

TITLE:

* + Dataset underlying the research of: Fit parameters for liquid-solid fluidisation models applied in drinking water treatment processes

SHORT DESCRIPTION:

* + In 2020 new accurate voidage prediction models were published in water treatment and multiphase flow related journal articles. The models were calibrated and validate for monodisperse spherical glass beads and fractionised calcite grains applied in water softening fluidised bed reactors. A spin off of this particular research project is that other granules also were examined, such as sand, steel and synthetic grains. The fit parameters for these grains were not shared with the scientific community. In short: this dataset consists of fit parameters for liquid-solid fluidisation models to predict the effective voidage applied in drinking water treatment processes and other multiphase flow systems in other industrial field for various granules, for various velocities, particle densities and temperatures.

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FORMAT:

* + Numerical data

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  + Delft University of Technology, Faculty of Mechanical, Maritime and Materials Engineering, Department of Process and Energy
  + Waternet, Amsterdam (funder)
  + HU University of Applied Sciences Utrecht, Institute for Life Science and Chemistry
  + Queen Mary University of London, Division of Chemical Engineering, School of Engineering and Materials Science

SUBJECT:

* + Hydraulic modelling of multiphase flow systems

KEYWORDS:

* + multiphase phenomena
  + liquid-solid fluidisation
  + drinking water treatment
  + circular sustainable processes
  + water softening
  + model fit parameters

METHODOLOGICAL INFORMATION:

* + Data set with fit parameters

ADDITIONAL TECHNICAL INFORMATION:

► O.J.I. Kramer, P.J. de Moel, J.T. Padding, E.T. Baars, Y.M.F. el Hasadi, E.S. Boek, J.P. van der Hoek, Accurate voidage prediction in fluidisation systems for full-scale drinking water pellet softening reactors using data driven models, Journal of Water Process Engineering. 37, 101481 (2020) 1–15. https://doi.org/10.1016/j.jwpe.2020.101481

► O.J.I. Kramer, J.T. Padding, W.H. van Vugt, P.J. de Moel, E.T. Baars, E.S. Boek, J.P. van der Hoek, Improvement of voidage prediction in liquid-solid fluidized beds by inclusion of the Froude number in effective drag relations, International Journal of Multiphase Flow. 127, 103261 (2020) 1–13. https://doi.org/10.1016/j.ijmultiphaseflow.2020.103261

# Minimum and maximum fluidisation points

## Minimum fluidisation points

Voidage prediction models are only valid for a fluidised state. For this reason, it is important to determine the incipient fluidisation point to check the prevailing state (Kramer et al., 2020a). The onset of fluidisation from fixed to fluidised state occurs when the drag force is equal to the weight of the particles and can be estimated using the very often used quadratic Equation (1), *e.g.* proposed by (Wen and Yu, 1966a) based on (Ergun, 1952). Although numerous prediction models are proposed in the literature, (Lippens and Mulder, 1993); (Anantharaman et al., 2018) there is no general agreement about the best approach. The degree of irregularity and polydispersity of particles as well as influences caused by the packing factor, surface forces, and wall effects increase the complexity of accurate prediction. For this reason, an established straightforward Wen–Yu method is chosen.

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

And where is the incipient particle Reynolds number (Equation (2)) and the Archimedes number (Equation (3)).

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

In the literature (Yang, 2003) many values can be found for parameters and independent for the voidage at incipient fluidisation. The Wen–Yu Equation (1), based on the incipient particle Reynolds number and the Archimedes number , were used to calculate the minimum fluidisation velocity. Fitting parameters for the Wen–Yu equation concerning spherical and natural were fitted through non-linear curve fitting and are given in Table 1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Table 1*** *Model fit parameters (Equation (1))* | | | | |
| **Granule type** |  |  |  |  |
| Reference |  |  |  |  |
| (Wen and Yu, 1966a) | 33.7 | 0.0408 | n.a. |  |
| (Richardson and Zaki, 1979) | 25.7 | 0.0365 | n.a. |  |
| (Saxena and Vogel, 1977) | 25.3 | 0.0571 | n.a. |  |
| (Babu et al., 1978) | 25.3 | 0.0651 | n.a. |  |
| (Grace et al., 2020) | 27.2 | 0.0408 | n.a. |  |
| (Chitester et al., n.d.) | 28.7 | 0.0494 | n.a. |  |
|  |  |  |  |  |
| Spherical particles 2) |  |  |  |  |
| Glass beads | 29.3 | 0.0426 | 0.998 |  |
| Steel shots | 96.1 | 0.0613 | 0.999 |  |
| Nylon balls | 31.8 | 0.0442 | 0.984 |  |
| Glass+steel+nylon | 32.1 | 0.0444 | 0.997 |  |
|  |  |  |  |  |
| Natural particles 2) |  |  |  |  |
| Rapid filter sand | 24.5 | 0.0423 | 0.953 |  |
| Sand 1) | 38.2 | 0.0594 | 0.929 |  |
|  |  |  |  |  |
| Calcite 2) |  |  |  |  |
| Calcite pellets | 24.6 | 0.0306 | 0.996 |  |
| Crushed calcite | 11.8 | 0.0271 | 0.898 |  |
|  |  |  |  |  |
| Other particles 2) |  |  |  |  |
| Zirconium balls | 34.2 | 0.0429 | 0.998 |  |
| Literature data 3) | 177 | 0.0780 | 0.970 |  |
| 1) Rapid filter sand, garnet sand, crystal sand + (Đuriš *et al.*, 2016; Dharmarajah, 1982)  2) Non-linear curve fit  3) Sources: (Wilhelm and Kwauk, 1948; Lewis *et al.*, 1949; Richardson and Zaki, 1954; Loeffler, 1953; (Wen and Yu, 1966b); Dharmarajah, 1982; Hartman *et al.*, 1992; Đuriš *et al.*, 2016) | | | | |

# Data-driven model fit parameters

Note: Table 2, Table 3,

1) Rapid filter sand, garnet sand, crystal sand + ((Đuriš et al., 2016); (Dharmarajah, 1982)

2) 6.35 mm metal balls (Richardson and Zaki, 1954)

3) Sources: (Wilhelm and Kwauk, 1948); (Lewis et al., 1949); (Richardson and Zaki, 1954); (Loeffler, 1953); (Wen and Yu, 1966a); (Dharmarajah, 1982); (Hartman et al., 1992); (Đuriš et al., 2016)

4) 60 < [m/h] < 120

## Single Reynolds–Froude model (Rep1Frp)

Source: (Kramer et al., 2020b)

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

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| --- | --- | --- | --- | --- |
| ***Table 2*** *Model fit parameters (Equation (4))* | | | | |
| **Granule type** |  |  |  |  |
| Spherical particles |  |  |  |  |
| Glass beads | 1.47 | -0.0817 | 0.429 | 0.990 |
| Steel shots | 1.40 | -0.0662 | 0.491 | 0.997 |
| Nylon balls | 1.87 | -0.122 | 0.475 | 0.995 |
| Glass+steel+nylon | 1.52 | -0.0870 | 0.438 | 0.988 |
|  |  |  |  |  |
| Natural particles |  |  |  |  |
| Crystal sand | 2.29 | -0.196 | 0.498 | 0.981 |
| Garnet sand | 2.01 | -0.193 | 0.425 | 0.968 |
| Rapid filter sand | 1.87 | -0.125 | 0.465 | 0.966 |
| Sand 1) | 1.81 | -0.132 | 0.422 | 0.934 |
|  |  |  |  |  |
| Calcite |  |  |  |  |
| Calcite pellets | 1.64 | -0.104 | 0.434 | 0.974 |
| Crushed calcite | 1.81 | -0.135 | 0.393 | 0.979 |
| Calcite pellets 4) | 1.99 | -0.168 | 0.444 | 0.986 |
|  |  |  |  |  |
| Other particles |  |  |  |  |
| Richardson–Zaki 2) | 28.5 | -0.422 | 0.844 | 0.995 |
| Zirconium balls | 1.19 | -0.0849 | 0.331 | 0.965 |
| Literature data 3) | 1.68 | -0.111 | 0.395 | 0.871 |

## Double Reynolds–Froude model (Rep2Frp)

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

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| ***Table 3*** *Model fit parameters (Equation (5))* | | | | | | |
| **Granule type** |  |  |  |  |  |  |
| Spherical particles |  |  |  |  |  |  |
| Glass beads | 1.46 | -0.375 | 0.677 | 0.0261 | 0.459 | 0.994 |
| Steel shots | 57.6 | -1.44 | 1.25 | -0.0502 | 0.491 | 0.997 |
| Nylon balls | 141 | -3.20 | 1.58 | -0.0855 | 0.452 | 0.994 |
| Glass+steel+nylon | 1.34 | -0.0621 | 1.08 | -0.813 | 0.459 | 0.988 |
|  |  |  |  |  |  |  |
| Natural particles |  |  |  |  |  |  |
| Crystal sand | 2.23 | -0.188 | 0.600 | -2.35 | 0.496 | 0.982 |
| Garnet sand | 1.96 | -0.182 | 0.104 | -0.877 | 0.435 | 0.969 |
| Rapid filter sand | 1.68 | -0.341 | 0.563 | 0.0492 | 0.462 | 0.995 |
| Sand 1) | 1.23 | -0.0511 | 1.07 | -0.538 | 0.465 | 0.992 |
|  |  |  |  |  |  |  |
| Calcite |  |  |  |  |  |  |
| Calcite pellets | 1.69 | -0.348 | 0.527 | 0.0575 | 0.456 | 0.994 |
| Crushed calcite | 1.62 | -0.104 | 0.492 | -0.917 | 0.400 | 0.981 |
| Calcite pellets 4) | 1.14 | -0.0652 | 1.12 | -0.445 | 0.464 | 0.993 |
|  |  |  |  |  |  |  |
| Other particles |  |  |  |  |  |  |
| Richardson–Zaki 2) | 11.1 | -0.518 | 5.43 | -0.246 | 0.722 | 0.996 |
| Zirconium balls | 1.39 | -0.369 | 0.382 | 0.0902 | 0.362 | 0.975 |
| Literature data 3) | 1.69 | -0.260 | 0.375 | 0.0709 | 0.454 | 0.967 |

# Reynolds-Froude numbers-based model fit parameters

## Stokes–Oseen–Newton model (SON)

Source: (Kramer et al., 2020b)

|  |  |  |
| --- | --- | --- |
|  |  | (6) |

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| ***Table 4*** *Model fit parameters (Equation (6))* | | | | | |
| **Granule type** |  |  |  |  |  |
| Spherical particles |  |  |  |  |  |
| Glass beads | 150 | 0.2313 | 0.1203 | 1.566 | 0.985 |
| Steel shots | 150 | 0.1975 | 0.1350 | 1.628 | 0.995 |
| Nylon balls | 150 | 0.2385 | 0.2193 | 2.422 | 0.997 |
| Glass+steel+nylon | 150 | 0.1509 | 0.1750 | 2.100 | 0.986 |
|  |  |  |  |  |  |
| Natural particles |  |  |  |  |  |
| Crystal sand | 150 | 0.4556 | 0.6373 | 6.669 | 0.971 |
| Garnet sand | 150 | 0.5882 | 0.7685 | 2.301 | 0.778 |
| Rapid filter sand | 150 | 0.2257 | 0.1450 | 1.928 | 0.978 |
| Sand 1) | 150 | 0.1463 | 0.2259 | 2.594 | 0.970 |
|  |  |  |  |  |  |
| Calcite |  |  |  |  |  |
| Calcite pellets | 150 | 0.1597 | 0.2060 | 2.311 | 0.990 |
| Crushed calcite | 150 | 0.5005 | 0.3839 | 3.382 | 0.937 |
| Calcite pellets 4) | 150 | 0.1413 | 0.2307 | 2.636 | 0.970 |
|  |  |  |  |  |  |
| Other particles |  |  |  |  |  |
| Richardson–Zaki 2) | 150 | 0.4587 | 0.6389 | 6.709 | 0.971 |
| Zirconium balls | 150 | 0.4139 | 0.4633 | 2.897 | 0.976 |
| Literature data 3) | 150 | 0.2274 | 0.1392 | 1.762 | 0.993 |

## Reynolds–Improved–Outlook model (RIO1)

|  |  |  |
| --- | --- | --- |
|  |  | (7) |

|  |  |  |
| --- | --- | --- |
|  |  | (8) |

|  |  |  |  |  |  |  |  |
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| ***Table 5*** *Model fit parameters (Equation (7) and (8))* | | | | | | | |
| **Granule type** |  |  |  |  |  |  |  |
| Spherical particles |  |  |  |  |  |  |  |
| Glass beads | 150 | 10.95 | 11.91 | 0.4014 | 1.292 | 0.2353 | 0.991 |
| Steel shots | 150 | 5.487 | 196.3 | 21.71 | 4.376 | 0.1787 | 0.995 |
| Nylon balls | 150 | 16.14 | 55.56 | 14.63 | 2.194 | 0.3023 | 0.997 |
| Glass+steel+nylon | 150 | 12.38 | 11.26 | 0.1340 | 1.190 | 0.2578 | 0.987 |
|  |  |  |  |  |  |  |  |
| Natural particles |  |  |  |  |  |  |  |
| Crystal sand | 150 | 2.195 | 10.45 | 52.51 | 4.129 | 0.1096 | 0.978 |
| Garnet sand | 150 | 5.658 | 66.33 | 7.773 | 3.577 | 0.05215 | 0.809 |
| Rapid filter sand | 150 | 4.574 | 6.986 | 0.1038 | 3.810 | 0.1590 | 0.976 |
| Sand 1) | 150 | 5.152 | 14.72 | 7.668 | 6.532 | 0.1939 | 0.970 |
|  |  |  |  |  |  |  |  |
| Calcite |  |  |  |  |  |  |  |
| Calcite pellets | 150 | 7.432 | 1.043 | 0.7184 | 1.128 | 0.2242 | 0.992 |
| Crushed calcite | 150 | 21.73 | 175.9 | 1.386 | 2.641 | 0.2191 | 0.949 |
| Calcite pellets 4) | 150 | 10.12 | 55.16 | 26.60 | 2.083 | 0.2731 | 0.942 |
|  |  |  |  |  |  |  |  |
| Other particles |  |  |  |  |  |  |  |
| Richardson–Zaki 2) | 150 | 1.786 | 6.417 | 40.00 | 3.773 | 0.08462 | 0.970 |
| Zirconium balls | 150 | 2.853 | 2,903 | 9.563 | 5.963 | 0.08959 | 0.986 |
| Literature data 3) | 150 | 6.715 | 7.610 | 0.2733 | 1.972 | 0.1919 | 0.994 |

## Reynolds–Improved–Outlook model (RIO2)

|  |  |  |
| --- | --- | --- |
|  |  | (7) |

|  |  |  |
| --- | --- | --- |
|  |  | (9) |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Table 6*** *Model fit parameters (Equation (7) and (9))* | | | | | |
| **Granule type** |  |  |  |  |  |
| Spherical particles |  |  |  |  |  |
| Glass beads | 150 | 5.157 | 4,816 | 0.1998 | 0.983 |
| Steel shots | 150 | 11.59 | 23,000 | 0.2915 | 0.993 |
| Nylon balls | 150 | 10.83 | 1,588 | 0.2936 | 0.997 |
| Glass+steel+nylon | 150 | 5.984 | 3,790 | 0.2192 | 0.986 |
|  |  |  |  |  |  |
| Natural particles |  |  |  |  |  |
| Crystal sand | 150 | 7.374 | 113.8 | 0.2000 | 0.973 |
| Garnet sand | 150 | 32.13 | 7,249 | 0.3190 | 0.834 |
| Rapid filter sand | 150 | 5.453 | 1,981 | 0.1995 | 0.973 |
| Sand 1) | 150 | 6.246 | 771.6 | 0.2263 | 0.970 |
|  |  |  |  |  |  |
| Calcite |  |  |  |  |  |
| Calcite pellets | 150 | 6.703 | 2,052 | 0.2409 | 0.989 |
| Crushed calcite | 150 | 30.64 | 688.5 | 0.4225 | 0.935 |
| Calcite pellets 4) | 150 | 6.669 | 1,388 | 0.2604 | 0.900 |
|  |  |  |  |  |  |
| Other particles |  |  |  |  |  |
| Richardson–Zaki 2) | 150 | 14.26 | 304.4 | 0.3000 | 0.971 |
| Zirconium balls | 150 | 5.039 | 48,780 | 0.2000 | 0.986 |
| Literature data 3) | 150 | 10.94 | 4,845 | 0.2842 | 0.989 |

## Eureqa symbolic regression model (EUR)

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| --- | --- | --- |
|  | ( < 15,000) | (10) |

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| ***Table 7*** *Model fit parameters (Equation (7) and (10))* | | | |
| **Granule type** |  |  |  |
| Spherical particles |  |  |  |
| Glass beads | 150 | 0.8762 | 0.974 |
| Steel shots | 150 | 0.7193 | 0.981 |
| Nylon balls | 150 | 0.9457 | 0.972 |
| Glass+steel+nylon | 150 | 0.8722 | 0.976 |
|  |  |  |  |
| Natural particles |  |  |  |
| Crystal sand | 150 | 1.503 | 0.954 |
| Garnet sand | 150 | 1.554 | 0.750 |
| Rapid filter sand | 150 | 1.023 | 0.968 |
| Sand 1) | 150 | 1.030 | 0.958 |
|  |  |  |  |
| Calcite |  |  |  |
| Calcite pellets | 150 | 0.9201 | 0.950 |
| Crushed calcite | 150 | 1.672 | 0.883 |
| Calcite pellets 4) | 150 | 0.9131 | 0.947 |
|  |  |  |  |
| Other particles |  |  |  |
| Richardson–Zaki 2) | 150 | 1.503 | 0.954 |
| Zirconium balls | 150 | 0.6824 | 0.860 |
| Literature data 3) | 150 | 0.6982 | 0.944 |

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PROJECT:

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SHARING AND ACCESS INFORMATION:

* + 4TU.ResearchData
  + Delft, 7 January 2021