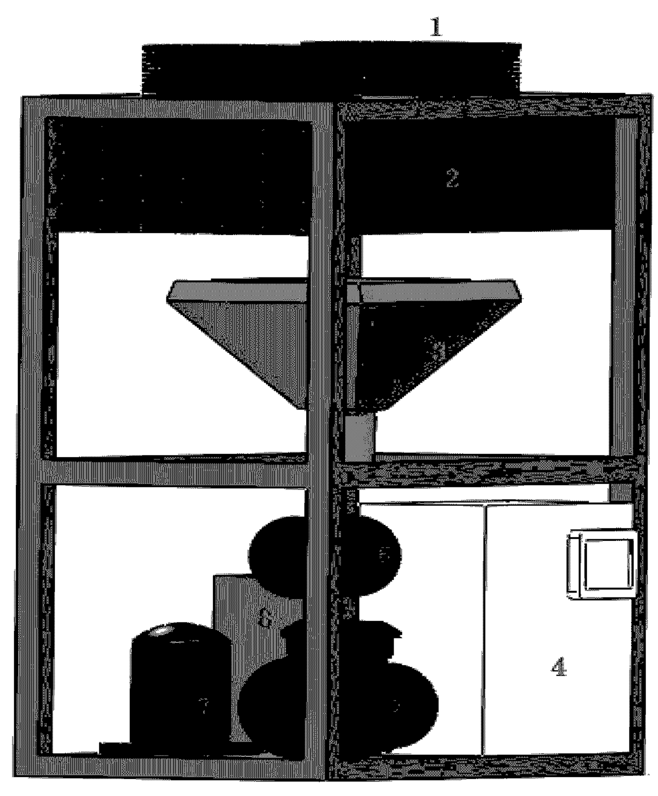

Fig.2 supersonic vaporization chiller design

Fig.3 supersonic vaporization chiller platform

B. Parameter setting

In this study, the experimental approach achieved the volume of atomization in relation to the heat dissipation that understand the supersonic vaporization chiller of heat dissipation characteristics. The Supersonic vaporization cooling system parameters are in Table 1.

Table 1 Supersonic vaporization chiller parameter

Condenser length	1.2m
Condenser width	1.1m
Condenser thick	0.4m
Condenser power	15000Kacl/HR
The volume of atomization	10L/Hr
air-cooled water chiller length	1.5m
air-cooled water chiller width	1.4m
air-cooled water chiller thick	2m

III. Methods

C. The Principle of Supersonic Vibration

It will produce a rapid water flow when the vibrator produces the ultrasonic in the water; the liquid at the surface will has the ultrasonic beam focusing effect, and formation of the ultrasonic fountain. Because the rapid water flow in the water, the pressure of the liquid is temporarily down, and form the small bubbles, but internal pressure is very low, will pull the liquid fission and form the hollowing. When the water pressure is restored to normal, the bubbles will come to inward, collapsing fission and blasting, issued a very small, but the effect is very huge shockwave, the moment of impact force will cause the liquid into particulate divergence and form a mist.

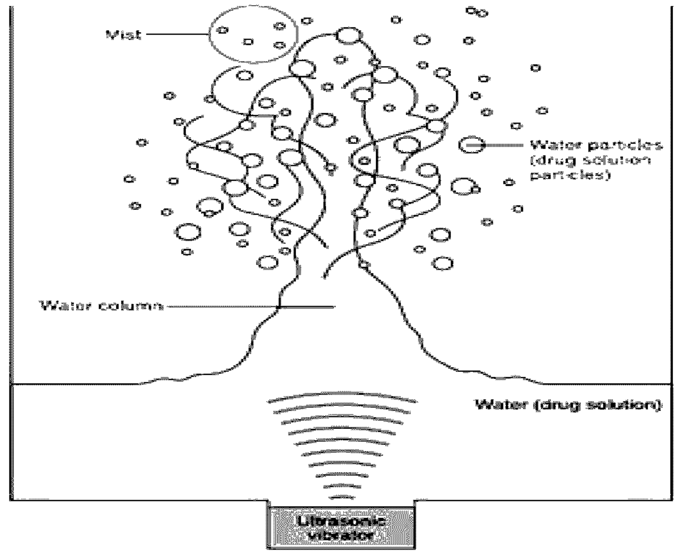

Fig.4 Principle of atomization

A kilogram of water absorbed by the evaporation latent heat (2,430.5 kJ at 30℃) is equal absorbs heat of seven kilograms by ice melting, the high pressure sprays droplet size is 15~40μm and the supersonic produces the micro mist diameter can be achieved in the range of 3~5μm, and the air contact the lager surface area, then cooling effects is better.

In atomization cooling the droplet diameter is defined as:

$$R = k\left(\frac{8\pi\sigma}{\rho f^{2}}\right)^{\frac{1}{3}}$$

(1)

Where R is droplet diameter (m), k is 0.34, σ is surface tension of droplet (N/m), ρ is droplet density (kg/ m3), f is the frequency of vibration. From the above equation ultrasonic fog droplet diameter inflict mainly by frequency of ultrasonic and the volume of atomization is decided by the vibration of ultrasonic, that (1) shows using the supersonic atomizer as the small mist supply source has one benefits, that the diameter of water mist is relation to the frequency of vibration, so as long as inflict the different vibration to control the volume of atomization and without change the spray quality.

That evaporative heat dissipation is defined as:

$$LE_0 = K \times D(T_a - T_{in}) + C_p \times P \times Q(T_a - T_{in})$$

(2)

Where L is the evaporative heat dissipation (kg/hr),E0 is the latent heat of water evaporation (kJ/kg),K is the wall transfer coefficient(w/m2 ℃), Cp is the air specific heat (=1006J/kg℃),P is air density (kg/m3),Q is ventilation rate (m3/hr),Ta is the outsides of tubes temperature (℃),Tin is the exhaust temperature(℃).

D. Weber Number Definition and Calculation

In atomization cooling, a Weber number (We) are defined as:

$$We = \rho U_m^2 d_{32} / \sigma \tag{3}$$

Where ρ is droplet density, σ is surface tension of droplet, U_m is the collision velocity that droplets collide the heating plate, d_{32} is the Sauter Mean Diameter (SMD). The relevant calculation is as follows:

1. U_m is the collision velocity at which the droplets collide with the heating plate, from Ghodbane [11] and Qiang [12] we get

$$U_m = (u_0 + \frac{2\Delta P}{\rho} - \frac{12\sigma}{\rho d_{0.5}} - 2gH)^2 \tag{4}$$

where U_0 is the velocity from the nozzle to the test chamber, ΔP is the pressure difference from nozzle to heating plate, $d_{0.5}$ is diameter of droplets that spray out the nozzle, H is the distance from nozzle to heating plate.

2. $d_{0.5}$ is the diameter of a droplet when it exits the nozzle; differing from the Weber Number (We), $d_{0.5}$ is SMD, which is provided by the manufacturer. From Ghodbane [11], we derive

$$d_{0.5} = \frac{9.5D}{\Delta P^{0.37} \sin \beta/2} \tag{5}$$

Where D is nozzle diameter, ΔP is differential pressure of nozzle profile, β is angle of spray cone, calculating $d_{0.5}$ is for getting the velocity at which droplets collide with the plate.

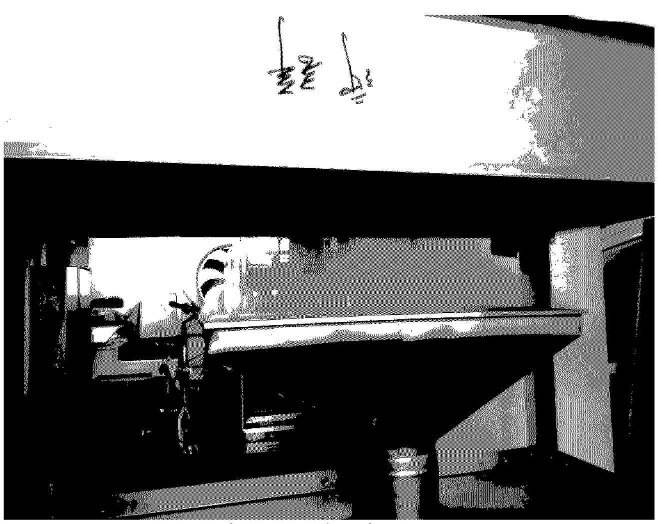

Fig.5 spray the mist

E. The Program Protection

In order to Prevention the program exception, need one protection Mechanism, shows in fig.6, that can see the identification start to see the program if remarkable then the program is not load the machine operating status and control, the program if yes the fan current protection compressor, ultrasonic vibrations, ice water pump fan motor shutdown and stay actions, if this program come into AI-2<=low pressure setting ,the supersonic atomizer turn off and time delay,fan motor turn off .

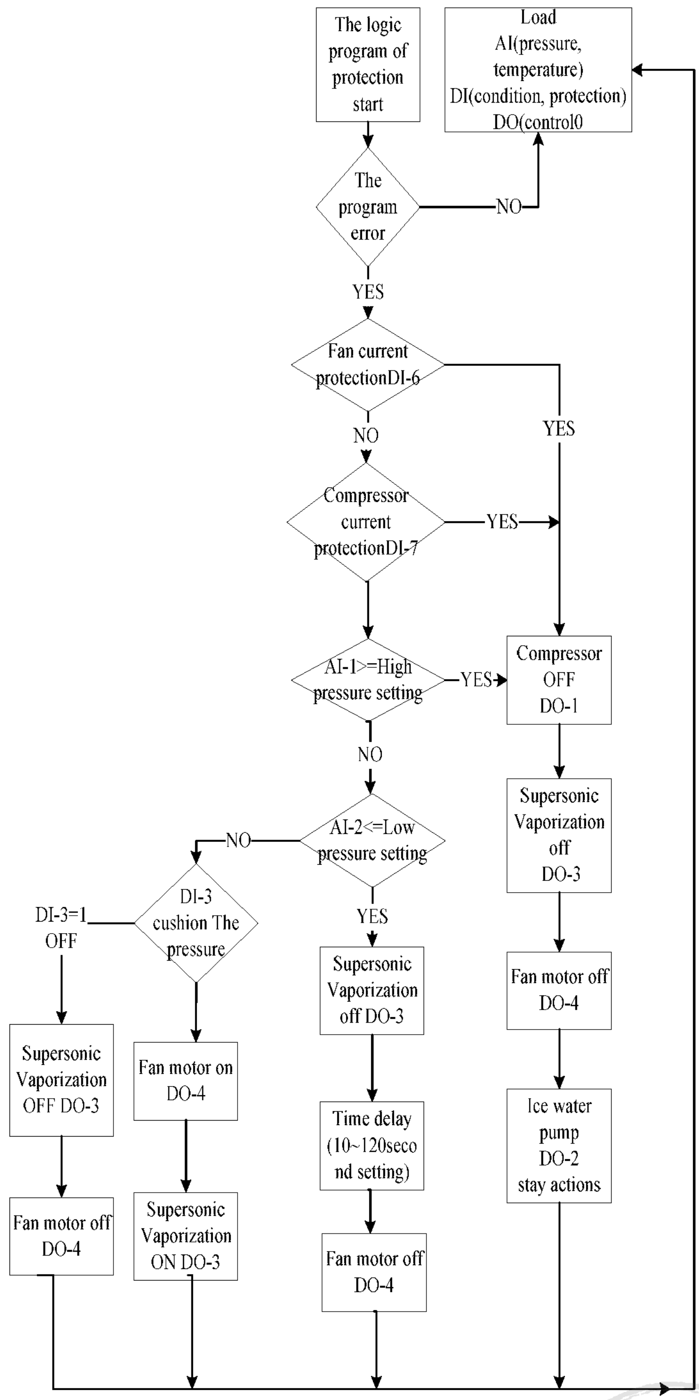

Fig.6 protection flow chart

F. Dual-effect Fuzzy Control System

A. System Design

As Fig. 7 closed-loop system, the system 's main control is by the 1. Ultrasonic Oscillation Driving Circuit (UOD); PWM control circuit; 3. Dual-effect Fuzzy Control Mode (DEFC),Their main functions are described as follows：

1. UOD：Produce the frequency of the ultrasonic vibrator.
2. PWM control circuit ：Adjust the volume of water misting via control the frequency of the ultrasonic vibrator.
3. DEFC：Determine the size of the PWM control signal.

Use the dual-effect fuzzy control system to cover the whole system, the other hand the volume of atomization output control can use the pwm (Pulse-width modulation)to adjust the frequency of ultrasonic, in response to actual demand for automatic adjust the volume of atomization, so that can achieve power savings and improved efficiency.

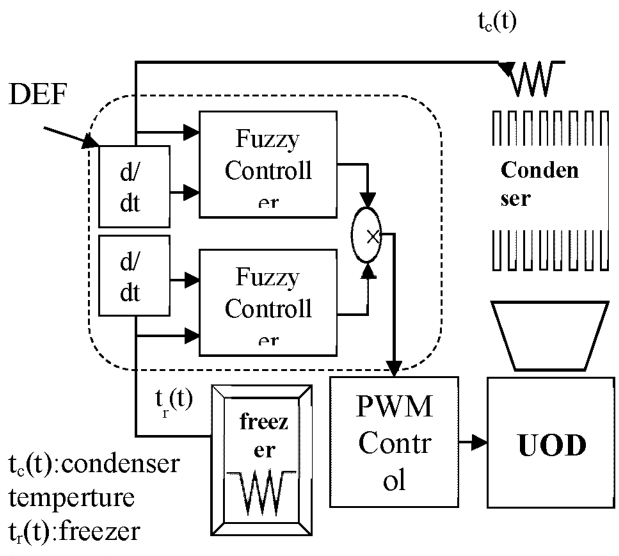

Fig.7 close loop system

IV. RESULTS AND DISCUSSION

The study observed temperature distribution with an infrared photo-detector after running the air-cooled water chiller for 2 hours; the condenser temperature is about 45.6°C when the supersonic atomization is not working, see Fig.8; the condenser temperature is about 44.2°C when the supersonic atomization is working, see Fig.9. The difference is about 1.4°C. The experiment further indicates that a general fixed-frequency air-cooled water chiller consumes 88kwh a day in average, while a variable-frequency air-cooled water chiller consumes 64kwh a day in average, as shown in Fig.10. by comparison, the variable-frequency air-cooled water chiller is 25% more energy efficient.

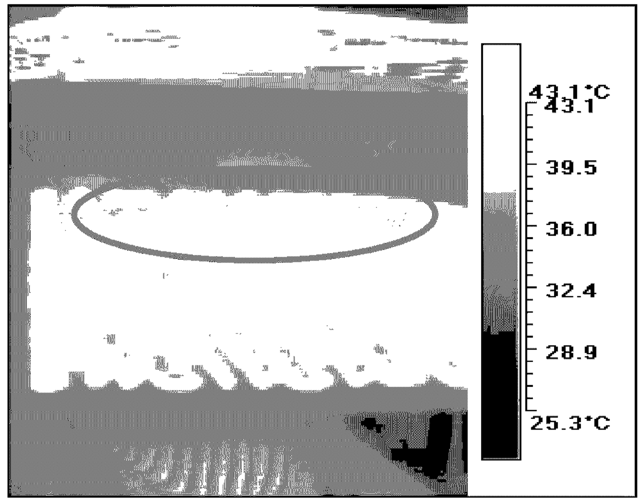

Fig.8 Without Supersonic Atomization

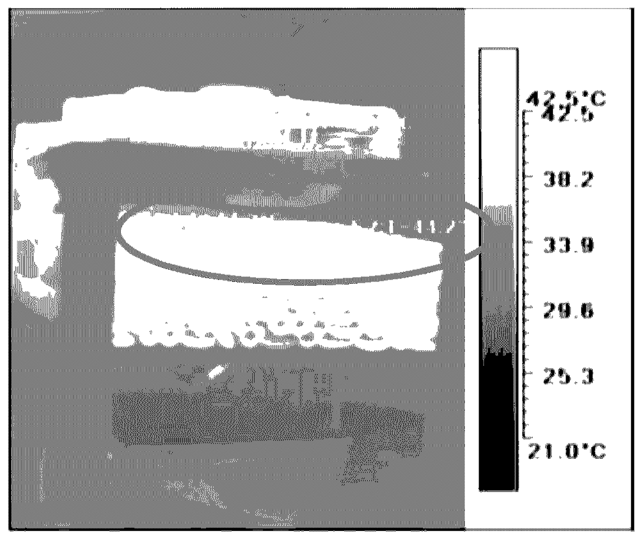

Fig.9 With Supersonic Atomization

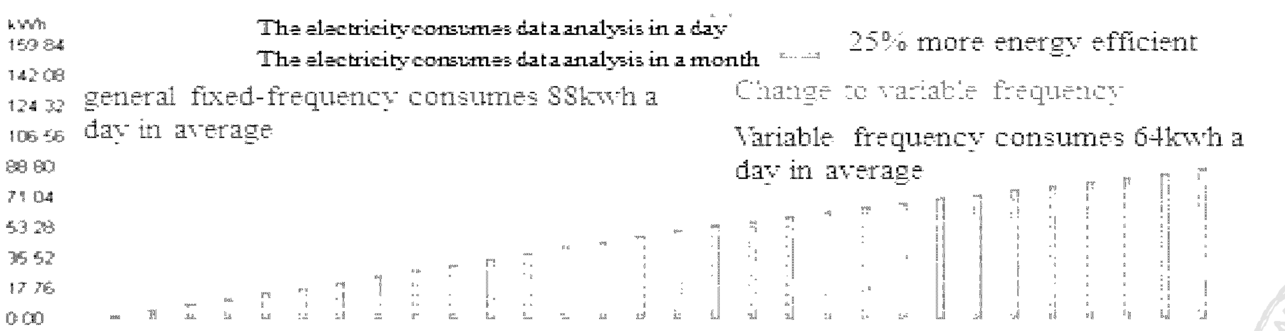

Fig.10 power consumption index

The fig.11 shows the fixed frequency and the variable frequency are different, the variable frequency is more stable, and more save energy.

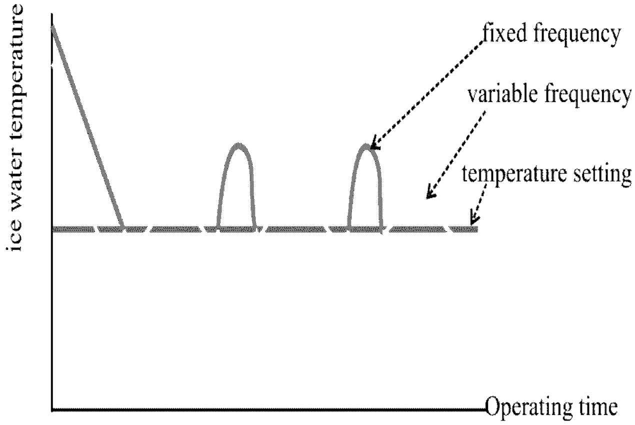

Fig.11 differences between the fixed frequency and variable frequency

V. CONCLUSIONS

Green industry is becoming the mainstream nowadays; people strive to search for methods that are power saving, efficient to a certain level, and pollution free to the environment at the same time, making this study significantly important.

The study establishes an experimental platform for carrying out tests, observing cooling efficiencies, and calculating power saving statuses. Comparing the observation of cooling efficiency, a temperature difference of 1.2°C is seen between before and after the application, which is quite significant in terms of efficiency, and the method causes no pollution to the environment, or water accumulation in the surroundings. In the respect of power saving, when compared with the fixed frequency air-cooled water chillers, a 25% energy saving is seen; in terms of power saving, this is exceptionally good. When both water and electricity fees rise, the newly developed supersonic mist-cooled water chiller is truly a better solution.

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BIOGRAPHIES

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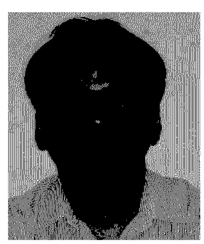

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