

REVAMPING EXISTING SEVERELY FOULING CONVENTIONAL HEAT EXCHANGERS INTO A SELF-CLEANING (FLUIDISED BED) CONFIGURATION: NEW DEVELOPMENTS AND EXAMPLES OF REVAMPS

D.G. Klaren¹ and E.F. de Boer¹

¹ KLAREN BV, Bunschotenweg 110, NL – 3089 KC Rotterdam, the Netherlands; info@klarenbv.com

ABSTRACT

The most elegant way to implement new technology in a particular process is by revamping an existing conventional problematic installation into a improved configuration, with the possibility of maximum use of existing components, like pumps, etc., and the possibility of an immediate fallback from the new technology into the old proven technology, when necessary.

When evaluating existing conventional fouling heat exchanger applications suitable for possible revamps, one might encounter typical design criteria which can be applied for the existing conventional heat exchangers, but may not be acceptable for the design of self-cleaning fluidised bed heat exchangers.

However, in the past years, as a result of more research and development work, these dilemmas, which seriously hampered the market introduction of revamped heat exchangers applying the self-cleaning (fluidised bed) technology, have been solved. As a consequence, this paper explains the progress which has been made in making the self-cleaning (fluidised bed) heat exchange technology ready for a much wider scope of revamps and also gives examples of such revamps.

INTRODUCTION

It can be very difficult to introduce a newly developed technology in the continuous processing industries due to the fact that the introduction of any new technology involves a certain risk for both the operation and the production of a processing plant. We have experienced such difficulties with the introduction of the self-cleaning fluidised bed heat exchange technology. As a consequence, we went through a learning process how to overcome these problems, and introduced the idea of revamping conventional severely fouling heat exchangers into a self-cleaning configuration.

Once you have decided for the method of revamping to implement the new self-cleaning fluidised bed heat exchange technology into existing heat exchangers, you may encounter new problems. For example, the tube diameter of the existing conventional heat exchanger and its multi-pass tube-side design may not be your preferred choice for the revamped installation, and if you are not completely sure that you can indeed handle all the design features of the conventional heat exchanger in your revamped configuration, you have to abandon the idea of revamping at the

consequence of loosing a potential order. The same also applies when the existing conventional heat exchanger operates on a very viscous liquid and you have serious doubt that the revamped heat exchanger can also operate on the same very viscous liquid. Later in this paper, we will show you that there were many more dilemmas which hampered the market introduction of the self-cleaning fluidised bed heat exchangers in revamped conventional heat exchangers.

However, once you know where the problems are, you also know where you have to focus your development work to solve, or at least, reduce these problems to acceptable proportions. This paper explains the progress in making the self-cleaning (fluidised bed) heat exchange technology ready for a much wider scope of potential revamps and also gives examples of such revamps.

REVAMPING AN EXISTING CONVENTIONAL REBOILER

The very first idea for the revamp of a conventional heat exchanger into a self-cleaning configuration came from a chemical plant in Europe which operated a very severe fouling reboiler with forced circulation. The conventional installation is shown in Fig. 1. The authors were 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. This is what we call: The fallback position from new technology to proven technology.

Management stipulated the fact that the retrofit work should be minimal. The installed pump must be used and the connection of the reboiler to the column should be maintained. An elegant design proposal was submitted that met all the design criteria and is shown in Fig. 2, which applies a widened outlet channel for the disengagement of cleaning particles from the liquid connected to an external downcomer for the recirculation of these particles through the control channel into the inlet channel. For this particular application, the cleaning particles consisted of chopped stainless steel wire with a diameter of 2 mm.

Although the plant had been shut down before the revamp could have been carried out, this example demonstrated the potential of revamping. It is quite evident that installations which operate at constant flow are the best suited for a revamp into a self-cleaning fluidised bed heat exchanger for reason that such heat exchangers prefer constant flow conditions. This means that severely fouling existing heat exchangers in forced circulation evaporators, reboilers and crystallizers represent an interesting potential for these revamps, even in spite of the fact that, preferably, the existing heat exchangers should be placed vertical.

Because of its importance, we like to summarize the important conditions for a successful revamp:

- The same process conditions should be maintained and, then, we refer particularly to the liquid velocities in the tubes and the inlet and outlet temperatures.
- The connections to columns or vessels should be maintained.
- The installed pumps should be used.
- The existing channels should be used where possible.
- The revamp must be carried out within the available space.
- A fallback position from the new technology to the proven technology is to be preferred.

Next, we like to emphasize that certain choices in the dimensions of components for the existing conventional heat exchanger and process conditions and/or physical properties of the liquid may not fit particularly well with the design required for the revamped self-cleaning configuration which, of course, applies circulation of particles through a downcomer, requires separation of particles from the liquid, excellent distribution of particles and liquid over all parallel tubes, etc. As a matter of fact, these 'misfits' may become serious problems in our strive for revamping and, consequently, could reduce the number of potential revamps available on the market.

POTENTIAL PROBLEMS

Tube diameter.

Existing conventional heat exchangers with tube diameters of 25 mm or less are problematic for revamps using stainless steel particles. All our experiences in the 90s and earlier with self-cleaning fluidised bed heat exchangers showed the necessity of a ratio internal tube diameter D_i divided by the particle size d_p , i.e. $D_i/d_p > 15$ to assure equal distribution of liquid and particles over all the tubes.

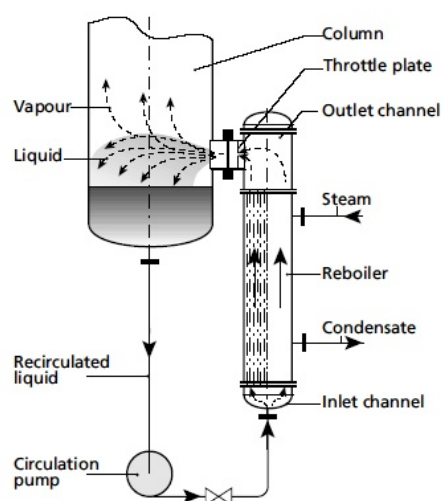


Fig. 1: Conventional reboiler.

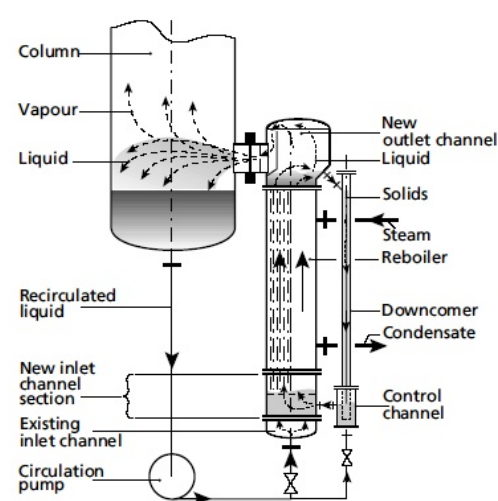


Fig. 2: Conventional reboiler revamped into self-cleaning configuration.

In combination with our preference to use particles larger than 2 mm, it becomes obvious that many existing conventional heat exchangers with above tube diameters are not suitable for revamps.

Liquid velocity in the tubes.

Existing conventional heat exchangers often apply liquid velocities in the tubes of 1.5 m/s or even higher. Using widened outlet channels for the disengagement of the particles from the liquid as shown in Fig. 2 often requires a very large diameter or flow area of the widened section of the outlet channel which is difficult to accommodate within existing plants operating on above liquid velocities.

Liquid viscosities.

The same problem as explained above for liquid velocities in the tubes also applies for liquids with high viscosities. Disengagement of particles from very viscous liquids also requires a very large diameter or flow area of the widened section of the outlet channel which is difficult to accommodate within existing plants operating on those viscosities.

SOLUTION OF THE PROBLEMS

New developments of the self-cleaning fluidised bed heat exchanger removed and/or reduced the influence of above potential problems but also contributed to the solution of other major problems. For proprietary reasons some of these improvements will only be mentioned, other will be explained in somewhat more detail with the help of Fig. 3.

Tube diameters.

A few years ago we discovered our proprietary method for the operation of our heat exchanger with small diameter tubes and rather large particles. As a matter of fact, we demonstrated reliable operation for ratio $D_i/d_p = 8$. Or using concrete numbers, we operated a test installation for a client of which the principle is shown in Fig. 3, consisting of a

bundle with a large number of parallel tubes with an internal diameter of 20 mm, stainless steel particles (chopped wire $l/d = 1$) with a diameter of 2.5 mm and a porosity of the fluidised bed in the tubes of approx. 85 %. This has never been achieved before and should be considered a 'breakthrough' in the design of self-cleaning fluidised bed heat exchangers with far reaching consequences.

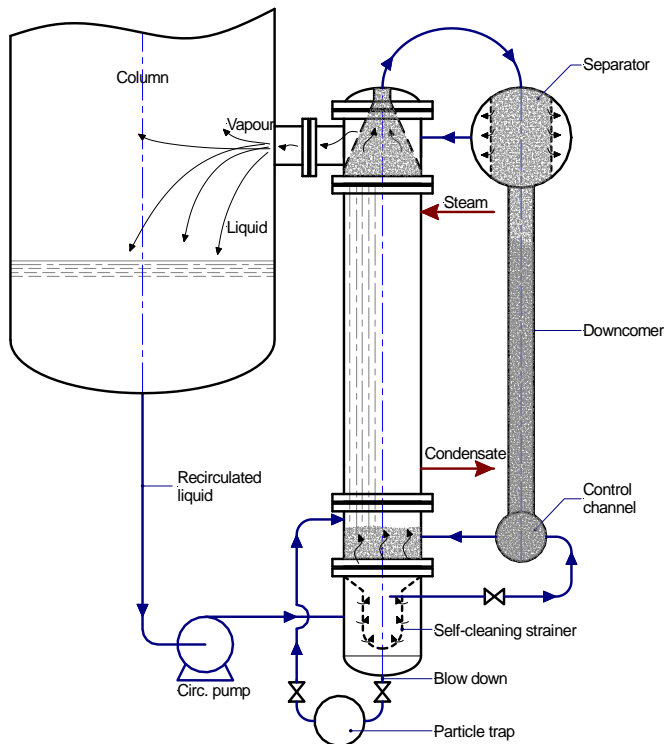


Fig. 3: Explanation of the various improvements.

Type of separators.

In Fig. 3, we also show that we pass all the liquid and all the particles through a rather small and compact outlet channel into an external separator, where the separation of the particles from the liquid takes place. In the past, we have used a cyclone as the separator, but, for a number of reasons, abandoned this concept. The separators we now use are either based on using a simple screen with holes smaller than the particles, or for the smaller particles, the separator uses 'separation of the particles by gravity' whether or not in combination with a 'separation as the result of a severe change of the direction of the liquid flow'. These type of separators allow for excellent separation in spite of very high liquid velocities in the tubes, whether or not combined with very high viscosities of the liquid.

Downcomer configurations.

The return flow of particles through the external downcomer can either be:

- Downward packed bed flow with a velocity generally lower than 0.15 m/s and a porosity of the particles in

the packed bed of 60 % and a small (counter-current) upward liquid flow.

- Downward flow of both particles and liquid with velocities very often larger than 1 m/s and a volume fraction of the particles larger than 75 %.

Both modes of operation have advantages and disadvantages:

- If the liquid contains too much solids (e.g. crystals), the downwards packed bed flow of particles should be avoided for reason that the solids carried with the small upward liquid flow through the packed bed might plug the lower section of this downward moving packed bed, which often stops the flow of particles, and, consequently, the recirculation of particles through the tubes, completely.
- In case of a downward flow of both particles and liquid at rather high velocities, the fear for plugging as described above does not exist, but now the recirculating liquid flow can become a substantial fraction of the actual feed flow of the heat exchanger and recirculating liquid flows which amount to 20 or even 30 % of the feed flow of the heat exchanger are no exception. Both flows, which have different temperatures, mix in the inlet channel. As we always have to handle fouling or scaling liquids, this temperature mixing may influence the solubility of the dissolved salts in the liquid and stimulate the precipitation of hard scales on critical parts of the distribution system in the inlet channel, which are not scoured by the cleaning particles. Another disadvantage is that temperature mixing always reduces the logarithmic temperature difference of the heat exchanger and, therefore, increases the installed heat transfer surface.

Fluid-driven self-cleaning strainer.

A gradual drop in the heat transfer coefficient points to fouling of the heat exchanger, but it should also be realised that fouling of a heat exchanger may have two completely different causes:

- Scaling of the tube walls, which can be handled and solved with the self-cleaning fluidised bed heat exchange technology using the scouring action of circulating particles applied to the tube wall.
- Plugging of the tubes by large pieces of 'dirt' carried by the feed flow entering the heat exchanger, which can only be solved by removing these large pieces of 'dirt' from the flow, before the flow enters the tubes.

To prevent plugging of the tubes of a revamped heat exchanger which is part of a rather complicated installation like a reboiler, evaporator or crystallizer, you may need a strainer. However, for most installations, it will be rather difficult to install a standalone strainer within the available space, taking into account that the circulating flows may require piping with diameters up to 500 mm or even more.

As a consequence, we have developed a very compact strainer which could easily be integrated in the existing lower section of the inlet channel as is shown in Fig. 3. We have added to this strainer a self-cleaning mechanism driven by the fluid flow passing through the strainer which, of course, corresponds with feed of the exchanger. The accumulated solids in the blow-down are removed in an external trap, e.g. a centrifugal separator, hereafter the liquid of the blow-down bypasses the distribution plate and is returned to the (upper section) of the inlet channel. Shutting down the blow-down to remove the solids out of the trap does not influence the operation of the heat exchanger. It should be emphasized that the control flow, which is obtained from the lower section of the inlet channel, is also cleaned by the strainer.

EXAMPLES OF POTENTIAL REVAMPS

In this paragraph, we will present a number of installations which can be classified as potential revamps as negotiations with plant management are still taking place and are progressing. For confidentiality reasons, we do not give the company names and the locations of these potential revamps.

Cooling crystallization using chilled water.

The cooling crystallization plant shown in Fig. 4 is equipped with a conventional shell and tube exchanger. In spite of velocities in the tubes of approx. 1.2 m/s, the precipitation of Glauber's salt causes such severe fouling of the exchanger that continuous operation between washings is limited to less than 24 h. Production loss is dramatic and energy consumption of the cooling installation much higher than originally specified.

Fig. 5 shows the installation after its revamp into a self-cleaning configuration. Cleaning particles consisting of glass spheres with a diameter of 3 mm are separated from the liquid in a screen-type separator. The use of glass spheres as cleaning particles makes it possible to use the existing low head pump.

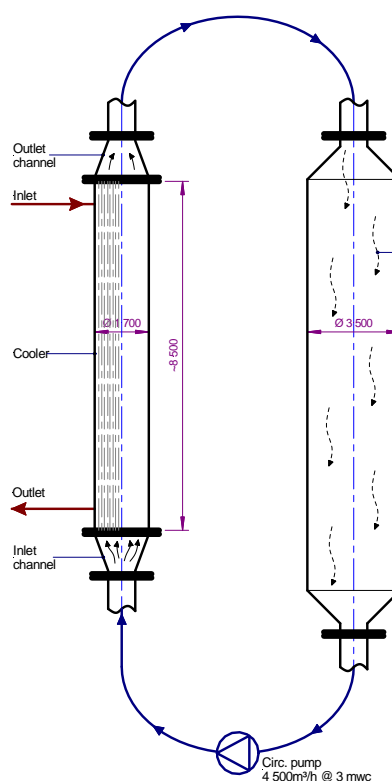


Fig. 4: Conventional cooling crystalliser.

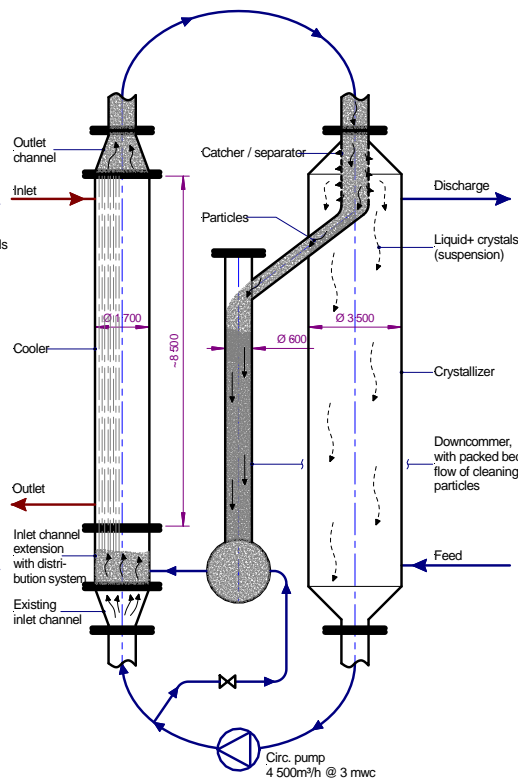


Fig. 5: Revamped into self-cleaning configuration of Fig. 4.

Cooling crystallization using evaporating ammonia.

A cooling crystallization plant for the production of sodium sulphate uses four horizontal kettle-type shell and tube heat exchangers with two-passes at the tube side and evaporating (pool boiling) ammonia in the shell. An example of such a kettle type heat exchanger is shown in Fig. 6. Severe fouling of the exchangers due to the precipitation of Glauber's salt required cleaning every four days resulting in production loss, excessive maintenance cost and a higher energy consumption.

Our proposed revamp looks quite different from the existing installation and is shown in Fig. 7. We intend to place the revamped exchanger vertical and instead of pool boiling in the shell, we propose an evaporating falling film at the shell side in combination with a single-pass design at the tube side. This quite labour intensive revamp is justified because the tubes are made of expensive Hasteloy C and local labour cost are rather inexpensive. An additional advantage of this evaporating falling film design versus the pool boiling is the reduction of the volume of ammonia in the shell by a factor 10. Further, this revamp uses glass spheres with a diameter of 4 mm in heat exchange tubes with an O.D. of 38 mm, a liquid velocity in the tubes of approx. 0.75 m/s, a screen-type separator and a fast running downcomer. The Fig. 6 and Fig. 7 show maximum use of the various components of the existing installation in the revamped configuration. Although not shown in these figures, this also applies for the existing large flow/low head pump. We need more information from the Client to

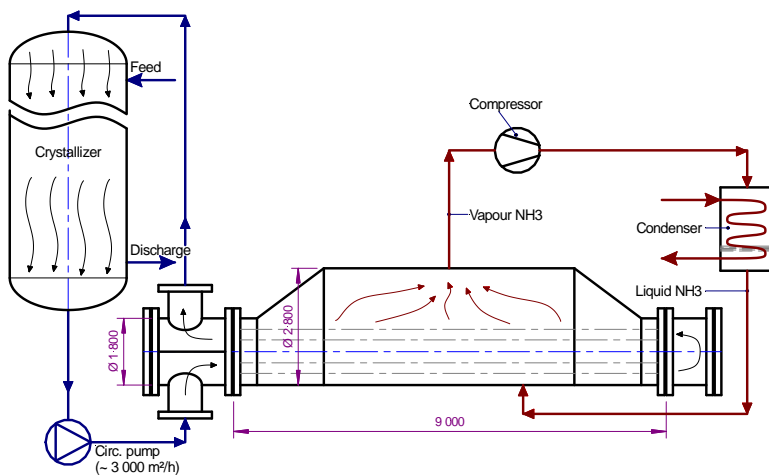


Fig. 6: Conventional cooling crystallisation plant using evaporating (pool boiling) ammonia in shell.

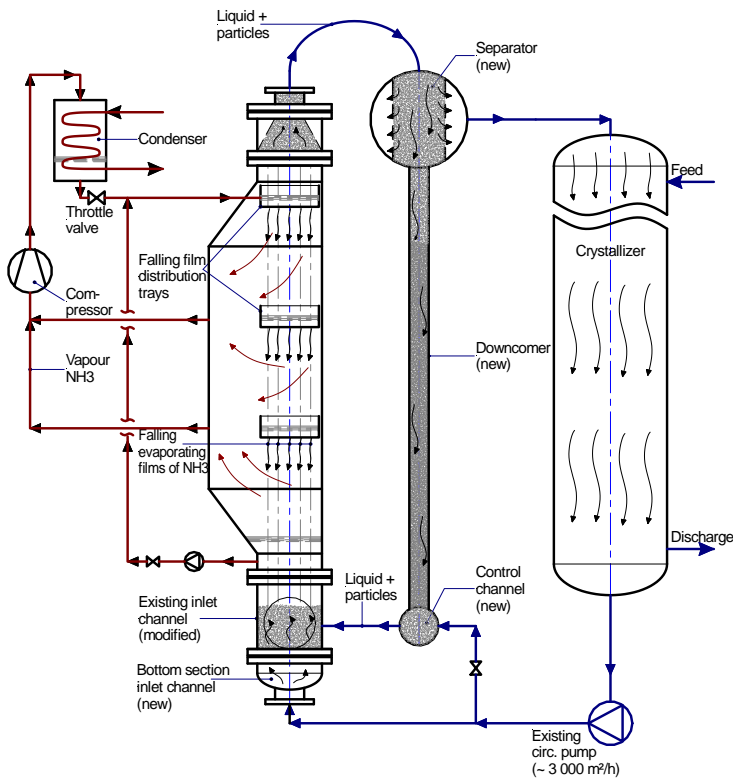


Fig. 7: Conventional cooling crystallisation plant using an evaporating falling film of ammonia in shell revamped into self-cleaning configuration.

decide if the installation of our fluid-driven self-cleaning strainer in the inlet channel is necessary.

Reboiler in nickel refining plant.

A nickel refining plant operates a reboiler, also referred to as 'copper boil'. The existing installation is shown in Fig. 8, has tubes with a O.D. equal to 25 mm and a liquid velocity in the tubes of 2.4 m/s. In spite of this high velocity, the heat exchanger suffers from severe fouling due to scale

but also caused by plugging of a large number of tubes caused by pieces of 'dirt or broken loose scale' carried with the flow. The connecting line between outlet channel of the heat exchanger and the flash column is long and winding.

A few years ago, a test with a single-tube self-cleaning fluidised bed heat exchanger has convincingly demonstrated that fouling due to the precipitation of scale on the tube walls can be solved and should not be a problem for the revamped full-size heat exchanger. Remains a solution for the plugging of the tubes. In Fig. 9 we show how we believe we can solve the complete problem.

Considering the fact, that for this installation, there is not much room available for the installation of our fluid-driven self-cleaning strainer between the outlet of the large circulation pump and the inlet of the tube bundle, we propose a quite different solution for the removal of solids responsible for the plugging of the tubes than our strainer. Fig. 9 shows that in such a case we will remove the pieces of dirt or scale larger than 3 mm with a two-stage separator consisting of a self-cleaning strainer and a cyclone installed in series and placed at the suction side of the circulation pump. We have calculated that for this installation the NPSH of the pump can handle the low additional pressure drop created by our two stage separator. The first stage of this separator consists of a strainer of proprietary design using a screen, which takes 50 % of the total flow and after passing this separator the flow is rather 'clean' and only contaminated with solids with an average size smaller than approx. 3 mm. The remaining 50 % of the flow, containing all other solids, even the relatively large pieces, passes through the second stage of our separator consisting of a cyclone, which should separate all solids larger than approx. 3 mm. Finally, all solids which are separated from the flow will be removed from the installation with the underflow of the cyclone.

Fig. 9 also shows how we can use the existing outlet channel by installing an internal which channels the flow of liquid and particles to the separator, where after the liquid flow of the separator is returned to the outlet channel and from there to the column using the same connection.

This revamp of an existing very problematic conventional heat exchanger into a self-cleaning configuration shows the benefits of the most recent new developments which allow large stainless steel particles (2.5 mm) to be used in small diameter tubes (I.D. 22 mm) at high liquid velocities in the tubes.

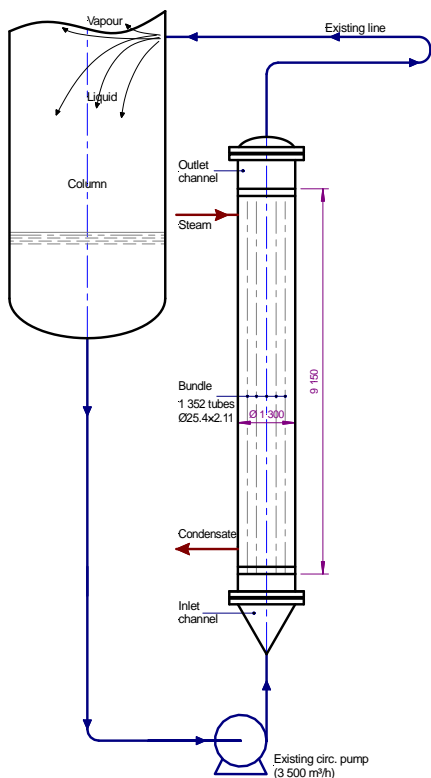


Fig. 8: Conventional reboiler ('copper boiler').

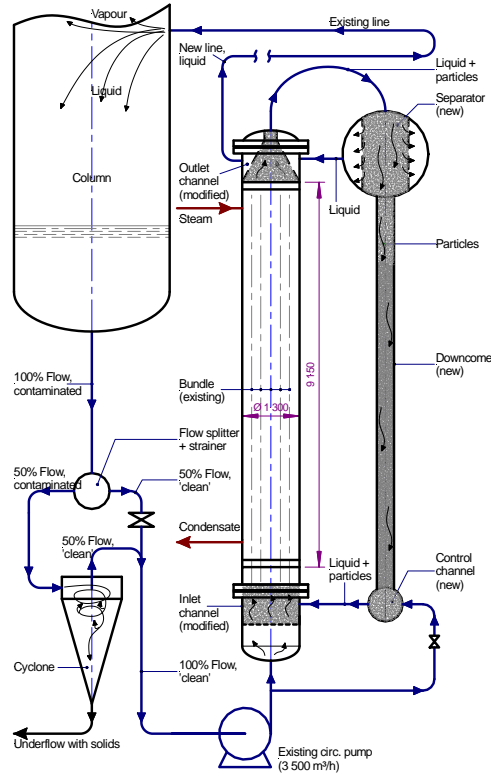


Fig. 9: Conventional reboiler ('copper boiler') revamped into self-cleaning configuration.

very large shell and tube heat exchanger suffers from severe fouling which sometimes requires one month (!) of cleaning after only three months of operation.

The existing evaporator and the test plant in parallel with the existing installation is presented in Fig. 10. The main dimensions of the existing installation shown in this figure give a good impression about the size of the installation, which, as also shown in this figure, uses rather small diameter heat exchange tubes with an I.D. equal to only 20 mm.

The proposal for the revamp of this installation shown in Fig. 11 is elegant and uses a maximum of the very large existing components, including the circulation pump. The first series of experiments with the test installation shown in Fig. 10 are promising and shear-thinning effects caused by the increased turbulence of the

Evaporator for concentration of very viscous severely fouling slurry.

A production plant of a proprietary product operates a very large MVR evaporator for the concentration of a slurry up to approx. 70 % solids. Even at a temperature of 100 °C this slurry which behaves non-Newtonian has a very high viscosity varying between 50 and more than 200 cP. This

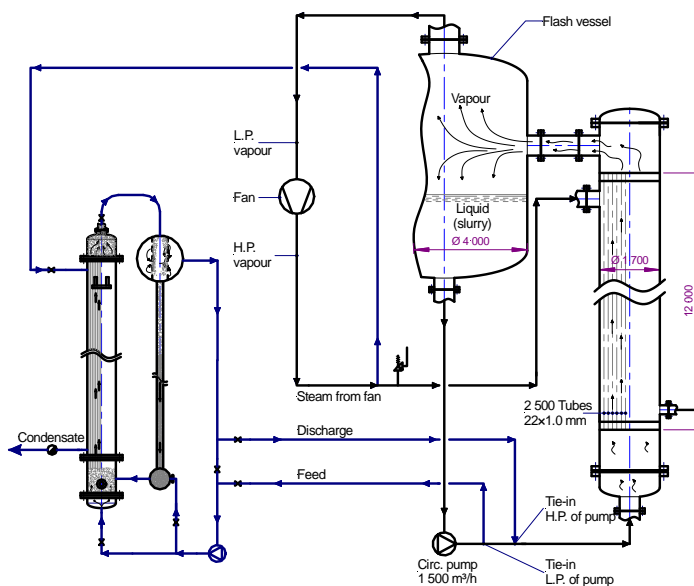


Fig. 10: Existing evaporator and test installation.

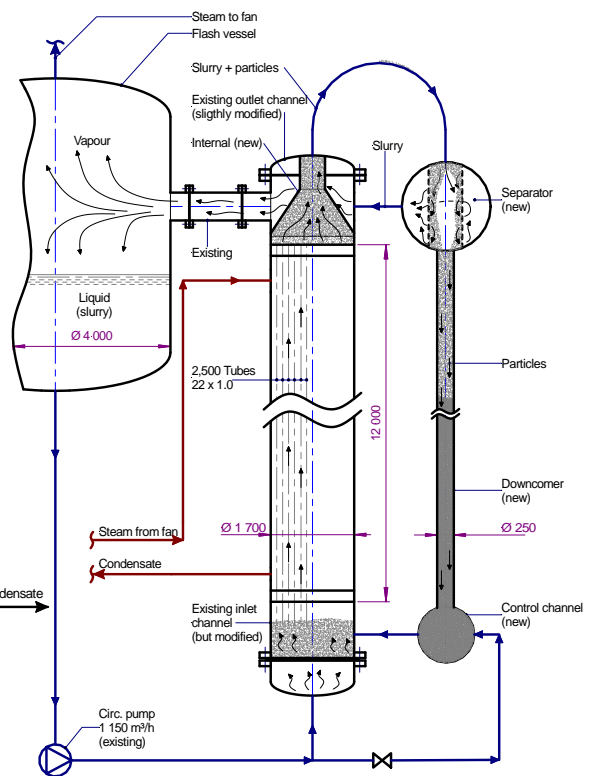


Fig. 11 Existing evaporator revamped into self-cleaning configuration.

slurry induced by action of the fluidised particles are reducing the viscosity of the slurry substantially and have produced heat transfer coefficients between 1000 and 2000 W/(m² K) depending on the concentration of the slurry. These coefficients should be compared with the clean heat transfer coefficients of approximately 600 W/(m² K) for the conventional heat exchanger, reducing due to fouling in only a couple of months to only a fraction of its clean value.

Also this potential revamp shows the enormous benefits of the most recent developments which, once more, allow for large stainless steel particles (2.5 mm) in even smaller diameter tubes (I.D. only 20 mm) and, for this application, at very high viscosities of the slurry.

Combination of preheater and thermal syphon reboiler.

A chemical plant operates the preheater in series with the thermal syphon reboiler shown in Fig. 12. The 8-pass preheater with tubes with an O.D. of 25 mm, a very high liquid velocity in the tubes of 4.5 m/s and heated by L.P. steam experiences severe fouling still requiring cleanings every two months, while the thermal syphon reboiler heated by M.P. steam requires cleanings every four months.

The solution we are proposing to solve this problem is quite unique and explained in Fig. 13. As a matter of fact, we have increased the tendency of fouling in the preheater due to the precipitation of solids by increasing the outlet temperature of the preheater. This can be realised by adding M.P. steam to the shell of the preheater instead of L.P. steam.

As a result of this temperature increase, the preheater will also partly contribute to the degassing of the liquid which is normally done in the reboiler. Above goals have been realised by revamping the existing 8-pass horizontal conventional heat exchanger into a vertical single-pass self-cleaning fluidised bed configuration using stainless steel cleaning particles with a diameter of 2.5 mm and also installing an extra circulation pump to maintain sufficient velocity in the tubes of our single-pass configuration for the transportation and/or circulation of the cleaning particles. Although, we have indeed increased the tendency for fouling, we expect that the introduction of our self-cleaning technology will keep the preheater clean.

The separation of the gasses from the mixture of liquid and particles takes place in the widened outlet channel of the preheater and these gasses are fed into the reboiler and evenly distributed over all the tubes of the reboiler where they contribute to the (natural) circulation effect of this thermal syphon reboiler.

Considering the fact that a substantial fraction of the totally required degassing is not done anymore in the reboiler, the heat load of the reboiler can be reduced, which reduces the condensing steam temperature, the tube wall temperature and, consequently, the fouling of the reboiler.

The advantage of this approach is the revamp of the conventional preheater into a self-cleaning configuration at an increased heat load. An experiment with a single-tube self-cleaning pilot plant in parallel with the existing severely fouling preheater should demonstrate the non-fouling performance of the self-cleaning heat exchange technology. If this is indeed the case, then, we have not only solved the fouling problem of the preheater at an even

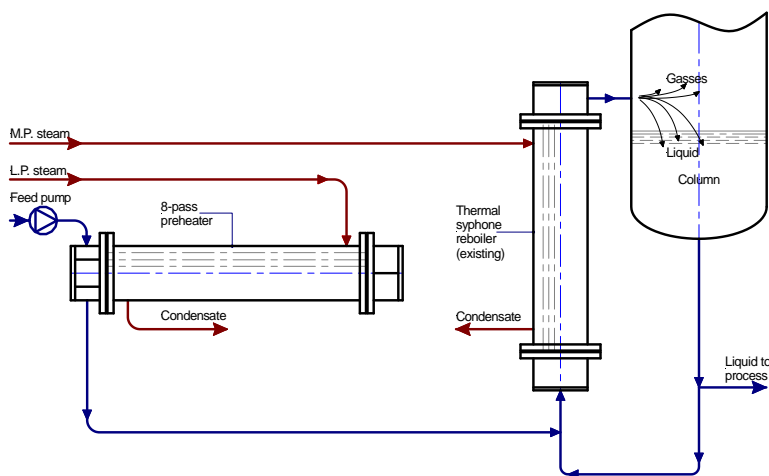


Fig. 12: Conventional preheater in series with thermal syphon reboiler.

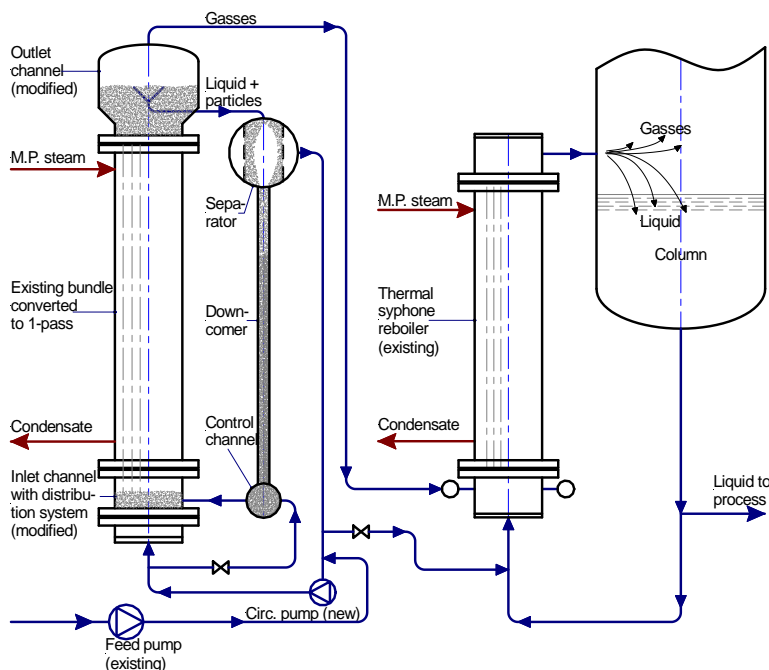


Fig. 13: Conventional preheater revamped into self-cleaning configuration and operating in series with thermal syphon reboiler.

higher heat load, but also reduced the fouling of the conventional thermal syphon reboiler.

For the proposed solution of this problem, we have introduced the concept of evaporation of a fraction of the liquid of a the mixture of liquid and particles in the tubes. We know that this is possible if certain design criteria are taken into account. As a consequence, with this example, we have presented the possibility that our self-cleaning heat exchange technology can also be applied for applications where we even experience boiling or evaporation in the tubes.

Direct heating replaced by indirect heating using self-cleaning fluidised bed heat exchangers.

In all the previous examples, we have only discussed the revamp of existing conventional severely fouling heat exchangers (hardware) into a self-cleaning configuration. In this example of a proven process, conventional heat exchangers have never been applied due to the enormous problems related to the operation and design of the installation equipped with such heat exchangers. Therefore, this example is not fully covered by the title of this paper, which refers to ‘...the revamp of conventional heat exchangers into a self-cleaning configuration...’, but we believe still worthwhile to be presented. The conventional solution for the process discussed in this paragraph has always been direct heating using a combination of mixing condensation of flash vapour and steam injection which avoids all problems associated with heat transfer surfaces. However, we will show that the revamping of the existing conventional process applying direct heating into an indirectly heated configuration using self-cleaning fluidised bed heat exchangers does have enormous advantages.

For the extraction of nickel and cobalt from laterite ore, High-Pressure-Acid-Leach (HPAL) is a new process with great potential. Several plants are already in operation and many more under construction. All these plants are based on direct heating and a typical example of the simplified flow diagram of the front-end of such a plant is shown in Fig. 16.

There has always been a strong drive to apply indirect heating in HPAL plants because of the benefits of indirect heating in comparison with direct heating, which we

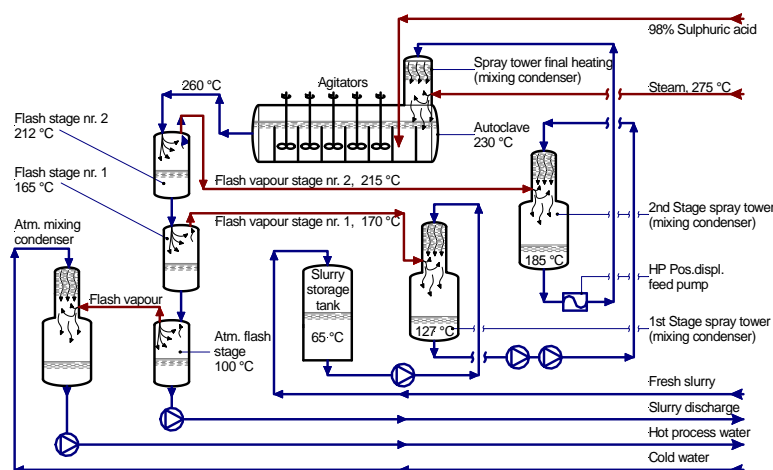


Fig. 16: HPAL plant for laterite nickel employing direct heat transfer.

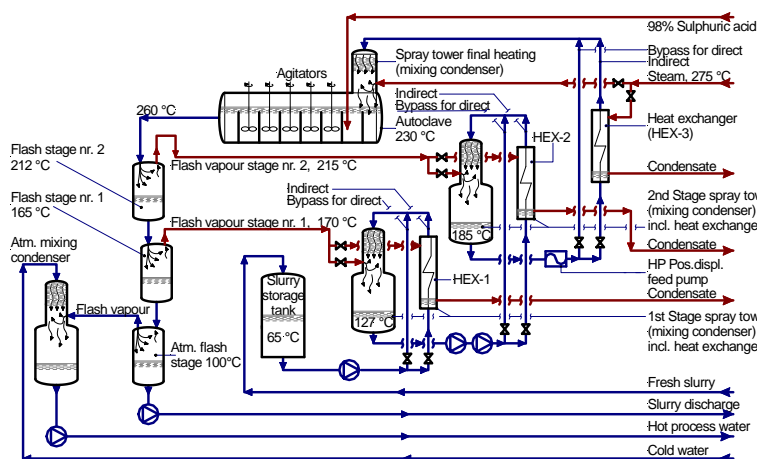


Fig. 14: HPAL plant for laterite nickel employing direct heat transfer revamped into indirect heated configuration.

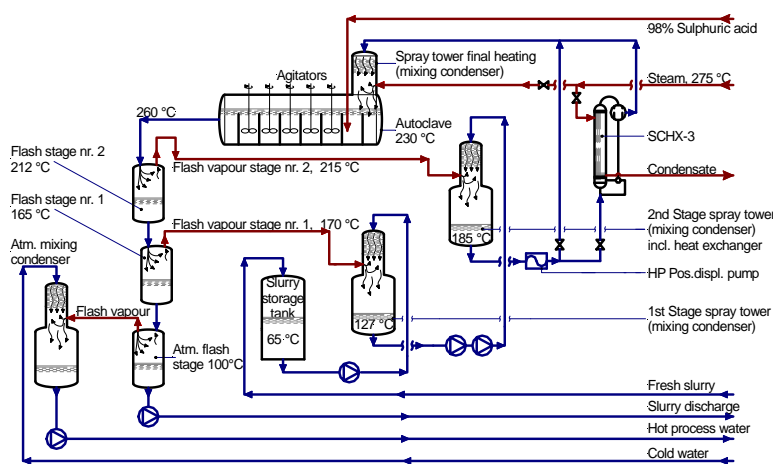


Fig. 15: HPAL plant for laterite nickel employing direct heat transfer equipped with self-cleaning fluidised bed heat exchanger SCHX-3.

summarize below:

- Increased autoclave production capacity.
- Reduced acid consumption.
- Reduced neutralising agent consumption.
- Recovery of demineralised condensate and process condensate.

Fig. 14 shows the above flow diagram, but now extended in such a way that direct heating can be fully replaced by indirect heating and vice versa. This approach is preferred in case of the introduction of new technology (indirect heating) in a proven process (direct heating) which offers the possibility of an immediate fall-back to the proven process in case of problems with the new technology. For the high temperature end of Fig. 16, we have engineered two indirect heating solutions. One of the indirect heating solutions uses conventional shell and tube heat exchangers, and the other solution, shown in Fig. 15, applies the self-cleaning fluidised bed heat exchange technology. Table 1 compares both indirect heating solutions as far as the total heat transfer tube length is involved, the number of shells required, the consequences for the required pump head, etc. The advantages in favour of the self-cleaning fluidised bed configuration are very convincing and we like to emphasize that these advantages are caused by the following facts:

- Shear-thinning of the non-Newtonian highly viscous slurry due to the increased turbulence of the slurry induced by the fluidised particles which does reduce the viscosity of the slurry,
- high heat transfer coefficients,
- low slurry velocities,
- low pressure drops in the tubes, and
- non-fouling due to the scouring action of the particles on the tube wall.

Particularly, the high heat transfer coefficients and low

slurry velocities do effect the totally installed tube length and, consequently, the number of shells in series for the self-cleaning fluidised bed configuration in a very favourable manner in comparison with the conventional heat exchangers. This easily follows from substitution of the relevant design and process parameters in the equation for the tube length:

$$L_t = D_o \times \left(\frac{D_i}{D_o} \right)^2 \times \frac{\rho_l \times c_l \times V_l}{4 \times k} \times \frac{\Delta T}{\Delta T_{\log}} \quad (1)$$

Where:

L_t	=	Tube length	[m]
D_o	=	Outer tube diameter	[m]
D_i	=	Inner tube diameter	[m]
ρ_l	=	Density of the slurry	[kg/m ³]
c_l	=	Specific heat of the slurry	[J/(kg K)]
V_l	=	Velocity of the slurry in the tubes	[m/s]
k	=	Overall heat transfer coefficient	[W/(m ² K)]
ΔT	=	Temperature increase of the slurry	[°C]
ΔT_{\log}	=	Mean logarithmic temperature difference	[°C]

The combination 'high heat transfer' at 'low slurry velocity' and 'low pressure drop' and 'non-fouling performance' for any liquid, but particularly for rather viscous and non-Newtonian slurry, is absolutely unique in heat transfer.

For this HPAL application, the scope of advantages increases when indirect heating is not only applied to the highest temperature stage but to all stages. It is not surprising that all major mining companies show much interest in the self-cleaning fluidised bed heat exchange technology for an even greater variety of applications than only HPAL of laterite ore slurries.

Table 1: Comparison significant parameters for indirect heating of high temperature stage of HPAL plant of Fig. 16.

		Conventional shell and tube	Self-cleaning fluidized bed
Inlet- / Outlet- / Steam temperature	[°C]	185 / 235 / 275	185 / 235 275
Density slurry	[kg/m ³]	1 340	1 340
Specific heat slurry	[kJ/(kg K)]	3.6	3.6
Tube velocity slurry	[m/s]	2.0	0.35
Diameter tube	[mm]	38×3.0	38×3.0
Diameter- / Material particles	[mm]	n.a.	4.0 / Titanium
Clean- / Design k-value	[W/(m ² K)]	~ 600 / 300	1 500 / 1 500
Tube length based on design k-values and Eq. (1)	[m]	166.8	5.84
Total number of shells in series for 1-pass tube-side and tube length per shell equal to 8 m	[-]	21	1
Total number of shells in series for 2-pass tube-side and tube length per shell equal to 8 m	[-]	11	n.a.
Pressure drop	[bar]	~ 6 - 10	< 1.0

For more information about above application, we refer to Ref. [1] and for more general information about the development of this technology during the past decades, we recommend Ref. [2].

CONCLUSIONS

We believe that we are on the right track to speed up the market introduction of the self-cleaning fluidised bed heat exchange technology in processes where conventional heat exchangers suffer from severe fouling by concentrating a majority of our efforts on the revamp of fouling conventional exchangers into a self-cleaning configuration.

We have explained how we have indeed widened the scope for such revamps by solving a number of problems, which, in the past, made such revamps impossible.

Last but not least, we have presented and discussed a number of severely fouling conventional heat exchangers, which are considered by plant management as potential candidates for a revamp.

NOMENCLATURE

c	specific heat, kJ/(kg K)
D, d	diameter, m
k	heat transfer coefficient, W/(m ² ·K)
L	length, m
T	temperature, °C
V	velocity, m/s
ρ	density, kg/m ³
ΔT	temperature difference, °C
ΔT _{log}	mean logarithmic temperature difference, °C

Subscript

i	inner tube
l	liquid
o	outer tube
p	particle
t	tube

REFERENCES

- [1] Klaren, D.G., de Boer, E.F. and B. Crossley (2008); “*Reflections on Indirect Heating of Laterite Ore Slurry in HPAL Plants Using Self-Cleaning Fluidized Bed Heat Exchangers.*”, Presented at ALTA 2008, Perth, Western Australia, June.
- [2] Klaren, D.G. and de Boer, E.F. (2004); “*Synoptic of the History of Thirty Years of Development and Achievements in Self-Cleaning Fluidised Bed Heat Exchangers*”, KLAREN BV, Internal Report KBV Nr.7, March.