

## **A NEW TECHNOLOGY FOR PREVENTING FOULING AND ENERGY CONSERVATION**

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### **ABSTRACT**

Fouling in heat exchange equipment is a common problem unsolved in many industries, and is also an important bottleneck that restricts the production. Among the existing technologies of solving the problem of preventing fouling and heat-transfer enhancement, the fluidized bed preventing - fouling and heat-transfer enhancement technology is an effective method with broad application prospects, which can online prevent fouling and enhance heat transfer in heat exchange equipment such as evaporator, preheater, condenser, cooler, reboiler, industrial boiler, gravity heat pipe, and so on. In this paper, the principle and characteristics of this technology are briefly introduced, and some industrial application achievements of the technology are also presented.

### **INTRODUCTION**

Fouling in heat exchange equipment is a common problem in many industries. According to the survey, more than 90% of the heat exchange equipment has the fouling problem to some extent, which seriously affects the normal operation of the equipment and causes huge economic loss and energy waste. The economic loss due to fouling accounts for about 0.25% of GDP in the world every year, while in China the proportion is more than this, so the economic loss is pretty amazing. For example, if the GDP of 2009 in China is

\$4.6 trillion, the economic loss caused by fouling is more than 60 billion Yuan. So it is very necessary and important to take effective measures to solve the fouling problem of heat exchange equipment. Many researchers have studied and put forward some preventing-fouling measures, such as method of ultrasonic, electromagnetic field, installing spiral parts or spring which can move back and forth in heat-transfer tube, adding scale inhibitors, special treatment for heat-transfer surface, avoiding boiling in the heating chamber (increasing the liquid column above heating chamber or reverse circulation), increasing the velocity of flow, and fluidized bed preventing-fouling and heat-transfer enhancement technology(FBPHT).

### **NOMENCLATURE**

$e$	[-]	Holdup of solid particles, the volume ratio between the added inert solid particles and the added liquid-solid two-phase in the heat exchanger
$G$	[kg/h]	Processing capacity
$h$	[W/m <sup>2</sup> K]	Convective heat-transfer coefficient
$p$	[kPa]	Steam pressure
$Q$	[W/m <sup>2</sup> ]	Heat flux
$V$	[L/h]	Circulation flow rate of liquid
$W$	[kg/m <sup>2</sup> h]	Evaporation intensity

The FBPHT is a new technology which can not only prevent fouling, but also enhance heat transfer, and has attracted much attention both at home and abroad [1-10]. This technology can be used in petroleum, chemical engineering, light industry, salt manufacturing, aluminum-making, food, pharmaceuticals, papermaking, desalination, wastewater treatment and many other industries.

### PRINCIPLE OF THE TECHNOLOGY

The basic principle of the technology is combining heat transfer process with fluidized bed technology, and forming a fluidized bed heat exchange system, which is called the fluidized bed heat exchanger. The random movement of solid particles in fluidized bed heat exchanger can destroy flow boundary layer and heat transfer boundary layer on the heat-transfer surface to reduce the thermal resistance and enhance heat transfer. The damage of solid particles to boundary layer in pipe inhibits the formation of supersaturation of the solute in solution in boundary layer and extends the induction period of fouling process to prevent fouling online. In addition, the increase of heat-transfer coefficient may reduce the wall temperature and corrosion of heating tube.

In China, the research group led by Professor Li Xiulun in Tianjin University first carried out the researches on the theory and techniques of the FBPHT in 1988. For its innovativeness and broad application prospects, the program was supported by the State Planning Commission and listed in the national key scientific research project of the ninth five-year plan in 1995, and after five years of research, the great successes were achieved. The research achievements obtained the national invention patent, Tianjin Outstanding Contribution Award of Industry-academy-research Joint Innovation, the second prize of Tianjin technical invention. Now, after many years of improvement, the technology has been successfully used in industrial production.

### EXPERIMENTAL RESEARCH RESULT

The effects of FBPHT on heat-transfer enhancement and prevention and removal of fouling can be seen in Figure 1 and Figure 2. Figure 1 shows the relationship between the flow boiling heat-transfer coefficient inside heating tube and the operation time. It can be seen in Figure 1, when there are no inert solid particles in heating tube, the two-phase flow boiling heat-transfer coefficient obviously decreases after 10 hours, which indicates the fouling begins to quickly form inside heating tube. While with the holdup of inert solid

particles increases gradually, the starting time when the flow boiling heat-transfer coefficient begins to dramatically decline extends gradually. For example, as the solid holdup is from 0.5% to 1.0%, the starting time is from 13 hours to 14 hours; while when the solid holdup is up to 1.5%, no obvious fouling phenomenon appears after continuous running more than 18 hours and the heat-transfer coefficient remains basically unchanged (actual continuous running time is more than two months), which effectively demonstrates the preventing-fouling effect of FBPHT. In addition, it can be also seen from Figure 1, at the initial phase of operation without fouling inside heating tube, the heat-transfer coefficient of fluidized bed is significantly higher than that without inert solid particles, which illustrates the FBPHT can not only effectively prevent fouling, but also enhance heat transfer, even if there is not fouling in heat transfer wall.

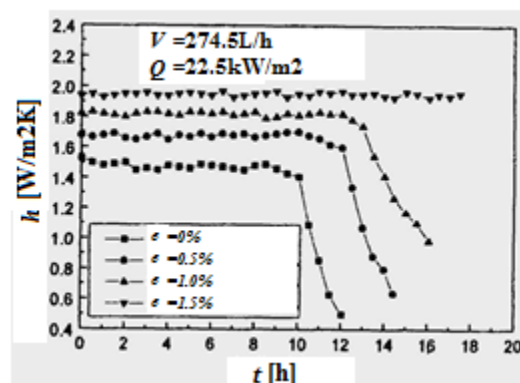
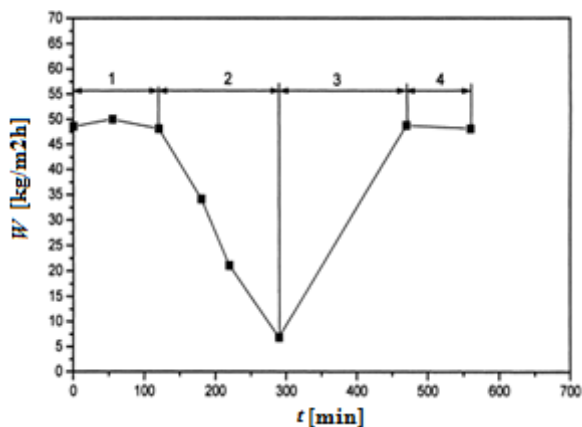


Figure 1 The relationship between the flow boiling heat-transfer coefficient inside heating tube and operation time

The FBPHT can also remove fouling formed on the heat exchanger wall online. Figure 2 reflects the relationship between the evaporation intensity of the evaporator and the operation time. The whole operation period is divided into four phases. Phase 1, 3, 4, are fluidized bed evaporation, and phase 2 is two-phase flow evaporation without solid added. It can be seen in Figure 2, at the phase 1, the fluidized bed evaporator can keep high evaporation intensity; at phase 2, the solid particles are collected by particle collector and are not involved in the circulation and heat transfer, the process is changed from fluidized bed evaporation to two-phase flow evaporation. The evaporation intensity rapidly reduces, which shows that fouling is quickly forming inside heating tube. At phase 3 and 4, the solid particles are released again to the evaporator and take participate in circulation and heat transfer. The evaporation capacity gradually rises again to the level of the phase 1 and remains basically unchanged, which shows

the FBPHT has obvious effect of fouling removal.



**Figure 2** The relationship between evaporation intensity and operation time

### CHARACTERISTICS OF THE FBPHT

The FBPHT can be widely applied in many industrial fields, and has mainly the following characteristics:

(1) The added inert solid particles don't contaminate material liquid, which can ensure product quality.

(2) The FBPHT can prevent fouling and remove fouling online.

(3) The FBPHT can be used not only in forced circulation but also in natural circulation.

(4) The mechanism of preventing fouling and heat - transfer enhancement has nothing to do with the properties of material liquid.

(5) The FBPHT has no significant amplifications, and the results in lab test, pilot scale test and industrial production are almost the same;

(6) The convective heat-transfer coefficient inside pipe can be increased by a factor of 1.5 to 2.0.

(7) For the heat-transfer enhancement effect of the FBPHT, the wall temperature and corrosion of the heating tube can be reduced.

(8) The FBPHT can be used not only to modify the original heat exchange equipment in enterprises, but also to build new type of heat exchange equipment.

In conclusion, this FBPHT can improve the heat transfer efficiency of heat exchange equipment, reduce the coal consumption and environmental pollution, extend the cleaning cycle, increase the actual production time, decrease labour intensity, improve the operating environment, save energy and reduce emissions. It can bring about huge economic benefits, environmental benefits and social benefits for the enterprises.

### INDUSTRIALIZATION ACHIEVEMENTS

After years of studying, the FBPHT has been at the stage of industrialization promotion at present. The research team led by Professor Li Xiulun who comes from School of Chemical Engineering and Technology of Tianjin University, has carried out industrialization in many fields and achieved a lot of valuable results and experience. Some major industrialization achievement are introduced as follows.

#### (1) Evaporation of magnesium chloride solution

The technology has run successfully in magnesium chloride evaporator with a production of 30 000 t/a. The original evaporator needs stopping to be cleaned every eight hours for serious fouling, while after using the FBPHT, no fouling can be found even continuously running for 5000 hours. When implementing the technology, the evaporator is modified from the original forced circulation to natural circulation and eliminate the forced circulation pump, which has no effect on the production and quality of the products. The results have passed the expert testimony organized by the State Planning Commission Organization and been considered to reach the international advanced level. The achievements of the technology have obtained national invention patent(boiling evaporation device with performance of heat-transfer enhancement and preventing fouling and its operation method), Tianjin Outstanding Contribution Award of Industry-academy-research Joint Innovation and the second prize of Tianjin technical invention. This industrialization achievement has been reported by many propaganda medias such as Tianjin Daily, Tianjin Daily News, Tianjin Workers Daily, China Technology Market News, Guangming Daily, Science Times, Technology Daily, China Chemical Industry News, Xinhua Agency, Hong Kong China News Agency and Shanghai Environmental Online.

#### (2)Evaporation and concentration of liquid extract of traditional Chinese medicine

To solve the fouling problem on the wall of equipment which is used to evaporate and concentrate the liquid extract of traditional Chinese medicine, Tianjin Municipal Economic Commission and Tianjin Science and Technology Commission listed the new technology into important development item of Tianjin Modernization Research of Traditional Chinese Medicine (project number: 201C04) in 2001. The productive experiment research of three-phase fluidized bed evaporation and concentration device for the liquid extract of traditional Chinese medicine was completed in September 2002 and achieved the expected target of heat -

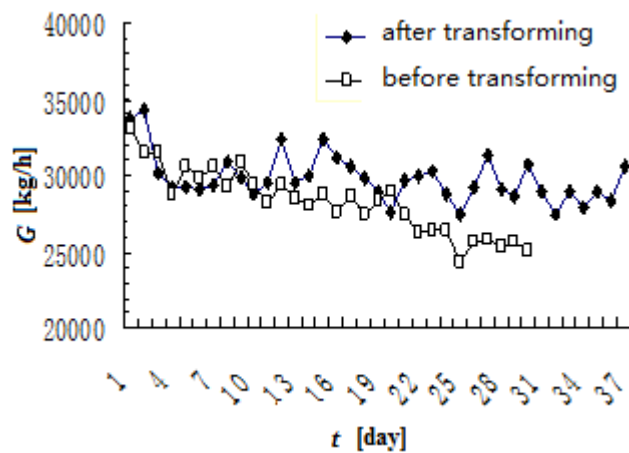
transfer enhancement and preventing fouling. On September 29, 2002, it passed the inspection and evaluation organized by Tianjin Municipal Economic Commission and Tianjin Science and Technology Commission. This achievement obtained national invention patent, and the third prize of Tianjin technical invention. Tianjin Daily reported the research achievement on the front-page on October 14, 2002.

### (3)Evaporation of calcium chloride solution

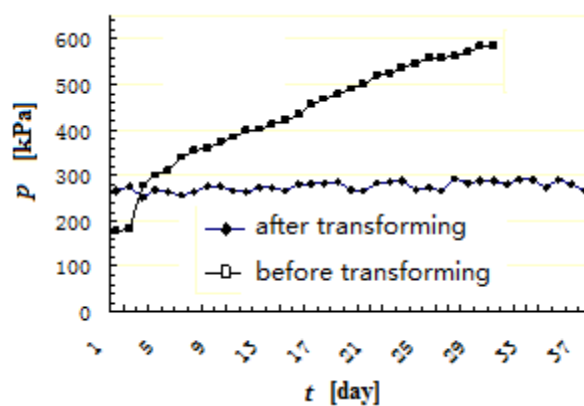
In 2006, the technology ran successfully in the evaporator of calcium chloride solution with a output 60 000 t/a, solving the fouling problem unsolved for a long time, which is an industrialization demonstration project, and a major technology progress of calcium chloride evaporation. The way of circulation of material liquid in calcium chloride evaporation plant is transformed from the original forced circulation to natural circulation, which eliminates the circulating pump and not only greatly saves the operation energy consumption of the equipment but also increases the production. The comparisons between before and after transforming are shown in Figure 3 and Figure 4.

It can be observed from Figure 3, the processing capacity of the evaporator before transforming is 33 t/h and then gradually down to 25 t/h after one month, which need stopping to be cleaned. With the modification of the technology, the processing capacity of the evaporator is basically more than 30 tons in a month and the average capacity is higher than before. With using this technology, the evaporator of calcium chloride solution can continuously operate for six months without stopping to be cleaned and no fouling can be observed on surface.

As we know, the heating steam pressure inside the shell side of heating chamber is an important symbol of measure the degree of fouling, the more severe the degree of fouling, the higher the steam pressure. Figure 4 shows, before transforming, the steam pressure of heating chamber is 200 kPa at the beginning of an operation cycle and then gradually rises to 565 kPa by the end of the month, which has reached the up limit of the steam operating pressure in the shell side and need stopping to be cleaned. After using the technology, the steam pressure in the shell side still maintains at about 270 kPa within one month, which fully illustrates the effect of preventing fouling of the FBPHT.



**Figure 3** The comparison of the processing capacity of the raw material between before and after transforming



**Figure 4** The comparison of the steam pressure in the shell side of heating chamber between before and after transforming

On August 7, 2007, the achievement passed the expert testimony organized by the Technology Achievements Department of Shandong Province and was considered to reach the international advanced level. China Chemical Industry News reported on the achievement on August 14, 2007.

### (4) The evaporation of caustic soda solution

This technology was applied in the evaporation equipment of caustic soda solution with a production of 40 000 t/a and also made important achievements. After changing the forced circulation to natural circulation, the production of the evaporator does not decrease. The fluidized particles do not affect the crystallization and removal of the salt in caustic soda solution, so it does not affect the quality of the products. It solves the fouling problem of the caustic soda evaporation equipment. At present, for the prefect results of transformation in caustic soda evaporation process, this technology has been listed as the key promotion plan of clean

production in caustic soda industry by the National Ministry of Industry and Information Technology (MIIT).

#### (5)Evaporation and desalination of waste water

It has also made obvious progress by the application of this technology in evaporation process of the pharmaceutical wastewater containing glauber salt. The original multi-effect wastewater evaporation appears obvious fouling phenomenon after ten hours, which results in the decrease of heat-transfer efficiency. After using the technology, the fouling problem is resolved.

#### (6) The evaporation of lithium hydroxide solution

In the evaporation process of lithium hydroxide solution, the fouling problem of is so severe that the workers have to stop the evaporation and clean fouling every 10 days. What's more, because the fouling is stiff and insoluble in water, the drills are required in removing fouling. After adopting the technology the fouling problem is basically solved. On the premise of guarantee quality, the obvious effect of energy saving and preventing fouling is achieved.

#### (7) The evaporation of lithium sulfate solution

In the evaporation equipment of lithium sulfate solution, the fouling is also very serious. This technology has good effects on heat-transfer enhancement and preventing fouling, which solves fouling problem in the lithium sulfate solution evaporation device.

#### (8)Preventing fouling and heat-transfer enhancement of industrial boiler

A lot of work has been done in this respect. The project of "New Technology of Energy Conservation and Emissions Reduction on Industrial Boiler Preventing Fouling", has been supported by Tianjin Science and Technology Commission and listed as key projects of Tianjin Science and Technology Support Plan, which has entered the stage of industrial boiler experiment at present.

## CONCLUSION

The technology has gone through a rough road from the fundamental researches to industrialization. After years of effort, it has been successfully used in industrial production and benefited some related enterprises, and it has a significant effect on energy conservation and emissions reduction.

Here we firstly thank the support of the State Development and Planning Commission, the Ministry of Education, the Ministry of Industry and Information Technology, Tianjin Planning Commission, the Science and Technology Commission, the Economic Commission. We

also thank the trust, understanding and cooperation of many enterprises, which makes the continuous improvement of the technology in the process of industrialization.

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