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Plate and Spiral Heat Exchangers for Wet Phosphoric Acid Production Processes

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Abstract

High effective plate and spiral heat exchangers now are widely used in different industries including production of mineral acids. The available information about their applications for heat treatment in conditions of such production lines is analyzed. Efficient and safe performance of heat exchanger determined mainly by its correct calculation and proper selection, especially of heat exchanger type and the material of heat transfer surface and gaskets.

The analysis of existing industrial processes of phosphoric acid production wet method lets to define two significant problems in implementation of compact heat exchangers: aggressive nature of phosphoric acid and tendency of gypsum to precipitate on heat exchange surface. The approaches directed to solve these problems are discussed. The problem of implementation of plate heat exchangers in closed loop circuit systems around the barometric condenser are also discussed.

For correct selection and modelling of heat exchangers in phosphoric acid production processes the interactive software is developed.

Keywords: wet phosphoric acid process, concentration, plate and spiral heat exchangers, corrosion.

1. Introduction

Wet method of phosphoric acid production is based on chemical digestion of the phosphate rock with mineral acids, such as sulphuric, hydrochloric and nitric. Widely used in industry is wet method with sulphuric acid. The chemical base of this method is on the conversion of the three calcium phosphate in phosphate rock by reaction with concentrated sulphuric acid into phosphoric acid and calcium sulphate.

Precipitated calcium sulphate may be of a number of different crystal forms depending on temperature, concentration of P_2O_5 and content of free sulphates. The operating conditions are generally selected so that the calcium sulphate is precipitated in dihydrate form or in hemihydrate form. The dihydrate process (DH) is the most frequently used industrial wet process of phosphoric acid production [1, 2].

The temperature of the reaction vessels is controlled by circulating the slurry through a vacuum flash chamber, where water evaporates and cooling down of the slurry occurs. The gypsum ($CaSO_4 \cdot 2H_20$) is filtered off on a multi-stage counter current filter. Water is added at the tail of the process. It gives the washed acid at about 4% P_2O_5, which is pumped over the filter and gives a washed acid at 8-10% P_2O_5, which is pumped over the filter too and gives a washed acid at about 22% P_2O_5. This washed acid is returned to the reaction vessels. The main filtrate, an acid of about 32% P_2O_5 is the product, which goes to concentration. The concentration is performed in evaporation station.

To realize the advantages of DH and HH methods the combined processes were developed [2]: hemi-hydrate recrystallization (HRC) process, hemi-hydrate (HDH) process, dehydrate -hemihydrate (DH/HH) process.

2. The concentration of phosphoric acid

To produce phosphorous containing and complicated fertilizers it is needed phosphorous acid with concentration of P_2O_5 42-55%. The concentration process is based on evaporation of water from acid after extraction stage. There is no dehydration of phosphoric acid occurs during the process.

There is a long way of the flow sheet principles and equipment evolution.

The main steps were:

– replacing the contact systems with hot combustion gas from a burner on indirect heat transfer because it caused fume problems and P_2O_5 significant losses;
– introducing bath-type vacuum concentrators and later the continuous vacuum evaporators with internal circulation and external heat exchangers, but because of severe fouling the operating periods between descaling were rather short;
– introducing forced circulation vacuum evaporators with external heaters. The increasing of internal velocity provides better heat transfer.

In DH processes when flash coolers are used to control temperature it is usual to remove the fluoride from the gas, evolved during acidulation and from the gas evolved during concentration, in separate systems. The fluoride scrubbing system is placed ahead of the condenser that follows the concentrator to avoid production of large quantities of highly contaminated water. Gas from the evaporator flash chamber is first fed through entrainment separator if a system operates under vacuum conditions. Generally one stage scrubbing is used and 17-23% fluosilicic acid is obtained with a recovery efficiency of about 83-86% [3]. The unit consists of a heat exchanger, vapour or flash chamber, condenser, vacuum pump, acid circulation pump and piping. A fluosilic scrubber is usually included in the forced circulation evaporator system. The evaporation unit usually may have one, two or there effects depending on the level of concentration required.

3. Compact Heat Exchangers in production of phosphoric acid

The plate heat exchanger principle is at least 100 years old. Because of its many unique characteristics that are of interest and importance for process engineering it is now used in industrial installations in ever greater frequency [4]. The plate heat exchanger is assembled from a series of thin (0.4 – 1 mm) pressed corrugated plates held closely together. The maximum temperature duty is 160°C, pressure – 25 bar. If one stream is clean, the semi welded plate and frame units may be used. The pack of semi welded heat exchanger consists of laser welded pairs of plates.

The hot and cold streams flow through alternative spaces. Corrugations and close spacing between adjacent plates create an intense turbulence of fluid in channel, so the high heat transfer coefficients are achieved that reduces the required surface area. Plate heat exchanger need less material than comparable other heat exchange units and need less area for installation. Plates can be fabricated from a wide range of materials including corrosion resistant stainless steels and alloys. The use of PHEs for process industries, including the handling of aggressive media, began in early 1950s in pulp and paper industry [5]. The PHEs became the key component of some complex technical decisions. One of the examples is the installation of plate and frame heat exchangers to cool sulphuric acid in quench acid service instead graphite tube heat exchangers at Olin Beaumont plant (USA). The use of Hastelloy C-276 and Hastelloy G as materials of plates had shown their excellent corrosive resistance [6].

The design of SHE is different from conventional shell-and-tube heat exchanger. It consist of a pair of long metal strips that are rolled around the core and form to channels in which each medium flows in a spiral path [4]. SHEs are fabricated from any materials that can be rolled and welded from carbon steel to Hastellloy. The spiral flow of the streams promotes the turbulence that cause high heat transfer coefficients comparatively with flow in tube. The spacing between metal strips is higher than spacing between plates in PHEs that lets to handle the fluids with high contamination of solids and with high viscosities. SHEs now are widely used in sulphuric acid plants to cool acid and oleum.

In wet method the range of application of plate heat exchangers (PHE) and spiral heat exchangers (SHE) is wider, but severe limitations connected with corrosive streams and possibility of precipitation are existing. PHEs and SHEs in wet method may be used for: take off the heat of reaction of sulphuric acid (PHE); cooling of weak phosphoric acid after cake washing on filter (PHE); heating of 30% phosphoric acid before calcium sulphate sedimentation (SHE or PHE); cooling of phosphoric acid as end product (40-42% P_2O_5 and 50-54% P_2O_5) after concentration (PHE or SHE); cooling of scrubber acid (PHE or SHE); cooling of water for barometric condensers.

To prevent emissions from water that contaminated with fluoride an indirect condensation systems may be used. The water required for condensing is recycled in the condensers but is cooled by heat exchanger fed from an independent water supply. These two water loops are independent. So there are no fluorine compounds in the effluent water [2].

It is possible to recycle the fluosilicic acid into phosphoric acid process and use it for rock acidulation (Fig.1). Such close-loop systems with plate heat exchangers as dividers of loops let:

- to reduce the amount of fluorine effluent at least on 50%;
- to reduce the amount of heat rejected into environment.

The effect may be more significant if the central cooling system based on plate and spiral heat exchangers is implemented for phosphoric acid plant.

Because of presence of fluorine in process streams the materials for plates of PHEs and surface of SHEs should be of stainless steels and alloys with molybdenum content. In table 1 characteristics of some materials are presented. The use of appropriate materials depends process streams composition.

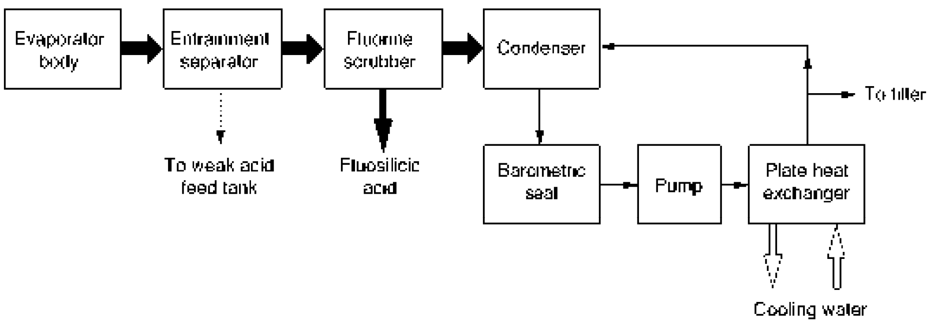

Figure 1 – Fluorine recovery and indirect cooling flowsheet

One of the feasible solutions offering corrosion resistance as well as good heat transfer properties is the use of synthetic resin impregnated graphite as material for heat transfer area of heat exchanger. The use of graphite shell and tube heat exchangers is common for forced circulation vacuum concentration of phosphoric acid. Graphite plate heat exchangers are the perspective kind of compact heat exchanger that may be used in wet phosphoric acid production process. Alfa-Laval and SGL Carbon GmbH have developed such units. A phluoroplastic bonded graphite composite material ®DIABON F100 was used as plates material.

The sealant is a self vulcanizing fluoroelastomer highly corrosion-resistant. The plate pattern is made with a corrugation that provides the enhanced turbulence of flows. Plate thickness is 6,5 – 8,0 mm for ®DIABON F100 heat exchangers, but excellent heat conductivity (about 20 W/K·m) may be compared with heat conductivity of plate made from Hastelloy. ®DIABON F100 plate heat exchangers may be used as acid coolers/heaters or for heat integration of product phosphoric acid. Maximum operating temperature is 120°C and pressure is 5 bar (Alfa-Laval Information IB67124E, 1992).

4. Software to select plate and spiral heat exchangers for phosphoric acid production

The specialized software for selection of plate and spiral heat exchangers for phosphoric acid production have been developed with implementation on IBM compatible PC. It enables the correct prediction of heat exchanger surface area and accurate enough simulation of its behaviour on different positions possible for exchanging heat between various process streams, including heat exchangers for phosphoric acid concentration. On the stage of process integration it gives the possibility for correct estimation for the cost of heat transfer equipment.

The calculation procedure is based on mathematical models of heat exchangers and semi empirical correlations for prediction of film heat transfer coefficients and pressure drop in channels of intricate geometry as described earlier [7 , 8]. When the phase change occurs in one or both streams the one dimensional model accounting for process parameters change along the heat transfer surface is used, as described in papers [9, 10]. The nature and rate of fouling increase is taken into account through special procedure for calculation of fouling factor. The initial process parameters for calculation and design of heat exchangers are taken from results of simulation of appropriate process flowsheet with the use of HYSYS® software.

5. Conclusions

The different processes of wet method of phosphoric acid production are discussed. The effectiveness of heat transfer equipment is one of the ways to increase the effectiveness of whole process. Efficient and safe performance of heat exchanger depends on correct calculation and proper selection of type of heat exchanger and especially the material of heat transfer surface and gaskets. The use of optimal compact plate and spiral heat exchangers is perspective. It is very important to take into account the corrosion resistance and decreasing the

fouling factor for compact heat exchangers implementation. Additionally the decrease of hazardous pollutions may be achieved.
The correct prediction of heat exchanger performance and correct selection of its type and size require the use of specialized software, which is developed as a result of this work.

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