COMPACT SELF-CLEANING FLUIDIZED BED HEAT EXCHANGERS WITH EM BAFFLES

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ABSTRACT

This paper presents a compact self-cleaning fluidized bed heat exchanger equipped with EM baffles in the shell of the exchanger. Compact self-cleaning fluidized bed exchangers are characterized by the utilization of relatively small diameter heat exchange tubes in combination with rather large cleaning particles. This combination of tube and particle size is a new development and creates a very compact and low height self-cleaning shell and tube heat exchanger still suitable for severely fouling applications with overall heat transfer coefficients competitive with the coefficients of plate heat exchangers. This improved fluidized bed exchanger performs even better, if it is equipped with EM (Expanded Metal) baffles in the shell, an innovation by Shell Global Solutions International.

Advantages of this unique combination of ‘self-cleaning fluidized bed’ and ‘EM baffles’ in comparison with the ‘traditional self-cleaning fluidized bed’ will be discussed.

INTRODUCTION

The 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 70s for seawater desalination service. Since that time, several generations of technological advancements made the modern self-cleaning heat exchanger the best solution for most severely fouling liquids. Klaren and de Boer (March 2004) give a review of the developments in fluidized bed heat transfer over the past 30 years.

In 1998 four large self-cleaning fluidized bed shell and tube heat exchangers were put into operation at a chemical plant in the USA in a severely fouling service. Their excellent performance in comparison with what could be achieved with severely fouling conventional shell and tube heat exchangers were a surprise. However, even more can be expected after explaining the design and advantages of the newly developed and highly innovative compact self-cleaning fluidized bed heat exchangers for the same severely fouling service equipped with EM baffles in the shell.

PRINCIPLE OF SELF-CLEANING HEAT EXCHANGER

The principle of operation is shown in Figure 1. The fouling liquid is fed upward through a vertical shell and tube exchanger which 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 through the tubes by the upward flow of liquid where they impart a mild scraping effect on

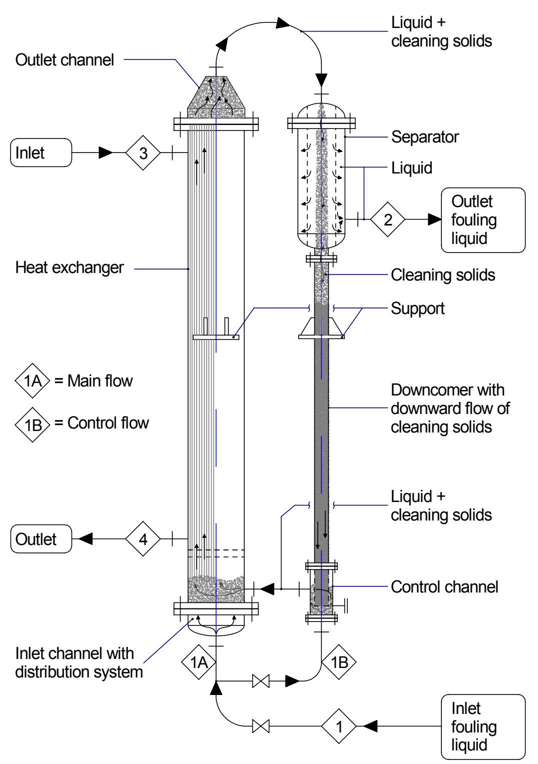

Figure 1: Principle of self-cleaning heat exchanger.

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, within the separator connected to the outlet channel, the particles disengage from the liquid and are returned to the inlet channel through a downcomer and the cycle is repeated.

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

EXAMPLE OF A SEVERELY FOULING SERVICE AND SOLUTION OF THE PROBLEM

A chemical plant in the United States 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.

An experiment with a small conventional shell and tube test exchanger indicated that the proprietary process liquid would cause very severe fouling in the tubes. The results of this test are shown in Figure 2. As an alternative, plant management decided to look into the possibility of using self-cleaning shell and tube heat exchangers. However, this required a test with a small self-cleaning heat exchanger. The results of this test in comparison with the results of the earlier test for the conventional configuration are also shown in Figure 2 and justified the decision by plant management in favor of the self-cleaning design, strengthened by a comparison of the design of both installations as shown in Table 1, while the self-cleaning heat exchangers actually installed at the plant site are shown in Figure 3.

What we have accomplished with the self-cleaning heat exchanger is a rather unique achievement in heat transfer:

<u>Excellent heat transfer without fouling, in spite of low velocities of the fouling liquid in the tubes, and requiring very little pressure drop and pumping power.</u>

As far as we know, there is no other heat exchange mechanism which combines these unique and, to a certain extent, contradictory characteristics. For a much more detailed comparison of conventional exchangers versus the self-cleaning exchangers, one is referred to Klaren and de Boer (October 2004).

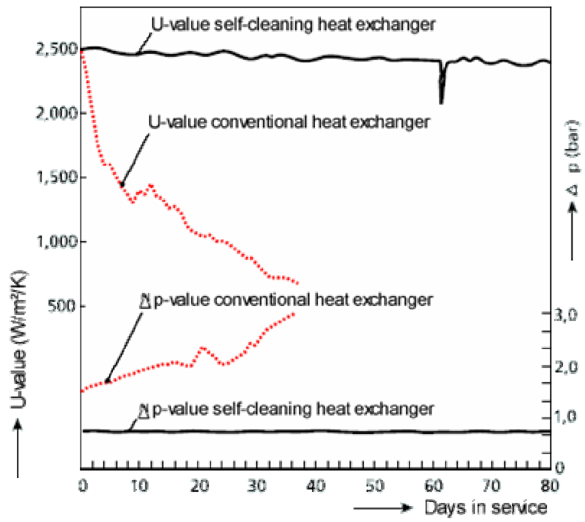

Figure 2: Test results conventional and self-cleaning heat exchanger.

Figure 3: 4,600 m² self-cleaning heat exchanger surface replacing 24,000 m² conventional surface.

THE COMPACT SELF-CLEANING HEAT EXCHANGER WITH EM-BAFFLES

Although, it has been shown that the performance of the self-cleaning heat exchangers in a severely fouling service is superior to that of conventional shell and tube exchangers, it is possible to do even better. Therefore, it is necessary to introduce the compact self-cleaning heat exchange technology in combination with the so-called EM baffles in the shell.

The compact self-cleaning heat exchanger

For 30 years, it was considered impossible to apply the self-cleaning fluidized bed heat exchange principle in tubes with an inner diameter D_i smaller than 30 mm and in combination with chopped metal wire cleaning particles with a diameter d_p of 2 mm. Or said otherwise: For a satisfactory operation of a self-cleaning heat exchanger employing chopped metal wire particles of 2 mm, it was generally recommended to use tubes with an inner diameter of at least 30 mm and maintain a ratio Di / d_p larger than 15. Until foreign researchers made a revolutionary discovery and demonstrated the feasibility of the self-cleaning principle in a single tube with an inner diameter of only 9.7 mm using chopped metal wire particles with a diameter of 2 mm, i.e. D_i / d_p < 5. KLAREN engineers have found the design rules to make this unique discovery also workable in bundles with many parallel tubes. The consequences of this new development are that self-cleaning heat exchangers can now be designed with the following characteristics:

1. Small hydraulic diameter,
2. thin tube wall,
3. high degree of turbulence,
4. low liquid velocities,
5. excellent film coefficients for heat transfer.

These characteristics result in very compact self-cleaning heat exchangers and, particularly, a drastic reduction of the height of the self-cleaning heat exchanger.

Table 1: Comparison significant parameters conventional vs. self-cleaning installation.

	Unit	Conventional	Self-cleaning
Duty	MW	140	140
Number of heat exchangers in operation	-	16	4
Number of spare heat exchangers to replace operating heat exchangers per cleaning	-	8	0
Total installed number of heat exchangers	-	24	4
Total installed surface	m²	24,000	4,650 [1)]
Number of passes tube-side	-	3	1
Number of passes shell-side	-	1	1
Baffle type shell-side	-	double segmented cross	double segmented cross
Tube length between tube plates	mm	12,000	16,000
Diameter heat exchanger tubes	mm	19.05 x 1.65	31.75 x 1.65
Liquid velocity in tubes	m/s	1.8	0.45
Total required pumping power for tube-side	kW	868	192
Total required pumping power for shell-side	kW	1,872	816
Total required pumping power	kW	2,740	816
Time between tube-side cleanings	weeks	5	>> 120

[1)] *Totally installed self-cleaning surface was overdimensioned by 38% which was not inspired by fouling.*

The EM baffle

Shell Global Solutions International in Amsterdam, the Netherlands (February 2005), developed a new type of baffle for shell and tube heat exchangers. This new and really innovative tube support technology is based on 'Expanded Metal' (EM) and an example is shown in Figure 4. Expanded metal is a rigid piece of cold rolled metal that has been slit and expanded. In the expansion process, the metal length can be expanded up to ten times its original size. The exchanger can be designed as a single–pass or multi-pass longitudinal flow exchanger on the shell side with one or more passes for the tube side. The EM baffle, of which an example is shown in Figure 5, combines the advantages of other non-segmental (rod-baffle) heat exchanger types, in comparison with other baffle types, such as less pressure drop, excellent heat

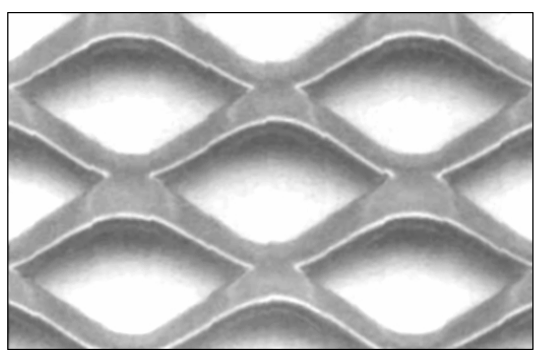

Figure 4: Expanded metal in EM baffle.

transfer, reduction of fouling and no vibrations. However, EM baffles can be fabricated and installed at much lower cost then rod-baffles. Many EM baffles in series create a static mixing effect of the liquid in the shell between the tubes which explains its excellent performance in heat transfer.

Figure 5: Example of EM baffle.

The combination of compact self-cleaning heat exchanger and EM baffles

Table 2 compares four self-cleaning designs for heat exchangers for the same application and the same duty. This duty corresponds with 25% of the total duty of 140 MW as referred to in Table 1. Three of these exchangers are compact (D_i / d_p < 15) and provided with EM baffles. For a fair comparison between these exchangers, all four self-cleaning heat exchangers are overdesigned by the same factor 1.38 as already mentioned in Table 1, but again, it should be emphasized that this difference between clean k-value and design k-value was not inspired by fouling. As no serious fouling was experienced at the shell-side and the very mild fouling could be solved with chemicals, the bundle was not removable from the shell and the minimum distance between the tubes could be made very small, determined by the minimum allowable tube pitch. This, of course, also contributes to the compact design. Figure 6 shows the self-cleaning heat exchanger with a longitudinal flow and EM baffles in the shell. It should be emphasized that only one of these four designs refers to an actual operating self-cleaning installation. The other three compact designs are with respect to their shell-side heat transfer performance and pressure drop rather theoretical designs, although calculations based on our own modeling show an excellent fit with results of the actual developers of the EM baffle.

OVERALL COMPARISON

Table 3 highlights and summarizes the important differences between the various designs for the complete installation. A newly introduced but also interesting parameter for comparison of the various designs for a particular application is the total heat transferred (i.e. also power) in MW divided by the volume of all heat exchanger shells, including the spares, in m³ and referred to in this publication as the 'Volumetric power factor'. This factor is an indication for the 'compactness' of the total installed heat transfer surface in the total number of shells of the installation. Table 3 presents this factor for the various designs and the compact self-cleaning heat exchanger is an excellent tool to transfer many megawatts in a small shell volume. It would be worthwhile to compare the achievements of the compact self-cleaning shell and tube heat exchanger with plate heat exchangers.

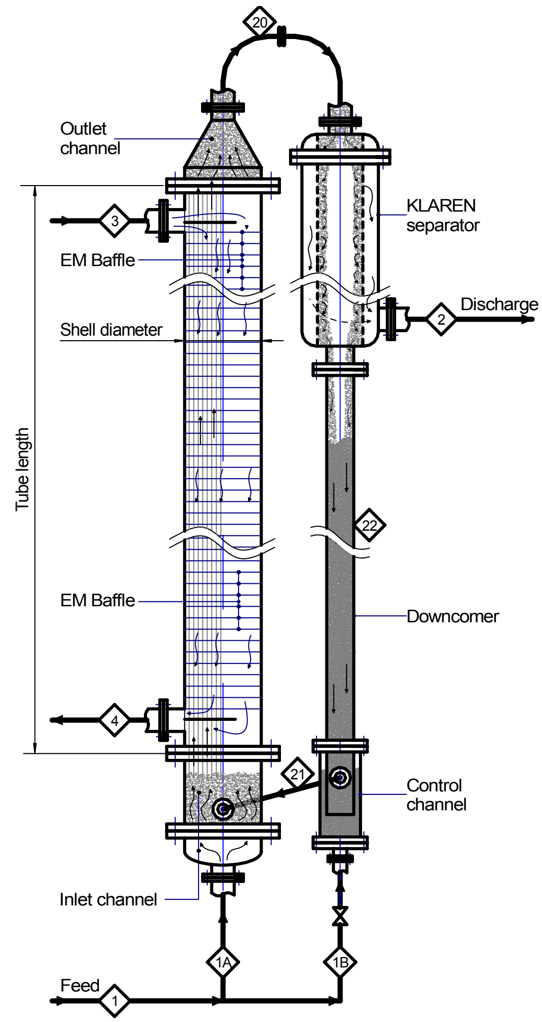

Figure 6: Self-cleaning fluidized bed heat exchanger with EM baffles.

CONCLUSIONS

It has been shown how the already superior self-cleaning heat exchange design of 1998 can be improved further by a compact self-cleaning design in combination with EM baffles at the shell-side. The results presented in Table 3 are a revelation in shell and tube heat transfer and have never been achieved before.

ACKNOWLEDGEMENTS

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Table 2: Comparison of significant parameters of self-cleaning heat exchangers.

	Unit	Self-cleaning	Self-cleaning compact #1	Self-cleaning compact #2	Self-cleaning compact #3
Duty	MW	35	35	35	35
Total number of tubes	-	704	1639	1981	4057
Tube diameter	mm	31.75 x 1.65	19.05 x 1.65	15.88 x 1.21	12.70 x 0.90
Tube pitch	mm	40	24	20	16
Tube pattern	-	Δ	Δ	Δ	Δ
Minimum distance between tubes	mm	8,25	4,95	4,12	3.30
Tube length	mm	16,000	9,700	8,700	5,100
Number of passes tube-side / shell-side	-	1	1	1	1
Baffle type	-	double segmented cross	EM	EM	EM
Baffle pitch	mm	550	unknown	unknown	unknown
Diameter shell	mm	1,350	1,065	970	1,110
Installed heat exchange surface	m^2	1,150	951	833	824
Liquid velocity in the tubes	m/s	0.45	0.6	0.7	0.5
Particle size	mm	1.6	2.5	2.5	1.6
D_i / d_p	-	17.8	6.3	6.4	6.8
Bed porosity	%	91	91	91	91
Total weight of particles	kg	9,000	5,700	5,000	3,900
Clean k-value	$W/(m^2 \cdot K)$	2,500 [1)]	3,300 [1)]	3,900 [1)]	3,900 [1)]
Design k-value	$W/(m^2 \cdot K)$	1,800 [1)]	2,391 [1)]	2,826 [1)]	2,826 [1)]
Overdimensioning factor	-	1,38	1.38	1.38	1.38
Pressure drop tube-side	bar	2.2	1.3	1.2	1.0
Pressure drop shell-side	bar	2.4	1.2	1.2	0.6
Total required pumping power tube-side	kW	48	29	26	22
Total required pumping power shell-side	kW	156	78	78	39
Total required pumping power tube + shell-side	kW	204	107	107	61

[1)] *Differences k-value by overdesign not due to fouling*

Table 3: Important differences between the various designs.

	Unit	Con-ventional	Self-cleaning	Self-cleaning compact #1	Self-cleaning compact #2	Self-cleaning compact #3
Duty	MW	140	140	140	140	140
Total number of heat exchangers	-	24	4	4	4	4
Total heat transfer surface installed	m^2	24 x 1,000 = 24,000	4 x 1,150 = 4,600	4 x 951 = 3,804	4x 833 = 3,332	4 x 824 = 3,296
Total pumping power required for tube-side based on design conditions	kW	868	192	116	104	88
Total pumping power required for shell-side based on design conditions and double segmented cross baffles	kW	1,872	624	-	-	-
Total pumping power required for shell-side based on design conditions and EM baffles	kW	-	-6	312	312	156
Total pumping power required	kW	868 + 1,872 = 2,740	192 + 624 = 816	428	416	244
Volumetric power factor	MW/m^3	0.37	1.52	4.22	5.45	7.10
Time between tube-side cleanings	weeks	5	>>120	>>120	>>120	>>120

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