

# Simulation Design of Separator for the Treatment of Emulsions

Irena Markovska, Dimitar Rusev, Nikolai Zaicev, Bogdan Bogdanov, Dimitar Georgiev, Yancho Hristov

**Abstract**—A prototype model of an emulsion separator was designed and manufactured. Generally, it is a cylinder filled with different fractal modules. The emulsion was fed into the reactor by a peristaltic pump through an inlet placed at the boundary between the two phases. For hydrodynamic design and sizing of the reactor the assumptions of the theory of filtration were used and methods to describe the separation process were developed. Based on this methodology and using numerical methods and software of Autodesk the process is simulated in different operating modes. The basic hydrodynamic characteristics - speed and performance for different types of fractal systems and decisions to optimize the design of the reactor were also defined.

**Keywords**—fractal systems, reactor, separation, emulsions

## I. INTRODUCTION

FRACTAL geometry, introduced by Mandelbrot in 1977 [1-3] is a non-Euclidean geometry, allowing the study of irregular shapes and chaotic phenomena present in nature. It is able to describe, in a very concise manner, objects characterized by the properties of self affinity or self-similarity [4].

In recent years the fractal systems are of particular interest, both of scientific and practical point of view, because of its great variety of types, methods for synthesizing and mostly because of its developed surface that allows exceptional range of applications, including treatment waste water, emulsions, suspensions and other contaminated liquids.

There are so called selective filters which are permeable or impermeable for water or organic oils. Such filters are produced in Germany, Japan, Russia, etc. An example is the material "Stratopore" which is two-layer polymer composition selectively permeable for hydrocarbons (but impermeable for water and aqueous solutions). There are other similar materials like various membranes and metal tissues permeable for water but impermeable for hydrocarbons. The main problem of all these materials is the saturation (fouling) of the surface so additional device or operation is necessary to "unload" the system.

Therefore, to avoid this difficulty, a self-regulating system has to be designed for the automatic separation of water and oils (hydrocarbons). This can be done using fractal systems (ceramic, polymeric, etc.). Some authors call them "thick" membranes. The rate of this separation can be controlled and the main parameter is the content of water and oils in the initial emulsion.

There are some additional advantages of the so called "thick" membranes with developed surface, compared to the thin highly selective filters. One of them is their ability to "destroy" the emulsion or microemulsion which are actually stable structures. Crude oil and other hydrocarbon systems often form thermodynamically stable micro-drops (size up to 200 nm) in water or aqueous solutions, which are practically very hard to separate. The suggested models of treated fractal systems can perform simultaneously the functions of destabilization (so called deemulgation) of the microemulsion and the function of separation of the two phases under regime of self-regulation, depending on the ratio and amounts of the phases.

The fulfillment of the extensive scientific research and practical program is connected with studies in different fields of applicability of the fractal systems and different methods of their synthesis and characterization. The construction of pilot plant planned for the synthesis of these systems according to one of the schemes suggested will engage the experience and knowledge of the specialists who have taken part in the project.

The studies on the separation properties of these systems as means for purification of water basins from petroleum and petroleum products is of special importance.

## II. THEORETICAL BACKGROUND

The hydrodynamics of a two-phase liquid system has been described in the monograph of Collins [5]. A great difference in the saturation can be observed at the boundary between the phases. The hydrostatic pressure in the wetting and non-wetting phase is a value different from the capillary pressure. At zero rate of emulsion inflow (water, oil), the oil is concentrated in the hydrophobic while water – in the hydrophilic part of the fractal system. The fluid flow is described by the laws of Darcy in porous anisotropic medium. There are a number of mathematical models of the movement and filtration of liquids based on the effect of wetting and non-wetting of the contacting surfaces. [6-7]. According to the classical hydrodynamic theory of flowing fluids, the so called "slip effect" occurs at the boundary between the solid state and liquid and intense studies on this effect are being carried out [8-10].

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The present scientific study deals with problems related to the possibilities to use fractal systems to solve some scientific and quite important practical problems connected with filtering and separation of aqueous phases from organic ones. In this connection a prototype model of an emulsion and suspension separator was designed and manufactured.

Generally, it is a cylinder filled with different fractal modules.

The emulsion was fed into the reactor by a peristaltic pump through an inlet placed at the boundary between the two phases.

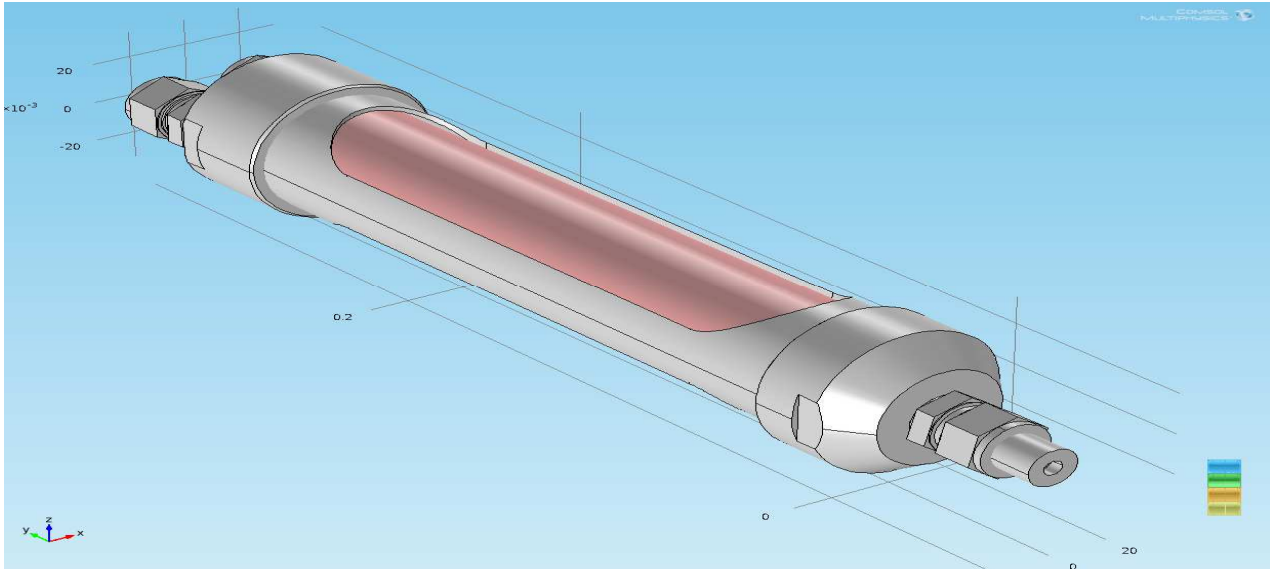


Fig. 1 Construction of separator

For designing and hydrodynamic sizing of reactor (Fig. 1) the assumptions from the theory of filtration were used and methods to describe the separation process were developed. Based on this methodology and using numerical methods and software of Autodesk - Inventor Professional 2012, Autodesk Simulation Multiphysics 2012 [11] the process is simulated in different operating modes (Figs. 2 and 3). The basic hydrodynamic characteristics - speed and performance for different types of fractal systems and decisions to optimize the design of the reactor were defined also. The density of the emulsion depends on the ratio:

$$n_E = \frac{Liq_1}{Liq_2} \quad (1)$$

this ratio can be represented by weight of the emulsified liquid in the emulsion:

$$n_E = \frac{Liq_1}{Liq_2} = \frac{1 - x_{Liq_2}}{x_{Liq_2}} \quad (2)$$

therefore to determine the density of emulsion we get the following dependence:

$$n_E = \frac{Liq_1}{Liq_2} = \frac{1 - x_{Liq_2}}{x_{Liq_2}}, \quad \left[ \frac{kg}{m^3} \right] \quad (3)$$

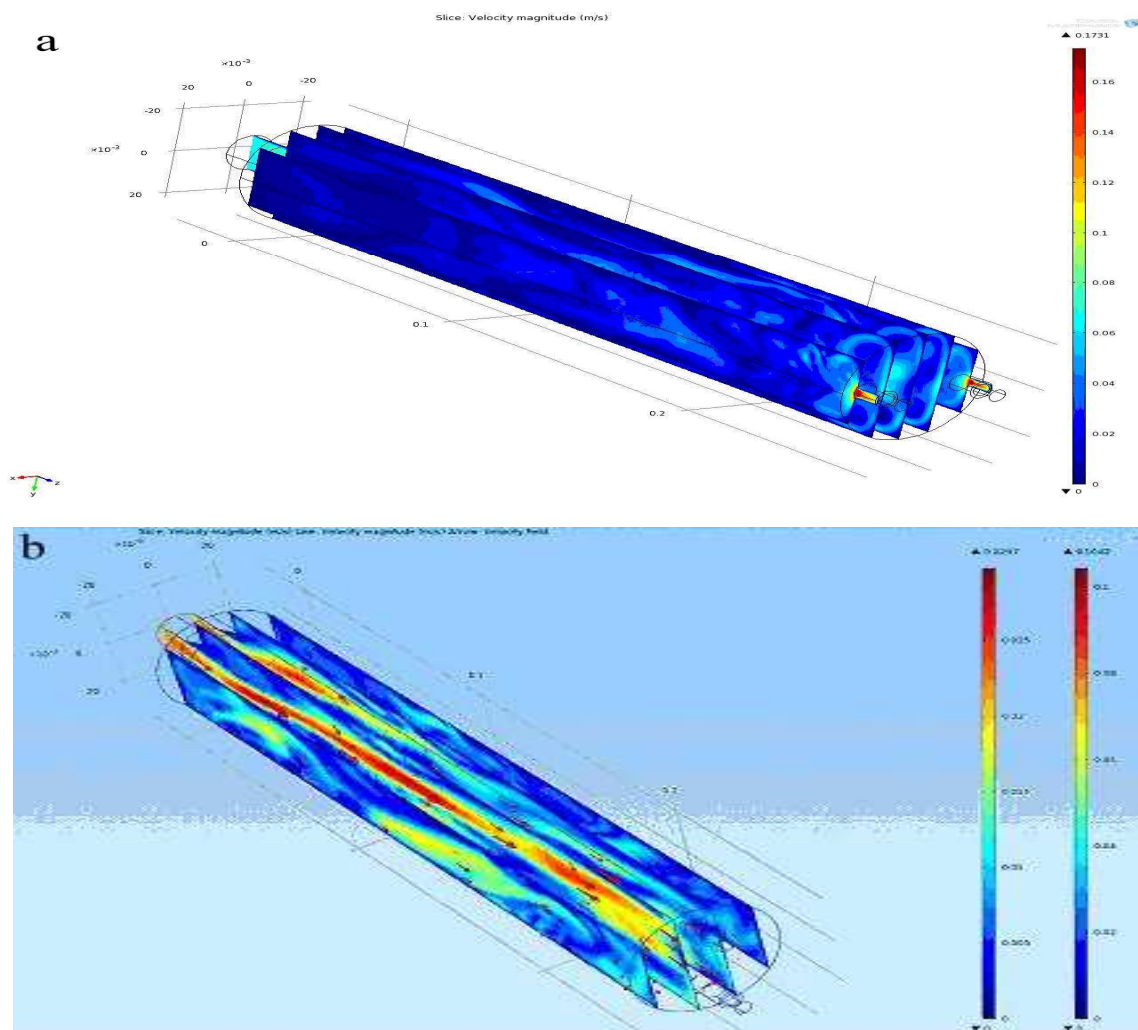
The viscosity of the emulsion is a function of the viscosity of emulsifier  $\mu_0$  and volume concentration of emulsified liquid phase  $q$  and it could be determined by the equation:

$$\mu_E = \mu_0 \cdot \frac{\sqrt[3]{\frac{1}{q}}}{\sqrt[3]{\frac{1}{q}} - 1}, \quad [Pa.s] \quad (4)$$

The speed of the emulsion is determined by the laws of motion of fluid in the layer. It is proportional to the driving force and it is inversely proportional to resistance and has the form: where:  $R$  - resistance of filtration of the emulsion

$$w = \frac{V}{F \cdot \tau} = \frac{\Delta p}{R}, \quad \left[ \frac{m}{s} \right] \quad (5)$$

Considering of the small size of the pores of fractal system and relatively low velocity of the liquid phases in them can be assumed that the process flow in a laminar field.



Figs. 2 a,b Distribution of velocity along the reactor

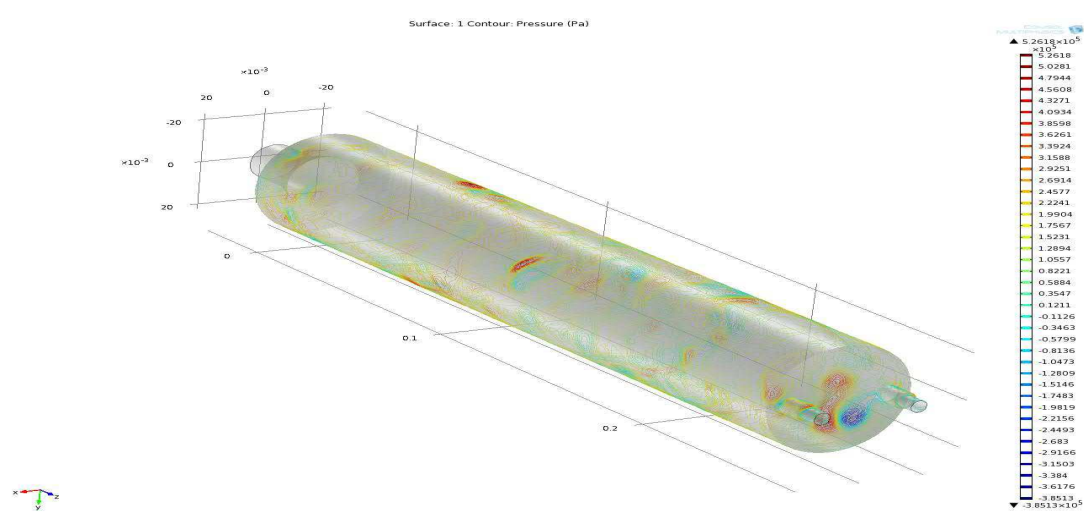


Fig. 3 Pressure distribution along the reactor

When  $\Delta p = \text{const}$  the volume of the emulsion  $V$  through the unit section of the reactor per unit time can be determined from the dependence:

$$V^2 + 2.V.C = K.\tau \quad (6)$$

where:  $C = \frac{\mu_E.R}{\Delta p.F}$  – constant, characterizing the hydraulic

resistance of the fractal system in  $\left[ \frac{m^3}{m^2} \right]$ ;

$K = \frac{\mu_E.R_0.X_0}{2.\Delta p.F}$  – constant connecting with the regime of

filtration and chemical properties of liquid phases, in  $\left[ \frac{m^2}{s} \right]$ .

For the current moment of time the equation (6) may be presents as:

$$\frac{dV}{d\tau} = \frac{K}{2.(V+C)} \quad \text{or} \quad \frac{d\tau}{dV} = \frac{2}{K}.V + \frac{2.C}{K} \quad (7)$$

dependence (7) appears straight between the magnitudes  $\frac{d\tau}{dV}$

and  $V$ , so this allows to defined constants  $C$  and  $K$  experimentally for the present type fractal system, and hence the speed of the emulsion in the reactor.

Integrating and transforming dependence (5) we may obtain an equation for determining the relative performance:

$$q = \sqrt{\left( \frac{R}{r.u} \right)^2 + \frac{2.\Delta p}{r.u}.\tau} - \left( \frac{R}{r.u} \right), \left[ \frac{m^3}{m^2} \right] \quad (8)$$

### III. EXPERIMENTAL

In connection with the results shown in the first part of the presented work the influence of speed and height of the filtration filter layer in reactor which half the volume is filled with hydrophobic ceramic and other part with hydrophilic ceramic, was investigated. The boundary of the section of the two layers is a plane passing through the axis of the cylinder. The separator has two outputs - one is from hydrophobic, another from hydrophilic part.

There are many methods to prepare the emulsions. In classical methods of emulsion preparation, the emulsifier is dissolved into the most soluble phase and after that the second phase is added. Then, the shear is applied to the mixture using vigorous agitation or high speed mixing. For O/W emulsions the agitation must be turbulent and is crucial to producing sufficiently small droplets [12]. The model emulsion used for this experiment was a mixture of hexadecane in equal quantity of water (1:1) which was vigorously homogenized before feeding it into the separator.

The emulsion was fed into the separator by a peristaltic pump through an inlet placed at the boundary between the two phases. The emulsion was fed from bottom to top, from top to bottom, horizontally or at certain angle versus the horizontal plane. The flow direction was varied by rotating the reactor. If the reactor was in vertical position, then the problem with emulsion densification arose. The same problem remained by feeding the emulsion both from below and from the top of the reactor. Finally, a possibility to solve the problem appeared when the reactor was positioned at an angle vs. the horizontal plane.

### IV. RESULTS AND DISCUSSION

Figure 4 presents the laboratory system for separation of emulsions using fractal modules. Filtering of the emulsion was conducted in a cylindrical reactor (1), the pressure in the reactor is created using a peristaltic pump (2).



Fig. 4 Laboratory installation for the separation of emulsions using fractal systems

At zero velocity of moving of the mixture the hydrocarbons have concentrated in the hydrophobic part of the separator and the water - in hydrophilic one. At small pump's pressure under liquid the hydrocarbon out from the hydrophobic part while the water out from the hydrophilic part of separator.

Experimental data describing the hydrodynamics of separation of emulsion at different rates on input in reactor where hydrophilic layer is on the top and hydrophobic is on bottom are shown in Table I as well as in fig. 5.

TABLE I  
DEPENDENCE OF VOLUME OF WATER IN THE RECEIVER FLASK TOWARD TO WATER CONSUMPTION

Hydrophilic layer on the top, hydrophobic layer on the bottom				
Capacity V, ml	time, min	Water consumption v, ml/min	Quantity from hydrophobic layer, ml	Quantity from hydrophilic layer, ml
500	4.28	111.9	285	155
	4.00	125.0	320	155
	2.59	167.6	360	110
	2.45	181.8	380	100
	2.25	206.9	360	115
	2.10	230.8	325	130

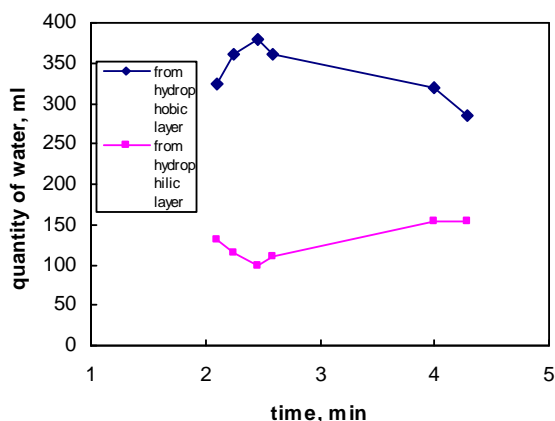


Fig. 5 Quantity of water from hydrophobic and hydrophilic part

Experimental results show that the volume of water and hydrocarbon outputs of hydrophobic and hydrophilic layer depends strongly on the pressure of the incoming emulsion. Increasing pressure occurs redistribution of volumes of pure quantities of water and hydrocarbon. Thus the low-pressure of peristaltic pump turns the water out of the hydrophilic layer while hydrocarbon goes out from hydrophobic layer. At high pressure of incoming mixture a very interesting phenomenon was observed - the hydrocarbon goes out from hydrophilic part while the water outlet from hydrophobic one. This fact show that some values of the input pressure cause inversion of the flow. The present problem can not be solved theoretically by modern hydrodynamics.

#### V. CONCLUSIONS

*Based on the results of the experiments the following conclusions were made*

1. A method to describe the separation process was developed. The process is simulated in different operating modes and their main hydrodynamic characteristics - speed and performance for different types of fractal systems were investigated.
2. Based on these studies a prototype model of reactor for separating of emulsions filled with fractal modules was designed and developed.
3. The possibilities of the developed model as a separator were investigated.
4. The experimental results for the quantity of separated phases in depending on the inlet pressure on separating emulsion were obtained.

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