SELF-CLEANING HEAT EXCHANGERS: PRINCIPLE, INDUSTRIAL APPLICATIONS AND OPERATING INSTALLATIONS

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Abstract.

A new development in fluidized bed non-fouling heat exchangers has demonstrated to be a major improvement in the technology of self-cleaning heat exchangers. The incorporation of sophisticated methods for the particle separation and the application of a downcomer for the external circulation of the cleaning particles have made the operation of these heat exchangers better controllable, more flexible in design and suitable for many more applications. Commercial applications will be cited including installations already in operation and new promising developments will be discussed.

1. Introduction.

Self-cleaning heat exchange technology applying a fluidized bed of particles through the tubes of a vertical shell and tube exchanger was developed in the early 1970s for seawater desalination service. Since that time, several generations of technological advancements have made the modern self-cleaning heat exchanger the best solution for most severely fouling liquids.

Now that the self-cleaning heat exchangers have proven to be successful in many severe fouling circumstances, a number of which will be discussed here, there are new applications that seem likely to usher in a new era for self-cleaning technology. For example, it is now possible to employ the self-cleaning technology in heat exchangers with evaporation in the tubes. Very large heat exchange systems can be equipped with this self-cleaning technology and existing vertical conventional highly fouling exchangers can be retrofitted into a self-cleaning configuration at relatively low cost.

2. Principle of operation.

The principle of operation of the self-cleaning heat exchanger is shown in figure 1.

The fouling liquid is fed upward through a vertical shell and tube exchanger that has specially designed inlet and outlet channels. Solid particles are also fed at the inlet where an internal flow distribution system provides a uniform distribution of the liquid and suspended particles throughout the internal surface of the bundle. The particles are carried by the upward flow of liquid through the tubes where they impart a mild scraping effect on the wall of the heat exchange tubes, thereby removing any deposit at an early stage of formation. These particles can be cut metal wire, glass or ceramic balls with diameters varying from 1 to 4 mm. At the top of the exchanger the particles disengage from the liquid in a widened outlet channel and are returned to the inlet channel through an external downcomer and are recirculated continuously.
In some applications a cyclone is connected to the outlet channel for the separation of the particles from the liquid. In this case the under-flow of the cyclone

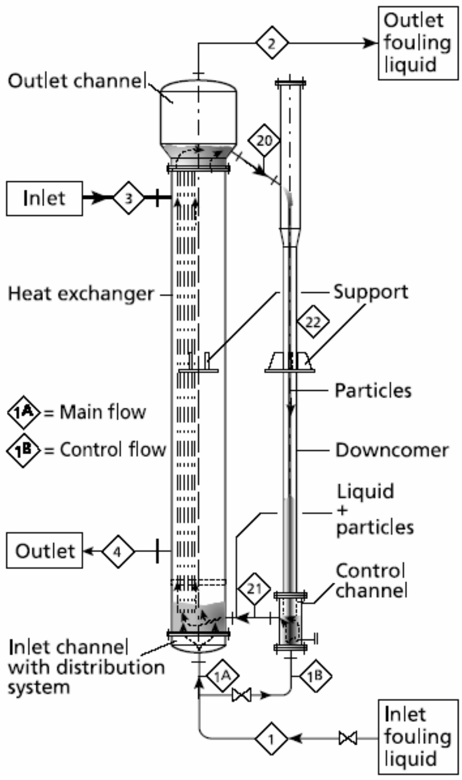

Figure 1: Principle of self-cleaning heat exchanger.

brings the particles into the downcomer, while the upper-flow only consists of the process liquid.

The process liquid fed to the exchanger is divided into a main flow and a control flow that sweeps the cleaning particles into the exchanger. By varying the control flow, it is possible to control the amount of particles in the tubes. This provides control of the aggressiveness of the cleaning mechanism. It allows the particle circulation to be either continuous or intermittent.

3. Treatable fouling services.

Fouling services which can be treated with the self-cleaning heat exchanger with external circulation of the cleaning particles, are the following:

- Forced circulation evaporators and reboilers.
- Chemical processes where heating or cooling causes polymerization fouling or resinous deposits.
- Heat recovery from fouling waste-waters.
- Concentration of waste-waters by evaporation.
- Cooling and evaporative crystallization.
- Process cooling with hard scaling and/or biologically fouled waters.
- White-water and black-liquor heating in pulp and paper industries.
- Raw juice heating in food processing.
- District heating and/or power generation with geothermal brines.
- Brackish water and sea-water desalinization.
- Production of medium and high pressure steam from severely fouling chemically untreated waters.
- Self-cleaning lube oil chillers to replace conventional scraped surfaces.

4. Operating installations in fouling services.

4.1. Quench coolers.

A chemical plant in the United States of America cooled large quench-water flows from a proprietary process in open cooling towers. This quench-water released volatile organic compounds (VOCs) into the atmosphere. As a consequence of environmental regulations the quench-water cycle had to be closed by installing heat exchangers between the quench-water and the cooling water from the cooling towers.
In August 1997, after considering other solutions, plant management decided to carry out a test with a small self-cleaning heat exchanger and compared its performance with that of a conventional shell and tube exchanger, which suffered from a severe fouling deposit consisting of a tarry substance. Figure 2 shows the results of this test, while figure 3 compares the design consequences for the self-cleaning heat exchangers and the conventional shell and tube exchangers.
Plant management decided in favour of the self-cleaning technology because of the above results and the substantial savings on investment cost.

Figure 4 shows the installation which serves two parallel production lines. In each production line two identical self-cleaning heat exchangers were installed. Each exchanger employs a cyclone for the separation of the particles, has a shell diameter of 1,200 mm, a total height of 20 m and a heat transfer surface of 1,150 m² consisting of 700 parallel tubes with an outer diameter of 31.75 mm. Each exchanger uses 9,000 kg cut metal wire particles with a diameter of 1.6 mm.

The exchangers serving the first production line were put into operation in October 1998. Figure 5 presents the trend of the overall heat transfer coefficient (k-value) after start-up till the end of April 1999. In spite of some fluctuations at the beginning, this figure shows a constant k-value of approximately 2,000 W/(m²·K). During a period of more than six months both exchangers operated continuously, with the exception of a few short stops caused by interruptions in the power supply. Figure 6 shows the trend of the two heat exchangers of the first production line for the period May 1999 till December 1999. During this period, there is a tendency of a decreasing k-value, which, however, improves again after adjustments of the chemical treatment of the cooling (tower) water. Apparently, this fouling phenomenon is caused by the cooling water in the shell and not by the severely fouling process liquid in the tubes.

Figure 6 also shows the trend of the k-value of the two exchangers of the second production line which were put into operation in May 1999. These values begin at 2,150 W/(m²·K) and, during a period of six months, decrease to approximately 2,000 W/(m²·K). The two exchangers of the second production line used cooling water of a different cooling tower, which apparently responded better to its chemical treatment and, as a consequence, did not cause much fouling of the exchangers at their shell side.

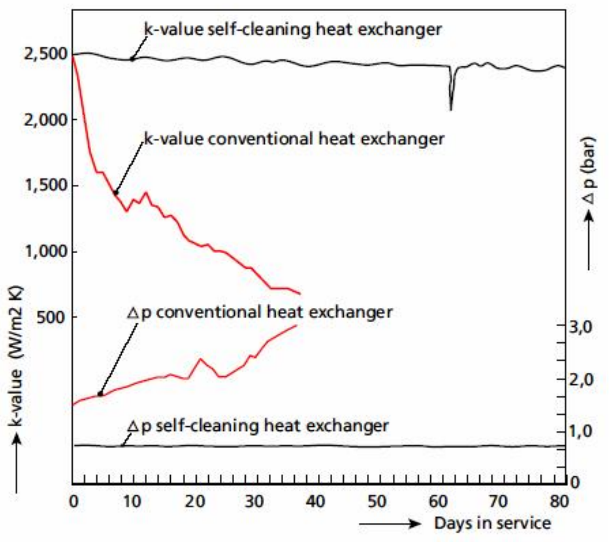

Figure 2: Overall heat transfer coefficient (k-value) and pressure drop (Δp) as function of operating time.

	Self-cleaning heat exchanger	Conventional heat exchanger
Heat transfer surface	4,600 m²	24,000 m²
Pumping power	840 kW	2,100 kW
Number of cleanings per year	0	12

Figure 3: Comparison of self-cleaning heat exchanger versus conventional heat exchanger.

Figure 4: Installation of 4,600 m² self-cleaning surface replacing 4,000 m² conventional surface.

At this moment, end of July 2000, the exchangers are still in operation without having been cleaned. The exchangers of the first production line, already in operation for 21 months, still show k-values varying sharply between 1,200 W/(m²·K) and 1,800 W/(m²·K) depending on the chemical treatment of the cooling tower water. The exchangers of the second production line, already in operation for 15 months, show a k-value of approximately 1,950 W/(m²·K).

The dotted line in figure 5 shows the trend of the k-value for conventional shell and tube exchangers as derived from the test results presented in figure 2. Of course, this trend, although not shown, is also applicable to all four exchangers during the operating period shown in figure 6.

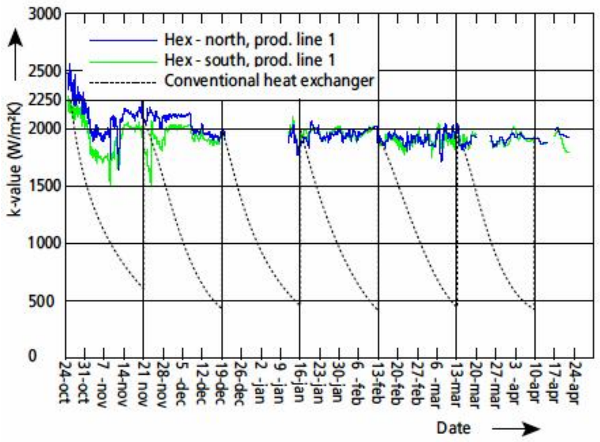

Figure 5: **k-values for self-cleaning heat exchangers of first production line, as a function of operating time and compared with the performance of conventional heat exchanger.**

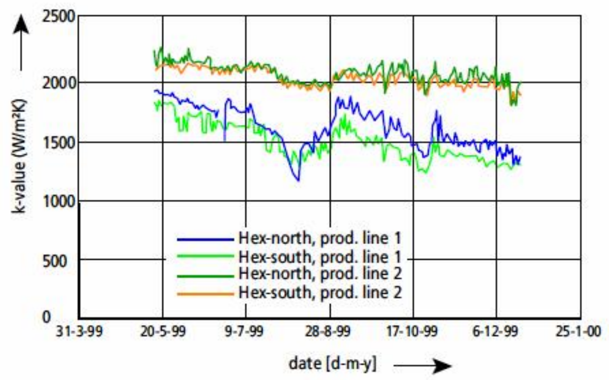

Figure 6: **Continuation of k-values for all four self-cleaning heat exchangers of both production lines as a function of operating time.**

During the operation some minor problems were observed. For example, some pieces of piping carrying a flow of liquid and particles from the lower part of the external downcomer into the inlet channel, and some parts of the lining of the cyclone needed minor repair after more than 12 months of continuous operation. Inspection of the heat exchanger tubes did not reveal any measurable wear. The cleaning particles showed a weight loss of only 2% after 12 months of operation. New developments and improvements of the system will reduce these wear problems further.

During 21 months of operation, all exchangers went through several power failures, which completely stopped the circulation of liquid and particles through the exchangers. After restoration of the power, all exchangers resumed operation smoothly and they returned to their original working point.

4.2. MDF-plant.

In early 1997, a manufacturer of Medium Density Fiberboard (MDF) in Europe ordered a forced circulation evaporator for the concentration of waste-water while producing steam of 200°C and 14 barg. This steam is used in the process, while the concentrate is combusted together with the bark and the wood scrap. At this high temperature level, the concentration of waste-water by evaporation causes severe fouling in a conventional exchanger.

The self-cleaning heat exchanger in this installation has a surface of 250 m² and a total height of 12 m. It uses 4,500 kg of cut metal wire particles with a diameter of 3 mm. The installation eliminated all fouling related problems. Figure 7 shows the installation.

Meanwhile, more MDF-plants are showing interest in this unique energy-efficient approach to solving waste-water problems in combination with the achievement of zero-water discharge.

4.3. Pulp mill.

In December 1996, a producer of pulp and paper-board in Europe ordered two self-cleaning heat exchangers. They replaced conventional exchangers which had suffered from severe fouling due to calcium carbonate deposits and other hard scales which required cleanings every two weeks.

The two heat exchangers total 250 m² and use cut metal wire of 2 mm as cleaning particles. Both exchangers have been operating without fouling for long periods of time. Figure 8 shows the exchangers at the pulp mill during installation.

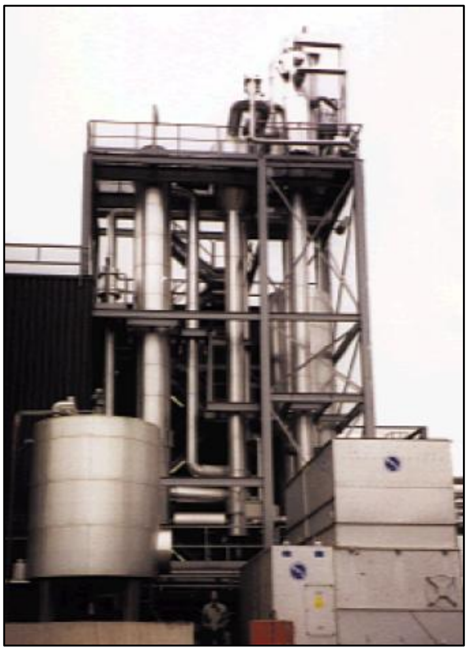

Figure 7: Evaporator with self-cleaning heat exchanger in MDF-plant in Europe.

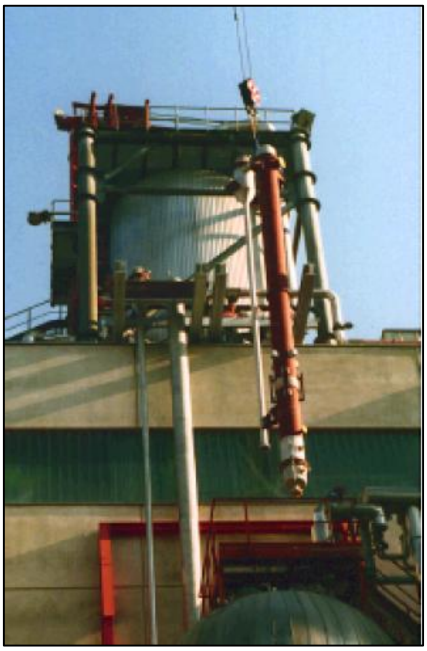

Figure 8: Installation of two self-cleaning heat exchangers in pulp mill in Europe.

Figure 9: Evaporator with self-cleaning heat exchanger for food processing plant in Japan.

Because of its technological superiority, this project has been selected and subsidized by the European Commission in Brussels as a demonstration project for the efficient use of energy in industry.

4.4. Food processing plant.

In August 1997, a self-cleaning heat exchanger was installed in Japan in an evaporator for the concentration of waste-water in a food processing plant. This forced circulation evaporator operates without boiling in the tubes at a temperature level of approximately 70°C. Conventional heat exchangers were never considered because the severely fouling liquid would cause a fouled blockage in just a few hours. After 30 months of almost continuous operation without cleanings, an inspection of the self-cleaning heat exchanger with a heat transfer surface of 85 m² employing cut metal wire with a diameter of 2.5 mm as cleaning particles, showed clean and shiny tubes. Figure 9 shows this installation.

4.5. Test installations.

At this moment, test installations are in operation in the United States, Saudi-Arabia and Australia. In general, this is a first step to install full-size installations. More tests are being planned in Germany, the Netherlands, Spain, Mexico, India, South Africa and Cuba.

5. Retrofitting existing exchangers in fouling services.

5.1. First revamp of existing heat exchanger.

A board mill in Europe carried out the first revamp of an existing heater into a self-cleaning heat exchanger configuration applying external circulation of cleaning particles consisting of glass balls with a diameter of 2 mm.

A small existing vertical heater, used for the heating of hard scaling well water, suffered from a variety of operational problems all caused by very severe fouling due to the precipitation of calcium carbonate. The actual heating source for this heater are exhaust gases of a combined-cycle power generation plant which outlet temperature has been reduced from 140°C to 65°C resulting in a total heat recovery of 1.2 MW. The actual revamp has been carried out last April and since then the installation is performing fine with a constant overall heat transfer coefficient of 2,100 W/(m²·K).

5.2. Revamp of an existing conventional reboiler.

A large chemical plant in Europe operates a reboiler with forced circulation. When allowing boiling in the tubes, the operation suffers from severe fouling of the exchanger. Suppressing the evaporation in the tubes by installing a throttle plate in the reboiler outlet did not inhibit fouling. The conventional installation is shown in figure 10.

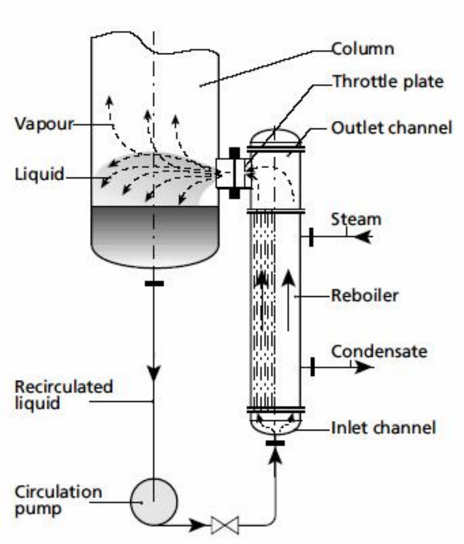

Figure 10: Existing conventional reboiler.

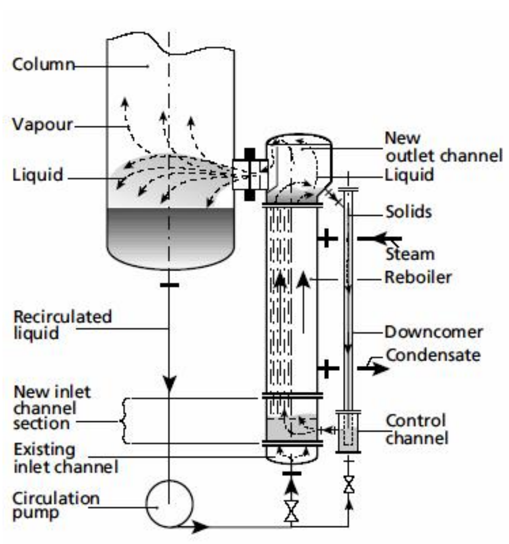

Figure 11: Existing conventional reboiler retro-fitted into self-cleaning configuration.

Recently, the author was approached by plant management to offer a solution for their severely fouling reboiler. Revamping the existing reboiler operating at a liquid velocity of 1.2 m/s, into a self-cleaning configuration at the same liquid velocity was appealing. Management appreciated the fact that the cleaning particles could be removed from the exchanger if the revamp did not totally solve the fouling problem. In that case, the exchanger could operate as before the retrofit.

Management stipulated the fact that the retrofit work should be minimal. The installed pump must be used and the connections of the reboiler to the column would be maintained. An elegant design proposal was submitted that met all the criteria and is shown in figure 11. Final project approval is pending.

5.3. Retrofit of cooling crystallization plant.

A 2-stage cooling crystallization plant in Egypt produces sodium sulphate. The chillers of both stages suffer from severe fouling caused by deposits of crystals. Shut-down of the installation every 24 hours for melting out these deposits is common. The conventional cooling crystallizer is shown in figure 12, while figure 13 presents this installation after its revamp into a self-cleaning configuration.

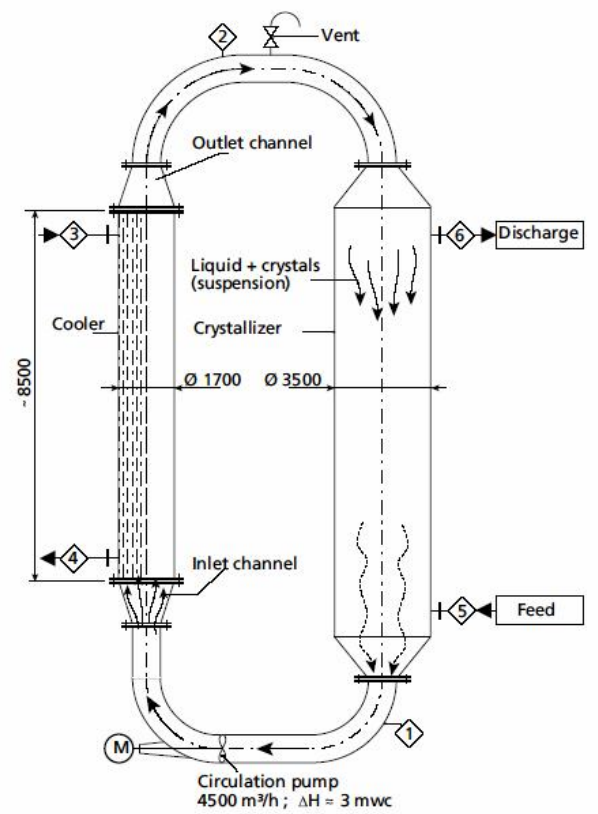

Figure 12: Existing conventional cooling crystallizer.

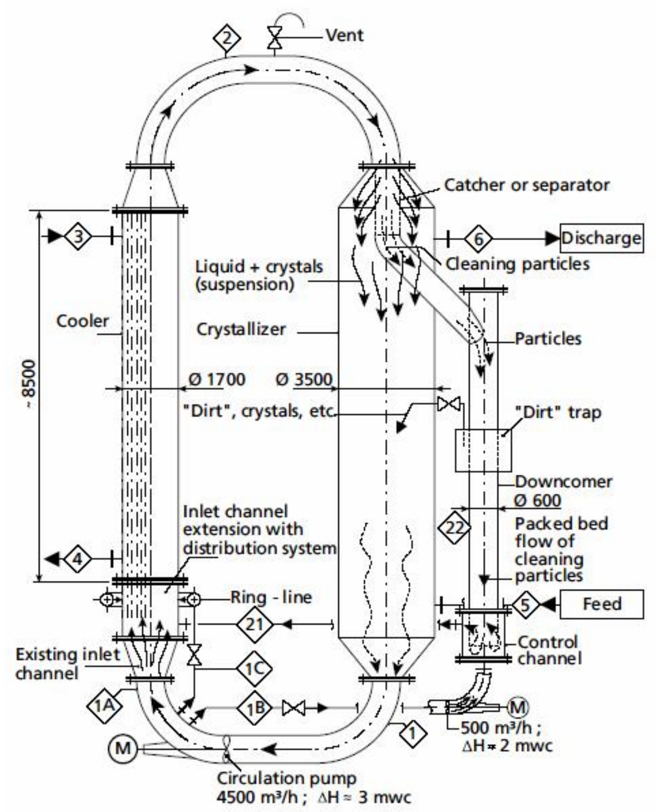

Figure 13: Existing conventional cooling crystallizer retro-fitted into self-cleaning configuration.

Calculations show that, if the self-cleaning principle does solve the fouling problem, the investments which are necessary for the modification of the existing installation will be paid back in approximately six months.

6. New applications.

6.1. Closed-loop coolers.

Very large self-cleaning heat exchangers are now being considered for new plants that are to be built in coastal areas such as the Caribbean and the Middle East, where there is little or no fresh water available for cooling service s. In these locations sea-water theoretically makes the best heat sink. However, in some of these locations, conventional heat exchangers could suffer from a combination of severe biological fouling and sedimentation fouling.

An excellent solution for this dilemma is to use the self-cleaning heat exchanger as a closed-loop cooler. The main purpose of the application of closed-loop coolers is to avoid the use of sea-water in a large number of plant coolers. As a consequence, the problems of corrosion and fouling are concentrated in a few very large sea-water cooled closed-loop coolers which are responsible for the cooling of the closed-loop fluid throughout the plant. Normally, this closed-loop fluid is conditioned water which does not foul or corrode the shell-side of either the closed-loop coolers or the exchangers in the plant. Neither does it foul or corrode the connecting piping, the pumps, the valves, etc. in the clean coolant circuit between the closed-loop coolers and the exchangers in the plant.

For one particular application under consideration, the process conditions are as follows:

- Heat load : 460 MW
- Closed-loop water flow : 40,000 m³/h
- Closed-loop water temperature in/out : 43.9 / 33.9 °C
- Sea-water flow : 80,000 m³/h
- Sea-water temperature in/out : 26.7 / 31.7 °C

For environmental reasons, the temperature increase of the sea-water has been restricted to 5°C, which explains the rather large sea-water flow.

For the handling of this thermal duty, four parallel operating coolers were selected. The simplified process diagram and the configuration of one of these coolers are shown in the figures 14 and 15. Figure 16 presents the specific mechanical design parameters.

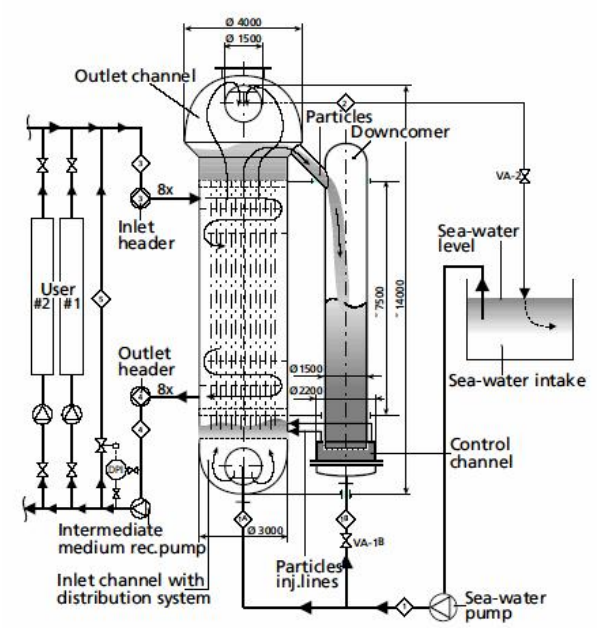

Figure 14: Process diagram and components for self-cleaning closed-loop cooler.

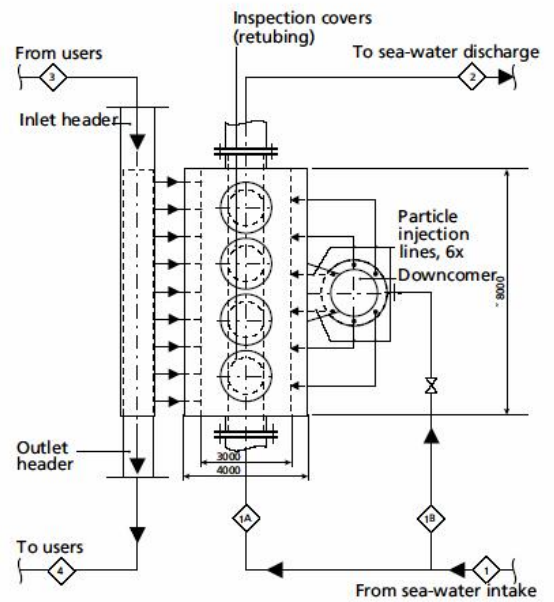

Figure 15: Top view of self-cleaning closed-loop cooler.

The large flat walls of the shell of the large rectangularly shaped cooler need strengthening. For the reinforcement of the side-walls, high tensile strength tiers connecting these side-walls are employed. These tiers can pass through the bundle without influencing the shell-side film coefficient. The flat end walls of the cooler are reinforced by welding T-profiles on the outside surface of these walls. The half cylindrical shape of the inlet and outlet channels guarantees sufficient strength without the need of additional reinforcement.

Cleaning of the inner-tube surface is achieved by the flow with 3 mm diameter glass or ceramic balls through 11,500 tubes with an outer diameter of 25.4 mm and a length of 7,500 mm. Approximately 120 kg of glass or ceramic balls will pass through each tube per hour. The cleaning particles are brought into the inlet channel from the bottom section of the downcomer, i.e. the control channel, through six injection lines with adjustable flows. The quantity of particles participating in the cleaning process can be influenced by varying the control flow through line 1^B. This self-cleaning technology guarantees a perfectly clean surface for all tubes even in case of the most severe fouling sea-water and without the risk of plugged tubes. The complete elimination of fouling lowers the risk of corrosion and makes it possible to consider the use of cheaper materials, e.g. duplex instead of titanium.

Total number of tubes	11.500 -
Diameter of tubes	25,4 x 1,21 mm
Total lenght of tubes	7.500 mm
Heat transfer surface	6.879 m²
Overall height of cooler	14.000 mm
Width of cooler	3.000 / 4.000 mm
Length of cooler	8.000 mm
Material shell-side	Carbon steel -
Material tube-side	Duplex -
Material cleaning particles	3 mm glass balls -
Design pressure inlet channel	2 barg
Design pressure outlet channel	-1/1 barg
Design pressure shell	2 barg
Pressure drop tube-side	0,35 bar
Pressure drop shell-side	1,8 bar

Figure 16: Mechanical design parameters for closed-loop cooler.

This self-cleaning closed-loop cooler can operate continuously, i.e. year after year without intermediate cleanings, with an overall heat transfer coefficient of 2,000 W/(m²·K) or even higher. The cost of this cooler, with a total heat transfer surface of 6,879 m² and completely made from duplex steel at its tube-side, is approximately US$ 2,450,000.- or US$ 32.- per ft² of heat transfer surface.

6.2. Foul water steam generators.

Self-cleaning heat exchangers with evaporation in the tubes are also being considered for the production of injection steam for enhanced oil recovery. The highly fouling produced water from the oil wells may be used directly in a steam generator without expensive water treatment. One major US oil company is showing interest in this potential application for a particular location in the United States.

As a result of their interest, a design has been made for a steam generation plant with a total production of 294 tons of steam per hour with a pressure of 45 barg. The required heat comes from the exhaust gases of large gas turbines and the excess of electrical power produced will be sold to the grid. For a more efficient operation, the self-cleaning heat exchangers are equipped with finned tubes. The chemical composition of the produced water allows for the use of carbon steel. The total steam production is produced in three units, each unit consisting of one gas turbine and one steam generator for a steam production of 98 ton/h.

The figures 17 and 18 show the lay out of the proposed foul water steam generator, while figure 19 presents the relevant process data. Typical characteristics of this installation are the split of the exhaust gas flow into two flows crossing the heat exchange tube bundle from opposite sides, and the tube pattern which results in rectangular inlet and outlet channels. This design has been chosen to minimize pressure drop and, consequently, power loss of the gas turbine, the performance of which is vulnerable to back pressure. Further, this design has the advantage of an almost equal heat load applied to each tube. Other characteristics of the installation are the discharge of the blow-down together with the produced steam into the injection hole.

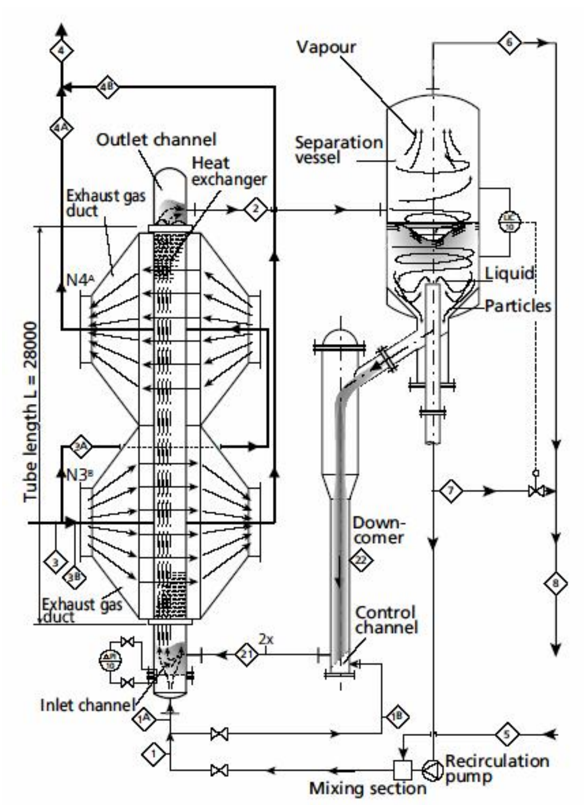

Figure 17: Process diagram and components for foul water steam generator.

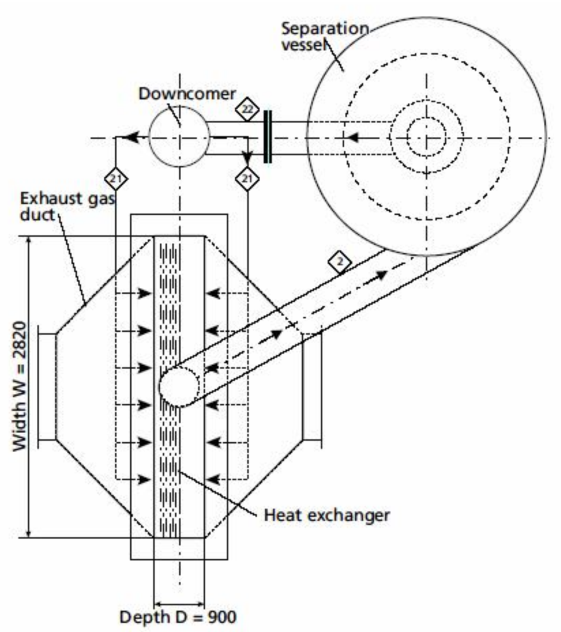

Figure 18: Process diagram and components for foul water steam generator.

It is very important that the undissolved solids produced in the system consist of rather fine crystals which easily flow with the blow-down. This can be realized by mixing the cold feed with the recirculated flow in a proprietary mixing section. Moreover, the formation of deposits on the walls of vessels and piping should be minimized so that such deposits cannot break off as large pieces during operation causing problems in the circulation of the flow through the exchanger. Very often, large pieces of deposits in the circulating flow are a result of an upset in the operating conditions which then may cause thermal shock. In the design of this steam generator various measures have been taken to prevent the presence of loose large pieces of deposits in the circulating liquid flow.

Line nr.	Medium	Flow (m³/h)	Flow (kg/h)	Temp. (°C)	Remarks
1	Process water (recirculated)	2031	$1{,}625 \times 10^6$	244,3	
1A	Process water	1950	$1{,}561 \times 10^6$	244,3	
1B	Process water	81	$0{,}064 \times 10^6$	244,3	
2	Water/vapour/ part. mixture	–	$1{,}625 \times 10^6$	258	Particles not incl. in numbers !
3	Exhaust gas from turbine	–	$1{,}012 \times 10^6$	538	
3A	Exhaust gas from turbine	–	~ 50% from "3"	538	
3B	Exhaust gas from turbine	–	~ 50% from "3"	538	
4	Exhaust gas to flue	–	1.012×10^6	276,4	
4A	Exhaust gas to flue	–	~ 50% from "4"	276,4	
4B	Exhaust gas to flue	–	~ 50% from "4"	276,4	
5	Cold feed water	–	$1{,}242 \times 10^5$	47,4	
6	Vapour (steam)	–	$0{,}980 \times 10^5$	258	
7	Blow-down (incl. sludge)	–	$0{,}262 \times 10^5$	258	
8	Steam / water / sludge mixture	–	$1{,}242 \times 10^5$	258	To bore-hole
9					
20	Particles	–	$3{,}28 \times 10^5$	–	
21	Process water + Particles	–	–	–	
22	Particles	–	$3{,}28 \times 10^5$	–	

Figure 19: Process data referring to figure 17.

Figure 20 gives some information regarding the mechanical design. For this particular location, the height of the installation, required by the tube length, is not a problem. In case it would become a problem, the tube length can be shortened by reducing the steam weight fraction at the tube outlets from 6% to 3% of the circulating flow. This reduces the tube length by a factor 2, increases the number of tubes by a factor 2 and also doubles the circulating flow.

The US oil company which encouraged this design study considers the result so promising that they are seriously evaluating the possibilities of building a pilot plant for the production of 5 tons of steam per hour as a next step in the realization of full-size foul water steam generators applying the self-cleaning heat exchange technology with evaporation in the tubes.

Total number of finned tubes	644
Diameter of tubes	38,0 x 3,2 mm
Total lenght of tubes (L)	28.000 mm
Heat transfer surface	2.150 m²
Overall height of exchanger	31.000 mm
Width of channels (W)	2.820 mm
Depth of channels (D)	900 mm
Material shell-side	Carbon steel -
Material tube-side	Carbon steel -
Material cleaning particles	2 mm Carbon steel (cut metal wire)
Operating pressure tube-side	45 bar
Operating pressure shell-side	Atm. -
Pressure drop tube-side ¹)	1.85 bar
Pressure drop shell-side (across tube bundle!)	0.02 bar

¹) Pressure drop mixing section not included!

Figure 20: Mechanical design data for heat exchanger of foul water steam generator.

6.3. Foul water distillers.

To enhance oil production, another major US oil company has a different approach to the production of injection steam from severely fouling produced water.

They are interested in producing clean distillate from the fouling produced water in a vapour recompression evaporator or distiller equipped with a self-cleaning heat exchanger. The clean distillate will be used in conventional boilers for the production of high pressure injection steam. The installation which has the interest of the US oil company, is explained in the figures 21 and 22. The figures 23 and 24 add some more information about the process and the mechanical design parameters of the installation.

A typical characteristic of the installation is the very large circulating flow which is realized, if necessary, in several parallel propeller pumps installed in the lower end of the down-takes and integrated in the bundle. These down-takes are in fact the suction lines of the propeller pumps.

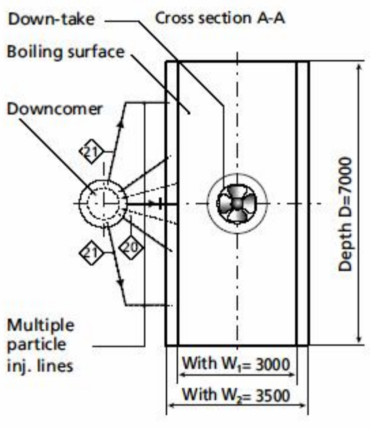

Figure 22: Cross section of figure 21.

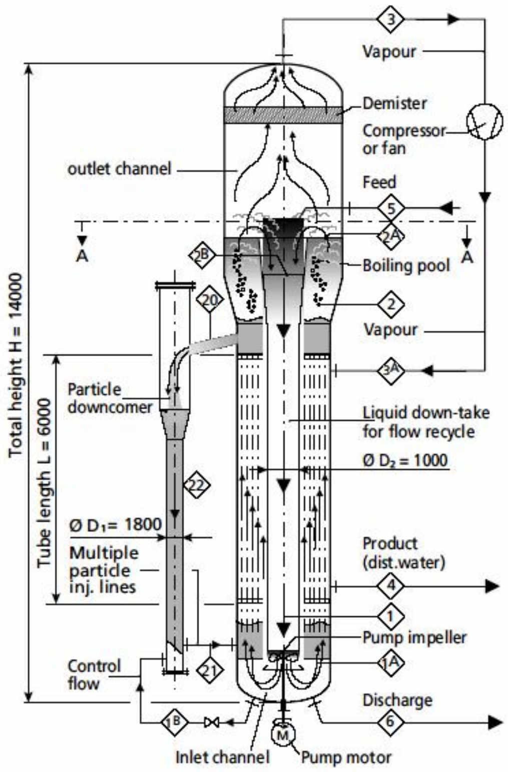

Figure 21: Vapour re-compression evaporator for production of distilled water from severely fouling 'produced' water (foul water distiller).

The large circulating flow is responsible for small temperature differences of the liquid across the bundle. This guarantees an attractive logarithmic temperature difference between the liquid in the tubes and the condensing vapour in the shell, and also makes it possible that evaporation of the liquid only occurs in the pool of liquid above the upper tube plate and the fluidized bed of particles above this plate. As a consequence, the boiling process in the pool does not interfere with the recirculation of the cleaning particles from the outlet channel of the exchanger into the downcomer. Also in this application, the cleaning particles are returned from the bottom section of the downcomer into the inlet channel through multiple injection lines with adjustable flows.

Line nr.	Medium	Flow (ton/h)	Temp. (°C)	Remarks
1	Produced water	18,000	98.0	
1A	Produced water	–	98.0	
1B	Produced water	–	98.0	
2	Produced water	17,870	102.0	
2A	Exhaust gas from turbine	17,740	98.0	AT equilibrium
2B	Produced water	18,130	98.0	
3	Vapour	130	97.0	B.P.E. =1°C
3A	Compressed vapour	130	104.0	Saturated due to water injection
4	Distillate	130	~ 103.0	
5	Feed produced water	260	98.0	Temperature assumed !
6	Blow-down	130	98.0	

Figure 23: Process data referring to figure 21.

Total number of tubes	9000
Diameter of tubes	31.75 x 0.77 mm
Total lenght of tubes (L)	6,000 mm
Heat transfer surface	5,400 m²
Overall height of exchanger	~14,000 mm
Width (W_1)	3,000 mm
Width (W_2)	3,500 mm
Depth (D)	7,000 mm
Diam. downcomer (D_1)	1,800 mm
Diam. liquid down-take (D_2)	1,000 mm
Material tubes	Titanium, Gr 12
All other materials	Duplex
Material cleaning particles	4 mm glass balls
Power fan	1,900 kW
Power propeller pump	225 kW

Figure 24: Mechanical design data for foul water distiller.

Another characteristic during operation of the installation is a system pressure close to atmospheric pressure. This allows for a rectangular construction with only a minimum of requirements for the reinforcement of these flat walls.

The rectangular construction simplifies the installation of multiple circulation pumps in parallel, in combination with the installation of multiple fans in parallel. This would make this superior vapour recompression evaporator with self-cleaning heat exchanger suitable for very large capacities and, therefore, also interesting for large scale sea-water desalinization.

Also this US oil company is pleased with the results of the design study and considers a test installation as a next step on their way to realizing a full-size installation.

6.4. Multi-stage flash evaporators.

Already in 1975, the first msf evaporator applying a self-cleaning fluidized bed heat exchanger was put into operation at one of the Technical Universities in the Netherlands. This evaporator had 5 stages, and 2 mm glass balls were used as cleaning media. The evaporator produced 1 ton of distillate per hour from severely fouling canal water. Its maximum water temperature was 100°C and its distillate production per ton of steam (i.e. yield or gain-ratio) is 2.5.

In 1978, again in the Netherlands, a 24-stage msf evaporator with a self-cleaning heat exchanger using glass balls of 2 mm diameter was put into operation and produced 20 ton/h of potable water from natural sea-water. The yield of this evaporator was 10.3 and its maximum sea-water temperature 115°C.

In 1982 and 1985 two 6-stage msf evaporators with self-cleaning heat exchangers and a production of 4 ton/h of distillate were put into operation at a municipal waste incinerator plant in Amsterdam, the Netherlands, for the production of boiler feed water from polluted and brackish harbour water. These evaporators used 3 mm glass balls, had a yield of 2.0 and a maximum water temperature of 100°C.

Although all these evaporators demonstrated convincingly that they could operate on chemically untreated waters, including natural sea-water, at relative high temperatures without fouling, they also had their weaknesses. These were mainly caused by the fact that the evaporators employed stationary fluidized beds instead of fluidized beds with circulation of the particles through an external downcomer.

Figure 25 presents an msf evaporator with self-cleaning heat exchangers with the unique feature that it applies a final heater using hot exhaust gases. In spite of many attempts in the 60s and 70s, a final heater using hot gases was never successful in conventional msf plants due to the fact that localized hot spots could not be avoided and, even in the case of chemical treatment of the sea-water, such localized hot spots became a source of severe scaling. Experiments in the Netherlands, carried out in the late 70s proved that an msf evaporator with self-cleaning heat exchangers can handle hot gases in its final heater. It offers possibilities to operate such evaporators on the exhaust gases of large gas turbines.

Other advantages of the msf evaporator with self-cleaning heat exchangers are:

- No chemical dosing required to prevent fouling caused by hard scales.
- Operation is possible at considerably higher maximum temperatures than applicable to conventional msf plants.
- With the possibility of higher maximum temperatures, the thermal efficiency can be increased by at least 30%.
- Distillate production can be varied from 0% to 100% and vice versa in approximately 20 minutes.

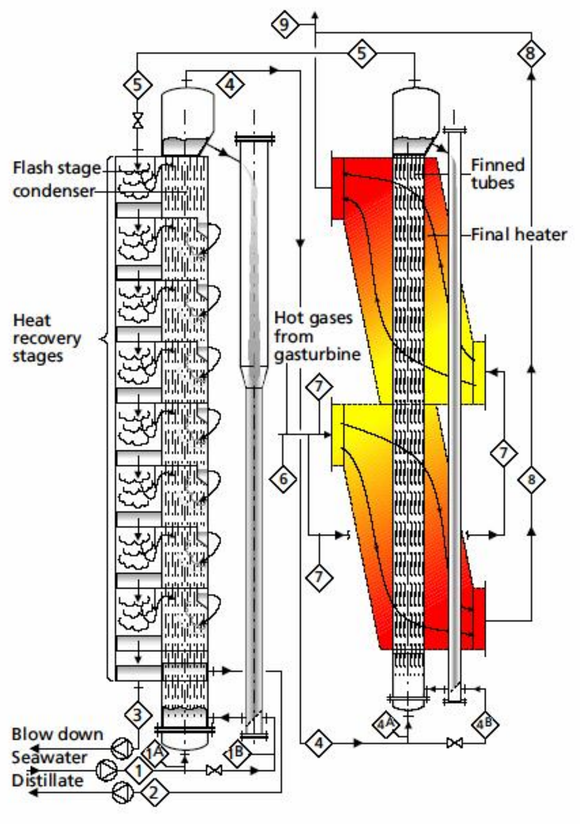

Figure 25: MSF - evaporator with self-cleaning heat exchangers including gas-heated final heater.

With all the improvements made during the past years, including the application of the external circulation of the cleaning media, the potential of the msf evaporator with self-cleaning heat exchangers looks very promising for applications involving sea-water desalinization.

7. Conclusions.

Non-fouling or self-cleaning fluidized bed heat transfer, already known for almost 30 years, went through various stages of development, and with the fluidized bed configuration which applies external circulation of the cleaning particles, very likely, has now reached its final stage of development.

Self-cleaning fluidized bed heat transfer with external circulation of the cleaning particles can even be applied in case of severe fouling applications with boiling in the tubes. Further, this self-cleaning technology can also be employed to retrofit some existing severely fouling vertical heat exchangers into a self-cleaning configuration.

Commercial operating experience gained with a substantial number of heat exchangers shown that the self-cleaning heat exchanger, which can remain clean for long operating periods or even indefinitely, is a cost effective alternative to the conventional heat exchanger which suffers from severe fouling in a couple of hours, days, weeks or months. Any type of fouling deposit, whether hard or soft, biological or chemical, fibrous or protein, or other organic types, or a combination of the above can be effectively handled by the self-cleaning heat exchanger.

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