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***Papers***

*Dedicated to the memory of*
*Academician Dr. Eng. Emilian BRATU (1904–1991)*

# *IN MEMORIAM* ACADEMICIAN DR. ENG. EMILIAN BRATU (1904 – 1991) THE FOUNDER OF THE CHEMICAL ENGINEERING EDUCATION IN ROUMANIA. 120 YEARS SINCE HIS BIRTH

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The present work is dedicated to the memory of our professor Emilian Bratu (1904–1991), the founder of chemical engineering education in Roumania.
The "road" of Chemical Engineering from empiricism to Process Engineering – a multi-disciplinary science in the postmodern era, was traced in Roumania by Professor Emilian Bratu who with art, clairvoyance and love built the School of Chemical Engineering in Roumania, in the middle of 20th century, being the first trainer of specialists in the field of chemical engineering – engineers, and phd. engineers.
This year we celebrate 120 years since the birth of the academician Prof. Dr. Eng. Emilian Bratu, the founder of the Roumanian school of chemical engineering. On this anniversary we experiment a double feeling. On the one hand, there is a strong feeling of gratitude for the immense wealth of knowledge passed on to his PhD students and the generations of students who trained in the profession of chemical engineer with his courses as a basis of study. On the other hand, I am also filled with a feeling of satisfaction because I have the opportunity to remind and review, even if briefly, the strong mark left in the science of chemical engineering in Romania by the distinguished academician university professor Emilian Bratu from "Politehnica" University of Bucharest (UPBuc.), chair of chemical engineering, outstanding personality of the Roumanian academic community and world-renowned scientist.
Professor Emilian Bratu left us a huge legacy, with a potential for use in all branches of the economy – the science of chemical engineering. An inheritance also means a great responsibility, and implies large obligations in its maintenance and development.


Acad. Prof. Dr. Ing. Emilian BRATU
(8 Aug. 1904 – 30 March 1991)

## INTRODUCTION

**Chemical engineering**. Although closely and inextricably linked to chemistry, chemical engineering had a slower development, for well-motivated historical reasons below described. Professor Emilian Bratu activated in the middle of the 20th century. In order to better frame his exceptional achievements, a brief description of the internal and external context in which he carried out his activity is necessary. More specifically, we will refer to the development level of the chemical industry, and of the chemical engineering science in Romania and world-wide during that period.

"Why is *chemical and biochemical engineering* (CBE) important now and in the future?" This it is a legitimate question, because

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the chemical and biochemical synthesis industries are large consumers of material and energy resources. The question *Why chemical engineering matters?*[14] also arises in the conditions where recent evaluations[9,10,11,12,13] indicated a decline in classic natural resources (coal, oil, natural gas, wood, etc., see chap.10 of[5]). An answer to this question was provided by the Chemical Engineering Society of U.K. (IChemE), which is partially reproduced below.[32]

Our world is a complex and evolving place. In the 21st Century, the requirements of a growing and ageing population will have significant impact on society. With global population expected to reach 8.5bn by 2030 and 11.2bn by the end of the century, demand on resources such as water, energy, food and raw materials will be greater than anything we have experienced. How do we meet the expectations of a modernised, global society whilst minimising the impact we have on our environment?[1, 5]

As one of IChemE's presidents, Dr. Ed Daniels from Shell co., wrote,[14] “the future is challenging and uncertain”. The puzzle is complex, but chemical engineering remains central to the delivery of sustainable water, energy, food and well-being. This applies to the developed economies and delivery of the UN sustainable development goals.

The breadth of the CBE discipline puts the profession in a unique position. As a technical community, we collaborate with many other disciplines and have a track record of high impact contributions. Chemical engineers have even made it into space. Chemical engineers can and will play an important role in the design and realisation of solutions for the grand challenges we face.[5]

In order to follow the evolution of the chemical engineering science and education, it is first necessary to follow the parallel evolution of the chemistry and of the chemical industry in Roumania and world-wide.

## 1. CHEMISTRY SCIENCE EVOLUTION UP TO 20th CENTURY

Chemistry and its study are deeply rooted in history, going back to ancient times. Records show that ancient civilizations accumulated practical knowledge of the chemistry involved in metallurgy, pottery, and dyeing. Egyptian artisans were famous not only in embalming the dead, but also in extracting metals from ores, obtaining alloys such as bronze, making glass, and various chemical combinations, and pigments for cosmetics and paintings, fermenting beer and wine, etc.[15]

Chinese craftsmen were making bronze from the 10th century BC and began to extract zinc from the 1st century BC. The Chinese practiced iron metallurgy from the 4th century BC, and from the 10th century BC, potters processed white clay, preparing porcelain for the first time. The Chinese introduced the process of making paper from silk, or textile material. The Chinese, in addition to porcelain and paper, also invented gunpowder, which was already in use since the 1st century BC. The materialist philosophers of ancient Greece arrive at the hypothesis of the diversity of matter, and the atomistic conception.[15]

Appearing since antiquity, *alchemy* experienced a special development in the Middle Ages, when more and more people believed that it was possible to transform ordinary metals into gold, provided they used a substance with magical powers (the “philosopher's stone”). One of the most important alchemists was Albertus Magnus (1195–1280), who managed to extract arsenic, silver nitrate, and sulphuric acid. He also describes the magical properties of various minerals and precious stones. But, the most famous representative of this period was Paracelsus (1495–1541). He perfected the distillation apparatus, prepared hydrogen from vinegar and iron filings, and ethyl ether from ethanol and vitriol. Combating the “*humoral*” theory of Galen, Paracelsus believes that the diseased state is due to the insufficiency or lack of one of the alchemical principles (salt, mercury or sulphur), and that the physician should restore the balance by the administration of medicines. The chemist Glauber (1604–1670) can be considered one of the precursors of preparative chemistry. He synthesized numerous inorganic compounds, such as HCl and sodium sulfate. He also developed numerous recipes, still used today, for preparing glass, mineral dyes, and potassium nitrate.[15]

The study of chemistry as a science began in the 1600s.[15] Thus, the Flemish scholar van Helmont (1577–1644), synthesizing certain substances, weighed the masses of reactants and reaction products. Thus, in 1648, his posthumous work appears in which, in addition to the description of numerous experiences, there is also a formulation of the law of mass conservation. This discovery exerted a strong influence on Robert Boyle who, in 1662, stated the law of the isothermal transformation of gases ($P \cdot V = N \cdot R \cdot T$), also known as the Boyle-Mariotte Law (independently of Edme Mariotte in 1676). In the same years, Van Helmont studied fermentations and noticed that they are due to certain substances, which he called enzymes, and thus, he can be considered one of the founders of enzymology. Van Helmont can be considered one of the forerunners of experimental chemistry. In the famous work ("The Skeptical Chemist") published in 1661, the English chemist and philosopher Robert Boyle (1627–1691) clearly demarcates chemistry from alchemy and marks the beginning of modern chemistry.

The modern period of the chemistry begins with the statement of the law of mass conservation. In 1774, performing an experiment in which mercury was burnt in a glass retort, the French chemist Antoine Lavoisier (1743–1794) experimentally confirmed this law. He is also the one who, recognizing the role of oxygen in the combustion process, gives a decisive blow to the phlogistic theory, being considered the father of modern chemistry. The law of mass conservation had been formulated as early as 1748 by the Russian encyclopedist Mikhail Lomonosov (1711–1765). Lomonosov contradicts the phlogistic theory by pointing out that metals are chemical elements and not compound substances.

In addition to the law of conservation of masses, in the development of chemistry as a science, an important role was played by Newtonian mechanics. Thus, chemists around the year 1800, led by the Englishman John Dalton (1766–1844), and Claude Berthollet (1748–1822) argued that between the particles that chemically react with each other there would be an attraction, which they called "chemical affinity", and which would be analogous to the gravitational attraction between celestial bodies. Also during this period, other fundamental laws of chemistry were discovered, such as: the "law of definite proportions" (Joseph Proust, 1797), the law of "multiple proportions" (John Dalton, 1803), the "law of constant volumes" (Joseph Louis Gay-Lussac, 1808). In 1803, Dalton formulated the modern atomic theory. It maintains the indivisible and immutable character of the atom, as it had been formulated in antiquity, but it transformed the philosophical hypothesis of ancient atomism into a scientific theory.

At the end of the 18th century and the beginning of the 19th century, a large number of chemical elements (H, O, N, Cl, Na, K, Ca, Al, etc.) were discovered. As a result, in 1869, the Russian chemist Dimitri Mendeleev (1834–1907) formulated the "law of periodicity of the properties of chemical elements". Based on this, he draws up the classification of elements, better known as the periodic system of elements (Mendeleev Table). By making this table, Mendeleev corrects the erroneous atomic masses of some elements and anticipates the existence of other elements unknown at that time (for example: gallium, germanium, scandium, polonium). The great Swedish chemist Jöns Jakob Berzelius (1779–1848) used the symbols of chemical elements for the first time and developed the first organic chemistry treatise in the world (appeared in 8 volumes between 1808 and 1830).

The series of organic syntheses in the lab continues with the synthesis of oxalic acid (1824), urea (Friedrich Wöhler, 1828), acetic acid (Adolph Kolbe, 1845), acetylene (Berthelot, 1862), methylene iodide, trioxymethylene, urotropin (A. Butlerov, 1850). All these discoveries revealed that there is no life force, and that all chemical processes obey the same laws.

Pasteur observed in 1849 that tartaric acid salts produce rotation of polarized light (enantiomers), thus being considered the founder of stereochemistry. A similar phenomenon is observed in 1815 by Jean-Baptiste Biot who studies the polarization of light. In 1874, the chemists van't Hoff, and Joseph Le Bel explained this optical effect by the spatial arrangement of the carbon atoms in the molecule.

The notion of valence is defined by the Italian Stanislao Cannizzaro in 1858, accepted by all scientists in 1860. Signaling the tetravalency of the carbon atom in 1858, the German chemist Kekulé von Stradonitz developed the theory of valence and came to the conclusion that the smallest components of molecules are atoms, and not free radicals. In the same year, the chemist Scott Couper develops this concept by showing that carbon atoms can join together to form chains that form the basis of molecules with a complex structure. In 1861, Butlerov claims that the properties of a substance depend not only on its chemical composition, but also on its structural formula (that is, on the way the atoms from molecules are joined together). To describe this property, Berzelius introduces the concept of isomerism.

An important event in the 20th century is the discovery of the cell gene and the role played by it in the transfer of cellular information. Thus, a novel field emerges, that is the molecular biology. In the second half of the 20th century, James Watson, Francis Crick, Rosalind Franklin and Maurice Wilkins determine the structure of DNA.

In 1927, the American physicist and chemist Robert Mulliken together with the German physicist Friedrich Hund developed the molecular orbital theory. The American John Slater introduces, in 1930, a mathematical model based on exponential functions to describe the atomic orbital. The American chemist Linus Pauling is noted for applying quantum mechanics to chemistry. His findings led British scientists to determine the double helix structure of the DNA molecule. The discovery, in 1895, of X-rays by Wilhelm Röntgen and, a year later, of the radioactivity of uranium by Antoine Becquerel, so that later Marie and Pierre Curie discovered new radioactive elements, all of which opened a new field of research: chemistry nuclear. The first nuclear reaction was carried out in 1919 by the English physicist Ernest Rutherford who bombarded nitrogen atomic nuclei with heliums, obtaining protons and oxygen isotope nuclei. His compatriot, James Chadwick, in 1932, by bombarding beryllium nuclei with helium, obtained carbon nuclei and neutrons. In 1938, the German chemist Otto Hahn demonstrates the phenomenon of nuclear fission of uranium.

## 2. CHEMICAL INDUSTRY EVOLUTION UP TO 20th CENTURY

With the advance of experimental chemistry and associated science, the chemical industry began to develop rapidly, even if, at first, on an empirical basis. In fact, the chemical industry appeared in the 18th century, due to the **industrial revolution**. Right from its beginnings, the **chemical industry** comprises the companies and other organizations that develop and produce industrial, specialty and other chemicals. Central to the modern world economy, it converts raw materials (oil, natural gas, air, water, metals, and minerals) into commodity chemicals for industrial and consumer products. It includes industries for petrochemicals such as polymers for plastics and synthetic fibbers; inorganic chemicals such as acids and alkalis; agricultural chemicals, such as fertilizers, pesticides and herbicides; and other categories such as industrial gases, speciality chemicals and pharmaceuticals.[16]

One of the first chemicals to be produced in large amounts through industrial processes was the sulphuric acid. In 1736 pharmacist Joshua Ward developed a process for its production that involved heating sulphur with saltpetre, allowing the sulphur to oxidize and combine with water. It was the first practical production of sulphuric acid on a large scale. John Roebuck, and Samuel Garbett were the first to establish a large-scale factory in Prestonpans (Scotland), in 1749, which used leaden condensing chambers for the manufacture of sulphuric acid.[16]

In the early 18th century, cloth was bleached by treating it with stale urine, or sour milk, and exposing it to sunlight for long periods of time, which created a severe bottleneck in production. Sulfuric acid began to be used as a more efficient agent as well as lime by the middle of the century, but it was the discovery of bleaching powder by Charles Tennant that spurred the creation of the first great chemical industrial enterprise. His powder was made by reacting chlorine with dry slaked lime and proved to be a cheap and successful product. He opened a company north of Glasgow, and production went from just 52 tons in 1799 to almost 10,000 tons just five years later.[16]

Nicolas Leblanc patented in 1791 a process to produce alkali (soda) from sea salt (sodium chloride), and then built a plant at Saint-Denis. In Britain, the Leblanc process became very popular. The British soda industry was rapidly expanded; several chemical works in Liverpool and Glasgow became the largest chemical production centres anywhere. By the 1870s, the British soda output of 200,000 tons annually exceeded that of all other nations in the world combined.

The Solvay process to produce soda (sodium carbonate) from salt brine (from inland sources or from the sea), and limestone (from quarries) was developed by the Belgian industrial chemist Ernest Solvay in 1861. In 1864, Solvay and his brother Alfred constructed a plant in Charleroi (Belgium). In 1874, they expanded into a larger plant in Nancy (France). The new process proved more economical and less polluting than the Leblanc method, and its use spread. In the same year, Ludwig Mond acquired the rights to use this process, and he built a Solvay plant at Winnington, England. Mond was instrumental in making the Solvay process a commercial success. He made several refinements between 1873 and 1880 that removed by-products that could inhibit the production of sodium carbonate in the process.[16]

The late 19th century saw an explosion in both the quantity of production and the variety of chemicals that were manufactured. Large chemical industries arose in Germany and later in the United States.

Production of artificial manufactured fertilizer for agriculture was pioneered by Sir John Lawes in 1840 near London, for the manufacture of superphosphate of lime. Processes for the vulcanization of rubber were patented by Charles Goodyear in the United States and Thomas Hancock in England in the 1840s. German industry quickly began to dominate the field of synthetic dyes. The three major firms, that is BASF, Bayer, and Hoechst produced several hundred different dyes. By 1913, German industries produced almost 90% of the world's supply of dyestuffs and sold approximately 80% of their production abroad. In the USA, Herbert Henry (Dow chemicals) used the electrochemistry to produce chemicals from brine. The result was a commercial success, which helped to promote the country's chemical industry.[16]

The first plastic was invented in 1856, by Alexander Parkes who patented “Parkesine“, a celluloid based on nitrocellulose treated with a variety of solvents. The industrial production of soap from vegetable oils was started at big industrial scale by William Lever in 1885 in Lancashire (U.K.) based on a modern chemical process invented by William Hough Watson that used glycerin and vegetable oils.

By the 1920s, chemical firms consolidated into large conglomerates. Thus, IG Farben (in Germany), Rhône-Poulenc (in France), Imperial Chemical Industries (ICI, in U.K.), and Dupont (USA) became the major chemicals companies in the early 20th century.

Chemicals are used in many different consumer goods, and are also used in many different sectors. This includes agriculture manufacturing, construction, and service industries.Other derivatives and basic industrials (specialty chemicals) include polymers and plastics, synthetic rubber, textiles, petroleum refining, pulp and paper, and primary metals, surfactants, dyes and pigments, turpentine, resins, carbon black, explosives, and rubber products, and contribute about 20% of the basic chemicals' sales. It also includes electronic chemicals, industrial gases, adhesives, and sealants, as well as coatings, industrial and institutional cleaning chemicals, and catalysts.[16]

Inorganic chemicals (about 12% of the revenue output) make up the oldest of the chemical categories. Products include salt, chlorine, caustic soda, soda ash, acids (such as nitric acid, phosphoric acid, and sulfuric acid), titanium dioxide, and hydrogen peroxide.

Fertilizers are the smallest category (about 6% from the total of produced chemicals) and include phosphates, ammonia, and potash chemicals.

Life sciences (about 30% of the chemistry business) include differentiated chemical and biological substances, pharmaceuticals, diagnostics, animal health products, vitamins, and pesticides. While much smaller in volume than other chemical sectors, their products tend to have high prices (over 10$/ pound). Life science products are usually produced with high specifications and are closely scrutinized by government agencies such as the Food and Drug Administration. Pesticides, also called “crop protection chemicals”, are about 10% of this category and include herbicides, insecticides, and fungicides.[16]

In the US production of 2000, the aggregate production volume of the top 100 chemicals totaled 502 million tons, compared to 397 million tons in 1990. Inorganic chemicals tend to be the largest volume but much smaller in dollar revenue due to their low prices. The top 11 of the 100 chemicals in 2000 were sulfuric acid (44 million tons), nitrogen (34), ethylene (28), oxygen (27), lime (22), ammonia (17), propylene (16), polyethylene (15), chlorine (13), phosphoric acid (13), and diammonium phosphates (12).[16]

## 3. THE BEGINNINGS OF THE CHEMICAL INDUSTRY IN ROUMANIA

The chemical industry in Roumania began to develop in the 19th century, through the exploitation of natural resources: oil, salt, natural gas, coal, wood/stuff, natural silicates, biomass (Figs. 1–2).

Thus, in 1896, the SOLVAY soda plant was put into operation at Ocna Mureș, financed by the Belgian company "Solvay et Co" and the Czech-Austrian company "Vereins fur Chemische und Metallurgische Produktion" from Karlsbad (Karlovy Vary). The two companies counted on the Ocna Mureș salt deposit, on the best quality limestone nearby, on the possibility of supplying industrial water, and on the possibility of transporting the finished products by rail. The plant initially operated with two sections (soda ash and crystallized soda ash). A caustic soda section was added to these in 1909.[17]

| Resources for raw materials | Created industry |
|---|---|
| • Salt | • of chlorosodium |
| • Crude oil | • extraction and refining<br>• petrochemical |
| • Natural gas (from fields) | • chemicals, ammonia, chemical fertilizers, etc. |
| • Coal | • carbochemistry |
| • Natural silicates (minerals, rocks…) | • of construction materials |
| • Raw materials for food use | • food industry |
| • Wood, reed, vegetable biomass | • of pulp and paper |
| • Biomass, spontaneous flora, etc. | • of biochemical synthesis<br>• of natural medicines |

Fig. 1 – Raw material resources and process industries created
by the Chemical and Biochemical Process Engineering (**CBPE**).[1]

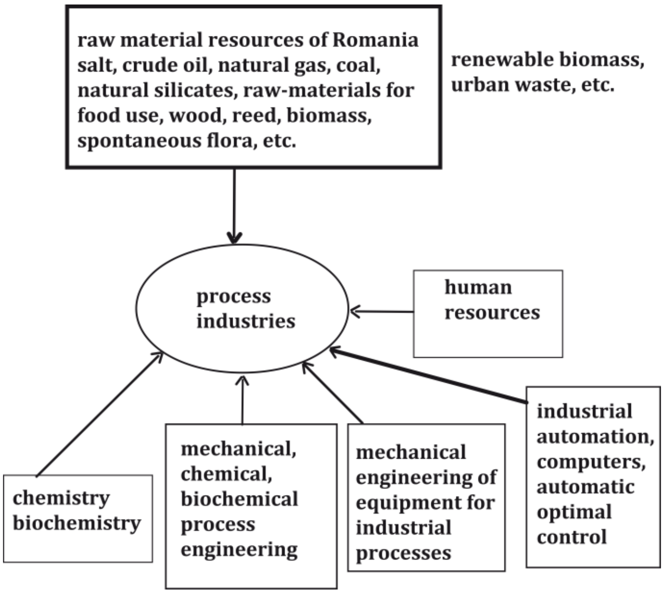


Fig. 2 – The connections of the Chemical and Biochemical Process Engineering (CBPE)
with the Roumania's basic engineering, fundamental sciences, and raw material resources.[1]

**The oil and petrochemical industry** took a considerable step forward after the 1850s. The year 1857 remained a reference year in the history of oil in Romania and in the world, having the significance of the transition from simple gasification to the oil industry in continuous development even today. For Romania, the year 1857 has a triple importance conferred by the recognition of three priorities on a world scale:[17]

The construction and commissioning of the first high-capacity industrial refinery in the world to obtain lamp oil through the primary distillation of the oil, used for lighting, based on original Romanian research and technologies and with full Romanian capital. This was operated in Lucaceşti (Bacău), being made by N. Choss in 1840 and developed by M. Heimsohn in 1844.[17]

The owner of the first "gas station" was the brothers Marin and Teodor Mehedinţeanu. The plant came into operation with a capacity of 2700 t/year in Râfov, near Ploieşti, based on an original technology that produces a high quality lamp oil, obtained by refining with a NaOH solution, respectively H2SO4. For comparison, in the USA, the starting moment of the oil industry is marked only in 1859, when, as a result of the drilling works carried out in Tituville, Pennsylvania, the first oil distillery in Pittsburg came into operation. Also in 1859, Russia registered the operation of its first distillery. Roumania thus became the first country in the world with an officially registered national oil production of 275 t (1817 barrels), officially registered in the international statistics. Thus, in 1857, Roumania had a production of 275 t, and of 495 t in 1858. In 1859, the USA had a production of only 274 t.[17]

The third priority recognized worldwide is the lighting of the first city in the world, namely Bucharest, with oil lamps (Şuţu Palace). Next comes Ploieşti, then Vienna, and then others. And from the etymological point of view, the Roumanians have contributed essentially since the time of the Daco-Romanians to specifying and using terms specific to the field. Thus the name "păcură" (HFO- heavy fuel oil) derives from "păcurari", a name worn by Transylvanian shepherds derived from the Latin "pecorarius" (shepherd).[17]

Roumanian researchers have made significant contributions to deciphering the composition of oil: Lazăr Edeleanu, Negoița Dănăilă, Costin D. Nenitescu, and many others, but especially to the separation of its components and to the valorization through chemicalization in consumer products. Thus:[17]

In 1897, the number of refineries in Roumania was 87, coming into operation at Câmpina (the "Steaua Română" refinery), then at Teleajen (the "Roumanian-American" refinery, 1904), then "Vega", "Astra Română", and "Concordia", all near Ploiesti (1904).

In 1904, the operation of the first school of foremen surveyors in Europe was registered in Câmpina (Roumania).

Between 1906–1924, the annual production of oil for domestic use and export fluctuated depending on the internal and international political conjuncture, between 1 and 2 million tons.

In the period 1935–1940 until WW2, in Roumania operated 5 large oil refineries with 42 atmospheric distillation plants, with an overall capacity of 240,050 barrels/day, and 7 thermal cracking (pyrolysis) plants with a capacity of 35,850 barrels/day. In 1936, the highest annual production of oil in Roumania was registered in the inter-war period of 8,704,000 t. At that time, Roumania was the 5th in the world, in the hierarchy of the oil producers after the USA, the USSR, the Dutch Indies, and Canada. After WW2, until the nationalization of June 11, 1948, the reconstruction of the refineries destroyed by the bombings took place, because the refining capacity decreased in 1944 by 53% compared to 1943, namely at the refineries: "Astra Română", "Standard", "Vega", "Roumanian-American" – Ploiesti, "Steaua Română" – Câmpina, and "Creditul Minier" (Brazi).[17]

After WW2, the chemical industry in Roumania experienced a rapid development. It represented an important branch of the industry, being present through a multitude of factories combined with various activity profiles, such as: the chemical works with a complex profile "Oltchim" (Rm. Vâlcea), oil refineries combined with petrochemical companies (Petrobrazi, Petrotel Lukoil, Astra Română, Petromidia, etc.), producers of chemical fertilizers (Azomureş, Donau Chem, Amonil), producers of chloro-sodium products (Govora chlorosodium works – GHCL, Upsom/calcinated soda), producers of plastics (Metaplast, Munplast, Teraplast, etc.), rubber producers (Artego, Carom) and paint producers (Azur Timişoara, Policolor, Sarcom, etc.).

After 1960, in parallel with modernization and extension of the refineries in Brazi and Teleajen, began as well as the construction of new refineries in Oneşti, Dărmăneşti, Piteşti and Midia – Năvodari. In 1989, the 11 existing refineries reached a capacity of 34 million t/year. The designed refineries had a high degree of capitalization of oil to produce fuels, mineral oils lubricants, and basic petrochemical raw materials, which ensures an optimal degree of oil chemicalization. The refineries have a high degree of Nelson complexity, as an integrated system that includes primary and vacuum distillation facilities, catalytic cracking, catalytic reforming, gasoline and diesel hydrorefining, alkylation, isomerization, sulfur recovery, coke production, etc.[17]

With all these variations in the production capacities, Roumania also stood out through a development of the petrochemical industry within industrial platforms. After 1955, the period of modern petrochemicals begins in Roumania, with the entry into operation of the synthetic rubber plant "Carom" (Oneşti) and, in 1960, of the petrochemical works "Petrobrazi" (Brazi, near Ploieşti) integrated with the oil refining. Since 1965, the petrochemical complexes “Arpechim” (Piteşti), “Oltchim” (Rm. Vâlcea), “Solventul” (Timişoara), have been integrated with the pyrolysis from Pancevo (Serbia), “Petrotel” / Lukoil (Ploieşti), and “Petromidia” – have been built (Năvodari.).[17]

The chemical industry in Roumania developed rapidly after WW2, especially after 1965 and until 1989. Before the war, the chemical industry generated less than 3% of all industrial production and the list of products was limited to carbon black, sulfuric acid, hydrochloric acid, caustic soda, varnishes and paints. In 1980, the chemical industry produced 15–20% of the total industrial production and represented over 25% of export receipts. The petrochemical branch was the heart of this industry producing about 50% of the industry's total output. The largest petrochemical plants were built in Ploieşti, Piteşti and Midia-Năvodari, but many smaller units were scattered throughout the country. After the construction and commissioning of the chlorsodium products factories in Turda, Târnăveni, Govora and Ocna Mureș, Roumania became one of the largest producers of sodium chloride-based products in Europe. New sulfuric acid factories were built in Victoria, Turnu-Măgurele, Năvodari, Copșa Mică, and the old ones were modernized. The design/chemical engineering activities were carried out both in large research/design institutes (IPROCHIM, IPRAN, IPROSIN, ICITPR, IITPIC) and in local sections next to large industrial complexes. Currently, efforts are being made to maintain the necessary level of development of the chemical and petrochemical industry, both industries being an essential factor for the progress of Roumanian society.[4]

**The inorganic industry.** In 1934, the inorganic chemical industry displays a little presence in Roumania, including only a small 2t/day ammonia factory in Târnăveni and a 7 t/day ammonia factory at “Nitramonia”, (Făgăraş). Under the leadership of the Eng. Ulisse Corina, these factories of ammonia and nitric acid in Făgăraş were expanded, new ones were built in the city of Victoria (Ucea).[18] In 1981, the Roumanian chemist Marin Vîlceanu patents a technology, based on the idea of Prof. Ulisse Corina, from the Inst. Polytechnic University of Bucharest, which almost reaches the thermodynamic limit of 17–18% NH3 in the reaction products.[18]

By leading a group of engineers and technicians, the eng. Ulisse Corina designed and built an ammonium sulfate plant, a hexamethylene-tetra-amine (urotropin) plant, as well as a plant for the direct manufacture of sodium nitrite by coupling it with the nitric acid plant. His process is totally different from the classical ones, by which a nitrite-nitrate mixture was obtained, which then had to be separated. Ulisse Corina designed and put into operation a plant for the manufacture of ammonium carbonate by using ammonia and residual carbon dioxide from the manufacture of ammonia. Also, he is the author of the process of manufacturing potassium nitrate from ores with a high content of salts, simple or complex, also using gases from the ammonia industry. He designed and built the high-capacity plant for the manufacture of nitrophos, nitrogen and phosphorus-based fertilizer, also managing to obtain non-agglomerating ammonium nitrate using sulfonated dyes in small quantities. [12]

In 1912, began the construction of the Târnăveni Chemical Works, where carbide was produced, as well as a wide variety of chemical products (1975–1980). It was established at the beginning of the 19th century due to the mineral deposits in the area, the methane gas reserves, the abundance of wood needed to produce the brazier and the railway built since the end of the 19th century. After the discovery of methane gas in 1912, near Târnăveni, the conditions were created for the development of the industry of inorganic chemicals (carbide, lime, zinc oxide, barium salts, chromic anhydride, m bichromate plant (1980), the chromic anhydride plant (1982), the formic acid and oxalic acid, polyvinyl chloride (PVC), calcium super-phosphate, sodium bichromate, hydrofluoric acid and cryolite, freon, etc.), and of the construction materials.[19]

## 4. CHEMICAL ENGINEERING AS SCIENCE – BEGINNINGS AND DEVELOPMENT

Following the significant advances in the experimental and theoretical chemistry, as well as the production of chemicals, the Chemical Engineering as a science, appeared and began to develop independently, only in the late 1800s, when George E. Davis coined the term “*chemical engineering*”. The increased understanding of the importance of chemical engineering was made during and after the WW1, when the first chemical factories appeared, and science took a considerable lead. This led to the establishment in 1922 of the Society of Chemical Engineers in England (IChemE).[14] From this moment, quantitative systematic theoretical studies of the physico-chemical processes that take place in industrial chemical equipments and plants began to appear, aiming at their optimal design, operation and control.

One of the "fathers" of the theoretical foundations of CPE (Chemical Process Engineering) is considered Dirk Willem Van Krevelen (1914–2001), professor at the Technical University of Delft (1952–1980) and research director at the companies DSM (1940–1959) and AKU/AKZO (1959–1976). He contributed decisively to the recognition of CRE (Chemical Reaction Engineering and Reactors) and CPE as branches of the CBE (Chemical and Biochemical Engineering) in the year 1957, through his actions, thus:[21]

In 1946/1947 he made a 3-month visit to the USA where he met the leading figures of CBE science: Sherwood T.K.; Lewis W.K.; Walker WH; McCabe W.I.; Chilton T.H.; Colburn AP; Hougen O.A.; Watson K.M. (names associated to the dimensionless criteria and mathematical models for the transfer of property used in CBE). In 1947 he was elected an active member of AIChE [American Institute (Society) of Chemical Engineering]. Working on gas-liquid processes he introduced the mass transfer criterion which he called Sherwood (Sh), that flattered the American CBE school, which recognized him as a leader in the kinetics of chemical operations.

In 1951, he was the founding editor of the *Chemical Engineering Science* journal (Elsevier), that is the highest level forum where CBE, CRE, CPE researches have been published. In 1953 he played a central role in the founding of the EFCE (European Federation of Chemical Engineering).

In 1955, together with Klinkenberg and Kramers, Van Krevelen introduced the teaching of "*unit operations*" preceded by the three types of transport (mass, heat, and momentum). See reviews,[10,12] and section 10 of Maria *et al.*[5] The idea was taken up by the American B. Bird who, in 1956 was a Fullbright scholar at Van Krevelen's laboratory in TU Delft. Upon returning to the USA, three proeminent professors Bird-Steward-Lightfoot published the famous basic book of CBE,[6] defining the 1st paradigm of this field. The fact once again demonstrated van Krevelen's leaning towards a more fundamental understanding of unit operations, including classical (physical) ones.

Having become a representative figure of the CBE in Europe, Van Krevelen was honored with the presidency of the Congress of the CBE in Amsterdam (Sept. 1957), which later became ESCRE 1 – the first European Congress on Chemical Reaction Engineering. In 1970, after 4 editions, ESCRE became ISCRE 1 (international) and continued every 2 years, reaching in 2014 ISCRE 23-Bangkok. According to Encyclopedia.com, Van Krevelen also coined the name CRE. He also outlined the directions of the new discipline in an ISCRE conference.[21] Mathematical modeling and optimization of the (bio)chemical reactor is possible only after elucidating the interaction between reaction kinetics and the property transfer in the reactor. In 1958, at his initiative, the "Working Party of Chemical Reaction Engineering" was established within EFCE with him as president. Van Krevelen is also known for a large number of fundamental contributions in CRE and CPE.[21]

In general, the Chemical Engineering (ChE) is distinctly different from other types of engineering sciences (mechanical, electronic, metallurgical, aeronautical, etc.) because it is a *process engineering*. In the "process engineering" and "process industries", the goal is to produce the *transformation* of raw materials *at the molecular level* (for example, chemical reactions, fermentation), and in some, only their physical transformation (distillation, shredding).[22]

This assumes that ChE deals with the study of chemical reactions (processes: kinetics, thermodynamics) from the practical perspective of their management in specific equipment (reactors) and included in complex chemical plants, that include a multitude of inter-connected specific equipments (distillation columns, absorption, heat exchangers, filters, centrifuges, pumps, compressors, dryers, crystallizers, separation columns, etc.) designed to facilitate the optimal operation of the chemical reactor, and then to ensure the separation and purification of the resulted useful products. In addition, the **ChE** computing techniques and algorithms are aiming at optimizing the industrial plant (having the chemical reactor as a central equipment) from an economic point of view, and at operating them in complete safety conditions.

Due to such a reason, ChE is inextricably linked to the experimental chemistry, other related chemical disciplines (physical chemistry, analytical chemistry, electrochemistry, etc.), and to the fundamental sciences (mathematics, and numerical calculus). For the reasons previously stated, the beginnings of the ChE are placed in the 19th century and the first half of the 20th century.

As reviewed by Maria,[5] the first numerical evaluations (based on math models) of the (mass, heat, moment) transfer processes are placed in the 19th century and the first half of the 20th century. The design calculations of the equipment in the technological schemes of the chemical plants had a high degree of empiricism. The relationships were simple (algebraic) and, to solve the scaling-up problems (from the lab-scale plant to the industrial-scale plant), "geometric simplexes" and "criterion equations" were used, based on the definition of dimensionless engineering criteria, that is the so-called "engineering numbers" (*e.g.* Reynolds, Prandtl, Froude, Schmidt, etc.;[6,23] see also the books of Bratu from [Table 1]), which evaluate by comparison the intensity of different transport mechanisms of properties and of the reaction rate. A brief presentation of the evolution of CBE (chemical and biochemical engineering) from empiricism, to concepts, principles and modern working methods, passing through the four "paradigms" is made in the literature.[5,10,12]

With the huge advances made in the computing techniques, and in the field of numerical algorithms for solving difficult math problems, as well as the use of an increasingly efficient (bio)chemical analytic equipment, that allows more and more precise experimental measurements, and at ever smaller (nano-) scale, the CBE and its applicative part of CBT (chemical and biochemical technology) took a new turn in their development. Thus, the math models moved on to differential property balances written for an infinitesimal (nano-, micro-) scale which, by integration in well-defined spaces and with correctly specified boundary and initial conditions, allow the (bio)chemical process dynamics to be obtained with a high precision at a macroscopic scale of the industrial reactors specific to the (bio)chemical synthesis industry. These high-precision differential math models solved in real time with the help of high-performance computers enabled essential developments of CBE/CBT, such as: (*i*) Optimization of (bio)chemical reactors/plants; (*ii*) Optimal and safe control of the industrial plants; (*iii*) Safety analysis of chemical reactors where risky (fast, exothermic) reactions are conducted. This includes:[24,25] (*iii-a*) *In-silico* (math models based) evaluation of the reactor/process safety operating limits in the operating space of the control variables]; (*iii-b*) *In-silico* simulation of the chemical accident scenarios (fires, explosions, toxic substances releases) that could occur in the analyzed chemical plant, as well as their effects and consequences on environment, including Domino effects.

There are many prominent figures of ChE science. Among them, we should mention: Prof. Dirk Willem Van Krevelen (TU Delft, Netherlands); Prof. Rutherford Aris (Univ. of Minnesota, USA); Prof. Gerhard Damköhler (University of Göttingen, Germany); Prof. Olaf Hougen (University of Wisconsin, USA); Prof. Kenneth Watson (Univ. California at San Diego, USA), etc.

**The paradigms of chemical engineering.** The chemical engineering development was guided by its four main paradigms: 1) unit operations, 2) transport phenomena, 3) product engineering, and 4) sustainable chemical engineering. "The starting point is the paradigm definition as "a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality for the community that shares them, especially in an intellectual discipline." Related to the paradigms role in the evolution of chemical engineering, it is relevant that even when paradigms are known to be inadequate, their inadequacies are frequently minimized, or even ignored by the scientific community. Nevertheless, if and when a paradigm reaches a crisis where its technical inadequacies are brought into focus, perhaps driven by social requirements, a new paradigm will arise to explain what the prior paradigm could not. During the evolution of chemical engineering, from its beginning at the end of 19th century up today's, each new paradigm was a step forward which has extended the manifold of the tasks that can be solved. However, no older paradigm is derelict. In fact, almost all paradigms must be used together in order to solve the complex chemical engineering problems".[9,10]

**P1) The first paradigm – unit operations** (1923–1960) – appeared as a necessity to systematize the physical-chemical processes involved as a result of the "explosion" of chemical industrial applications at the end of the 19th century. In 1887 prof. Geoge Davies from Manchester Technical College has taught a lot of chemical engineering lessons. These lessons were the roots of his further Handbook of Chemical Engineering published in 1901, and next in a second edition consisting in two volumes in 1904.[9]

"The Davies' book contained a novelty, which subsequently it appears to be more important as it incipiently looked: instead to describe each technological process existent at that time, Davies regards an industrial chemical process to be composed by distinct sections which are present – in different sequences and conditions – in many other processes. As this Davies' priority was not explicitly announced, it was assigned to Arthur D. Little, which in a report to Massachusetts Institute of Technology (USA) has introduced the notion of *unit operations*. Much more later, in 1958, Davies' priority about the concept of unit operations has been recognized (Bratu, 1976, in Table 1). This concept and its application can be assumed to be the first paradigm of chemical engineering, namely *the unit operations paradigm*. Therefore, the explosion of chemical industrial applications at the end of 19th century and at the beginning of the 20th century imposed the requirements of the process details knowledge systematization. It can be considered that the first paradigm has appeared as a necessity of systematization. The representative book of this paradigm is Walker *et al*., "Principles of chemical engineering", McGraw-Hill, NY, 1923.

"The tens thousands industrial chemical processes can't be individually treated to the detailed scale as imposed by design and operation of the corresponding plants. Nonetheless, these processes are made from a much smaller number (about 80) of unit operations. Based on unit operations paradigm, an enormous amount of information concerning both theoretical and experimental studies, as well as results about unit operations is systematized, in a huge literature (books, papers, patents)".[9]

**P2) The second paradigm – transport phenomena** (1960–2000) – appeared at the end of the 50s as a consequence of the need for a deep, scientific knowledge of the phenomena to explain what happens inside the unit operations. "While still useful to the present day, the unit operations paradigm proved inadequate for solving some important classes of problems (Hill, 2008)."[9] This awareness led to the emergence of chemical engineering science as a second paradigm in the late 1950s, as best exemplified by the Birds' textbook "Transport Phenomena".[6] This is the *transport phenomena paradigm*, an upper systematization and synthesis evolution. At the moment of issue of this book, the field of transport phenomena has not been yet recognized as a distinct engineering subject. The authors have considered that it is important to put more emphasis on understanding basic physical principles, than on the blind use of empiricism. Their thought has been that the subject of transport phenomena should rank along thermodynamics, mechanics, and electromagnetism as one of the key "engineering sciences". The paradigm of transport phenomena approaches the three elementary physical processes, which take place in any kind of unit operation: momentum, energy, and mass transport. Thus, unit operations can be considered as specific applications of these three fundamental processes. As combinations of unit operations give technologies, combinations of transport processes give unit operations.

The paradigm of transport processes press for the mechanisms of these processes, on the phenomena, which take place close to the border of two physical phases; the aim of the paradigm consists in the deep understanding of the elementary causes and effects which explain the features and applications of each unit operation. The transport phenomena paradigm extend the content of chemical engineering to a fundamental, theoretical science, closely linked with physics, mathematics, mechanics, thermodynamics, electromagnetism etc, becoming a true "Nucleus of Discovery."[9] The birth of the second paradigm was, therefore, the consequence of the need for a deep, scientific knowledge of the phenomena which explain what happened inside of unit operations. Engineering, in the last analysis, depends heavily on heuristics to supplement incomplete knowledge. Transport phenomena can, however, prove immensely helpful by providing useful approximations, starting with order of magnitude estimates, and going on to successively more accurate approximations, such as those provided by boundary layer theory."[6,9,10]

"At last, it appears the trend to gather all the three transport phenomena in a single concept, respectively the property transport. This very high systematization is justified by the analogy of the transport phenomena, respectively the structural similitude of differential equations and boundary conditions which describe them. In this treatment, each fundamental transport process becomes a specific case".[9]

**P3) The third paradigm: chemical product engineering.** It appeared in the second part of the 20th century and the beginning of the 21st century when the importance of the properties and of the chemical products quality became essential, due to the competition for them on the market. Consequently, additional and even new fundamental approaches were needed.

"In the second part of 20th century the diversity of industrial products (in many cases with close properties and with the same utilization) has a huge growth, and correspondingly, very strong market fights have evolved between producers companies. The same things happened with chemical products. The importance of properties and qualities of chemical products have become essentially. Until recently, the main purpose of chemical engineering has been to obtain the lowest cost process. Even process related issues like reliability, product purity, pollution control, etc. have been ultimately translated into costs that must be minimized. In contrast, chemical product design try to obtain the most added value for a product through enhanced product properties. This is a more complex task than a mathematical treatment to maximize profit. The profit depends in some unidentified way upon the complex set of product properties. Therefore, product engineering problems can't be solved by traditional chemical engineering approaches. Their solution requires not just additional chemical engineering approaches, but even more fundamentally, and that is why *product engineering* should be recognized as a *third paradigm* of chemical engineering, as first hinted in 1988 by the "Committee on Chemical Engineering Frontiers". It can be assumed that the third paradigm was imposed by the fight for technical and economical products performances generated by a strong competitive market environment."[9]

"New chemical products have been created by combining a wide knowledge of existing chemical products with a big amount of scientific experimentation. A combinational explosion of product options will limit all experimental techniques. Therefore, it is desirable to minimize experimentation through a systematic consideration of product formulation prior to experimentation. *Product engineering techniques* are largely based on heuristics when data are limited, followed by detailed calculations when data become available, this being the essence of the third paradigm. The basics of the third paradigm were stated on 2001, by the book of Cussler and Moggridge.[27]

Related to the controversy of the key to product design, management or technology, Cussler and Moggridge[27] consider that the application of technology is central to chemical product design. Product design and process design must be used together (Fig. 3), in agreement with these changes in the chemical industry.[9]

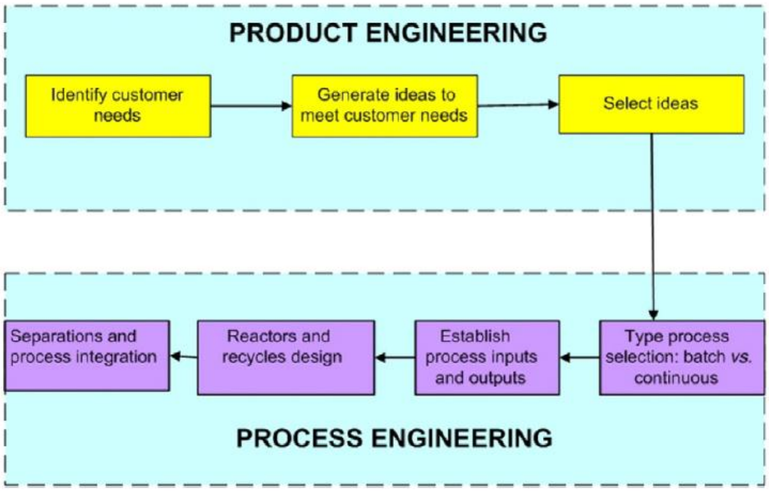


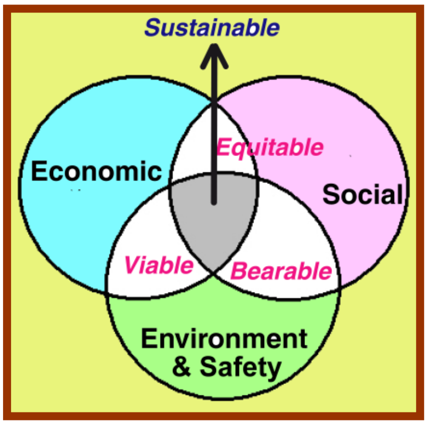
Fig. 3 – The link between chemical product engineering, and chemical process engineering. Adapted from Woinaroschy.[10]

**P4) The fourth paradigm: sustainable chemical engineering.** Nowadays, the chemical industry is a huge consumer of raw materials, materials and energy and with a strong environmental impact. Therefore, the chemical industry could not remain outside the requirements of sustainability. Consequently, the bases and principles for the development of a *sustainable* chemical engineering were formulated. In short, the main concepts of the sustainable development of CBPE (chemical and biochemical process engineering) refer to:[5] (*i*) sustainability of the process (Fig. 4); (*ii*) operational safety; (*iii*) optimal design / operation / control; (*iv*) maximum security conditions; (*v*) minimum energy consumption; (*vi*) minimum negative impact on the environment; (*vii*) a high economic return; (*viii*) circular economy (“reduce, recycle and regenerate”); (*ix*) the design of chemical industrial plants through a hierarchical approach; (*x*) ensuring an optimal social impact.

Some of the modern chemical process engineering (CPE) paradigms currently used to achieve its sustainable development, can be re-formulated as followings:[5] (a) multi-criteria and multi-level optimization of chemical industrial facilities; (b) application of math modeling, and of the advanced numerical calculus for the design, simulation, optimization, and control of the chemical industrial processes / planta; (c) development of the above techniques (a-b) based on the principles / concepts / approaches, and the numerical algorithms of the classical CPE (unit operations; transport phenomena; engineering oriented towards the chemical finished product *vs*. engineering oriented towards the development/ optimization of the process).

In other words, a chemical/biochemical/ biological industrial process is defined as sustainable when all three of its components are considered simultaneously (Fig. 4): (*i*) economically efficient (profitable); (*ii*) environmentally friendly (with a minimal negative impact on the environment, *i.e.* minimization of toxic by-products/pollutants; (*iii*) with a positive impact on the development of society.

“Sustainability becomes more and more important in the modern economy, and in 1999 the Dow Jones Sustainability Indices were started. Corporate sustainability is considered a business approach that creates long-term shareholder value by embracing opportunities and managing risks deriving from economic, environmental, and social development (Heinzle *et al*., 2006, see Maria[24]). For these, Peters *et al*.[28] is the standard reference book.”[9]



**Economic goal** (costs, productivity, yield, benefit, profit, net income, recovery of investment costs, etc.)

**Safety goal** (minimization of the probability of process runaway, operation without violating technological restrictions, low parametric sensitivity, adaptive/flexible operation, minimization of the probability of non-compliance with the production performance indicators, even in the presence of the inherent random fluctuations of the operating parameters.

**Environmental goal**: minimal impact on the environment, evaluated on the basis of the ecological index (EI) [Biwer and Heinzle, 2004, see Maria[24]], based on mass balances and the LCA – “life cycle assessment” (the ecological impact of handled chemical substances, or of a chemical process on during its entire “life”).[24]

– environmental accident index (EAI) (chemical substances spread on soil, in soil or in surface water) [Scott, 1998][24]

– SAL environmental risk index [Koller, 2000].[24]

**Social goal.** This index is difficult to be quantified. It relates to: quality of work and life, safety and health, education and training, information management, innovation, consumer acceptance, social benefit, social dialogue.

Fig. 4 – The 4th paradigm – Sustainable development. It realizes a compromise of the three constituent parts: i) minimum impact on the environment, ii) maximum safety in operation, iii) social responsibility (positive social impact) and maximum economic efficiency.[5]

To conclude, these four CPE paradigms had/have a paramount importance in the past/present evolution of chemical engineering. Related to the paradigms role in the evolution of CPE, it is relevant the Kuhn conception (Kuhn, 1996),[9] respectively that even when paradigms are known to be inadequate, their inadequacies are frequently minimized, or even ignored by the scientific community. Nevertheless, if and when a paradigm reaches a crisis where its technical inadequacies are brought into focus, perhaps driven by social requirements, a new paradigm will arise to explain what the prior paradigm could not. During the evolution of CPE each new paradigm was a step forward which has extended the manifold of the tasks that can be solved. However, no older paradigm is derelict. In fact, almost all paradigms must be used together in order to solve the complex chemical engineering problems.

## 5. THE EMERGENCE OF CHEMICAL ENGINEERING EDUCATION IN ROUMANIA. THE DECISIVE CONTRIBUTION OF PROF. EMILIAN BRATU

The "road" of Chemical Engineering from empiricism to Process Engineering – a multi-disciplinary science in the postmodern era, was traced in Romania by Professor Emilian Bratu who with art, clairvoyance and love built the School of Chemical Engineering in Romania, in the middle of 20th century, being the first trainer of specialists in the field of chemical engineering – engineers, and phd. engineers.

Before the appearance of Prof. Emilian BRATU at the Bucharest Polytechnic, only a few timid attempts to introduce chemical engineering techniques. So, driven by the advance of the chloro-sodium and petrochemical industry, and by the progress made worldwide, chemical engineering, in its experimental form, made its presence in Romania since the 19th century.

Thus, the development of oil extraction and crude oil refining in Roumania did not remain without notable achievements in the field of chemical engineering. Many of them are due to Lazăr Edeleanu (1861–1941), who in 1906 held the position of head of the Chemistry laboratory at the Geological Institute and director of the Vega refinery (near Ploieşti). In 1907 he was the main organizer of the 2nd World Petroleum Congress held in Bucharest. In the same year, together with Ion Tănăsescu, he published a monography about the Ruomanian oil (physical and technical properties). In 1908, he registered the invention that bears his name: "The Edelean Process for refining petroleum products with sulfur dioxide", applied in 1910 at the Vega-Ploiesti refinery, and which is still used today in many refineries around the world. "Throughout his life, he obtained 212 invention patents in Roumania, USA, Germany, France, Austria, Sweden, Netherlands, which brought him international recognition. The scheme of the Edeleanu process is preserved in the original from 1924 at the Delft University of Technology in the Netherlands.

It is to mention, that the chemical industry in Roumania developed rapidly after WW2, especially after 1965 and until 1989. Before the WW2, the chemical industry generated less than 3% of all industrial production and the list of products was limited to carbon black, sulfuric acid, hydrochloric acid, caustic soda, varnishes and paints. In 1980, the chemical industry produced 15–20% of the total industrial production and represented over 25% of export receipts. The petrochemical branch was the heart of this industry producing about 50% of the industry's total output. The largest petrochemical plants were built in Ploiesti, Pitesti and Midia-Navodari, but many smaller units were scattered throughout the country. After the construction and commissioning of the chlorsodium products factories in Turda, Târnăveni, Govora and Ocna Mureș, Romania became one of the largest producers of sodium chloride-based products in Europe. New sulfuric acid factories were built in Victoria, Turnu-Măgurele, Năvodari, Copșa Mică, and the old ones were modernized. Design/ chemical engineering activities were carried out both in large research/design institutes (IPROCHIM, IPRAN, IPROSIN, ICITPR, IITPIC) and in local sections next to large combines.

Such a near exponential development of the Romanian chemical industry after WW2 requires huge research and design efforts. The engineering research part used the acquisition of licenses, but also through own works developed within the research centers of the chemical industrial complexes/works, and from ICECHIM Bucharest. The chemical engineers involved in these design / construction / commissioning activities have successfully completed these complex projects. They were trained at the main chemical engineering schools in Romania, established according to the model of the one at the Inst. Politehnic Bucharest founded and developed by Prof. Emilian BRATU.

The traditions of the engineering school in Roumania are related to the organization, since 1818, of the first Higher Technical School (with university teaching) in the Roumanian language, by Gheorghe Lazăr, at the Sfântul Sava monastery in Bucharest and who, in 1832, is reorganized into the College of Saint Sava. In

1864, by the Decree of ruler Al. I. Cuza, the "School of Bridges and Roads, Mines and Architecture" was established, which in 1867 it became the "School of Bridges, Roads and Mines" by the Decree of the King Charles I. In 1881, the institution acquires a new structure, under the name "National School of Bridges and Roads". In 1920, it became the Polytechnic School of Bucharest, by the Decree of King Ferdinand. The name was changed from1921 to Polytechnic University of Bucharest, and after 1948 to Polytechnic Institute of Bucharest. Some hesitant trials to develop CBT at University of Bucharest have been made by Negoiţă Dănăilă between 1914–1920.[29]

In 1937, entered into force the "Law for the exercise of the engineering profession and the establishment of the College of Engineers" which, decided that the training of engineers should be done only in the Polytechnic Institutes. As a result, the all chemical engineering schools merged, by leading to the Faculty of Industrial Chemistry at the Polytechnic School of Bucharest, having Prof. Emilian Bratu as head of the "Chemical engineering department." [29]

Under this favorable conjuncture, when the chemical industry in Romania reported an nearly exponential increase, as well as the tremendous progresses made by the chemical engineering science in the world, it was Roumania's chance that, in the 1940–1950s, a scientist of the caliber of Prof. Emilian Bratu, trained at the German engineering school, appeared, who, with the support of Prof. Prof. C.D. Nenitescu, to establish and consolidate at the Bucharest Polytechnic Institute, the "Department of Processes and Apparatus", which later (1937) became the "Chemical Engineering Department", being the first such department in the country and among the first in Europe.

Prof. Emilian Bratu was the founder of the School of Chemical Engineering in Roumania, being the one who campaigned for the establishment and development, at the Bucharest Polytechnic Institute/High School (UPB), of the "Department of Chemical Engineering" (by Decision 296253/1.XII.1948, of the Ministry of Public Education). Prof. Em. Bratu also has the merit of having written and published the first Chemical Engineering course ("Procedures and Apparatus in the Chemical Industry", 1948, re-edited in 1954–1957, then in 1960–1961, in 1969–1970, and in 1984, Table 1). Based on this model, similar Chemical Engineering departments were established in the main university centers in the country, taking over the Chemical Engineering course of Prof. Em. Bratu.[1,2]

By summarizing, acad. Dr. Eng. Emilian BRATU was a reference figure in Roumanian education and scientific research. He became a corresponding member of the Roumanian Academy in 1963, and then a full member in 1974. In the period 1977–1990 he was the President of the Chemical Sciences Section of the Romanian Academy. The contribution of Prof. Emilian BRATU to the development of chemical engineering science and practice in Romania was overwhelming, through the foundation and rapid development of the chemical engineering school in Romanian university education. The "Department of Chemical Engineering" founded by Prof. Em. Bratu at the UPB was the first in the country and among the first in the world. All Em. Bratu was the creator of the first textbooks for this essential discipline (1949, Table 1).

## 6. Acad. Dr. Eng. EMILIAN BRATU (1904–1991) – SHORT BIOGRAPHY

Acad. Emilian Bratu was born in Bucharest on 8 Aug. 1904, in a family of intellectuals. After completing his high school secondary education, he enrolled at the National School of Bridges and Roads 1922–1927 (later the UPB), where he had famous teachers such as Traian Lalescu (mathematics). No physical chemistry course is taught at the UPB. Therefore, for in-depth studies in this area, the young engineer Em. Bratu went abroad, first to Technical University in Vienna (1928), where he studied physical chemistry and industrial electrochemistry under the guidance of professors E. Abel and O. Redlich, by carrying out studies on galvanic cells in order to evaluate thermodynamic functions. Later, in 1929 he studied methane pyrolysis at the University of Karlsruhe, and in 1930 he studied electrochemistry at the Charlottenburg Technical University in Berlin. Between 1928–1941, Em. Bratu started his university career in Roumania as an assistant at the UPB, in the discipline of "Chemical Technology and Electrochemistry", led by Professor Staehelin, carrying out research works on waste water treatment, optimization of drinking/wastewater networks in Bucharest, Azuga, and Iaşi.[1,2,26]

Between 1932–1935, during vacations or study leaves, Em. Bratu prepared his doctoral thesis at the Higher Technical School in Vienna, under the supervision of Prof. E. Abel and O. Redlich, with a topic of very high relevance at the time: "The preparation of the heavy isotope of hydrogen and determination of the dissociation constant of heavy water ($D_2O$)", held in 1936. It is worth noting that, at that time, he had to build the apparatus with which to obtain deuterium (D), from which he could then prepare small amounts of heavy water, whose properties he could precisely determine. The results published in *Zeitschrift für physikalische Chemie* in 1934–1935 are still cited today. His doctoral thesis has a special resonance world-wide, being mentioned in the well-known Landolt-Börnstein Encyclopedia.[1,2]

## 7. EMILIAN BRATU – THE FOUNDER OF THE CHEMICAL ENGINEERING EDUCATION IN ROUMANIA

Due to his exceptional teaching and research qualities at the UPB, in short time, Em. Bratu became a lecturer and then a full professor (1948–1971), and dean of the Faculty of Industrial Chemistry (1955–1957; 1962–1971), and supervised over 30 PhD theses.[1] His course of "Apparatus and plants used in the chemical industry" ("Aparate şi instalaţii utilizate în industria chimică"), is based on his original research and a rich bibliography. His original course is characterized by scientific rigor and systematization. The course was re-edited and appeared in several editions (Table 1). The 1960–1961 edition was awarded the Roumanian Academy Award. By explaining some fundamental chemical processes, a synthesis of thousands of chemical technological processes is achieved, only by exemplifying a few dozen of case studies. Still today, its course remains a reference book for the university training in this field, through the basic concepts/principles exposed, and by including information on specific industrial equipment and plants.

Following the model of the department founded, run, and developed by Prof. Em. Bratu at the UPB, similar departments of Chemical Engineering were established in the main technical universities of the country (Iaşi, Timişoara, Cluj), taking over the course "Operations and equipment in the chemical industry" of Prof. Em. Bratu.

Through his research and university courses, Prof. Emilian Bratu is among the worldwide precursors who define the concepts of chemical engineering, and is considered the founder of the Romanian school of industrial chemistry / chemical engineering.

His fundamental scientific contributions in the field of industrial chemistry/chemical engineering science can be traced in time, between the years 1928–1974. These remained benchmarks for the progress of science in Romania. Due to the recognition acquired, exclusively as a result of his scientific activity, and for their exceptional scientific merits, over time Prof. Em. Bratu owned various and important attributions, such as:

– head of the engineering division of ICECHIM,

– adviser in the Ministry of Chemistry,

– coordinator of two volumes (3–4) of the first edition of "The chemical engineer's handbook" ("Manualul inginerului chimist"),

– dean of the Faculty of Industrial Chemistry at UPB,

– PhD supervisor in chemical engineering,

– corresponding member (1963), and full member (1974) of the Roumanian Academy,

– president of the Chemical Sciences Section of of the Roumanian Academy (1977-1990),

– member of the editorial boards of the Romanian scientific journals *Revista de Chimie* (Bucharest), and *Revue Roumaine de Chimie* (Fig. 5).

For his prodigious and exceptional scientific and teaching activity, Professor Em. Bratu was awarded several awards at that time, respectively:

– the award of the Roumanian Republic ("premiul de stat"),

– Labor Order ("ordinul muncii"),

– the "Scientific Merit" award (ordinal "meritul ştiinţific").

In June 1969, he was awarded the title of *Emeritus University Professor* of the Republic of Roumania, for "their meritorious activity in the field of teaching students, and for his contribution to the development of education and culture in our homeland".[1]

**Scientific achievements.** The scientific work of Prof. Em. Bratu expands on several fields: analytical chemistry (at the beginning of his activity), chemical technology and chemical engineering (at his scientific maturity). It is focused on major issues of the chemical engineering. For instance, for the first time, the separation of toluene from gasoline by azeotropic distillation with methyl-ethyl-ketone, work for which he was awarded the award of the Roumanian Republic ("Premiul de Stat"). His works in the field of physico-chemistry of heavy water retain their topicality, the dissociation constant appearing in international data collections. Their works on the activity coefficients of gases, the development of general equations for the saturated vapors pressure, and the equilibrium in liquid-vapor systems are part of the same field. Between 1928–1941 he carried out research on: (1) the purification of industrial water used by the tanks of the Grozăvesti Factory, Bucharest. (2) Water purification procedures with lime or phosphorus in order to remove the hardness of iron and manganese, patented in Romania and Germany. In the period 1942–1948, he was also concerned with: (3) putting into operation the oil refining plant at the Brazi Refinery; (4) chemical thermodynamic studies, (5) anisotropic distillation; adsorption, fluidization. Emilian Bratu linked his name to erudite studies devoted to the elucidation of the mechanisms of several unitary operations, and the computational methods to evaluate a certain number of engineering quantities useful for the design of industrial equipment. Among his many achievements we can mention: a) determining the optimal reflux of the rectification columns; b) dimensioning of spiral heat exchangers; c) a technique to determine the structure of the fluidized bed; d) the study of the heat and mass transfer during the evaporation of droplets in a gaseous environment, etc.[1,2,30]

It is also to mention his praiseworthy scientific activity over the last decades of activity. During this period, professor Em. Bratu initiated and carried out, together with his doctoral students, a large number of researches dealing with intensification of the mass and heat transfer phenomena in order to increase the performances (efficiency) of the industrial chemical equipment. For example, techniques based on the pulsation of fluid phases, or the vibration of some parts of the equipment structure. Here we should mention his valuable contributions in the field of absorption intensification in pulsed columns, increasing the separation capacity in rectification columns with vibrated fillings, intensification of the mass/heat transfer in vibro-fluidized beds, the increase of the vaporization rate of droplets in a pulsed gas, and others.[1,2,30]

**Teaching achievements.** From the vast bibliography signed by Prof. Bratu,[1,2,4,30] we quote some titles of applied research works: "*Electrolytic dissociation of heavy water*" (1935); "*Laboratory Guide for Chemical Technology Works*" (1942); "*Benzene and Toluene*" (1948).

*Table 1*

The first chemical engineering textbooks in Romania, written and published by Prof. Emilian Bratu

| |
|---|
| Bratu, E. *Principii de tehnologie chimică. Aparate şi instalaţii întrebuinţate în Industriile Chimice*, Vol. 1–4, litografie, Ministerul Învățământului și Culturii, 1954–1957 |
| Vol. 1–2 (ed. 1), *Operations and equipment in the chemical industry* ("Operaţii şi utilaje în industria chimică"), Edit. Tehnică, București, 1960–1961. |
| Vol. 1–2 (ed. 2), *Operations and equipment in the chemical industry* ("Operaţii şi utilaje în industria chimică"), Edit. Tehnică, București, 1969–1970. |
| Vol. 1–3 (ed. 3), *Unit operations in the chemical engineering* ("Operaţii unitare în ingineria chimică"), Edit. Tehnică, București, 1984–1985. |
| Bratu, Bratu, E., *The chemical engineer's handbook* ("Manualul inginerului chemist"), vol. 3-4, Edit. Tehnică, București, 1953–1955. |
| Bratu, Bratu, E., *Corrosion in the Chemical Industry* ("Coroziune în Industria Chimică"), Institutul Documentare Tehnică, București, 1951. |

Prof. Emilian Bratu was the founder of the university education in Chemical Engineering in Roumania, being the one who campaigned for the establishment and consolidation in UPB, of the Department of "Processes and Equipments in the Chemical Industry", which later (1948) became the "Department of Chemical Engineering", being the first chair of its kind in the country and among the first in Europe. Prof. Bratu also has the merit of having written and published the first Chemical Engineering course (1954–1957, Table 1). Based on this model, similar Chemical Engineering departments were established in the main university centers in the country (Iaşi, Cluj, Timişoara), taking over the Chemical Engineering course of Prof. Em. Bratu.[1,2,4,30]

The *definition given to chemical engineering* in his reception speech at Roumanian Academy

(1974) remained memorable: “Chemical engineering is the science that studies, through general and specific methods, the operations, reactions and systems of the chemical industry, with the ultimate goal of realizing processes, devices and industrial plants with an optimal operation. Chemical engineering is also the engineering profession whose task is to serve the chemical industry in research, design, production, and education.”

An evaluation of this definition and of the entire activity of acad. Emilian Bratu is also made by Acad. Radu Voinea (1923–2010), the president of the Roumanian Academy in 1984, at the celebration of the Professor's 80th birthday (Fig. 6): The academician Emilian Bratu embodies chemical engineering, and the expressions “Emilian Bratu” and “Chemical engineering” have become, in a certain sense, synonymous in our country.”

Equally memorable are his assessments about the “chemical technology”, or the “fundamental-vs.-/applied research”, etc. For example, Professor Em. Bratu considered that a clear demarcation between the “*fundamental*” and the “applied research” (the last being considered to be carried out only by the engineers) cannot be real. This is because the research activity is characterized by its purpose, based on deep theoretical foundations. The original notes of Prof. Emilian Bratu are full of lessons in this respect, namely: [3]

**The original note by Prof. Emilian Bratu**: When asked what is the difference between the *fundamental research* and the *applied research*, Urey (the discoverer of deuterium) answered: “the difference is 20 years”. It was like that in the 1930s; now the difference is even smaller, and is continuously decreasing. We are also given a means of recognizing fundamental research: “if you ask a researcher – what does he do? – and if he doesn't explain it clearly, then he's doing fundamental research.

Much has been discussed and written about research and researchers, about creativity, about research methodology, and methods have been proposed to accelerate the scientific research, about writing scientific reports, about theoretical research versus experimental research, and about many other topics related to the scientific research.

It is now recognized that ideas – both the main ones and the secondary ones of a research, or discoveries, appear – we don't know how – in the researcher's brain, sometimes triggered by external sensations. The laboratory only confirms and measures them.

Asked how he discovered the laws of gravity, Newton replied: “Always thinking about them.” Thinking can be considered a force for the both scientific and material production.

…I end with a quote from Linus Pauling: “To have a good idea, you have to have a lot of ideas.” I wish you that the ideas in your works will be many and good.”

In the same context, his below note regarding chemical technology is remarkable:[3]

**The original note by Prof. Emilian Bratu**: Another issue that concerns education is where it is better to direct education: towards theory (*i.e.* towards science) or towards practice (*i.e.* towards technology).

It could be answered by the words of the physicist Boltzman “Nothing is more practical than a good theory”. Or, it can be answered by analogy with the answer to the question: “what is more useful? The sun or the moon?” with the answer as a joke: “The moon, of course, because it lights up the night when it's dark.”

In fact, the theory “illuminates” the field, so that practice can “see” where it is going, in order to achieve what it seeks.

Fundamental research (theoretical, scientific) and applied research (practical, technical) are not independent. They always appear together, complement each other, stimulate each other, in a synergistic symbiosis.

However, there are researchers with natural or cultivated inclinations towards the theoretical or the practical part, in which they give the highest yield. They must be encouraged and used as they are. The maximum yield will result from their collaboration.

This question – provisional for now – for education is not: “theory or practice”, but how much theory and how much practice? And here, the optimum should not be sought in extremes.

**Development of the Roumanian School of Chemical Engineering** at the UPB. Professor Emilian Bratu not only founded (1940–1945), with the help of Prof. C.D. Nenitescu, the Dept. of chemical engineering at UPB, but also contributed decisively to its development and direction both towards fundamental research, and towards outstanding industrial applications, being the first department of this kind in the country, and among the first in Europe.

Prof. Em. Bratu was concerned with training students in scientific research. He read a lot, and always asked himself problems related to creativity, the qualities of researchers, research methodology, about methods to accelerate research, about writing scientific reports (it has long been considered a perfect model of technical and scientific writing, the way the professor wrote his work), about the relationship between theoretical and experimental research. He considered that: "*in fact fundamental research is a first phase of applied research*".

Professor Em. Bratu believed in the ability of the school to create the *specialist-creator*, which he characterizes as follows.[3] I quote from his reception speech at the Romanian Academy from 1974: "The specialist-creator is a complex psychic entity and very different from case to case; however, some common attributes can be listed: competence and intelligence; patience and perseverance; work power and physical endurance; initiative – imagination, fantasy; spirit of observation and discernment; work method and discipline; accommodation and integration into the collective; conscientiousness and character; interest to the point of passion, but not to the point of obsession; flexibility but also personality in thinking; logical, rational thinking; to have humor, to be optimistic." "In fact, the school of all grades must be conducive to the cultivation of intelligence. Is it exaggerated if we consider the cultivation of intelligence as the hope of saving humanity?". All these qualities perfectly define Professor Emilian Bratu.

Professor Emilian Bratu left us a huge legacy, with a potential for use in all branches of the economy – the science of chemical engineering. An inheritance also means a great responsibility, and implies large obligations in its maintenance and development.

Our world is a complex and evolving place. In the 21st Century, the requirements of a growing and ageing population will have significant impact on society. With global population expected to reach 8.5bn by 2030 and 11.2bn by the end of the century, demand on resources such as water, energy, food and raw materials will be higher than anything we have experienced. How do we meet the expectations of a modernised, global society whilst minimising the impact we have on our environment?[1,5]

On the other hand, history has proven that without chemistry, chemical substances and synthetic materials, there is no society development and well-being. The new paradigms and methods of chemical engineering science, coupled with "green chemistry", lead to the ecological and sustainable design of chemical installations.

The large area covered by the Chemical and Biochemical Process Engineering (CBPE) topics puts the chemical engineer profession in a unique position. Belonging to the technical community, the chemical engineer will continue to collaborate with many other technical disciplines and with the natural (chemistry, physics, biology) and fundamental (mathematics) sciences. The history of these collaborations has shown that they have led to diverse applications with a very high socio-economic impact. These range from water and energy to medical research and contributions to the safety of the industrial plants. Chemical engineers have even gone into space. An extensive discussion of the chemical engineering paradigms and its development trends was made in the section 2, and by Maria,[1] and Woinaroschy.[9,10]

The target objectives of the process engineer profession (chemist or biochemist) can become a reality as long as we keep the continuous connection between generations, and as long as personalities of the caliber of the savants – our teachers – are placed in the nodal points of this connection, as was by excellence the Professor Emilian Bratu.

In a simplistic way, we can say that until the 1960s–1970s, the classic chemical engineering education in Roumania mainly follows the 1st and the 2nd paradigms, meaning the separate study of unit operations and transfer phenomena_within the physical-chemical processes that take place in specific equipments, as well as that of chemical, biochemical or biological reactors in which industrial (bio-) chemical reactions are conducted. Then, starting to 1960, during the weekly scientific seminar held at the Chemical Engineering department of UPB, under the direction of Prof. Em. Bratu, and of the assoc. prof. Ely Ruckenstein,[3] moved on to the "translation" of the transfer phenomena, to their representation using mathematical models, leading to their advanced numerical simulation (by using increasingly powerful computers). Such CBPE activities concern the (bio-)chemical processes, the dynamics of reactor operation, as well as the design, optimization and on-/off-line control of their operation, by using increasingly complex math models.

Perhaps, the most important aspect of the teaching activity of Prof. Em. Bratu was to lead the phd theses and to initiate the future professors of chemical engineering of the profile departments from the main technical universities in Roumania. Later, they became, in their turn, creators of new development directions of chemical engineering education in the country's university centers (Iaşi, Timişoara, Cluj), and supervisers of new phd students in the CBPE topics. The first phd students of prof. Em. Bratu are presented in Table 2. All of them became professors in various CBPE sub-topics. They promoted application of all four (P1–P4) paradigms of CBPE (described in the chap. 2).

To conclude, the professional evolution of the Department of Chemical Engineering at UPB was coordinated and strongly marked by the personality of Professor Emilian Bratu, who created around him, through his doctoral students, a strong teaching and research team in chemical engineering. After his retirement, in 1974, the department was coordinated by his main collaborators: professors Octavian Smigelschi (1974–1985), Octavian Floarea (1985–1986) and Emil Danciu (1986–1996). Through their personal prestige and well-balanced demands, in the spirit of the tradition established by Professor Bratu, Professors Smigelschi, Floarea and Danciu have maintained in the department the necessary climate for teaching and scientific activities of a high academic standard. The successors of the disciples of prof. Em. Bratu mentioned in (Table 2) introduced modern math/computational tools for solving difficult engineering problems referring the the plant design, its safe operation, and optimal control (professors V. Pleşu, A. Woinaroschy). Other professors introduced modern border teaching and research topics, like biochemical engineering, bioreactors, bioengineering, bioinformatics (prof. O. Muntean, prof. G. Maria), or quantitative evaluation of the safe operation of chemical plants (Prof. G. Maria).[1,31] The used up to date engineering software includes Aspen, Hysim, Prosim, Comsol, Matlab, etc., being the same with those used by the top CBPE departments world-wide. Additionally, a modern experimental base supports the research program of the department's laboratories.[1,31]

*Table 2*

The list of the first PhD students of prof. Em. Bratu.[4] Notations: UPB = Bucharest Polytechnic Institute; UPT= Polytechnic University of Timişoara; UPI = Polytechnic University of Iaşi

| Name and surname (place of activity); remarks | Thematic area of the PhD thesis | Year and place of completion |
|---|---|---|
| Raul Mihail (UPB);<br>the founder of the “Chemical and Biochemical Reactors” school in România | Heterogeneous chemical reactors | 1961, UPB |
| Eli Ruckenstein (U.S.A.) | Transfer phenomena in the chemical industry equipments | 1963, UPB |
| Zeno Gropşian (U.P.T.) | Heat transfer | 1962, UPB |
| Ion Teoreanu (UPB) | Heat transfer in the fluidized bed | 1963, UPB. |
| Octavian Floarea (UPB) | Mass transfer in columns with plates | 1964, IMUICh Moscova. |
| Radu Z. Tudose (U.P.I.) | Intensification of the mass transfer in the chemical industry equipments | 1964, UPB |
| Octavian Smigelschi,<br>the founder of the “Numerical computing and optimization in chemical engineering, 1970” | Marangoni effects when boiling | 1966, UPB |
| Dan Suciu (U.S.A.) | Mass transfer intensification through the Marangoni effect | 1965, UPB |
| Emil Danciu (UPB) | Phase equilibria during distillation | 1967, UPB |

**Collaboration with Professor Costin D. Nenitescu.** Prof. Emilian Bratu and Prof. Costin Nenitescu were two elite professors of the Faculty of Industrial Chemistry of the UPB (currently “National University of Science and Technology Politehnica Bucharest” (UNSTPB)). The two scientists were good friends, who deeply respected each other throughout their lives. Both, of German background, sensed from an early stage the need to introduce in Romania the discipline of Chemical Engineering in the higher polytechnic education, starting from the favorable external and internal perspectives of the development of a Romanian chemical industry (Fig. 2), based on the national resources of domestic raw-materials (Fig. 1), and on the theoretical-fundamental basics provided by the two scientists and their collaborators, doctoral students, and their generations of students. They fought together for the affirmation of chemistry inside the UPB.

Due to them, in 1938 the name "Industrial Chemistry" was introduced to name their faculty of chemistry in the UPB. Thus, in the years 1940–1950, Prof. C.D. Nenitescu supported Prof. Em. Bratu to found/ establish and consolidate here at UPB, the "Department of Processes and Equipments", which later became the "Department of Chemical Engineering", being the first such department in the country and among the first in Europe. On the other hand, during the period 1940–1945, Prof. Em. Bratu answered the request of Prof. C.D. Nenitescu to hold several lectures about the progress of chemical engineering, especially in the area of applying the criteria of similarity in the field of chemical reactions, in front of the teaching and research staff working in Organic Chemistry. These conferences enjoyed a great interest.[2] As an example of this fruitful collaboration, both scientists supported the Ruomanian chemical profile publication *Revue Roumaine de Chimie*, being active members of the journal's editorial board (Fig. 5).

Under the direct coordination of Prof. Em. Bratu, his disciples and the next generations of the CBPE professors, all 4 paradigms (P1–P4, chap. 2) of the CBPE science, were acquired by Roumanian education, being applied and developed within the numerous researches.[4,9] These paradigms are the following: (1) unit operations; (2) transport phenomena; (3) chemical product engineering; (4) sustainable chemical engineering. The last three ones included an advanced mathematical modeling of chemical/ biochemical processes, and an advanced numerical calculation (process simulation) in all stages of the development of a chemical, biochemical (enzymatic), or biological process. Some examples are presented below.[4,9]

The first paradigm *–unit operations* (P1) appeared as a necessity to systematize the physical-chemical processes involved as a result of the "explosion" of chemical industrial applications at the end of the 19th century, and the beginning of the 20th century. In other words, the operations in chemical plants are similar, although the technological processes may be different. They are based on two fundamental considerations: i) unit operations are repeatedly found in industrial practice and have become a convenient way of organizing chemical engineering knowledge; ii) the knowledge acquired regarding a unit operation, governed by a mathematical model, can be easily applied to any conditions imposed by the materials.

The training system, and the professional practice generated in CBPE by this paradigm quickly spread throughout the world because it contained all the elements of success, namely: (1) the curriculum base to develop the CBPE education; (2) the ability to organize the knowledge useful for research, and to create the framework for the development of this knowledge; (3) effective in solving , in real time various CBPE problems in plant operation, in research, or in design; (4) generates a set of tools for solving most problems raised by industrial processes (oil and gas separations, petrochemical developments, production of fertilizers, syntheses of new polymers, etc.).

In Roumania, the promoter of the unitary operations paradigm in chemical engineering was the academician Emilian Bratu. After a brilliant doctorate in Vienna in the period 1928–1941, Prof. Em. Bratu comes to the UPB, where he will be active throughout his life. Here, as early as 1948, he teaches the course *Unit operations in the chemical industry*, which he publishes in 1–4 volumes in three editions (Table 1), starting with 1954, together with a *Laboratory Guide* lithographed in 1941.

Over time, this system lead to a research stagnation, determined by its difficulties to respond to new challenges, namely: (a) the development by researchers of new technologies, which demand a deep engineering education (special materials, integrated technologies , etc.); (b) the requirements of chemical engineers to have new tools to define new concepts from chemistry, physics, technology, biochemistry, etc.; (c) the difficulty of creating new streams of interesting subjects for the CBPE research and education, required by the chemical and petrochemical industry.[4]

This is how the phd students of Prof. Em. Bratu (Table 2), among which we find important names of professors, have passed the CBPE education in Roumania, from the paradigm of "unit operations", to the 2nd paradigm of *transfer phenomena* (P2, chap. 2).[6] Also as a result of the specialization of the first two paradigms, in the development of the chemical industry in Roumania, the circulation of personnel and information materialized, in the inter-connected system of chemistry. With reference to the period 1955–1972, it can be observed that out of 400 graduates per year with a specialization in CBPE from Bucharest, Iaşi, Timişoara and Cluj, 75% go into the field of industrial exploitation, and only 5% into research, and 20% in design.[4] Regarding the circulation of technical-scientific information, it is biunivocal between the three components of the chemical system.

This 2nd paradigm is strongly supported by advanced math knowledge/rules, completed by complex numerical algorithms. In this sense, professors Aris, R. (Univ. Minnesota, USA) and Amundson, N. (Univ. Minnesota, USA) published (1966) their manual *Mathematical Methods in Chemical Engineering*,[7–8] and state that the progress of CBPE (science and practice) cannot be achieved without the use of very advanced mathematical and numerical computations methods (see chap. 2).

Thus, the effects of this new way of developing CBPE, it is worth noting that it determined:[4] (*i*) an "explosion" of creative research activities in CBPE (education, experimental research, design, development of industrial plants), in the USA and Europe; (*ii*) the American chemical industry, dominant worldwide and dominated by Du Pont and Exxon, massively recruits high-quality academic staff to train graduates who want to study modern CBPE; (*iii*) CBPE occupies a first place among the engineering sciences, so that specialized faculties are established in all the large technical universities in the USA and Europe; (*iv*) AIChE (American Soc. of Chemical Engineering) conditions the accreditation of CBPE disciplines/ courses by imposing the use of math modeling, based on the differential equations models that characterize the property transport phenomena (mass, energy/heat, momentum); (*v*) the research funding agencies, and the main chemical engineering journals/publications are starting to turn their backs on empirical and qualitative research, deemed to be outdated and ineffective; (*vi*) the large industrialization begins in Roumania based on the strong use of the CBPE science in the development of technologies for small, medium and large tonnage chemical production.

Fig. 5 – The editorial board of the *Revue Roumaine de Chimie* in 1979. From right to left: Acad. Emilian Bratu, Acad. Petru Spacu, Prof. Margareta Avram, Prof. Dumitru Săndulescu, Acad. Ilie Murgulescu, Acad. Victor Sahini, Acad. Ecaterina Ciorănescu-Nenițescu, Acad. Alexandru Balaban, Flavia Cuiban, editorial secretary.

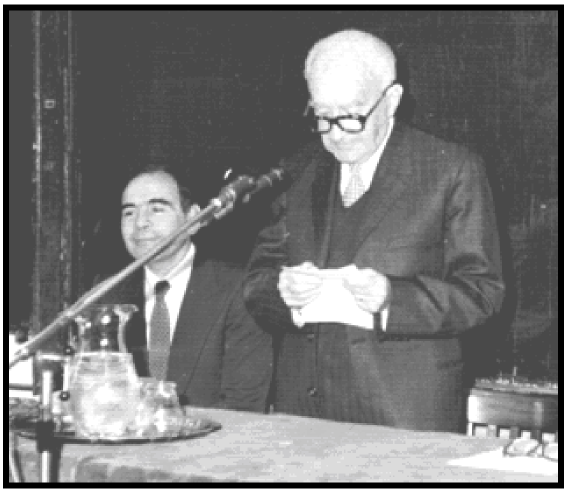


Fig. 6 – Acad. Dr. Eng. Emilian BRATU honored at the age of 80s (1984), by the Department of Chemical Engineering at the "Politehnic" Univ. a of Bucharest, addressing a word of thanks, together with Prof. Dr. Eng. Octavian Smigelschi (head of the department).

Thus, as a result of the advancement of CBPE education boosted by Prof. Em. Bratu, and his disciples, the all four CBPE paradigms were also felt strongly in Romania, producing substantial changes in the Roumanian CBPE education, which culminated in the establishment in 1977 of the faculty of “Chemical Equipment and Process Engineering (UIPCh)” at the “Politehnica” Univ. of Bucharest (U.P. Bucharest – the novel name of UPB), whose curriculum did not differ in any way from that of the CBPE large schools in the USA and Europe. This faculty of UIPCh operated independently, between 1979–1987, then, until 1999, as a section of the Faculty of Industrial Chemistry of the U.P. Bucharest. The faculty UIPCh has graduated high-value engineers who held important positions in management/ executive structures in the chemical industry, research, or design. Moreover, the disciples of Prof. Em. Bratu have decisively contributed to the widening and deepening of the CBPE education. So that, since 1977 laboratories and research collectives have been established, covering the main transport phenomena, plus Chemical Reactors, Biochemical Engineering, and Applied Informatics in Chemical Engineering (1995).

Since 2005–2006, UPB started to implement the study program structured in 3 cycles (Bologna-type): bachelor's, master's and phd. In the new study framework, the novel “Department of Chemical and Biochemical Engineering” was appointed to coordinate the undergraduate study program “Chemical and Biochemical Process informatics and engineering” and the master's study program “Chemical Process Engineering”. Impulsed by the last two paradigms of CBPE, and by the very rapid development of novel research areas at the border with CBPE, such as “Bioinformatics”, “Systems biology”, “Synthetic biology”, CBPE starts to be involved in these novel disciplines, by contributing with applying its own concepts, computational techniques / algorithms with multiple purposes: a) math modeling and numerical simulation of the dynamics of essential cellular metabolic processes; b) *in-silico* (math model based) design of genetically modified micro-organisms (GMO); c) *in-silico*, *off-line* optimization of industrial bioreactors, or of multi-enzymatic reactors. In such subjects, it is the merit of Prof. Gh. Maria who introduced new disciplines in the curriculum of the chemical engineer at U.P. Buc (2004, 2010). Also, to align the curriculum of the CBPE with that of the E.U. and the U.S.A., Prof. Gh. Maria introduced the novel discipline (2006) “Quantitative risk assessment of chemical reactors and chemical plants”.

## Abbreviations[32]

| | | | |
|---|---|---|---|
| ChE | Chemical engineering | CPE | Chemical process engineering |
| CBE | Chemical and biochemical engineering | CRE | Chemical reactions engineering |
| CBPE | Chemical and biochemical process engineering | UPB | University Politehnica of Bucharest |
| CBT | Chemical and biochemical technology | | |

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