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poświęcone są publikacjom naukowym z zakresu teorii i badań doświadczalnych w dziedzinie mechaniki i termodynamiki przepływów, ze szczególnym uwzględnieniem problematyki maszyn przepływowych

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exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machinery

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Opole

Gas-Liquid Mass Transfer in Column with Cocurrent Swirl Trays***

A variety of operations involving mass transfer with gas-liquid systems can be carried out in columns with cocurrent trays, but additional data are needed to develop more reliable design methods. The results of the experimental investigations of mass transfer in column with cocurrent swirl trays are presented in this paper. High values of gas and liquid side mass transfer coefficients were obtained and were successfully correlated in terms of Sherwood, Schmidt and Reynolds numbers and dimensionless geometric characteristic of vortex generator.

Nomenclature

A_0 – dimensionless geometric parameter of vortex generator,
a – specific interfacial area (area of interface per unit area of contact tube) [m^2/m^2],
D – kinematic diffusion coefficient [m^2/s],
d – inside diameter of the contact tube [m],
$k_G a$ – superficial side mass transfer coefficient [m/s],
$k_L a$ – superficial liquid side mass transfer coefficient [m/s],
w_G – superficial gas velocity [m/s],
Γ_L – liquid mass flow rate per circumference of the contact tube [kg/(ms)],
η – dynamic viscosity coefficient [Pa·s],
ν – kinematic viscosity coefficient [m^2/s],
ρ – density [kg/m^3],
θ – angle of blade deflection [deg].

Dimensionless numbers:

$Re_G=\frac{w_G d\rho_G}{\eta_G}$ – gas Reynolds number,

$Re_L=\frac{4\Gamma_L}{\eta_L}$ – liquid Reynolds number,

$Sc=\frac{\nu}{D}$ – Schmidt number,

$Sh_G=\frac{k_G ad}{D_G}$ – gas Sherwood number,

$Sh_L=\frac{k_L ad}{D_L}$ – liquid Sherwood number.

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*** This paper was presented at the Colloquium EUROMECH 162 organized by the Institute of Fluid-Flow Machinery, Polish Academy of Sciences and the Technical University Karlsruhe in 1982.

The permanent development of chemical industry set up a necessity of continuous searching for more economical column contactors. It resulted in the development of columns with cocurrent trays. First designs of such columns have appeared in literature in the beginning of the sixties. In comparison with typical packings or trays the cocurrent trays offer certain advantages such as high flow rates of gas and liquid unlimited by flooding as well as higher values of overall mass transfer coefficient. Additional increase of mass transfer rate may be achieved in two-phase swirl flow which at the same time gives facilities for more accurate separation of phases on each tray.

The principle of operation is shown in Fig. 1. Cocurrent contact device operates in upward two-pase annular or annular-mist flow which is created by high values of gas

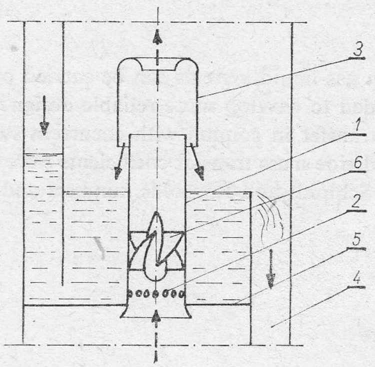

Fig. 1. The principle of operation of column with cocurrent trays *1* – contact tube, *2* – holes for liquid inlet, *3* – separating tube, *4* – downcomer, *5* – tray, *6* – vortex generator

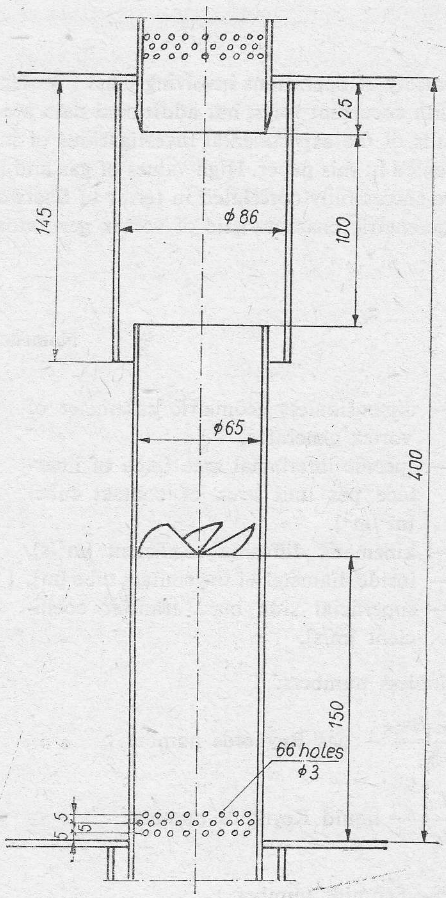

Fig. 2. The proposed construction of the contact device

velocity. Liquid enters the contact tube through inlet holes or sprayers and then is raised up with gas stream. After passing over the contact tube, two-phase stream is separated in separator and then gas phase flows up to upper tray whereas liquid phase flows down to the lower one. It is evident from presented orientation of phase flows that counter-current flow is the general one in the whole column.

The task of our work was to develop the simple construction of cocurrent tray and experimentally determine the effect of gas/liquid flow rates and swirl intensity on the gas/liquid controlled mass transfer rates. Few experimental work have been reported for mass transfer in two-phase swirl flow, so we hope that the results of the investigations presented here will be an aid in both planning and execution of a desired experimentation. The operation of cocurrent trays is still unsatisfactorily known from both hydrodynamics and diffusion points of view.

Among the various previously proposed or patented constructions of columns with cocurrent trays which are described in detail elsewhere [1 ÷ 8] – the tubular trays with swirl flow are worth notice. They are characterized by simple construction and certain operating advantages. Furthermore, the tubular contact devices can be used easily to substitute valves or caps in existing tray columns with the purpose of obtaining a bigger output.

Fig. 2 shows a new construction of contact device. It has been developed on the base of the detailed analysis of different constructions [5, 6]. The main part of this device is a

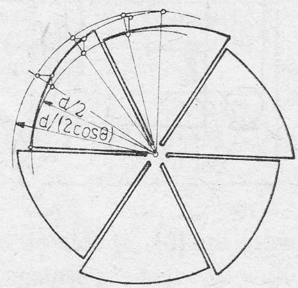

Fig. 3. The structure of vortex generator

contact tube equipped with the static vortex generator. The contact tube has also a set of holes at the bottom end for liquid inlet and a coaxial tube of bigger diameter at the upper end for separating purposes. A structure of vortex generators used in the study is illustrated in Fig. 3.

Details of the research apparatus are shown on schematic diagram in Fig. 4. The main part of this apparatus is a column consisting of two cocurrent trays. All measurements were made on upper tray of the column where proper hydrodynamic conditions were created by the lower tray. For the experiments on mass transfer controlled by liquid phase the water solution of carbon dioxide was pumped from a tank through a calibrated rotameter, before passing over the contact tube. Air humidified in a packed column with a cyclone separator and measured by an orifice plate, was supplied to the column by a fan. For experiments on mass transfer controlled by gas phase, the water solution of ammonia was used. The flow rates of air and liquid were controlled with a butterfly valve on the pipe going from the fan and with valve at the outlet of the circulating pump. The tank was provided with a heating section that allowed the liquid to be maintained at any desired temperature. The temperature of air was controlled by the temperature of water circulating in a humidifying loop.

In order to determine the extent of desorption, sampling was carried out by careful withdrawing gas-free liquid samples through narrow tubes. Concentration of carbon dioxide and ammonia in liquid samples was determined by nitration. Final gas composition was calculated from the material balance.

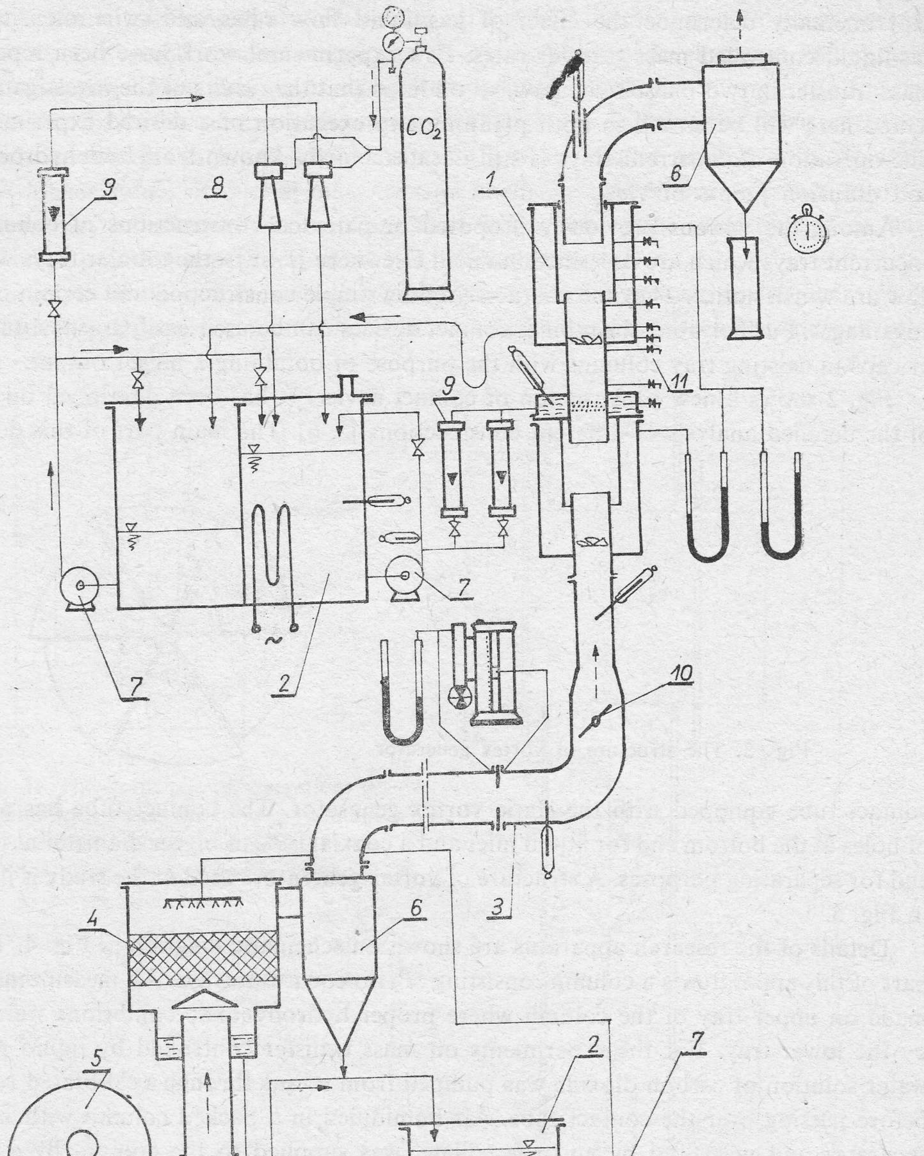

Fig. 4. The schematic diagram of the apparatus

1 – column, *2* – storage tank, *3* – pipeline with orifice plate, *4* – humidifier, *5* – fan, *6* – cyclone separator, *7* – pump, *8* – injector, *9* – rotameter, *10* – regulating valve, *11* – liquid samplers

The number of previous investigations involving mass transfer in two-phase swirl flow is very restricted. Because of the uselessness of the published correlations of mass transfer in ordinary flow for swirl flow, an attempt has been made to suggest a new form of dimensionless correlations. After the detailed analysis, the following formula is proposed for correlating the mass transfer results:

$$Sh = \text{const}\, Re_L^a\, Re_G^b\, Sc^c\, A_0^d. \tag{1}$$

The proposed form of correlation includes Reynolds numbers of both phases, Schmidt number of suitable phase and the swirl intensity which is expressed by a dimensionless geometric parameter of the vortex generator. This parameter is similar to the one developed by Abramovich [9] for the theory of centrifugal sprayers. Sherwood numbers used in the correlation (1) contain superficial mass transfer coefficients, whereas Reynolds numbers are based on superficial velocities of the phases. The values of the geometric parameter for the three different types of vortex generators used in the study have been found in experimental way with the use of the Abramovich equations and are presented in Table 1.

Table 1

Type of vortex generator	Number of blades	Angle of blade deflection	Geometric parameter A_0
I	6	30°	1.427
II	6	40°	0.883
III	8	40°	0.746

Some results obtained during desorption of carbon dioxide [6, 10] are shown in Fig. 5 where liquid side mass transfer coefficient is plotted against gas velocity with the irrigation rate as a parameter. After the regression analysis, the following equation has been obtained for predicting the values of liquid side mass transfer coefficient:

$$Sh_L = 6.546 \cdot 10^{-3} Re_L^{0.597} Re_G^{0.784} Sc_L^{0.5} A_0^{0.304}. \tag{2}$$

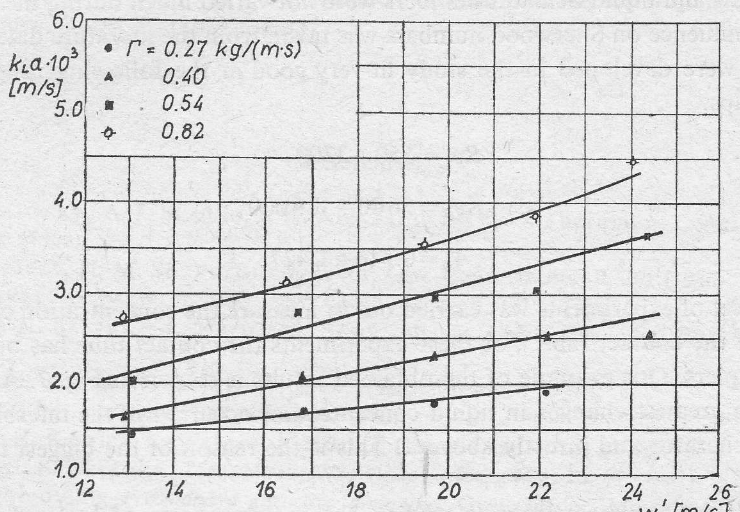

Fig. 5. Liquid side mass transfer coefficient versus gas velocity

The exponent on gas Reynolds number shows a big influence of gas flow rate on mass transfer in liquid phase. Next chart (Fig. 6) shows the results obtained in the desorption of ammonia. In the case of gas side controlled mass transfer, the following formula has been obtained from the experimental data:

$$Sh_G = 2.847 \cdot 10^{-2} Re_L^{0.208} Re_G^{0.844} Sc_G^{0.44} A_0^{0.259} . \tag{3}$$

As it can be seen from this formula, the values of the constant and the exponent of gas Reynolds number are very close to those of the well-known Gilliland-Sherwood corre-

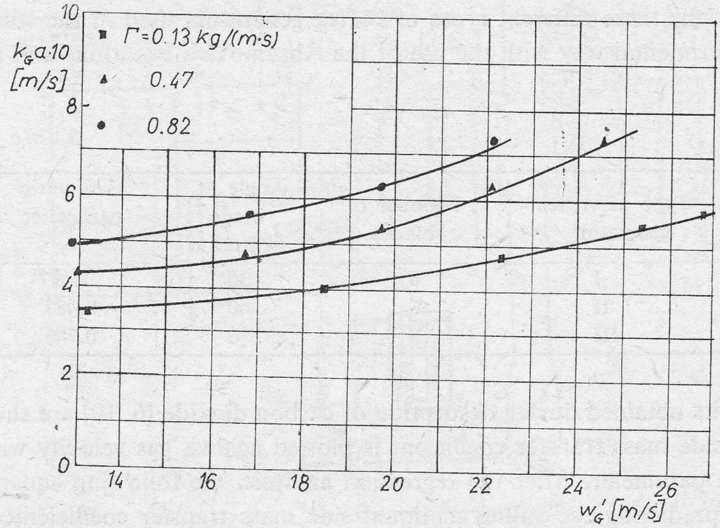

Fig. 6. Gas side mass transfer coefficient versus gas velocity

lation. The gas and liquid Schmidt numbers were not varied much during the experiments, hence their influence on Sherwood numbers was taken from the literature data. Both equations which were developed in the study fit very good in the following range of dimensionless groups:

$$Re_L = 550 \div 3700 ,$$

$$Re_G = 5600 \div 126000 ,$$

$$A_0 = 0.746 \div 1.427 .$$

Another set of experiments was carried out to measure the concentration changes along the length of the contact tube. For these experiments the contact tube has been equipped with six samplers. One example of the obtained results is shown in Fig. 7. As it has been expected, the greatest changes in liquid concentration occurred in the interblade space of the vortex generator and directly above it. This is the reason of the biggest turbulence of both phases.

Together with the mass transfer studies, the measurements of hydraulic parameters such as pressure drop, liquid entrainment and permissible range of flow rates have been

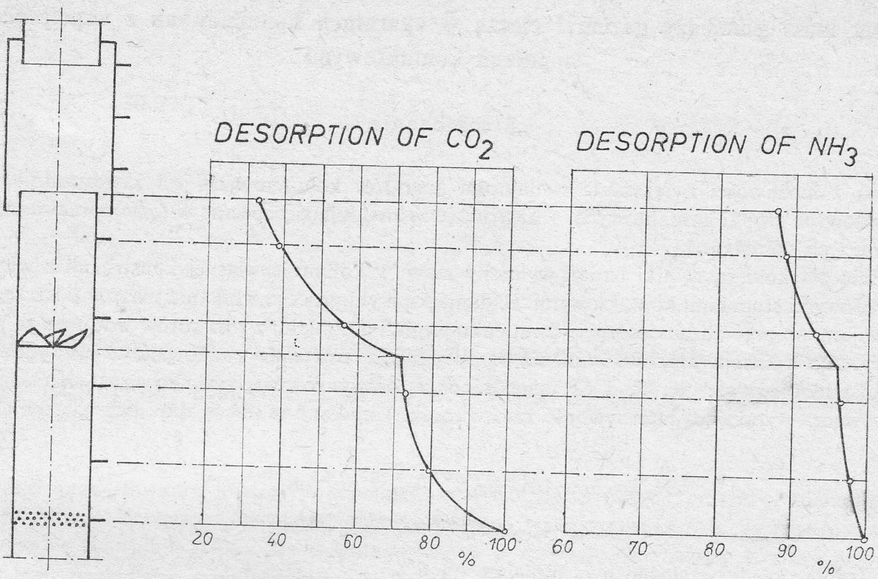

Fig. 7. Concentration changes along the length of the contact tube

made. The results and the discussion of these studies as well as the developed correlations are the subject of other papers [5, 11].

Generally, it may be concluded that:

– the proposed contact device operates stably in the wide range of gas and liquid flow rates,

– the vortex generator fixed in the contact tube gives certain advantages such as: higher values of mass transfer coefficients, wider area of correct operation, lower liquid entrainment and very good conditions for separation of the phases,

– very good accuracy of the mass transfer correlations has been achieved as a result of their new, more suitable form.

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Wymiana masy pomiędzy gazem i cieczą w aparatach kolumnowych z współprądowymi stopniami kontaktowymi

Streszczenie

Jedną z możliwości zwiększenia wydajności aparatów kolumnowych jest zastosowanie w nich współprądowych stopni kontaktowych. Konstrukcje te znajdują się obecnie w fazie opracowań, badań i pojedynczych wdrożeń.

Treścią artykułu są wyniki badań wymiany masy w kolumnie własnej konstrukcji z wirowymi, współprądowymi stopniami kontaktowymi. Badania kinetyki procesu wnikania masy w poszczególnych fazach wykonano prowadząc desorpcję dwutlenku węgla i amoniaku z roztworów wodnych za pomocą powietrza. Do opisania procesu wnikania masy przyjęto równanie zbudowane z bezwymiarowych modułów podobieństwa: *Sh*, *Re* i *Sc* uzupełnione o bezwymiarową, geometryczną charakterystykę zawirowywacza wyrażającą intensywność zawirowania. Uzyskano w ten sposób dwa następujące równania:

$$Sh_L = 6{,}546 \cdot 10^{-3}\, Re_L^{0,597}\, Re_G^{0,784}\, Sc_L^{0,5}\, A_0^{0,304}$$

$$Sh_G = 2{,}847 \cdot 10^{-2}\, Re_L^{0,208}\, Re_G^{0,844}\, Sc_G^{0,44}\, A_0^{0,259},$$

których średnie błędy względne były mniejsze od 6%.

W pracy opisano również wyniki pomiarów zmian stężenia roztworów wzdłuż rurki kontaktowej obrazujące udział poszczególnych fragmentów rurki kontaktowej i zawirowywacza w procesie wymiany masy.

Массообмен между газом и жидкостью в колонных аппаратах с прямоточными контактными ступенями

Резюме

Одной из возможностей повышения производительности колонных аппаратов является применение в них прямоточных контактных ступеней. Эти конструкции находятся сейчас в фазе разработки, исследований и одиночных внедрений.

Сутью статьи являются результаты исследований массообмена в колонне собственной конструкции с вихревыми, прямоточными, контактными ступенями. Исследования кинетики процесса массопроникновения в отдельных фазах производились осуществляя десорпцию двуокиси угля и аммония из водяных растворов при помощи воздуха. Для описания процесса массопроникновения принято уравнение построенное из безразмерных модулей подобия: *Sh*, *Re* и *Sc*, пополненное безразмерной геометрической характеристикой завихрителя, выражающей интенсивность завихрения. Получены таким образом два следующих уравнения

$$Sh_L = 6{,}546 \cdot 10^{-3}\, Re_L^{0,597}\, Re_G^{0,784}\, Sc_L^{0,5}\, A_0^{0,304},$$

$$Sh_G = 2{,}847 \cdot 10^{-2}\, Re_L^{0,208}\, Re_G^{0,844}\, Sc_G^{0,44}\, A_0^{0,259},$$

которых средние относительные ошибки меньше 6%.

В работе описаны также результаты измерений концентрации растворов вдоль контактной трубки, отображающие участие отдельных фрагментов контактной трубки и завихрителя в процессе массообмена.