The Dutch connection of Bob de Vogel

Van Den Akker, Harry E.A.

DOI
10.1063/5.0084383

Publication date
2022

Document Version
Final published version

Published in
Physics of Fluids

Citation (APA)
Van Den Akker, H. E. A. (2022). The Dutch connection of Bob de Vogel. *Physics of Fluids*, *34*(3), Article 037106. https://doi.org/10.1063/5.0084383

Physics of Fluids

The Dutch connection of Bob de Vogel

Cite as: Phys. Fluids **34**, 037106 (2022); https://doi.org/10.1063/5.0084383
Submitted: 05 January 2022 • Accepted: 15 February 2022 • Published Online: 09 March 2022

Harry E. A. Van den Akker

COLLECTIONS

Paper published as part of the special topic on Celebration of Robert Byron Bird (1924-2020)

The Dutch connection of Bob de Vogel

Cite as: Phys. Fluids **34**, 037106 (2022); doi: 10.1063/5.0084383
Submitted: 5 January 2022 · Accepted: 15 February 2022 ·
Published Online: 9 March 2022

View Online Export Citation CrossMark

Harry E. A. Van den Akker[1,2,a),b)]

AFFILIATIONS

[1]Bernal Institute, School of Engineering, University of Limerick, Limerick, V94 T9PX, Ireland
[2]Transport Phenomena Group, Dept. of Chemical Engineering, Delft University of Technology, 2629HZ, Delft, The Netherlands

Note: This paper is part of the special topic, Celebration of Robert Byron Bird (1924-2020).
[a)]**Currently at:** Dept. of Chemical and Biological Engineering, Princeton University, Princeton, New Jersey 08544, USA
[b)]**Author to whom correspondence should be addressed:** h.e.a.vandenakker@tudelft.nl and harry.vandenakker@ul.ie

ABSTRACT

This contribution to the journal issue commemorating Professor Robert Byron Bird focuses on his Dutch connection, which dates back to as early as 1950. Bird twice spent a semester-long period at (the current) Delft University of Technology. The development over time of two different schools of teaching transport phenomena and their mutual influencing are reviewed in quite some detail. The cornerstone in both schools is the analogy between the transport modes for mass, momentum, and energy. However, the role of fluid mechanics and its treatment is different. In addition, the didactic concepts underpinning the textbooks from the two schools are rather different as well, both having their pros and cons. This is illustrated for the mechanical energy balance and its derivation.

INTRODUCTION

This paper aims at contributing to the memory of Professor Robert Byron Bird by highlighting his importance to the field of Transport Phenomena, from the inception of the field in the 1950s as a separate and fundamental discipline for chemical engineers (and further engineering fields) and continuing over already more than 60 years. His Transport Phenomena textbook[1] was a milestone in the broader field of chemical engineering. Bob Bird may best be described as the Godfather of Transport Phenomena. One may wonder whether any other textbook in science and engineering was so successful. The first edition of 1960[1] even remained unchanged, as a Bible, for more than 40 years. More recently, several revised editions were published.[2–4] In 2004, Bird himself commented on 50 years of Transport Phenomena in a review paper in *AIChE Journal*.[5]

Bird's Dutch connection took off in 1950–1951 when he was postdoc, thanks to a Fulbright Fellowship, at the University of Amsterdam after having earned his Ph.D. degree at the University of Wisconsin. The link with Delft started in Spring 1958 with his semester-long stay in Delft during which Bob also learnt the Dutch language. Upon his return to Madison, he started informally teaching Dutch and writing a Dutch grammar; eventually, this resulted in 1963 in a reader "Een goed begin," with William Shetter as coauthor. In addition, Bob founded the Dutch club in Madison and helped set up the Netherlandish Studies Program in the German Department at the University. Then, in 1977, Bird was awarded an Honorary Doctor's Degree in Delft, his first outside the US. In 1985, Bird became Member of the Royal Dutch Academy of Sciences.

In 1994, Bird spent a second semester-long stay in Delft; during this period, he even published a paper in Dutch: on the mechanical energy balance and its derivation. For years, the current author received Christmas cards, always accompanied by a small crossword in the Dutch language and signed by "Bob de Vogel," where "vogel" is the Dutch word for "bird." In 2004, Bird was granted the Dutch Royal Distinction "Ridder in de Orde van Oranje-Nassau" (a type of knighthood) for his "exceptional contributions to the promotion of the Dutch language and culture in the United States and at the University of Wisconsin." According to a witness, the ceremony at which Bird was knighted through an attaché at an annual meeting of the Dutch club, brought tears to Bob's eyes while very few things could do so.

In this contribution, the link between "Wisconsin" and "Delft" will be described in greater detail. In addition, several aspects of Bird's approach of transport phenomena will be highlighted and compared with that in Delft.

BIRD'S FIRST VISIT TO DELFT

In 1958, Bob Bird spent a semester in Delft as a Fulbright Lecturer and a Guggenheim Fellow, being a guest of Professor Hans Kramers who was the first Professor and Director of the

"Laboratorium voor Fysische Technologie" (in 1999 named after Kramers) of the "Technische Hogeschool Delft," currently Delft University of Technology. This Laboratorium was founded after World War II, thanks to a donation of the Bataafsche Petroleum Maatschappij (the Dutch branch of Royal Dutch/Shell), to stimulate the field of chemical engineering, which was considered of vital importance to the recovery and expansion of chemical industry in the Netherlands.

While in the 1950s the fundamental theory of transport processes was not recognized as one of the key engineering sciences, much of the material was just taught within the framework of elementary problems of unit operations and design. In 1956, Hans Kramers in Delft published his first mimeographed lecture notes (in Dutch) on "Fysische Transportverschijnselen." According to Bird himself—in the Acknowledgments section of his 1960 edition,[1] in Bird,[5] and in Bird and Van Nederveen[6]—it was the first systematic treatment to teach the emerging discipline of Transport Phenomena. A more formal version of Kramers' course notes[7] was published in September 1961 by the Delftsche Uitgevers Maatschappij (see Fig. 1). His treatment (in 206 pages) started with a short chapter presenting the conservation laws of mass, energy and momentum (in this order), and the molecular transport laws (Fick, Fourier, and Newton, in this order). The successive chapters then dealt with applied fluid mechanics (70 pages), heat conduction and heat transfer (80 pages), diffusion and mass transfer (20 pages), and mixing and stirring (11 pages).

Bird and his colleagues were developing their systematic and fundamental treatise of Transport Phenomena in 1957 at the University of Wisconsin. His fall semester 1957 class material was condensed as their Notes on Transport Phenomena[8] published by Wiley in April 1958 (see Fig. 2). In Spring 1958, Bird taught a course on Transport Phenomena in Flowing Media to Delft students, which was supported by a course manual of just 100 pages[9]—in the Dutch language: "Transportverschijnselen in stromende media" (see Fig. 3). Then, in 1960, the official Wiley edition of the famous Transport Phenomena textbook by Bird, Stewart, and Lightfoot was published.[1] The 1960 edition with 780 pages, just like the 1958 "Notes"[8] with 455 pages, comprised 22 chapters distributed over three parts: Part A on Momentum Transport, Part B on Energy Transport, and Part C on Mass Transport. Because fluid mechanics was deemed essential for a decent understanding of Parts B and C, momentum transport was treated first and in all detail.

Bird's visit and stay with Kramers gave the two Professors the excellent opportunity to discuss and improve their own ways of teaching Transport Phenomena. BSL's textbook conquered the world and became unaltered, as a Bible, for some four decades. In Delft, the Dutch students kept using Kramers' shorter lecture notes in Dutch

FIG. 1. Course manual (in Dutch) on "Transport Phenomena" by Professor Hans Kramers, dated 1961.

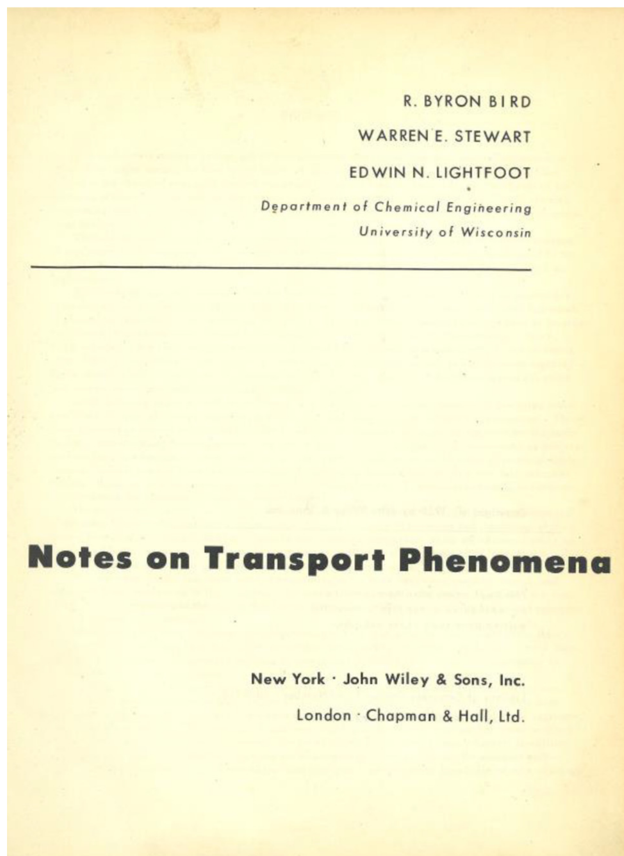


FIG. 2. Front cover of the provisional 1958 "Notes on Transport Phenomena."

FIG. 3. The cover page of the course manual (in Dutch) by Bird and Van Nederveen[9] for the course "Transport Phenomena of flowing media" given by Bird in Spring 1958. In the upper right corner: the signature of Professor Hans Kramers and the address of his Delft Lab.

which in the course of the years were continuously improved, also by Kramers' successors Wiero J. Beek and John M. Smith. During all those years, the analogy of momentum, heat, and mass transport remained the leading theme, just like in Bird's textbook. An essential element in the way Transport Phenomena has been taught in Delft has always been the emphasis on developing the students' ability of solving realistic engineering problems, although the number of examples or exercises in the textbook was very limited. Over the years, hundreds of challenging exam problems were developed.

BIRD'S SECOND VISIT TO DELFT

26 Years later, in Spring 1994, Bob Bird was the first Burgers Visiting Professor of Fluid Mechanics in the Dutch J. M. Burgers Center of Fluid Mechanics with its headquarters in Delft. During this visit, Bird also went back to the Delft Laboratorium voor Fysische Technologie where he spent his earlier visit in 1958 and had discussions with the current author on teaching Transport Phenomena. As Bird still mastered the Dutch language, he had seen an early version of a revised Transport Phenomena textbook in the Dutch language written by the current author and Robert F. Mudde. The discussion between Bird and the current author focused on the mechanical energy balance and its derivation; it prompted his paper in Dutch shown in Fig. 1 in which Bird commented on the various "sloppy and misleading" ways authors of several textbooks explained and derived the mechanical energy balance and Bernoulli's equation. The difference in opinion about teaching the (derivation of the) mechanical energy balance will be discussed in greater detail further on in this contribution.

BIRD'S TRANSPORT PHENOMENA IN MORE RECENT YEARS

After the First Edition of 1960 had remained unchanged for over 40 years, a revised second edition was published in 2002[2] followed by a third edition[3] correcting typographical errors. In their Preface to the second edition, the Three Musketeers "BSL" reported as many as 14 major changes most of them updating the book in the light of the scientific advances in these 40 years. They added improved treatments of the boundary-layer theory and turbulent transport and also inserted "modern" topics such as polymeric liquids, ionic systems, and membrane separations. The price to be paid was an increase in the number of chapters (from 22 to 24) and an increase in the number of pages (from 780 to 895). In a prelude to the discussions further on in this paper, a complete derivation of the mechanical energy balance was added along with new sections on convective transport of energy (Sec. 9.7) on work associated with molecular motions (Sec. 9.8) and on mass and molar transport by convection (Sec. 17.7). In addition, an introductory chapter 0 was inserted explaining the subject of transport phenomena.

In the recent decade or so, the interest from students in the more traditional chemical engineering programs at academia in the US (and elsewhere in the world) has decreased. At the same time, some version of Transport Phenomena is judged to be relevant for other academic programs such as in the fields of biotechnology, environmental engineering, "green" chemical engineering, and biological engineering. In many programs, however, the time allocation for a course on Transport Phenomena has been reduced or is restricted to a single semester rather than the two consecutive semesters, which earlier were more or less the rule. All these developments ask for a reconsideration of what is the essence of Transport Phenomena that should and could be taught in a single course.

Against this background, a new version of the Transport Phenomena textbook was published in 2015, named Introductory Transport Phenomena,[4] with the help of a fourth author: University of Wisconsin Professor Daniel J. Klinkenberg. While keeping the original overall organization of the contents similar in still 24 chapters (though not all being the same as before), the size of this edition was reduced to again 770 pages by removing most material that was felt beyond the level of mathematical preparation of most (current) undergraduates and simultaneously filling in missing steps in many mathematical derivations. Not unimportantly, some new chapters on dimensional analysis were inserted.

A REJUVENATION OF TRANSPORT PHENOMENA IN DELFT

In 1996, the author of this contribution, together with Dr. Robert F. Mudde, published a new version of the Delft lecture notes on Transport Phenomena which for various reasons was different from the traditional Delft version. Students, their interest, their prior education, access to internet, and the way they prepare for exams had changed. Also in Delft, the course got a different role and place. New applications in biotechnology, biomedical, smart materials, and solar energy (just to name a few) developed—remote from the traditional chemical industry—and in response new academic programs were initiated. In addition, Computational Fluid Dynamics (CFD) developed into a real analytical tool. We judged all these required different didactic methods for teaching as well as different examples and different exam problems.

The new version of the Delft textbook Transport Phenomena (still in Dutch) built on the earlier Delft lecture notes and was still based on the classical analogy of momentum, heat, and mass transport. However, the order of treatment was changed: fluid mechanics largely moved to the end, provoked among other things by ideas developed by Professor Kees Rietema, once the current author's Ph.D. advisor at Eindhoven University of Technology. Rietema made a plea for exploiting an inductive method going from observing simple cases to generalizations rather than a deductive method starting at the general balance or transport equations and then simplifying to more specific simple cases. His textbook "Fysische Transport- en Overdrachtsverschijnselen" (also in Dutch) comprised Part A on molecular transport of heat, mass, and momentum (in this order) and Part B on applied fluid mechanics, boundary layer flow and turbulence, convective heat and mass transport, and chemical reactors. Rietema argued this approach was didactically more sound and more directed on stimulating physical intuition and understanding.

Most importantly, the new Delft textbook put a much stronger emphasis on the basic method of drawing up balances, either about a particular device (a macro-balance) or about a differential element anywhere in a material or fluid (a micro-balance)—in this order. In most cases, such a balance turns into a differential equation such as the famous transient second-order diffusion of conduction equation. Here, the leading idea was that teaching (undergraduate) students as to how to draw up balances and derive and solve the resulting differential equations is helpful when studying the theory of transport phenomena; in addition, it is an excellent preparation for exploiting modern CFD techniques. The exam requirement that students should be capable of solving original problems was maintained.

As a result, the first chapter of the new Delft book was on drawing up balances, mostly macro-balances, for mass, heat, and momentum (in this order). The second chapter introduced the molecular transport laws, non-dimensional numbers, dimensional analysis, and the force balance on an immersed object. The following three chapters then dealt with heat transport, with mass transport, and with engineering fluid mechanics and laminar flows of both Newtonian and non-Newtonian fluids. The Navier–Stokes equations, with an outlook to CFD, are presented just in the final section of the fifth chapter.

Our textbook in Dutch was quite successful: a revised second edition was released in 2003 and a third further improved edition in 2008. The progressive internationalization of Delft University prompted the authors to publish an English version of the Dutch textbook, simultaneously updating and improving a Dutch fourth edition. This textbook—Transport Phenomena: The Art of Balancing—is the result.

THE ORDER OF THE INGREDIENTS IN TEACHING TRANSPORT PHENOMENA

In general, one might say, that, in comparison with the Delft "Art of Balancing,"[10] the treatment in Bird's textbooks is scientifically more rigorous and more exhaustive, not in the least due to the numerous cases treated on the very large number of pages, while the Art of Balancing restricts itself to the simple base cases and sometimes makes shortcuts to avoid mathematical hurdles. A more detailed comparison may be illustrative of the differences in approach.

All versions of Bird's Transport Phenomena treat in Chapter 2 (shell) momentum balances and flows such as those of a falling film, through a circular tube, through an annulus, and around a sphere, followed by the more general Navier–Stokes equation in Chapter 3. In the Delft Art of Balancing, these topics are postponed until the last chapter of the five, since the vector character of momentum and shear stress tensor is considered to be rather complex and difficult for students, while most students may be mainly interested in heat and mass transport rather than in the underpinning fluid mechanics.

From the onset, in the notes,[8] the order in the BSL textbooks has always been first momentum transport, second heat transport, and finally mass transport. Already within the Preface of the First Edition, and later on in Chapter 0, BSL provided a table with columns and rows accompanied by a recommendation about alternative ways of using the textbook: undergraduates could study the material by columns, that is, taking one type of transport on at a time, while graduate students would benefit from studying by rows to see better the analogies between mass, momentum, and energy transport. Some universities may use a mixed approach, also depending on the time available for Transport Phenomena in the curriculum. However, the first column in the table has always been "momentum transport."

In the Delft Art of Balancing methodology,[10] the order is deliberately different and is in Chapter 1 different from that in the remainder of the textbook. In Chapter 1, the order is mass transport, heat transport, and momentum transport, because in drawing up balances and dealing with concentrations starting with species transport looks more appealing and logical. Furthermore, just the phenomenological character of molecular and convective heat and mass transport in terms of Fourier, Nusselt, and Sherwood numbers allows for postponing the treatment of both engineering and fundamental fluid mechanics. Chapter 2 also comprises dimensional analysis with the view of promoting physical intuition and order-of-magnitude thinking, particularly with respect to the essential role of the Reynolds number. Chapters 3–5 deal with the actual transport phenomena; the order is heat transport, mass transport, and momentum, because

(a) to (undergraduate) students, heat transport may be more intuitive and appealing than momentum transport;
(b) mass transport suffers from additional complications such as drift flux, the partition coefficient (or Henry's law) in two-phase systems, and multicomponent mixtures;
(c) momentum transport is more complex because of the inherent vector character, the concept of shear stress, and non-Newtonian liquids.

Another difference between the two approaches is that BSL starts with the shell balances and ends with the macroscopic balances, while the Art of Balancing takes the reverse order for didactic reasons: undergraduate students may feel more comfortable with first drawing up macroscopic balances; the concept of dealing with slices or shells embedded in a fluid or solid material may then be an easier second step. Overall, the technique of drawing up macroscopic balances is very useful in the industrial chemical engineering practice anyhow.

One of the characteristics of the Art of Balancing is that it shows undergraduate students that differential equations are not just mathematical constructions but represent balance equations for variables with a physical meaning over infinitesimally thin slices or shells and, in the case of transients, over infinitesimally short time intervals. The variables represent concentrations with units: kg/m^3, J/kg, W/kg, Ns/kg, etc. Furthermore, this approach is an excellent preparation for dealing with computational fluid dynamics, where the partial differential equations have to be discretized in a procedure that may be conceived as the reverse of drawing up balances.

THE MECHANICAL ENERGY BALANCE

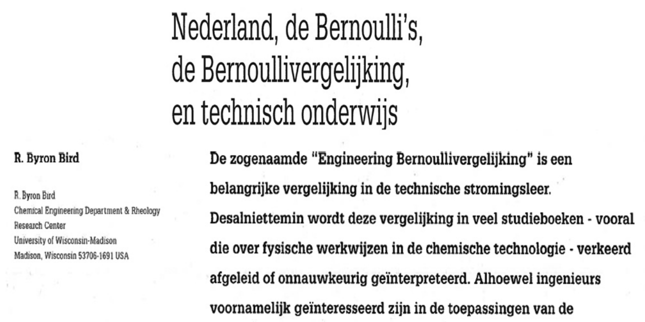
In the 1958 Notes on Transport Phenomena,[8] the mechanical energy balance was still treated in a rather concise way: Sec. 7.3 first says the equation of mechanical energy can be derived by forming the dot product of the velocity vector and the equation on motion, and then reports it can be integrated over the volume of the flow system to arrive at the macroscopic mechanical energy balance. The topic is then discussed in greater detail in Secs. 15.2 and 15.4. The total energy balance and some macroscopic heat transfer problems were treated in Sec. 15.1.

In BSL's First Edition,[1] the derivation by forming the dot product of the velocity vector is already presented in Sec. 3.3 while the integration over a macro volume still is in Sec. 7.3. Then, as before, the macroscopic (total) energy conservation equation is considered in Sec. 15.1. Finally, only in Sec. 15.5, macroscopic heat transfer (or internal energy balance) problems are treated. In a rather different approach, the Delft Art of Balancing first "derives" a macroscopic thermal energy balance on the basis of physical intuition and subtracts this from the macroscopic energy conservation equation to find the (correct) macroscopic mechanical energy balance. During his second semester-long stay in Delft in 1994, Bird learnt about this alternative approach, which was mainly introduced for didactic reasons. He raised concerns about it as being insufficiently rigorous, and it prompted him to write the Dutch journal paper[11] shown in Fig. 4. Some of these Dutch comments were repeated by Bird.[5] This, however, was not the last word from his part on this matter.

In BSL's Second Edition,[2] two new sections had been added, viz., on convective transport of energy (Sec. 9.7) and on work associated with molecular motions (Sec. 9.8). In the latter section, a combined energy flux vector was introduced that comprises the work done per unit of area by molecular mechanisms, resulting in an enthalpy term. This resonates the discussions in Delft in the late 1990s and early 2000s not only on the proper shape of convective energy fluxes but also about the proper use of enthalpy in dealing with evaporation and boiling in/from a tea kettle (see the prefaces of the second and third editions of the Dutch predecessor of the Art of Balancing[10]). This tea kettle is one of the daily-life examples exploited to familiarize students with drawing up proper heat balances. In addition, BSL rewrote parts of Sec. 3.3 about the derivation of the mechanical energy equation and introduced in a new section (Sec. 15.4) so-called *d*-forms of the macroscopic mechanical and total energy balances.

In the BSL Editions (even undergraduate), students were supposed to avail some advanced mathematics, whereas in the 2015 Introductory Transport Phenomena Edition,[4] the student is taken by the hand in problem3C[4] for forming the dot product with the view of deriving the mechanical energy equation of change. In addition, a new 3-page section was inserted (Sec. 7.7) on the derivation of the macroscopic mechanical energy balance.

All the above alterations in the treatment and derivation of the various mechanical energy balance equations illustrate how teaching transport phenomena to particularly undergraduate students can be both challenging and intricate, particularly when mathematical and physical rigor are taken to be leading.


Nederland, de Bernoulli's,
de Bernoullivergelijking,
en technisch onderwijs

R. Byron Bird

R. Byron Bird
Chemical Engineering Department & Rheology Research Center
University of Wisconsin-Madison
Madison, Wisconsin 53706-1691 USA

De zogenaamde "Engineering Bernoullivergelijking" is een belangrijke vergelijking in de technische stromingsleer. Desalniettemin wordt deze vergelijking in veel studieboeken - vooral die over fysische werkwijzen in de chemische technologie - verkeerd afgeleid of onnauwkeurig geïnterpreteerd. Alhoewel ingenieurs voornamelijk geïnteresseerd zijn in de toepassingen van de

FIG. 4. Paper in the Dutch language in the Dutch periodical "NPT Procestechnologie" (1994).[11] The title translates to "The Netherlands, the Bernoulli's, the Bernoulli equation, and teaching engineering students."

CODA

While it may be obvious that the present author prefers the Delft Art of Balancing methodology for teaching Transport Phenomena to particularly undergraduate students, it may be equally evident that he also wholeheartedly recognizes and appreciates the pioneering role of Robert Byron Bird in establishing the field of transport phenomena worldwide by providing a rigorous and extensive textbook that for decennia served as a beacon for generations of engineering students worldwide. This paper just put Bird's gigantic lifelong oeuvre in a further international perspective while highlighting Bird's Dutch connections and evaluating Bird's didactic approach against that in the Delft Art of Balancing. Both methods have their pros and cons.

The BSL approach enjoys the advantages of substantial rigor, but it does so at the cost of a lengthy delay before students can engage realistic engineering problems. Most engineering students have a thirst for contact with real problems and may, therefore, lose motivation. The formality of the BSL approach may also deny the students a good sense of the underlying physics. An inductive approach as in the Art of Balancing can provide early contact with real problems and a better "feel" for the physics. However, its more intuitive, more phenomenological, and mathematically less rigorous methods, sometimes exploiting some hand waving reasoning, did not find mercy in Bird's eyes. Thus, both approaches require talented teachers who avoid the pitfalls that they choose as their lesser evil.

AUTHOR DECLARATIONS

Conflict of Interest

The author declares there is no conflict of interest.

DATA AVAILABILITY

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

REFERENCES

[1] R. B. Bird, W. E. Stewart, and E. N. Lightfoot, *Transport Phenomena* (Wiley, 1960).
[2] R. B. Bird, W. E. Stewart, and E. N. Lightfoot, *Transport Phenomena*, 2nd ed. (Wiley, 2002).

[3]R. B. Bird, W. E. Stewart, and E. N. Lightfoot, *Transport Phenomena*, 3rd ed. (Wiley, 2007).
[4]R. B. Bird *et al.*, *Introductory Transport Phenomena* (Wiley, 2015).
[5]R. B. Bird, "Five decades of transport phenomena," AIChE J. **50**(2), 273–287 (2004).
[6]R. B. Bird and B. Van Nederveen, "Hendrick Kramers," in *Memorial Tributes* (The National Academies Press, 2008), pp. 162–167.
[7]H. Kramers, "Fysische transportverschijnselen," in *Course Notes* (Delftsche Uitgevers Maatschappij, Delft, 1961).
[8]R. B. Bird, W. E. Stewart, and E. N. Lightfoot, *Notes on Transport Phenomena* (Wiley, 1958).
[9]R. B. Bird, "Transportverschijnselen in stromende media," in *Course Notes*, edited by B. Van Nederveen (Delft, 1958).
[10]H. Van den Akker and R. F. Mudde, *Transport Phenomena: The Art of Balancing* (Delft Academic Press, 2014).
[11]R. B. Bird, "Nederland, de Bernoulli's, de Bernoullivergelijking en technisch onderwijs," NPT Procestechnol. **1**(5), 6–10 (1994).