Two-Phase Flow Hydrodynamics Research in The LWR Ozonation Contact Apparatus


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Introduction

This work presents a technique for the numerical simulation of two-phase flows in a contact apparatus designed for ozonization of liquid radioactive waste (LRW) containing surfactants. The aim of the work was to study a two-phase flow hydrodynamics in a contact apparatus.

Objectives of the work were to simulate the processes of formation and destruction of the liquid phase film on the distribution nozzles and in the slotted channels of the packed of apparatus. In addition, one of the objectives was to establish the boundary of the regimes of stable film flow at the distribution nozzles and in the slotted channel of the packed bed of the contact apparatus.
In this work, the finite element method (FEM) has been used as a numerical research method. For the calculation, two-dimensional element grids with a density of $8 \times 10^5$ elements have been used.

To simulate the hydrodynamics of the flow of the operating environment, we used:
- $k-\varepsilon$ turbulence model;
- models of a multiphase mixture.

The operating mixture in the apparatus was considered as two-phase at a temperature of 50 °C, consisting of two components: water and air.

To describe the flow of a multiphase mixture, we used the volume of liquid (VOF) method.


The equation of the volume fraction phase:

\[ \frac{\partial}{\partial t} (\rho_q \alpha_q) + \nabla (\rho_q \alpha_q \vec{v}_q) = 0 \]  

(1)

Where \( \alpha \) – volumetric content of the phase, \( \rho \) – density of the phase, \( \vec{v} \) – speed of the phase.

Time discretization of the equation 1:

\[ \frac{\alpha_{q}^{n+1} \rho_q - \alpha_{q}^{n} \rho_q}{\Delta t} V = -\sum_{f} \left( \rho_q U_f^n \alpha_{q,f}^n \right) \]  

(2)

Where \( U_f^n \) – volume flow through this border, \( V \) – cell volume.

**Navier-Stokes equation:**

\[ \frac{\partial}{\partial t} (\rho \vec{v}) + \nabla (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \left[ \mu (\nabla \vec{v} + \nabla \vec{v}^T) \right] + \rho \vec{g} + \vec{F}_{vol} \]  

(3)

Where \( \mu \) – friction ratio, \( \rho \) – resultant density \( (\rho = \sum_q \rho_q \alpha_q) \), \( \vec{g} \) – gravity.

Volume force simulating surface tension:

\[ \vec{F}_{vol} = \sigma \frac{\rho k_i \nabla \alpha_i}{0.5(\rho_1 + \rho_2)} \]  

(4)
The geometry of the distribution nozzles

The area of the entrance to the contact apparatus was a collector made in the form of a plate. From the plate, LRW, upon reaching a predetermined level, flowed down the distribution pipes (nozzles) into the packing of the packed.

**Picture 1.** Geometry of the distributor

**Picture 2.** Geometry of the distributor element
The result of modeling the processes of formation and destruction of a liquid phase film at the distribution nozzles

Picture 3 shows the film flow of water in the distributor element of the contact apparatus.

LRW has been simulated with clean water, and the ozone-air mixture was simulated with clean air.

Flow rate water – 2...4 m³/hr
Flow rate air – 300 m³/hr
The geometry of the slotted channel of the packed

The actual design of the packing from Sulzer Chemtech was chosen as the prototype of the geometric model.

The packed channel is formed by symmetrically concave corrugations with an amplitude and period of concavities of 6 mm and 20 mm, respectively. The minimum slit gap was 4 mm.

PICTURE 4. Geometry and computational grid of a flat channel.
The result of modeling the processes of formation and destruction of the liquid phase film in the slotted channel of the packing

At $q = 1 \cdot 10^{-3} \text{ m}^3/(\text{s} \cdot \text{m})$, a stable liquid film is observed (Figure 5a).

At $q = 2 \cdot 10^{-3} \text{ m}^3/(\text{s} \cdot \text{m})$, thickening of the film is observed at certain places of the corrugated surface (Figure 5b). These nubs then disappear as you move down the channel.

At $q = 35 \cdot 10^{-3} \text{ m}^3/(\text{s} \cdot \text{m})$, drops are formed in the places of thickening of the film, which break down the channel (Figure 5d). In this case, the liquid film is not destroyed and wets the remaining surface of the channel.

$q$ - specific volume flow rate
Conclusion

In the course of the work, the processes of formation and destruction of the liquid phase film at the distribution nozzles and in the slotted channels of the packing of the contact apparatus were simulated. The boundaries of the regimes of stable film flow were established:

- Water flow rate $2...4 \, \text{m}^3/\text{ч}$, air flow rate $300 \, \text{m}^3/\text{ч}$ – for distribution nozzles;
- Specific volume flow rate $q=1\cdot10^{-3} \, \text{m}^3/(\text{с} \cdot \text{м})$ – for slotted channel of the packed.

It was established that the process of LRW flow in the contact apparatus cannot be reproduced entirely in one geometric model using the available computational equipment. Therefore, it must be broken down into separate stages.

From the results of the calculation, we can see, that numerical simulation makes it possible to reproduce the picture of the formation of a film in the channel at different flow regimes. So, using the numerical method, it could be selected the optimal LRW flow regime in the packing channel and recalculate it for the entire packed bed.
Thanks for your attention!