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Immersion cooling technology development status of data center

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Abstract. With the continuous development of data centers and information technology equipment, data center energy consumption continues to increase, China's data center energy consumption has accounted for 4% of the power consumption of society as a whole, while the data center cooling system accounts for 30–50% of the data center energy consumption. At the same time, with the development of new high-energy chips, the traditional cooling methods have been unable to meet the requirements of IT equipment cooling, so how to reduce the energy consumption of data centers, especially the cooling system energy consumption, and to meet the cooling requirements of data centers with high heat flux density is becoming the focus of research in the field of data centers. In order to solve the data center cooling system of high energy consumption and high heat flow density needs, immersion cooling technology came into being, this paper is mainly on the data center immersion cooling technology research, and the use of the current situation is introduced and explained, compared to the single-phase immersion cooling technology and two-phase immersion cooling technology cooling principle, the current state of development and use of the prospects for elaboration, while the data center immersion cooling system waste heat utilization is explored, providing readers with a wide range of data center cooling system. At the same time, the utilization of waste heat in the data center immersion cooling system is discussed, providing readers with extensive and detailed background knowledge of data center immersion cooling technology.

Keywords: Data center, Cooling system, Liquid cooling, Immersion cooling, Waste heat utilization.

1 Introduction

A data center is an end-of-infrastructure room containing information technology (IT) equipment and communications technology (CT) equipment, with the primary function of storing and processing data, as well as sending and receiving data across data center boundaries. In addition to IT equipment, data centers also have infrastructure such as network routers, network connections, power supplies, data storage, switches, fire suppression systems, advanced security systems, and cooling facilities [1]. With the development of information technology, data centers can now be divided into various types such as traditional data centers, 5G base station data centers, cloud computing data centers, fog computing data centers, edge computing data centers, and bitcoin miners. Along with the rapid development of data centers, their energy consumption, especially power consumption, has been increasing, for example, the power consumption of global data centers in 2005 was twice as much as in 2000. By 2010, this percentage increased by another 56%, accounting for 1.3% of global power consumption, while China's data center energy consumption accounted for 4% of the total energy consumption of the whole society, and the power consumption of data centers is expected to grow by 15–20% per year [2]. The energy consumption of IT equipment accounts for 40–50% of the total energy consumption of data centers, and the proportion of cooling systems reaches 30–50%. Therefore, the high energy consumption of data centers is becoming the biggest constraint for the development of data centers, and how to reduce the energy consumption of data centers, especially the cooling system, has become the focus of the development of the entire data center.

At the same time, with the development of high-performance core chips, the heat flow density of data centers continues to grow. Typically, IT equipment evolves in accordance with Moore's Law: when the price remains constant, the number of components that can be accommodated on an integrated circuit doubles approximately every 18–24 months, and the performance doubles as well. This means that the energy consumption and heat dissipation of IT equipment, especially chips, in data centers will double. For example, Intel's server Central Processing Unit (CPU) power consumption has been increasing, from 35 W to 24 W, the next generation of CPUs and Graphics Processing Units (GPUs), the heat load is even as high as

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500 W, for high-performance servers, if the deployment of a number of chips will make the server heat flux density has increased exponentially, Figure 1 for the Intel chip heat dissipation heat flux density of the growth trend. At the same time, semiconductor components are subject to the "10-degree rule" of constraints, that is, if the temperature of semiconductor components rises by 10 °C, its reliability will be reduced by half. Moreover, according to statistics, 55% of the failure of electronic devices is caused by high or uneven temperatures, and the limit temperature of the chip is 85 °C [3]. Therefore, data centers have increasing thermal requirements for cooling systems. With the increasing heat density of IT equipment, three challenges have emerged for data center cooling systems: (1) IT equipment with high heat flow density CPU and GPU components will generate hot spots if cooled using only air cooling, and IT equipment such as servers will face significant cooling design challenges, while the maximum heat flow density of forced air cooling is 1.6 W/cm^2, so traditional air cooling technology can no longer meet the needs of data center cooling of high heat flow density IT equipment; (2) The traditional data center precision air conditioning system is unable to provide enough cold air to meet the overall heat dissipation needs of the data center, and the current cooling capacity of air-cooled cabinets is 10–15 kW, while the high heat flow density cabinets have reached 100 kW or even higher heat dissipation; (3) the traditional air-cooled system for data centers consumes more energy, making the Power Usage Effectiveness (PUE) of the data center (the average PUE of air-cooled data centers is generally 2.0 or so) is large and the maintenance cost is rising, and at present, the control of energy consumption of data centers at home and abroad is extremely strict, for example, Beijing has banned the construction of data centers with PUE of 1.4 or more, and Shanghai has explicitly banned the construction of data centers with PUE of 1.3 or more. Therefore, in order to cope with the challenges faced by data centers, liquid cooling technology has emerged as the key technology to solve the cooling system of data centers (Fig. 2).

Over the past decade, a variety of alternative air-cooled cooling liquid-cooling technologies have been introduced to address the limitations of air-cooled IT equipment in data centers and find better efficiencies. The earliest liquid cooling methods are still encapsulating IT equipment at the cabinet level and focusing on cooling by introducing coolant to server hotspots (e.g., CPUs, GPUs, and graphics cards), which are classified as cold plate liquid cooling, jet liquid cooling, and spray liquid cooling based on the end cooling method [4], and these three traditional liquid cooling methods are mainly used to achieve IT equipment cooling by cooling with water or refrigerant, providing cooling system efficiency and heat flow density, mainly for chip-level cooling, in data centers still need to be mixed with precision air conditioning (air-cooled) to achieve the cooling of data centers, so its energy consumption is still high and the cooling system is complex [5, 6].

In summary, with the growth of IT equipment in data centers, there is an urgent need for a simple, compacts, and inexpensive liquid cooling technology that minimizes energy consumption and global warming emissions. It must

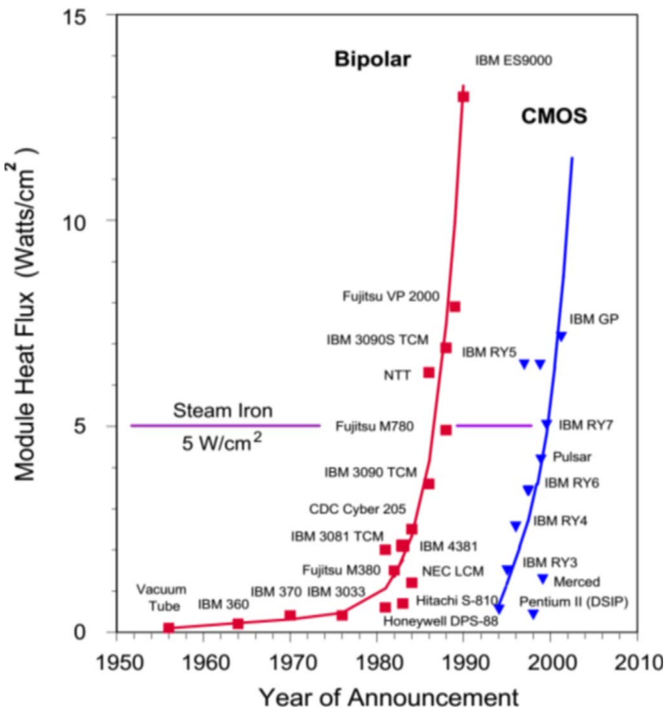

Fig. 1. Growing trend of heat flow density of chip heat dissipation (the Advancement of North American Electronics Manufacturing).

dissipate all the heat generated by data center servers while minimizing data center PUE. As IT equipment replacement frequency accelerated, new liquid cooling technology should be modular, flexible, and can be quickly deployed with the data center. Therefore, the immersion cooling technology came into being and has attracted the attention of domestic researchers. At present, the immersion cooling method can be divided into single-phase immersion cooling technology and two-phase immersion cooling technology according to whether the cooling phase change occurs [3]. It should be noted that immersion cooling technology is not a new technology, before being used in data center IT equipment cooling, the technology has been widely used in other areas of cooling, such as transformers, cables, generators, and other equipment. For data centers, immersion cooling technology will be mainly applied to cooling high heat flow density IT equipment in data centers, such as edge computing data centers, fog computing data centers, cloud computing data centers, supercomputing centers, and Bitcoin mining machines, which can realize the elasticity and rapid deployment of data centers.

Submerged liquid cooling technology is favored by the data center cooling system, mainly because of the outstanding performance of this technology in data center cooling, which can solve the problem of high energy consumption and high heat flow density in data centers. First of all, the cooling capacity of the submerged liquid is 1,000–3,000 times that of the air, and the phase change is higher; secondly, because it does not have compressors, fans, and other power components, the submerged liquid can realize the advantages of high-density, low-noise (noise is less than

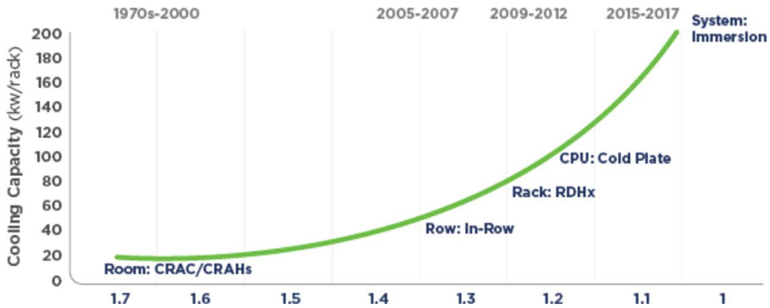

Fig. 2. PUE values of data centers with different cooling methods

50 dB), low heat transfer temperature difference (the high cooling temperature at the outer end can realize the use of residual heat in the data center), natural cooling, etc.; in addition, the heat flow density of the submerged liquid cooling can be more than 100 kW or even 500 kW per. In addition, the heat flow density can be more than 100 kW or even 500 kW per cabinet volume, and the PUE is as low as 1.02, which can significantly reduce the energy consumption of the data center; and the submerged cooling technology can eliminate the traditional air-cooled data centers from overheating, temperature fluctuations, server fan failures, dust, poor air quality and corrosion and other problems. In recent years domestic and foreign immersion cooling technology users, have begun to show their respective immersion cooling server cabinets and commercialize them, especially in 2017.

The development of data center cooling technology for the data center industry as a whole as well as significant, this paper is mainly on the data center immersion cooling technology research and use of the status quo to introduce and explain, the single-phase submerged cooling technology and two-phase submerged cooling technology, cooling principle, development status and use of the prospects for the elaboration, while the data center submerged cooling system to explore the use of waste heat, to provide readers with extensive and detailed background knowledge of data center immersion cooling technology.

2 Single-phase immersion cooling technology

In order to keep pace with the development of high heat flow density of IT equipment in data centers, next-generation cooling technologies need to be closer to the heat source of the IT equipment, making the heat dissipation of IT equipment faster and more efficient. At the same time, high-performance servers (e.g., supercomputing, Bitcoin miners, etc.) now consume more energy than ever before, making traditional energy-intensive cooling technologies no longer suitable for new data centers, and requiring more energy-efficient and effective cooling technologies. Since 2009, single-phase immersion cooling has been used in high heat flow density data center cooling systems. As the earliest immersion cooling technology used in data center cooling systems, single-phase immersion cooling has been commercialized to achieve cooling densities up to 100 kW/cabinet.

Single-phase immersion cooling technology by placing the server as a whole directly into the coolant for direct cooling, its heat dissipation is a single-phase immersion coolant and the server heat source convection heat transfer, mainly the use of single-phase immersion coolant sensible heat to the server to absorb the heat generated away, and at the same time, through the pump will be heated coolant into the heat exchanger and the circulation of warm water for heat exchange, the coolant should be filtered to remove possible impurities before entering the heat exchanger. Before entering the heat exchanger, the coolant should be filtered to remove possible impurities. At the end of the general use of a water-cooled towers or dry cooling towers for natural cooling will heat transfer to the environment, but also can use the waste heat utilization system will cool the heat recovery in the warm water, which is due to the export temperature can reach a higher temperature. The single-phase immersion cooling system is shown in Figure 3.

For immersion cooling technology the core technology is the coolant, the current single-phase immersion coolant main coolant commonly uses coolant mineral oil, white oil, and synthetic media coolants such as the Green Revolution Company's Electro-Safe coolant and high-boiling point fluoride liquid, such as the 3M Company's Noverc engineer fluid. Since no phase change occurs single-phase immersion coolant evaporation rate is zero, which can guarantee that in the operation process of immersion cooling will not occur steam overflow (compared with two-phase immersion coolant), in the data center operation cycle does not need to be replenished and replaced; at the same time, the single-phase immersion coolant is usually a stable chemical state, will not occur thermal decomposition, non-toxic; at the same time, its auto-ignition temperature is also high, high flash, non-flammable, generally above 300 °C. Flammable, generally up to 300 °C or more and fluorinated liquid has a flame retardant effect, safety is guaranteed; density is larger, and the specific heat can be larger through convection heat transfer with the server heat source to complete the heat transfer will heat absorption; in addition to the fluorinated liquid, the price of single-phase immersion coolant is lower, making the single-item submerged coolant technology of the economy is stronger; the global warming potential is zero, no ozone depletion; due to the compatibility of mineral oil and server there are some problems, therefore, it is not necessary to replenish; at the same time, the chemical state of the single-phase immersion coolant is usually stable. server

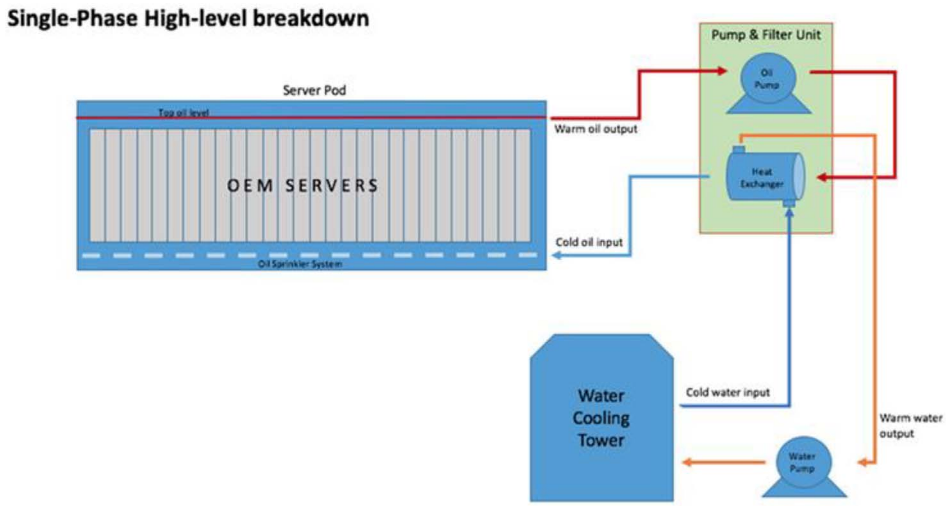

Fig. 3. Diagram of single-phase immersion cooling system for data center.

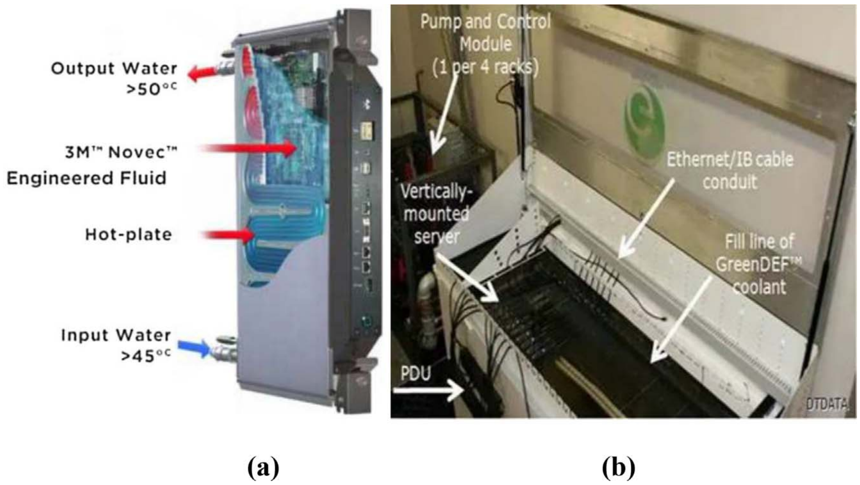

Fig. 4. Single-phase immersion cooling unit. (a) Knife-back server [3]; (b) Fully submersible cabinet [3].

compatibility there are some problems, so single-phase submerged but liquid before use after a long period of testing and improvement, in order to protect the data center IT equipment can be 365 days a year to continue to run without failure. 2012 Intel Corporation jointly with the GRC company carried out a year of testing the reality of single-phase immersion cooling, the report pointed out that the single-phase submerged cooling technology not only can make the server safe operation, but also in the future, it will turn into a large data center base cooling technology that requires large computer capacity or data center capacity (Fig. 4).

Single-phase immersion cooling technology immerses servers in liquid, allowing for overall improvements in rack density, cooling capacity, data center layout, and location options. There is no need for specialized building design and traditional data center equipment such as chillers, Computer Room Air Conditioning (CRAC), and movable floors necessary for traditional data centers. As a result, initial investment costs and operating costs can be significantly reduced. According to the GRC, single-phase immersion cooling technology can reduce upfront data center costs by 60%, cooling power consumption by 95%, server power consumption by 10–20%, and cooling capacity up to 100 kW in a single rack, allowing for rapid containerized deployment in 10–12 weeks. Applied to the Ranger supercomputer single-phase immersion submerged cooling system test results are realistic, can save 50% of the total energy cost for the Midas network workloads, the return on the initial investment in the liquid cooling system ranges from 1 to 3 years, the PUE of the data center with immersion cooling is less than 1.08 [2]. Experiments demonstrated that 123 servers encapsulated in mineral oil resulted in an 81% reduction in the temperature between the heat source and discharge temperature compared to water cooling experiments [8].

Reducing energy consumption means reducing carbon dioxide (CO_2) emissions, and data show that each kilowatt-hour of electricity produced produces about 1 pound of CO_2 on average. Therefore, the use of single-phase immersion

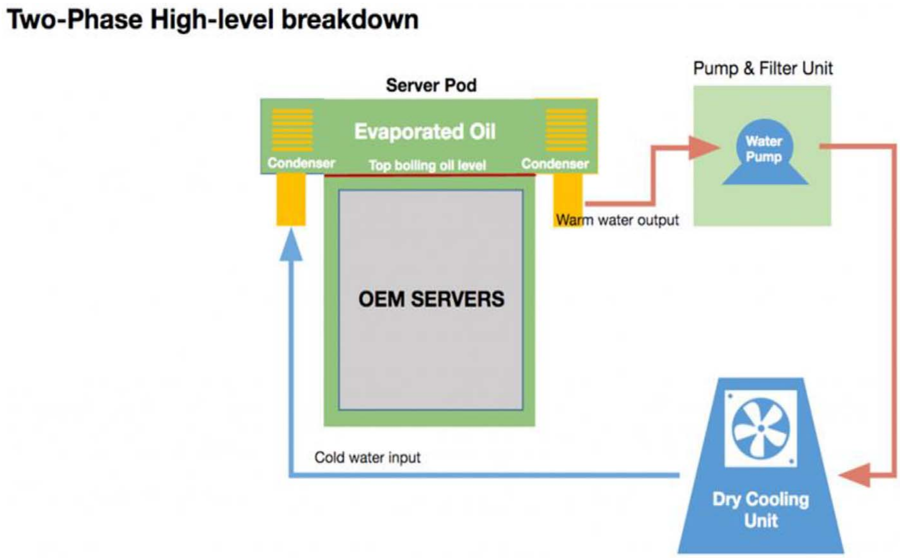

Fig. 5. Schematic diagram of two-phase immersion cooling system.

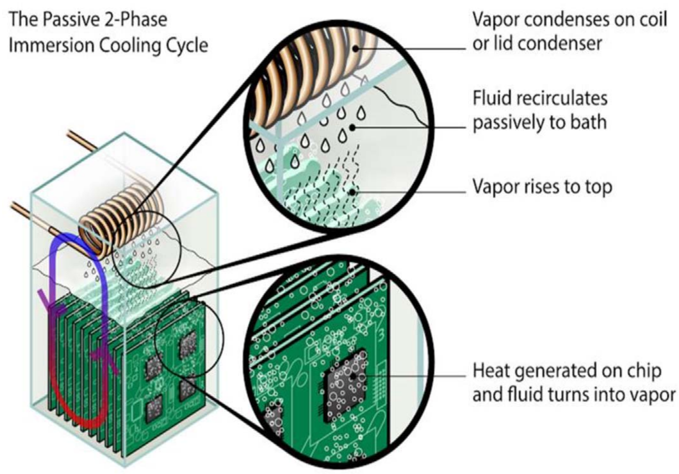

Fig. 6. Schematic diagram of two-phase immersion cooling cabinet shown by allied-control company.

cooling technology in data centers not only reduces the energy consumption of data centers but also reduces the CO_2 emissions of data centers, making data centers truly green data centers, which are used in green supercomputing. In addition to saving energy and reducing CO_2 emissions, single-phase immersion cooling cabinets also help to directly reduce data center water consumption. This is because on the one hand, single-phase immersion cooling technology indirectly reduces the water consumption of the power plant while reducing electrical energy consumption, and on the other hand, single-phase immersion cooling cabinets allow the use of hybrid cooling towers or adiabatic dry coolers, which have very low water consumption [9, 10].

While single-phase immersion cooling technology has many advantages, there are still problems with single-phase immersion cooling technology. Single-phase immersion cooling technology may be the biggest obstacle to the operators and managers of the data center itself, due to its use of mineral oil and other combustibles as a coolant so that the data center in the event of a fire, although its ignition point is high the consequences are still unimaginable, there is a great safety risk; Secondly, because single-phase submerged cooling technology is mainly used in the coolant sensible heat and the servers through the convection heat transfer, and therefore its Heat flow density relative to two-phase submerged cooling phase change heat absorption to be low, according to the water single-phase heat transfer and evaporation heat transfer research found that the maximum heat flow density of water cooling is only 16 W/cm^2, while evaporation heat transfer can reach the maximum heat flow density of 500 W/cm^2. Therefore, the improvement of submerged cooling technology is mainly focused on solving the safety and reliability of the solution and improving the strength of its heat transfer.

3 Two-phase immersion cooling technology

Immersion cooling technology another way is two-phase immersion cooling technology, two-phase immersion cooling technology is the use of immersion cooling boiling point low can occur boiling phase change, in the boiling process using latent heat absorption heat to achieve the effect of data center IT equipment cooling. In the two-phase immersion fluid, when the surface temperature of the server heat source exceeds the saturation temperature of the coolant, resulting in the nuclear boiling of the coolant. Thus, the cooling method involves latent heat transfer, gravity-driven two-phase flow, and bubble-induced flow mixing [11]. In a typical boiling cell, vapor bubbles formed around the surface of the heat source rise to the vapor zone above the coolant bath, where the coolant is condensed through a water-cooled heat exchanger [12]. The current two-phase immersion cooling technology is mainly open bath immersion (OBI) cooling. Electronic components are cooled by convection or when the immersion coolant boils (phase change from a liquid to a gas) in the vicinity of the component generating high heat. The gas, which is less dense than the liquid but denser than air, rises into the space above the liquid where it comes into contact with a condenser integrated into the bath. The vapor condenses back into the liquid through the condenser, which is cooled by a water circuit connected to a cooling water source. The condensate falls back into the liquid in the form of droplets. For submerged coolant two-phase immersion cooling, no recirculation or return pumping of any phase (liquid or gas) is required. The vapors produced during the boiling process form a distinct layer on top, which is a region of air and vapors called the headspace. The heat output from the server varies with the workload. This in turn causes a change in the steam level. Thermal control keeps the vapor level within the desired limits by regulating the flow rate of cooling water. Submerged IT equipment can be removed by opening the lid and simply lifting the equipment out of the tank. As the server is slowly removed from the tank via steam, the liquid on the surface of the equipment quickly evaporates and is captured by the condenser. As a result, the server keeps the tub essentially dry with minimal fluid loss due to normal maintenance. The OBI system operates at atmospheric pressure, with the electrical connection entering the tub from above through a sealed pipe that terminates below the liquid level. Cooling water flows through the condensing coil, which removes heat from the vapor. Since the immersion coolant boils at 50–100+ °C, the system can be cooled with cooling water in the 40–60 °C range, and higher temperatures usually do not require mechanical refrigeration for thermal cooling. The heat discharged from the cooling water is exhausted to the outside atmosphere through a dry cooler. It is also possible to reuse waste heat from the higher-temperature cooling water, as described in the next section of this paper. The schematic diagram of the two-phase immersion cooling system is shown in Figures 5 and 6. The use of surface enhancement technology to improve the rate of heat transfer in submerged liquid cooling technology is currently the focus of research in this field, and studies have shown that two-phase cooling technology is effective for equipment with a heat flow density greater than 1,000 w/cm^2 or more [13]. The advantages of using two-phase coolant boiling phase change can significantly improve the cooling process heat transfer coefficient significantly, while the strengthening of heat transfer measures. At present, two-phase immersion cooling technology can make the data center PUE reach 1.05–1.07, energy-saving effect is obvious.

The most significant advantage of the two-phase immersion liquid cooling technology cooling system is that there are no traditional liquid-cooled server-level piping systems, connectors, and sealed enclosures, so it has the advantages of easy maintenance and adaptability while removing the traditional also cooled servers in the chip-level cooling pumps to make it more reliable.

Currently, two-phase immersion coolants are mainly 3M Novec, such as Novec 649, Novec 7100, FC-72, and PF-5060. Currently through the test found that the two-phase immersion cooling technology's still has many problems, mainly:

3.1 Two-phase immersion cooling technology is less economical

The two-phase immersion cooling technology poor economy is mainly reflected in two aspects: (1) two-phase immersion coolant price is expensive, as shown in Table 1, and its price is much higher than single-phase immersion coolant; (2) for the beginning of a two-phase immersion cooling cabinet coolant loss is serious. The commonly used coolant in a two-phase immersion cooling is 3M's Noverc engineered fluids, of which 3M Novec 649 is considered the best immersion coolant [14]. 3M's two-phase immersion fluids are very expensive, with Noverc 649 priced at $75/L ($284/L) gallon. Also in OBI cooling units, the vapor state of the cooling will evaporate in the environment resulting in wasted coolant, according to the US Department of Defense 3M Novec 649 immersion cooling system testing found that during one year of operation the volume of coolant evaporated off to 102 L, while the total coolant of the unit is 595 L [14], so the coolant will need to be replenished continually during the operation of the unit (Table 1).

3.2 Failure of electronic equipment in submerged liquid cooling

Failure of the immersion cooling electronics is the main operational problem and the failures are categorized into two groups: (1) power supply failures and (2) logic board failures. Both groups fail after a short period of operation within the immersion-cooled vessel [14]. The power supply failures were caused by short circuits in the leads of certain field effect transistors (FETs). Novec 649 that submerges electronic equipment absorbs accumulated contaminants, i.e., oil contained in wires or harness sleeves. This buildup itself may not be conductive and may form a matrix structure where conductive debris (such as whiskers) or chemicals have built up, creating conductive paths that can lead to component or electronic failure. Whisker-like objects were also observed within and near the shorted structure, and these consisted primarily of metals, including tin (Sn)

Table 1. Immersion coolant prices.

Coolant	Company	Product	Price
Two-phase	3M	3M Novec	200~1500 RMB/L
Single-phase	GRC	Electro-Safe	20~100 RMB/L
	DSI	OptiCool Fluid	
	BiXBiT	Miner OIL	
	BitCool	Engineered fluids	
	DCX	Nanoparticle Enhanced Engineering Fluid	
	Midas Green	XCI^{TM} Coolant	
	Engineered fluids	Electro-Cool	

Table 2. Summary of heat sources and flows in a typical water-cooled data center [18].

Parameter	Value
Server water supply temperature	20–60 °C (standard) 70–75 °C (maximum)
Server outflow temperature	2–5 °C, server temperature rise
The water flow rate per rack	5–10 GPM
Temperature difference from water to lid ΔT	5–18 °C
Buffer heat exchanger flow rate	5–10 GPM
Buffer heat exchanger supply temperature above ambient temperature	3–5 °C above ambient

Table 3. Summary of heat sources and heat flows in a typical two-phase cooled data center [19].

Parameter	Value
Coolant supply evaporator	60 °C saturated liquid (standard), 70–75 °C (maximum)
Evaporator outlet coolant mass	62 °C 30% by mass (standard) 75–80 °C (maximum)
Vapor compressor outlet coolant temperature	90 °C
Condenser coolant inlet	30 °C
Condenser coolant outlet	90 °C

(26%) and aluminum (Al) (42%), the cause of which would be the presence of a certain amount of corrosion of metals such as solder joints from the submerged fluid. Overall, the main reason for the server failure is still due to the lack of compatibility between the submerged coolant and the material of the server itself.

3.3 Compatibility of the submerged liquid with the server

It was found [7] that Novec 649 in contact with water can form perfluoropropionic acid (PFPA), and that dioctyl phthalate (DOP) is the primary plasticizer for cables made from polyvinyl chloride (PVC).PFPA (acid) and DOP ("goop") can concentrate in the region where Novec 649 boils, potentially leading to reliability problems. FK fluid (Novec 649) can maintain electrical signal integrity above 15 gigahertz (GHz), while HFE fluid may not maintain electrical signal integrity above a few gigahertz. Researchers at the Institute of Electrotechnology, Chinese Academy of Sciences [14, 15] found through long-term experimental studies on the material compatibility of a variety of submerged coolants with electronic equipment that different two-phase submerged fluids have very different material compatibility with electronic equipment, and there exists a coolant that has the best compatibility. Plastic material aging in electronic equipment is the most common problem at the same time cable plastic shells can appear to soften and decompose, mechanical hard disk in the coolant cannot work therefore it is recommended to use a solid state hard disk, and some of submerged liquid appeared tin solder joint corrosion condition.

3.4 Submerged liquid toxicity

During testing [13], if the product is exposed to extremely high temperatures due to misuse or equipment failure, toxic decomposition products including hydrogen fluoride and perfluoroisobutene (PFIB) may be produced, although the risk of large-scale production of PFIB is very small.

3.5 Critical heat transfer density

At the same time, two-phase immersion cooling mainly through boiling heat transfer form of heat dissipation on the server, immersion liquid cooling technology system of heat dissipation performance and heat flow characteristics depends on a variety of parameters in the heat source of different surface roughness and submerged coolant, the coolant in the process of boiling heat transfer, there is a critical heat flow density [16]. During testing [13], submerged cooling is not ideal for chip temperature control relative to the cold plate, so it is necessary to develop enhanced two-phase submerged cooling technology to further improve the ability of two-phase submerged cooling.

Although two-phase immersion cooling technology in the testing process has many problems, with the improvement of two-phase immersion cooling technology problems, in 2017 two-phase immersion cooling technology has begun to realize commercialization, but now the two-phase immersion cooling cabinets shown invariably chose 3M Noverc as the coolant, as mentioned earlier 3M Noverc coolant price is expensive and seriously limited the Two-phase immersion cooling economy and promotion, while the core technology is always in the hands of others in the future is likely to be restricted, especially for the national key center – data center. Therefore, for two-phase immersion cooling technology, the most urgent task is to develop a cheap, safe, reliable, and environmentally friendly immersion coolant.

4 Prospects for waste heat recovery with immersion cooling technology

Due to the large amount of energy consumed by data centers, data center CO_2 emissions are huge and must be controlled in future data centers. Zero-emission data centers are the current development direction of green data centers. To reduce or even eliminate CO_2 emissions from data centers, data centers can be improved from two aspects, on the one hand, it is necessary to reduce the consumption of electrical energy in data centers, and the use of immersion cooling technology is one of the very effective measures, and on the other hand, it is necessary to start from the energy system of data centers, and the most possible use of the waste heat generated by the data center, which can be achieved through a scientific thermal management system, and the waste heat generated during the use of data centers can be reused in data centers. This can be achieved through a scientific thermal management system, which can reuse the waste heat generated in the process of data center application in the data center or other places to improve the efficiency of energy use.

The main barrier to waste heat recovery and reuse systems entering operational data centers today is that the waste heat, while abundant, is of low quality compared to many industrial waste heat recovery systems. Capture temperatures are limited by the temperature of the electronics, which in most cases remains below 85 °C. The lower temperatures make it challenging to reuse heat through traditional thermodynamic cycles and processes. Current research on heat transfer liquid-cooled data center waste heat benefit and waste heat use has found that both single-phase water-cooled data centers [17] and two-phase cooled data centers [18] their prospects for waste heat use are very large, mainly due to the high outflow temperature of their coolant after heat exchange with the servers as shown in Tables 2 and 3.

For single-phase immersion cooling systems, the typical characteristics of water-cooled data centers in traditional liquid-cooled data centers can be utilized. The return temperature of the external cooling water in a single-phase immersion cooling system can reach more than 60 °C, offering good prospects for waste heat utilization. For two-phase immersion cooling systems, similar to traditional two-phase cooled data centers, the return temperature of the external cooling water in two-phase immersion cooling systems can reach over 60 °C, with good prospects for waste heat utilization.

In order to reuse the low-temperature energy produced by heat dissipation from servers in data centers, the researchers involved in [17] analyzed eight technologies that can be used for waste heat recovery in data centers to determine their suitability for low-temperature, high-volume waste heat production. These technologies include plant or district heating/hot water production, co-generation with power plants, absorption refrigeration, organic Rankine cycle, piezoelectricity, thermoelectricity, biomass co-generation, and desalination/water purification co-generation. The analysis of these waste heat utilization technologies shows that the reuse of waste heat from data center immersion cooling systems is promising and can further reduce the energy consumption of immersion-cooled data centers, providing strong technical support for reducing CO_2 emissions.

5 Conclusion

This paper summarizes the data center immersion cooling technology:

(a) From the reduction of data center energy consumption, compared with the traditional air cooling method and traditional liquid cooling technology, immersion cooling can significantly reduce the data center cooling system energy consumption, reduce the data center PUE value, and significantly reduce data center energy consumption and operating costs.

(b) From the reduction of data center construction and operating costs, immersion cooling system can simplify the data center building facilities, can be quickly deployed through the container mode, reducing the requirements of the data center floor space, eliminating the need for air-cooled infrastructure, reducing the overall construction cost of the data center. At the same time, the data center immersion cooling system's remaining heat utilization efficiency is higher, which can significantly reduce the data center energy consumption.

(c) Immersion cooling system can improve the efficiency of data center waste heat utilization, in the immersion cooling data center design needs to be considered, to improve the overall energy efficiency of the data center.

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