

**Резюмета на научната и научно-приложната продукция**  
на доц. д-р инж. Крум Ангелов Семков  
(След първа хабилитация)

**I. Публикации и доклади в пълен текст**

20. Н. Колев, Р. Даракчиев, **Кр. Семков**, А. Мирчев, Утилизационни системи с контактни економайзери или апарати тип КТАН?, *Енергетика*, 8/9, 6-10 (1990).

**ТОПЛОЕНЕРГЕТИКА**

*Н. Колев, Р. Даракчиев, К. Семков и др. — Утилизационни системи с контактни економайзери или апарати тип КТАН?*

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В работата са разгледани два основни типа инсталации за утилизация на топлина от отпадни газове и са посочени техните предимства и недостатъци. Отбелязано е, че системите тип КТАН за разлика от контактните економайзери с пълнеж работят при режим различен от пълния противоток вследствие на което от термодинамична гледна точка, работят при по-неблагоприятни условия

21. N. Kolev, R. Darakchiev, **Kr. Semkov**, Systems containing contact economizers for flue gas heat utilization, *Energy Efficiency in Process Technology*, Elsevier Applied Science, London and New York, 683-691 (1993).

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SYSTEMS CONTAINING CONTACT ECONOMIZERS FOR FLUE GAS  
HEAT UTILIZATION

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ABSTRACT

A reference is made to the fact that a significant part of the heat generated by combustion, is lost in the atmosphere with exhausted flue gases. Contact economizer systems are considered which help to utilize this heat by heating up the water before entering the boiler or by heating up urban heat supply water of the central heat supply network, as recycled back to the heating plant. Attention is drawn to some features of the new contact economizers which allow pressure drop values as low as 10-20 mm water head at high gas superficial velocities, i.e. up to 3 m/s. New process flow charts with contact economizers which helping to utilize heat at higher temperature levels by simultaneous reduction of nitric oxides emissions down to 33 %, are given. The method developed for designing such systems is described, and data obtained in experiments with such industrial systems developed by the authors, are presented.

22. N. Kolev, R. Billet, **Kr. Semkov**, J. Mackowiak, Sv. Nakov, On the Optimal Form of Stacks in Packed Columns, *FAT Science Technology*, **96**, 267-270 (1994).

### On the Optimal Form of Stacks in Packed Columns

*N. Kolev, R. Billet, R. Semkov, J. Mackowiak and Sv. Nakov* •

The performance of a column packing depends besides physical properties of the systems to be separated and the operational conditions mainly on the basic shape, the thickness of the material and the main dimensions of the packing elements. These magnitudes of construction govern the specific area including the void fraction of the packing and therefore its efficiency, pressure drop and capacity. It is reported about constructive measures for optimization of a packing geometry.

#### Über die optimale Form von Packungselementen

Die Wirksamkeit einer Kolonnenpackung hängt neben den physikalischen Stoffgrößen des zu trennenden Systems und den Betriebsbedingungen in entscheidendem Maße von der geometrischen Grundform, von der Materialstärke und von den Hauptabmessungen der Packungselemente ab. Diese konstruktiven Größen bestimmen die spezifische Oberfläche sowie das relative freie Lückenvolumen der Packung und somit deren Trennwirkung, Druckverlust und Belastbarkeit. Es wird über konstruktive Möglichkeiten zur Optimierung einer Packungsgeometrie berichtet.

23. N. Kolev, **Kr. Semkov**, R. Darakchiev, Mathematical modeling of heat and mass transfer in packed bed columns, *Proceedings of 7<sup>th</sup> International Summer School of Chemical Engineering*, Varna 19-25 September 1995, 66-80.

## MATHEMATICAL MODELLING OF HEAT AND MASS TRANSFER IN PACKED BED COLUMNS

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### 1. Introduction

Packing height evaluation by packed columns presents still a major design problem. Up to now, there is still no unified approach for the determination of this parameter. The hitherto known design methods and relationships are valid for particular design applications and vary depending on the type of operation (absorption, distillation, direct heat transfer) or, as in the case of distillation columns, also on the system employed. Thus, in the general case the industrial equipment design requires additional experiments which lead to extensive investments and delayed production. The objective of this paper is to analyse packed column design considering the similarities between absorption, desorption, distillation and direct heat transfer, as well as to propose a unified approach to the design of these operations by dimensionless equations derived through experiments based on “cold” models.

- 23a. N. Kolev, **Kr. Semkov**, R. Darakchiev, Mathematical modeling of heat and mass transfer in packed bed columns, *New developments in separation processes associated with processes industries, biotechnology and environmental protection*, European Federation of Chemical Engineering, Warsaw 29-31 May 1996, 32-44.

## **Mathematical Modelling of Heat and Mass Transfer in Packed Bed Columns**

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### **1. Introduction**

Packing height evaluation by packed columns presents still a major design problem. Up to now, there is still no unified approach for the determination of this parameter. The hitherto known design methods and relationships are valid for particular design applications and vary depending on the type of operation (absorption, distillation, direct heat transfer) or, as in the case of distillation columns, also on the system employed. Thus, in the general case the industrial equipment design requires additional experiments which lead to extensive investments and delayed production. The objective of this paper is to analyse packed column design considering the similarities between absorption, desorption, distillation and direct heat transfer, as well as to propose a unified approach to the design of this operations by dimensionless equations derived through experiments based on "cold" models.

24. N. Kolev, R. Darakchiev, **Kr. Semkov**, Butyl acetate and butanol stripping from waste waters in antibiotic production, *Water Research*, **30**, 1312-1315 (1996).

## BUTYL ACETATE AND BUTANOL STRIPING FROM WASTE WATERS IN ANTIBIOTIC PRODUCTION

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*(Received October 1995; accepted November 1995)*

**Abstract**—The waste waters from the production of antibiotics contain certain quantities of butyl acetate or butanol. For the purpose of their purification by removal of these organic solvents a technology and an installation have been created. The installation described operates steadily with waters tending to cause settling of solids, when heated in a heat exchanger or when decreasing the concentration of the organic solvent in the stripping column. The investigation of the industrial column shows a degree of purification of 99–100% at different regimes of operation. The five year exploitation of the installation for removal of butyl acetate and the two year operation of that for the removal of butanol showed that the solids coagulating from waste water did not settle on the apparatus walls. Copyright © 1996 Elsevier Science Ltd.

**Key words**—antibiotic production, waste waters, butyl acetate, butanol, organic solvents, stripping columns

25. N. Kolev, R. Darakchiev, **Kr. Semkov**, D. Kolev, Second generation contact economizers. Industrial experience, *Heat and Mass Transfer, Chemical and Biochemical Reactors, Bulgarian-Hungarian Workshop'96*, Veszprém 23-26 April 1996, 69-71.

## SECOND GENERATION CONTACT ECONOMIZER SYSTEMS - INDUSTRIAL EXPERIENCE

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### 1. Introduction

The systems with contact economizers [1-3] are the most effective recent installations for utilization of waste heat of the flue gases. They consist of a heat-mass-transfer apparatus, usually a simple packed-bed column, a pump section, and a water-water heat-exchanger. The flue gases are cooled in the column during the direct contact with water circulating countercurrently to the gas flow. The water is heated and simultaneously the major part of the water vapor in the gas is condensed. In the heat-exchanger the warm water from the economizer transfer its heat content to a pure water flow. Usually this is the water going to the department for chemically purified water, the feed water for the boilers and for the district heating network. Simple balance calculations show that the flue gases contain much more heat than is necessary to warm the encountered flows. A large quantity of water that has to be heated, is a partially cooled flow (about 55°C) returning from the district heating network to the heat power plant. When burning natural gas, the temperature of the wetted thermometer of the flue gases is about 60°C. Because of the high efficiency of the economizers the temperature of the recycled water after contacting the gases is only 2°C lower, i.e. about 58°C. In a plate heat-exchanger the temperature difference between the heating and heated flow is about 3°C. Consequently, with the heating systems described above the pure water flow can be warmed up to 55°C. Evidently, their use is not appropriate for this case. The present paper considers the application of improved contact economizer systems for heating of water of district networks using the heat of flue gases.

- 25а. Н. Колев, Р. Даракчиев, **Кр. Семков**, Д. Колев, Системи с контактни економайзери второ поколение. Промислен опит, *Енергиен форум'96* (с международно участие), Варна 12-14 юни 1996, Доклади т. II, 45-48.

**СИСТЕМИ С КОНТАКТНИ ЕКОНОМАЙЗЕРИ ВТОРО ПОКОЛЕНИЕ  
ПРОМИШЛЕН ОПИТ**

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**1. Въведение**

Системите с контактни економайзери [1-3] са най-ефективните известни до сега инсталации за утилизация на топлината на димни газове. Те се състоят от топло-масообменен апарат, обикновено колона с пълнеж, помпен блок и топлообменник. Димните газове се промиват в противоток в колоната с пълнеж с циркуляционна вода, която се нагрява за сметка на тяхното охлаждане и на кондензация на основната част от носената от тях водна пара. В топлообменника нагрявата в економайзера вода отдава топлината си за нагряване на чиста вода. Обикновено това е водата постъпваща в отделението за химически очистена вода, подпитката на котлите или на топлофикационната мрежа. Елементарните балансови изчисления показват, че топлината, която може да се утилизира от димните газове обикновено е многократно повече от топлината необходима за нагряване на тези потоци. Един голям резерв от сравнително студена вода представлява връщащата се в топлофикационните централи охладена топлофикационна вода. На нейното нагряване, при използването на усъвършенствувани системи с контактни економайзери е посветена и настоящата работа.



26. N. Kolev, R. Darakchiev, **Kr. Semkov**, Chloroform stripping from waste waters, *Ind. Eng. Chem. Res.*, **36**, 238-240 (1997).

## **Chloroform Stripping from Waste Waters**

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The problem treated in this paper is the purification of waste industrial waters from chloroform. An industrial installation with a stripping column is designed, and the results of its study and industrial tests are presented. It is shown that, in a column with 6400 mm total height of the used packing (Holpack), the chloroform concentration in the waste water decreases 150 000 times, approaching that of drinking water.

27. **Kr. Semkov**, N. Kolev, R. Popov, Liquid phase axial mixing in packed columns with Honey-comb structured packing, *Bulg. Chem. Commun.*, **31**, 403-413 (1999).

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## LIQUID PHASE AXIAL MIXING IN PACKED COLUMNS WITH HONEY-COMB STRUCTURED PACKING

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*Dedicated to Professor Dimitar G. Elenkov on the occasion of the 80th anniversary  
of his birth*

Received November 11th, 1999

Experimental studies were carried out to estimate the axial mixing in the liquid phase in a column with a novel, highly effective "honey-comb" structured packing of polypropylene. A method with a single  $\delta$ -impulse of electrolyte tracer was used. The results were obtained and processed "on-line" using a personal computer in combination with a measuring system based on analogue-digital converter. The disturbance caused by the measuring cell was taken into account, too. For this purpose, preliminary experiments in a column without packing were carried out in a wide range of the liquid load.

Three different hydrodynamic regimes were registered along the rise of the Reynolds number – an increase, decrease and again increase of the Bodenstein number. Consequently, three dimensionless equations for determination of the Bodenstein number and the transient values of Reynolds number for each regime were obtained.

The results were used to determine the influence of the liquid phase axial mixing on the packing's efficiency. Earlier obtained data for the integral mass transfer coefficient in the liquid phase was processed by means of a combined solution of the one-parameter dispersion model and the plug-flow model, using an appropriate iterative procedure. As a result, local mass-transfer coefficient values, not influenced by the axial mixing, were obtained. It was shown that the axial mixing can reduce the packing's efficiency by up to 40% and the minimal influence was found at Reynolds number value of about 108.

**Key words:** packed columns, axial mixing, mass transfer

29. **Kr. Semkov**, T. Petrova, P. Moravec, Parameter identification of a mathematical model for liquid distribution in packed-bed columns, *Bulg. Chem. Commun.*, **32**, 497-516 (2000).

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## PARAMETERS IDENTIFICATION OF A MATHEMATICAL MODEL FOR LIQUID DISTRIBUTION IN PACKED-BED COLUMNS

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A complex identification method for determination of parameters of a mathematical model describing the liquid distribution in packed columns with biparametric boundary condition at the column wall is proposed. One of the parameters is directly determined from experimental data for two cases of initial irrigation: uniformly distributed initial flow and wall-introduced one. The other parameter is derived by consequent nonlinear optimization for itself and for the liquid spreading coefficient minimizing the residual variance.

The method is tested with three types of packing – Pall rings 25 mm, Intalox saddles 25 × 50 mm, and Minirings 17 × 50 mm. The experiments are carried out in a packed-bed column 188.6 mm in diameter, with both uniformly distributed and wall initial liquid flow, according to the method's requirements.

For Pall rings and Intalox saddles, the parameters of boundary conditions, as well as the coefficient of liquid spreading are obtained. The existence of conditions under which the method is not applicable is illustrated in the case of Minirings packing.

A comparison is made with data of other authors for the distribution coefficient obtained by other methods.

**Key words:** packed columns, random packing, liquid distribution, mathematical modelling.

30. T. Zhelev, **Kr. Semkov**, More efficient flue gas energy recovery through Pinch analysis, *PRES'01 Conference, Process Integration, Modelling and Optimization for Energy Saving and Pollution Reduction*, Florence 20-23 May 2001, Proceedings, 235-240.

PRES'01, 4<sup>th</sup> Conference on Process Integration, Modelling, and Optimisation for Energy Saving and Pollution Reduction, Florence, May, 20-23 2001

### MORE EFFICIENT FLUE GAS ENERGY RECOVERY THROUGH PINCH ANALYSIS

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The paper addresses the problems of energy conservation and environment protection in industrial applications where simultaneous heat and mass transfer processes are in place. The attention is concentrated towards possible flue-gas energy utilisation accompanied with strong environmental impact. It is shown that in case of coal fired industrial boilers the flue gas temperature can be lowered substantially without increasing the risk of back-end condensation. This is possible through dehumidification of flue gas in a packed-bed economiser system with ... water. Different design contact economiser systems (CES) are presented and compared. Pinch principles are deployed for targeting and design guiding purposes. The influence of the process variables on the design and efficiency of heat and mass transfer processes are analysed and supporting combination of tools is proposed. An attempt is made to apply Pinch principles for better design and operation of systems of contact economisers balancing the heat and mass transfer in a second generation CES of parallel type. The results are expected to make these systems more sophisticated and more suitable for industrial applications. They open the door for total efficiency improvement of power stations and generalisation of methodology for management of energy and water resources.

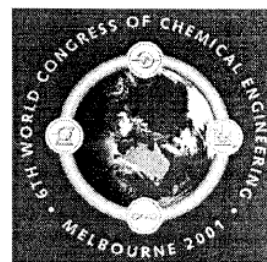
31. T. Zhelev, **Kr. Semkov**, Combined heat and mass Pinch analysis for more efficient flue gas energy recovery, *6<sup>th</sup> World Congress of Chemical Engineering*, Melbourne, Australia 23-27 September 2001, Proceedings/papers/energy/other, 1-12.

### Combined Heat and Mass Pinch Analysis for More Efficient Flue Gas Energy Recovery

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The paper attempts to combine the exceptionally successful Thermal Pinch concept with Mass transfer Pinch, creating a procedure for targeting two major components in power production - water and energy. It addresses the problem of energy conservation and environment protection in industrial applications where simultaneous heat and mass transfer processes take place. The contact economizer system used for low-level energy utilization of flue gases is considered as an example. The influence of flue gas moisture content, dew point, phase conditions, column height, etc. on the contact economizer system's structure and efficient operation are also addressed. The effect of the closest approach between the equilibrium curve and the operating line are discussed and the effect of Pinch allocation on system design and efficient unit operation are analyzed. The methodology uses a combination of the concepts applied in the classical H/T presentation of the operating line/equilibrium curve and in Composite curves for Pinch analysis for mass transfer optimization and system structure design. A possible application of a contact economizer system for an existing power station is demonstrated, forming the basis for further methodology refinement and generalization.

32. T. Zhelev, **Kr. Semkov**, Optimal design and efficient operation of contact economizer systems based on combined thermal and mass transfer Pinch analysis, *9<sup>th</sup> International Summer School of Chemical Engineering*, Sozopol 18-24 September 2001, Proceedings 329-332.

**D4 OPTIMAL DESIGN AND EFFICIENT OPERATION  
OF CONTACT ECONOMISER SYSTEMS BASED  
ON COMBINED THERMAL AND MASS TRANSFER PINCH  
ANALYSIS**

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**CONTACT ECONOMISER SYSTEMS**

It is well known why designers hesitate to cool flue gases from industrial boilers below 130-140°C. The danger of back-end acidic condensation is justified by the dew point of the SO<sub>3</sub> contained in the flue gas. The sulphur content of South African coal differs from that of other countries and is in the range of 0.5-0.7%. This fact, as well as successful application of contact economiser systems for flue gas energy recovery from natural gas fired European boilers [1] has provided the impetus to explore the compelling opportunity to combine energy efficiency improvement with strong positive environmental impact.

33. **Kr. Semkov**, T. Zhelev, Efficient resources management applied to flue gas energy recovery from coal fired boilers, *Bulg. Chem. Commun.*, **33**, 395-413 (2001).

BULGARIAN CHEMICAL COMMUNICATIONS

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## EFFICIENT RESOURCES MANAGEMENT APPLIED TO FLUE GAS ENERGY RECOVERY FROM COAL FIRED BOILERS

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The paper proposes the application of contact economizer systems to energy and water recovery from coal fired boilers in power production. The combined thermal and mass transfer pinch analysis is used for efficient resources management. The mathematical modeling of the contact economizer systems, where simultaneously direct heat and mass transfer processes are taking place, is given. The problems of energy conservation and environmental protection in industrial practice, the influence of flue gas moisture content, dew point, phase conditions, column height, system's structure and efficient operation are also addressed. The real operating parameters, obtained from the model and experiment on first and second generation pilot contact economizer system, are presented. It is shown the effect of increasing the potential of utilized heat with 9.6°C using the second generation contact economizers related to the first generation system. A possible application in an existing power station with the expected energy and water utilization is shown. The environment protection effect is demonstrated too.

**Key words:** resources management, direct heat and mass transfer, mathematical modeling, pinch analysis, environmental protection

34. T. Petrova, **Kr. Semkov**, P. Moravec, Determination of the characteristic packing size in the mathematical model for liquid phase spreading in packed-bed columns with deflecting rings, *Bulg. Chem. Commun.*, **34**, 82-98 (2002).

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**DETERMINATION OF THE CHARACTERISTIC PACKING SIZE  
IN THE MATHEMATICAL MODEL FOR LIQUID PHASE  
SPREADING IN PACKED-BED COLUMNS WITH DEFLECTING  
RINGS**

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A method is proposed for determination of the packing characteristic size on the basis of a mathematical model, describing the liquid phase spreading in a packed-bed column with deflecting rings. The mathematical model gives the theoretical irrigation density as a function of the packing characteristic size and the width of deflecting ring. The method is aimed at finding the minimum of the variance between theoretical and experimental data for irrigation density at various values of the characteristic size.

The experimental data for irrigation density are obtained by a liquid collecting device mounted at the bottom of a glass column 0.1886 m in diameter. The column has two deflecting rings along its height. The packings studied are Pall rings and Intalox saddles. The values of the characteristic size are obtained for packings of the above types using previous own results as well. The estimated values and irrigation density are presented in the form of tables and graphs.

**Key words:** packed bed column, liquid distribution, mathematical modeling, parameter estimation.



35. T. Petrova, **Kr. Semkov**, Ch. Dodev, Mathematical modeling of gas distribution in packed columns, *Chem. Eng. Process.*, **42**, 931-937 (2003).



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## Mathematical modeling of gas distribution in packed columns

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### Abstract

A dispersion model is proposed for the description of gas distribution in a packed column in the absence of liquid flow. The radial gas velocity profile is simulated for three different packing heights and compared with appropriate experimental data, obtained in a column with 'honey-comb' structured packing and gas distribution device (GDD). By separating the effect of the distributor from that of the packing layer, the additivity of packing redistribution capability and GDD is proved. The model parameters (distribution ability) are identified by means of non-linear optimization, minimizing the residual variance between the experimental and theoretical gas velocity. The model and experiment adequacy is checked. An analytical formula for the maldistribution factor is proposed, based on the model distribution parameter and initial condition only, and compared with the measured experimental maldistribution factor. Considering the studied packing, gas distribution coefficient is found based on the additivity of the obtained model parameters.

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*Keywords:* Gas distribution; Packed columns; Maldistribution factor; Structured packing; Identification of the parameters

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36. T. Zhelev, **Kr. Semkov**, Cleaner flue gas and energy recovery through pinch analysis, *Journal of Cleaner Production*, **12**, 165-170 (2004).



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Journal of Cleaner Production 12 (2004) 165–170

Journal of  
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## Cleaner flue gas and energy recovery through pinch analysis

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### Abstract

The paper addresses the problems of cleaner energy generation in industrial applications. Its aims further flue gas energy recovery accompanied with additional environmental impact. It shows how the widely accepted flue gas temperature of industrial coal fired boilers can be lowered substantially without increasing the risk of back-end condensation. This is possible through dehumidification and partial absorption of the flue gas in a packed-bed economiser system by circulating water. Different design contact economiser systems (CES) are presented and compared. Pinch principles are deployed for targeting, design and operation-guiding purposes, balancing the heat and mass transfer in a second generation CES of parallel type. The results are expected to make these systems more sophisticated and more suitable for industrial applications. They open the door for valuable boiler efficiency improvement and generalisation of methodology for simultaneous management of energy and water resources.

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*Keywords:* Contact economiser; Pinch analysis; Flue gas

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37. T. Petrova, **Kr. Semkov**, Mathematical modeling of single-phase flows in packed-bed columns, *Proceedings of 11-th Workshop on Transport Phenomena in two-phase flow*, Sunny beach resort, Bulgaria, September 1-5, 93-106, (2006).

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11<sup>th</sup> Workshop on Transport Phenomena in Two-phase flow, 2006

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Petrova and Semkov. Mathematical modeling of single-phase flows in packed-bed columns

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## MATHEMATICAL MODELING OF SINGLE-PHASE FLOWS IN PACKED-BED COLUMNS

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Key words: mathematical modeling, identification of parameters, packed-bed columns, maldistribution factor

**ABSTRACT:** Dispersion models for simulating the radial maldistribution of single-phase flows in packed-bed columns have been developed. Two cases for their application on liquid phase, spreading over random packing in the column, were considered: respectively with and without wall flow deflecting rings, mounted on the column wall to restrict a wall flow. Model parameters have been identified with the help of experimental data by non-linear optimization of minimum of residual variance between the model and experimental values. It was proposed to describe the radial gas maldistribution in packed column by means of dispersion model too. On this model's solution bases an additivity of gas redistribution abilities for both packing layer and preceded gas distribution device is proven. The theoretical relationship for maldistribution factor explaining the development of maldistribution factor along the packing layer's height has been worked out. The models are checked up on an experimental data for structured and random packings.

38. С. Даракчиев, Кр. Семков, Влияние на неравномерното разпределение на парите върху ефективността на колоните с пълнеж при ректификация на системата етанол-вода, *VI национална младежка научно-практическа сесия 2008*, София 21-22 април 2008 г., Сборник доклади, 134-138.

## ВЛИЯНИЕ НА НЕРАВНОМЕРНОТО РАЗПРЕДЕЛЕНИЕ НА ПАРИТЕ ВЪРХУ ЕФЕКТИВНОСТТА НА КОЛОНИТЕ С ПЪЛНЕЖ ПРИ РЕКТИФИКАЦИЯ НА СИСТЕМАТА ЕТАНОЛ-ВОДА

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### 1. Въведение

Един от основните недостатъци на колоните с пълнеж е неравномерното разпределение на потоците по напречното сечение на апарата. Образуването на канали от течността и парите води до загуба на междуфазна повърхност и следователно понижава значително ефективността на пълнежа. Известно е [1], че при ниски флегмови числа (ниски скорости на течността и високи скорости на парата) се наблюдава влошаване на ефективността заради неравномерност на течната фаза. Това се дължи на доближаването на работната линия до равновесната, което води до увеличаване броя на теоретичните тарелки, като в някои секции на колоната двете линии могат дори да се пресекат заради разликата в отношенията L/G.

Развитието на модерните ненаредени пълнежи доведе до създаването към края на 70-те години на т.нар. пълнежи от трето поколение, характеризиращи се с ниско хидравлично съпротивление, висока ефективност и висока степен на технологичност при изработката. Това са Nutter Ring, CMR Ring, IMTP Ring и др., които значително превъзават параметрите на традиционните Pall Ring и Intalox Saddle – ненаредени пълнежи от второ поколение. Още по-добри характеристики показва предложения през 1995 г. Raschig Super – Ring [2], поради което се счита за първия представител на ненаредени пълнежи от четвърто поколение. Изследванията [3, 4] обаче показват, че поради отворената си структура и ниското си хидравлично съпротивление, тези пълнежи имат сравнително висока степен на неравномерност на газовата фаза.

Целта на настоящата работа е да се изследва ефективността на пълнежите при ректификация на системата етанол-вода при променливо флегмово число и да се установи влиянието на неравномерността.

39. S. Darakchiev, **Kr. Semkov**, Study of modern high effective random packings for ethanol-water rectification, *Chem. Eng. Technol.*, **31**, 7, 1039-1045 (2008). ISSN 0930-7516

Simeon Darakchiev<sup>1</sup>  
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Research Article

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## A Study on Modern High-Effective Random Packings for Ethanol-Water Rectification

Raschig Super-Ring is a modern and high-efficient packing used for intensification of absorption and distillation processes. The aim of this work is to characterize the efficiency of this packing applied to rectification of an important industrial system, ethanol-water, and to compare its efficiency to that of some random packings of the third generation as well as to the structured packing, HOLPACK, which is used in the ethanol production industry. The experiments were carried out in a column installation, 0.213 m in diameter with a packing height of 2.8 m. The column is heated by a number of electrical heaters (total power 45 kW), which can be switched gradually. Operation at total and partial reflux is possible. Eight types of random packings were studied: five types of Raschig Super-Ring, four metallic (with characteristic dimensions 0.5, 0.6, 0.7, and 1") and one of plastic material 0.6"; two types of packing IMTP and one plastic Ralu Flow. Some experiments were conducted at total reflux operation at vapor velocity, 0.253–0.936 m/s, and liquid superficial velocity,  $4.44 \cdot 10^{-1}$ – $1.63 \cdot 10^{-3}$  m<sup>3</sup>/(m<sup>2</sup>s). Experiments at partial reflux were carried out at constant liquid superficial velocity and changeable vapor velocity as well as at constant vapor velocity and changeable liquid velocity. The results are presented as height of transfer unit, HTU, and height equivalent to a theoretical plate, HETP, as a function of the velocity of phases.

**Keywords:** Distillation, Mass transfer, Packed bed columns, Raschig rings

*Received:* January 18, 2008; *accepted:* February 08, 2008

**DOI:** 10.1002/ceat.200800029

40. T. Petrova, R. Darakchiev, **Kr. Semkov**, S. Darakchiev, Estimation of Gas Flow Maldistribution in Packed-Bed Columns, *Chem. Eng. Technol.*, **31**, 12, 1723-1729 (2008). ISSN 0930-7516.

*Chem. Eng. Technol.*, 2008, 31, 12, 1723-1729

1723

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Krum Semkov<sup>1</sup>  
Simeon Darakchiev<sup>1</sup>

Review

## Estimations of Gas Flow Maldistribution in Packed-Bed Columns

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A review of research articles dealing with estimation of the rate of gas flow maldistribution in packed-bed columns is presented. The proposed relations for determination of the maldistribution factor are given along with the conditions at which they are obtained. It is shown that the indices of maldistribution are usually based on particular terms, i.e., variation coefficient, dispersion or standard deviation. However, they cannot be regarded as a single indicator of gas maldistribution if the gas flow irregularities are not homogeneously distributed over the cross-section. There is no unified methodology for measuring the gas flow velocity profile. Schemes for measuring the velocity profiles, as well as equations for calculating the maldistribution factor are recommended.

**Keywords:** Gas flow maldistribution, Maldistribution factor, Packed-bed columns, Velocity distribution

*Received:* July 7, 2008; *revised:* September 9, 2008; *accepted:* September 10, 2008

DOI: 10.1002/ceat.200800321

41. Т. Петрова, **Кр. Семков**, С. Даракчиев, Р. Даракчиев, Разтичане на течността в колони с ненаредени пълнежи, *Научни трудове от Научна конференция с международно участие "ХРАНИТЕЛНА НАУКА, ТЕХНИКА И ТЕХНОЛОГИИ - 2009"*, Пловдив 23-24 октомври 2009 г., том.LVI, св. 2, 245-250. ISSN 0477-0250.

"ХРАНИТЕЛНА НАУКА, ТЕХНИКА И  
ТЕХНОЛОГИИ – 2009"  
23 – 24 октомври, Пловдив



FOOD SCIENCE, ENGINEERING AND  
TECHNOLOGIES '2009  
23 – 24 October, Plovdiv

## РАЗТИЧАНЕ НА ТЕЧНОСТТА В КОЛОНИ С НЕНАРЕДЕНИ ПЪЛНЕЖИ

Татяна Петрова, Крум Семков, Симеон Даракчиев, Румен Даракчиев

### Резюме

Въз основа на всички открити до момента данни за коефициента на разтичане  $D$  за конвенционални и съвременни наредени пълнежи, е направен анализ на влиянието на структурата, размерите на пълнежа, както и на начините за определяне, върху стойността на  $D$ . Установено е, че колкото е по-отворена структурата на пълнежния елемент, толкова повече  $D$  намалява, а в отделни случаи и спира да зависи само от основния (номинален) диаметър на пълнежа.

## LIVID FLOW DISTRIBUTION IN PACKED COLUMNS

Tatyana Petrova, Krum Semkov, Simeon Darakchiev, Rumen Darakchiev

### Abstract

An analysis of the impact of the structure and size of packing as well as the manner of determination of liquid spreading coefficient  $D$ , on the value of  $D$  is done, based on all founded until now literature data for spreading coefficient of conventional and modern random packings. It is shown that as the packing element structure became more open  $D$  decreases more and occasionally  $D$  stops to depend on just the basic (nominal) diameter of the packing.

42. Р. Даракчиев, Т. Петрова, **Кр. Семков**, С. Даракчиев, Разтичане на течността в колони с пълнеж „Пчелна пита”, *Научни трудове от Научна конференция с международно участие "ХРАНИТЕЛНА НАУКА, ТЕХНИКА И ТЕХНОЛОГИИ - 2009"*, Пловдив 23-24 октомври 2009 г., том.LVI, св. 2, 251-255. ISSN 0477-0250.

“ХРАНИТЕЛНА НАУКА, ТЕХНИКА И  
ТЕХНОЛОГИИ – 2009”  
23 – 24 октомври, Пловдив



FOOD SCIENCE, ENGINEERING AND  
TECHNOLOGIES '2009  
23 – 24 October, Plovdiv

## РАЗТИЧАНЕ НА ТЕЧНОСТТА В КОЛОНИ С ПЪЛНЕЖ “ПЧЕЛНА ПИТА”

Румен Даракчиев, Татяна Петрова, Крум Семков, Симеон Даракчиев

### **Резюме**

*Изследван е коефициентът на разтичане  $D$  на блоков керамичен пълнеж “Пчелна пита”, като показател за разтичащата способност на пълнежа. Изследвани са както прави блокове и такива с различен наклон, различен размер на шестоъгълните отвори и различна височина. Показано е, че силно влияние на коефициента оказва ъгъла на наклона и диаметъра на вписаната окръжност в шестоъгълните отвори.*

## LIQUID FLOW DISTRIBUTION IN COLUMNS WITH HONEYCOMB PACKING

Rumen Darakchiev, Tatyana Petrova, Krum Semkov, Simeon Darakchiev

### **Abstract**

*The radial spreading coefficient  $D$  as an indicator of the packing spreading ability of ceramic stacked packing Honeycomb has been investigated. There are examined straight stacked as well as inclined packing blocks with different slopes, sizes of hexagonal holes and different block heights. It is shown that the angle of inclination and the diameter of a circle inscribed into hexagonal hole have great influence on the value of packing spreading coefficient.*



43. **Kr. Semkov**, S. Darakchiev, Influence of Smallscale Maldistribution in the Vapor Phase on the Efficiency of Rectification in Packed Columns, *Bulg. Chem. Commun.*, **42**, 3, 194-204 (2010). ISSN 0324-1130

*Bulgarian Chemical Communications, Volume 42, Number 3 (pp. 194-204) 2010*

The influence of small scale maldistribution in the vapor phase on the efficiency of the rectification in packed columns

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Received November 2, 2009, Revised March 29, 2010

An analysis is made of the possibilities for accounting for small and large scale maldistribution in gas and liquid phases in packed columns. A stochastic parallel model is proposed for mathematical modeling of small scale maldistribution in gas (vapor) phase. It is assumed that the non-uniformity is normally distributed with standard deviation, equal to the maldistribution factor  $M_f$ . The reality of this assumption is confirmed by an analysis of previous experimental data for gas phase small scale maldistribution using modern random IMTP and RSRM packing. The model is tested for ethanol–water rectification using structured HOLPACK packing. Experimental data for seven types of modern packing (IMTP, Raschig Super-Ring (RSR) Metal and Plastic, and Ralu Flow Plastic) at high ethanol concentration are used to estimate the impact of vapor phase small scale maldistribution. It is found that its influence on mass transfer efficiency is quite different, and for various packing it is between 14 and 38 %. For comparison, this value for structured HOLPACK packing is 10-12 %. It is shown that a preliminary analysis of the efficiency reduction due to small scale maldistribution can provide information about the expedience of using a particular type of packing at particular operational conditions.

**Keywords:** Gas maldistribution, distillation, efficiency, packed columns

44. S. Darakchiev, **Kr. Semkov**, Separation Efficiency of HOLPACK Packing for Ethanol-Water Rectification in Different Concentration Ranges, *Journal of International Scientific Publications: Materials, Methods & Technologies*, V. 4., Part 2, 263-274 (2010). ISSN 1313-2539, <http://www.science-journals.eu>.

Journal of International Scientific Publication:  
Materials, Methods & Technologies, Volume 4, Part 2  
ISSN 1313-2539, Published at: <http://www.science-journals.eu>

**SEPARATION EFFICIENCY OF HOLPACK PACKING FOR ETHANOL – WATER  
RECTIFICATION IN DIFFERENT CONCENTRATION RANGES**

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1113 Sofia, Bulgaria

**Abstract**

*In this study the mass transfer efficiency of HOLPACK packing is investigated in ethanol-water rectification in terms of high ethanol concentrations. The results are compared with previous study of this packing for low ethanol concentrations. The comparison shows variation of the efficiency depending on the investigated composition area. The reason is sought in highly variable physico-chemical properties of the system, its vapor-liquid equilibrium character and the different influence of some effects on mass transfer. The most part of the rectification column operates in the range of the highest concentrations, due to the specific type of this system equilibrium. Therefore it is important to study the process in these conditions.*

**Key words:** *Distillation, rectification, packed columns, HOLPACK packing, separation efficiency.*

45. T. Petrova, S. Darakchiev, **Kr. Semkov**, R. Darakchiev, Method for Estimation of the Gas Phase Maldistribution Packed Bed Columns, *Journal of International Scientific Publications: Materials, Methods & Technologies*, V. 4., Part 2, 323-332 (2010). ISSN 1313-2539, <http://www.science-journals.eu>.

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Materials, Methods & Technologies, Volume 4, Part 2  
ISSN 1313-2539, Published at: <http://www.science-journals.eu>

**METHOD FOR ESTIMATION OF THE GAS PHASE MALDISTRIBUTION  
IN PACKED BED COLUMNS**

Tatyana St. Petrova<sup>1</sup>, Simeon R. Darakchiev<sup>2</sup>, Krum A. Semkov<sup>3</sup>, Rumén D. Darakchiev<sup>4</sup>

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**Abstract**

*A detailed analysis of the gas phase maldistribution in packed bed column is carried out based on the experimental data for some random and structured packing at different packing heights. The maldistribution is expressed by the maldistribution factor, calculated from the radial velocity profiles sampled by different number of measuring points. It is shown that by increasing the number of measuring points over the column cross-section the gas maldistribution factor increases gradually but after a definite number of points it does not change more - a "plateau" is reached. This number of the sampling points, respectively the size of the sample area determines the scale of the registered maldistribution – large or small one. This way the different scale maldistributions and the zones where they appear could be identified.*

**Key words:** *Packed columns, Gas maldistribution, Large/small scale maldistribution*

46. **Kr. Semkov**, Evaluation of the Influence of the Vapor Phase Smallscale Maldistribution on the Efficiency of Distillation Packed Columns using a Stochastic Parallel Model, *20<sup>th</sup> European Symposium on Computer Aided Process Engineering (ESCAPE 20)*, 6-9 June, Ischia, Italy, S. Pierucci and G. Buzzi (Editors), Computer Aided Chemical Engineering, 28, ELSEVIER, 1441-1446 (2010). ISBN 978-0-444-53718-8.

20<sup>th</sup> European Symposium on Computer Aided Process Engineering – ESCAPE20  
S. Pierucci and G. Buzzi Ferraris (Editors)  
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## **Evaluation of the influence of the vapor phase maldistribution on the efficiency of distillation packed columns using a stochastic parallel model**

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### **Abstract**

A modeling of the influence of the vapor phase smallscale maldistribution, caused by the discrete structure of the packing on the distillation column efficiency is considered. A recently proposed two parameters stochastic model is used based on experimentally approved normal random distribution of the smallscale non-uniformities where the standard deviation is the maldistribution factor  $M_j$ . A simplified model and numerical solution are proposed, suitable for strongly non-linear system equilibrium, approximating the normal distribution with 9 discrete intervals – so called “stanines” (standard nines). A detailed description of the solution using an example of ethanol-water system is presented. Numerical experiments for wide range of parameter values are carried out for high ethanol concentrations, typical for the majority of the height of an industrial rectification column. A comparison of the influence of the parameters on the mass transfer efficiency is made and some recommendations of the appropriate packing properties for efficiency improvement are given.

47. С. Даракчиев, **Кр. Семков**, Ректификация в колони със съвременни ненаредени пълнежи при променливо флегмово число, *Сборник доклади от Лятна школа за докторанти, постдокторанти и млади учени*, Бургас, 6-8 юли 2010 г., Университет “Проф. д-р Асен Златаров”, 7 -13 (CD).

Лятна школа

06.07. – 08.07.2010 г. – Бургас

“Химични, биохимични технологии и опазване на околната среда”

### РЕКТИФИКАЦИЯ В КОЛОНИ СЪС СЪВРЕМЕННИ НЕНАРЕДЕНИ ПЪЛНЕЖИ ПРИ ПРОМЕНЛИВО ФЛЕГМОВО ЧИСЛО

Симеон Даракчиев, Крум Семков

### RECTIFICATION IN COLUMNS WITH MODERN RANDOM PACKINGS AT VARIABLE REFLUX RATIO

Simeon Darachiev, Krum Semkov

***ABSTRACT** The efficiency of some modern random packing is investigated in ethanol – water rectification depending on the reflux ratio. It was found that decreasing the reflux ratio the efficiency increase to a certain value and then begin to decline. The value of the reflux ratio at which the packings are most effective is determined. It is also shown packing efficiency at a concrete reflux ratio  $R = 3.5$ , where most often the process is accomplished for ethanol production. A comparison between the different packings is made in these conditions.*

***Key words:** packed columns, random packings, distillation, rectification, reflux ratio*

48. С. Даракчиев, **Кр. Семков**, Влияние на флегмовото число върху ефективността на пълнежи за колонни апарати при ректификация на система етанол – вода, *Научни трудове на университета по хранителни технологии – Пловдив*, Том LVII, Св.2, 561-566 (2010).

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15 – 16 октомври, Пловдив



FOOD SCIENCE, ENGINEERING AND  
TECHNOLOGIES '2010  
15 – 16 October, Plovdiv

## ВЛИЯНИЕ НА ФЛЕГМОВОТО ЧИСЛО ВЪРХУ ЕФЕКТИВНОСТТА НА ПЪЛНЕЖИ ЗА КОЛОННИ АПАРАТИ ПРИ РЕКТИФИКАЦИЯ НА СИСТЕМА ЕТАНОЛ - ВОДА

Симеон Даракчиев, Крум Семков

*Изследвана е ефективността на някои съвременни ненаредени пълнежи при ректификация със система етанол – вода в зависимост от флегмовото число. Установено е, че с намаляване на флегмовото число ефективността се повишава до определена стойност, след което започва да се понижава. Определена е стойността на флегмовото число, при която пълнежите са най-ефективни. Направено е сравнение между отделните пълнежи при конкретно флегмово число.*

## INFLUENCE OF THE REFLUX RATIO ON PACKING EFFICIENCY FOR RECTIFICATION OF ETHANOL – WATER SYSTEM

Simeon Darakchiev, Krum Semkov

**Abstract:** *The efficiency of some modern random packing is investigated in ethanol – water rectification depending on the reflux ratio. It was found that decreasing the reflux ratio the efficiency increase to a certain value and then begin to decline. The value of the reflux ratio at which the packings are most effective is determined. It is also shown packing efficiency at a concrete reflux ratio  $R = 3.5$ , where most often the process is accomplished for ethanol production. A comparison between the different packings is made in these conditions.*

49. R. Darakchiev, **Kr. Semkov**, S. Darakchiev, T. Petrova, Methods of approach for reducing the maldistribution in packed columns by dividing the packing into sections, Transactions of Academenergo, Edition of Research Centre for Power Engineering Problems, Kazan, Russian Academy of Sciences, 1, 31-40 (2011). ISSN 2070-4755.

## ПРОМЫШЛЕННАЯ ТЕПЛОЭНЕРГЕТИКА

### METHODS OF APPROACH FOR REDUCING THE MALDISTRIBUTION IN PACKED COLUMNS BY DIVIDING THE PACKING INTO SECTIONS

**R.D. Darakchiev, Kr.A. Semkov, S.R. Darakchiev, T.S. Petrova**  
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Key words: packed columns, liquid maldistribution, gas flow maldistribution, maldistribution factor, wall flow effect, uniformity limit, redistribution devices

#### **Abstract**

The uniform gas and liquid distribution on the packed column cross-section is pivotal for their effective work. Both liquid and gas has tendency to form wall flow at their counter current motion, therefore a distortion of the liquid-gas ratio both on the cross-section and in the height of the apparatus appears. To solve this problem, most often the packing layer (needed for process implementation) is divided into sections. In this work methods for determination of these segments' heights are presented and the flow distribution along this height is demonstrated.

50. A. Korobejnikov, J. M<sup>c</sup>Carthy, A. Melnik, E. Mooney, J. Rojas, **Kr. Semkov**, J. Varghese, T. Zhelev, Mathematical Modelling of Internal Heat Recovery in Flash Tank Heat Exchanger Cascades, *Proceedings of the 75<sup>th</sup> European Study Group with Industry, University of Limerick, June 27<sup>th</sup> – July 2<sup>nd</sup> 2010, Limerick, Ireland* (accepted).

MATHEMATICAL MODELLING OF INTERNAL HEAT  
RECOVERY IN FLASH TANK HEAT EXCHANGER CASCADES

Problem considered at the 75<sup>th</sup>  
EUROPEAN STUDY GROUP WITH INDUSTRY

28<sup>th</sup> June – 3<sup>rd</sup> July 2010

Mathematics Applications Consortium for Science and Industry  
(MACSI), University of Limerick, Ireland

March 18, 2011

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**Abstract**

Flash tank evaporation combined with a condensing heat exchanger can be used when heat exchange is required between two streams and where at least one of these streams is difficult to handle (tends severely to scale, foul, causing blockages). To increase the efficiency of heat exchange, a cascade of these units in series can be used. Heat transfer relationships in such a cascade are very complex due to their interconnectivity, thus the impact of any changes proposed is difficult to predict. Moreover, the distribution of loads and driving forces in different stages and the number of designed stages faces tradeoffs which require fundamental understanding and balances. Addressing these problems this paper offers a mathematical model of a single unit flash tank evaporator combined with a condensing heat exchanger unit. This model is then developed for a chain of units. The purpose of this model is to allow an accurate study of the factors influencing efficiency of the system (maximum heat recovery) and evaluation of the impact of any alteration of the system, thus allowing for guided design or new or redesign of existing system. The proposed model is validated on digester area of RUSAL Aughinish Alumina factory in Ireland.



51. V. Gololo, T. Majozi, T. Zhelev, **Kr. Semkov**, Guided Design of Heating and Cooling Mains for Lower Water and Energy Consumption and Increased Efficiency, *14<sup>th</sup> International Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, PRES'11*, 8-11 May 2011 Florence, Italy, *Chemical Engineering Transactions*, **25**, 755-760 (2011).

## **Guided Design of Heating and Cooling Mains for Lower Water and Energy Consumption and Increased Efficiency**

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Water cooling and water heating is an important source of energy consumption, accounting for more than 20% of all energy consumption in manufacturing industry. It is clear that the development of heat recycling schemes and better structural design can allow reaching significant savings. It is also known from power generation and from the bulk chemicals production that the cooling water systems are generally designed with a set of heat exchangers arranged in parallel. This arrangement results in higher cooling water flowrate and low cooling water return temperature thus reducing cooling towers efficiency. This indicates the importance of the system structure, the possibility of mixing of heating or cooling water; recycling and reuse of heating and cooling resources and finally the importance of distribution of the driving forces to heat transfer. This paper reports a technique for grassroot design of centralised cooling and heating water system for water and wastewater minimization which incorporates the performances of the cooling/heating providers involved. The study focuses on cooling/heating systems consisting of multiple chillers and/or boilers that supply a common set of heat exchangers. The paper takes a conceptual approach to the stated problems, but traces the way for exact solution using the superstructure based mathematical approach (formulating the problem). It explores cooling/heating water reuse opportunity and predicts thermal performance of thermal systems involved.

52. **Kr. Semkov**, Highly effective rectification plants for ethanol production, *BAS NEWS 2005*, “Prof. Marin Drinov” Academic Publishing House, 39-42 (2006).

Брой 6, 2005

Highly effective rectification plants for ethanol production

Ст. н. с. Инст. д-р Крум Семков

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**Области на приложение:** Химическа и хранително-вкусова промишленост, екология

**В** Лаборатория „Топло- и масо- пренос в системи газ-течност“ към ИИХ-БАН се провеждат

дългогодишни изследвания в областта на колонните апарати с пълнеж за провеждане на широкоразпространените процеси абсорбция, десорбция и ректификация, както и за директен топлообмен. Разработени и изследвани са нови високоефективни пълнежи и вътрешни устройства за колони, които позволяват съществено интензифициране на процесите. Успоредно с това се разработват методи за математично моделиране, които да намалят или премахнат необходимостта от провеждане на експериментални изследвания при проектиране на промишлени обекти.

No 6, 2005

Highly effective rectification plants for ethanol production

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**Application areas:** Chemical Industry, Food Industry, and Ecology

**I**n the department of “Heat- and mass transfer in gas-liquid systems” of the Institute of Chemical Engineering

(IChE) – Bulgarian Academy of Sciences investigations of many years in the field of packed columns for the widespread processes like absorption, desorption and rectification, as well direct heat exchange were carried out. New highly effective packing and internal devices for columns were developed and investigated, which contribute to an essential intensification of the processes. Simultaneously, new approaches for mathematical modelling were worked out in order to reduce the experimental investigations necessary for the design of new industrial objects.

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- 52а. **Кр. Семков**, Високоэффективни ректификационни инсталации за етилов алкохол, *БАН Новости, Месечен информационен бюлетин за наука и технологии*, бр.6(22) 2-3 (2005).

## Високоэффективни ректификационни инсталации за етилов алкохол

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*Области на приложение: Химическа и хранително-вкусова промишленост, екология*

**В** Лаборатория „Топло- и масопренос в системи газ-течност“ към НИХ-БАН се провеждат дълготрайни изследвания в областта на колонните апарати с цел да се провежда процесите на широко разпространените процеси абсорбция, десорбция и ректификация, както и за директен топлообмен. Разработени и изследвани са нови високоэффективни пълнеж и вътрешни устройства за колоните, които позволяват съществено интензивизиране на процесите. Успоредно с това се разработват методи за математично моделиране, които да намалят или премахнат необходимостта от провеждане на експериментални изследвания при проектиране на промишлени обекти.

Прилагането на тези постижения при технологичното оборудване за производството на етилов алкохол доведе до създаването на ново поколение инсталации, характеризирани се с изключително високи конструктивни

и енергийни параметри, които ги правят уникални в дадената област. Беше разработен типоред ректификационни инсталации, изградени на модулна принцип с производителност от 1000 до 10 000 l/24 h. Не представлява проблем създаването на инсталации с по-висока производителност.

Инсталациите представляват три, четири или пет колонни системи, изградени в самостоятелни етапа на посеща конструкция, оборудвана с вътрешно съоръжение площадки. Конструкцията включва и всички допълнителни съоръжения (главно топлообменно оборудване) и образува модул с входни и изходни потоци бързо вкопката „0“. Самите колонни апарати също са изградени от модули и позволяват лесно преустройство или ремонт. Сечението на конструкцията е 3x4 m за по-малките инсталации и 3,60x4,90 m за производителност 10 000 l/24 h, а височината е под 15 m. Колоните са с високоэффективна структурен пълнеж „ХОШИАК“ и съответните вътрешни устройства и работят със скорост на парите до 1,0 m/s при хидравлично съпротивление под 40 nPa. Това намалява около 2,5 пъти обема на колоните в сравнение с традиционните колоните с тарелки. Инсталациите се характеризират с ниско енергийно потребление – под 4 kwh пара за литър готов продукт. Апаратите са изработени изцяло

## II. Доклади, кратки съобщения и постерни доклади с резюмета

21. Н. Колев, Кр. Семков, Р. Даракчиев, З. Братанова, Т. Ризов, Резултати от обследване на инсталации за очистване на отпадни води във фармацевтичната промишленост от органични разтворители, VI симпозиум с международно участие "Технически прогрес в канализацията и пречистването на битови и промишлени отпадни води", София 10-11 октомври 1991, Резюме, 25.

### РЕЗУЛТАТИ ОТ ОБСЛЕДВАНЕ НА ИНСТАЛАЦИИ ЗА ОЧИСТВАНЕ НА ОТПАДНИ ВОДИ ВЪВ ФАРМАЦЕВТИЧНАТА ПРОМИШЛЕНОСТ ОТ ОРГАНИЧНИ РАЗТВОРИТЕЛИ

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Зл. Братанова, Т. Ризов  
НИХПЗ-МА, ИТЕМ, ИИХ-БАН

Създадени са и са пуснати в експлоатация инсталации за очистване на отпадни води от производството на антибиотици във фирма "Антибиотик" - гр. Разград от бутилацетат и бутанол, и инсталация за очистване на отпадни води в ЗПМ - гр. Сандански от хлороформ. Принципът на действие на тези инсталации се основава на изпаряване на разтворителите в скрининг колона, концентриране на парите и сепарирането им.

Обследвана е инсталация за доказване на заложените технологични параметри: температурен режим, количество обработени води, начални и крайни концентрации. Концентрацията на хлороформ е определена с газов хроматограф - Сигма-1, Перкин Елмер, снабден с електрон-улавящ детектор и хейд-спейс техника, а на бутилацетат и бутанол - с газов хроматограф 8500 Перкин Елмер - пламъчно-йонизационен детектор.

На базата на направения анализ е определена ефективността на инсталацията и годността и за очистване на промишлени отпадни води от органични разтворители.

22. Н. Колев, **Кр. Семков**, Р. Даракчиев, А. Мирчев, Инсталация за утилизиране на топлината на димните газове при топлофикационни котли, при редуциране на концентрацията на азотните окиси, изхвърляни в атмосферата, *VIII Национална научно-техническа конференция с международно участие "Топло- и ядреноенергийни проблеми на България"*, Варна 1-3 юни 1992, Резюме, 6.

ИНСТАЛАЦИЯ ЗА УТИЛИЗИРАНЕ НА ТОПЛИНАТА НА ДИМНИТЕ ГАЗОВЕ  
ПРИ ТОПЛОФИКАЦИОННИ КОТЛИ, ПРИ РЕДУЦИРАНЕ НА КОНЦЕНТРАЦИЯТА НА АЗОТНИТЕ  
ОКСИДИ ИЗХВЪРЛЯНИ В АТМОСФЕРАТА  
Н.Колев; К.Семков; Р.Даракчиев; А.Мирчев

Добре известно е, че с димните газове се изхвърля в атмосферата една значителна част от топлината на изгаряне на горивото. Тази част е особено голяма при изгарянето на природен газ, където на всеки kg гориво в димните газове се изхвърлят по над 2 kg водна пара. От своя страна предварителното охлаждане на газа подобрява абсорбцията на серен двуокис, в случаите, когато горивото съдържа сяра, а газовете подлежат на почистване. В предлаганата работа е разгледан един нов метод за обработка на димните газове в двустепенен контактен економайзер, при който утилизираната във високотемпературната степен топлина се използва за нагриването на топлофикационна вода. Топлината улесни в високотемпературната степен се използва за нагриване на въздуха, постъпващ в котела. Нагриването на въздуха става при директен контакт в колона с пълнеж, при едновременното му овлажняване. Изгарянето на горивото с влажен въздух повишава температурата на пламъка, при което концентрацията на азотните окиси се повишава с 33%. Повишаването на влагосъдържанието на димните газове от своя страна води до повишаване на температурата на мокрия термометър, а следователно и до повишаване на температурното ниво на утилизираната топлина.

В работата са разгледани две технологически схеми за провеждането на процеса и са дадени технико-икономическите резултати на проектираната по новата технология инсталация.

23. R. Darakchiev, N. Kolev, **Kr. Semkov**, Instalation for recovery of chloroform waste waters flow, 11<sup>th</sup> *International Congress of Chemical Engineering, Chemical Equipment Design and Automation (CHISA)*, Prague 29 August – 3 September 1993, Abstracts E, 141.

## INSTALLATION FOR RECOVERY OF CHLOROFORM FROM WASTE WATERS FLOWS

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The chlorinated hydrocarbons and especially the chloroform are some of the most dangerous pollutants of the environment. On the other side chloroform is an excellent selective extractant in the extraction of valuable products and above all in the field of medicine chemistry. Its high density which allows its easy separation from the water phase and its comparatively low evaporation heat makes it power advantageous. The great harmfulness of chloroform for the environment and its high technical-economic indicators as extractant make the development of highly effective installations for purification for this purpose an especially actual task.

The stripping process is a universal method for purifying of waste waters from volatile organic solvents during regeneration of the solvent. In the present work the experience of the authors in the development of highly effective stripping installation for the purification of waste waters of the pharmaceutical industry from chloroform and some basic results from its investigation are given.

The technological scheme of a stripping installation allowed not only the purification of the water from chloroform but also from free and connected ammonia as the last was utilized in the form of 25% ammonia water. The stripping column was filled with a packing Holpack from arranged in a certain way horizontally displaced sheets of expanded metal. The distance between the neighbouring sheets was 15 mm, and the general height of the packing 6400 mm. The specific surface of the packing was 49 m<sup>2</sup>/m<sup>3</sup>. At first sight a packing with so low specific surface is uneffective. But a characteristic peculiarity of the packing Holpack is that because of the high surface of the droplets and streamlets flowing down between the packing's elements, its effective surface is up to three times greater than the specific. Another circumstance which makes the choice of the packing for this case very appropriate is that the waste industry waters subject to purification contained certain amounts of solid phase and the packing Holpack is one of the most insensitive in relation to clogging packings. Its investigation showed that it ensures a decrease of the concentration of chloroform in the waste waters up to 150 000 times thus getting its final concentration near that in the drinking water. It is seen from the economic estimation of the installation's work that a profit is gained from the purification of the waste waters from chloroform in the proposed installation.

24. N. Kolev, Kr. Semkov, R. Darakchiev, Plants for removal of butyl acetate and butanol from waste waters in antibiotic production, 11<sup>th</sup> *International Congress of Chemical Engineering, Chemical Equipment Design and Automation (CHISA)*, Prague 29 August – 3 September 1993, Abstracts E, 140.

## PLANTS FOR REMOVAL OF BUTYL ACETATE AND BUTANOL FROM THE WASTE WATERS IN ANTIBIOTIC PRODUCTION

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Antibiotics are extracted from their relevant culture media by means of butyl acetate and butanol. The subsequent recovery of these solvents from the waste waters effluent from the extraction unit is obligatory both ecologically and economically. However, both solvents form azeotropic mixtures which transform into two phases upon cooling. The equilibrium curves in both cases show that the waste waters could be purified economically profitable by using a stripping process. The problems of stripping application is that, at high temperature, some organics present in the waste water, settle and cause clogging of the equipment. In the present work, the authors' experience in designing industrial plants for waste water treatment is described. Both plants were designed to treat 30 m<sup>3</sup> waste water per hour each. In both cases, small industrial plants existed before the reconstruction. The authors' accumulated industrial experience showed that heating waste waters in the heat exchanger at temperature over 50°C led to fast deposition of solid phase. On the other hand, to the experience of the authors, the only equipment which could resist clogging, was the hollow spray columns with liquid jet distributors. Naturally, these columns, especially the classical ones, showed low effectiveness, which together with the low heat recuperation rate, determined their high steam consumption and low efficiency for waste water purification. The high economical and ecological effect expected by designing the new plants was made to compensate for the incomplete information on the scale effect by designing new industrial plants at the lack of previous pilot plant studies. The plants considered were designed on the basis of the following:

- (1) The main material which settles when the solution subject to regeneration is being heated, are the proteins contained in the waste waters which coagulate upon heating.
- (2) The removal of the organic solvent may be accompanied by removal of solid substances as well.

These assumptions led to the following technical solutions:

1. Fluid velocity, in the heat exchanger area of water temperature exceeding 50 C, has to be significant, i.e. 2.5 m/s.
2. It is well known that the main part of the solvent in the stripping columns is recovered within a relatively rather small portion of its height. That's why the stripping column was built of two parts, the first hollow sprayed by a nozzle and a special redistributor of the liquid phase and the second with a special, hardly clogged packing.

It is noteworthy that during a four year operation of the plant for removal of butyl acetate and half-year operation of the plant for removal of butanol, no accumulation of solid phase in the units was observed.

25. N. Kolev, R. Darakchiev, **Kr. Semkov**, New generation contact economizers systems for flue gas heat utilization, 11<sup>th</sup> *International Congress of Chemical Engineering, Chemical Equipment Design and Automation (CHISA)*, Prague 29 August – 3 September 1993, Abstracts G, 41.

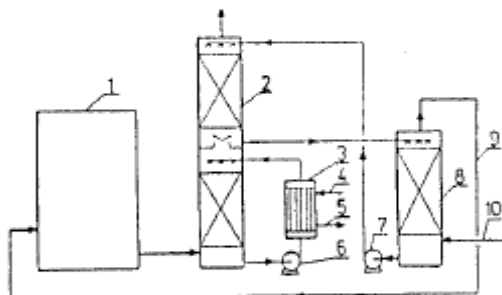
NEW GENERATION CONTACTING CONTACT ECONOMIZERS FOR  
FLUE GAS HEAT UTILIZATION

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A reference is made to the fact that a significant part of the heat generated by combustion, is lost in the atmosphere with exhausted flue gases. Contact economizer systems are considered which help to utilize this heat by heating up the water before entering the boiler or by heating up urban heat supply water of the central heat supply network, as recycled back to the heating plant. Attention is drawn to some features of the new contact economizers which allow pressure drop values as low as 10-20 mm water head at high gas superficial velocities, i.e. up to 3 m/s. New process flow charts with contact economizers which helping to utilize heat at higher temperature levels by simultaneous reduction of nitric oxides emissions down to 33 %, are given.

The plant illustrated in figure operates as follows: The flue gases coming from boiler 1, enter the lower section of the contact economizer where they are cooled whih water coming from heat exchanger 3. The latter is cooled down by central heat



supply water entering through line 4 and leaving through line 5. Circulation is carried out by the pump 6. The partially cooled flue gases are scrubbed additionally in the contact economizer upper section by means of recycle water introduced by pump 7. The water heated in the economizer upper section goes into the distributor of column 8, where air is introduced through line 10, by a blower. The heated and humidified air enters the boiler along line 9, for fuel combustion. The method developed for designing such systems is described, and data obtained in experiments with industrial systems developed by the authors, are presented.

*Acknowledgment*

The study has been supported financially by the National Science Fondation of Bulgaria under Contract No TH 95/91.



26. **Kr. Semkov**, N. Kolev, Unified modeling of absorption, distillation and direct heat transfer processes in packed bed columns, 11<sup>th</sup> *International Congress of Chemical Engineering, Chemical Equipment Design and Automation (CHISA)*, Prague 29 August – 3 September 1993, Abstracts E, 169.

## Unified Modelling of Absorption, Distillation and Direct Heat-Transfer Processes in Packed-Bed Columns

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An unified approach has been proposed for packed column's design for gas (vapour)-liquid systems. As a main principle is adopted that accompanying the basic mass transfer process, certain superposing effects ("side" phenomena") develop, originating from various sources. The most important "side" effects are hydrodynamical nonuniformities (liquid's large and small scale maldistribution) which causes axial and radial mixing and the Marangoni instabilities. That effects may present in absorption as well as in distillation, varying in strength depending on the given conditions. For the evaluation of the main mass transfer and "side" processes unified models and equations for model's parameters have been presented. Based on a similar approach the direct heat transfer can be analysed using the analogy between heat and mass transfer in the gas boundary layer. Evidence for the adequacy of the method has been presented. The method has already been used in designing industrial absorbers, distillation columns and contact economizers.

29. N. Kolev, R. Darakchiev, **Kr. Semkov**, D. Kolev, Second generation of systems with contact economizers for utilizing the heat of flue gases with a significant reduction of nitrogen oxides concentration, *7<sup>th</sup> International Summer School of Chemical Engineering*, Varna 19-25 September 1995, Proceedings, 263.

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SECOND GENERATION OF SYSTEMS WITH CONTACT ECONOMIZERS FOR  
UTILIZING THE HEAT OF FLUE GASES WITH A SIGNIFICANT REDUCTION OF  
NITROGEN OXIDES CONCENTRATION

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The contact economizers are heat and mass transfer apparatuses, usually packed columns, in which the waste flue gases are scrubbed with circular water. The heated water is cooled in a plate heat exchanger, heating pure water. The comparison of different kinds of utilization systems shows, that the best of them from an economical point of view are the contact economizer systems. Their pay-back term is only a few months.

The known contact economizer systems have a substantial disadvantage. The maximal temperature of the heated pure water in them is comparatively low, about 55 °C. This temperature is determined from the temperature of the wet thermometer of the flue gases, which is about 60 °C. The water flows near the boilers, which can be heated to a temperature up to 55 °C are quite limited. In the same time such a great consumer as the water in the district heating systems, because of its high initial temperature, about 55 °C, cannot be used. A new technical device is presented, which gives a possibility for using the heat, utilized in contact economizers, in district heating systems. The principle of the new systems, called second generation systems, is preliminary heating and humidifying of the air used for the combustion of the fuel, using water heat in contact economizers. Two technological schemes with contact economizers are presented and their advantages and disadvantages are discussed. Experimental results from the operation of a steam boiler with preliminary humidified air are given. The results show that the using of second generation contact economizer systems can reduce NO<sub>x</sub> concentration in the flue gases up to 3,8 times. The amount of the utilized heat is 10 to 13% of the heat produced in the boiler itself. It is noted, that the first industrial system of that type is under construction.

30. **Kr. Semkov**, N. Kolev, R. Popov, Influence of axial mixing in liquid phase in packed columns with honey-comb structured packing, *7<sup>th</sup> International Summer School of Chemical Engineering*, Varna 19-25 September 1995, Proceedings, 254.

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**INFLUENCE OF AXIAL MIXING IN LIQUID PHASE IN PACKED COLUMNS  
WITH HONEY-COMB STRUCTURED PACKING.**

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Experiments are performed in order to study the axial mixing in the liquid phase in a column with a new type highly effective structured honey-comb polypropylene packing.

An impulse method with electrolytic tracer is used. The results are obtained "on-line" using a personal computer in combination with a measuring system based on an analogue-digital converter. The disturbance caused by the measuring cell is accounted.

Dependencies for the PÉCLET number (Pe) as a function of the REYNOLDS number (Re) in a large scale of the liquid flow density are obtained.

It is find out that with the rise of the REYNOLDS number three different hydrodynamic regimes take place in the column - an increase, a decrease and again an increase of the PÉCLET number. Critical values of the REYNOLDS number for the different regimes are determined.

Assuming the dispersion model and using an appropriate iterative procedure the liquid boundary layer mass-transfer coefficients with excluded axial mixing are obtained. An analytical expression for these coefficients is derived.

It's found out that the influence of the axial mixing in the honey-comb polypropylene packing reduces the efficiency of the packing with up to 40% and that the same influence is a minimal by Reynolds number  $\approx 108$ .

- 30а. **Кр. Семков**, Н. Колев, Р. Попов, Надлъжно смесване в течната фаза при пластмасови структурирани пълнежи тип пчелна пита, *Трета национална конференция по химия*, Пловдив 14-16 април 1998, Резюме, 270.

270.

**VI/13**

### **НАДЛЪЖНО СМЕСВАНЕ В ТЕЧНАТА ФАЗА ПРИ ПЛАСТМАСОВИ СТРУКТУРИРАНИ ПЪЛНЕЖИ ТИП ПЧЕЛНА ПИТА**

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Проведени се експериментални изследвания за определяне на надлъжното смесване в течната фаза при високоефективни структурирани пълнежи тип "пчелна пита", изготвени от полипропилен и полистирол. За целта е използван метод с електролитен трейсер и единичен  $\delta$ -импулс. Резултатите са получени "on line" при използването на персонален компютър и аналогово-цифров преобразувател. Това позволява пълното автоматизиране на експеримента, включително и обработката на кривите на отклик до получаването на числото на Bodenstein. Смущавашото влияние на измерителната клетка е отчетено по разработен по-рано метод. За целта са проведени предварителни експерименти в колона без пълнеж в широк диапазон на изменение на плътността на оросяване.

Получените резултати и при двата изследвани пълнежа показват наличието на три различни хидродинамични режима. При нарастване на критерия на Reynolds числото на Bodenstein отначало расте, след това намалява, а при още по-височи стойности на Reynolds отново расте. Това очевидно е свързано с особеностите на филмовото течение по стените на пълнежа при различни плътности на оросяване. Определени са критичните стойности на критерия на Reynolds, при които става преходът между различните режими.

Получените резултати са използвани за определяне влиянието на надлъжното смесване в течната фаза върху ефективността на пълнежите. Чрез решаването на еднопараметричния дисперсионен модел по подходяща итеративна процедура са обработени получени по-рано данни за интегралния коефициент на масопредаване в течностния граничен слой. В резултат на това са получени стойностите на локалните коефициенти на масопредаване, върху които надлъжното смесване не оказва влияние. Показано е, че надлъжното смесване може да намали ефективността на пълнежите до 40 %, като минималният ефект е при стойности на Reynolds около 108.

31. **Kr. Semkov**, N. Kolev, Effect of additional diffusion resistance by rectification of systems with positive surface tension gradients, 7<sup>th</sup> *International Summer School of Chemical Engineering*, Varna 19-25 September 1995, Proceedings, 284.

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**EFFECT OF ADDITIONAL DIFFUSION RESISTANCE BY RECTIFICATION OF SYSTEMS WITH POSITIVE SURFACE TENSION GRADIENTS**

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Experimental investigations on vacuum distillation of system chlorobenzene-ethylbenzene in a column with novel highly effective "honey-comb" packing of polypropylene (HC-PP) were carried out. A wide range of experimental conditions was studied, including infinite reflux ( $G/L = 1$ ) and variable reflux ( $G/L < 1$ ) by  $G = \text{const.}$  and  $L = \text{const.}$ , respectively. The effectiveness of the HC-PP packing at the given condition was essentially lower than in absorption. By appropriate representation of the data obtained at constant liquid load and variable vapour rates was shown unambiguously that an additional diffusion resistance (EADR) on the interface appears. It was supposed that the EADR is associated to the influence of the positive surface gradient which stabilizes the interface and smoothes down the hydrodynamic fluctuations. These conditions make possible an diffusion layer in the liquid phase, just to the interface, to be created, where the mass transfer is very slow due to the molecular diffusion. In the cases investigated this effect is very strong and reduces the mass transfer coefficient in the liquid boundary layer up to 40 times. An analysis of the influence of EADR upon the overall mass transfer coefficient was made. It is shown that in the cases investigated this influence is from 1,1 to 3,5 times depending on the mass transfer resistance ratio. So can be explained that in number of cases where the mass transfer is almost wholly controlled by the vapour phase, due to the equilibrium and/or the characteristics of packings, the overall effect of EADR can be very small and could be pass unnoticed.

- 31a. **Kr. Semkov**, N. Kolev, Effect of additional diffusion resistance by rectification of systems with positive surface tension gradients, 12<sup>th</sup> *International Congress of Chemical Engineering, Chemical Equipment Design and Automation (CHISA)*, Prague 25-30 August 1996, Summaries 3, 161.

**Effect of additional diffusion resistance by rectification of systems with positive surface tension gradients**

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Experimental investigations on vacuum distillation of system chlorobenzene-ethylbenzene in a column with novel highly effective "honey-comb" packing of polypropylene (HC-PP) are carried out. A wide range of experimental condition is studied, including infinite reflux ( $G/L=1$ ) and variable reflux ( $G/L<1$ ) by  $G=\text{const}$  and  $L=\text{const}$ , respectively. It is shown that the effectiveness of the HC-PP packing at the given conditions is essentially lower than in absorption.

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32. **Kr. Semkov**, Liquid boundary layer mass transfer coefficients in structured packings with vertical walls, 7<sup>th</sup> *International Summer School of Chemical Engineering*, Varna 19-25 September 1995, Proceedings, 285.

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**LIQUID BOUNDARY LAYER MASS TRANSFER COEFFICIENTS IN  
STRUCTURED PACKINGS WITH VERTICAL WALLS**

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It is supposed that the local liquid boundary layer mass transfer coefficients in structured packings with vertical walls could be determinate using the theoretical dependences for film flow. In order to prove the given assumption, experimental investigations of the liquid boundary layer controlled mass transfer in a column with a novel highly effective structured "honey-comb" packing (HC-PP) of polypropylene were carried out. From the results obtained, the local mass transfer coefficients were calculated, using the one-parameter dispersion model and an appropriate iterative procedure. The Bodenstein number, which characterises the axial mixing in this model, was determined from equations, derived by another experiments with electrolyte tracer. The so-found local liquid boundary layer mass transfer coefficients were used for deducing of three criterial equations for different range of Reynolds number. The discrepancy between the equation for the middle range (when the packing is fully wetted and there are not undulations on the film surface) and the theoretical equation is only 3,4%. At  $Re_t > 108$  undulations on the surface appear and the mass transfer coefficients are higher than the theoretical and at  $Re_t < 64,2$  - is smaller due to the not full wetting of the packing.

- 32a. **Kr. Semkov**, Liquid boundary layer mass transfer coefficients in structured packings with vertical walls, 12<sup>th</sup> *International Congress of Chemical Engineering, Chemical Equipment Design and Automation (CHISA)*, Prague 25-30 August 1996, Summaries 3, 162.

**Local liquid boundary layer mass transfer coefficients and effective surface area of structured packings with vertical walls**

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33. Р. Даракчиев, Н. Колев, **Кр. Семков**, Системи с контактни економайзери за оползотворяване на топлината на отпадни газове, *Втора национална конференция по химия*, Пловдив 12-14 април 1995, Резюме, VII/1 339.

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### СИСТЕМИ С КОНТАКТНИ ЕКОНОМАЙЗЕРИ ЗА ОПОЛЗОТВОРЯВАНЕ НА ТОПЛИНАТА НА ОТПАДНИ ГАЗОВЕ

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Известно е, че от 13 до 18% от топлината отделяна при изгарянето на горивото в парни и водогрейни котли се изхвърля с димните газове в атмосферата. От всички типове съоръжения, за оползотворяване на тази топлина, най-подходящи от икономическа гледна точка, са системите с контактни економайзери. Една такава система, при вариант първо поколение, се състои от колона с пълнеж, в която димните газове се промиват с циркуляционна вода и топлообменен блок, с висок коефициент на топлопреминаване, в който нагретият воден поток отдава топлината си на чиста вода. Най-същественото предимство на тези системи е, че нагряването с газовата фаза, характеризиращо се с нисък коефициент на топлопреминаване, се извършва върху ефективната повърхност на пълнежа на колонния апарат, която е много евтина. Докладът разглежда някои конструктивни особености на създадените от авторите системи с контактни економайзери, както и тяхното оразмеряване, на базата на решаването на системата от нелинейни балансови диференциални уравнения на топло и масообмена в апарата. Дадени са технологичните схеми на системите контактни економайзери второ поколение и е отбелязано, че тяхното използване позволява да се понижи с до 3,8 пъти концентрацията на азотните окиси в димните газове. Друго съществено предимство на тези системи е обстоятелството, че утилизираната при тях топлина е на по-високо температурно ниво, което позволява използването и за нагряване на топлофикационна вода, при градското топлоснабдяване. Отбелязано е, че досега в промишлеността работят 4 системи с контактни економайзери първо поколение. Изгражда се първата система от второ поколение.

34. **Кр. Семков, Н. Колев, Р. Даракчиев**, Единен подход за изчисляване на височината на колони с пълнеж за провеждане на абсорбционни и десорбционни процеси, ректификация и директен топлообмен, *Втора национална конференция по химия*, Пловдив 12-14 април 1995, Резюме, VII/4 342.

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### ДИНЕН ПОДХОД ЗА ИЗЧИСЛЯВАНЕ НА ВИСОЧИНАТА НА КОЛОНИ С ПЪЛНЕЖ ЗА ПРОВЕЖДАНЕТО НА АБСОРБЦИОННИ И ДЕСОРБЦИОННИ ПРОЦЕСИ, РЕКТИФИКАЦИЯ И ДИРЕКТЕН ТОПЛООБМЕН

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От всички известни апарати за провеждане на топло-масообменни процеси колоните с пълнеж се характеризират с най-ниско хидравлично съпротивление, отнесено към една преносна единица. Един съществен техен недостатък, който пречи на широкото им разпространение е ненадеждното изчисляване на височината на пълнежа при отсъствие на данни за промишелни апарати. Ето защо създаването на единна методика, с помощта на която могат да се изчисляват апаратите при всички изброени по-горе процеси, при използването на едни и същи нелинейни балансови диференциални уравнения и едни и същи критериални уравнения за определяне на коефициентите на масопредаване и на ефективната повърхност на пълнежа е толкова актуално. В работата са описани етапите по решаването на тази задача. Първият етап включва осигуряването на равномерност в разпределението на потоците по сечинието на пълнежа. Показано е, че при осигуряване на равномерно разпределение, проблемът на мащабния преход престава да съществува. Вторият етап на изследванията включва отчитането в математичния модел на надлъжното смесване и ефекта на Марангони. Показано е, че при отчитането на тези явления, в единен модел на топло-масообменния процес, полученото съвпадение между експерименталните и изчислени данни за височината на пълнежа, при различни типове процеси, е много добро. Дадени са примери за промишлени апарати, оразмерени с помощта на получения модел.

36. N. Kolev, R. Darakchiev, **Kr. Semkov**, D. Kolev, New generation contact economizer systems for flue gas heat utilization, 12<sup>th</sup> *International Congress of Chemical Engineering, Chemical Equipment Design and Automation (CHISA)*, Prague 25-30 August 1996, Summaries 5, 10.

NEW GENERATION CONTACT ECONOMIZER SYSTEMS  
FOR FLUE GAS HEAT UTILIZATION

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Significant part of the heat generated by combustion is thrown out in the atmosphere with exhausted flue gases. The contact economizer systems are designed to utilize the flue gases heat contents for heating up the feed water for the boilers or for district heating network. A disadvantage of the existing systems of previous generation is the fact that they can warm up the water to about 55°C. This limit is imposed by the temperature of the flue gases wet thermometer - usually about 60°C. Because of the limited amount of the feed water that could be heated with the energy recuperated at this temperature, the heat contents of a great part of the flue gases can not be utilized.

The second generation systems of contact economizers are intended to heat the water flows circulating in the district heating systems. The temperature of the cooled flow is about 55°C. To warm up a flow with such a great initial temperature by using contact economizers, it is necessary to increase the temperature of the flue gases wet thermometer. It is obtained by a preliminary humidification of the air fed in the boiler. The new system contact economizers consists of two consecutively mounted apparatuses. The water circulating in the first of them heats up through a heat exchanger the water for central heating use. The water heated in the second contact economizer by the flue gases, partially cooled in the first one, heats and humidify in a packed column the air used for the combustion of the fuel.

The mathematical model for dimensioning of the contact economizers is presented in the paper. Also the results of tests of the first industrial installation are given. It is shown that by humidifying the gas it becomes possible to reduce significant the nitrogen oxides concentration. The quantity of the heat energy utilized in the installation is between 12-15 % of the heat energy of the boiler.

40. **Кр. Семков**, Идентификационен метод за определяне на надлъжното смесване в колони с пълнеж, *Трета национална конференция по химия*, Пловдив 14-16 април 1998, Резюмета, 268.

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## ИДЕНТИФИКАЦИОНЕН МЕТОД ЗА ОПРЕДЕЛЯНЕ НА НАДЪЛЖНОТО СМЕСВАНЕ В КОЛОНИ С ПЪЛНЕЖ

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Разработен е нов идентификационен метод за определяне на надлъжното смесване и локалните коефициенти на масопредаване в течностния граничен слой в колони с пълнеж. Методът се базира на измерване на интегралния коефициент на масопредаване при процес, контролиран от двата гранични слоя. Провеждат се експериментални серии при постоянна плътност на оросяване и различна скорост на газа (парите). За всяка експериментална точка се решават система уравнения, съставена от уравнението на дисперсионния модел, адитивността на фазовите съпротивления и критериално уравнение за коефициента на масопредаване в газовия (паровия) граничен слой. При това за свободен параметър се избира числото на Bodenstein в течната фаза, а решението се търси като локален коефициент на масопредаване в течностния граничен слой. За всяка серия експериментални изследвания се идентифицира числото на Bodenstein при критерий минимално средно квадратично отклонение на получените стойности на коефициента на масопредаване.

Методът дава възможност за определяне на надлъжното смесване при реалните условия на процеса и конкретните свойства на работните системи. Това е основното му предимство пред методите с електролитен трейсер. Той може да бъде използван във всички случаи, когато не се проявяват съществени повърхностни ефекти в течната фаза.

За тестване на метода са проведени изследвания с пълнеж от полипропилен тип "пчелна пита" при десорбция на амоняк от водни разтвори. По идентификационния метод са получени стойности на числото на Bodenstein в широк диапазон на плътности на оросяване. Съвпадението с резултатите, получени при същия пълнеж с електролитен трейсер е много добро, като по такъв начин е доказана приложимостта на метода.

41. T. Petrova, **Kr. Semkov**, P. Moravec, Determining the characteristic size of the packing in the mathematical model describing spreading of liquid in the packed bed columns with wall flow deflecting rings, *9<sup>th</sup> International Summer School of Chemical Engineering*, Sozopol 18-24 September 2001, Proceedings, 63.

**DETERMINING THE CHARACTERISTIC SIZE OF  
THE PACKING IN THE MATHEMATICAL MODEL,  
DESCRIBING SPREADING OF THE LIQUID  
IN PACKED BED COLUMNS WITH WALL  
FLOW DEFLECTING RINGS**

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A method is proposed for determining of the characteristic size of a packings with complex geometry which is a parameter in the mathematical model, describing spreading of liquid in packed bed column with wall flow deflecting rings. The model determines the theoretical density of irrigation as a function from the characteristic size of the packing and the width of the wall flow deflecting ring. The method is based on locating the minimum of the residual variance between theoretical and experimental data for the density of irrigation, at different values of the characteristic size.

The experimental data for the density of irrigation are obtained in a column with diameter 188.6 mm, packings Pall rings and Intalox saddles, at the presence of two wall flow deflecting rings along the height of the packing. The values for the characteristic size of the investigated packings are obtained. The results are presented graphically and in tables also.

42. T. Petrova, **Kr. Semkov**, Ch. Dodev, Identification of the parameters of the mathematical model describing the distribution of the gas in a packed bed column with new gas-distribution device, *9<sup>th</sup> International Summer School of Chemical Engineering*, Sozopol 18-24 September 2001, Proceedings, 62.

**A9**            **IDENTIFICATION OF THE PARAMETERS OF THE  
MATHEMATICAL MODEL DESCRIBING THE DISTRIBUTION  
OF THE GAS IN A PACKED BED COLUMN WITH NEW GAS-  
DISTRIBUTION DEVICE**

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A mathematical model is proposed for describing the distribution of gas in a packed bed column at different initial feeding of the gas. A simulation is performed on the radial profile of the speed of the gas flow at a new device, which supplies the inlet gas flow around the whole perimeter of the column under the packing. The results are compared with experimental data, obtained in columns with "Honey-comb" structured packing at several packing heights. The maldistribution factor of the gas flow is also measured for this type of gas-distribution device and for different geometry for the column and for the packing.

Through subsequent two-parameter optimisation by minimizing the residual variance among the experimental and theoretical data of the speed of the gas are identified two of the parameters of the model.

The optimal height of the packing section is calculated, for which the outlet profile should be regular.

The results from the identification and from the comparison between the experimental and the theoretical speed profiles are given graphically.

43. Т. Петрова, **Кр. Семков**, Математично моделиране на разтичането на течността в колони с пълнеж при наличие на отражателни пръстени за подобряване на радиалното разпределение. Идентификация на параметрите, *Четвърта национална конференция по химия*, София 27-29 септември 2001, Резюме, 211.

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**МАТЕМАТИЧНО МОДЕЛИРАНЕ НА РАЗТИЧАНЕТО НА ТЕЧНОСТТА В КОЛОНИ С ПЪЛНЕЖ ПРИ НАЛИЧИЕ НА ОТРАЖАТЕЛНИ ПРЪСТЕНИ. ИДЕНТИФИКАЦИЯ НА ПАРАМЕТРИТЕ**

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Показано е използването на комплексен идентификационен метод за определянето на неизвестни параметри в два различни математични модела, описващи разтичането на течност в колона с пълнеж при отсъствие и наличие на отражателни пръстени. Граничното условие при стената на колоната е двупараметрично и едно и също за двата модела. При първият модел методът ползва експериментални данни за равномерно и пристенно начално оросяване, откъдето директно се определя единият от параметрите. За намирането на втория параметър и на коефициента на разтичане е проведена последователна нелинейна оптимизация с критерий минимална остатъчна дисперсия между модела и експеримента. Методът е демонстриран за три вида пълнеж - пръстени на Pall, сегла Intalox и MiniRing. За първите два са получени съответните параметри на граничното условие и на коефициента на разтичане. За пълнеж MiniRing е показано наличието на условия, при които този метод не е приложим. При втория модел методът има за цел определянето на характерния размер на пълнежа при разтичане в колона с пълнеж и отражателни пръстени по стената на колоната. Наличието на отражателни пръстени налага въвеждането в модела на вероятностна функция, която участва в началното условие след всеки отражателен пръстен. Тя отчита разпределението на течността в близост до стената на колоната като функция от характерния размер на пълнежа. Идентифицирани са характерните размери за пръстени на Pall и сегла Intalox чрез оптимизация по минимума на дисперсията. За целта се използват експериментални данни, измерени в колона с два отражателни пръстена и параметрите на граничното условие, получени от идентификацията по първия модел. Двамата математични модела бяха тествани за адекватност по критерия на Fisher. Резултатите са дадени графично и с таблици.

44. Н. Колев, Р. Даракчиев, **Кр. Семков**, Св. Наков, Резултати от изследванията в областта на колоните с пълнеж, провеждани в Института по инженерна химия при БАН, *Юбилейна научна сесия “50 години Инженерна химия в България”*, София 23-25 септември 2003, Резюме, I Пленарни доклади, 17.

**I-9. РЕЗУЛТАТИ ОТ ИЗСЛЕДВАНИЯТА В ОБЛАСТТА НА КОЛОНИТЕ С  
ПЪЛНЕЖ ПРОВЕЖДАНИ В ИНСТИТУТА ПО ИНЖЕНЕРНА ХИМИЯ ПРИ БАН**

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Разгледани са постиженията на лаборатория “Топло и масообменни процеси в системи газ-течност” в областта на колоните с пълнеж. Отбелязани са следните основни резултати от проведените изследвания:

1. Създадени са четири нови типа високоефективни пълнежи за колони апарати, както и три нови конструкции преразпределители на течната фаза.

2. Създадени са отражателни пръстени за премахване на вредното влияние на разтичането на течната фаза по стената на апарата, както и методика за тяхното оразмеряване.

3. Създадени са три вида наредени пълнежи за преразпределяне на течната фаза под оросителното устройство.

4. Създадена е единна методика за определяне височината на колоните с пълнеж отчитаща надлъжното смесване, стефановския поток и ефекта на Марангони. Показано е че тя позволява оразмеряването на абсорбционни, десорбционни и ректификационни колони, както и колони за директен топлообмен при използване на едни и същи критериални уравнения за изчисляване на ефективната повърхност и частните коефициенти на масопредаване.

5. Получени са нови критериални уравнения за определяне на работните характеристики на колоните с пълнеж.

6. На базата на новите пълнежи и оросителни устройства и методиката за тяхното оразмеряване са развити и внедрени в промишлеността нови технологии за почистване на отпадни води и газове и за утилизация на отпадна топлина от отпадни газове.

На базата на проведените изследвания са проектирани и внедрени в промишлеността, у нас и в чужбина, инсталации и отделни апарати за провеждането на 19 различни технологически процеса. Общият брой на патентно защитените внедрени апарати е над 900.

**Ключови думи:** *колони с пълнеж, интензификация, изчисляване, надлъжно смесване, внедряване*



45. T. Petrova, **Kr. Semkov**, New approach for modeling of gas distribution in packed columns, *Jubilee Scientific Conference with International Participation, University of Chemical Technology and Metallurgy, Sofia 4-5 June 2003, Abstracts*, 209.

**III.P.4 NEW APPROACH FOR MODELING OF GAS  
DISTRIBUTION IN PACKED COLUMNS**

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A method for mathematical modeling of gas distribution in a packed column is proposed by means of a dispersion model, in which the redistribution ability of gas distribution device (GDD) and that of the packing are separately accounted. The additivity of the packing redistribution capability and the GDD has been proved. The distribution ability is a parameter of the model and is identified by non-linear optimization for the minimum of residual variance between theoretical and experimental gas velocity. The adequacy between the model and the experiment for "Honey-comb" packing is checked.

An analytical formula has been derived for the maldistribution factor of the gas flow, which depends on the model distribution parameter and the initial conditions for GDD. A comparison has been made between the theoretical and the experimentally measured maldistribution factor for "Honey-comb" packing. The same is done with experimental data of other authors for three different sizes Pall rings.

Keywords: packed columns, maldistribution factor, mathematical modeling, distribution ability

46. **Kr. Semkov**, S. Darakchiev, Mathematical modeling of horizontal expanded sheet packing efficiency for distillation of the system ethanol-water, 10<sup>th</sup> *International Summer School of Chemical Engineering*, Varna 24-31 May 2004, Proceedings, 290.

**MATHEMATICAL MODELING OF HORIZONTAL EXTENDED SHEET  
PACKING EFFICIENCY FOR DISTILLATION OF THE SYSTEM  
ETHANOL-WATER**

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**SUMMARY**

The main difficulty in determination of distillation columns height are due to attendant phenomena, which influence the interphase mass transfer. The most important among them are axial mixing, radial irregularity of flow distribution, and superficial phenomena as hydrodynamic instability of the interphase (Marangoni effect), etc. The rate of influence of these phenomena depends on the physico-chemical properties of phases as well as on the distribution of resistance between them. In previous investigations an unified approach to modeling of packed-bed columns has been proposed that accounts for the mentioned phenomena.

The present work examines the possibility for using of this approach in the treatment of experimental data obtained at distillation of ethanol-water mixture in a column with horizontal extended sheet packing at very large variation of alcohol concentration. The peculiarity of this data is a strong dependence of packing efficiency on ethanol concentration.

The mathematical model is applied separately to the analysis of longitudinal mixing influence and to Marangoni effect. Very good coincidence of experimental and calculated packing height is obtained at low and medium ethanol concentrations. At very high concentrations the model shows some deviation, which is attributed to the insufficient accounting of the physico-chemical properties. A correction for elimination of this shortcoming is proposed.

47. S. Darakchiev, **Kr. Semkov**, Performance of extended sheet packing in distillation of ethanol-water mixture in high alcohol concentration range, 10<sup>th</sup> *International Summer School of Chemical Engineering*, Varna 24-31 May 2004, Proceedings, 291.

**PERFORMANCE OF EXTENDED SHEET PACKING IN DISTILLATION OF ETHANOL-WATER MIXTURE IN HIGH ALCOHOL CONCENTRATION RANGE**

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**SUMMARY**

The packing of horizontally arranged extended sheets is very efficient for realization of absorption and distillation processes. Studies on this packing applied to an important industrial system ethanol-water in low and medium ethanol concentrations have shown potentials for significant apparatus intensification. The purpose of this work is to investigate the packing operation in high alcohol concentration range. Due to particular system equilibrium, a prevailing part of the column operates in this concentration range.

The experiments are carried out in an installation, including a column 0.213 m in diameter with 1.54 m packing height, condenser, pipelines, control and measurement devices, and control panel. Column heating is done by twenty six electric resistance heaters with total power of 37.15 kW, which can be gradually changed. The samples are analyzed by an interferometric method. In order to improve the analysis precision, high concentrated samples are diluted to become lower than  $9 \cdot 10^{-2}$  mol/mol.

All experimental results are obtained in full reflux regime. The density of irrigation has been varied from  $1.44 \cdot 10^{-3}$  m/s to  $7 \cdot 10^{-2}$  m/s. The vapor velocity has been varied from 0.421 m/s to 0.777 m/s.

The results are presented as volume mass transfer coefficient, height of a transfer unit HTU and height of a theoretical stage HETP as a function of the mean vapor velocity in the column. The analysis of results shows strong influence of ethanol concentration on efficiency. Maximal efficiency is obtained at medium concentrations about 0.56 mol/mol. The efficiency is reduced at lower and higher concentrations, which is explained by the strong change of physico-chemical properties of the system.

48. T. Petrova, **Kr. Semkov**, Simulation of gas distribution in modern high-efficient random packings using an enhanced dispersion model, 10<sup>th</sup> *International Summer School of Chemical Engineering*, Varna 24-31 May 2004, Proceedings, 288.

**SIMULATION OF GAS DISTRIBUTION IN MODERN HIGH-EFFICIENT  
RANDOM PACKINGS USING AN ENHANCED DISPERSION MODEL**

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**SUMMARY**

An enhanced dispersion model for gas distribution accounting for the discrete structure of the packing is applied to modern high efficient packings. A large number of experimental results for different packings are treated: metal Raschig-Super Rings – 6 sizes, metal saddles IMTP – 4 sizes, and plastic rings Ralu Flow – 2 sizes. The experiments have been carried out in a 470 mm column diameter with the same inlet gas distribution device. For all packings, the values of radial gas spreading coefficient are identified by means of non-linear optimization. The influence of discrete packing structure is taken into account by experimental determination of maldistribution factor at uniformity limit.

The influence of inlet gas distribution device is identified on the base of all experimental data. The same influence is determined also by treatment of experimental data for column without packing. A comparison of both results is done.

It is shown that the enhanced dispersion model accounting for both the packing discrete structure and inlet gas distributor influence gives the possibility for high precision simulation of the maldistribution factor for all investigated packings.

49. **Kr. Semkov**, S. Darakchiev, Performance of Raschig Super Ring packings in distillation of ethanol-water mixture, *1<sup>st</sup> South East European Congress of Chemical Engineering*, Belgrade, Serbia and Montenegro, September 25-28, 2005, Book of Abstracts, 54.

1<sup>st</sup> South East European Congress of Chemical Engineering

GCEN P-24 Iph

### Performance of Raschig Super Ring Packings in Distillation of Ethanol-Water Mixture

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The Raschig Super Ring packings are modern high efficient random packings for realization of absorption and distillation processes. The purpose of this work is to investigate the efficiency of this packing in distillation of the important industrial system ethanol-water mainly in the high alcohol concentration range. Due to particular system equilibrium, a prevailing part of the column operates in this concentration range.

The experiments are carried out in an installation including a column 0,213 m in diameter with 2,8 m packing height. Column heating is done by electric resistance heaters with total power of 45 kW, which can be gradually changed. The installation construction enables operating with constant and variable reflux ratio.

Three types of Raschig Super Ring packings made of metal are studied: No.No. 0,5; 0,7; 1. A part of the experiments are carried out in total reflux regime in the vapor velocity range from 0,253 m s<sup>-1</sup> to 0,936 m s<sup>-1</sup> and density of irrigation from 4,44·10<sup>-4</sup> m<sup>3</sup>/(m<sup>2</sup> s) to 1,63·10<sup>-3</sup> m<sup>3</sup>/(m<sup>2</sup> s) respectively.

Also experiments are carried out with variable reflux ratio realized by: constant density of irrigation and variable vapor load; constant vapor load and variable density of irrigation.

The results are presented as height of a transfer unit (HTU) and height equivalent to a theoretical plate (HETP) as function of the phases' velocities. Comparison of the efficiency of the investigated packings with another high efficient packing - HOLPACK, used in distillation of the same system, was made.

50. **Kr. Semkov**, T. Petrova, Simulation of gas distribution in packed bed columns accounting for the discrete structure of the packing, *1<sup>st</sup> South East European Congress of Chemical Engineering*, Belgrade, Serbia and Montenegro, September 25-28, 2005, Book of Abstracts, 55.

September 25-28, 2005, Belgrade, SCG

**Simulation of Gas Distribution in Packed-Bed Columns Accounting  
for the Discrete Structure of the Packing**

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GCEN-P-23 (p)

An enhanced mathematical model of the gas distribution in packed-bed columns is proposed. It takes into account the packed bed inhomogeneity due to the discrete structure of the packing and the difference between the local geometry in the bulk and in the wall zone.

The real maldistribution factor can be expressed as a result of superposition of the maldistribution factor derived from the dispersion model for isotropic medium and a "noise" maldistribution ones due to the packing inhomogeneity. It is shown theoretically that the superposition can be present as additivity of the squares of above mentioned maldistribution factors. The "noise" factor is considered as a sum of static and dynamic components. The static component reflects the influence of the packing discrete structure and the dynamic one – the influence of height of packing on the ratio between the bulk and the wall zone gas permeability. The definition of the both components is given.

The application of the enhanced model requires an experimental data for change of maldistribution factor with the packing height and also the minimal value of maldistribution factor (uniformity limit) for some height (penetration depth). It is shown that the uniformity limit represents the static "noise" component and characterizes the packing discrete structure. The influence of dynamical component is demonstrated in the model based on the experiments, for which the maldistribution factor is investigated after the penetration depth.

The model is tested with the author's experimental data for modern high-effective random packings and structured ones as well as for results from other literature published.

51. T. Petrova, R. Darakchiev, **Kr. Semkov**, S. Darakchiev, On the precision of measuring the gas flow maldistribution factor in packed columns, *5-th International conference of the Chemical Societies of the South-East European Countries*, Ohrid, Republic of Macedonia, September 10-14, Book of abstracts, vol.I, CHE-19, 231 (2006).

**CHE – 19**  
**ON THE PRECISION OF MEASURING THE GAS FLOW**  
**MALDISTRIBUTION FACTOR IN PACKED COLUMNS**

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To estimate the uniform distribution of a gas flow, the integral index maldistribution factor  $M_f$  is normally used which takes into account the local values of the gas velocity in the column cross section, as well as the area of this cross section. The maldistribution factor is a measure of different kinds of maldistribution - large-scale and small-scale, which deteriorates the packed column efficiency.

A matter of interest is what is the minimum number of measuring points for accounting the different kinds of maldistribution and how should they be situated on the column cross section to have a correct value of  $M_f$ . Experimental data for velocity profiles at the end of a packed layer of different structured and random packings (Honey-comb, Holpack, Raschig Super-Ring (metal and plastic), IMTP, Pali rings) is analyzed to this end. Two kinds of data are used - measurements taken in equal by area cells covering the whole apparatus' cross section, and measurements taken along two perpendicular diameters.

At increasing the number of points,  $M_f$  increases gradually and after a definite number of points it does not change - a "plateau" is reached. The degree of accounting the small-scale maldistribution increases at increasing the point's number and after reaching the "plateau" the maldistribution is completely accounted by  $M_f$ .

Large-scale maldistribution in packed columns is due to different reasons. These are the initial maldistribution caused by the inlet device, the higher porosity at the wall zone as well as the variation of the equivalent packing diameter in the wall zone and in the bulk of the packing layer at increasing the packing height (for some packings).

It is shown that the large-scale maldistribution and the enhanced porosity of the wall zone can be accounted correctly by measuring the gas flow velocities along two perpendicular diameters. The variation of  $M_f$  (depending on the number of measuring points in the wall zone and in the central zone) at increasing the packed layer height for some modern random packings is also investigated.

52. S. Darakchiev, T. Petrova, **Kr. Semkov**, R. Darakchiev, On the velocity influence on the gas maldistribution in packed columns, *Sixth International Conference of the Chemical Societies of the South-Eastern European Countries*, Sofia 10-14 September, Book of Abstracts, 287 (2008).

Sixth International Conference of the Chemical Societies  
of the South-Eastern European Countries  
10-14 September 2008, Sofia, Bulgaria

Chemical Engineering

#### **6-O4. On the velocity influence on the gas maldistribution in packed columns**

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The packed columns, especially those with modern random or structured packing, have good heat and mass transfer characteristic and low pressure drop. One of the main reasons for their insufficient use is the non-uniform gas and liquid distribution, which decrease their efficiency.

It is of interest to investigate the influence of the gas velocity on the gas flow non-uniformity at uniform liquid distribution across the column cross section. This comes from operating reasons of the packed columns as technological regimes lead sometimes to velocity change. In these cases is important to be kept the uniform distribution of the flows at velocity change at wide range.

The review of the publications, which discuss the gas velocity influence on the maldistribution factor  $M_f$  for random and structured packings shows that at short layers the maldistribution increase with gas velocity increase. It is shown that the most used gas distribution devices do not change the gas distribution at velocity change across the column cross section. It is determined that these gas distributing devices with different initial maldistribution provides equal maldistribution after a definite packing height. It is important that after reaching the typical of every packing penetration depth the packing keep the maldistribution at velocity change. Thus, they provide the packing's characteristic uniformity limit at wide range – for example by changing velocity three times. All of this guarantee enough gas flow uniformity at technological regimes change at operating conditions.



53. T. Petrova, S. Darakchiev, **Kr. Semkov**, R. Darakchiev, About an estimation of a degree of gas flow maldistribution in packed bed columns. Determining of the maldistribution factor, *Sixth International Conference of the Chemical Societies of the South-Eastern European Countries*, Sofia 10-14 September, Book of Abstracts, 293 (2008).

Sixth International Conference of the Chemical Societies  
of the South-Eastern European Countries  
10-14 September 2008, Sofia, Bulgaria

Chemical Engineering

**6-P5. About an estimation of the degree of gas flow maldistribution in packed bed columns. Determining of the maldistribution factor**

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One of the main problems that deteriorate packed beds' performance is the non-uniformity of the gas and liquid phases' distribution in the column bulk. The sources of the non-uniformity depend on the type of the gas and liquid inlet device, gas and liquid velocities in the apparatus, and the height and type of the packing layer – random or structured.

A review on the existing methods for estimation of gas flow non-uniformity across the column cross-section is made. The main criterion enabling the quantity measure of the gas flow non-uniformity in the column is the maldistribution factor. It is a measure of the deviation of the local gas flow velocities from their mean value, measured for an arbitrary column cross-section. Depending on the area of column cross-section, on which they are observed, different types of gas flow non-uniformity are estimated through this value. It is possible to obtain the gas flow non-uniformity estimation by means of ratios of motion's quantity or kinetic energies of the gas flow across the given column cross-section. A third method for the gas-flow non-uniformity estimation is by the ratio between the maximum local and mean velocities of the gas flow.

It is determined that the correctness and precision of the maldistribution factor depends on the packing structure – random or structured, the distance between the flow velocity measuring device and the packing layer, the packing recharging, the number of measuring points and their location over the column cross-section. The basic formulas for calculating the maldistribution factor, proposed by a variety of investigators are analyzed, as well as the used different measuring schemes. In the circumstance that every kind of packing has its own non-regularity, unified method for calculating the maldistribution factor to be used as the only criterion to estimate the non-uniformity in the apparatus can not be generalized. The cases in which the using of a concrete measuring scheme for the gas-flow velocity profile is preferred are shown with a view to giving an account of the correct value of gas flow maldistribution factor.

54. E. Mooney, T. Zhelev, **Kr. Semkov**, J. Varghese, Improving Industrial Energy Performance through Low Grade Waste Heat Recovery, ENVIRON 2010, Dep.of Applied Science & Environmental Sciences Association of Ireland (ESAI), Limerick Institute of Technology 17-19 Feb. 2010, Limerick, Ireland.



## Improving Industrial Energy Performance through Low Grade Waste Heat Recovery



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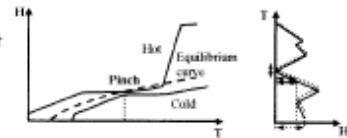
### INTRODUCTION

Improving the energy performance of industries in Ireland is very important for both industry itself and for the Irish Nation, ensuring more flexibility and energy security. One of the priority research themes of this programme is low grade waste heat recovery. The work is aimed at recovery and utilization of low grade energy improving overall process efficiency.

### The Process

The main investigation is focused towards:

- i. Identification of sources of low grade energy and waste energy streams in Industry
- ii. Identification of the proportion of low grade heat currently generated but not used in Industry.
- iii. Research of the potential for using recovered heat or other forms of energy derived from it.
- iv. Investigation of the state of the art in low grade energy utilisation in literature.
- v. Identification of principles, methods, tools and procedures suitable for application or adaptation for Irish environment.
- vi. Formulate promising projects for I2E2 consortium member companies.



55. **Kr. Semkov**, T. Zhelev, E. Mooney, J. Varghese, General Approach of Low Grade Energy Management (GALGEM) for Energy Efficiency Improvement, *Intel European Research and Innovation Conference Ireland*, Leixlip 12-14 October 2010.

## **General Approach of Low Grade Energy Management (GALGEM) for Energy Efficiency Improvement**

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### **Summary**

A General Approach of Low Grade Energy Management (GALGEM) is proposed for energy efficiency improvement in complex manufacturing technologies. The investigations are supported in the frame of I2E2 (Innovation Ireland & Energy Efficiency) program. The Approach consists in consequent steps, including: Full hierarchic analysis of the manufacturing system, identifying all "low grade" heat streams; Classifications of the streams according of group of parameters; Streams coupling analysis (sources and sinks); Elimination of combinations on the base of heuristic, cost-benefit and thermodynamic assessments; Optimisation of the solutions. Main guidelines for an enhanced equipment efficiency improvement are included as well as boiler NO<sub>x</sub> emissions reduction, flue gas heat recovery, compressors energy reduction etc. An example on Intel manufacturing technology is shown.

56. E. Mooney, **Kr. Semkov**, T. Zhelev, Simultaneous Energy Efficiency Improvement and NO<sub>x</sub> emissions reductions in Industrial Boiler Systems, ENVIRON 2011, The 21<sup>st</sup> Irish Environmental Researchers' Colloquium, Environmental Sciences Association of Ireland (ESAI), University College Cork, 6-8 Apr. 2011.

### Energy & Climate Change - Poster

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#### Simultaneous Energy Efficiency Improvement and NO<sub>x</sub> emissions reductions in Industrial Boiler Systems

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Reducing environmental emissions generated through industrial processes is important to both industry and the Irish Nation. Government commitment to minimising emissions is demonstrated through participation in the EU NEC Directive and the National Climate Change Strategy. This support is confirmed through projects such as the I2E2 (Innovation for Ireland's Energy Efficiency) Research Programme, which is co-funded by Enterprise Ireland and the IDA. One of the priority research themes of this programme is low grade waste heat recovery. The main investigation of this research focuses on emission reduction, primarily NO<sub>x</sub>, with simultaneous energy efficiency improvement in natural gas fired boilers. This is to be achieved through the prehumidification and heating of combustion air, and consequent condensing of the water vapour from the flue gas, using a second generation contact economiser system. Two potential impacts are expected: i. Environmental: a reduction in NO<sub>x</sub> emissions and a decrease in fuel related carbon and water vapour emissions. ii. Economic: supplementary waste heat recovery of 10 to 13% equivalent saving of fuel. Currently second generation contact economiser systems are successfully installed in large boiler systems. The focus of this research is the extension of application of the technology to widely used medium and small boilers, as well as to contribute to the design of a pilot plant and to conduct and assess pilot experiments. Prehumidification of combustion air up to 11% v can be applied to all types of burners achieving up to 3.6 times reduction in NO<sub>x</sub> emissions. In currently installed systems a 12% reduction in fuel consumption has been achieved with a reduction in NO<sub>x</sub> emissions from 133 to 37 ppm. Another part of the research is to optimise the required prehumidification level according to impact/cost term depending on the boiler design and recovered heat sink parameters. The expected result is the development of a cost and energy efficient device for small to medium boilers. The I2E2 project brings together researchers in several energy efficiency related areas creating the ground for fruitful cross-projects collaboration and synergistic impact in the area of efficiency improvement and environmental protection.

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