Supplementary material

Residence Time Distribution: Literature Survey, Functions, Mathematical Modeling, and Case Study – Diagnosis for a Photochemical Reactor

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Table S1. Dankwerts' works, followers, and contributors to RTD methodology progress

Name	Period/year	Representative study	Other works
Dankwerts P. V.	1950 - 1960	Continuous flow systems. Distribution of residence times [1], reprinted in 1995 [2]	[3-6]
Zwietering Th. N.	1959	The degree of mixing in continuous flow systems [7]	[8]
Bischoff K. B. and McCracken, E. A.	1966	Tracer tests in flow systems [9]	[10]
Cholette A. and Cloutier L.	1960 - 1970	Mixing efficiency determinations for continuous flow systems [11]	[12-14]
Levenspiel O.	1960 –1970 2011	Tracer curves and the residence time distribution [15]	[16-21]
Shinnar R.	1960 –1970 1993	Representation and Evaluation of Residence Time Distributions [22]	[23-25]
Buffham B. A.	1970 - 1990	The washout curve, residence-time distribution, and F curve in tracer kinetics [26]	[27-36]
Gibilaro L. G.	1970 - 1980	On the residence time distribution for systems with open boundaries [37]	[32,33,38,39]
Nauman E. B.	1970 – 1990 2008	Residence Time Theory [40]	[36,41-48]
Martin A. D.	2000	Interpretation of residence time distribution data [49]	[50]
Leclerc J. P., et al.	2000	Theoretical interpretation of residence-time distribution measurements in industrial processes [51]	[51-53]

Table S2. Prominent chemical engineering student's textbooks covering RDT methodology*

Authors/Editors	Title	Vol./Ed.	Year	Ref. no
Levenspiel, O.	Chemical reaction engineering	3^{rd} Ed.	1998	[54]
Schmidt, L. D.	The engineering of chemical reactions	2^{nd} Ed.	2005	[55]
Nauman, E. B.	Chemical reactor design, optimization, and scaleup	2^{nd} Ed.	2008	[56]
Fogler, S. H.	Essentials of Chemical Reaction Engineering	1^{st} Ed.	2010	[57]
	Elements of chemical reaction engineering	4^{th} Ed.	2016	[58]
Green, D. W. and Southard, M. Z	Perry's Chemical Engineers' Handbook	8^{th} Ed.	2019	[59]
Ravi, R.; Vinu, R. G.; Sathyanarayana, N.	Coulson and Richardson's Chemical Engineering	Vol. 3/4^{th} Ed.	2017	[60]

*Only the last editions are chronologically reported.

Table S3. Residence time distribution reviews in various industrial fields

Authors	Title	Year	Area of application	Ref. no.
Swaine, D. E. and Daugulis, A. J.	Review of Liquid Mixing in Packed Bed Biological Reactors	1988	Bioreactors	[61]
Ramaswamy, H. S et al.	Residence time distribution (RTD) in aseptic processing of particulate foods: a review	1995		[62]
Torres, A. P. and Oliveira, F. A. R.	Residence time distribution studies in continuous thermal processing of liquid foods: a review	1998	Food processing	[63]
Ganjyal, G. and Hanna, M.	A Review on Residence Time Distribution (RTD) in Food Extruders and Study on the Potential of Neural Networks in RTD Modeling	2002		[64]
Gao, Y. et al.	A review of the Residence Time Distribution (RTD) applications in solid unit operations	2012	Solid particles processing	[65]
Leray, E. et al.	Residence time distributions for hydrologic systems: Mechanistic foundations and steady-state analytical solutions	2016	Hydrology	[66]
Sheoran, M. et al.	Residence time distribution studies using radiotracers in chemical industry—A review	2018	RTD diagnosis using radiotracers in various industries	[67]
Bérard, A. et al.	Experimental methods in chemical engineering: Residence time distribution—RTD	2020	Chemical engineering	[68]
Reis M.H. et al.	The Influence of Residence Time Distribution on Continuous-Flow Polymerization	2019	Polymers	[69]
Bhalode, P. et al.	Using residence time distribution in pharmaceutical solid dose manufacturing – A critical review	2021	Pharmaceutics	[70]

Stephenson, R. and Sheridan, C.	Review of experimental procedures and modelling techniques for flow behaviour and their relation to residence time in constructed wetlands	2021	Wetland modelling	[71]
Rodrigues, A. E.	Experimental methods in chemical engineering: Residence time distribution—RTD	2021	Chemical engineering	[72]
Wang Z. et al.	Residence Time Distribution (RTD) Applications in Continuous Casting Tundish: A Review and New Perspectives	2022	Metallurgy	[73]
Ding, C. et al.	Challenge of Residence Time Distribution Curve in Tundish for Continuous Casting of Steel	2022		[74]
Sarkar M. et al.	Application of tracer technology in wastewater treatment processes: a review	2023	Wastewater treatment	[75]
Cherkasov, N. et al.	Continuous stirred tank reactors in fine chemical synthesis for efficient mixing, solids-handling, and rapid scale-up	2023	Chemical engineering	[76]

Table S4. Typical dimensionless numbers used in RTD analysis

Formula	Representative relations	Observations	Ref. no.
$\mathrm{Pe} = \frac{v \cdot l}{D}$	$E(\theta) = \frac{\sqrt{Pe}}{2 \cdot \sqrt{\pi \cdot \theta}} \cdot \exp\left(-\frac{Pe \cdot (1-\theta^2)}{4 \cdot \theta}\right)$ (standard dispersion model)	$\mathrm{Pe} = \mathrm{Bo} \cdot \frac{L}{l}$	[72,77]
$\mathrm{Bo} = \frac{v \cdot L}{D_{ax}}$	$\sigma_\theta^2 = \frac{\sigma^2}{\tau^2} = \frac{2}{\mathrm{Bo}} + \frac{8}{\mathrm{Bo}^2}$ (open-open boundaries)	$\mathrm{Bo} \to \infty$ plug flow	[78,79]
	$\sigma_\theta^2 = \frac{\sigma^2}{\tau^2} = \frac{2}{\mathrm{Bo}} - \frac{2}{\mathrm{Bo}^2} \cdot \left(1 - e^{\mathrm{Bo}}\right)$ (closed – closed boundaries)	$\mathrm{Bo} \to 0$ perfectly mixed flow	[80]
$\mathrm{Da}_1 = k \cdot t$ first order reaction $\mathrm{Da}_2 = k \cdot C_A^0 \cdot t$ second order reaction	$\eta = 1 - \frac{4 \cdot q \cdot \exp\left(\frac{Pe}{2}\right)}{(1+q)^2 \cdot \exp\left(\frac{Pe \cdot q}{2}\right) - (1-q)^2 \cdot \exp\left(-\frac{Pe \cdot q}{2}\right)}$, $q = \sqrt{1 + \frac{4 \cdot Da}{Pe}}$ (closed – closed boundaries, first-order reaction)	If Da < 0.1 then η < 0.1 If Da > 10 then η > 0.9	[58]

where v represents flow velocity; L represents the systems length; l represents the characteristic length; D_{ax} = axial dispersion coefficient; D = mass diffusion coefficient, η = conversion

Table S5 Representative non-ideal flow models

Name	Description	Parameters	Representative equation	Ref. no.
Cholette-Cloutier	The model associates a perfectly mixed tank, a bypass, and a dead zone. $V_D=(1-\beta)\cdot V$	*α*, β	$E(t) = \alpha \cdot \delta(t) + (1-\alpha) \cdot \frac{(1-\alpha)}{\beta \cdot t_s} \cdot \exp\left(-\frac{(1-\alpha) \cdot t}{\beta \cdot t_s}\right)$ where δ(t) is Dirac delta function	[13,72]

	$V_R=\beta\cdot V$			
Tank-in-series	The model associates an "n" number of perfectly mixed, equal-volume tanks. $M_v^0 = M_v^i = M_v^n$ $t_s = t_s^1 + ... + t_s^i + ... t_s^n$	*n* (or *N*)	$E(\theta) = \frac{n^n}{(n-1)!}\cdot\theta^{n-1}\cdot e^{-\theta\cdot n}$ $F(\theta) = 1 - e^{-\theta\cdot n}\cdot\left[1+\sum_{i=1}^{n}\frac{(n\cdot\theta)^{i-1}}{i!}\right]$ $\delta_\theta^2 = \frac{1}{n}$ If n → 0, the series behaves as a perfectly mixed tank If n → ∞ the series behave as a plug flow	[17,32,81,82]
Axial dispersion	The model considers a plug flow that admits mixing and axial dispersion in the flow direction. System boundaries can be open, closed, or a combination of the two. C = f(t, z)	D_{ax}	$E(\theta) = \frac{1}{2\cdot\theta}\cdot\sqrt{\frac{Bo}{\pi\cdot\theta}}\cdot\exp\left(-\frac{(1-\theta)^2\cdot Bo}{4\cdot\theta}\right)$ open – open boundaries $E(\theta) = e^{\frac{Pe}{2}}\cdot\sum_{i=1}^{\infty}\frac{(-1)^{i+1}\cdot 8\cdot\alpha_i^2\cdot e^{\left(-\frac{4\cdot\alpha_i^2+Pe^2}{4\cdot Pe}\right)}}{Pe^2+4\cdot Pe+4\cdot\alpha_i^2}$, Where α_i are the positive roots of the equation: $tg\alpha = \frac{4\cdot Pe\cdot\alpha}{4\cdot\alpha^2 - Pe^2}$ Closed – closed boundaries	[82-84]

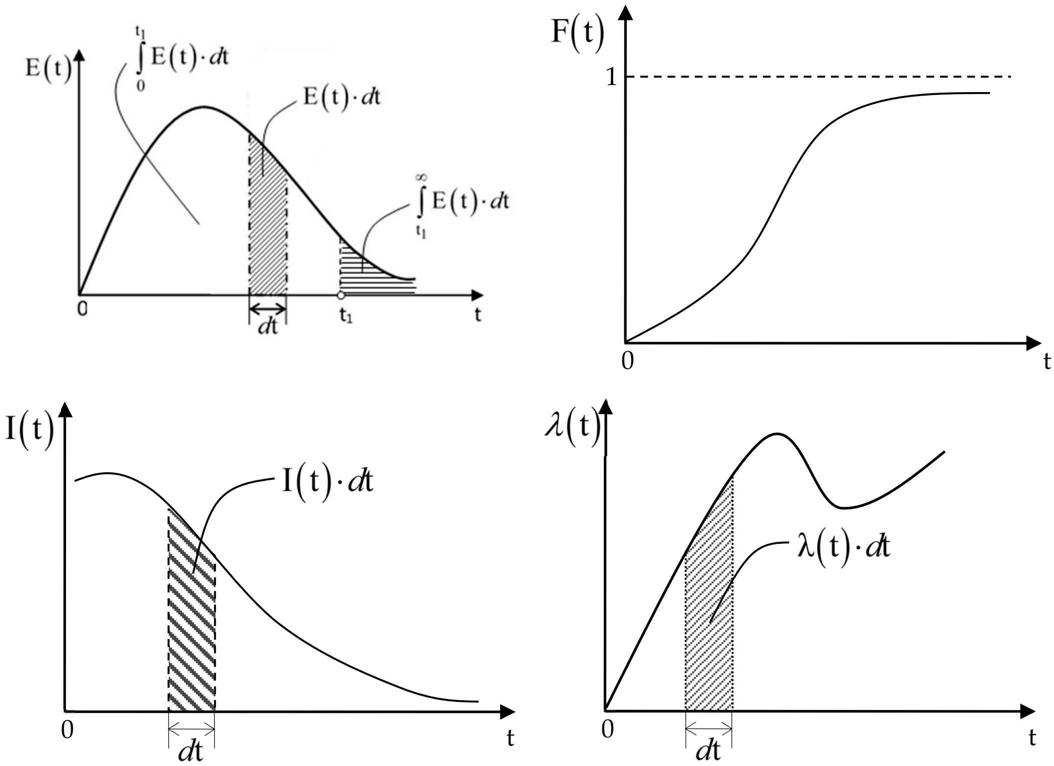
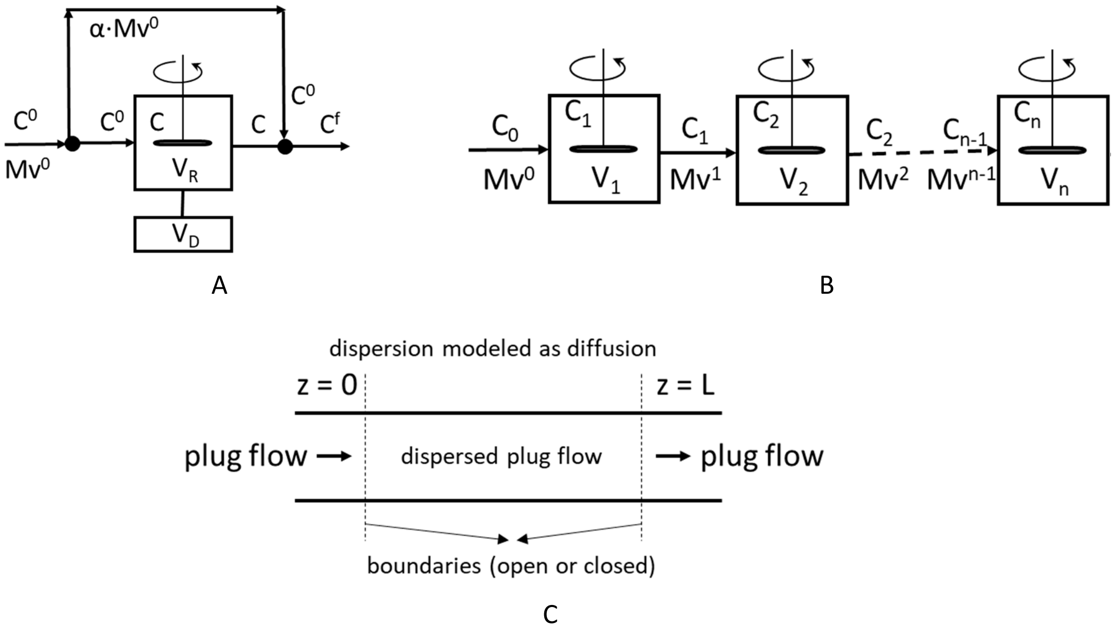


Figure S1. Typical RTD functions



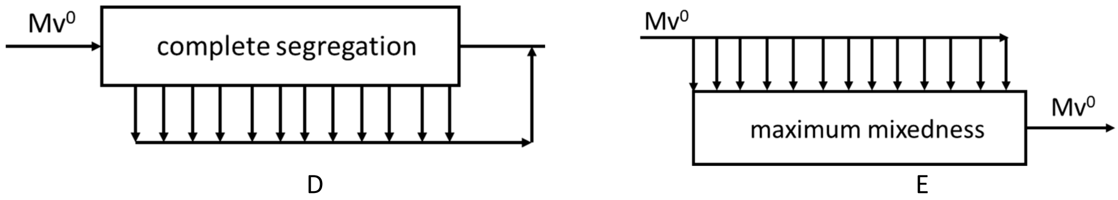


Figure S2. Representative non-ideal flow and mixing models: **A:** Cholette-Cloutier model; **B:** Tank-in-series model; **C:** Axial dispersion model; **D:** Complete segregation model; **E:** Maximum mixedness model

References

1. Danckwerts, P.V. Continuous flow systems. Distribution of residence times. *Chemical Engineering Science* **1953**, *2*, 1-13, doi:10.1016/0009-2509(53)80001-1.
2. Danckwerts, P.V. Continuous flow systems. Distribution of residence times. *Chemical Engineering Science* **1995**, *50*, 3857-3866, doi:https://doi.org/10.1016/0009-2509(96)81811-2.
3. Danckwerts, P.V. Local residence-times in continuous-flow systems. *Chemical Engineering Science* **1958**, *9*, 78-79, doi:https://doi.org/10.1016/0009-2509(58)87011-6.
4. Danckwerts, P.V. The effect of incomplete mixing on homogeneous reactions. *Chemical Engineering Science* **1958**, *8*, 93-102, doi:https://doi.org/10.1016/0009-2509(58)80040-8.
5. Danckwerts, P.V.; Jenkins, J.W.; Place, G. The distribution of residence-times in an industrial fluidised reactor. *Chemical Engineering Science* **1954**, *3*, 26-35, doi:https://doi.org/10.1016/0009-2509(54)80004-2.
6. Danckwerts, P.V.; Wilson, R.A.M. Flow-visualization by means of a time-reaction. *Journal of Fluid Mechanics* **1963**, *16*, 412-416, doi:10.1017/S0022112063000860.
7. Zwietering, T.N. The degree of mixing in continuous flow systems. *Chemical Engineering Science* **1959**, *11*, 1-15, doi:https://doi.org/10.1016/0009-2509(59)80068-3.
8. Zwietering, T.N. A backmixing model describing micromixing in single-phase continuous-flow systems. *Chemical Engineering Science* **1984**, *39*, 1765-1778, doi:https://doi.org/10.1016/0009-2509(84)80112-8.
9. Bischoff, K.B.; McCracken, E.A. Tracer tests in flow systems. *Industrial & Engineering Chemistry* **1966**, *58*, 18-31, doi:10.1021/ie50679a005.
10. Bischoff, K.B. Mixing and contacting in chemical reactors. *Industrial & Engineering Chemistry* **1966**, *58*, 18-32, doi:10.1021/ie50683a006.
11. Cholette, A.; Cloutier, L. Mixing efficiency determinations for continuous flow systems. *The Canadian Journal of Chemical Engineering* **1959**, *37*, 105-112, doi:10.1002/cjce.5450370305.
12. Chiang, D.; Cholette, A. Internal age and residence time distributions of a fluid in non-ideal stirred tanks in series. *The Canadian Journal of Chemical Engineering* **1971**, *49*, 484-487, doi:https://doi.org/10.1002/cjce.5450490409.
13. Cholette, A.; Blanchet, J.; Cloutier, L. Performance of flow reactors at various levels of mixing. *The Canadian Journal of Chemical Engineering* **1960**, *38*, 1-18, doi:https://doi.org/10.1002/cjce.5450380102.
14. Cloutier, L.; Cholette, A. Effect of various parameters on the level of mixing in continuous flow systems. *The Canadian Journal of Chemical Engineering* **1968**, *46*, 82-88, doi:https://doi.org/10.1002/cjce.5450460203.
15. Levenspiel, O.; Lai, B.W.; Chatlynne, C.Y. Tracer curves and the residence time distribution. *Chemical Engineering Science* **1970**, *25*, 1611-1613, doi:https://doi.org/10.1016/0009-2509(70)85084-9.

16. Levenspiel, O.; Smith, W.K. Notes on the diffusion-type model for the longitudinal mixing of fluids in flow. *Chemical Engineering Science* **1995**, *50*, 3891-3896, doi:https://doi.org/10.1016/0009-2509(96)81817-3.
17. Levenspiel, O. *Tracer technology: modeling the flow of fluids*; Springer Science & Business Media: 2011; Volume 96.
18. Levenspiel, O.; Turner, J.C.R. The interpretation of residence-time experiments. *Chemical Engineering Science* **1970**, *25*, 1605-1609, doi:https://doi.org/10.1016/0009-2509(70)85083-7.
19. Levenspiel, O.; Bischoff, K.B. Patterns of Flow in Chemical Process Vessels. In *Advances in Chemical Engineering*, Drew, T.B., Hoopes, J.W., Vermeulen, T., Eds.; Academic Press: 1964; Volume 4, pp. 95-198.
20. Levenspiel, O.; Bischoff, K.B. Backmixing in the Design of Chemical Reactors. *Industrial & Engineering Chemistry* **1959**, *51*, 1431-1434, doi:10.1021/ie50600a023.
21. Levenspiel, O. Mixed models to represent flow of fluids through vessels. *The Canadian Journal of Chemical Engineering* **1962**, *40*, 135-138, doi:https://doi.org/10.1002/cjce.5450400402.
22. Naor, P.; Shinnar, R. Representation and Evaluation of Residence Time Distributions. *Industrial & Engineering Chemistry Fundamentals* **1963**, *2*, 278-286, doi:10.1021/i160008a007.
23. Shinnar, R. On the behaviour of liquid dispersions in mixing vessels. *Journal of Fluid Mechanics* **1961**, *10*, 259-275, doi:10.1017/S0022112061000214.
24. Shinnar, R. Residence-time distributions and tracer experiments in chemical reactor design: the power and usefulness of a "wrong" concept. *revce* **1993**, *9*, 97, doi:10.1515/REVCE.1993.9.1-2.97.
25. Zvirin, Y.; Shinnar, R. Interpretation of internal tracer experiments and local sojourn time distributions. *International Journal of Multiphase Flow* **1976**, *2*, 495-520, doi:https://doi.org/10.1016/0301-9322(76)90012-4.
26. Buffham, B.A.; Kropholler, H.W. The washout curve, residence-time distribution, and F curve in tracer kinetics. *Mathematical Biosciences* **1970**, *6*, 179-184, doi:https://doi.org/10.1016/0025-5564(70)90065-9.
27. Buffham, B.A. Impulse Response of Infinite and Semi-Infinite Sequences of Identical Stirred Tanks with Backflow. *Industrial & Engineering Chemistry Fundamentals* **1969**, *8*, 428-430, doi:10.1021/i160031a011.
28. Buffham, B.A. On the residence-time distribution for a system with velocity profiles in its connections with the environment. *Chemical Engineering Science* **1972**, *27*, 987-991, doi:https://doi.org/10.1016/0009-2509(72)80013-7.
29. Buffham, B.A. Mean residence times in steady-flow and some non-flow systems. *Nature* **1978**, *274*, 879-880, doi:10.1038/274879a0.
30. Buffham, B.A. INTERNAL AND EXTERNAL RESIDENCE-TIME DISTRIBUTIONS. *Chemical Engineering Communications* **1983**, *22*, 105-107, doi:10.1080/00986448308940048.
31. Buffham, B.A. Residence-time distributions in regions of steady-flow systems. *Nature* **1985**, *314*, 606-608, doi:10.1038/314606a0.
32. Buffham, B.A.; Gibilaro, L.G. A generalization of the tanks-in-series mixing model. *AIChE Journal* **1968**, *14*, 805-806, doi:https://doi.org/10.1002/aic.690140521.
33. Buffham, B.A.; Gibilaro, L.G. A unified time delay model for dispersion in flowing media. *The Chemical Engineering Journal* **1970**, *1*, 31-36, doi:https://doi.org/10.1016/0300-9467(70)85028-6.
34. Buffham, B.A.; Kropholler, H.W. Tracer kinetics: some general properties, the mean residence time and applications to phase and chemical equilibria. *Chemical Engineering Science* **1973**, *28*, 1081-1089, doi:https://doi.org/10.1016/0009-2509(73)80011-9.
35. Buffham, B.A.; Mason, G. Holdup and dispersion: tracer residence times, moments and inventory measurements. *Chemical Engineering Science* **1993**, *48*, 3879-3887, doi:https://doi.org/10.1016/0009-2509(93)80366-X.

36. Buffham, B.A.; Nauman, E.B. On the limiting form of the residence-time distribution for a constant-volume recycle system. *Chemical Engineering Science* **1975**, *30*, 1519-1524, doi:https://doi.org/10.1016/0009-2509(75)85030-5.
37. Gibilaro, L.G. On the residence time distribution for systems with open boundaries. *Chemical Engineering Science* **1978**, *33*, 487-491, doi:https://doi.org/10.1016/0009-2509(78)80008-6.
38. Gibilaro, L.G. Mean residence times in continuous flow systems. *Nature* **1977**, *270*, 47-48, doi:10.1038/270047a0.
39. Gibilaro, L.G. Residence time distributions in regions of continuous flow systems. *Chemical Engineering Science* **1979**, *34*, 697-702, doi:https://doi.org/10.1016/0009-2509(79)85116-7.
40. Nauman, E.B. Residence Time Theory. *Industrial & Engineering Chemistry Research* **2008**, *47*, 3752-3766, doi:10.1021/ie071635a.
41. Nauman, E.B. Residence time distribution theory for unsteady stirred tank reactors. *Chemical Engineering Science* **1969**, *24*, 1461-1470, doi:https://doi.org/10.1016/0009-2509(69)85074-8.
42. Nauman, E.B. Residence times and cycle times in recycle systems. *Chemical Engineering Science* **1974**, *29*, 1883-1888, doi:https://doi.org/10.1016/0009-2509(74)85005-0.
43. Nauman, E.B. Mixing in Polymer Reactors. *Journal of Macromolecular Science, Part C* **1974**, *10*, 75-112, doi:10.1080/15321797408080005.
44. Nauman, E.B. Residence time distributions and micromixing. *Chemical Engineering Communications* **1981**, *8*, 53-131, doi:10.1080/00986448108912576.
45. Nauman, E.B. Residence time distributions in systems governed by the dispersion equation. *Chemical Engineering Science* **1981**, *36*, 957-966, doi:https://doi.org/10.1016/0009-2509(81)80080-2.
46. Nauman, E.B. Reactions and residence time distributions in motionless mixers. *The Canadian Journal of Chemical Engineering* **1982**, *60*, 136-140, doi:https://doi.org/10.1002/cjce.5450600123.
47. Nauman, E.B. On residence time and trajectory calculations in motionless mixers. *The Chemical Engineering Journal* **1991**, *47*, 141-148, doi:https://doi.org/10.1016/0300-9467(91)85019-R.
48. Nauman, E.B. Residence Time Distributions. In *Handbook of Industrial Mixing*; 2003; pp. 1-17.
49. Martin, A.D. Interpretation of residence time distribution data. *Chemical Engineering Science* **2000**, *55*, 5907-5917, doi:https://doi.org/10.1016/S0009-2509(00)00108-1.
50. Burrows, L.J.; Stokes, A.J.; West, J.R.; Forster, C.F.; Martin, A.D. Evaluation of different analytical methods for tracer studies in aeration lanes of activated sludge plants. *Water Research* **1999**, *33*, 367-374, doi:https://doi.org/10.1016/S0043-1354(98)00249-8.
51. Leclerc, J.; Claudel, S.; Lintz, H.; Potier, O.; Antoine, B. Theoretical interpretation of residence-time distribution measurements in industrial processes. *Oil & Gas Science and Technology* **2000**, *55*, 159-169.
52. Claudel, S.; Fonteix, C.; Leclerc, J.P.; Lintz, H.G. Application of the possibility theory to the compartment modelling of flow pattern in industrial processes. *Chemical Engineering Science* **2003**, *58*, 4005-4016, doi:https://doi.org/10.1016/S0009-2509(03)00269-0.
53. Haag, J.; Gentric, C.; Lemaitre, C.; Leclerc, J.-P. Modelling of Chemical Reactors: From Systemic Approach to Compartmental Modelling. *International Journal of Chemical Reactor Engineering* **2018**, *16*, doi:10.1515/ijcre-2017-0172.
54. Levenspiel, O. *Chemical reaction engineering*; John wiley & sons: 1998.
55. Schmidt, L.D. *The engineering of chemical reactions*; Oxford university press New York: 2005.
56. Nauman, E.B. *Chemical reactor design, optimization, and scaleup*; John Wiley & Sons: 2008.
57. Fogler, H.S. *Essentials of Chemical Reaction Engineering*; Pearson Education: 2010.
58. Fogler, H.S. *Elements of chemical reaction engineering*; Prentice Hall: 2016.
59. Green, D.W.; Southard, M.Z. *Perry's chemical engineers' handbook*; McGraw-Hill Education: 2019.
60. Ravi, R.; Vinu, R.; Gummadi, S.N. *Coulson and Richardson's Chemical Engineering: Volume 3A: Chemical and Biochemical Reactors and Reaction Engineering*; Butterworth-Heinemann: 2017.

61. Swaine, D.E.; Daugulis, A.J. Review of Liquid Mixing in Packed Bed Biological Reactors. *Biotechnology Progress* **1988**, *4*, 134-148, doi:10.1002/btpr.5420040304.
62. Ramaswamy, H.S.; Abdelrahim, K.A.; Simpson, B.K.; Smith, J.P. Residence time distribution (RTD) in aseptic processing of particulate foods: a review. *Food Research International* **1995**, *28*, 291-310, doi:https://doi.org/10.1016/0963-9969(95)00005-7.
63. Torres, A.P.; Oliveira, F.A.R. Residence time distribution studies in continuous thermal processing of liquid foods: a review. *Journal of Food Engineering* **1998**, *36*, 1-30, doi:https://doi.org/10.1016/S0260-8774(98)00037-5.
64. Ganjyal, G.; Hanna, M. A Review on Residence Time Distribution (RTD) in Food Extruders and Study on the Potential of Neural Networks in RTD Modeling. *Journal of Food Science* **2002**, *67*, 1996-2002, doi:https://doi.org/10.1111/j.1365-2621.2002.tb09491.x.
65. Gao, Y.; Muzzio, F.J.; Ierapetritou, M.G. A review of the Residence Time Distribution (RTD) applications in solid unit operations. *Powder Technology* **2012**, *228*, 416-423, doi:https://doi.org/10.1016/j.powtec.2012.05.060.
66. Leray, S.; Engdahl, N.B.; Massoudieh, A.; Bresciani, E.; McCallum, J. Residence time distributions for hydrologic systems: Mechanistic foundations and steady-state analytical solutions. *Journal of Hydrology* **2016**, *543*, 67-87, doi:https://doi.org/10.1016/j.jhydrol.2016.01.068.
67. Sheoran, M.; Chandra, A.; Bhunia, H.; Bajpai, P.K.; Pant, H.J. Residence time distribution studies using radiotracers in chemical industry—A review. *Chemical Engineering Communications* **2018**, *205*, 739-758, doi:10.1080/00986445.2017.1410478.
68. Bérard, A.; Blais, B.; Patience, G.S. Experimental methods in chemical engineering: Residence time distribution—RTD. *The Canadian Journal of Chemical Engineering* **2020**, *98*, 848-867, doi:https://doi.org/10.1002/cjce.23711.
69. Reis, M.H.; Varner, T.P.; Leibfarth, F.A. The Influence of Residence Time Distribution on Continuous-Flow Polymerization. *Macromolecules* **2019**, *52*, 3551-3557, doi:10.1021/acs.macromol.9b00454.
70. Bhalode, P.; Tian, H.; Gupta, S.; Razavi, S.M.; Roman-Ospino, A.; Talebian, S.; Singh, R.; Scicolone, J.V.; Muzzio, F.J.; Ierapetritou, M. Using residence time distribution in pharmaceutical solid dose manufacturing – A critical review. *International Journal of Pharmaceutics* **2021**, *610*, 121248, doi:https://doi.org/10.1016/j.ijpharm.2021.121248.
71. Stephenson, R.; Sheridan, C. Review of experimental procedures and modelling techniques for flow behaviour and their relation to residence time in constructed wetlands. *Journal of Water Process Engineering* **2021**, *41*, 102044, doi:https://doi.org/10.1016/j.jwpe.2021.102044.
72. Rodrigues, A.E. Residence time distribution (RTD) revisited. *Chemical Engineering Science* **2021**, *230*, 116188, doi:https://doi.org/10.1016/j.ces.2020.116188.
73. Wang, Z.; Yang, Z.; Wang, X.; Yue, Q.; Xia, Z.; Xiao, H. Residence Time Distribution (RTD) Applications in Continuous Casting Tundish: A Review and New Perspectives. *Metals* **2022**, *12*, 1366.
74. Ding, C.; Lei, H.; Chen, S.; Zhang, H.; Zhao, Y.; Zou, Z. Challenge of Residence Time Distribution Curve in Tundish for Continuous Casting of Steel. *steel research international* **2022**, *93*, 2200187, doi:https://doi.org/10.1002/srin.202200187.
75. Sarkar, M.; Sangal, V.K.; Pant, H.J.; Sharma, V.K.; Bhunia, H.; Bajpai, P.K. Application of tracer technology in wastewater treatment processes: a review. *Chemical Engineering Communications* **2023**, *210*, 16-33, doi:10.1080/00986445.2021.1995371.
76. Cherkasov, N.; Adams, S.J.; Bainbridge, E.G.A.; Thornton, J.A.M. Continuous stirred tank reactors in fine chemical synthesis for efficient mixing, solids-handling, and rapid scale-up. *Reaction Chemistry & Engineering* **2023**, doi:10.1039/D2RE00232A.

77. Patrick Jr., R.H.; Klindera, T.; Crynes, L.L.; Cerro, R.L.; Abraham, M.A. Residence time distribution in three-phase monolith reactor. *AIChE Journal* **1995**, *41*, 649-657, doi:https://doi.org/10.1002/aic.690410321.
78. Bachmann, P.; Bück, A.; Tsotsas, E. Experimental investigation and correlation of the Bodenstein number in horizontal fluidized beds with internal baffles. *Powder Technology* **2017**, *308*, 378-387, doi:https://doi.org/10.1016/j.powtec.2016.11.025.
79. Shadpoor, S.; Pirouzi, A.; Hamze, H.; Mazaheri, D. Determination of Bodenstein number and axial dispersion of a triangular external loop airlift reactor. *Chemical Engineering Research and Design* **2021**, *165*, 61-68, doi:https://doi.org/10.1016/j.cherd.2020.10.018.
80. Pietsch, S.; Schönherr, M.; Kleine Jäger, F.; Heinrich, S. Measurement of Residence Time Distributions in a Continuously Operated Spouted Bed. *Chemical Engineering & Technology* **2020**, *43*, 804-812, doi:https://doi.org/10.1002/ceat.201900453.
81. Mason, D.R.; Piret, E.L. Continuous Flow Stirred Tank Reactor Systems. *Industrial & Engineering Chemistry* **1950**, *42*, 817-825, doi:10.1021/ie50485a022.
82. Li, S. Chapter 5 - Residence Time Distribution and Flow Models for Reactors. In *Reaction Engineering*, Li, S., Ed.; Butterworth-Heinemann: Boston, 2017; pp. 213-263.
83. Ravi, R. Chapter 2 - Flow Characteristics of Reactors—Flow Modeling. In *Coulson and Richardson's Chemical Engineering (Fourth Edition)*, Ravi, R., Vinu, R., Gummadi, S.N., Eds.; Butterworth-Heinemann: 2017; pp. 103-160.
84. Real Reactors and Residence Time Distribution (RTD). In *Microstructured Devices for Chemical Processing*; 2014; pp. 89-128.