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The Legend of Pure Spring Water: The Development of Industrial Water Treatment and its Diffusion through Technology Transfer as the Basis for the Industrialization and Internationalization of Brewing

Die Legende vom reinen Quellwasser: Die historische Entwicklung der industriellen Wasseraufbereitung als Grundlage für die Industrialisierung und Internationalisierung des Brauens

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Abstract: By examining the horizontal and vertical, international knowledge and technology transfer of specific industrial water-treatment-technologies, this paper reflects on their interaction with beer production. Against the background of the discrepancy between the importance of narratives on *naturalness* and *originality* in relation to brewing water and the industrial mass production in its historicity, an insight into a largely invisible but nevertheless fundamentally important technology will be given.

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Keywords: industrial water treatment, history of brewing technologies, vertical and horizontal transfer of technologies, industrielle Wasseraufbereitung, Geschichte der Brautechnologien, vertikaler und horizontaler Technologietransfer

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1 Introduction

A central element of beer advertising is the idea of a special water as the foundation of the product.[1] This practice has a long tradition, and it seems that it can be found in all industrialized nations. Frequently, advertising utilised links between brand identity and specific, positively connotated regions. These links have remained stable over relatively long periods of time as can be seen in advertising slogans such as "[...] pure Rocky Mountain Spring Water"[2], "Fellsquellwasser"[3], "[...] from the Land of Sky Blue Waters"[4] or "L'eau de source"[5]. Furthermore, it was a common phenomenon that a local water quality was named as an essential prerequisite for a particular beer brand. To name but a few: The Olympia Brewing Company, formerly Capital Brewing Company, in Tumwater, Washington since 1902[6] or the Krombacher-brand of the Schadeberg-Brewery in Krombach/Westphalia since 1961.[7] These associations serve potential consumers' ideas of untouched natural landscapes or at least rural idylls. This utilisation of *nature* and *down-to-earthness* reflects a fundamental discrepancy with the reality of industrial production. And thus, this is an indication of escapist tendencies, a factor that takes on a special quality in the context of the potentially dangerous nature of the drug alcohol.[8]

In the pre-industrial period, locally accessible water was used to brew beer.[9] Especially in urban agglomerations where watercourses were used as sewers

1 *C.F. Keithan*, The Brewing Industry: Staff Report of the Bureau of Economics, Federal Trade Commission, Washington D.C 1978, p. 117.

2 https://www.molsoncoors.com/about/history, 26.01.2022.

3 Engl.: "rock source water" or "rock water"; https://www.krombacher.de/braukunst/brauprozess, 26.01.2022.

4 *J.D. Gatrell/D.J. Nemeth/C.D. Yeager*, Sweetwater, Mountain Springs, and Great Lakes: A Hydro-Geography of Beer Brands, in: *M. Patterson/N. Hoalst-Pullen (Eds.)*, The Geography of Beer: Regions, Environment, and Societies, Dordrecht 2014, pp. 89-98, here: p. 92.

5 Engl: "spring water"; https://www.appenzellerbier.ch/de/home.html, 26.01.2022.

6 https://www.brewerygems.com/olympia.htm, 29.03.2022.

7 *C.W. Thomsen (Ed.),* Krombacher: Brauwesen im Siegerland, Siegen 2005, pp. 63, 110-113.

8 *Technoseum / Landesmuseum für Technik und Arbeit in Mannheim (Ed.)*, Bier: Braukunst & 500 Jahre Deutsches Reinheitsgebot, Mannheim 2016, pp. 32 f., 102-125; *G. de Gaetano et al.*, Effects of moderate Beer Consumption on Health and Disease: A Consensus Document, in: Nutrition, Metabolism & Cardiovascular Diseases 26, 2016, pp. 443-467, here: pp. 447 ff.; *S. Sohrabvand/ A.M. Mortazavian/K. Rezaei*, Health-Related Aspects of Beer: A Review, in: International Journal of Food Properties 15/2, 2012, pp. 350-373.

9 *J. Sumner*, Brewing Science, Technology and Print, 1700-1880, London 2013, passim esp. pp. 17, 19, 21, 66, 72.

and for the disposal of heavily polluted wastewater such as that from dye works and tanneries,[10] there was also a long tradition of constructing deep wells to access drinking water.[11] Apart from the associated health issues, the composition of the water determines the quality and taste of beer.[12] Soft water with a low salt content is more suitable for light beers with a relatively high proportion of hops, such as *Pilsener*, like the crisp clean lagers in Bohemia.[13] While other regional beer specialties are not least dependent on the respective water quality. In Dortmund, for example, the comparably high water-hardness, which is not due to the carbon content of the water, is more suitable for the *Export* type, and the hard water of Munich or London with high *carbonate hardness* for the dark beer.[14] Ever since temperature-controlled fermentation became possible in beverage technology – an innovation of the late 19th century that was made possible by another invention: refrigeration machines[15] – the supply of adequate water was the bottleneck of beer production and so the technology of water treatment found its costumers among brewers.[16]

10 *G. Stanzl*, Technische und kulturgeschichtliche Aspekte der Entsorgung, in: *O. Wagener (Ed.)*, Aborte im Mittelalter und in der Frühen Neuzeit, Petersberg 2014, pp. 47-54, here: p. 47; *O. Borst*, Alltagsleben im Mittelalter, Frankfurt a.M. 1983, p. 284.

11 *E. Höfler/M. Illi*, Versorgung und Entsorgung der mittelalterlichen Stadt, in: *Landesdenkmalamt Baden-Württemberg/Stadt Zürich (Eds.)*, Stadtluft, Hirsebrei und Bettelmönch: Die Stadt um 1300, Stuttgart 1992, pp. 351-363, here: pp. 356 ff.; *K. Voudouris/A. Kaiafa/Z.X. Yun et. al.*, A Brief History of Water Wells Focusing on Balkan, Indian and Chinese Civilizations, in: IWA 2nd Regional Symposium on Water, Wastewater and Environment, Izmir 2017, https://www.academia.edu/download/52372245/History_of_wells_Izmir_full_paper.pdf, 05.08.2022.

12 *R. DeSalle/I. Tattersall*, A Natrural History of Beer, New Haven 2019, p. 74; *J.S. Hough/D.E. Briggs/R. Stevens*, Malting and Brewing Science, London 1971, p. 191.

13 *M.W. Patterson/N. Hoalst-Pullen*, (Re)visiting Geographies of Beer, in: *M.W. Patterson/N. Hoalst-Pullen (Eds.)*, The Geography of Beer: Culture and Economics, Cham 2020, pp. 1-3 here: p. 2.

14 www.lebensraumwasser.com/ohne-wasser-gaebe-es-kein-bier-zum-internationalen-tag-des-bieres, 01.01.2022; https://braumagazin.de/article/von-der-wasseranalyse-zum-brauwasser, 25.01.2022; *M. Cornell*, Porter for the Geography of Beer, in: *M.W. Patterson/N. Hoalst-Pullen (Eds.)*, The Geography of Beer: Culture and Economics, Cham 2020, pp. 4-22 here: p. 8; *Sumner*, Brewing Science, p. 17; *S. Yool/A. Comrie*, A Taste of Place: Environmental Geographies of the Classic Beer Styles, in: *M. Patterson/N. Hoalst-Pullen (Eds.)*, The Geography of Beer: Regions, Environment, and Societies, Dordrecht 2014, pp. 99-108, here: p. 103.

15 *M. Hård*, Machines are frozen Spirit: The Scientification of Refrigeration and Brewing in the 19th century: a Weberian Interpretation, Frankfurt 1994; *W. Redenbacher*, Die maschinentechnische Betriebsleitung in der Brauerei, Stuttgart 1927, pp. 122 ff.

16 Interview with Rudolf Orcellet (retired Technical Director of H+E), 02.11.2006; *Technoseum*, Bier, p. 43.

Three main phases of the adaptation of industrial water treatment in brewing can be named. First, the softening of process water to protect the existing equipment from damage by encrustation; second, the modification of the quality of the brewing water in order to be able to prepare different types of beer at one location; and finally, the creation of the same water quality at different locations in order to be able to generate an identical product worldwide. Globalization after the Second World War resulted in a small number of internationally operating corporations developing an interest in manufacturing identical products in different locations. This meant both entering new markets by distributing established product lines and taking over foreign brands and selling them in domestic markets. In the U.S.A., for example, Carling National with *Tuborg* and Miller with *Löwenbräu* had already done this in the 1970s.[17] Due to the relationship between price and weight of the product, it was an obvious practice to produce in relative proximity to the consumer, which, especially in the case of the United States, led to brewing in diverse locations. This has been demonstrated by Gatrell and others in the case of the Budweiser brand.[18] At the end of this development, the knowledge base was reached which made it possible that "today, brewing water can be 'tailor-made' at any location and for any desired type of beer."[19]

The three phases named here are not to be understood in the sense of a stringent sequence. Since the work of Edgerton, it has been clear that technical change at no time would have excluded adherence to traditional practices.[20] The discrepancy mentioned at the beginning between consumer perception and the application of innovative technology may serve as a stimulus to trace the vertical technology transfer of water treatment processes such as those used in brewing.

For this purpose, it will be necessary to trace the interplay between scientific research and technical application and to consider the diffusion in different industries.

The conditio sine qua non of high-quality beer production before the scientification and mechanisation of brewing was the natural availability of water of sufficient quality and quantity,[21] which means that the special local water quali-

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17 *Keithan*, The Brewing Industry, p. 118.

18 *J.D. Gatrell et al.*, Sweetwater, p. 89.

19 *R. Uhlig/H. Taschan*, Bier und Braustoffe, in: *Wolfgang Frede (Hg.)*, Taschenbuch für Lebensmittelchemiker. Lebensmittel - Bedarfsgegenstände - Kosmetika - Futtermittel, Berlin 2006, pp. 609-625.

20 *D. Edgerton*, The Shock Of The Old: Technology and Global History since 1900, London 2008.

21 *J.D. Gatrell et al.*, Sweetwater, p. 90.

ty often used in advertising need not have been a myth to begin with.[22] Yet, with the growth of industrial production, this basic requirement became a production bottleneck. Accordingly, the breweries sought out solutions, such as special technical processes that will be detailed in the next section. This, in turn, made the idea of a special water as the basis of a specific product absurd.

Hence, technological advancements and the growing importance of scientific procedures in food production seem far apart from the consumers' ideas about the products. In sociology, this is described as a "Fiction of Rationality", the decision-making processes in complex social networks of relationships. Since the mid 2000s this concept has been applied to technical consumer products in the works of Wengenroth and Neumeier.[23] In modern mass consumer society the individual is exposed to a constant excessive challenge in his consumption decisions. To make decisions, individuals fall back on supposedly rational explanations, that often tell us more about the consumer's background, level of education and social integration than about the products. Accordingly, this is not a static phenomenon; rather, the use of abstract ideas such as *nature* in advertising for beer is subject to both temporal change and local particularity.[24]

At the same time, this phenomenon is not limited to the brewing industry but implies the social relevance of complex issues in terms of consumer behaviour, consumer power but not least the social acceptance of technical change.

2 Water and Brewing

From a process-engineering point of view, however, spring water is conceivably unsuitable for this purpose of brewing due to the high level of hardeners it contains. Already in the late 1870s, scientific research showed that special kinds of

22 *B. Smith*, BeerSmith home brewing, Brewing Water - Hard or Soft? http://beersmith.com/blog/2008/08/24/brewing-water-hard-orsoft/, 05.08.2022; *J.D. Gatrell et al.*, Sweetwater, p. 97.

23 *U. Schimank*, Rationalitätsfiktion in der Entscheidungsgesellschaft, in: *D. Tänzler/H. Knoblauch/H.-G. Soeffner (Eds.)*, Zur Kritik der Wissensgesellschaft, Konstanz 2006, pp. 57-81, see: p. 57; *U. Wengenroth*, Gute Gründe: Technisierung und Konsumentscheidungen, in: Technikgeschichte 71/1, 2004, pp. 1-18.

24 From the perspective of a sociology of technology, this insight allows conclusions to be drawn about the acceptance of a technological environment or, ex negativo, about escapist tendencies.

beers required specific water qualities.[25] Hence, along with the development of the large-scale technical realization of brewing,[26] industrial water treatment developed. Especially in the second half of the 20th century, this business field was served by a very small group of U.S.-American, German, British and Japanese companies, often acting as subcontractors for plant manufacturers and thus, showing a high degree of specialization. At the same time, they were asymmetrically dependent on their suppliers, especially the chemical industry. The aim of this paper is to present this largely invisible aspect of the history of the internationalization of brewing, building on the contents of an older research project that also included a local oral history project.[27]

From the point of view of a history of technology committed to cultural studies, this aspect is of particular interest, since the discrepancy between the scientification and mechanization of the food industry with the simultaneous utilization of notions of naturalness, tradition, and identification in marketing were a regularly occurring phenomenon across borders and industries. Critical engagement with this phenomenon has a long tradition, extending from Upton Sinclair's description of Chicago slaughterhouses to Jackson's work on wine or Salzmann's on drinking water.[28] Accordingly, this approach is inspired by current discourses on consumerism and industrial food production and builds on an investigation of the genesis of a number of relevant technologies. For the understanding of this complex of questions, it is essential that two diffusion phenomena can be proven as they have been typical for innovations from the time of the high modernity; on the one hand the horizontal and on the other hand the vertical transfer of applied science.[29]

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25 I thank Astrid Schneck for this advice; *C. Lintner*, Beiträge zur Beurtheilung der Brauwässer, in: Zeitschrift für das gesamte Brauwesen, Neue Folge I., 1878, pp. 369-370; *P. Mathias*, The Brewing Industry in England, Cambridge 1959, pp. 16, 174, 192.

26 *Technoseum,* Bier, pp. 22-24.

27 Based on the 75th anniversary of the company, the medium-sized plant manufacturer Hager + Elsässer in Stuttgart Vaihingen commissioned the Chair for the History of Science and Technology with a comprehensive review of its own history. The research project, which was completed in 2007, included the processing and preparation of archival records and a comprehensive oral history project: https://www.hi.uni-stuttgart.de/gnt/forschung/, 25.07.2022; The transcriptions of the interviews and the sources are today held in the *Baden-Württembergisches Wirtschaftsarchiv*.

28 *U. Sinclair*, The Jungle, New York 1906; *R.S. Jackson*, Wine Science: Principles and Applications, Cambridge [4]2014, *J. Salzman*, Drinking Water: A History, London 2012.

29 *J.R. Harris*, Industrial Espionage and Technology Transfer: Britain and France in the Eighteenth Century, Aldershot 1998; *K. Sachpazidu-Wójcicka,* Vertical and Horizontal Technology Transfer and Firm Innovativeness, in: Studia i Materiały 28/2, 2018, pp. 140-153; *M. Gilbert/M.*

The first, the horizontal, is the transfer of knowledge at a comparable institutional level; in this specific case, it was a matter of companies, such as breweries and plant manufacturers, but also highly specialized suppliers. Whereas vertical technology transfer describes the genesis from the episteme to the product, in other words the path from basic research via application-oriented development work to the dominant design of a product accepted on the market. To understand the concept of technology transfer as distinct from the purchase of a technical product or service, it should be mentioned that technology transfers have proven to be lengthy, cost-intensive and by no means always successful processes. Only after a technology transfer process has been successfully completed – a process which is also always a process of exchange and negotiation between the relevant groups of actors – can the result of this process become a product in the sense of a dominant design.

As will be shown in the following, both transfer models, which are used in economics to explain the external exploitation of technological knowledge, can be demonstrated in the case examined here. However, it should not be neglected in this regard that this is a theoretical approach which only gained importance in connection with the renewed Schumpeter reception in the wake of the structural crisis of the 1970s, and it is therefore an anachronistic systematization of the phenomena – accordingly, no corresponding content can be found in contemporary discourses.[30]

Cordey-Hayes, Understanding the Process of Knowledge Transfer to Achieve Successful Technological Innovation, in: Technovation 16, 1996, pp. 301-312; *W.A. Sazali/A. Haslinda/C.R. Raduan*, A Holistic Model of the Inter-Firm Technology Transfer Based on Integrated Perspective of Knowledge-Based View and Organizational Learning in: The Journal of International Social Research 2/9, 2009, https://www.researchgate.net/publication/40426306_A_Holistic_Model_of_the_Inter-Firm_Technology_Transfer_Based_on_Integrated_Perspectives_of_Knowledge-Based_View_and_Organizational_Learning, 28.10.2023.

30 On the „Renaissance“ of the Schumpeterian Concept of Innovation see: *H. Trischler*, Das bundesdeutsche Innovationssystem in den “langen 70er Jahren”: Antworten auf die „amerikanische Herausforderung“, in: *J. Abele/G. Barkleit/T. Hänseroth (Eds.)*, Innovationskulturen und Fortschrittserwartungen im geteilten Deutschland, Köln 2001, pp. 47-70, here: p. 66; *H. Grupp*, Messung und Erklärung des technischen Wandels: Grundzüge einer empirischen Innovationsökonomie, Berlin 1997, pp. 3-20.

3 Treatment of Hardness Components

Hardness components of water such as calcium or magnesium have the capability to damage technical equipment, and especially in the production of food or pharmaceuticals, these and other dissolved substances can negatively influence the product properties as well.[31] Thus, the need to use the cleanest or softest possible water in industrial processes has a relatively long tradition. In terms of the brewing industry, according to Krauß, it was academic teachers at the *Institut für Gärungsgewerbe zu Berlin*, founded in 1874, where Wilhelm Windisch (1860–1944) and Paul Kohlbach (1894–1920) in particular worked on the modification of brewing water. Accordingly, they recognized that the bicarbonate hardness of the brewing water reduced the acidity, while calcium ions had the opposite effect. Based on this knowledge, they produced manuals for the practical application of this knowledge in actual brewing operations and operated their own Water Technology Department as part of the institute.[32] In view of the brewing industry's self-portrayal and probably also its own perception, especially in the period of high modernity, as progressive and open to science and technology, the finding that the supposedly relatively trivial treatment of brewing water was not the industry's own achievement may be surprising. As will be shown below using two technologies as examples, vertical and horizontal technology transfer was the rule. For instance, this can also be demonstrated by the history of refrigeration technology as studied by Hård or Dienel.[33] In this case, the innovation came from the field of mechanical engineering, and the breweries were initially merely customers, irrespective of the implications and options that the innovative processes brought with them.

A wide range of different biological, mechanical, and chemical processes underwent continuous development over the course of time, which has not only resulted in the capability to produce pure water, but also the capability to design water according to precise specifications. Companies specialising in this field developed as early as the end of the 19th century, setting up and operating water treatment plants primarily for the operation of steam engines. Breweries, dairies,

31 *J.D. Gatrell et al.*, Sweetwater, pp. 93, 95.

32 *G. Krauß*, Bericht aus dem Forschungsinstitut für Technologie der Brauerei und Mälzerei, in: 100 Jahre Institut für Gärungsgewerbe und Biotechnologie zu Berlin 1874-1974, Berlin 1974, pp. 48, 54, 67.

33 *M. Hård*, Machines are frozen Spirit; *H.-L. Dienel,* Ingenieure zwischen Hochschule und Industrie. Kältetechnik in Deutschland, 1870-1930, Göttingen 1995, pp. 141-323.

and laundries relatively quickly expanded the clientele.[34] At the same time, innovations in mechanical engineering and plant technology were adopted by the brewing industry with a time lag.

From the broad variety of different technical solutions, two key technologies will now be examined in more detail in order to provide a basis for further discussion of the economic implementation and transfer of the technology to the brewing industry: Precipitation by means of binder aggregates and the ion exchange process. Although these technologies are by no means the only or exclusive methods of water filtration and treatment, they may suffice as examples at this point. One the one hand it can be shown that the precipitation-technology was a direct predecessor technology, through the deficits of which the discussion of ion exchange filters was first inspired. And furthermore, complex ion exchange processes from the 1960s onward were to make it possible for the first time to shape the composition of liquids largely freely. These are examples that were not only particularly widespread and common in use, but also demonstrate the transfer of knowledge within the cluster of industrially developed regions.

3.1 Soda and Lime-Soda-Method

Already in the late 1830s, the Scottish chemist Thomas Clark (1801–1867) implemented the application of calcium bicarbonate for the process of lime softening of hard water. Until today, this is still known as the *Clark process* in the English-speaking world.[35] But the treatment of feedwater was not yet in his focus or that of his colleagues. Rather, the scientific discourse was focused on the treatment of freshwater in municipal supply systems to reduce the costs from maintenance and servicing. Moreover, even though his work received broad support from his fellow scientists, the effective implementation was only realized in a few exceptional cases. The municipal water suppliers feared the associated costs and left the problem of encrusted water pipes to the customer.[36]

At least since 1857, soda was used to precipitate hardness components in feedwater.[37] In this procedure, water and soda were mixed in a tank. The soda

34 *The Permutit Company (Eds.)*, Water Conditioning Handbook, New York 1954, p. 10/7.

35 *L. Stephen (Ed.)*, Clark, Thomas (1801-1867) in: Dictionary of National Biography 10, 1887; Journal of the Society of Arts 32, 1884, p. 926; Society of Engineers: Transactions for 1884, 1885, p. 118.

36 *A. Frühling (Ed.)*, Handbuch der Ingenieurwissenschaften, Leipzig 1910, p. 292.

37 *R. Schmidt*, Die Fortschritte in der Construction der Dampfmaschine während der neuesten Zeit (1854-1857), Leipzig 1857, p. 84.

formed chemical bonds with some of the dissolved hardness components and heavier molecules were created. Due to the specific weight in relation to the water they sink to the ground of the tank.[38] After the process of precipitation, comparable soft water could be extracted from the top of the tank, while milky goo remained as deposit at the bottom and was drained into the sewage. The addition of unslaked lime in aqueous solution had a similar effect. However, it would not have been reasonable to combine soda and lime in the same reaction vessel, because they would have reacted together. The solution was found in 1867 by the chemist Franz Ferdinand Schulz (1815–1873),[39] who taught at the University of Rostock. He proposed to use two redundant reactors, a first one for soda and a second one for lime.[40]

Since the second half of the 19th century this lime-soda-method was widely used in the industrialized regions and even though later developments, like the ion-exchange process, promised faster and more effective ways to gain soft water, the lime-soda-method was used until far into the 20th century.[41] In particular, the decarbonization with lime was frequently used in the industrial production of food and beverages.[42] In his 1896 manual on industrial brewing, Paul Petit, director of the *École de Brasserie* of Nancy, described the combination of filters and soda-lime plants as an established practice in large breweries. Because of the cost and time involved, he recommended for smaller breweries to have the water analysed and then use targeted reagents to precipitate the undesirable components of the water.[43]

Although the lime-soda-method was originally developed to clear feedwater for steam engines, the procedure found a widespread application even when steam engines lost their importance after the 1950s. However, apart from the complex method to determine the hardness of the water the lime-soda-method was rather time-consuming.[44] Depending on the amount and desired purity, the

38 *E. von Hoyer*, Kurzes Handbuch der Maschinenkunde, München 1898, p. 282; *W.T. Read*, Boiler Waters: Their Chemical Composition, Use, and Treatment, Austin 1917, p. 54.

39 *B. Lepsius*, Schulze, Franz Ferdinand, in: Allgemeine Deutsche Biographie, 1892, pp. 749-751.

40 *A. Schulze-Förster*, Geschichte des Kalk-Soda-Enthärtungsverfahrens, in: Chemikerzeitung 55, 1931, p. 549.

41 *K. Hancke*, Wasseraufbereitung: Chemie und chemische Verfahrenstechnik, Berlin 1998, p. 145.

42 Allgemeine Hopfen-Zeitung, 03.06.1871, S. 251; Wochenschrift für Brauerei 1891, p. 31, 1042, https://babel.hathitrust.org, 16.08.2022.

43 *P. Petit*, La biere et l'industrie de la brasserie, Paris 1896, pp. 133-140.

44 *H. Klut*, Die Untersuchung des Wassers an Ort und Stelle, Berlin 1927, p. 113; *C. Morgenstern*, Neue Wasserreiniger für Kesselspeise- und gewöhnliche Zwecke, in: Zeitschrift des Vereins Deutscher Ingenieure 41, 1897, pp. 944-948.

process took between two and three hours.[45] To prevent shortages in water supplies, it became customary to install large tanks and to produce the necessary feedwater in advance. The technology was loaded with a whole series of desiderata in terms of user-friendliness, process efficiency and, not least, costs. Not surprisingly, based on further and more up-to-date scientific findings, more efficient methods of water treatment were sought as the following example of ion-exchange illustrates.

3.2 Ion Exchange

When the two British scientists John T. Way and Harris S. Thompson examined different sorts of earth in 1850, they discovered the principle of ion-exchange – a principle, the technological application of which meant a significant change for the industrial purification of water. [46] Way and Thompson were examining diverse samples of earths in the service of the Royal Agricultural Society in London, when they realized the impact of ion exchange on the growth and nourishment of plants.[47] In an experimental approach they had passed a liquid fertilizer through a sample of earth that contained natural zeolites and observed that the ammonia was retained while calcium was rejected. On the basis of this observation they came to the four fundamental conclusions concerning ion exchange in natural zeolites: ions were exchanged equivalently, some ions were exchanged more readily than others, the aluminium silicates present in the zeolites enabled them to exchange ions, and the exchange was different from physical adsorption.[48] Shortly after, the German chemists Wilhelm Henneberg (1825–1890)[49] and Friedrich Stohmann (1832–1897)[50] proved the reversibility and equivalence of the process[51] and in 1870 the chemist and mineralogist Johann Lemberg (1842–1902)

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45 *Permutit Aktiengesellschaft (Ed.)*, 50 Jahre Permutit Aktiengesellschaft: 50 Jahre im Dienst des Ionenaustausches, Berlin 1962, p. 7.

46 *H. Deuel/F. Hostettler*, Hundert Jahre Ionentausch, in: Experientia VI/12, s.a. pp. 445 ff.

47 *H.S. Thompson/J. Roy*, Agr. Soc. Engl. 11, 1850, p. 68; *J.T. Way/J.Roy*, Agr. Soc. Engl. 11, 1850, p. 131; *G.W. Thomas*, Historical Developments in Soil Chemistry: Ion Exchange, in: Soil Science Society of America 41, 1977, pp. 230-238.

48 https://www.resintech.com/wp-content/uploads/2021/03/Essential_of_Ion_Exchange-1.pdf, 17.11.2023.

49 *W. Lenkeit*, Henneberg, Johann Wilhelm Julius, in: Neue Deutsche Biographie 1969, pp. 540 f.

50 *C. Leisewitz*, Stohmann, Dr. philos. und med. h. c. Friedrich, in: Allgemeine Deutsche Biographie 1908, pp. 543-546.

51 *W. Henneberg/F. Stohmann*, Über das Verhalten der Ackerkrume gegen Ammoniak und Ammoniaksalze, in: Annalen der Chemie und Pharmazie 107,1858, pp. 152-174.

found out that other minerals besides zeolites had the same capability to exchange ions.[52] By then it was known among scientists that natural zeolites had the capability to exchange hardness components, like calcium and magnesium, against alkalis[53] but it took approximately 50 years till the industrial utilization of the principle was considered.[54]

In 1905, the chemist and entrepreneur Leo Ludwig Gans (1843–1935)[55] described the capability of natural zeolites[56] to exchange hardness components like calcium and magnesium for bases.[57] At this time in his life, Gans was already a successful businessman who had established a flourishing chemical factory in his hometown Frankfurt, founded in 1868 and which specialized in the field of aniline colour. Gans recognized that zeolites could exchange their free positive ions and that the sodium-aluminium-silicate group of the zeolites was responsible for this phenomenon. This knowledge enabled Gans to synthetize zeolites, and after a period of experimental baking of different sorts of clay he was able to produce artificial zeolites with a much higher efficiency than their natural counterparts.[58] The results of his research concerning zeolites led in 1912 to the foundation of the Permutit AG in Berlin where he started to produce artificial zeolite and marketed it under the brand name of Permutit.[59]

The first applications of this innovative technology were found in the field of water purification where it was used in combination with different forms of the established soda and lime technology, these were series of aggregates which could also be preceded by particle filters, to gain higher degrees of water softening and demineralization.[60] Philip Anderson and Michael Tushmann have

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52 *J. Lemberg*, Über einige Umwandlungen finnlandischer Feldspate, in: Zeitschrift der deutschen Geologischen Gesellschaft 22, 1870, p. 355; *Ders.*, Über Silikatumwandlungen, in: Zeitschrift der deutschen Geologischen Gesellschaft, 28, 1876, p. 519.

53 *Permutit*, 50 Jahre, p. 5.

54 *K. Dorfner*, Ionenaustauscher. Eigenschaften und Anwendung, Berlin 1964, p. 2.

55 *F. Lerner*, Gans, Leo Ludwig, in: Neue Deutsche Biographie 1964, p. 64.

56 *G. Gottardi/E. Galli*, Natural Zeolites, Berlin 1985, p. 1 ff.

57 *B. Neumann*, Chemische Technologie der anorganischen Industriezweige, Braunschweig 1927, pp. 1324 ff.

58 *A. Dix*, Industrialisierung und Wassernutzung: Eine historisch-geographische Umweltgeschichte der Tuchfabrik Ludwig Müller in Kuchenheim, Köln 1997, p. 192.

59 *N.N. Drawe*, Die Wasserreinigung und das Permutitverfahren, in: Zeitschrift des Vereins Deutscher Ingenieure 54, 1910, p. 764.

60 *D. Seyffer*, Innovationsforschung und Unternehmensgeschichtsschreibung: Beispiele aus der Historie der Firma Hager+Elsässer, in: *T. Schuetz/D. Seyffer (Eds.)*, Wissenschaft und Technik als Motoren unternehmerischen Handelns: Aufsätze zu Ehren von Armin Hermann, Diepholz 2008, pp. 65-100.

demonstrated that the phase between an innovation and the establishment of a dominant design is usually a process that is as lengthy as it is costly.[61] This is also true for Permutit water filters. According to a 1913 estimate by the Illinois Water Supply Association, there were only about 1.000 plants in the world at that time.[62] The function of such ion exchange reactors is comparably easy.[63] The water is filled into a vessel filled with zeolite or another ion exchanger and is given some time for the reaction where the hardness components form an adhesion with the ion exchanger.[64] After a couple of fillings, the vessel needs to be regenerated. For the first generation of ion exchangers plain saltwater was sufficient, the salt reacts with the hardness components and is flushed while the ion exchanger is ready for new adhesions. Because of the time-consuming regeneration phase, it became customary to use redundant systems when a continuous supply of purified water was needed.[65]

The aim of such facilities was to remove hardness components from feedwater to protect steam engines and turbines. Very soon breweries, the textile industry, and laundries used the technology as well, because it enabled them to reduce their operating costs while it preserved their machinery. In this way, the technical personnel became familiar with the technology at an early stage, without it already being used for the actual production process. A 1913 study had shown that the early forms of ion exchange filters were suitable for the treatment of industrial water, but not brewing water. Small amounts of alkali carbonate remained in the water when Permutite was used, and these had a far more negative effect on the quality of the beer than the natural calcium salts.[66] Only later generations of artificial ion exchange resins would no longer have these negative by-products and thus also become attractive for the softening of brewing water.

The practice of water treatment by ion exchange was soon applied in all industrialized nations. Permutit AG sold its patents for the use in France and Great Britain to the United Water Softeners Ltd. in London in 1911. United Water

61 *P. Anderson/M.L. Tushman*, Technological Discontinuities and Dominant Designs / A Cyclical Model of Technological Change, in: Administrative Science Quarterly 35/4, 1990, pp. 604-633.

62 *J.F. Garrett*, The Use of Permutit in Water Softening, in: Proceedings of the Illinois Water Supply Association 5, 1913, pp. 76-80.

63 *Read*, Boiler Waters, pp. 64 ff.

64 Interview with Kurt Waldbauer (retired technical director of Hager+Elsässer) 28.11.2006; *E. Verg/G. Plumpe/H. Schultheis*, Meilensteine: 125 Jahre Bayer 1863-1988, Leverkusen 1988, pp. 420 ff.

65 *Permutit Aktiengesellschaft (Ed.)*, Permutit Taschenbuch, Berlin 1977, pp. 51 ff.

66 *Garrett*, The Use of Permutit, pp. 76-80.

Softeners Ltd. retained the brand name and changed the name of the company into The Permutit Company in 1937 and mutatis mutandis developed into the EcoWater Systems Ltd., which currently concentrates on the manufacturing of domestic water softeners.[67] Furthermore, Gans founded Permutit S.A. in Brussels in 1912 with an initial capital of two million Marks. This stock corporation was founded for the marketing of the ion exchange technology on a world-wide scale. Just before the outbreak of the Great War, the syndicate tried to open the U.S.-American market and installed an agency in New York which developed into the American Permutit Company after the end of the war.[68] It continued to develop independently and after 1945 had production facilities in Birmingham, New Jersey and Lancaster, Pennsylvania.[69]

Moreover, the development of ion exchange did not stop with Gans and Permutit. In 1935, B.A. Adams and E.L. Holmes found out that artificial resins could substitute zeolites and the responsible decision-makers at the head of IG Farbenindustrie AG were the first to realize the potential of this discovery. With this knowledge it was possible to design artificial ion-exchange resins for specific purposes. IG Farben bought the relevant patents from Adams and Holmes and started a systematic research programme.[70] Paul Robert Grießbach (1886–1970) developed the first artificial ion-exchange resin as head of the laboratory for inorganic chemistry at the Farbenfabrik Wolfen, a subsidiary of IG Farben. He received the patent for it in 1938 and the resin was marketed under the name of "*Wofatit*" (short for: <u>Wo</u>lfener <u>Fa</u>rbenfabrik Permu<u>tit</u>-Ersatz (engl.: Permutit alternative from the Farbenfabrik Wolfen)).

The Second World War and the Nazi dictatorship led to a certain slowdown in the development, and supply difficulties led to the use of natural zeolites in ion exchange vessels that had been designed for artificial resins.[71] But after 1945, a couple of international companies like General Electric, BASF, Bayer or Glent+Co. showed a lively interest in the development and the production of artificial resins for ion-exchange. The principle of ion exchange could not be patented though, only the composition of the ion exchangers.

The two main German suppliers for ion exchange suffered heavily from the consequences of the war. The Farbenfabrik Wolfen was in the zone under Soviet

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67 www.ecowater.co.uk/, 17.11.2023.

68 *Permutit*, 50 Jahre, p. 10.

69 *The Permutit Company*, Water Conditioning, p. 6.

70 *P.R. Grießbach*, Über die Herstellung und Anwendung neuerer Austauschadsorbentien, in: Angewandte Chemie 215, 1939, p. 52.

71 Interview with Rudolf Orcellet (retired Technical Director of H+E), 02.11.2006.

occupation and subsequently became part of the socialist GDR. As part of the VEB Chemiekombinat Bitterfeld and following the demands of the socialist state-directed economy, the research and production of artificial ion exchange resins soon lost all significance. However, Permutit AG followed an unconventional business strategy in comparison to its competitors. While IG Farben limited its efforts on research and production and left the actual technological implementation to plant manufacturers, Permutit AG tried to succeed in both areas. For this reason, Permutit AG had bought Ruhlandwerke AG in Rathenow in 1930, to produce, with approximately 350 employees, facilities for industrial water purification completely on their own.[72] The array of products was not limited on established filter- and precipitate technologies but included also further developments like rapid decarbonisation. This method was basically used to filter out calcium hydroxide by using contact agents in conic reactors in which the water was spun around.[73] Even though the aim of Permutit was to develop complete systems, the rapid decarbonization development found its separate market, especially for breweries which mainly searched for a way to minimize the carbonate hardness in well water.[74] These plants had been developed primarily for breweries. The promise of a massive reduction in throughput time harmonized with the volume growth in contemporary industrial beer production. The fact that it now took only around ten minutes for one reactor charge to flow through the system was greeted with euphoria in the trade press, where it was described as a "revolution in decarbonization technology".[75] However, the equipment was relatively large and therefore expensive. The conical reactors extended over several floors and were often built outside the fabrication buildings. This meant that the customer base was de facto limited to large breweries.

The rapid decarbonization was marketed under the name of *Wirbos* and found an imitator with Hager + Elsässer in Stuttgart which promoted a comparable application in 1953 with the additional innovation that the calcium hydroxide reacted with the water under pressure.[76] This innovation enabled them to construct much smaller installations, only about one fifth in comparison to

72 *Permutit*, 50 Jahre, p. 17.
73 *Hancke*, Wasseraufbereitung, p. 148.
74 *Department of Scientific and Industrial Research (Eds.)*, Water Pollution Research. Summary of current Literature, London 1947, p. 266.
75 *H. Kurt,* Wasseraufbereitung in Brauereien, in: Tageszeitung für Brauereien / Sonderbeilage zu Nr. 73/74 vom 26.06.1962, p. 4.
76 *Seyffer*, Innovationsforschung, p. 87.

the older *Wirbos* aggregates, thus opening a new market segment by delivering these applications to smaller breweries.[77]

After the war, the headquarters of Permutit AG was moved to West Berlin while its production facilities were placed in the zone under Soviet occupation. The Soviets dismantled[78] the entire site and Permutit AG was not able to recover from the blow. It diminished into a mere design company and was finally taken over by its direct competitor Hager + Elsässer.[79]

The first generation of ion exchange resins had been produced by condensation polymerization. After 1945, research and subsequently production were focused on polymerisation once Gaetano Frank D'Alelio (1909–1980)[80] had developed the procedure for General Electric.[81] As Dorfner had shown, the following advance concentrated on the development of specialized ion exchange resins: A. Skogseid[82] developed an ion exchange resin for potassium while Harold Gomes Cassidy (1906–1991) created one with oxidizing capability,[83] to name but a few. Since the 1950s, the scientific study of ion exchange had grown dramatically, while the number of scientific publications concerning this issue had counted only approximately ten articles in 1946, growing to 200 in 1950 and reaching 800 in 1954.[84] For the technological implementation of the process especially concerning the demands of the food industry, this broad verity of ion exchange resins meant that specialized applications could be designed to absorb specific ingredients of liquids. It was thus possible to remove dissolved substances from a liquid according to their electrochemical properties, whereas older methods such as filtration or decantation separated substances on the basis of their size or spe-

77 Letter from „Zwiefalter Klosterbräu", 04.02.1955; Test report, 09.06.1954, of a pressurized decarbonization plant of the type „*Servo DK 2000 Liter*", Staatliche Brautechnischen Prüf- und Versuchsanstalt der Technischen Hochschule München-Weihenstephan, in: „Nachlass Willy Hager", Wirtschaftsarchiv Baden-Württemberg, Hohenheim.

78 *W. Abelshauser*, Deutsche Wirtschaftsgeschichte seit 1945, München 2004, pp. 113 f.

79 *T. Schuetz/D. Seyffer*, Hager + Elsässer: Die ersten 75 Jahre: Von Menschen und Leidenschaften, Stuttgart 2007.

80 *G.E. Ham*, In Memoriam: Professor Gaetano F. D'Alelio, in: Journal of Macromolecular Science: Part A – Chemistry 16/6, 1981, pp. 1061-1063.

81 *G.F. D'Alelio*, Interpolymer of Dimethyl Itaconate and Ethyl Methacrylate. US 2298039 A, 06.10.1942 (google.com/patents), 11.06.2014.

82 *A. Skogseid*, Dissertation, Oslo 1948.

83 *H.G. Cassidy*, Electron Exchange-Polymers, in: Journal of the American Chemical Society 402, 1949, p. 71.

84 *Dorfner*, Ionenaustauscher, p. 2.

cific gravity. This new technology first found its use in laboratories for analysis purposes, while the utilization on an industrial scale again took decades.[85]

4 Technology Transfer Between Sectors

And once again, the food industry was not at the vanguard of development, but adapted the new technology only after it was safely mastered in other industries and medium-sized plant manufacturers were actively working on its diffusion. This development was triggered when IBM produced its first computer system family, the IBM System/360, which was produced between 1964 and 1978.[86] Two basic principles of IBM are relevant concerning the question of industrial water purification: local production and global standards. Concerning the demands for local manufacturers and suppliers, the American headquarters defined the standards but wherever feasible local resources were applied. The production of circuit boards for the IBM System/360 needed unseen degrees of cleanness concerning the rinsing water, which was needed after galvanization and electroplating, because the comparably small circuit paths could easily be damaged by even the smallest encrustation from hardness components.[87] Managed by John W. Gibson, who was responsible[88] for project-wide components manufacturing,[89] the solution for the rinsing water lay in the utilization of not one or two ion exchange reactors but required so-called ion exchange trains.[90] These systems had separate reactors for strong-acid cation, weak-base anion and strong-base anion exchange resins. While in the reactor for strong-acid cation exchange all cationic substances, such as iron, aluminium, chromium, zinc and others were removed from the rinsing water, sulfuric acid, hydrochloric acid, nitric acid, chromic acid or hydrofluoric acid formed inside the downstream weak-base anion exchange reactor; all these substances were neutralized in the downstream strong-base anion exchange reactor. When the removal of weak

85 *Ibid.*, pp. 79-129.
86 https://www.ibm.com/docs/en/zos-basic-skills?topic=today-s360-turning-point-in-mainframe-history, 17.11.2023.
87 *W.P. Dugan*, Internal Connection Method for Circuit Boards US3426427 A, 11.02.1969, 06.10.1942 (google.com/patents), 11.06.2014.
88 *E.W. Pugh*, Building IBM: Shaping an Industry and Its Technology, Cambridge 1995, p. 292.
89 https://www.ibm.com/docs/en/zos-basic-skills?topic=today-s360-turning-point-in-mainframe-history, 17.11.2023.
90 *Hancke*, Wasseraufbereitung, p. 219.

acids, such as carbonic acid or boric acid was wanted, a further strong-base anion exchange reactor was necessary. The regeneration was carried out with acids and accordingly with bases.[91] If a continuous process was desired, a parallel redundant reactor train was required. Systems like this were able to filter up to 98 percent of the dissolved substances. Without the upstream filter technology, such ion exchange trains consisted of three to eight reactor vessels.

In fact, ion exchangers can be found today in a wide range of everyday applications, from dishwashers to nuclear power plants. The genesis and location of the artifact of ion exchanger trains, on the other hand, is a very specific and not atypical form of development: Only after the efforts of IBM, an actor in a highly innovative industry, had developed the existing body of knowledge into an established technology, did the initiative of medium-sized plant manufacturers lead to a transfer of this technology to other industries, such as electroplating, power plant and mechanical engineering, and even the food industry and thus brewing. In the course of globalization from the late 1970s onward, brewing groups began to produce and market branded beers that were as identical as possible at locations around the world.[92] This was a process that was accompanied by the elimination of smaller breweries and was a typical phenomenon of cluster formation in the course of globalization.[93] The conclusion of this observation implies at the same time that, prior to this development, local production of beer in many cases simply solved the treatment of the process water by means of special technical equipment and, if necessary, resorted to the modification of the brewing water by the targeted addition of reagents, so-called brewing salts, which had already been recommended by Petit. This means that the ion exchanger trains developed under the auspices of IBM found their way into industrial beer production. Euwa in Gärtingen near Stuttgart, a company founded by former Hager + Elsässer employee Hanns-Heinz Eumann in 1965, was particularly successful in participating in this trend and continues to play a dominant role in this market segment to the present day. The fact that the application of state-of-the-art water treatment technology stands in stark contrast to the use of

91 *Permutit*, Permutit Taschenbuch, pp. 51 ff.

92 *J.D. Gatrell et al.*, Sweetwater, p. 90; *P.H. Howard*, Too big to Ale? Globalization and Consolidation in the Beer Industry, in: *Patterson/Hoalst-Pullen (Eds.)*, The Geography of Beer: Regions, pp. 155-166, here: p. 156; *D.F. Greer*, The Causes of Concentration in the US Brewing Industry, in: Quarterly Journal of Business and Economics 21, 1981, pp. 87-106; *Keithan*, The Brewing Industry, p. 14.

93 *Idem*, Beer: Causes of Structural Change, in: *LL. Duetsch (Ed.)*, Industry Studies, New York 2002, pp. 27-58. *I. Cabraz*, Craft Beer in the EU: Exploring Different Markets and Systems Across the Continent, in: *Patterson/Hoalst-Pullen (Eds.)*, The Geography of Beer, pp. 149-157, here: p. 150.

the ideal of the pure mountain spring as a means of marketing, as mentioned in the introduction, is also reflected in the fact that the companies, breweries and plant engineers alike, acted with great reservation when it came to the visibility of these practices.[94] This statement that closes the circle to the introductory remarks about the discrepancy between the rationality fiction of consumers regarding the properties of brewing water and the relevance of this condition for the advertising and public relations of breweries in the past and present.

5 Conclusion

A striking feature of the examples described here is the relatively long time between scientific findings and their transformation into a marketable product. Even though there are comparable case studies from other sectors for the establishment of a dominant design, they rarely took longer than a decade, even in the case of large-scale industrial process technologies.[95] In this context, Anderson and Tushmann assume phases of between five and 20 years between market launch and the establishment of a dominant design. In addition, they also provide empirical evidence that the largest revenues can be generated from an innovation after the establishment of a dominant design.[96]

The phase of discursive openness,[97] which was largely characterized by expert discourse, was also at no point exclusively focused on the food industry, or indeed brewing in particular. In fact, some efforts at product diversification on the part of large-scale industry, which was significantly involved in the research and development work, failed, and it was only due to the specific market knowledge

94 A list of EUWA customer references can be found here: https://www.euwa.com/referenzen.html, 03.08.2022.

95 *D. Scigliano,* Das Management radikaler Innovationen, Wiesbaden 2003, p. 62.

96 *P. Anderson/M.L. Tushman*, Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change, in: Administrative Science Quarterly 35/4, 1990, pp. 604-633, see: p. 611; *G. Dosi*, Coordination and Transformation: An Overview of Structures, Behaviours and Change in Evolutionary Environments, in: *G. Dosi et al. (Eds.)*, Technical Change and Economic Theory, London 1988, pp. 13-37, see: p. 17; *E. Helmstädter*, Wissen und Innovation: Die wirtschaftswissenschaftliche Fragestellungen, in: A. Butzin/D. Rehfeld/B. Widmaier *(Eds.)*, Innovationsbiographien: Räumliche und sektorale Dynamik, Baden-Baden 2012, pp. 19-55, see: p. 45.

97 *W. Bijker*, Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change, Cambridge 1997, p. 86; *A.O. Krueger*, Benefits and Costs of Late Developments, in: *P. Higonnet/D.S. Landes/H. Rosvsky (Eds.)*, Favorites of Fortune: Technology, Growth, and Economic Development since the Industrial Revolution, Cambridge 1991, p. 459-481, see: p. 464.

of the medium-sized plant manufacturers that the various technologies for industrial water treatment found their way to the customers, and thus also to the breweries. Only after this ultimately open-ended negotiation process between the relevant groups of actors did the concepts turn into products. The consideration of the intentionality of the groups of actors demanded by Callon, which is a fundamental prerequisite for understanding the systemic character of innovative change, can also be traced in the case of industrial water treatment.[98] Scientists were striving for recognition and to strengthen their position, medium-sized plant manufacturers were interested in expanding their product portfolio, and breweries were striving for reliable processes that could be planned both in terms of process technology and economics.

The description of these key technologies can by no means claim to be a comprehensive account of the genesis of industrial water treatment or even its application in brewing. No consideration could be given at this point to techniques such as the use of reverse osmosis, electrofiltration, different established practices of filtering, or the practice of using different additives before and during brewing, to name but a few.[99]

As has been shown, the typical vertical and horizontal transfer of technology can be demonstrated for the case study of industrial water treatment in brewing. For the latter, the relatively hesitant adaptation of the innovative technology could again be explained by an application of Schumpeter.[100] In the question of sector-specific innovative capacity raised by Malerba[101] – in other words, the distinction between established and thus difficult-to-access markets and new and thus open markets – the computer industry was one of the fastest growing and most innovative sectors in the second half of the 20th century. In contrast, the food industry and thus brewing as an established sector in a constricted market with only marginal room for manoeuvre was much more hesitant in

98 *M. Callon*, Réseaux technico-économiques et irréversibilité, in: *R. Boyer/B. Chavance/O. Godard (Eds.)*, Figures de irréversibilité en économie, Paris 1991, pp. 195-230.

99 https://didaktik-projekte.chemie.uni-halle.de/lernen/download/Wein-Bier%2008.pdf; https://www.reiki-bierbrauer.de/index_htm_files/WASSERAUFBEREITUNG.pdf, 01.01.20211.

100 *R. Nelson*, An Evolutionary Theory of Economic Change, Cambridge 1985, pp. 275-307.

101 *F. Malerba/S. Breschi*, Sectoral Innovation Systems: Technological Regimes. Schumpeterian Dynamics and Spatial Boundaries, in: *C. Edquist (Ed.)*, Systems of Innovation: Technologies, Institutions and Organizations, London 1997, pp. 130-156; *F. Malerba*, Innovation and the Evolution of Industries, in: *U. Cantner/F. Malerba (Eds.)*, Innovation, Industrial Dynamics and Structural Transformation: Schumpeterian Legacies, Berlin 2007, pp. 7-28.

adapting innovative methods.[102] Even if this statement contradicts the self-perception and self-portrayal of the brewing industry as technology-affine and science-oriented, the comparative, quantifying studies on the innovativeness of individual industries, as well as the historical transfer of cooling technology from chemical science to brewing as made by Dienel, are able to substantiate this idea. Since the brewing industry, like the food industry, has generally been a recipient rather than an innovator, it is also not surprising that the decisive development steps for the example of water treatment technology examined here did not come from the industry itself.

The behaviour can be explained by market conditions. The problem of ambidexterity, meaning the long-term economically successful balancing between the return on old investments and the necessity of spending on innovations in order to be able to survive in competition, resulted in a rather hesitant performance for breweries in a competitive and limited market with regard to innovation behaviour due to the system.[103] Accordingly, the technology of the ion exchanger train was only of interest to brewers from the time when a dominant design had become established and the medium-sized plant manufacturers had acquired a wealth of experience in the planning, construction and maintenance of such facilities.

However, it would be a false or abbreviated representation to leave it at this monocausal explanation. With the growing importance of internationally placed branded beer products, like Heineken or Anheuser-Busch, demand from international brewery and food companies for this very technology also began in the 1980s and grew with the massive market shakeout and clustering in the industry that began around the turn of the millennium.[104] And these developments, too, were not made possible by water treatment technology alone. Other tech-

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102 *W.E. Steinmüller*, The European Software Sectoral System of Innovation, in: *F. Malerba (Ed.)*, Sectoral Systems of Innovation: Concepts, Issues and Analyses of Six Major Sectors in Europe, Cambridge 2004, pp. 193-242.

103 *H. Corsten*, Der nationale Technologietransfer: Formen - Elemente - Gestaltungsmöglichkeiten - Probleme, Berlin 1982, pp. 1 ff., 103 ff.; *G. Kronlechner*, Ambidextrie als Ansatz zur Balancierung von Effizienz und Innovativität in Organisationen, in: *W. Burr (Ed.),* Innovation: Theorie, Konzepte und Methoden der Innovationsforschung, Stuttgart 2014, pp. 345-372.

104 *J. Aizenmann/E.L. Brooks*, Globalization and Taste Convergence: The Case of Wine and Beer (Working Paper/National Bureau of Economic Research 11228, 2005), p. 4, https://www.nber.org/papers/w11228, 10.08.2022; *E.S. Madsen/Y. Wu*, Marketing and Globalization of the Brewing Industry, in: *I. Cabras* et al *(Eds.)*, Brewing, Beer and Pubs, London 2016, pp. 34-53, here: p. 35; *W.J. Adams*, Markets: Beer in Germany and the United States, in: Journal of Economic Perspectives 20/1, 2006, pp. 189-205, here: p. 189; *Slack*, Monastries, p. 210.

nologies, especially in process control, automation, and not least packaging, were considered by contemporaries, as in historical reflection, to be the sine qua non of these economic developments.[105]

As has been shown, the driving force behind this horizontal transfer process, which was as successful as it was comprehensive, was an achievement of medium-sized plant manufacturers. Their market knowledge, flexibility and, in the course of globalization, mobility, made it possible to be successful in a market segment that previously could not be served by large international chemical groups.

Bionote

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105 *C. Garavaglia/J. Swinnen*, The Craft Beer Revolution: An International Perspective, in: Choices 32/3 Quarter, pp. 1-8, here: p. 1-2; *Technoseum*, Bier, pp. 74-84; *Keithan*, The Brewing Industry, pp. 34 f., 37 f.