

EXTENSION OF FERTILIZER PLANTS AVAILABILITY VIA INCREASING THE LIFESPAN OF PLATE HEAT EXCHANGERS

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ABSTRACT

Fouling problems with cooling water inside CO₂ coolers in different Egyptian fertilizer plants were investigated. Thermodynamic and hydraulic solutions were proposed, which included redesign of the existing PHEs and new plate geometries. The main problems arose from the large surface margins required to meet pressure drop limits on the CO₂ side. Reducing the surface area of the heat exchanger increased the fluid velocity (shear stress from 5.31 to 10.84 Pa) inside the gaps and hence decreased fouling. Using computer-modeled plate geometries from the new technology (NT) series with larger gap velocities due to better fluid distribution over the plates could decrease fouling and increase the availability of fertilizer plants.

INTRODUCTION

Due to their compact size, Plate Heat Exchangers (PHEs) are widely used in industrial processes. They have higher heat-transfer performance, lower temperature gradient, higher turbulence, and easier maintenance in comparison with shell and tube heat exchangers (Bani Kananeh et al., 2010). To guarantee production reliability in chemical complex urea fertilizer manufacturing process, PHEs are installed in several process chains including CO₂ cooling, residual gas scrubbing, and other process sections in addition to the primary urea production plant.

Industrial processes are using commonly water for cooling purposes. Open circuit cooling system is used in some processes, while closed loop system involving cooling towers is used in others. Closed loop systems cause usually less fouling than open ones, but they are more expensive (Kukulka and Leising, 2009). Cooling water contains normally dissolved or suspended solids like calcium carbonate and calcium sulfate. If the concentration of these dissolved solids exceeds certain limits, it leads to the accumulation of deposits on the heat exchanger surface (Müller-Steinhagen, 1999). These deposits create an insulating layer over the surface of the heat exchanger that decreases the heat transfer between the two fluids. The thermal performance of the unit decreases with time as the thickness of the deposit increases, resulting in an undersized heat exchanger and causing the process efficiency to be reduced (Kukulka and Leising, 2009). Deposits formation can be reduced either by changing the configuration of the heat exchanger or by regular cleaning procedures.

Deposit formation is influenced by the heat exchanger surface and geometry, cooling medium and the operating conditions. Its composition depends on the flow rate, temperature and chemical composition of the cooling medium (Kukulka and Leising, 2009). Pana-Suppamassadu et al. (2009) studied the effect of plate geometry (contact angle) and the gap velocity on calcium carbonate fouling in plate heat exchanger. They found that an increase in the gap velocity could reduce the fouling rate on the surface of plate heat exchanger. On the other hand, Gavin et al. (2009) studied fouling of wastewater inside PHE installed in textile industry. They found a positive linear relationship between the fouling resistance and both time and liquid flow rate. They claimed that the fouling behavior is mass transfer controlled rather than shear stress controlled.

In the present work, deposits formation on the surface of plate heat exchangers in different Egyptian fertilizer plants will be investigated. The effect of heat exchanger geometry and flow patterns on the fouling behavior will be shown.

PROCESS DESCRIPTION

Ammonia is the basic raw material in urea production. The ammonia plants in question operate using Uhde's proprietary ammonia process that is based on the well-established Haber-Bosch process. In the first stage, the raw material natural gas is desulphurized, then cracked into its individual chemical components catalytically by adding steam to generate the hydrogen required for ammonia synthesis. This process also generates carbon monoxide, carbon dioxide, hydrogen and residues of methane from the natural gas cracking process. In the next stage nitrogen is added to the process by combusting methane, CO and H₂ using air. With the addition of steam, carbon monoxide is converted to CO₂ using catalytic converters and then scrubbed out of the synthesis gas formed. The selectively scrubbed CO₂ is fed into the urea processing plant as the process medium together with the produced ammonia as starting material. The urea plants operate using the Stamicarbon process that was developed in the Netherlands.

In the CO₂ scrubbing process three GEA plate heat exchangers are switched in parallel, two in operation (A and B) and one in standby (C). Figure 1 shows the three coolers with their operating conditions. The CO₂ flows into the PHEs as a gas-steam mixture at 94 °C and is cooled down in

a countercurrent process to 33 °C. Nile-River water at 30 °C is used as coolant.

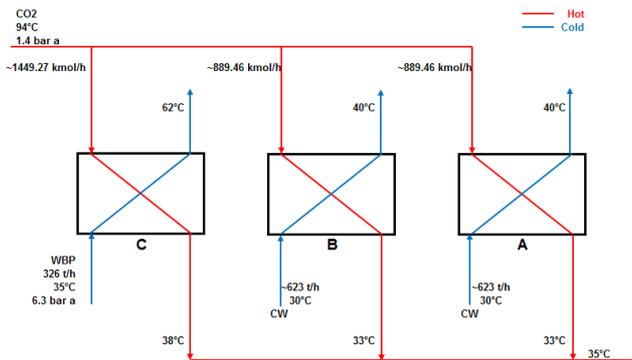


Fig. 1 CO₂ coolers used in the scrubbing process

Each of the 10 tons and 3 meter high GEA PHEs has 1000 m² of high-performance stainless steel (1.4539; AISI 904 L) VT-plates. Each plate has an effective area of 2 m² and a dimension of 2.45 m length and 1.20 m width. The transferred heat capacity is 14.5 megawatts.

Nile river water treated by Nalco inhibitors is used in an open loop as cooling medium for the CO₂ coolers, the specifications of the cooling water used are found in table 1.

Table 1. Cooling water specifications

	CaH	Alkalinity	Chlorides	Inhibitors
Nile water	90 ppm	138	25 ppm	N-7356P: 30ppm N-73203: 95ppm

The average molar ratio (SO₄/HCO₃) of the River Nile water is about 0.12 (El-Manharawy and Hafez, 20029). A typical analysis for Nile river water is shown in table 2.

Table 2. Analysis of Nile river water

Substrate		Unit
pH	7.8	-
Alkalinity	180	ppm CaCO ₃
Chloride	77.5	ppm
Ca	48	ppm
Mg	14.5	ppm
Na	60	ppm
K	9	ppm
Fe	0.1	ppm
SO ₄	57.5	ppm
SiO ₂	2	ppm
HCO ₃	180	ppm
KMnO ₄	10.1	ppm
Total hardness	172.5	ppm CaCO ₃
TDS	380	ppm

PROBLEM DESCRIPTION AND OBSERVATIONS

The cooling water flow rate on the CO₂ coolers (HP Scrubber) dropped from 500 m³/hr to 300 m³/hr due to fouling on the cooling water side, which caused operation problems in the Urea plant. The CO₂ outlet temperature was increasing with time and achieved about 50 °C after 30 days

of operation before the shutdown of the unit for mechanical cleaning. The CO₂ coolers were opened for mechanical cleaning; the PHE's inlet was plugged with plastic bags and pieces of bottles. Deposits were accumulated at an area about 20 cm from the plate inlet and selectively covered the plate surface, as can be seen in figure 2. They could plug the channels and restrict the water flow over the plate. These deposits accumulated due to the reduction of the gap velocity (shear stress) which increased the surface temperature.

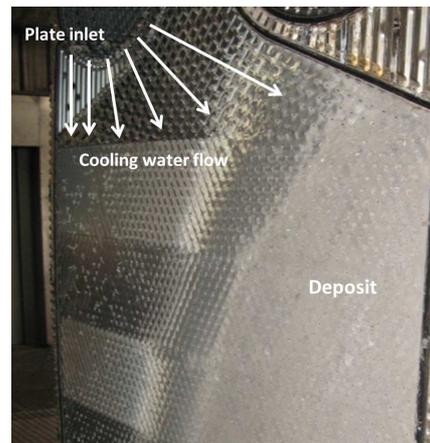


Fig. 2 Deposits formed on the surface of VT-plate.

A sample from the deposits was taken and analyzed using ashing and X-ray Fluorescence (XRF). The sample was dried at 105 °C before ashing and XRF analysis. Dry ashing was done using a high temperature furnace. Organic substances were burned in the presence air and minerals were converted to oxides. The sample was weighed before and after ashing in order to determine the concentration of ash present. The results are shown in table 3.

Table 3. (a) Ashing results, (b) Elemental analysis as oxides using XRF.

(a)

Loss at 500 °C	14 %
Loss at 925 °C	23 %

(b)

Substrate	Mass %
Magnesium (MgO)	3
Aluminium (Al ₂ O ₃)	1
Silicon (SiO ₂)	2
Phosphorous (P ₂ O ₅)	20
Sulphur (SO ₃)	1
Calcium (CaO)	11
Iron (Fe ₂ O ₃)	1
Zinc (ZnO)	38
Total oxides (normalized to loss 925 °C)	77

The ashing results showed that 14% of the sample was lost at a temperature below 500 °C, which represents the organic material and can be considered as normal range. The XRF analysis showed that the main element in the

deposits is zinc hydroxide as ZnO (38%) and the second is calcium phosphate (11%), which participated as a result of the increase of the plate surface temperature resulting from the reduction in the cooling water flow rate.

TECHNICAL SOLUTIONS

Redesigning of the PHEs

The surface area of the heat exchanger was reduced by removing 86 plates from the unit. The average cooling water velocity inside the gaps was increased from 0.30 to 0.42 m/s, as can be seen in table 4.

Table 4. Design modification for CO₂ cooler in Helwan fertilizer plant, Egypt.

	Original Design	After modification
Plates number	254	168
Gap velocity [m/s]	0.30	0.42
Surface tension [Pa]	5.31	10.84
Reynolds number	3259	4599
Surface temperature [°C]	72	69

The deposits formed on the surface of the plates were decreased as a result of the increase in the shear stress and the decrease of the surface temperature from 72 to 69°C. The operation time for the cooler was increased from 30 days to 43 days and the plates were cleaned after more than 40 days of operation, as shown in figure 3.

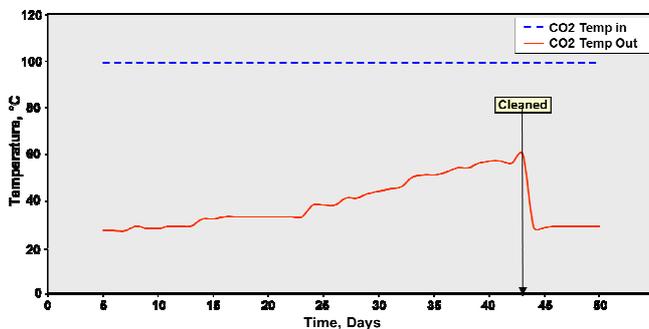


Fig. 3 Inlet and outlet CO₂ temperatures as a function of time.

The CO₂ outlet temperature started to increase after about 23 days of operation due to the deposits accumulation on the cooling water side which led to a reduction in the cooling water flow rate. The unit was opened after about 43 days for mechanical cleaning.

New plate geometry

A new cooler with computer-modeled plate geometry from the GEA NT series was installed in parallel with the existing two coolers. The PHE has 350 m² of high-performance stainless steel (1.4539; AISI 904 L) NT-plates. Each plate has an effective area of 1.5 m² and a dimension of 2.15 m length and 1.00 m width. The new plates have the advantage of higher gap velocities of 0.52 m/s (shear stresses of 16.5 Pa) due to better fluid distribution over the

plates and smaller gap diameter. The flow channels of the NT-plates vary in their width and were optimized based on Computational Fluid Dynamics (CFD). The channels located further away from the inlet hole have bigger size than those closer to the inlet hole.

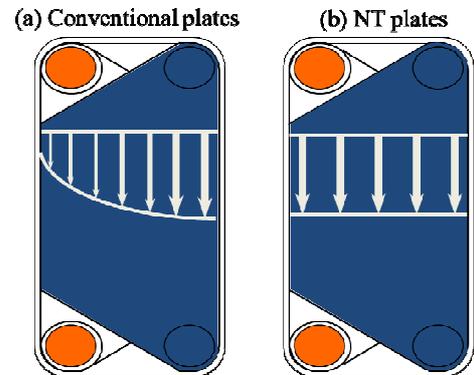


Fig. 4 Conventional plates in comparison with NT plates

Fewer deposits were accumulated on the NT plates due to the asymmetric flow distribution over the channels as can be seen in figure 5. These deposits were formed because the unit was taken into operation in parallel with the old two VT-plates units and hence most of the cooling water was flowing inside them. The NT-plates unit was designed in principle to replace one of the VT-plates units so that the gap velocity could be more increased.



Fig. 5 Deposits formed on the surface of NT-plate.

CONCLUSIONS

Nile water treated with NALCO inhibitors caused fouling problems inside CO₂ coolers in different Egyptian ammonia plants. Technical solutions including redesign of the PHEs and new plate geometries were investigated. Reducing the surface area of the CO₂ coolers by 34% increased the gap velocity from 0.30 to 0.42 m/s (shear stress from 5.31 to 10.84 Pa) and hence decreased fouling. The operation time for the cooler was increased from 30 days to 43 days. GEA NT-plates with asymmetric flow distribution over the channels and higher shear stress decreased the rate of deposition on the surface of the plates. It is recommended to replace the other two VT-plates units with NT-plates ones so that fouling can be more reduced.

NOMENCLATURE

NT New technology
PHE Plate heat exchanger
VT Varitherm
XRF X-ray Fluorescence

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