**Table 1** Spherical particles employed for experiments

|  |  |  |  |
| --- | --- | --- | --- |
| Particle | Size  [mm] | **b  [kg/m3] | Source (ID in AS-ONE catalogue ) |
| Glass beads (GB) small | 1.2 | 1.52×103 | BZ-1 |
| Glass beads (GB) medium | 2.0 | 1.52×103 | BZ-2 |
| Glass beads (GB) large | 3.1 | 1.53×103 | BZ-3 |
| Zirconia heavy (ZR-H) | 2.0 | 3.91×103 | CZC0200 |

**Table 2** Typical results of heat transfer experiments

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | *N*R  rpm | *F* | *T*IN | *T*OUT | *Q* | **AV,L | *hS* |
| [cm3/rot] | [K] | [K] | [W] | [K] | [W/K] |
| GB | 2 | 33.7 | 23.0 | 55.2 | 48 | 19.9 | 2.4 |
| small | 4 | 34.0 | 24.2 | 48.6 | 74 | 22.7 | 3.2 |
| GB | 2 | 35.7 | 25.1 | 52.0 | 43 | 21.4 | 2.0 |
| med. | 4 | 36.3 | 21.0 | 43.9 | 74 | 27.2 | 2.7 |
| GB | 2 | 36.1 | 23.9 | 51.1 | 44 | 21.9 | 2.0 |
| large | 4 | 34.6 | 26.8 | 48.7 | 67 | 21.8 | 3.1 |
| ZR-H | 2 | 32.2 | 17.5 | 50.2 | 67 | 22.2 | 3.0 |
|  | 4 | 32.7 | 21.7 | 43.7 | 92 | 22.9 | 4.0 |

**Table 3** Estimation of heat transfer rate by packet-renewal model

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | *N*R  rpm | ** [s] | *h*av(*τ*/3) | *h*av(*τ*/4) | *h*cal*S* |
|  | [W/(m2・K)] | [W/(m2・ K)] | [W/K] |
| GB | 2 | 30 | 179 | 206 | 4.9 |
| small | 4 | 15 | 254 | 292 | 6.9 |
| GB | 2 | 30 | 180 | 207 | 4.9 |
| med. | 4 | 15 | 255 | 292 | 6.9 |
| GB | 2 | 30 | 180 | 206 | 4.9 |
| large | 4 | 15 | 254 | 292 | 6.9 |
| ZR-H | 2 | 30 | 255 | 293 | 6.9 |
|  | 4 | 15 | 360 | 414 | 9.8 |