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Effects of Time and Height on Behavior of Emissions

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The effect of the two parameters is reviewed. Variability with time is discussed in relation to stability and other atmospheric conditions. The magnitude of ground level concentrations from elevated release is discussed as an interaction between rate of emission release, physical height of stack, and thermal conditions. The point is made that plant effluent rates have increased in proportion to stack height.

Time Variation of Emissions

The time variation of emissions may be used to modify downwind ground concentrations of an effluent but does not change the overall pollutant loading in the atmosphere. Two types of time modification can be used: the period of time over which a given amount of pollutant is emitted can be varied, and the specific time of day the release period occurs can be chosen.

Effluent release periods can vary from instantaneous (puff) to continuous (plume) emissions. All other things being equal, the puff has the potential for giving both the highest and lowest ground level concentration at a fixed location within a few miles of the emission point. The continuous release can be thought of as an infinite series of puff releases and, because of the variation in transport direction over a given period of time, the concentration at a fixed point will be lower, the longer the averaging period. Thus, a particular puff may be transported directly to a fixed point giving a high, short-term concentration. Succeeding puffs will tend to miss this same fixed point by varying degrees, giving lower or even zero concentrations, and, when averaged, give a lower, long-term concentration. The statistical stability of the continuous plume makes possible the use of diffusion models to predict downwind, fixed point concentrations whereas this is not now possible with puff emissions because of their extreme short-term, time-space variability.

Because the variability of average meteorological conditions from hour to hour affects atmospheric pollutant diffusion rates and effective plume rise in the case of stacks, a wide range of downwind concentrations can occur for a constant emission rate and source emission configuration. In general, more rapid diffusion occurs during the daylight hours, especially in the lower 1000 ft above the ground. On the other hand, nighttime inversions inhibit diffusion especially in the vertical direction. Table 1 is a diffusion categorization scheme related to weather conditions as devised by Pasquill (*1*) ranging from type A (rapid diffusion characteristic of daytime) to type F (slow diffusion characteristic of

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Table 1. Relation of Pasquill diffusion types to weather conditions.[a]

Surface wind speed, m/sec	Daytime insolation			Nighttime conditions	
	Strong	Moderate	Slight	Clouds covering ≥1/2 of sky	Clouds covering <1/2 of sky
<1	A	A–B	B	F	*
2	A–B	B	C	E	F
4	B	B–C	C	D	E
6	C	C–D	D	D	D
>6	C	D	D	D	D

[a] Code: A = extremely unstable; B = moderately unstable; C = slightly unstable; D = neutral; E = slightly stable; F = moderately stable; * = very stable.

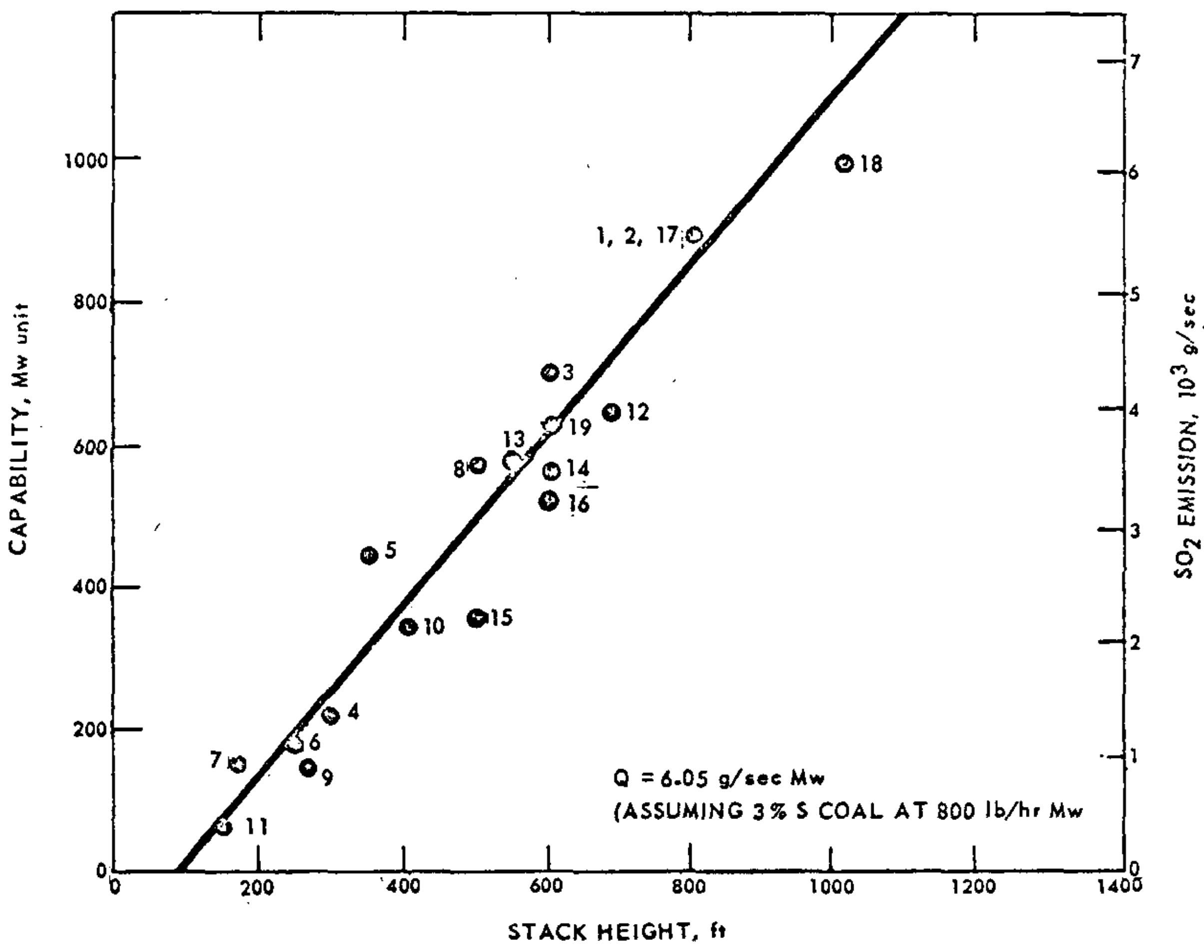

FIGURE 1. Sulfur dioxide emission vs. stack height: (1) Keystone; (2) Bull Run; (3) Paradise; (4) Colbert; (5) John Sevier; (6) Kingston; (7) Widows Creek, No. 3; (8) Widows Creek, No. 7; (9) Johnsonville, No. 5–6; (10) Johnsonville, No. 7–10; (11) Watts Bar; (12) Cliffy Creek; (13) Joliet; (14) Fort Martin; (15) Northport; (16) Sioux; (17) Homer City; (18) Conemaugh; (19) Cleveland. HEW data (2).

night). Note the separation into daytime and nighttime conditions. The stronger the solar insolation during the day and the greater the cloudiness at night, the more rapid is the diffusion. Also, lower wind speeds are related to rapid diffusion during the day and slow diffusion at night. However, lower wind speeds and ambient temperatures characteristic of the night enhance effective plume rise, which results in lower ground-level concentrations. At this point it should be pointed out that rapid diffusion does not necessarily result in lower downwind concentrations. For a fixed plume centerline height above the ground, the more rapid the diffusion, the higher is the maximum ground-level concentration and the closer is the maximum to the source. However, for ground-level releases, the more rapid the diffusion, the lower the downwind concentration.

Effect of Height of Emissions

It is obvious that the higher the release point of an effluent is above the surface, the greater the volume of air that is available for mixing will be, and the longer it will take for the pollutant to reach the ground. Consequently, in the last decade there has been a steady increase in the height of power plant stacks reaching to 1000 ft. At the same time, plant effluent rates have increased in proportion to stack height, as indicated by the U.S. Department of Health, Education and Welfare (*2*) (Fig. 1). There appears to be an almost one-to-one correspondence between the height of the stack in feet and the electric power capability in megawatts. Thus, a great deal of the benefit afforded by a high emission point is offset by a greater pollutant release rate. It should also be noted that no matter what the height of the emission, the pollutant loading into the atmosphere remains unchanged (unless scavenging and/or chemical change is enhanced at higher elevations). Also, the effect of emission height upon ground-level concentration becomes less with downwind distance.

The magnitude of ground-level concentration from an elevated release is the result of the interaction of numerous factors. Two obvious factors are pollutant emission rate and the physical height of the stack. Added to the latter is the initial plume rise due to buoyancy and inertia forces. The stack characteristics which control plume rise are effluent exit temperature and velocity and stack diameter. The meteorological parameters controlling plume rise are atmospheric temperature and stability and wind speed. Furthermore, the aerodynamic effect of the surrounding building complex may cause a phenomenon known as downwash. This is especially true of small, rooftop stacks with low effluent exit velocity and temperature. Finally, the Gaussian diffusion expression is a function of wind speed and the horizontal and vertical dispersion coefficient, the latter being dependent upon atmospheric turbulence.

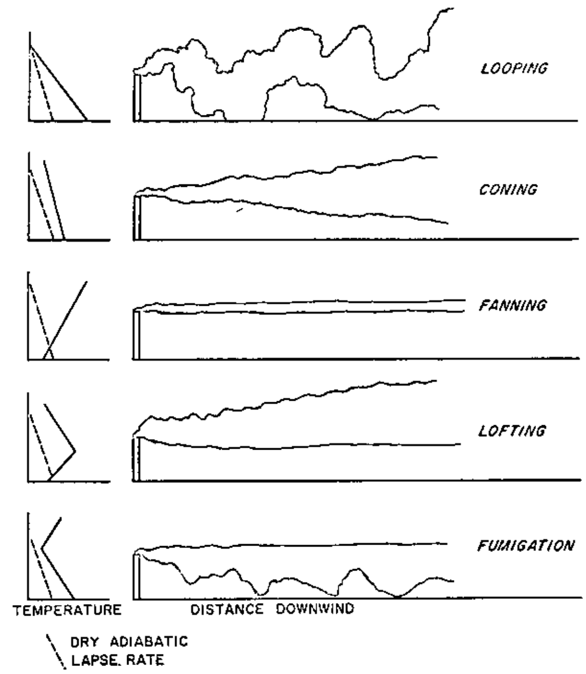

FIGURE 2. Types of plumes.

Elevated plumes can be described visually and meteorologically as looping, coning, fanning, lofting, and fumigating and are shown in Figure 2. Highest short-term (about 1 min) concentrations at the ground occur with looping plumes characteristic of daytime convective thermals and light winds. Highest longer-term (½ hr to several hours) concentrations occur with fumigating plumes characteristic of sunrise with light winds, limited mixing height and near-surface ther-

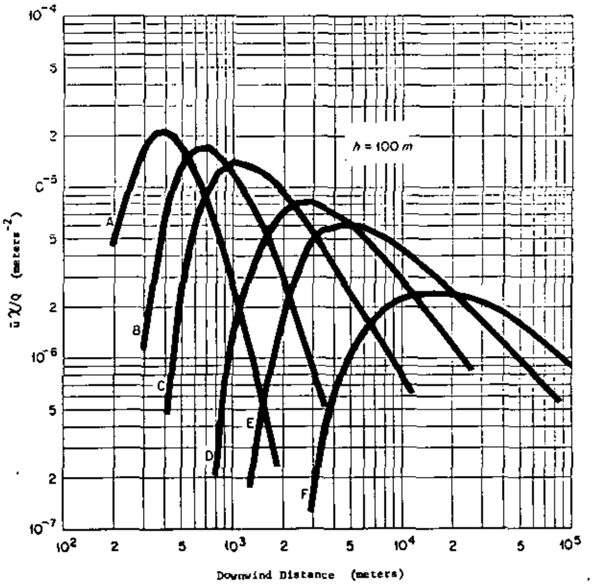

FIGURE 3. Ground concentrations vs. distance for 100 m elevated plume for six stability conditions.

mal instability. When averaged over a period of an hour the looping plume is analogous to a type A or B diffusion rate described in Table 1. Coning is related to diffusion type C or D, and fanning to type E or F. Lofting is a special case of fanning, where, because of a turbulent layer of air aloft, the plume is "lofted" upward. Figure 3 shows a plot of hourly average concentration χ normalized by source emission rate Q and wind speed $\bar{u}$ as a function of downwind distance and assuming the Gaussian diffusion model, a 100-m stack height, and Pasquill's (*1*) diffusion categorization and parameters. Note the peak concentration occurs closest to the source under looping conditions where the effluent at particular instances during the hour is

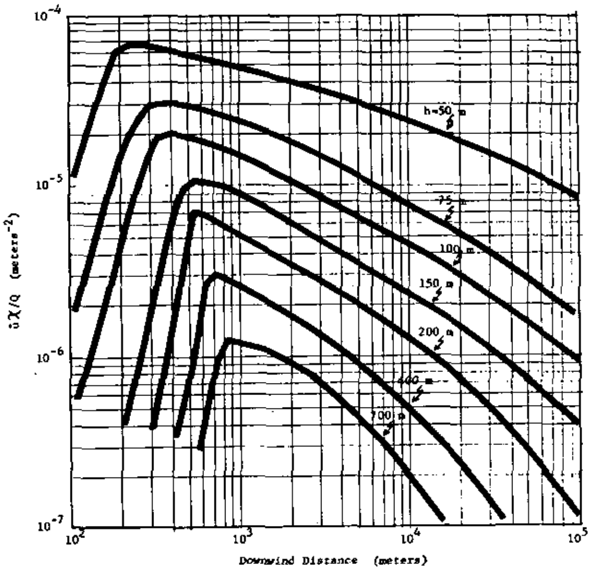

FIGURE 4. Envelope curves of peak ground concentration for various stabilities and elevated plume heights.

brought rapidly to the ground. An envelope curve can be drawn over the peaks as is shown in Figure 4 for plume centerline heights of 50–700 m. The point to be made is that peak, close-in concentrations are the result of rapid diffusion, while at greater distances (10^4–10^5m) the peaks are the result of slow diffusion characteristic of inversion conditions.

REFERENCES

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