**Supplementary Information for**

Experimental Study of Oil Particle Emission Rate and Size Distribution during Milling

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**momentum equation of particle**

$m\frac{d\vec{u\_{p}}}{dt}=F\_{D}\left(\vec{u}-\vec{u\_{p}}\right)+\frac{g\_{x}m\left(ρ\_{p}-ρ\right)}{ρ\_{p}}+\vec{F}\_{x}$ S1

$u\_{p}$- particle velocity m/s、$t$-time，$F\_{D}$- Relaxation time ，$u$-airflow velocity surrounding the particle m/s，$g\_{x}$-gravitational acceleration m/s2，$ρ$- air density kg/m3，$ρ\_{p}$- particle density kg/m3。Fx- forces except drag forces including visual mass force, Besset force, Saffman force, Brownian force, thermophoretic force. Since Fx is far less than drag force, gravity, buoyant force, it is ignored in this paper.

$R\_{e}=\frac{ρD\_{p}\left|\vec{u}-\vec{u\_{p}}\right|}{μ}$ S2

$R\_{e}$- Reynolds number，$C\_{d}-$ drag force coefficient, $C\_{c}-$Cunningham coefficient

$R\_{e}<3$:

$F\_{D}=3πD\_{p}μ$ S3

$3<R\_{e}<500$:

 $F\_{D}=\frac{πD\_{p}^{2}|(\vec{u}-\vec{u\_{p}})|C\_{d}}{8C\_{c}}$ S4

$C\_{d}=\frac{24}{R\_{e}}+\frac{4}{\sqrt[3]{R\_{e}}}$ S5

Equation 1 can be solved by Runge-Kutta method. Fig S1 shows the horizontal distances that particles of sizes from 0.1µm to 10µm can move at initial velocity ranging from 0 to 50m/s in conditions where the airflow velocity is 0m/s. The max distance for particles of size 0.1µm, 1µm, 10µm is 2×10-3mm, 0.2mm, 7mm respectively

When drag force caused by vertical airflow plus buoyant force equals gravity, the particle can be suspended in air. Fig S2 shows the suspended airflow velocity as a function of particle sizes ranging from 0.1µm to 10µm. The suspended airflow velocity of particles of sizes 0.1µm, 1µm, 10µm is 2.8×10-7m/s，2.8×10-5m/s and 2.8×10-3m/s respectively.

Hence the surrounding airflow has more effect on the particle dispersion and deposition than the initial velocity. Therefore, the air distribution caused by the exhaust system may suspended more oil particles.



Fig. S1 Max distance particle can move in still air at an initial speed



Fig. S2 Airflow velocity to suspend particles

Table S1 Oil particle emission rate by milling in MQL mode variety cutting depth variable cutting depth

|  |  |  |  |
| --- | --- | --- | --- |
| ParticleDiameter | Case1 Cutting depth 6mm, 500rpm | Case2 Cutting depth 4mm, 500rpm | Case3 Cutting depth 0.2mm 500rpm |
| Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) |
| 0.265um | \* | 7.279 ±0.300 | \* | 7.069±0.347 | \* | 0.000±0.043  |
| 0.35um | 1.38E+11±5.77E+09 | 8.548 ±0.337 | 1.29E+11±6.25E+9 | 8.223±0.365 | 0.00E+00±1.50E+09 | 0.000±0.050  |
| 0.45um | 9.09E+10±4.31E+09 | 11.270 ±0.535 | 8.55E+10±3.35E+9 | 10.611±0.415 | 0.00E+00±7.73E+08 | 0.000±0.096  |
| 0.575um | 5.38E+10±3.11E+09 | 13.929 ±0.805 | 5.01E+10±2.39E+9 | 12.965±0.618 | 1.23E+08±2.77E+08 | 0.031±0.071  |
| 0.725um | 2.56E+10±1.70E+09 | 13.300 ±0.884 | 2.31E+10±1.73E+9 | 11.964±0.898 | 1.74E+07±1.19E+08 | 0.012±0.060  |
| 0.9 um | 9.25E+09±1.04E+09 | 9.182 ±1.036 | 8.11E+9±9.62E+8 | 8.053±0.954 | 4.98E+07±6.36E+07 | 0.050±0.064  |
| 1.3 um | 1.03E+10±1.08E+09 | 30.745 ±3.232 | 8.68E+9±1.03E+9 | 25.952±3.076 | 5.90E+07±7.16E+07 | 0.177±0.215  |
| 1.8 um | 3.68E+09±5.42E+08 | 29.178 ±4.305 | 3.11E+9±5.24E+8 | 24.709±4.164 | 3.12E+07±5.46E+07 | 0.249±0.433  |
| 2.5 um | 1.17E+09±2.22E+08 | 24.886 ±4.712 | 9.19E+8±1.92E+8 | 19.544±4.075 | 2.29E+07±2.85E+07 | 0.488±0.606  |
| 3.5 um | 2.30E+08±6.69E+07 | 13.453 ±3.906 | 1.68E+8±6.16E+7 | 9.787±3.597 | 6.48E+06±1.28E+07 | 0.377±0.744  |
| 4.5 um | 6.86E+07±3.48E+07 | 8.510 ±4.311 | 5.05E+7±3.28E+7 | 6.261±4.070 | 1.02E+07±1.51E+07 | 1.263±1.879  |
| 6.25 um | 1.10E+07±1.30E+07 | 3.669 ±4.310 | 6.75E+6±1.00E+7 | 2.242±3.329 | 6.94E+06±1.09E+07 | 2.307±3.617  |
| 8.75 um | 0 | 0 | 0 | 0 | 9.26E+05±3.79E+06 | 0.844±3.454  |
| 12.5 um | 0 | 0 | 0 | 0 | 1.16E+06±5.03E+06 | 3.078±13.371 |
| PM1.0 | \* | 63.509 ±1.730 | \* | 58.885 ±1.589 | \* | 0.093±0.162 |
| PM2.5 | \* | 148.319 ±7.360 | \* | 129.089±6.777 | \* | 1.006±0.792 |
| PM5.0 | \* | 170.282 ±9.382 | \* | 145.137±8.685 | \* | 2.646±2.170 |
| PM10 | \* | 173.951 ±10.324 | \* | 147.378± 9.302 | \* | 5.797±5.452  |

Table S2 Oil particle emission rate by milling in MQL mode variable rotation speed

|  |  |  |  |
| --- | --- | --- | --- |
| ParticleDiameter | Case3 Cutting depth 0.2mm 500rpm | Case4 Cutting depth 0.2mm 1000rpm | Case5 Cutting depth 0.2mm 1000rpm |
| Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) |
| 0.265um | \* | 0.000±0.043  | \* | 0.661±0.118 | \* | 3.921±0.425 |
| 0.35um | 0.00E+00±1.50E+09 | 0.000±0.050  | 9.71E+08±2.50E+09 | 0.761±0.136 | 6.70E+10±8.20E+09 | 4.470±0.478 |
| 0.45um | 0.00E+00±7.73E+08 | 0.000±0.096  | 5.46E+09±1.69E+09 | 0.671±0.210 | 4.71E+10±5.60E+09 | 5.836±0.695 |
| 0.575um | 1.23E+08±2.77E+08 | 0.031±0.071  | 3.92E+09±8.33E+08 | 1.020±0.215 | 2.62E+10±3.22E+09 | 6.775±0.833 |
| 0.725um | 1.74E+07±1.19E+08 | 0.012±0.060  | 2.20E+09±4.71E+08 | 1.135±0.245 | 1.12E+10±1.37E+09 | 5.801±0.710 |
| 0.9 um | 4.98E+07±6.36E+07 | 0.050±0.064  | 6.67E+08±2.34E+08 | 0.667±0.232 | 3.27E+09±5.54E+08 | 3.244±0.549 |
| 1.3 um | 5.90E+07±7.16E+07 | 0.177±0.215  | 5.80E+08±2.25E+08 | 1.738±0.672 | 2.76E+09±5.54E+08 | 8.242±1.656 |
| 1.8 um | 3.12E+07±5.46E+07 | 0.249±0.433  | 1.34E+08±1.04E+08 | 1.064±0.822 | 5.18E+08±2.11E+08 | 4.112±1.671 |
| 2.5 um | 2.29E+07±2.85E+07 | 0.488±0.606  | 2.58E+07±2.99E+07 | 0.550±0.636 | 6.82E+07±4.10E+07 | 1.452±0.873 |
| 3.5 um | 6.48E+06±1.28E+07 | 0.377±0.744  | 3.02E+06±8.21E+06 | 0.175±0.478 | 2.73E+06±6.85E+06 | 0.159±0.399 |
| 4.5 um | 1.02E+07±1.51E+07 | 1.263±1.879  | 2.49E+06±6.93E+06 | 0.309±0.859 | 1.01E+06±4.33E+06 | 0.126±0.537 |
| 6.25 um | 6.94E+06±1.09E+07 | 2.307±3.617  | 2.28E+06±5.94E+06 | 0.756±1.971 | 9.11E+05±3.74E+06 | 0.303±1.243 |
| 8.75 um | 9.26E+05±3.79E+06 | 0.844±3.454  | 1.11E+06±4.31E+06 | 1.014±3.928 | 4.05E+05±2.54E+06 | 0.369±2.314 |
| 12.5 um | 1.16E+06±5.03E+06 | 3.078±13.371 | 3.18E+05±2.25E+06 | 0.845±5.984 | 4.05E+05±3.12E+06 | 1.077±8.301 |
| PM1.0 | \* | 0.093±0.162 | \* | 4.915±0.487 | \* | 30.045±1.546 |
| PM2.5 | \* | 1.006±0.792 | \* | 8.268±1.329 | \* | 43.852±2.947 |
| PM5.0 | \* | 2.646±2.170 | \* | 8.752±1.653 | \* | 44.137±3.022 |
| PM10 | \* | 5.797±5.452  | \* | 10.522±4.696 | \* | 44.809±4.004 |

Table S2 Oil particle emission rate by milling in MQL mode variable rotation speed

|  |  |  |  |
| --- | --- | --- | --- |
| ParticleDiameter | Case6 Cutting depth 0.2mm 1000rpm | Case7 Cutting depth 0.2mm 1000rpm | Case8 Cutting depth 0.2mm 1000rpm |
| Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) |
| 0.265um | \* | 16.474±1.255 | \* | 22.984±1.640 | \* | 30.810±1.606 |
| 0.35um | 3.13E+11±2.47E+10 | 19.070±1.441 | 4.27E+11±3.16E+10 | 26.332±1.926 | 6.46E+11±3.66E+10 | 35.495±1.851 |
| 0.45um | 2.07E+11±1.56E+10 | 25.675±1.941 | 2.64E+11±1.87E+10 | 32.717±2.317 | 3.74E+11±1.94E+10 | 46.340±2.403 |
| 0.575um | 1.18E+11±9.18E+09 | 30.615±2.377 | 1.30E+11±9.86E+09 | 33.760±2.551 | 1.66E+11±8.81E+09 | 42.983±2.279 |
| 0.725um | 5.02E+10±4.56E+09 | 26.016±2.366 | 4.55E+10±3.92E+09 | 23.614±2.035 | 5.19E+10±3.92E+09 | 26.890±2.035 |
| 0.9 um | 1.49E+10±1.67E+09 | 14.786±1.656 | 1.09E+10±1.22E+09 | 10.775±1.210 | 1.07E+10±1.17E+09 | 10.594±1.165 |
| 1.3 um | 1.14E+10±1.31E+09 | 34.026±3.915 | 6.17E+09±9.76E+08 | 18.433±2.920 | 5.44E+09±8.04E+08 | 16.270±2.402 |
| 1.8 um | 1.96E+09±4.67E+08 | 15.559±3.705 | 6.57E+08±2.41E+08 | 5.213±1.912 | 4.37E+08±2.01E+08 | 3.470±1.593 |
| 2.5 um | 2.55E+08±9.62E+07 | 5.420±2.046 | 6.37E+07±4.84E+07 | 1.356±1.030 | 3.73E+07±3.46E+07 | 0.794±0.735 |
| 3.5 um | 1.46E+07±1.64E+07 | 0.850±0.958 | 7.15E+06±1.18E+07 | 0.416±0.687 | 6.66E+06±9.68E+06 | 0.387±0.564 |
| 4.5 um | 7.55E+06±1.20E+07 | 0.936±1.483 | 7.24E+06±1.18E+07 | 0.898±1.462 | 6.66E+06±1.03E+07 | 0.826±1.274 |
| 6.25 um | 7.04E+06±1.20E+07 | 2.339±4.001 | 6.97E+06±1.21E+07 | 2.315±4.032 | 3.96E+06±9.50E+06 | 1.316±3.159 |
| 8.75 um | 2.29E+06±6.13E+06 | 2.089±5.588 | 1.99E+06±6.34E+06 | 1.816±5.786 | 2.88E+06±7.11E+06 | 2.627±6.487 |
| 12.5 um | 8.48E+05±3.62E+06 | 2.256±9.624 | 3.62E+05±2.40E+06 | 0.963±6.387 | 5.40E+05±2.92E+06 | 1.436±7.779 |
| PM1.0 | \* | 132.635±4.627 | \* | 150.182±4.887 | \* | 193.112±4.741 |
| PM2.5 | \* | 187.640±7.393 | \* | 175.184±6.093 | \* | 213.646±5.596 |
| PM5.0 | \* | 189.426±7.600 | \* | 176.498±6.303 | \* | 214.859±5.767 |
| PM10 | \* | 193.853±10.247 | \* | 180.629±9.459 | \* | 218.801±9.237 |

Table S3 Oil particle emission rate by milling in cooling mode with cutting variable rotation speed

|  |  |  |  |
| --- | --- | --- | --- |
| ParticleDiameter | Case9 Cutting depth 0.2mm, 1000rpm | Case10 Cutting depth 0.2mm, 1000rpm | Case11 Cutting depth 0.2mm, 1000rpm |
| Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) |
| 0.265um | \* | 0.000±0.022 | \* | 0.793±0.114 | \* | 2.231±0.179 |
| 0.35um | 0.00E+00±8.77E+08 | 0.000±0.026 | 9.20E+09±2.13E+09 | 0.910±0.131 | 4.07E+10±3.33E+09 | 2.567±0.206 |
| 0.45um | 0.00E+00±3.96E+08 | 0.000±0.050 | 8.19E+09±1.47E+09 | 1.020±0.182 | 2.64E+10±2.26E+09 | 3.269±0.280 |
| 0.575um | 0.00E+00±1.68E+08 | 0.000±0.043 | 4.63E+09±8.95E+08 | 1.202±0.232 | 1.16E+10±1.39E+09 | 3.004±0.359 |
| 0.725um | 6.97E+07±7.60E+07 | 0.038±0.039 | 1.94E+09±4.86E+08 | 1.006±0.252 | 3.44E+09±6.22E+08 | 1.782±0.322 |
| 0.9 um | 2.32E+07±4.18E+07 | 0.023±0.042 | 4.36E+08±2.27E+08 | 0.436±0.227 | 8.44E+08±2.65E+08 | 0.841±0.261 |
| 1.3 um | 2.96E+07±4.65E+07 | 0.089±0.139 | 3.83E+08±1.98E+08 | 1.148±0.592 | 5.88E+08±2.21E+08 | 1.763±0.659 |
| 1.8 um | 2.79E+07±4.37E+07 | 0.223±0.347 | 1.50E+08±1.32E+08 | 1.188±1.045 | 2.61E+08±2.11E+08 | 2.074±1.672 |
| 2.5 um | 2.61E+07±3.62E+07 | 0.556±0.771 | 1.33E+08±1.01E+08 | 2.831±2.150 | 2.52E+08±1.67E+08 | 5.355±3.544 |
| 3.5 um | 7.33E+06±1.28E+07 | 0.427±0.747 | 9.20E+07±4.74E+07 | 5.368±2.768 | 1.97E+08±6.26E+07 | 11.481±3.652 |
| 4.5 um | 1.02E+07±1.50E+07 | 1.266±1.856 | 1.08E+08±4.54E+07 | 13.341±5.637 | 2.18E+08±6.30E+07 | 27.095±7.813 |
| 6.25 um | 6.48E+06±1.28E+07 | 2.153±4.257 | 8.80E+07±3.85E+07 | 29.247±12.781 | 1.81E+08±6.00E+07 | 60.094±19.950 |
| 8.75 um | 9.16E+05±3.75E+06 | 0.835±3.419 | 1.81E+07±1.83E+07 | 16.525±16.664 | 4.82E+07±3.18E+07 | 43.921±28.969 |
| 12.5 um | 6.34E+05±3.15E+06 | 1.686±8.374 | 4.74E+06±8.83E+06 | 12.608±23.483 | 1.18E+07±1.50E+07 | 31.339±39.885 |
| PM1.0 | \* | 0.061±0.094 | \* | 5.366±0.482 | \* | 13.693±0.673 |
| PM2.5 | \* | 0.928±0.862 | \* | 10.533±2.509 | \* | 22.886±4.030 |
| PM5.0 | \* | 2.622±2.179 | \* | 29.242±6.762 | \* | 61.461±9.520 |
| PM10 | \* | 5.610±5.879 | \* | 75.015±22.063 | \* | 165.476±36.439 |

Table S3 Oil particle emission rate by milling in cooling mode with cutting variable rotation speed

|  |  |  |
| --- | --- | --- |
| ParticleDiameter | Case12 Cutting depth 0.2mm, 1000rpm | Case13 Cutting depth 0.2mm, 1000rpm |
| Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) |
| 0.265um | \* | 2.104±0.242 | \* | 3.297±0.379 |
| 0.35um | 4.25E+10±5.29E+09 | 2.423±0.278 | 7.89E+10±1.04E+10 | 3.812±0.437 |
| 0.45um | 2.56E+10±3.19E+09 | 3.183±0.395 | 4.23E+10±5.45E+09 | 5.234±0.677 |
| 0.575um | 9.71E+09±1.39E+09 | 2.509±0.360 | 1.40E+10±2.07E+09 | 3.633±0.535 |
| 0.725um | 2.39E+09±5.19E+08 | 1.234±0.270 | 3.45E+09±6.02E+08 | 1.791±0.312 |
| 0.9 um | 6.58E+08±2.45E+08 | 0.657±0.243 | 7.78E+08±2.30E+08 | 0.777±0.228 |
| 1.3 um | 6.31E+08±2.58E+08 | 1.891±0.770 | 8.86E+08±2.83E+08 | 2.649±0.844 |
| 1.8 um | 4.91E+08±3.19E+08 | 3.902±2.534 | 7.41E+08±3.87E+08 | 5.884±3.075 |
| 2.5 um | 5.29E+08±2.27E+08 | 11.260±4.820 | 8.21E+08±3.24E+08 | 17.470±6.902 |
| 3.5 um | 4.13E+08±8.70E+07 | 24.117±5.078 | 6.62E+08±1.17E+08 | 38.634±6.811 |
| 4.5 um | 4.52E+08±9.08E+07 | 56.108±11.265 | 7.40E+08±1.19E+08 | 91.836±14.721 |
| 6.25 um | 3.80E+08±9.10E+07 | 126.385±30.222 | 6.31E+08±1.19E+08 | 209.631±39.558 |
| 8.75 um | 9.35E+07±3.73E+07 | 85.308±34.046 | 1.60E+08±5.61E+07 | 146.373±51.152 |
| 12.5 um | 2.51E+07±1.98E+07 | 66.676±52.545 | 4.15E+07±2.89E+07 | 110.415±76.818 |
| PM1.0 | \* | 12.111±0.744 | \* | 18.544±1.108 |
| PM2.5 | \* | 29.164±5.549 | \* | 44.548±7.683 |
| PM5.0 | \* | 109.389±13.545 | \* | 175.018±17.948 |
| PM10 | \* | 321.082±47.497 | \* | 531.022±67.107 |

Table S4 Oil particle emission rate by milling in cooling mode without cutting variable rotation speed

|  |  |  |  |
| --- | --- | --- | --- |
| ParticleDiameter | Case14 1000rpm without cutting | Case15 2000rpm without cutting | Case16 3000rpm without cutting |
| Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) |
| 0.265um | \* | 0.000±0.021 | \* | 0.067 ±0.025 | \* | 0.102 ±0.026 |
| 0.35um | 7.92E+08±6.67E+08 | 0.025±0.023 | 0.00E+00±8.72E+08 | 0.000 ±0.029 | 0.00E+00±7.08E+08 | 0.000 ±0.030 |
| 0.45um | 0.00E+00±3.32E+08 | 0.000±0.041 | 4.56E+08±3.62E+08 | 0.061 ±0.045 | 4.47E+08±2.56E+08 | 0.057 ±0.032 |
| 0.575um | 0.00E+00±1.12E+08 | 0.000±0.030 | 1.59E+08±1.34E+08 | 0.046 ±0.034 | 2.46E+08±1.70E+08 | 0.068 ±0.043 |
| 0.725um | 3.79E+07±5.44E+07 | 0.021±0.030 | 8.79E+07±8.09E+07 | 0.048 ±0.042 | 2.08E+08±1.22E+08 | 0.108 ±0.062 |
| 0.9 um | 1.54E+07±3.74E+07 | 0.015±0.037 | 4.09E+07±5.67E+07 | 0.041 ±0.057 | 1.28E+08±1.07E+08 | 0.128 ±0.107 |
| 1.3 um | 3.48E+07±5.21E+07 | 0.104±0.156 | 1.03E+08±9.10E+07 | 0.310 ±0.273 | 3.19E+08±1.76E+08 | 0.957 ±0.527 |
| 1.8 um | 3.78E+07±5.27E+07 | 0.302±0.419 | 9.81E+07±1.05E+08 | 0.780 ±0.833 | 2.37E+08±1.87E+08 | 1.882 ±1.487 |
| 2.5 um | 3.25E+07±3.84E+07 | 0.692±0.816 | 9.60E+07±8.40E+07 | 2.041 ±1.785 | 2.60E+08±1.61E+08 | 5.520 ±3.416 |
| 3.5 um | 1.46E+07±1.73E+07 | 0.853±1.011 | 7.77E+07±4.51E+07 | 4.533 ±2.635 | 2.19E+08±5.85E+07 | 12.800 ±3.418 |
| 4.5 um | 1.73E+07±1.91E+07 | 2.145±2.363 | 7.99E+07±4.12E+07 | 9.910 ±5.116 | 2.01E+08±5.67E+07 | 24.982 ±7.041 |
| 6.25 um | 1.48E+07±1.69E+07 | 4.931±5.613 | 7.00E+07±3.37E+07 | 23.275 ±11.195 | 1.73E+08±5.52E+07 | 57.539 ±18.341 |
| 8.75 um | 3.61E+06±8.12E+06 | 3.289±7.406 | 1.74E+07±1.62E+07 | 15.830 ±14.807 | 4.34E+07±2.86E+07 | 39.587 ±26.109 |
| 12.5 um | 9.41E+05±3.79E+06 | 2.502±10.094 | 4.55E+06±8.42E+06 | 12.107 ±22.390 | 9.77E+06±1.26E+07 | 25.979 ±33.543 |
| PM1.0 | \* | 0.037±0.076 | \* | 0.333 ±0.098 | \* | 0.586 ±0.140 |
| PM2.5 | \* | 1.135±0.934 | \* | 3.464 ±1.992 | \* | 8.944 ±3.765 |
| PM5.0 | \* | 4.133±2.734 | \* | 17.907 ±6.089 | \* | 46.726 ±8.685 |
| PM10 | \* | 12.353±9.687 | \* | 57.012 ±19.536 | \* | 143.852 ±33.068 |

Table S4 Oil particle emission rate by milling in cooling mode without cutting variable rotation speed

|  |  |  |
| --- | --- | --- |
| ParticleDiameter | Case17 4000rpm without cutting | Case18 5000rpm without cutting |
| Counts/h(Mean±SD) | mg/h(Mean±SD) | Counts/h(Mean±SD) | mg/h(Mean±SD) |
| 0.265um | \* | 0.219 ±0.046 | 　\* | 0.162 ±0.052 |
| 0.35um | 0.00E+00±1.15E+09 | 0.000 ±0.052 | 0.00E+00±9.28E+08 | 0.000 ±0.050 |
| 0.45um | 1.60E+08±4.69E+08 | 0.026 ±0.058 | 6.11E+08±3.20E+08 | 0.080 ±0.040 |
| 0.575um | 5.35E+08±2.39E+08 | 0.143 ±0.063 | 6.48E+08±2.32E+08 | 0.161 ±0.061 |
| 0.725um | 4.12E+08±1.88E+08 | 0.214 ±0.098 | 6.07E+08±2.32E+08 | 0.315 ±0.120 |
| 0.9 um | 2.61E+08±1.34E+08 | 0.261 ±0.134 | 3.69E+08±1.59E+08 | 0.369 ±0.159 |
| 1.3 um | 6.04E+08±2.27E+08 | 1.811 ±0.678 | 9.31E+08±2.70E+08 | 2.782 ±0.805 |
| 1.8 um | 4.80E+08±3.00E+08 | 3.809 ±2.383 | 7.15E+08±3.96E+08 | 5.678 ±3.142 |
| 2.5 um | 4.57E+08±2.24E+08 | 9.714 ±4.770 | 7.25E+08±2.92E+08 | 15.424 ±6.203 |
| 3.5 um | 4.23E+08±9.04E+07 | 24.717 ±5.277 | 6.99E+08±1.16E+08 | 40.804 ±6.774 |
| 4.5 um | 3.98E+08±9.12E+07 | 49.358 ±11.316 | 6.56E+08±1.16E+08 | 81.393 ±14.424 |
| 6.25 um | 3.47E+08±8.09E+07 | 115.272 ±26.889 | 6.10E+08±1.30E+08 | 202.757 ±43.151 |
| 8.75 um | 9.33E+07±4.60E+07 | 85.064 ±41.952 | 1.67E+08±7.20E+07 | 152.683 ±65.674 |
| 12.5 um | 2.43E+07±2.24E+07 | 64.635 ±59.498 | 4.44E+07±3.37E+07 | 118.156 ±89.548 |
| PM1.0 | \* | 1.115 ±0.199 | \* | 1.279 ±0.226 |
| PM2.5 | \* | 16.449 ±5.378 | \* | 25.162 ±7.003 |
| PM5.0 | \* | 90.523 ±13.595 | \* | 147.359 ±17.406 |
| PM10 | \* | 290.859 ±51.651 | \* | 502.800 ±80.486 |







Fig. S3 Oil particle emission rate at each size as a function of rotation speed in MQL mode with 0.2mm cutting depth



 12.5µm 8.75µm 6.5µm



4.5µm 3.5µm 2.5µm



1.8µm 1.3µm 0.9µm



0.725µm 0.575µm 0.45µm



0.35µm 0.265µm

Fig. S4 Fitting curve of particle emission rate at each size on rotation speed in cooling mode with 0.2mm cutting depth

**Cutting programme**

%

O1503

G54S500M3

S1000M3

G90G0Z150.

X-100.Y-100.

Z50.

#102=3000

S#102M3

Z10.

#100=0.4

G1Z-[#100\*0.5]F100

#101=66.5

WH[#101GE10]DO1

G1X-#101

Y0.F100

G2I#101

#101=#101-4

EN1

G0Z150.

M5

M30

%