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INERTIAL LIMITATIONS IN SAMPLING COARSE DUST*

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1. INTRODUCTION

Current interest in the sampling of total dust is mainly concerned with the measurement of the concentration of total inhalable dust to which a person is exposed in his daily work. This paper is concerned with total dust sampling for another purpose, namely to compare dust concentrations on corresponding workplaces in different industries. There is a difference between these two types of total dust measurement.

The first type of measurement, e.g. a total dust sampler near the mouth region of an individual, will show a scatter in the results which somehow include the fact that mouth and nose are not the ideal reference dust samplers. On the contrary in comparative measurements it is important to obtain representative and reproducible results, upto a fixed particle size which is independent of wind and turbulence. This we call "comparable sampling".

Our investigation of the inertial limitations of dust sampling mainly serves the second purpose. To make a dust sampler with a fixed flow rate as well as possible independent of wind and turbulence, we should use the highest aspiration velocity not giving impaction on the wall of the probe. This investigation is part of a project to develop simple design rules, based on physical effects for standardisation of comparable sampling of total dust.

2. ASPIRATION CHARACTERISTICS

To obtain comparable samples with different probes in coarse dust sampling, the high-cut-off particle diameter should be the same for each probe. From the aspiration characteristics of two probes in figure 1 it is seen that the only direction of the inlet which gives predictable high-cut-off curves is vertically downward ($\theta = 180^{\circ}$), because the vertical upward inlet ($\theta = 0^{\circ}$) gives no high-cut-off curves at all and for the horizontal probe ($\theta = 90^{\circ}$) the efficiency theoretically approaches to 90 % for large particles, but in practice it will be determined by the

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component of the wind velocity parallel to the axis of the probe. Therefore the downward inlet is an evident forward requirement for comparable sampling of total dust.

3. CRITERION FOR COMPARABLE SAMPLING

Last year the theoretical criterion for comparable sampling[1] was introduced (figure 2) which is analysed in a recent report[2]. For coarse dust sampling with downward tubes, this criterion gives three different physical limitations depending on the diameter of the tube inlet. In the figure, the aspiration efficiency for calm air sampling depends on two dimensionless magnitudes: $\eta\,(m_{DQ}, k_{dQ})$. On the horizontal axis the tube size number, m_{DQ}, is plotted. This depends only on device parameters and is proportional with the diameter of the inlet:

$$m_{DQ} = R_o \left(\frac{4\pi}{Q}\right)^{0.4} g^{0.2} = 2.17\, D_o Q^{-0.4} \quad \text{(S.I. base units)} \qquad (1)$$

On the the vertical axis the particle size number, k_{dQ}, is plotted. This is proportional with the aerodynamic diameter (d_{ae}) of the particle and nearly independent of the volume flow:

$$k_{dQ} = \left(\frac{4\pi\,\tau^2 v_s^{\,3}}{Q}\right)^{0.1} = 4470\, d_{ae} Q^{-0.1} \quad \text{(S.I. base units)} \qquad (2)$$

Here the settling velocity is given by

$$v_s = \tau g = 3\;10^7\, d_{ae}^{\;2} \quad \text{(S.I. base units)} \qquad (3)$$

In figure 2, the theoretical limits for an aspiration efficiency of 94 % are given by three straight lines. The influence of sedimentation, which is determined by the relative velocity $\frac{v_s}{v_e}$, limits the efficiency to 94 % for $\frac{v_s}{u_e} < \frac{1}{16}$. Here u_e is the effective aspiration velocity which is determined by the outer radius of the tube.

The influence of dynamic escape, which is determined by k_{dQ}, limits the efficiency to 96 % for $k_{dQ} < 0.55$. The influence of impaction on the wall of the tube, which is determined by the Stokes' number limits the efficiency to an unknown small amount for Stk < 74. This third limitation is highly questionable. For comparable sampling it was shown[2] that dynamic escape gives the most sharp cut-off curve, for the largest particles which can be sampled with a given volume flow. Therefore the dynamic limit is to be used preferably. For sampling tubes with different values of m_{DQ} between 0.2 and 0.9 the efficiency is limited by dynamic escape. This means

that for

tubes with different diameters and the same volume flow the high-cut-off particle diameter is the same. On this interval of m_{DQ} the aspiration velocity is greatest for $m_{DQ} = 0.2$, at the intersection of the impaction limit and the dynamic limit. Therefore, to make dust concentration measurements most insensitive for the influence of wind and turbulence, it is advantageous to use probes with m_{DQ} values near this intersection.

To determine the impaction limit experimentally particle trajectories were photographed on the points marked ⊕ in figure 2, for a tube with $m_{DQ} = 0.1$ and particles with $k_{dQ} = 0.58$ and 0.69. This gives Stk = 600 and Stk = 1000, respectively. These values are far beyond the present impaction limit of Stk = 74.

Before showing these results I must give an impression of the effects being investigated. Therefore, the calculated particle trajectories are shown for dynamic escape in figure 3 and for impaction on the wall of the tube in figure 4.

Figure 3 gives the trajectories of particles falling through the flow field of a point sink. This simple flowfield can be used because dynamic escape is independent of the size of the tube and of the aspiration velocity. It is seen that dynamic escape limits the region where the particles come from to a cylindrical space with radius X_c which is inside the region for 100 % efficiency with a radius X_a. Here, X_a is the analytical aspiration distance for 100 % efficiency:

$$X_a = (Q/(\pi\ v_s))^{\frac{1}{2}}.$$

The influence of dynamic escape calculated from boundary trajectories:

$$0.62 < \eta_c < 0.65,$$

corresponds very well with the theoretical approximation of LEVIN:

$$\eta_L = 0.62.$$

Therefore LEVIN's formula for the aspiration efficiency is used to define the dynamic limit:

$$\eta_L = 1 - 0.8\ k_{dQ}^{5} + 0.08\ k_{dQ}^{10}$$

In figure 4 the calculated trajectories are shown for two particles in a potential flowfield of a thin-walled tube. From this figure, it appears that some particles between these two trajectories may impact on the opposite wall of the inlet. Moreover, impaction losses appear to reduce the aspiration of particles which fall closely along the tube wall, whereas dynamic escape reduces the aspiration of particles far from the tube wall. Therefore the two effects are additive. From other theoretial considerations we deduced that at least for Stk < 74 impaction losses will be negligible.

4. EXPERIMENTAL RESULTS

The experiments were conducted with tubes of 2 mm inner diameter and aspiration velocities of about 125 m s^{-1}, with particle sizes of 60 and 75 μm. These particles were generated with a vibrating orifice generator. Furthermore the settling velocity of the particles could be measured from the photographs.

In figure 5, Stk = 600. We expected that the innermost particles would orbit in front of the inlet, but apparently none of them crosses the axis of the tube significantly. The orbiting particles would certainly have been detected because an Argon ion laser lights a small region in front of the inlet. This means that for Stk = 600 we find no impaction limitation.

In figure 6, Stk = 1000. Here the same result is found: the innermost trajectories give no orbiting particles. However, this is not definite, because we had no laser here to lighten the particles closely in front of the inlet. For this case we determined the dynamic efficiency from a number of boundary trajectories. The measured dynamic efficiency is

$$\eta_m = 0.50$$

where LEVIN's theory gives $\eta_L = 0.89$.

5. CONCLUSIONS

For downward sampling impaction on the wall of the inlet can be neglected and the loss of dynamic escape is greater than in LEVIN's theory. For comparable sampling the aspiration velocity can be taken as high as necessary to make the measurements less dependent on environmental conditions, without introducing serious errors due to impaction of particles on the wall of the probe.

6. REFERENCES

1. KUILE, W.M. TER Dust sampling criteria, Proceedings of the Annual Conference of the GAF, Sept. 1978 Vienna, Austria, p. 365.
2. KUILE, W.M. TER Comparable sampling at the workplace, Report F 1699, TNO Research Institute for Environmental Hygiene, Sept. 1979, Delft, The Netherlands.

Table 1. Experimental data of the photographs in figure 5 and 6

		Figure 5	Figure 6	
Tube size number	m_{DQ}	= 0.10	0.10	
Particle size number	k_{dQ}	= 0.58	0.69	
Stokes' number	Stk_o	= 600	1000	
Tube diameter (inner)	D_i	= 2.0	2.0	mm
(outer)	D_o	= 2.6	4.0	mm
Volume flow	Q	= 370	422	$cm^3 s^{-1}$
Aspiration velocity	u_i	= 118	134	$m\ s^{-1}$
Aerodyn. particle diam.	d_{ae}	= 59	75	µm
Strob. frequency	ν_{str}	= 200	250	Hz
puls energy	E_{puls}	= 2	2	J per puls
Ar laser power (blue)	P_{laser}	= 30	--	mW

Figure 1

SHAPE OF THE ASPIRATION CHARACTERISTICS FOR TWO SAMPLING DEVICES

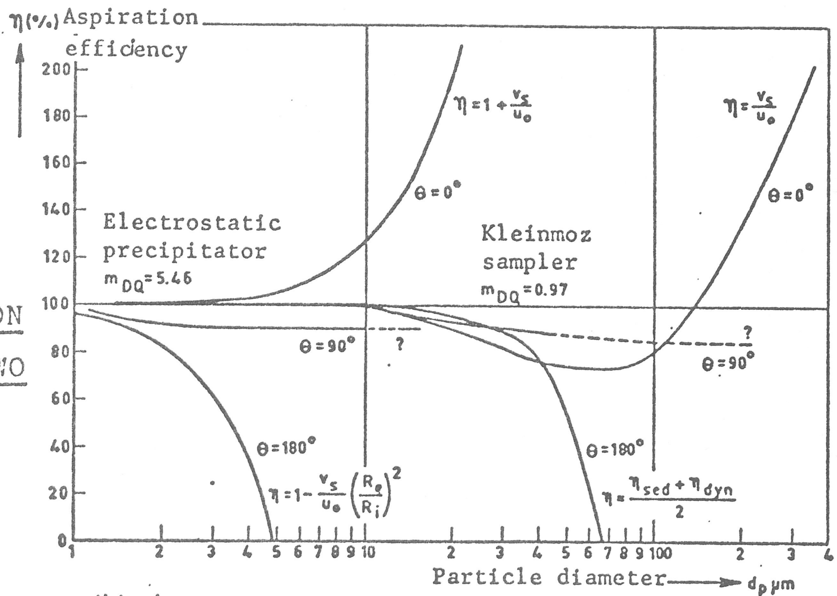
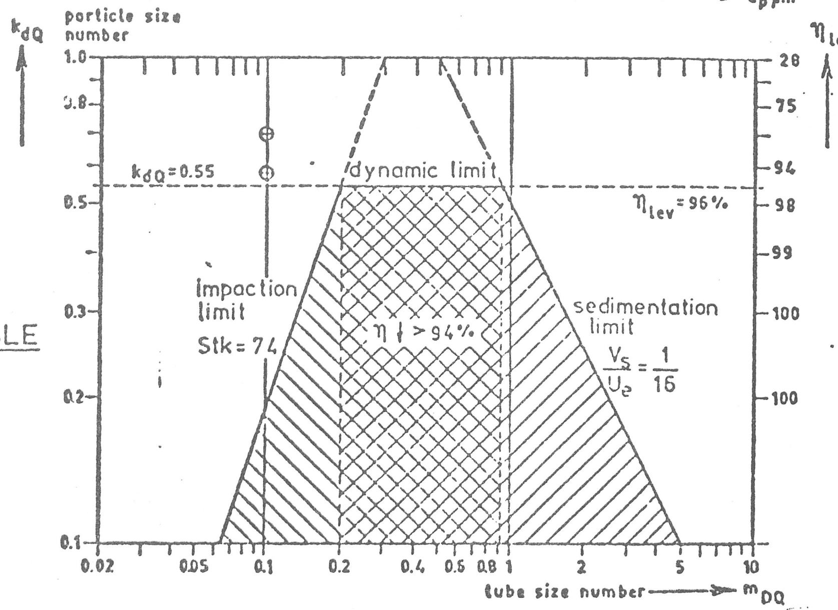


Figure 2

CRITERION FOR COMPARABLE SAMPLING



Levin theory:

$$\eta_L = 1 - 0{,}8\,k_{dQ}^{5} + 0{,}08\,k_{dQ}^{10} = 0{,}62$$

Calculated boundary trajectories:

$$\eta_c = \frac{x_c^2}{x_a^2} \longrightarrow 0{,}62 < \eta_c < 0{,}65$$

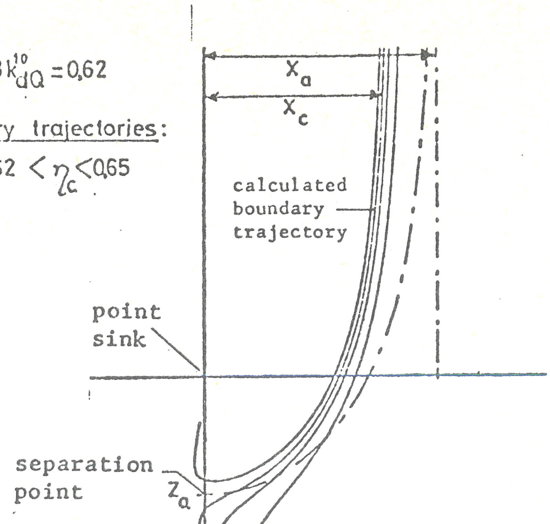


Figure 3

DYNAMIC ESCAPE

The figure shows trajectories of particles falling in the flowfield of a point sink. They come from a limited region, inside the region for 100% efficiency.

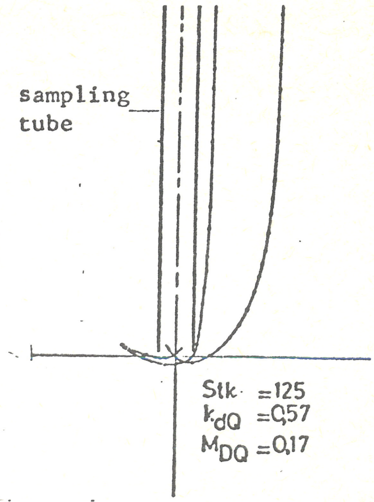


Figure 4

IMPACTION ON THE WALL

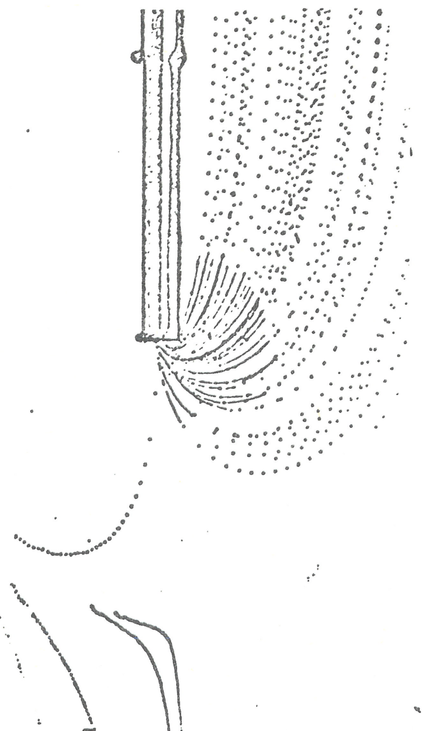


Figure 5

Photograph of the aspiration of sedimenting particles with Stk = 600. Data in table 1.

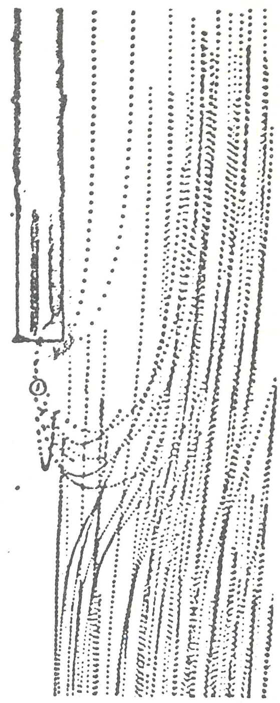


Figure 6

Photograph of the aspiration of sedimenting particles with Stk = 1000. Data in table 1.