analysis: that Van de Hulst “had been raised in a religious tradition that emphasizes humility.… He had a strong sense of the relativity of all things. He was a man of great talents, but without a mission. He labored where he considered himself able to contribute, but had no explicit need to achieve great things. In that respect his personality was different from that of Jan Oort, his immediate colleague and paragon.” Hovenier writes: “Henk … seemed to consider his fame more like a burden than something of which to be proud. He considered other things far more important, such as authenticity, sincerity and simplicity.”

Van de Hulst himself wrote (1998, p. 15): “What I enjoyed most in my research were not the big successes, but rather the little discoveries when a sudden insight revealed a surprising connection between bits of information that had seemed to be far apart.” Though modest indeed, he clearly was a leader, who took decisions where required, after listening carefully to everyone concerned; but he acted as a guide rather than a chief.

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Hugo van Woerden

VAN GOORLE, DAVID

SEE **Gorlaeus, David**.

VAN KREVELEN, DIRK WILLEM

(*b.* Rotterdam, Netherlands, 8 November 1914; *d.* Arnhem, Netherlands, 27 October 2001), *chemical engineering, coal science, polymer science.*

Van Krevelen was a prominent industrial chemist who successfully combined a career in the management of research and industry with a scientific career in three different fields. He was among a small number of scientists who introduced the American chemical engineering approach to Europe, and he was one of the first scientists who emphasized that "unit operations" could better be understood in terms of the transfer of mass, momentum, and energy. His research on chemical gas absorption led to an improved understanding of the combined effects of physical transport and chemical reactions. Van Krevelen was a founder of an entirely new branch of chemical engineering: chemical reaction engineering. He was also an important contributor to coal science; he applied the graphical-statistical method of his former supervisor Hein Waterman to coal, obtaining results that were relevant both for geology and the coal industries. His handbook on coal went through several widely used editions. Van Krevelen published extensively on polymer science as well. He developed an additive method of (atomic) group contributions that was used worldwide, and he wrote an important handbook that was reprinted several times. His name lives on in several of his results and methods, in all of these fields: the "Van Krevelen–Hoftyzer diagram" (on chemical gas absorption); the "Mars–Van Krevelen mechanism" (on catalytic oxidation); the "Van Krevelen–Chermin method" (on the estimation of the free energy of organic compounds); the "Van Krevelen diagram" (on coal and coal processes); the "Van Krevelen method" (on additive properties of polymers); and the "Van Krevelen–Hoftyzer relationship" (on the viscosity of polymer fluids).

Childhood and Education. Dirk van Krevelen (known to his friends as Dick) was born in Rotterdam on 8 November 1914, the son of Dirk Willem van Krevelen, Sr., a bookkeeper in the stevedore firm of A. A. Hoogerwerff, and Huberta van Krevelen (née Regoort). From 1927 to 1933 he attended the Marnix Gymnasium at Rotterdam, where he developed a strong interest in both the sciences and the humanities. His decision to study chemistry was inspired by the example of Jacobus Hendricus van 't Hoff and was also influenced by his father, who argued that there were good employment opportunities in that field, even in times of economic crisis. In October 1933 Van Krevelen was enrolled at Leiden University. Though he was quite disappointed by the courses in chemistry during his first year, the academic environment changed significantly with the appointment of Anton E. van Arkel as professor of inorganic chemistry at Leiden in 1934. Van Arkel was an inspiring teacher, and his book *De chemische binding als electrostatisch verschijnsel*, written with Jan de Boer, was a revelation to Van Krevelen, as it demonstrated an ingenious synthesis of theoretical insights, systematic classification, and presentation of empirical facts. After his *kandidaats* examination (bachelor's degree) in 1935, Van Krevelen decided to study physical and inorganic chemistry with Van Arkel, who asked him to work on the cohesive forces in liquid mixtures.

With an industrial career in mind, Van Krevelen in April 1937 also started with a minor in chemical technology, at the laboratory of professor Hein Waterman at the Technological University of Delft. This step had a decisive influence on his future career. Waterman helped him to find a job in industry, and, more importantly, Waterman's scientific approach—the use of graphical-statistical methods—would become the paradigm that Van Krevelen followed, and perfected, in most of his scientific work.

Since 1927 Waterman had been a scientific advisor to the oil company Royal Dutch/Shell, which provided funds for the employment of three private assistants, who did fundamental research on oil products and processes. Waterman, who wrote dozens of reports every year for Shell (more than 300 in total between 1927 and 1940), also engaged some of his students in research on oil. Van Krevelen was given the task of synthesizing model substances, related to oil components, and of measuring their physical parameters. From November 1937 Waterman employed Van Krevelen as one of his private assistants. Until the end of 1939 Van Krevelen worked for Shell on three topics: the chemical thermodynamics of oil hydrocarbons, related to Waterman's graphical-statistical enterprise; the polymerization of ethylene, as part of attempts to improve the anti-knock properties of gasoline; and the induced pyrolysis of methane, which would become the topic of Van Krevelen's dissertation. Meanwhile, in March 1938, he did his *doktoraal* examination (master's degree) at Leiden University—only four and a half years after his enrollment. At the time, most Dutch chemistry students took six or seven years to achieve the master's degree.

As with all previous private assistants to Waterman, a career at Shell was an almost certain prospect for Van Krevelen. By the time he received his doctorate, though, in December 1939, at the age of twenty-five, the situation had changed dramatically. In September 1939 World War II had broken out and Shell stopped employing new researchers. Moreover, Waterman, who was Jewish, decided to resign as scientific advisor by the end of 1939. He helped Van Krevelen to obtain a position, starting 1 January 1940, within the research organization of DSM (Dutch State Mines), which was just building its new Central Laboratory. Meanwhile, in July 1939, Van Krevelen had married Frieda Kreisel. They had three sons and one daughter.

Research Leader at DSM. When Van Krevelen in January 1940 entered the service of DSM, Frits van Iterson and Daan Ross van Lennep (manager of DSM's chemical division) had just founded DSM's Central Laboratory (under the leadership of the chemist Gé Berkhoff), modeled after the example of the Physics Laboratory of Philips, which was headed by Gilles Holst. Van Iterson and Ross van Lennep wanted to establish a research laboratory that, like the lab at Philips, would create an academic atmosphere in which high-level research was conducted. Initially, though, the differences between the laboratories were great. Whereas the Philips Laboratory in 1940 had a staff of about 520 employees, the staff of the Central Laboratory of DSM was about 80, 20 percent of whom were academics. In the following years the DSM laboratory would grow considerably. By 1941 there was a staff of about 200, including 29 academic scientists and engineers. When Van Krevelen left the laboratory in 1959, there were almost 100 academic scientists and engineers and about 650 employees in lower ranks.

In 1940 Van Krevelen began his research activities in DSM's physical chemistry department, which was headed by Henk de Bruijn. In 1943 Van Krevelen became a department manager himself, as head of the newly created research department on chemical engineering. In early 1948 Berkhoff decided that he would concentrate on the overall supervision of research and development at DSM, which, next to the Central Laboratory, included various chemical pilot plants and a research laboratory on mining technologies, as well as on technology transfer and licensing. Therefore a new position was created for someone who would directly supervise the research at the Central Laboratory. At that time the future course of the DSM research organization was hotly debated. Henk de Bruijn, who had visited the IG Farben laboratories at Ludwigshafen as part of a military mission in June 1947, advocated transforming the Central Laboratory into a laboratory of basic research, and erecting additional applied research laboratories, in close contact with the production departments. Van Krevelen had a far more pragmatic view. He was in favor of a mix of fundamental and applied research at the Central Laboratory, in permanent close contacts with the chemical plants. Van Krevelen won the battle, and in August 1948 he was promoted to the position of research leader of the Central Laboratory of DSM. In early 1955 he became head of the Central Laboratory, directing not only research, but also personnel and administration, which since 1948 had been supervised by his colleague Jan Selman.

During his years as research leader at DSM, Van Krevelen maintained a balance between fundamental high-level research and research with direct economic relevance to the company. He created an academic atmosphere at the Central Laboratory, with colloquia and study groups, and decided that all researchers could spend 20 percent of their time on topics of their own choice. In his yearly reports he eloquently defended the relevance of research against the conservative board of directors, who in general did not support purely scientific work. At the same time, Van Krevelen initiated research projects with direct relevance to the production departments. The fact that research and production at DSM were located quite close to each other played a great role in collaboration between departments. Van Krevelen was in frequent exchange with chemists and engineers working in the production plants.

One of the most striking features of Van Krevelen's career is that, even as a manager, he continued to engage in high-level research himself. He had a few assistants doing the laboratory work for him, but he was active in writing publications and books and in giving numerous lectures. Moreover, Van Krevelen did important work in three large, but very different, fields: chemical engineering, coal science, and polymer science.

Although Van Krevelen's work was highly valued at DSM, there was no chance that he would be promoted to the board of directors. The conservative majority of the DSM board thought that one scientist on the board—chemist Jan van Aken—was enough. They were not willing to add Berkhoff to the board, let alone his deputy Van Krevelen. Therefore, when in March 1959 Van Krevelen was asked to become a member of the board of directors of the Algemene Kunstzijde Unie (AKU; General Rayon Union), a far larger company than DSM, he accepted the offer. In September 1959 Van Krevelen joined the board of directors of AKU with the special task of supervising the research and development activities of the company. Surprisingly, in his new and demanding managerial role, he continued to be actively engaged in research.

Chemical Engineering. In June 1940, soon after he had entered the services of DSM, Van Krevelen was given the task of studying the removal of carbon dioxide (CO_2), hydrogen sulfide (H_2S), and other gases from coal gas with the help of an ammonia (NH_3)–water mixture. This was necessary because coal gas had to be purified before it could be used for lighting purposes by the households in the region, but also because DSM had planned to use CO_2 as a feedstock for the production of soda and urea. The problem was quite new to Van Krevelen. It involved the study of chemical engineering problems such as mass transfer (diffusion) in combination with chemical reactions. Waterman had been one of the first professors of chemical technology on the Continent who had used the American approach to chemical engineering in his lectures, following a visit to the United States in the 1920s; he introduced the concepts of "unit operations" and "unit processes" to the Netherlands. Van Krevelen had of course heard these lectures, but he was not really familiar with the study of unit operations, or of other chemical engineering topics.

Consequently, Van Krevelen started to study books on chemical engineering, such as William H. Walker, Warren K. Lewis, and William H. McAdams's *Principles of Chemical Engineering* (3rd ed., 1937), Walter L. Badger and Warren L. McCabe's *Elements of Chemical Engineering* (1931), and Thomas K. Sherwood's *Absorption and Extraction* (1937). Together with his research assistant Jan Hoftijzer (called Hoftyzer in English sources), he successfully solved the problems concerning the purification of coal gas in 1941; in the following years they worked on improving their theoretical understanding of the process. In 1946 Van Krevelen and his colleague Honoré A. J. Pieters published a book on the new process of coal gas purification developed at DSM. Two years later Van Krevelen and Hoftijzer published their theoretical views on the combined effects of mass transfer and chemical reactions. This represented a great breakthrough in chemical engineering, and their publication was one of the first papers on that particular topic. Their paper became a classic, and the "Van Krevelen-Hoftyzer diagram" on chemical gas absorption (1948), informally called the "shunting yard" by chemical engineers, was often quoted in the literature.

The reason that the Van Krevelen–Hoftijzer paper became a classic had to do with the improved theoretical understanding of chemical engineering that Van Krevelen had acquired during World War II. In 1942 Van Iterson, who was on the supervisory board of the Middelbare Technische School (Polytechnic School) at Heerlen, near DSM, asked Van Krevelen to introduce a course on chemical engineering at that school. Until that time chemical engineering had only been taught in the Netherlands at the Technological University at Delft (by Waterman, until the Nazis forced him to resign in October 1940, and by Willem J. D. van Dijck, a part-time professor who worked at Royal Dutch/Shell), and at the Polytechnic School at Dordrecht. Van Krevelen was thus among the first in the Netherlands who taught about unit operations and unit processes. In 1943 Adriaan Klinkenberg and Herman Mooy of the development group within the engineering department of Royal Dutch/Shell at The Hague published a paper in which they argued that there were strong analogies between the transfer processes of momentum, energy (heat), and matter. They rewrote the fundamental conservation laws of momentum, energy, and matter in such a way that similar equations resulted, with four different terms: changes as a function of time; changes by convection; changes by diffusion; and changes by production (for instance, as a result of an external forces, in the case of momentum, or by a chemical reaction, in the case of the production of heat and matter). They studied these equations, and their boundary conditions, by introducing dimensionless groups, such as the Reynolds number or the Nusselt number, thus combining in a creative way the study of transport phenomena with P. W. Bridgman's "dimensional analysis" and M. Weber's "theory of similitude," which was crucial for the scaling-up of laboratory experiments to the level of production plants. By so doing, they succeeded in providing a well-structured and rather complete picture of the different dimensionless groups that played important roles in chemical engineering.

Van Krevelen was delighted by the paper of Klinkenberg and Mooy, and he completely restructured his chemical engineering course at the Heerlen Polytechnic School. In his lecture notes, called *Een nieuw ordenend beginsel bij de studie der technologische bewerkingen* (A New Ordering Principle in the Study of Technological Operations), he systematically extended the approach of Klinkenberg and Mooy as a basis for the understanding of unit operations. In Van Krevelen's view, all unit operations—such as distillation, ion exchange, crystallization, filtration, mixing, and gas absorption—could be understood in terms of four fundamental processes: transfer of mass, transfer of momentum, transfer of energy, and transfer of electric charge (which he had added). And, even more systematically than Klinkenberg and Mooy, Van Krevelen developed a complete overview of all possible dimensionless groups, introducing a uniform notation for them. This systematic approach would also characterize much of Van Krevelen's later work.

After 1948 this new, more fundamental understanding of unit operations was introduced at Delft Technological University by Hans Kramers, the successor to Van Dijck as professor of chemical engineering. His course on "transport phenomena" of momentum, energy, and mass followed the classification systems introduced by Klinkenberg, Mooy, and, probably, Van Krevelen, but went into far greater detail with respect to the quantitative empirical study of the transfer processes. R. Byron Bird, who in 1956 worked in Kramers's laboratory as a Fullbright lecturer, followed Kramers's example in his very successful textbook on *Transport Phenomena* (1960), which he wrote with Warren E. Stewart and Edwin N. Lightfoot. Through the use of that text, the approach pioneered by Klinkenberg, Mooy, and Van Krevelen became a standard ingredient of all chemical engineering curricula in the United States and Europe.

Theoretical studies such as the one done by Klinkenberg and Mooy, and by Van Krevelen, were typical of much of the research work done during World War II in the Netherlands. Because of the war, the construction of new installations slowed down, or even came to a halt, as in the case of Royal Dutch/Shell. Without projects with tight deadlines, several industrial scientists and engineers embarked on theoretical studies. Indirectly, these studies had great practical relevance. The theory of gas-liquid reactions and the improved processes for gas absorption developed by Van Krevelen and Hoftijzer clearly built on Van Krevelen's new approach to unit operations with the help of dimensionless parameters. His well-organized "shunting yard" graph was the result of an intelligent choice of three dimensionless parameters that provided insight into the relative importance of the physical diffusion and of the rate of the chemical reaction of the components. Van Krevelen coined the term "Sherwood number" for one of these parameters, named after his American colleague Thomas K. Sherwood.

In 1941 and 1942 Van Krevelen also started a thorough empirical and theoretical study of nitric acid manufacture, one of the key products of the chemical plants of DSM. Absorption of gases by liquids played a significant role in that chemical process. Van Krevelen developed a mathematical model of nitric acid production, which greatly improved the process control of the existing nitric acid plants of DSM, and which also led to the design of a completely new plant, which was built between 1947 and 1951. The new process was a success, and several licenses were sold to chemical companies in England, Germany, Portugal, South Africa, Egypt, and India.

In 1946 and 1947 Van Krevelen made a three-month study tour through the United States to learn about the latest developments in chemical engineering. He met most of the leading figures in the field—such as T. K. Sherwood, W. K. Lewis, W. H. Walker, W. L. McCabe, T. H. Chilton, A. P. Colburn, O. A. Hougen, and K. M. Watson—and was elected as an active member of the American Institute of Chemical Engineers in 1947. Between 1947 and 1951 Van Krevelen published about thirty papers on gas absorption and on many other aspects of chemical engineering, such as the dissolution of solids, the drying of solids, fluidization, and the principles of chemical reaction engineering. In 1951 Van Krevelen was one of the founding editors of the journal *Chemical Engineering Science*. Two years later, the European Federation of Chemical Engineering (EFCE) was established, and Van Krevelen took an active part in organizing its first congress, the First Congress on Chemical Reaction Engineering, which was held in Amsterdam in 1957. At that congress the EFCE Working Party on Chemical Reaction Engineering was formally established, and Van Krevelen became its first chairman; the term *chemical reaction engineering*, which refers to the interplay of chemical engineering and the study of reaction kinetics, had been coined by Van Krevelen himself.

In addition to his other fields of research (see below), Van Krevelen continued to contribute to chemical engineering during the 1950s and 1960s. Between 1951 and 1971 he published more than fifty papers. One important (and still cited) paper was a study with his colleague Pieter Mars of the mechanism of oxidation reactions over oxidic catalysts, such as vanadium oxide (which plays a role, for instance, in sulfuric acid manufacture). Mars and Van Krevelen discovered that oxidation takes place via a two-step mechanism: first, the absorbed reactant is oxidized by the oxygen present in the crystal lattice of the catalyst, followed by desorption of the product; in a second step, the reduced catalyst is oxidized by oxygen from the gas phase. This so-called "Mars–Van Krevelen mechanism" appeared to have a quite universal significance, as it plays a role in numerous catalytic reactions. In 1958 Mars, who worked at the Central Laboratory of DSM, received his PhD from the Technological University at Delft on the basis of his research on the mechanism of oxidation reactions, with the chemist Jan de Boer and Van Krevelen as his supervisors.

Another often-cited publication by Van Krevelen with great relevance to industrial chemical reactions was his work on the "estimation of the free enthalpy (Gibbs free energy) of formation of organic compounds from group contributions," published in 1951, together with his assistant Huub Chermin. Building on Waterman's graphical-statistical method, Van Krevelen showed that the group contributions were additive—a fact that greatly helped to predict the course of new industrial processes. Later, in his work on polymers, Van Krevelen would extend this "atomic group approach" to other physical parameters.

After Van Krevelen left DSM for AKU, he introduced his expertise in chemical engineering to that company. Although a member of the board of directors, he supervised research by Rob Vroom on the chemical reaction engineering aspects of the viscose rayon spinning process, and coauthored several papers on polymer processing. For his "fundamental research on chemical reaction engineering" Van Krevelen was awarded an honorary doctorate by the Technische Hochschule Darmstadt in 1966.

Coal Science. After Van Krevelen had been promoted to research manager of the Central Laboratory of DSM, Berkhoff asked him, at the end of 1948, to become the Dutch representative to the European Working Party on Coal Classification. As a result, Van Krevelen decided to embark on a second large field of research, namely the scientific study of coal. Apart from the direct relevance to the work of the Working Party, this was also a strategic choice because Dutch State Mines primarily was a mining company, though it had a large chemical component, and the mining operations of the company were the primary concern of the board of directors. By taking coal as his topic of research, Van Krevelen was able to show the relevance of chemical research to the mining engineers and coal merchants of the board of DSM, a factor that facilitated the expansion of the Central Laboratory during the 1950s.

The cornerstone of Van Krevelen's coal research was the fruitful application to coal of the graphical-statistical method that his former supervisor Waterman had applied to oil products. Traditionally the properties of crude oil and of oil fractions had been characterized by fractional distillation and by measuring its specific density. For the higher boiling fractions of oil, these methods were far too rough. Before the introduction to the oil industry, in the 1950s, of gas chromatography, mass spectroscopy and NMR, other methods therefore had to be developed to characterize oil fractions. Of these, Waterman's method was one of the most successful.

In 1932 Waterman had published the idea that it was not necessary to characterize oil fractions by identifying all their dozens of components, but that it was sufficient to determine the statistical averages of the three most important structural characteristics of molecules in oil: the percentage of carbon in the aliphatic parts of the molecules (alkanes; paraffines); the percentage of carbon in the cycloalkane (naphtenic) parts of the molecules; and the percentage of carbon in the aromatic parts of the molecules. Together with his students Jozef C. Vlugter and Hendrik A. van Westen, Waterman presented his results in graphs in which the hydrogen percentage was plotted against the average molecular weight for different "ring indices," that is, the average number of naphtenic rings per molecule. It appeared that with the help of these three parameters, crude oils and oil fractions could be characterized quite accurately. Between 1932 and 1942 Waterman and his students also showed that by measuring physical parameters—such as the refraction (n), the density (d), and the average molecular weight (M) (the so-called n-d-M method)—and several other parameters such as the viscosity (ν)—the hydrogen percentages and ring indices could be calculated, so that oil fractions could be characterized with sufficient precision by physical measurements alone. Later in his career Waterman also applied these methods to the characterization of chemical processes such as hydrogenation and aromatization.

Van Krevelen transferred Waterman's methodology to the investigation of coal. As early as 1950 he published a seminal paper in the British journal *Fuel* that would influence the entire field of coal research for decades. With the help of two seemingly simple, dimensionless ratios—the atomic hydrogen to carbon (H/C) ratio, and the atomic oxygen to carbon (O/C) ratio—Van Krevelen constructed a diagram that summarized numerous publications as well as the extensive empirical investigations done by his assistants. On the one hand, the diagram permitted the rational classification of pre-stages of coal formation and different types of coal, such as wood, cellulose, lignin, peat, brown coal, different grades of bituminous coal, and anthracite. On the other hand, the diagram showed different reaction paths, such as decarboxylation, dehydration, and demethanation, which played a role both during natural coal formation (coalification) and in the industrial processes of coal gas production and coke manufacture (carbonization), hydrogenation, and oxidation.

With the help of the "Van Krevelen diagram," important new insights on coalification and on industrial processes could be gained, and many of these new insights were already in Van Krevelen's 1950 publication. That work accelerated Van Krevelen's very productive research trajectory in coal science. Between 1948 and 1965 he would publish over a hundred papers on coal and coal products. As a result, the "Van Krevelen diagram" found its way into geology and geochemistry, where it is applied today also to the study of the formation of oil and natural gas, and to the study of coal products such as coke, gas, and artificial gasoline. It helped manufacturers to understand which type of coal was best suited for the production of a particular final product.

In 1957 Van Krevelen summarized his research in the book-length monograph *Coal Science: Aspects of Coal Constitution*, which he published with his assistant Jan Schuijer. The book became a great success. In 1961 Van Krevelen published a thoroughly revised edition under the title *Coal: Typology, Chemistry, Physics, Constitution.* The graphical-statistical method and the "Van Krevelen diagram" played a key role in these books. After his retirement from industry in 1976, Van Krevelen again published a revised edition, in 1981. The book had to be reprinted in 1982, and again in 1984. In 1993, at the age of seventy-nine, Van Krevelen published a fourth, updated edition of *Coal: Typology, Chemistry, Physics, Constitution.* Through these books and his numerous papers Van Krevelen dominated the field of coal science for over thirty years. In 1954 he was awarded the medal of the University of Liège for his work on coal, and in the same year he was awarded the Coal Science Medal of the British Coal Utilisation Research Association. In 1959 he was elected a Fellow of the Institute of Fuel. In a generalized form, the H/C and O/C "Van Krevelen diagrams" are today also used in mass spectrometry.

Professor of Fuel Technology and Polymerization Processes at Delft. In 1952 Gerard A. Brender à Brandis, the part-time professor of fuel technology at the Technological University of Delft, retired, and Van Krevelen was invited to succeed him. After the board of directors of DSM gave him permission to teach two days a months at Delft, Van Krevelen in October 1952 was formally appointed as professor of chemical technology, with the special task of teaching about the technology of solid and liquid fuels and the associated production of energy. He held this professorship until his retirement from the Technological University of Delft in 1980.

During his professorship Van Krevelen lectured on all three scientific fields to which he made major contributions: from 1953 to 1957, and in 1959 and 1961, he lectured on fuel technology; in 1958, 1960, and 1963 he gave courses on chemical reaction engineering; and he taught on the process technology of polymers in 1962 and from 1964 to 1980. After his move to AKU, in 1959, the subject of his professorship at Delft was formally changed to the process technology of polymers. For the supervisory board of AKU this had been a pre-condition for granting permission to Van Krevelen to combine his membership on the board of directors with a part-time professorship at Delft.

Although a part-time professor, Van Krevelen supervised the considerable number of twenty-three dissertations. In most cases these PhD students were staff members of the research organizations of DSM (and, later, AKU), who did their research in industry, supervised by Van Krevelen, and who were awarded the doctorate at Delft when their results had enough substance and coherence. Between 1952 and 1966 Van Krevelen supervised nine PhD students in coal research, between about 1955 and 1960 four PhD students in chemical engineering, and between about 1961 and 1977 ten PhD students in polymer production and processing. Several of his PhD students and research assistants later became university professors themselves: Rinus Groenewegen and Jaap Smidt in molecular spectroscopy (which they had applied at DSM to the study of coal); Jan Schuijer and Leen Struik in the technology of polymers; Piet Mars in catalysis; and Rob Deelder in analytical chemistry.

Member of the Board of Directors of AKU and AKZO. When, on 1 September 1959, Van Krevelen succeeded Jan Weeldenburg, who had just died, as board member of AKU with the overall responsibility for research, he entered a company that differed from DSM in many respects. In contrast to DSM, AKU had been a multinational company for many decades. Founded in 1929 as a holding company that united the activities of the Dutch rayon firm Enka and the German Vereinigte Glanzstoff Fabriken, AKU in 1959 had plants for fiber production in Germany, Austria, Britain, Spain, Italy, the United States, Mexico, and the Netherlands. Even before World War II, AKU was one of the leading synthetic fiber producers, together with companies such as Du Pont and IG Farben. Around 1960 its major fiber was still rayon, but nylon-6 (Enkalon®), produced from caprolactam made by DSM, had been produced since the early 1950s, and the company was constructing plants for glass fibers (together with Pittsburgh Plate Glass) and polyesters (Terlenka®) based on dimethyl terephtalate (together with Amoco). In 1960 the central research and development laboratories near the AKU headquarters at Arnhem had a staff of 1,075 employees. There were also large research laboratories in Germany and the United States. Van Krevelen now had responsibility for a research and development organization that was about four times as large as the Central Laboratory of DSM.

The 1960s were a period of vigorous expansion of the chemical and synthetic fibers industries. Through huge investment programs and mergers, companies tried to improve their economies of scale. Against that background Van Krevelen was a strong advocate of a merger between AKU and DSM. He had the vision that the backward integration of AKU into the domain of organic chemistry and fiber intermediates would strengthen the technological and economic basis of the company. There was a strong synergy, because DSM made growing amounts of caprolactam for AKU's nylon production. At least three times during the 1960s Van Krevelen and his colleagues negotiated seriously with Van Krevelen's former boss Jan van Aken and the other board members of DSM. Although both Van Krevelen and Van Aken were strongly in favor of the merger, members of DSM's advisory board were against the integration of the state-owned DSM into a private corporation, in view of the social responsibility for the miners at a time when all Dutch coal mines were closing their gates. To Van Krevelen's great disappointment, the negotiations between AKU and DSM came to a final end in early 1969.

Only a few months later, AKU merged with Koninklijke Zout Organon (KZO), a company that was a conglomerate of pharmaceutical (Organon and Noury van der Lande), coatings (Sikkens), and chemical (Ketjen and Koninklijke Zout) companies. The result of the merger was incorporated as AKZO (since 1994, Akzo Nobel). Van Krevelen remained a member of the board of directors, and he was, as a result of the divisional structure introduced shortly after the merger, at the same time president of AKZO Research and Engineering. In that role he had the difficult task of integrating the research and development laboratories of the different companies that were now part of AKZO. When Van Krevelen retired from AKZO in 1976, the integration process was still incomplete. He was succeeded by Hans Kramers, his former colleague as professor of chemical engineering at Delft.

Polymer Science. As leading manager and scientist at AKU, Van Krevelen decided to focus his scientific activities on polymer science. This field was not completely new to him. At DSM he had been involved in the supervision of research on the fiber intermediates caprolactam and nylon salt, and on the polymerization of these intermediates. He also had been involved in the acquisition of the technology of the production of high-density and low-density polyethylene, from the German chemist Karl Ziegler and the British company Imperial Chemical Industries (ICI), as well as in organizing the research activities that went hand in hand with those acquisitions.

He again formed a small group of private assistants (including his long-time assistant Jan Hoftijzer, who had followed him from DSM to AKU); he was in close contact with other research scientists at AKU, and he lectured at Delft on polymer science and technology. As the combined result of these activities, Van Krevelen succeeded for the third time in mastering a new field. Between 1960 and 1978 he published about forty papers on polymers and polymer processing. In 1972 he summarized his results, and numerous papers by others, in a handbook written in collaboration with Hoftijzer, called *Properties of Polymers: Correlations with Chemical Structure*. Again, he built on Waterman's graphical-statistical method, on his own approach developed in his book on *Coal*, and on the seminal publication that he wrote with Chermin on the group contributions to the Gibbs free energy of molecules. Van Krevelen and Hoftijzer showed that many physical properties of polymer molecules could be estimated by summing the contributions made by the various structural groups in the polymer repeat unit. The correlations were semi-empirical in nature. In cases of strong interatomic and intermolecular interaction between the groups, or between the molecules, the physical properties are not additive. But in those cases, Van Krevelen showed, the deviations from the additive rule again followed certain regularities.

His book *Properties of Polymers* was considered groundbreaking by organic chemists and chemical engineers working in industry, because it brought order to a large and rapidly developing new field. Van Krevelen realized that the book was not for the polymer scientist proper, "its design being too empirical for him and too much directed to practice" (Van Krevelen and Hoftyzer, 2nd ed., 1976, p. v). The group additive method used in the book is known as the "Van Krevelen method" (or "Van Krevelen–Hoftyzer method"). Because his method was easy to use and covered a wide range of properties, it was quickly accepted by many scientists working in industry. In 1976 Van Krevelen had already published a second edition, reprinted in 1980 and 1986, and in 1990 a third edition came out, which was reprinted in 1997. His work clearly went beyond the skillful summarizing of known results. Many original empirical studies were included in his books. In 1975 Van Krevelen and Hoftijzer published new work on the viscosity of so-called non-Newtonian (polymer) fluids. The relationship they found between the temperature, the chemical structure of the polymer unit, and the viscosity is known as the "Van Krevelen–Hoftyzer relationship."

Retirement and Awards. After his retirement from AKZO in 1976, Van Krevelen remained active for many years. From 1980 to 1983 he was international research advisor to the oil company Shell, and from 1980 to 1986 he also was research advisor and president of the advisory board of Norit, a company active in the production of adsorbents. In his spare time Van Krevelen studied the history of Egypt and other ancient civilizations.

In 1977 he was awarded the Chemistry Prize of the Society of the Dutch Chemical Industry for his great contributions to the development of that industry in the Netherlands. In 1984 he received the honorary doctorate of the Technological University Delft, in view of his achievements in coal technology, polymer technology, and the fundamentals of chemical engineering. Seven years later, in 1991, he became an honorary member of the Royal Dutch Chemical Society. Dick van Krevelen died on 27 October 2001 after a short period of illness following a stroke.

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