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SOURCE MEASUREMENT: DETERMINING THE RELEASE FROM A POINT SOURCE BY REMOTELY LOCATED SAMPLERS*

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ABSTRACT

The effluent from some chemical and nuclear processes may be offensive or constitute a health hazard. Proper control requires a knowledge of the source characteristics. Often, measurement of the source cannot be accomplished by a direct technique. By employing a distant, circular sampling array, Sutton's equation can be modified for the calculation of the release from any such inaccessible point source.

To fully evaluate the hazard from experiments and processes involving the release of gaseous material to the atmosphere, it is necessary to measure the source in terms of total release. A modification of Sutton's equation is well suited for such an analysis. The method used is to consider a cylinder of infinite height surrounding the source with a radius determined by a sampling array. Now provided the samplers are operated for a sufficient period both before the cloud reaches the array and after it has passed, all of the material released must cross the boundary.

Sutton's equation for a continuous ground level point source is:(1)

$$\chi = \frac{2Q}{\pi C_y C_z u x^{2-n}} \exp \frac{-y^2}{C_y^2 x^{2-n}} \exp \frac{-z^2}{C_y^2 x^{2-n}}$$

where:

χ is the concentration of material at the point x, y, z in units of material per cubic meter

Q is the release rate from the source in units of material per unit time

x is the distance from the source in downwind direction

y is the horizontal displacement from the x direction z is the height above ground

u is the mean wind speed in units of meters per unit time

C_y, C_z, and n are Sutton's diffusion parameters.

The quantity of material passing any point per square meter per unit time is given by $\chi \cdot u$. If x is equal to the radius of the cylinder, this gives the amount of material leaving the cylinder per square meter per unit time at that point. The total amount of material leaving the cylinder at that point per square meter is $\int_{t_o}^{t_1} \chi \cdot u \, dt$ where the limits are chosen so as to include the total release. Using the fact that the integral may be taken by parts, we may take as many sampling periods as are convenient during the release time.

$$\int_{t_o}^{t_1} \chi \, u \, dt = \int_{t_o}^{t_1} \frac{2Q}{\pi C_y C_z x^{2-n}} \exp \frac{-y^2}{C_y^2 x^{2-n}} \exp \frac{-z^2}{C_z^2 x^{2-n}} \, dt = \chi' \quad (1)$$

If the sampling periods are chosen so that the meteorological parameters may be averaged over the period we obtain:

$$\chi' = \frac{2}{\pi C_y C_z x^{2-n}} \exp \frac{-y^2}{C_y^2 x^{2-n}} \exp \frac{-z^2}{C_z^2 x^{2-n}} \int_{t_o}^{t_1} Q \, dt \quad (2)$$

but $\int_{t_o}^{t_1} Q \, dt$ is the total release M provided Q is zero for $t < t_o$ and $t > t_1$.

Therefore:

$$\chi' = \frac{2M}{\pi C_y C_z x^{2-n}} \exp \frac{-y^2}{C_y^2 x^{2-n}} \exp \frac{-z^2}{C_z^2 x^{2-n}} \quad (3)$$

The cylinder can be divided into segments according to the placement of samplers around the base. Let the location of the K^{th} sampler be y_K, with y_{Kl} the midpoint between the K^{th} sampler and the adjacent sampler on the left, and y_{Kr} the similar right midpoint.

The total amount of material leaving the segment is then:

$$M' = \int_0^{\infty} \int_{y_{Kl}}^{y_{Kr}} \chi' \, dy \, dz \quad (4)$$

Due to variations in the wind direction during the sampling period, the second integral must be approximated. However, these variations will have an averaging effect over the length L and we could use:

$$\int_{y_{Kl}}^{y_{Kr}} \chi' \, dy = L \, \chi'(y_K) \quad (5)$$

where L is the arc length determined by y_{Kl} and y_{Kr}.

Now we have:

$$M' = \frac{2M}{\pi C_y C_z x^{2-n}} \exp \frac{-y_K^2}{C_y^2 x^{2-n}} L \int_0^\infty \exp \frac{-z^2}{C_z^2 x^{2-n}} dz \qquad (6)$$

$$M' = \frac{2M}{\pi C_y C_z x^{2-n}} \exp \frac{-y_K^2}{C_y^2 x^{2-n}} L \frac{\sqrt{C_z^2 x^{2-n}}\;\pi}{2} \qquad (7)$$

At the sampling stations we have

$$\chi' = \frac{2M}{\pi C_y C_z x^{2-n}} \exp \frac{-y_K^2}{C_y^2 x^{2-n}} \exp \frac{-z^2}{C_z^2 x^{2-n}} \qquad (8)$$

If the sample is collected at or near ground level we have:

$$\chi' = \frac{2M}{\pi C_y C_z x^{2-n}} \exp \frac{-y_K^2}{C_y^2 x^{2-n}} = \frac{D}{A_e} \qquad (9)$$

where D is the amount of material in the sample and A_e is the effective area of the sample in square meters.

A_e may be defined as follows:

$$A_e = A_g \frac{v_s}{u} \qquad (10)$$

where: A_g is the geometrical area of the sampler

v_s is the face velocity through the sampler, and

u is the wind speed.

Since $v_s = \frac{V}{A_g}$

where V is the volume sampling rate

now

$$A_e = A_g \frac{1}{u} \frac{V}{A_g} = \frac{V}{u} \quad (11)$$

By substituting (11) and (9) into (7) we have:

$$M' = D \frac{u}{v} L \frac{\sqrt{C_z^2 x^{2-n} \pi}}{2} \quad (12)$$

These values then may be summed around the cylinder to find the total release M.

A more elaborate derivation is possible starting with Sutton's elevated continuous point source equation. Using these conditions we find at the sampler:

$$X' = \frac{2M}{\pi C_y C_z x^{2-n}} \exp \frac{-y^2}{C_y^2 x^{2-n}} \exp \frac{-h_e^2}{C_z^2 x^{2-n}} = \frac{D}{A_e} \quad (13)$$

where h_e is the effective stack height.

By substitution we now have:

$$M' = D \frac{u}{V} L \frac{\sqrt{C_z^2 x^{2-n} \pi}}{2} \exp \frac{h_e^2}{C_z^2 x^{2-n}} \quad (14)$$

The wind speed can easily be measured for the sampling period and an average value taken. C_z and n are functions of atmospheric stability and can be measured. Since these parameters change through the day the sampling periods are best chosen so as to take advantage of periods when these parameters are fairly constant.

Thus any point source may be evaluated by the proper placement of air sampling units on the ground surrounding the source, the measurement of two of Sutton's parameters, and a sampling period sufficiently long to measure the total passage of the cloud.

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REFERENCES

1. O. G. Sutton, "Micrometeorology," (McGraw-Hill, New York, 1953), p. 293.