A Century of Chemical Engineering

Edited by

WILLIAM F. FURTER
Royal Military College of Canada
Kingston, Ontario, Canada

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PREFACE

Chemical engineering has reached the approximate Centennial of its emergence as a profession in its own right, that is, separate from the profession of chemistry and from all other forms of engineering. The date must be considered approximate, because the exact point of origin cannot be established definitively. The reason is that chemical engineering resulted from the fusion of two major components, which developed along differing time scales. One was industrial, or applied, chemistry; the other was the physical, unit operations. While some historians would place the origin of the profession as recently as 1908 with the founding of the American Institute of Chemical Engineers, others would locate it much earlier, and perhaps even back into antiquity. However, a reasonably general consensus seems to exist for placing it in conjunction with events taking place in England about a century ago. Frank Morton, writing in this volume, states that "The year 1880 is regarded by many as the year in which Chemical Engineering was first recognized." Among other reasons, this was the year in which the first attempts were made to found a 'Society of Chemical Engineers' in London. Others regard the famous lecture series on chemical engineering given by George E. Davis in 1887 at the Manchester Technical School, which formed the basis for his later *Handbook of Chemical Engineering* (1901), as the point of emergence. Miall (1931) reports that the first firm to advertise its services as 'chemical engineers' in the *Journal of the Society of Chemical Industry* was Messrs. Kirkham and Co. of Runcorn, England, in 1884.

In order to honor the profession of chemical engineering at its approximate Centennial, the American Chemical Society commissioned a two-part, international symposium on the History of Chemical Engineering, which was subsequently held at the ACS National Meetings in Honolulu in 1979, and Las Vegas in 1980. The chapters of the present book have been selected primarily from the papers of the second, or Las Vegas, part of the symposium, while an earlier book (Furter, 1980) presented papers from the first, or Honolulu, part. Hence, the two books can be considered companion volumes in presenting the American Chemical Society's centennial tribute to chemical engineering, and in recording the accomplishments of its first century of existence as a recognized and distinctive profession.

The two main roots of chemical engineering, industrial chemistry and the unit operations, are examined in various chapters. The more recent root, the physical unit operations, and claims to its mainly American development (although not necessarily its founding; Lewis, 1959), are addressed in the first chapter. This chapter, by Martha Trescott, was the keynote paper of the Las Vegas portion of the symposium. Frank Morton outlines early British contributions, and Max Appl and André Thépot some of the early German and French contributions, respectively. The remaining chapters have been selected to range widely over chemical engineering's first century of independent existence, both in topic and geographically. Of particular note is the chapter by Marcinkowsky and Keller outlining developments which took place in the Kanawha Valley region of West Virginia around and before 1930 which led to the establishment of the North American petrochemical industry. Other chapters address the early development of chemical engineering education, and still others deal with significant developments in the chemical engineering fundamentals and their applications.

This book is dedicated to my wife Pamela, my daughters Lesley, Jane, and Pamela, and to three of my former (and late) teachers: Edwin R. Gilliland, Albin I. Johnson, and W. Reginald Sawyer.

William F. Furter

July 1981

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CONTENTS

UNIT OPERATIONS IN THE CHEMICAL INDUSTRY:

AN AMERICAN INNOVATION IN MODERN CHEMICAL ENGINEERING

Martha M. Trescott

University of Illinois at Urbana-Champaign
College of Engineering
1308 W. Green St.
Urbana, IL 61801

I

My work on the history of chemical engineering has stemmed from my dissertation research on the history of the American electrochemicals industry and, therefore, especially draws upon that sector and the manufacture of heavy chemicals. However, the particular viability of American electrochemicals production before the turn of the century points to forces in the American technical and business climate in general which were strengthening this industry and also other chemical sectors before World War I. After many years of research and a view of developments from the vantage point of electrochemicals, which combine chemical, mechanical, metallurgical and electrical technologies in an impressive blend, and drawing upon my own work in chemistry and in the histories of various mechanical and other technologies, I became very convinced about this paper's subtitle, "An American Innovation in Modern Chemical Engineering", and about approaching a book on the history of the American electrochemicals industry as a study in the cultural context of technological and industrial change.

Just as by 1900 distinctively American forms of art, music and literature were becoming more and more visible, so in the realm of technology, the same kind of phenomenon could be seen. In the days between the emergence of the "American System" of manufacture and Henry Ford's moving assembly line, we had become a nation of machine builders, and also scientific management had begun to be articulated and implemented by some of our foremost mechanical engineers in the metallurgical and mechanical sectors.[1] Indeed, foreign visitors remarked repeatedly on our distinctive mechanical and managerial expertise, both before and after 1900. Even the German chemist, Fritz Haber, discussed such American expertise in relation to our electrochemicals industry in 1902.[2]

I believe that in the rise of chemical engineering, the U. S. contributed the widespread adoption of the "unit operations" concept, as it emerged from our particular mechanical process industries (particularly metal-working firms) and from our metal-making (particularly steel) sectors, both of which focused on mass production with coordination of units of production. I like to emphasize the historic foundation of American chemical engineering, especially in mechanical engineering and also the historic linkages between developments in two closely related sectors--metallurgical production and chemical manufacture.

I feel that historians of technology have too long considered developments in the chemical, mechanical, and metallurgical areas separately, and I think that the electrochemicals study has forced me to think about likanges and overlaps among them.[3]

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[1]Paul J. Uselding, Studies in the Technological Development of the American Economy During the First Half of the Nineteenth Century, doctoral idssertation, Northwestern University, 1970, published in the series Dissertations in American Economic History by the Arno Press, 1975, especially cf. pp. 142-149. Professor Uselding's comments and advice have been most indispensable throughout this work on unit operations. Also, cf. Martha M. Trescott, "Lillian Moller Gilbreth and the Founding of Modern Industrial Engineering," Berkshire Conference, June, 1981, mimeo.

[2]It is interesting to note, as does H. J. Habbakkuk in American and British Technology in the Nineteenth Century, 1962, that English visitors were remarking on the uniqueness of certain American machines as early as the 1830s, as he noted on p. 4. See also Nathan Rosenberg, The American System of Manufactures (Chicago, 1969) and John E. Sawyer, "The Social Basis of the American System of Manufacturing," Journal of Economic History, XIV (1954), 361-379. In addition, Paul Uselding's "Studies in Technology in Economic History," Research in Economic History, Supplement 1 (Greenwich, Connecticut, 1977), pp. 160-180 is useful. "Prof. Haber on Electrochemistry in the United States," Electrochemical Industry, I (1903), 350.

[3]Generally, in histories of the chemical industries such as those by Williams Haynes, American Chemical Industry,

II

Elevating various American contributions to modern chemical engineering in no way undermines the popular notion that Germany was the seedbed of many aspects of modern chemical engineering. It is a fact that one of Germany's most notable contributions lies in the early use of chemical science, especially physical chemistry and thermodynamics, in chemical production. We know that, as Alfred H. White and other important chemical engineers of this century have said, physical chemistry is the very foundation of modern chemical engineering.[4]

William J. Reader, Imperial Chemical Industries, A History, 1970, and L. F. Haber's two, The Chemical Industry During the Nineteenth Century, 1958, and The Chemical Industry, 1900-1930 (1971), it is most difficult to trace what happened to chemical equipment. If one searches long enough, one might find some clues as in Haynes, Vol. I, p. 361. But this information is typically hard to come by, and once one has, it is difficult to determine the context (that is, the historical evolution). Similarly, in essays and books on mechanical engineering, one often does not see a discussion of the chemical industry's equipment per se, as in Aubrey F. Burstall, A History of Mechanical Engineering, 1965, and others.

The metallurgical and chemical industries are typically separated explicitly, as in Williams Haynes, American Chemical Industry, which does not explicitly include the metallurgical sector but in actuality does include some metallurgical production, which is inseparable from chemical production in some cases (as with certain electrochemicals). Also, Census classifications have separated metallurgical from chemical industries.

[4]Alfred H. White, "Chemical Engineering Education", ed. American Institute of Chemical Engineers, Twenty-Five Years of Progress in Chemical Engineering, 1933, pp. 353-4 and 359-60. Particularly in the synthetic dyestuffs industry, physical chemistry found early industrial importance, as Paul M. Hohenberg indicates in Chemicals in Western Europe, 1850-1914, An Economic Study of Technical Change, 1967, p. 112, e.g. Also, cf. Aaron J. Ihde, The Development of Modern Chemistry, 1964, p. 417, e.g. Of course, numerous works such as John J. Beer's The Emergence of the German Dye Industry, 1959; William J. Reader's Imperial Chemical Industries, A History, 1970; and the report by William E. Wickenden, A Comparative Study of Engineering Education in the United States and Europe, 1929, conducted for the Society for the Promotion of Engineering Education, along with the excellent monograph by Edward H. Beardsley, The Rise of the American Chemistry Profession, 1850-1900 (1964), all note the

Yet, physical chemistry, as important as it is here, is not sufficient for successful chemical engineering and production. A statement from Olaf Hougen is useful to understand what is really involved. In his popular textbook, Chemical Process Principles, 1943, he and his co-author, Kenneth M. Watson, assert:

> The design of a chemical process involves three types of problems, which although closely interrelated, depend on quite different technical principles . . .
>
> These three types may be designated as process, unit-operation, and plant design, respectively . . . Process problems are primarily chemical and physico-chemical in nature; unit-operation problems are for the most part purely physical; the plant-design problems are to a large extent mechanical.[5]

This statement is useful to historians trying to sort out the different strands as they evolved and came together in modern chemical engineering. In the case of the rise of process technology with emphasis on physical chemistry in chemical production, Germany can largely be credited as the wellspring. But in the rise of the concept of unit operations, credit must primarily go to the British for its general introduction and to Americans for its widespread popularization, both in the educational and industrial sectors, and for its concomitant integration with physical chemistry.

The Englishman, George E. Davis, who had served as a factory inspector under the Alkali Works Regulation Act in England, has been credited with the "first written description of these unit physical changes" in the first edition of his book, Handbook of Chemical Engineering, 1901, in two volumes.[6] Earlier, in 1887, he had first presented his ideas on unit operations in a series of lectures at the Manchester Technical School but did not publish these ideas until 1901.

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incorporation of chemical science into the German chemical industries before 1900, but we are mainly interested here in stressing physical chemistry.

[5]Hougen and Watson, Chemical Process Principles, p. v.

[6]R. Norris Shreve, "Unit Operations and Unit Processes", Encyclopedia of Chemical Technology, XIV, 422. Also, see History of Chemical Engineering Symposium and Symposium volume by the American Chemical Society, ed. William F. Furter, Advances in Chemistry series, 1980, especially D. C. Freshwater, "George E. Davis, Norman Swindin and the Empirical Tradition in Chemical

Almost all of Davis's two volumes deal with various equipment and apparatus used in chemical production, such as evaporators, distillation equipment, crushers, grinders and so on. Since unit operations in chemical engineering are operations which deal with physical changes in materials, such as boiling, freezing or grinding operations, one can sense that considerations of machines and equipment are integral to unit operations and can really determine the definition of a "unit" and how the units for carrying out a given physical change will be related to one another.

The rapid improvement in chemical equipment in industry, especially after the 1870s and 1880s, as Williams Haynes has noted,[7] undoubtedly helped foster the rise of unit operations for organizing chemical production. Yet the literature from the late nineteenth century on chemical equipment in both European and American industry is scarce.

The triangulation of opinions from secondary sources such as Haynes, Paul Hohenberg and Aubrey Burstall, who has discussed mechanical engineering in the rise of process engineering in various industries,[8] tends to be corroborated by contemporaries in the late nineteenth and early twentieth century, such as the Briton George Davis, the American Magnus Swenson, the German Parnicke, and the German-American Oskar Nagel. Each of these sources discusses the importance of machines and/or mechanical engineering in chemical production and engineering for the period between 1880 and 1910.[9]

Engineering," now published as History of Chemical Engineering, pp. 97-111.

[7]Williams Haynes, American Chemical Industry, I, 361: this discussion does not highlight very well changes in chemical equipment.

[8]Burstall, A History of Mechanical Engineering, especially p. 358.

[9]A. Parnicke, a civil engineer, wrote Die Maschinellen Hilfsmittel der Chemischen Technik in 1898, and Oskar Nagel published in the U.S. The Mechanical Appliances of the Chemical and Metallurgical Industries in 1909. Parnicke's book is cited by Nagel as the only other book besides his "on the market along similar lines." (Preface to Nagel's 1909 work.) In comparing the Nagel and Parnicke works, one cannot help but be struck by certain differences. One of these is that the German work focuses a good bit on pumps and other machines which deal with gases (as measuring devices, e.g.) and thereby concern thermodynamics, while the American book would seem to include more milling, crushing, and grinding machines. But this is an entirely subjective impression

And, of course, chemical engineering curricula in American universities have historically been heavily oriented to mechanical engineering.[10]

Davis and Swenson both felt that much more than chemical science is needed for successful chemical engineering, and both stressed the importance of mechanical engineering here. Davis commented in his 1904 edition that "though the Chemical Engineer must possess an almost perfect knowledge of applied chemistry, it must not be forgotten that he deals principally with the suitability of plant and apparatus to perform certain operations, of which the construction and maintenance are the most important features."[11] Consequently, his two volumes deal mainly with such apparatus and equipment.

Davis apparently never employed the term "unit operation" in

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on the author's part. It might be desirable to count the different kinds of equipment illustrated and discussed in these works. Also, and another subjective judgment, it seems that the German equipment illustrated was in some sense less substantial, smaller or more complex than many of the American machines in Nagel's volume.

Nagel, probably a German immigrant, judging from his name and his ability to translate German, was a prolific writer on the chemical process industries, judging from the appendix in his 1909 book. He translated a German work by Hanns v. Juptner on Heat Energy and Fuels, 1909, advertised as a "complete and up-to-date treatise on the chemistry and production of fuels for use in Metallurgy, Boilers, Gas Producers, Etc." (appendix, p. vi) This is just one more piece of evidence that the Germans concerned themselves with the thermodynamic considerations perhaps more so than with matters of equipment design. For an interesting discussion of the use, or non-use, of thermodynamics in machine design before 1860, cf. Lynwood Bryant, "The Role of Thermodynamics in Evolution of Heat Engines," Technology and Culture, XIV (1973), 152-165.

[10]Catalogues from the University of Pennsylvania, the University of Wisconsin, Lehigh University and other schools show that programs in chemical engineering in the late nineties and/or early 1900s, contain a goodly amount of mechanical engineering courses, not infrequently the first two years of an M.E. program. The author's survey of college and university engineering curricula can be made available to interested scholars.

[11]Davis, Handbook of Chemical Engineering, I, second edition, p. 3.

his discussions. Instead, Arthur D. Little evidently coined the phrase in his 1915 report to the President of Massachusetts Institute of Technology, as F. J. Van Antwerpen and others have noted.[12] And it is useful to note that Little's statement was very much in the vein of scientific management and came during the heyday of its rise.

The credit for a beginning at systematizing the study of chemical engineering around unit operations as such apparently should not only go to Little but also to his partner William H. Walker. Having been a business partner with Little prior to 1904, when Walker was asked to develop the chemical engineering program at M.I.T., Walker was one of the authors of the 1923 textbook which is universally said by chemical engineers to have been first to treat comprehensively (in any language) unit operations: Principles of Chemical Engineering.[13]

In the first edition of their text, Walker, Lewis and McAdams commented:

> The unit operations of chemical engineering have in some instances been developed to such an extent in individual industries that the operation is looked upon as a special one adapted to these conditions alone, and is, therefore, not frequently used by other industries. All important unit operations have much in common, and if the underlying principles upon which the rational design and operation of basic types of engineering equipment depend are understood, their successful adaptation to manufacturing processes becomes a matter of good management rather than of good fortune.[14]

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[12] F. J. Van Antwerpen, "The Origins of Chemical Engineering," read at the American Chemical Society, Honolulu, April 1-6, 1979 (also see the symposium volume, edited by William F. Furter, History of Chemical Engineering, pp. 1-14).

[13] White, "Chemical Engineering Education," p. 358; the Encyclopedia of Chemical Technology, XIV, p. 423; A. Eucken and M. Jakob, Der Chemie-Ingenieur, Ein Handbuch der Physikalischen Arbeitsmethoden in Chemischen und Verwandten Industriebetrieben (1937), with an introduction by Fritz Haber, p. vii. Also, Professor Richard C. Alkire of the University of Illinois, Department of Chemical Engineering, corroborates the idea that the Walker, Lewis and McAdams text set a precedent in discussion of unit operations as such. In addition, see White, "Chemical Engineering Education," p. 356; Shreve, "Unit Operations and Unit Processes," pp. 422-23; and Van Antwerpen, "The Origins of Chemical Engineering," p. 5, of typescript sent to the author.

Two things in this statement are especially interesting: 1) the equipment associated with unit operations and 2) the prior evolution of industrial practice. Concerning the latter, the industrial case studies from U.S. and German industry, noted later on, suggest that American industrial practice in the chemical process industries differed significantly from German counterparts prior to World War I (as well as afterward) and that certain aspects of this difference may well suggest reasons for the rapid popularization of the unit operations concept among American chemical engineers.

In the statements made by Little in 1915 and Walker and his co-authors eight years later, one not only notices the explicit phrase "unit operation," but, related to this terminology and highly significant for the comparative view, are such phrases as "coordinate series," "rational design and operation," and "good management." It is important that these terms appeared in sources by American, and not European, engineers. In the 1930s, the American Institute of Chemical Engineers adopted the following definition of modern process chemical engineering:

> Chemical engineering is that branch of engineering concerned with the development and application of manufacturing processes in which chemical or certain physical changes of materials are involved. These processes may usually be resolved into a coordinated series of physical operations and unit chemical processes. The work of the chemical engineer is concerned primarily with the design, construction, and operation of equipment and plants in which these unit operations and processes are applied. Chemistry, physics, and mathematics are the underlying sciences of chemical engineering, and economics its guide in practice.[15]

Texts by American chemical engineers such as R. Norris Shreve and Olaf Hougen, subsequently followed the basic themes expressed in the official A.I.Ch.E. statement of 1938, stressing mainly the bases of modern chemical engineering as 1) unit operations (and its related concept unit processes), 2) equipment and plant design and the importance of mechanical engineering here, 3) physical chemistry, and 4) economics.[16]

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[14] William H. Walker, Warren K. Lewis, and William H. McAdams, Principles of Chemical Engineering, second edition (1927), p. ix.

[15] Shreve, Chemical Process Industries, p. 1, citing a definition written for the A. I. Ch. E. in 1938.

It would appear that unit operations, as explicitly stated and as related to coordinated series of such operations, in chemical engineering came to be a part of engineering thought and curricula, in a widespread way first in the U.S. In fact, the important and comprehensive two-volume text on modern chemical engineering in German by Eucken and Jakob in 1937 (with an introduction by Fritz Haber), cited the precedence of the American textbook by Walker, Lewis and McAdams in treating unit operations. According to Jakob and Eucken, the orientation to modern process chemical production as based on coordination of unit operations first took hold in the U.S. And they saw it as having occurred mainly in the 1920s.[17]

Like these German authors, others too have seen this transition and change in the chemical industries, with significant streamlining of operations, as having taken place no earlier than after the First World War.[18] However, our case studies show that, to some extent, the concept--both intuitive and explicit--of unit operations (and perhaps _by implication_ unit processes, such as electrolysis) was operative in the U.S. chemical industry around 1900.

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[16]Cf., _e.g._, Shreve, _Chemical Process Industries_, p. 9 and Hougen and Watson, _Chemical Process Principles_, p. v.

[17]Eucken and Jakob, _Der Chemie-Ingenieur_, p. vii, with title cited in full in fnt. 13. Similarly, neither Van Antwerpen, "The Origins of Chemical Engineering," nor Jean-Claude Guedon, "Conceptual and Institutional Obstacles to the Emergence of Unit Operations in Europe," note the likelihood that unit operations was already a part of industrial chemical practice in the U.S. before World War I.

[18]For example, Eduard Farber in "Man Makes His Materials," _Technology in Western Civilization_, ed. Melvin Kransberg and Carroll W. Pursell, Jr., II (1967) provides a brief mention of Arthur Little's 1915 statement about unit operations, saying that these ideas simplified chemical instruction and planning _thereafter_ but fails to point out that these ideas emanated from the existing chemical sector and the evolution of thought and practice in chemical instruction and industry. Moreover, it is not clear which "new field of chemical industry," to Farber's mind, really spear-headed the development of "unit operations." (p. 194) If he means synthesis, then the question becomes synthesis of which products? Our data here show that the chemical industry in the U.S. was under-going revolutionary changes in heavy chemicals around 1900, changes which are suggestive of a unit operations approach in industry.

Therefore, in viewing the rise of modern chemical production and engineering, it is not enough to stress the German scientific contributions. As has been seen above, chemistry--including physical chemistry and the industrial research laboratory--constitute only one major avenue through which modern chemical production arose. The other major components have practically nothing to do with chemistry directly: 1) coordination of unit operations, 2) mechanical engineering in equipment and plant design, and 3) economics and management, as managerial practices and theory evolved from American leadership in the scientific management movement. I feel that the American technical and industrial climate by the early 1900s possessed a comparative advantage in these three areas.[19]

III

Some of the most prominent aspects of distinctive American manufacturing practice in general, within which our modern chemical firms grew, I delineate as: 1) a mass market mindset, which entails rapid, volume production of an inexpensive good, 2) building of cheap machines, as opposed to mere machine use; or, stated another way, mechanical know-how distinctive from the European, 3) volume production of inexpensive metals, especially steel, and other inorganic materials, 4) experience with large-scale plant design (as seen particularly in the steel sectors), and 5) unit operations and their

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Also, by concentrating too heavily on the lack of newness of products at the turn of the century, Farber has failed to capture the revolution in production of these "same old products." True, the alkalies were not new, but electrochemical production of some of them constituted new methods of production. (cf. p. 184, e.g.) Further, one cannot necessarily judge accurately the timing of the introduction of revolutionary ideas by quantity of production, as amount produced will only begin to reflect a change in production technique some time after the innovation has been adopted and implemented. Of course, much of our thought about innovations in the chemical sector has been conditioned by our knowledge of the growth of petroleum refining and innovations in that area, along with the rise of petrochemicals, mostly after World War I. Cf. John T. Enos, Petroleum, Progress and Profits, A History of Process Innovation, 1962. Also the fact that the concept of unit operations did not become explicitly stated in chemical engineering texts until the 1920s has had a lot to do with our having been misled into dating the beginnings of industrial changes in the 1920s.

[19]David F. Noble, America by Design, 1977, notes the origins of Taylorism in the shop culture, p. 40.