DOI: 10.5604/20830157.1212267

COMPUTER MODELLING OF AUTOMATIC CONTROL PROCESS OF DISTILLATION COLUMN

Volodymyr Drevetskiy, Vasyl Ivanchuk
National University of Water Management and Natural Resources Use, Rivne, Ukraine

Abstract *Here the process of distillation in the production of ethanol is considered. Developed a mathematical model of determination and regulation of ratio of distillation column and its impact on concentration and quantitative composition of impurities of outgoing product. Suggested a method of calculation and schematic diagram of ratio automatic control and regulation in order to improve the quality of the final product and to reduce the energy costs.*

Keywords: distillation unit, ratio, automatic control system, distillation column, ethanol

KOMPUTEROWA SYMULACJA KOLUMNY DESTYLACYJNEJ Z AUTOMATYCZNYM STEROWANIEM

Streszczenie. *W artykule przedstawiono proces destylacji wykorzystywany przy produkcji etanolu. Opracowano model matematyczny określania i regulacji proporcji kolumny destylacyjnej i jego wpływ na stężenia i skład ilościowy zanieczyszczeń produktu końcowego. Zasugerowano sposób obliczania i schemat ideowy stosunku automatycznego sterowania i regulacji w celu poprawy jakości produktu końcowego, przy jednoczesnym zmniejszeniu kosztów energii.*

Introduction

Rectification is the process of separating liquid volatile mixtures into components or groups of components (fractions) by multiple bilateral mass and heat transfer between counterflow moving steam and liquid flows. Prerequisite of the rectification process is diverse volatility (vapour pressure) of the individual components.

For many years the most widely used in alcohol production is distillation units of indirect action, consisting of mash, epuration and distillation column with reflux, condensers and auxiliary equipment.

1.1. Analysis of automated control system of distillation process

Distillation unit (DU) is a complex object of technological process management, characterized by considerable energy consumption, complexity of mass transfer processes, instability of technological parameters. The objective of distillation process is to release ethyl alcohol from most impurities, receiving standard alcohol concentration. Simultaneously selected impurities should be maximum concentrated, which increases the output of finished products. In this case, the loss of alcohol and by-products will be minimal. However, modern automated control systems of DU are based on control of indirect indicators such as expenditures of the main material flow, pressure, temperature, which to some extent ensures the stability of the process, but do not allow for a timely response to various technological situations caused by the change of quality characteristics of the main raw material flow, which leads to the loss of energy and quality of output products.

Significant achievements in the field of distillation were obtained in the 60`s-80`s by scientists such as V.M. Stabnikov, P.S. Tsygankov, V.H. Artyukhov and others. The most promising areas of DU improvement in terms of reducing the cost of the product and complete removal of impurities are the following [10, 17, 23]:

- built-up columns by additional side-bars;
- enter additional columns for the allocation of alcohol by-products and additional cleaning (acceleration, final cleaning column, firming column);
- use of directed extractive distillation (hydroselection);
- work of the column at different pressures and vapour recuperation;
- the use of new types of dephlegmators and condensers;
- use additional purification by adsorbents.

At the present stage automated control systems provide only stabilization of DU set operating modes, and handling of the other tasks assigned to the operators-technologists. In other words it is necessary to improve the existing system of automated control of DU to implement rapid correction functions of defined operation modes of DU. To search for ways of improvement, it is necessary to analyze existing approaches to managing of distillation units implemented on alcohol plants and described in the literature.

Nowadays the task to automate DU can be divided into two main components:

- maintenance of defined parameters of the unit in certain permissible range and adjust those parameters depending on the input values of technological parameters;
- minimizing energy consumption on DU at permissible alcohol regulation loss with secondary products of distillation.

In alcohol plants DU equipped with automation systems based on microprocessor controllers and connected to them through special interfaces of electronic computers (EC). Thus, automated working places (AWP) of operator-technologist of DU are created. Typically, these systems allow, in addition to the organization of the dialogue of machine and person, to record the values of controlled variables in a special database to be able to view them later. AWP operator can work independently or can be combined in industrial networks that allow to combine all microprocessor controllers and AWP operators of all department of alcohol plant, and implement the integration of the level of automated process control systems (APCS) of alcohol plant and the level of automated enterprise control system, which also includes the management of business processes of alcohol production.

Analysis of a typical automation system 3 column DU shows that control of DU is based on indirect indicators: temperatures, pressures and costs of basic material flow. As shows the experience of work of the ACSs, they reliably implement set tasks the condition of consistent quality of material flows. However, control loops almost do not react to changes in quality indicators of material flows DU as measuring values are not sensitive to this type of perturbation. So distillation process control in complex conflict situations is entirely based on intuition and experience of the operator, which is based on the results of subjective observations, analyzes the value of temperature and pressure in control points of the equipment, takes the operational decision to manage the process. But since occasional disturbances constantly effect the operating process, in this case, there is a great delay in circuit regulation on the quality output product. DU operator cannot quickly perceive and process this information flow and make optimal decision to manage the process, and here appears a so-called uncertainty in solving the problem. The operator is obliged to analyze a set informational parameters and make control decisions, sometimes in conditions of insufficient information and lack of time.

In critical situations the person is not able to cope with the influx of information and often is mistaken in identifying situations that arise. Recognition of the situation at the level of local automation tools, and even microprocessor techniques (in software, which incorporated classical approaches to DU control) is not possible because the necessary analysis system settings as a whole or its specific functionally – related to consolidated parts. This reduces the efficiency and quality of decision-making, making them largely dependent on experience and personal characteristics of the operator.

Basic control algorithms of DU developed in the 50's-70's. Main approaches to automation process are based on distillation works of Mandelshteyn M.L. [11–15, 18, 20], and approaches to automation process of distillation in the chemical industry Anisimov I.V. [2], and others. Mathematical modeling of distillation are described in works of Mandelshteyn M.L., Stabnikov V.N., Nikolaev A.P. [21], Anisimov I.V., Bodrov V.I. [1], Demidenko N.D. [4], Kafarov V.V. [8, 9], Ostapchuk N.V. [16], Zavork I. [3] and others.

Thus, it is clear that a relevant task is the development and implementation of new control algorithms in automation systems of DU for high quality ethanol and minimization of energy costs.

1.2. Research purpose

The purpose this work is to create a mathematical model distillation unit to study the impact ratio of the column on concentration and quantitative composition of the product and the development of automatic control of distillation process.

1.3. Basic materials and results

The objective of the distillation process is to release rectified alcohol from most impurities and to receive standard alcohol concentration. Simultaneously selected impurities should be maximum concentrated, which increases the output of finished products. In this case, the loss of alcohol and by-products will be minimal. Thus, the main indicator of the DU process is given concentration and purity of the output product of the distillation column. The main factor that determines the concentration of pasteurized alcohol is ratio which is regulated by change of steam supply to the column with the appropriate change in water supply to the dephlegmator. Optimal ratio is determined on the basis of technical and economic calculations [22].

Current tasks on improving the purificationof alcohol and methods of structural modeling of distillation process requires detailed knowledge of the behavior of impurities, their distribution and concentration due to the height of the columns. Volatile mash part due to five main components or groups of components:

- ethanol,
- main impurities,
- provisional impurities,
- final and tail impurities.

Main impurities coefficient of distillation is always greater than one and they are easily separated from the water-alcohol mixture and concentrate at the top of the column.

Tail impurities have less volatility than alcohol at any concentration, will be included in the residue.

Provisional impurities have great volatility than alcohol at low concentrations will be removed in stripping profile and be placed down the column. Under these conditions, the provisional impurities will accumulate in the middle of a full column, where their distillation coefficient is equal to one, so below this zone provisional impurities behave as principal, and strive to move up the column; above, they behave like tail and pushed down by more volatile component – ethanol. Provisional impurities are usually selected from the area of max accumulation, typically, in the second quarter from the bottom of full distillation column. Each provisional impurity has its own max accumulation zone, where the distillation coefficient is equal to one.

Provisional impurities with distillation coefficient eaul to one at the concentration of ethanol 70% vol. conventionally called upper, at a lower concentration – lower provisional impurities. Among the upper provisional impurities are isovalerianic and isobutyric ethyl esters, among lower – alcohol fusel oil (excluding isopropanol) ethereal layer. This separation of the provisional impurities conditional, but it provides an opportunity to detail their group concentration zone [19].

The final impurity with low volatility in the area of low alcohol concentrations, and with greater volatility in the area high alcohol concentrations, do not accumulate in the middlw of the column, but depending on the alcohol concentration shifts upwards (as the main impurity) or downwards (like a tail). Typical final impurity is methanol.

Knowledge of alcohol and impurities evaporation coefficients enables reasonably approach to creating schemes of distillation units for allocation of alcohol out of mash and clean it from impurities.

To achieve this task with the help of software CHEMCAD was created a model of determination and regulation of ratio of distillation column and its impact on the concentration of impurities and quantitative composition of the output product (figure 1). Studied how ratio of the column changes by regulating the pressure drop in the column, expenses of reflux returns to the column, the initial expenditures of products and unpasteurized alcohol. Established that in obtaining alcohol concentration of 96.2% vol. optimal ratio ranges 3.5 ± 0.5, if the column is at atmospheric pressure [7].

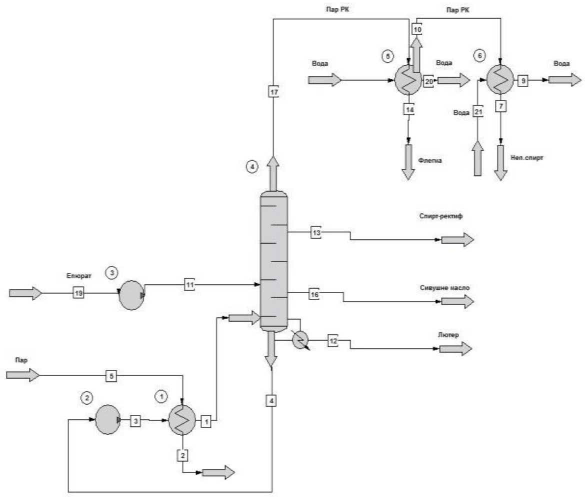

Fig. 1. Definition and regulation model of ratio of distillation column and its impact on the concentration of impurities and quantitative composition of the output product

On figures 2, 3 and 4 shows the concentration of impurities and ethanol on each plate of distillation column at ratio 3.0, 3.5, 4.0, if the column is at atmospheric pressure. Analyzing data graphs, it can be concluded that the limit values of ratio of distillation column the deterioration in the quality of output products is observed, ie rectified spirit, reduce of column productivity and increase of expenses of energy carriers required by distillation. Therefore, in order to get rectified spirit of improved quality it is necessary to conduct systematic monitoring of quantitative indicators of impurities of output products at certain stages of distillation and implement automatic stabilization of ratio.

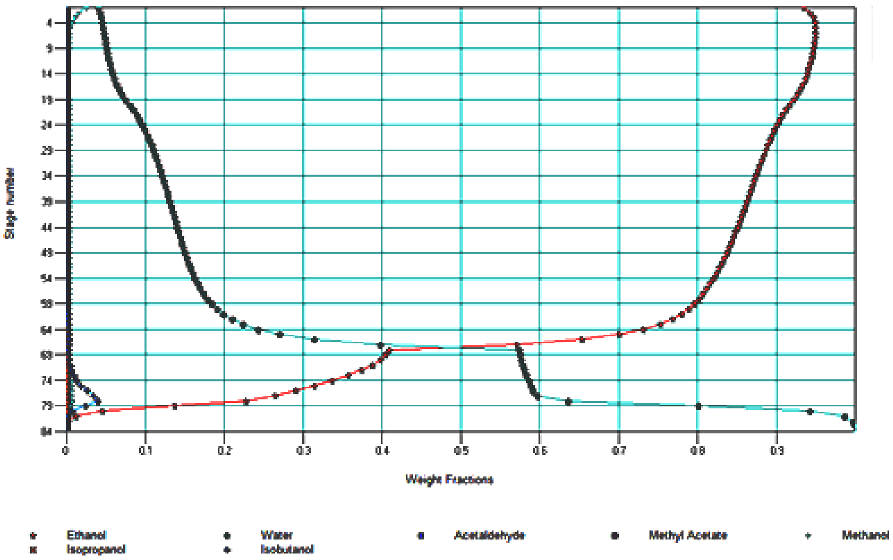

Fig. 2. The concentration of impurities and ethanol on each plate of distillation column at ratio 3.0

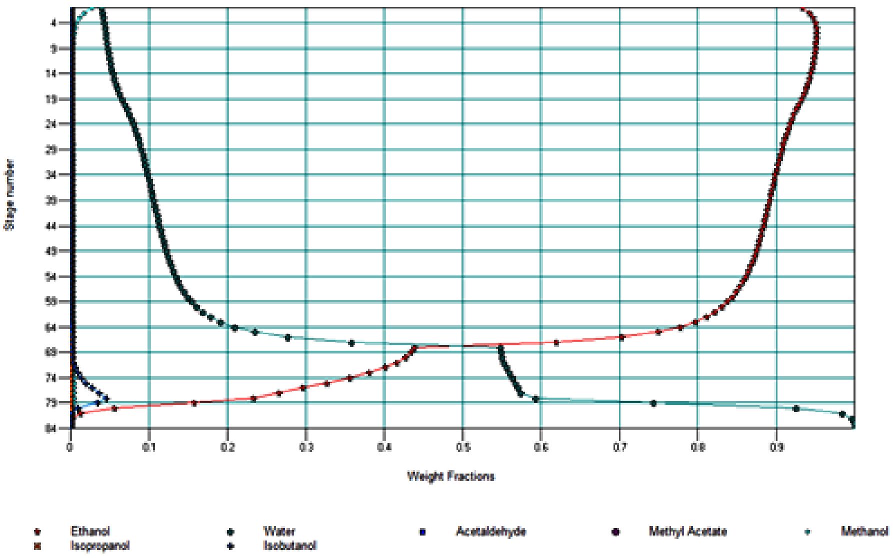

Fig. 3. The concentration of impurities and ethanol on each plate of distillation column at ratio 3.5

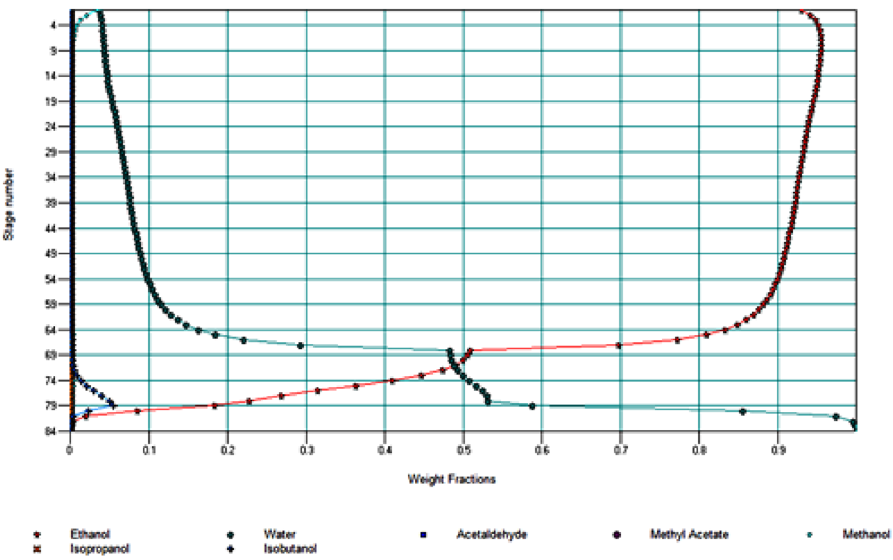

Fig. 4. The concentration of impurities and ethanol on each plate of distillation column at ratio 4.0

It is known that distillation column is complex object of control. Therefore, for the effective flow of technological process distillation it is necessary to design a system of automation that provides adjustment of basic parameters of the column and controls a number of other parameters that calculates controlling influences.

The task of DU automation can be divided into two main components and formulate as the following:

- maintenance of given unit parameters in a particular permissible range and adjust these parameters depending on the input values of technological parameters;
- maintain the balance of material and energy flows.

In order to ensure optimal consumption of energy flows, in addition to stabilizing the main technological parameters of DU, the implementation of automatic calculation and maintenance of optimal ratio value that affects energy expenses are suggested.

Ratio is based on the following parameters: reflux expense supplied to the top of distillation column; reflux strength; alcohol consumption; alcohol strength.

Taking into account these parameters we proposed calculate the ratio of absolute alcohol of reflux to selected distillate. The value of absolute alcohol is calculated by multiplying the cost of strength of, in accordance, reflux and distillate [5].

To solve this problem developed schematic diagram of automatic control distillation unit of indirect action with the main technological flows and means of automatic control and regulation.

Adjusting the ratio carried by stabilizing correlation of expenses of vapour and water considering quantitative indicators of impurities at certain stages of distillation, which helps minimize the energy expenditures [6] and its control will increase the qualitative characteristics of each column

Conclusions

Conducted computer modelling of distillation process enabled to determine the relationship between the main technological parameters, list of controlled, regulated parameters and controlling influences, formulate requirements for automated system of control of technological process. Implementation of the proposed methods of identification, control and stabilization of basic technological parameters of distillation units, including ratio carried by stabilizing correlation of expenses of vapors and water considering quantitative indicators of impurities at certain stages of distillation, which helps minimize the energy expenditures. Therefore, maintaining optimal ratio will improve the quality characteristics of the column.

Proposed solutions included in the project documentation of reconstruction of alcohol production on plant in Belarus, and some technological contours of automatic control, in light of the theoretical calculations tested on alcohol plant in Lithuania.

References

[1] Anisimov I.V., Bodrov V.I., Pokrovskiy V.B.: Matematicheskoye modelirovaniye i optimizatsiya rektifikatsionnykh ustanovok. Khimiya, Moskva 1975.
[2] Anisimov I.V.: Avtomaticheskoye regulirovaniye protsessa rektifikatsii. Gostoptekhizdat, Moskva 1961.
[3] Chermak I., Peterka V., Zavorka I.: Dinamika reguliruyemykh sistem v teploenergetike i khimii. Mir, Moskva 1972.
[4] Demidenko N.D.: Modelirovaniye i optimizatsiya teplomasoobmennykh protsesov v khimicheskoy tekhnologi. Nauka, Moskva 1991.
[5] Ivanchuk V.V., Drevets′kyy V.V.: Sposib avtomatychnoho upravlinnya protsesom rektyfikatsiyi. Avt. svid. Ukrayina No99430, Byul. 11, 2015.
[6] Ivanchuk V.V.: Avtomatyzovana systema upravlinnya braho rektifikatsiynoyu ustanovkoyu nepryamoyi Diyi, Naukovi pratsi NUKHT, Kiev 2013.
[7] Ivanchuk V.V.: Systema avtomatychnoho keruvannya flehmovoe chyslo rektifikatsiynoyi kolony, IIRTK-2012, 197–198.
[8] Kafarov V.V., Dorokhov I.N., Kol'tsova E.M.: Sistemnyy analiz protsessov khimicheskoy tekhnologii: Entropiynyy i variatsionnyy metody neravnovesnoy termodinamiki v zadachakh khimicheskoy tekhnologii. Nauka, Moskva 1988.
[9] Kafarov V.V.: Osnovy massoperedachi. Vyssh. shkola, Moskva 1979.
[10] Leont'yev V.S.: Tekhnicheskoye perevooruzheniye rektifikatsionnykh otdeleniy spirtovykh zavodov. Proizvodstvo spirta i likerovodochnykh izdeliy 2, 2002, 18–20.
[11] Mandel'shteyn M.L., Aksel'rod L.A.: Nomogramma dlya optimal'nogo upravleniya rektifikatsionnoy kolonnoy, Fermentnaya i spirtovaya promyshlennost', 6, 1969, 6–10.
[12] Mandel'shteyn M.L., Satanovskiy V.R., Aksel'rod L.A., Samonova N.A., Motrenko P.I., Rybakov A.P., Mironchuk YA.A.: Usovershenstvovannaya sistema avtomaticheskogo regulirovaniya (SAR) v trekhkolonnom bragorektifikatsionnom apparate, Fermentnaya i spirtovaya promyshlennost', 3, 1972, 11–14.
[13] Mandel'shteyn M.L., Satanovskiy V.R., Gryaznov V.P., Bogdanov YU.P.: Avtomaticheskoye upravleniye yepyuratsionnoy kolonnoy, Fermentnaya i spirtovaya promyshlennost'. 6, 1971, 6–8.
[14] Mandel'shteyn M.L.: Avtomaticheskiye sistemy upravleniya tekhnologicheskim protsessom bragorektifikatsii. Pishchevaya promyshlennost', Moskva 1975.
[15] Mandel'shteyn M.L.: Matematicheskaya model' i staticheskiye kharakteristiki rektifikatsionnoy kolonny. Fermentnaya i spirtovaya promyshlennost', 1, 1969, 11–16.
[16] Ostapchuk N.V.: Osnovy matematicheskogo modelirovaniya protsessov pishchevykh proizvodstv. Vishcha shkola, Kiev 1991.
[17] Rimareva L.V., Overchenko M.B., Ignatova N.I., Kadiyeva A.T., Shelekhova T.M.: Tekhnologicheskiye aspekty polucheniya vysokokachestvennogo spirta, Proizvodstvo spirta i likerovodochnykh izdeliy, 3, 2002, 16–19.
[18] Satanovskiy V.R., Mandel'shteyn M.L.: Sistema avtomaticheskogo regulirovaniya brazhnoy kolonny s pereklyucheniyem upravlyayushchikh vozdeystviy, Fermentnaya i spirtovaya promyshlennost', 4, 1971, 8–11.
[19] Shyyan P.L. Tekhnolohiya spyrtu, Podillya-2000, Vinnytsya 2003.
[20] Stabnikov V.N., Nikolayev A.P., Mandel'shteyn M.L.: Rektifikatsiya v pishchevoy promyshlennosti.Teoriya protsessa, mashiny, intensifikatsiya. Legkaya i pishchevaya promyshlennost', Moskva 1982.
[21] Stabnikov V.N.: Peregonka i rektifikatsiya etilovogo spirta, Pishtevaya promyshlennost’, Moskva 1969.
[22] Tsyhankov P.S.: Rektyfikatsiyni ustanovky spyrtovoyi promyslovosti, Lehka i kharchova promyslovist′, Moskva 1984.
[23] Yarmosh V.I.: Problemy i perspektivy spirtovoy otryasli. Proizvodstvo spirta i likerovodochnykh izdeliy, 2, 2002, 4–5.

Prof. Volodymyr Drevetskiy
e-mail: v.v.drevetskyi@nuwm.edu.ua

Vice President of Engineering Academy of Ukraine, Head of Automation, electrical engineering and computer integrated technologies Department (NUWMNRS).
The main scientific direction – development of methods and devices for continuous automatic monitoring of the physical and mechanical parameters of Newtonian and non-Newtonian fluids, as well as the quality of oil products. Author of over 200 scientific papers, including 51 patents, most of which are implemented in production.

M.Sc. Vasyl Ivanchuk
e-mail: v.v.ivanchuk@nuwm.edu.ua

Research engineer of computer system and automation, postgraduate student.
The main scientific direction – automation of process of rectification, designing distributed systems and remote control, software information and measurement systems, the study of quantitative and qualitative characteristics of the product in the distillation.

otrzymano/received: 17.05.2016 *przyjęto do druku/accepted: 01.07.2016*