Pipeline Agglomerator Design Problem: Applications of Population Balances

You have produced a population of .25 micron aerosol primary particles that you have successfully quenched by cooling the gas without forming heavily sintered agglomerates. You now need to collect them. You plan to use a combination of collectors, capturing the large agglomerates in a cyclone separator and the smaller particles in a baghouse. The bags are kept clean by regularly back pulsing them with high pressure gas. The frequency of pulsing is related to the inlet particle mass concentration (the more mass, the more frequent pulsing). To minimize baghouse size and to keep bag fatigue to an acceptable level, your design must collect 75% of the particle mass in the cyclone. You hope to form loose agglomerates large enough to be collected in the cyclone in a length of pipe connecting the aerosol formation zone with the cyclone.

Given a total flowing mass of 35000 pph at 200 C and 10 psig, with equivalent molecular weight (mass gas+solids)/mol gas of 44.5, gas viscosity of .0157 cp, solids mass fraction of .15, and solids density of 2.2 g/cc, develop a model of simultaneous agglomeration and fragmentation that allows you to calculate the particle size distribution from:

$$u_z \frac{\partial n(V)}{\partial z} = \frac{1}{2}\int_0^V \beta(\phi, V-\phi)n(\phi)n(V-\phi)d\phi - n(V)\int_0^\infty \beta(\phi, V)n(\phi)d\phi$$
$$+\int_V^\infty \Gamma(\Phi)b(V;\Phi)n(\Phi)d\Phi - \Gamma(V)n(V)$$

You are to develop a sectional model in which the particle volumes increase geometrically by a factor of 2 from section to section. This will allow you to calculate the evolution of the particle size distribution at steady-state along the pipe axis.

Use your model to find the minimum pipe diameter that allows you to capture 75% of the particle mass in a cyclone separator having a cut size (d_{pc}) of 24 micron with a grade efficiency curve equal to:

$$\eta = \frac{\left(d_p / d_{pc}\right)^2}{1+\left(d_p / d_{pc}\right)^2}$$

Consider only integer values of the pipe diameter in inches. Check the pipe pressure drop to be sure that you lose no more than 20% of the gage pressure in the pipeline agglomerator. You may need to use a length of pipe shorter than would allow you to reach the equilibrium distribution. Assume d_p in the grade efficiency equation is the fractal agglomerate mobility diameter obtained from:

$$d_p = d_0\left(\frac{6V}{\pi d_0^3}\right)^{1/D_f}$$

where d_0 is the primary particle diameter (.25 micron). Assume the fractal dimension is that for cluster-cluster aggregation (1.8). Assume agglomeration via the sum of the continuum Brownian and Saffman-Turner turbulent kernels:

$$\beta(\phi, V-\phi) = \frac{2kT}{3\mu}\left[2+\left(\frac{\phi}{V-\phi}\right)^{1/3}+\left(\frac{V-\phi}{\phi}\right)^{1/3}\right] + .31\sqrt{\frac{\varepsilon}{\nu}}\left[V+3\phi^{1/3}\left(V-\phi\right)^{2/3}+3\phi^{2/3}\left(V-\phi\right)^{1/3}\right]$$

assume breakage via:

$$\Gamma(V) = \Gamma_0\left(\frac{\varepsilon}{\nu}\right)^{3/2} V^{1/3}$$

where $\Gamma_0 = 1\times10^{-8}$ s^2/cm, and use the kinematic viscosity calculated as the ratio of the gas viscosity to the density of the total flowing stream. Assume a binary equisized daughter distribution:

$$b(V;\Phi) = 2\delta\left(V - \frac{\Phi}{2}\right)$$