ISSN 2686-7575 (Online)

https://doi.org/10.32362/2410-6593-2019-14-6-39-47

UDC 66.0

About chemical technology: Notes on student projects in the Mendeleev competition

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The general results of the 2018-2019 Mendeleev competitions for chemistry students have been presented and a detailed analysis of technological work of the last few years are given from the point of view of compliance of their subject and content to modern representations about chemical technology as science. An increased interest by representatives of leading companies, scientific organizations, and enterprises in the Mendeleev competition has been demonstrated. This is largely determined by the request of the chemical industry to train motivated chemical and technical specialists that possess research and implementation competencies. The possibility of forming the topics and content of students' scientific research based on the hierarchical structure of the chemical-technological system, the achievements of the theoretical foundations of chemical technology, and the principles of technology creation is shown.

Keywords: *Mendeleev competition, chemical technology, system approach, chemical-technological education, scientific work.*

For citation: Frolkova A.K. About chemical technology: Notes on student projects in the Mendeleev competition. *Tonk. Khim. Tekhnol. = Fine Chem. Technol.* 2019;14(6):39-47 (in Russ.). https://doi.org/10.32362/2410-6593-2019-14-6-39-47

О химической технологии. Заметки на полях студенческих работ Менделеевского конкурса

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Представлены общие результаты Менделеевских конкурсов студентов-химиков 2018–2019 г.г. и дан более подробный анализ технологических работ последних лет с точки зрения соответствия их тематики и содержания современным представлениям о химической технологии как науки. Отмечен возросший интерес представителей ведущих компаний, научных организаций и предприятий к Менделеевскому конкурсу, что в значительной степени определяется запросом химической промышленности на подготовку мотивирован-

ных специалистов химико-технологического профиля, обладающих научно-исследовательскими и внедренческими компетенциями. Показана возможность формирования тематики и содержания научных исследований студентов, исходя из иерархической структуры химико-технологической системы, достижений теоретических основ химической технологии и принципов создания технологий.

Ключевые слова: *Менделеевский конкурс, химическая технология, системный подход, химико-технологическое образование, научная работа.*

Для цитирования: Фролкова А.К. О химической технологии. Заметки на полях студенческих работ Менделеевского конкурса. *Тонкие химические технологии.* 2019;14(6):39-47. https://doi.org/10.32362/2410-6593-2019-14-6-39-47

The unity of the educational and scientific processes in the higher chemical technology school has long been a prerequisite for training highly qualified personnel. Olympics for different specialties, schools for young scientists within the framework of prestigious Russian and international conferences, the possibility of obtaining individual grants and scholarships, including presidential and government ones, allow students from all courses to declare their research aspirations. One of the places to have stood the test of time is the Mendeleev Competition for chemistry students. In 2019, this competition and subsequent school-conference were held for the 29th time confirming the prestige, relevance, and attractiveness of this event in the eyes of students and potential employers. The Mendeleev Competition organizes and conducts a non-profit partnership "Promotion of Chemical and Environmental Education" with the support of universities, the Russian Academy of Sciences and technology companies. This year, the competition was supported by a grant from the President of the Russian Federation for the development of civil society provided by the Presidential Grants Foundation.

The 150th anniversary of D.I. Mendeleev's Periodic Table of Elements gave the traditional competition, bearing the name of the great Russian scientist, solemnity, significance, and a sense of involvement in the great discoveries. Looking ahead, it is appropriate to gratefully recall the lecture that was delivered to the young people by Doctor of Physics and Mathematics Sergey Nikolaevich Dmitriev, director of the Laboratory of Nuclear Reactions from the Joint Institute for Nuclear Research in Dubna. The contemporary work of Russian nuclear physicists, physicists and chemists, the technological equipping of research, the material and technical and methodological base, the openness of Russian scientists to interact with international colleagues moved the audience, filled our hearts and minds with pride. However, more about this will be mentioned later on.

The competition was hosted by the Ivanovo State University of Chemistry and Technology – a university with a rich history, a high level school of chemical technology, benevolent instructors, administration, and volunteers.

The history of the competition's creation, its rules, and the results of the competitions from 2010 to 2017 are described in great detail in an article by a professor at M.V. Lomonosov Moscow State University, a permanent member of the jury who was behind the origins of the competition's creation, Georgy Vasil'evich Lisichkin [1]. The material he presented (cities, universities, the number of works in part-time and full-time tours, the share of Moscow students in the total number of participants and award recipients) showed the formation of trends that persist today. The competition's indicators in 2018 (Novosibirsk) and 2019 (Ivanovo) complement the overall picture (Table 1).

This report is primarily devoted to the analysis of the topics and results of the chemical and technological profile work submitted to the competition over the past three years, the role of technological sections in attracting industry representatives to participate in competition events, and increasing student motivation.

A high share (36%) of students from institutes in Moscow remains strong among the participants in the Mendeleev Competition; the combined share of students from Moscow and St. Petersburg universities and the university hosting the school conference was 52.5%. The latter, in my opinion, is not a contradiction, but only strengthens the significance of the competition as an event of federal significance, since holding a competition in various Russian cities and universities helps increase the mobility of young scientists, and strengthens the scientific and educational contacts of the center and regions. Moreover, it is important to note that the competition is approaching the locations of chemical industrial facilities and, with skillful vocational guidance, can facilitate the transfer of talented young scientists from Moscow universities to those regions.

The largest teams of participants formed by universities in various Russia's cities are shown in Table 2.

Table 1. Statistical data characterizing the composition of the Mendeleev competitions of chemistry students in 2010–2019

Competition number, year	Competition city	Number of participants	Number of cities	Number of universities
XX, 2010	Arkhangelsk	129	28	41
XXI, 2011	Dubna	153	30	40
XXII, 2012	St. Petersburg	100	22	31
XXIII, 2013	Kazan	143	33	41
XXIV, 2014	Volgograd	147	31	39
XXV, 2015	Tomsk	201	40	57
XXVI, 2016	Samara	201	37	51
XXVII, 2017	Ufa	208	41	55
XXVIII, 2018	Novosibirsk	240	38	59
XXIX, 2019	Ivanovo	219	39	58

Note: data for 2010-2017 is given in [1].

As noted in [1], the nomination for "Research on chemical technology" introduced in 2005 at the initiative of Organizing Committee members and, above all, the president of the M.V. Lomonosov Moscow Institute of Fine Chemical Technologies Vladimir Savel'evich Timofeev, has allowed for the scope of the competetion to be expanded, and senior students from technological universities enrolled in master's and specialty programs to be attracted. It seems to me that support for the competition by leading companies, especially in recent years, is to a large extent precisely connected with the possibility for future employers to evaluate not only the theoretical, but also the practical orientation and level of the specialists' training in chemical and technological universities. This was also reflected in the new name of the category "Research and Development in Chemical Technology" in the amended Regulation about the competition.

Table 2. Statistics characterizing the largest teams of participants (at least 5 students) in the 2019 competition

City	Total number of participants	Universities	Number of participants
Moscow	79	Moscow State University, Faculty of Chemistry	25
		Moscow State University, Faculty of Materials Science	20
		Moscow State University, Faculty of Fundamental Physical and Chemical Engineering	2
		RTU MIREA (M.V. Lomonosov Institute of Fine Chemical Technologies)	24
		D.I. Mendeleev University of Chemical Technology of Russia	4
		Moscow Pedagogical State University	3
		National University of Science and Technology "MISIS"	1
Ivanovo	21	Ivanovo State University of Chemistry and Technology	17
		Ivanovo State University	3
		Lyceum No. 67	1

Table 2. Continued

City	Total number of participants	Universities	Number of participants
St. Petersburg	15	St. Petersburg State University	10
		St. Petersburg State Institute of Technology (Technical University)	2
		St. Petersburg National Research University of Information Technologies, Mechanics and Optics	2
		A.I. Herzen State Pedagogical University of Russia	1
Yaroslavl	12	Yaroslavl State Technical University	10
		K.D. Ushinsky Yaroslavl State Pedagogical University	1
		P.G. Demidov Yaroslavl State University	1
Ufa	8	Bashkir State University	6
		Ufa State Petroleum Technical University	2
Nizhny Novgorod	6	N.I. Lobachevsky State University of Nizhny Novgorod	4
		R.E. Alekseev Nizhny Novgorod State Technical University	2
Tver	6	Tver State Technical University	6
Kazan	5	Kazan (Volga) Federal University	3
		Kazan National Research Technological University (KNRTU)	2
Nizhnekamsk	5	Nizhnekamsk Institute of Chemical Technology (branch of KNITU)	5
Samara	5	Samara State Technical University	3
		Academician S.P. Korolev Samara National Research University	2

Table 3. Distribution of student works by category in the full-time round of the competition (2017–2019)

Category, section	Year		
	2017	2018	2019
Category I «Chemistry Research»	54	59	63
Inorganic chemistry and materials science	22	20	20
Organic, bioorganic and organoelemental chemistry	16	22	18
Physical and analytical chemistry	16	17	25
Category II «Research and Development of Chemical Technology»	46	46	44
General chemical technology, basic organic and petrochemical synthesis	13	12	9
Technology of biologically active compounds	7	12	8
Technology of inorganic materials	10	13	10
Technology of polymers and the materials based on them	16	9	17
Total	100	105	107

Table 4. Distribution of works acknowledged by awards from the competition (2016–2019) in the categories I and II

Reward	2016		2017		2018		2019	
	Chemistry	Chem. Tech.	Chemistry	Chem. Tech.	Chemistry	Chem. Tech.	Chemistry	Chem. Tech.
"Future of Russian Science" Medal	O.A. Khomich (Higher Chemical College, RAS, Moscow)	-	-	-	E.V. Pokochueva (Nat. Research University, Novosibirsk)	-	-	-
1st degree diploma	3	-	4	-	2	-	2	2
2nd degree diploma	9	-	5	3	5	2	8	4
3rd degree diploma	15	3	8	8	12	5	9	6
Share (%) of award recipients by category	**90.3**	**9.7**	**60.7**	**39.3**	**74.1**	**25.9**	**61.3**	**38.7**

Based on a review of student work (more than 200) over the last five years in the correspondence round, approximately half of the work is usually selected for participation in a further school conference, the distribution of which by category and section is presented in Table 3.

Certain changes occurred in 2019 with the number of chemical technology works that have earned awards in various denominations (Table 4).

This is partly due to the amendments made to the "Regulations on the Competition" concerning the independent evaluation of work in categories, but primarily with the improvement of the quality of students' chemical technology projects themselves and the aforementioned interest in them by the industry.

There are numerous special diplomas from companies and partnerships that are considered to be worth a lot: diplomas from the company *Haldor Topsoe* for work related to heterogeneous catalysis, the results of which have prospects for industrial applications (1 person); diplomas from the company *Fosagro* for high level and relevance of applied research (3 people); diploma from International Organizing Committee for the celebration of the International Year of the Periodic Table of Chemical Elements "Be in Trend!" (2 people); special certificate from the chemical and biological cluster *SCAMT* (2 people): diplomas from the Non-Profit Partnership "Promoting Chemical and Environmental Education" (5 people): for vivid presentation of scientific results; for an original technological idea; for synthetic work in the field of medical chemistry; for "The first step in science."

Over the years, the conference has been sponsored by the following companies: *Schlumberger, KuibyshevAzot, Gazprombank, Haldor Topsoe, Solvex, AnalitProducts,* and *Acrus*. For many years, *SIBUR Holding* was the general partner of the contest. I wish to express enormous gratitude to the sponsors, but not just that. The direct participation of these sponsors and other business partners with the Mendeleev Competition in master classes, trainings, lecture programs in the person of leading scientists from the Russian Academy of Sciences and engineering companies, technologists, personnel management specialists, and strategic development of industry enterprises allows us to increase the motivation of future engineers. Unfortunately, the qualification of "engineer" has practically disappeared from educational programs and federal state educational standards, although many people understand the importance of this status: from a particular university and enterprise to state bodies that shape the priorities of the country's scientific and technological development.

I have been working with the jury and as the head of the section "General Chemical Technology, Basic Organic and Petrochemical Synthesis" for four years. I hope my ten-year experience as rector of the M.V. Lomonosov Moscow Institute of Fine Arts and current status of the Head of the Department of Chemistry and Technology of Basic Organic Synthesis

give me the right to share some of my impressions and thoughts. Quite complex and long-discussed issues were specific requirements specifically for a chemical technology profile. There are many reasons for this and most of them are subjective. In particular, contrasting the fundamental and applied nature of the works presented in different categories seems artificial to me. Purely chemical works are a theory, chemical technology works are those aimed at solving only practical problems.

Who can forget the quote by M.V. Lomonosov: "Chemistry is broadly spreading its hands into human affairs." The great Russian encyclopedic scientists Mikhail Vasil'evich Lomonosov and Dmitry Ivanovich Mendeleev knew a lot about this business and turned many of their scientific ideas into advanced technologies of their time and beyond.

And if we talk about state priorities for Russia's development as a whole along with science, engineering and technology in particular [2], and recall the list of critical technologies [3], then the relevance of the work presented in the category "Research and Development in Chemical Technology" of the Mendeleev Competition leaves no room for doubt.

The direction of "Chemical Engineering" was formed long ago all over the world and is now actively developing; the theoretical foundations of chemical technology (the core of the science of chemical engineering) and the principles of creating high-tech chemical technologies have been integrated [4, 5]. An analysis of the tender documentation requirements of the Russian Science Foundation, the Russian Foundation for Scientific Research, the Federal Target Programs of the Ministry of Education and Science and the topics of supported grants shows that the leader who clearly defines the place of specific research in fulfilling certain state priorities and realistically assesses the prospects for putting the results into practice wins. Such an approach should be implemented when choosing the subject matter for research of a chemical-technological nature: whether it is an initiative research work by a department instructor or a student's scientific qualification work. To clearly imagine the possible topics for student projects and the range of objects of study, it is sufficient to consider chemical technology from the perspective of a systematic approach [4, 6].

Any chemical technology system (CTS) can be represented in the form of a technological triad [4], including (Fig. 1):

– raw material preparation unit (I),
– chemical transformation unit (II),
– separation unit of multicomponent reaction mixtures (III).

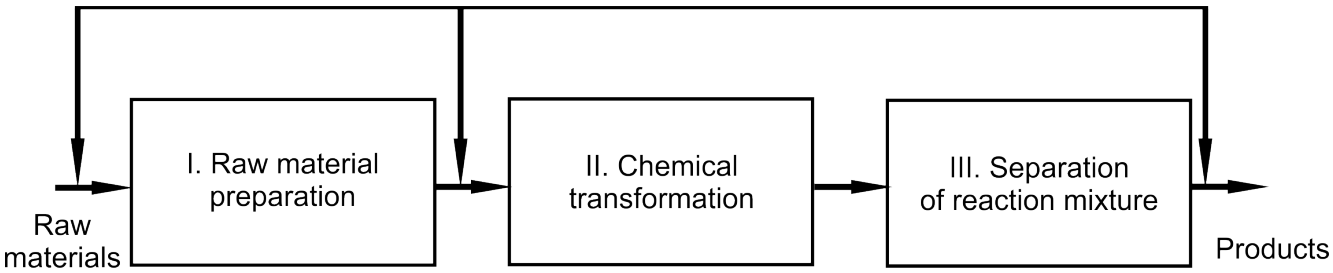

Fig. 1. Technological triad.

Such a representation of CTS, regardless of the scale of technology, immediately determines three large groups of tasks, objects, and, to a large extent, research methods that may make up the content of student scientific work. However, the competition for category II mainly presents works related to the second (chemical) unit, which is also associated with the content of special disciplines of educational programs that are traditionally focused on the chemical component of the technology. But today, the search for alternative raw materials, new methods for the deep processing of traditional raw materials, and the development of resource and energy-saving schemes for the separation of complex multicomponent mixtures obtained at the stage of chemical transformation are also relevant.

The triad's units are linked by both direct connections and feedback (recycles). The study of such systems is characterized by a certain complexity and requires the use of not only physical, but also computational experiments. But chemical technology works devoted to methods of mathematical modeling of the properties of systems and processes using modern software systems (PRO-II, ChemCad, Aspen Tech, and HYSYS) are also units.

On the other hand, the process of creating any chemical-technological system can be hierarchically divided into a number of components (subsystems), shown in Fig. 2.

In subsystems 1 and 2, many tasks relate to the establishment of "composition – property – structure" relationships, which relate to the synthesis

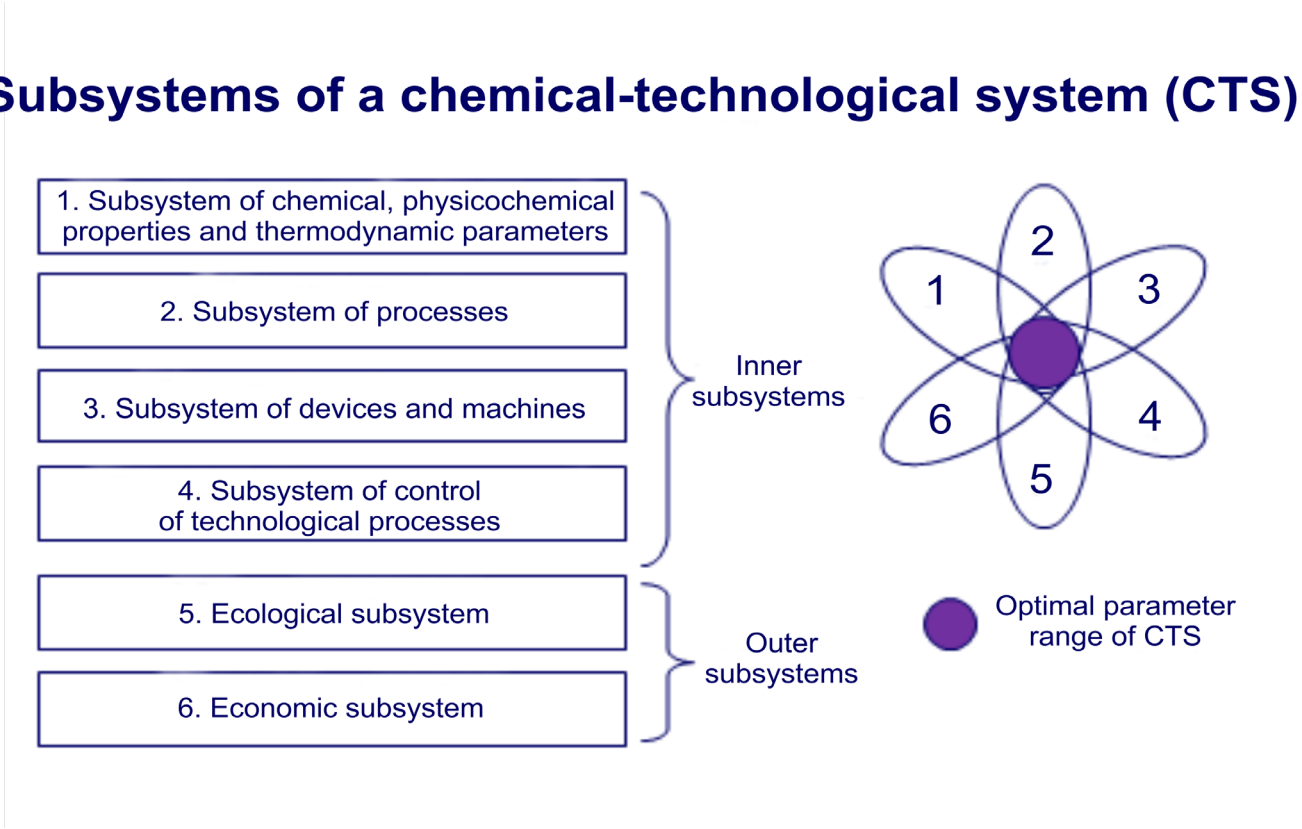

Fig. 2. Chemical-technological system structure.

of a chemical compound, production of functional materials and development of technological schemes based on phase diagram structures, etc. Incidentally, the decomposition of CTS shown in Fig. 2 perfectly illustrates the balanced curriculum for the training of specialists in the field of chemical technology, where each subsystem has a group of disciplines (chemical, physical, chemical, engineering, economic). But such an idea of the CTS also includes the possibility of choosing the topic of scientific student work and even its structure. Competitive work may contain the results of a specific chemical study, but its author should see the technological and economic prospects of the proposed solution and the possibility of its scaling and prototyping.

Unfortunately, for a long time there were no clear requirements for the content of chemical technology works submitted to the Mendeleev Competition. In 2019, a number of amendments were introduced to the Regulations on the Competition, which in a concise manner reflected at least a three-year discussion among representatives of various chemical and technological universities that implement a wide range of specialties on this issue. Today in the "Regulations on the Competition" the requirements for the work are formulated as follows:

Entries with significant scientific novelty and/or potential practical significance, corresponding to the main trends in the development of modern chemistry and carried out with the use of modern research methods are accepted for the competition in the category "Chemistry Research."

The competition in the category "Research and Development of Chemical Technology" accepts works on the development of new substances, materials and devices, various aspects of scaling up their production, the development of new processes of chemical technology, their improvement or optimization, as well as the control of production and product quality.

Below, as an example, the topics of student projects are listed that, to one degree or another, meet the requirements for technological work: development of environmentally friendly diesel fuels with bio additives and improved lubricating properties; development of a reagent for the destruction of oil-water emulsions; research and increase of the efficiency of an industrial reforming plant with mathematical modeling; the study of phase equilibrium and the development of concepts for the separation of mixtures formed in the production of cyclohexanone; investigation

of the causes of degradation of the catalytic activity for sulfide catalysts of hydrogenation processes and methods of its recovery; oxidation and polymerization of vegetable oils isolated from waste oil extraction production; redistribution of narrow fractions of middle distillates during the electromagnetic processing of oil raw materials; improving the technology of chloroform purification from boiling impurities.

Work on the program to formulate the sections for category II, a number of problems remain: 1) the correspondence of the form and content of student work to the objectives of the competition, the solution of which largely depends on the supervisor of the work; 2) an adequate assessment of the work at the correspondence stage, in order to increase the objectivity of which section managers involve several reviewers, including third-party ones, for "blind" reviewing.

The positive history of the competition, the spirit of goodwill, healthy competition, and the grand mission of attracting young scientists to science allow us to hope for the further dissemination of the competition's ideas in a university atmosphere.

In conclusion, I would like to note several aspects of this competition.

1. It would not be amiss to note with gratitude the participation of industry representatives in the competition (work in the jury; sponsorship, lectures, and master classes), which shows the interest of large companies, specific industrial enterprises, engineering firms in motivated, well-trained specialists and their orientation in a future profession.

2. The benevolent support of the competition by the administration of universities and cities testifies to the understanding of the role of the competition as a platform to promote the achievements of students of host universities, since with the positive examination results of works at the first stage, the number of such participants is not strictly limited.

3. The broad geography of the participants in the Mendeleev Competition and universities hosting an out-of-school conference allows us to raise the question of giving the Mendeleev Competition and Conference the status of an all-Russian event with international participation. And our competition, in fact, has had it for many years.

On the eve of the jubilee 30th Mendeleev contest, I would like to recall with fondness all the students participating in our intellectual competition, their advisors, and members of the jury. And to express gratitude to the inspirers and organizers of the Mendeleev Competition, the chairman of the jury, Academician of the Russian Academy of Sciences, Doctor of Chemical Sciences M.P. Egorov, Chairman of the Organizing Committee, Corresponding Member of the Russian Academy of Sciences, Doctor of Chemical Sciences O.I. Koifman, vice-chairmen of the organizing committee – Editor-in-Chief of the journal *Chemistry and Life* L.N. Strelnikova, Director of the Promoting Chemical and Environmental Education research enterprise E.S. Rotina and the scientific secretary of the jury Doctor of Chemical Sciences D.S. Perekalin.

The author declares no conflicts of interest.

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Submitted: October 25, 2019; Reviewed: November 28, 2019; Accepted: December 06, 2019.

Translated by H. Moshkov