Aeration Blower Requirements

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Aeration blowers receive a lot of attention from design engineers, suppliers, and end users. That is understandable since blowers account for more than 50% of the energy used in a typical wastewater treatment plant (WWTP). They represent “low hanging fruit” for energy conservation measures in wastewater treatment!

In some industries blower applications are specified with a single operating point consisting of the design flow and discharge pressure. Municipal wastewater treatment applications, however, usually require blower systems that provide a spectrum of flows and discharge pressures. Although this can be frustrating for suppliers, it reflects variability in the treatment process. Understanding the changing demands on the system is critical to optimizing the performance of the blowers.

Basic wastewater treatment process

Sewage isn’t inherently poisonous. The destruction of aquatic life that results from wastewater discharge is caused by oxygen depletion. Microbial metabolism depletes water’s dissolved oxygen below the level needed to support aquatic organisms. Municipal wastewater processes are designed to concentrate and accelerate the metabolism of pollutants in the WWTP, minimizing the impact on the receiving water.

Figure 1 shows one of many process arrangements in municipal WWTPs.

Primary treatment removes solids from the wastewater. Primary treatment may include screens, grit removal tanks, and primary clarifiers. Clarifiers are essentially large basins where low turbulence allows solids to settle to the bottom for removal to additional treatment. The wastewater then goes to secondary treatment. Secondary aeration is the principal WWTP application for blowers.

In the aeration basin microorganisms (sludge), a food source (pollutants in the wastewater flow), and oxygen are brought together. This results in controlled metabolism of the pollutants. The oxygen is typically supplied by blowers and the air is bubbled into the bottom of the basin.

From the aeration basin the wastewater flows into another set of clarifiers. Treated wastewater passes out for additional treatment and/or disinfection. Most of the settled microorganisms are returned to the aeration basins to continue metabolizing pollutants. They are referred to as Return Activated Sludge (RAS). Reproduction of microorganisms in the aeration process produces an excess population, which is removed as Waste Activated Sludge (WAS).

Blower functions

The air supplied by the blowers to the aeration basin has several functions. The first is to supply oxygen needed for metabolizing organic compounds in the wastewater. The organic compounds are referred to as “BOD_5” (biochemical oxygen demand), named after the 5-day test used to measure the concentration of these compounds. The oxygen must be dissolved in the wastewater in order to be used by the microorganisms. The diffusers use tiny bubbles of air to efficiently dissolve oxygen into the wastewater.

Additional oxygen is required when microorganisms convert ammonia (NH_3) into nitrate (NO_3), a process known as nitrification. Nitrification often represents half of the total process oxygen demand.

The combination of sludge and wastewater in the aeration basin is called mixed liquor. The air supplied by the blowers creates turbulence in the mixed liquor to maintain the sludge in suspension. Mixing also keeps the contents of the aeration basin homogeneous. In many plants mixing limitations, rather than oxygen demand, dictate the minimum air flow rate. A typical value for mixing air flow is 0.12 SCFM per square foot of aeration basin plan area.

Most diffusers have an upper limit on air flow rate to prevent physical damage. The maximum flow varies with diffuser design.

Basics of determining air flow rate

The first problem for many blower suppliers is understanding the units of air flow. The process demand is based on the mass flow rate of oxygen needed to treat the wastewater, so designers generally specify the required mass flow rate of air. However, this mass flow rate is expressed as Standard Cubic Feet per Minute (SCFM). This is confusing because it looks like a volumetric flow rate. The key factor is that “standard” defines the air to be at 68 °F, 14.7 psia, and 36% Relative Humidity. This in turn establishes the density as 0.075 lb/ft^3. The effect of humidity can usually be ignored, making conversions to volumetric flow straightforward:

$$\mathrm{ACFM} = \mathrm{SCFM} \cdot \frac{460 + \mathrm{T}}{528} \cdot \frac{14.7}{\mathrm{p}}$$

ACFM = volumetric flow rate

SCFM = mass flow rate

T = temperature, °F

p = absolute pressure, psia

The process demand for air can be estimated if the flow rate of wastewater and the concentration of pollutants are known:

$$\mathrm{SCFM} = \frac{0.335 \cdot \mathrm{mgd}}{\mathrm{OTE}} \cdot (\mathrm{ppm\ BOD} \cdot 1.1 + \mathrm{ppm\ NH_3} \cdot 4.6)$$

SCFM = required mass air flow rate

mgd = wastewater flow rate, million gallons per day

OTE = oxygen transfer efficiency, decimal

ppm BOD = concentration of organic pollutants, parts per million

ppm NH_3 = concentration of ammonia, parts per million

One of the difficulties of specifying aeration blower flow is that the process rarely operates at steady state. Rain events or snow melt can dramatically change both hydraulic loading (wastewater flow) and organic loading (combined BOD and NH_3). Wastewater temperature varies seasonally - affecting microorganism metabolism and OTE. Slug loads from industrial discharges or internal plant side streams will increase organic loads.

Treatment plants are designed to meet the peak load projected twenty years into the future. The process equipment must be sized to meet the worst case loading at that future date. The result is that WWTPs usually operate at loads well below their capacity. Most facilities are operating at approximately one third of design loads.

The most important loading variation for most plants is the diurnal (daily) fluctuation in load associated with normal human activity. As Figure 2 illustrates, the process load shows a 2:1 range between nighttime low and daytime peak.

A final complicating factor in establishing air flow is the impact of ambient conditions on air density. Blowers are essentially volumetric machines. Because the air density is lower in summer than in winter, the volumetric flow rate in summer must be higher than in winter for identical mass flow rates.

The consequence of all these variations is that the blower system rarely operates at one specified design point. Another result is that turndown is a critical parameter in optimizing process performance and providing satisfactory blower system operation. Most individual blowers only provide 50% turndown. A minimum system turndown of 80% is needed in most WWTPs to satisfy process requirements:

$$\text{Turndown} = \frac{q_{max} - q_{min}}{q_{max}} \cdot 100$$

Turndown = ability to reduce blower flow rate, %

q_{max} , q_{min} = maximum and minimum blower or system flow rates

Turndown is more critical to optimizing blower energy consumption than efficiency. Supplying excess air wastes more energy than the savings available by using a more efficient blower. An oversized blower with the highest best efficiency point (BEP) may not provide the lowest energy consumption for actual operating conditions.

Regulatory agencies require standby blower capacity: the system must be able to provide design air flow with the largest blower out of service. Many designers provide two blowers at 100% of design capacity in order to minimize equipment cost. This arrangement will result in 50% system turndown – much lower than needed. Another common arrangement is three blowers - each with a capacity of 50% of design flow; this provides about 75% turndown.

A better arrangement is four blowers. Each may be sized to provide 33% design capacity; the resulting turndown is 83%. Alternatively, two may be sized at 50% design flow and two at 25% design flow; then 88% turndown can be achieved.

Basics of determining discharge pressure

Once the air flow rates for the system are established, it is possible to define the discharge pressure – the second parameter needed to make a blower selection. As with air flow, the discharge pressure in most WWTPs is not a single value but rather a range of values.

It should be noted that blowers produce air flow, not pressure. The process resistance to air flow creates pressure. The blower must be capable of overcoming that pressure at a given air flow. If this seems counterintuitive, consider a blower operating without discharge piping. The result would be zero pressure, but lots of flow!

The most substantial portion of the system resistance to flow is due to the submergence of the diffusers. The resulting static pressure is essentially constant:

$$p_{static} = \frac{d}{2.31}$$

p_{static} = static pressure, psig

d = depth of submergence at top of diffuser, feet

Air distribution piping, fittings, and valves create friction. The resistance to flow is proportional to the square of the air flow rate:

$$\Delta p_{friction} = k \cdot q^2$$

$\Delta p_{friction}$ = pressure drop from friction, psig

k = empirical constant for a given piping system

q = air flow rate, CFM

When air is drawn off a common header at multiple points, the velocity changes. This results in an increase in pressure from the change in velocity head. In some systems this change is negligible, but in others it may affect air distribution between basins:

$$p_{velocity} = \frac{\rho \cdot V^2}{3.335 \cdot 10^7}$$

$P_{velocity}$ = velocity head (pressure), psi

ρ = air density, lb_m/ft^3

V = air velocity, feet/minute

The gradient in air pressure throughout the distribution system is a function of air flow, static pressure, friction, and velocity head. This is illustrated in Figure 3.

Further complicating blower selection is the potential impact of air density on a blower's pressure capability. The pressure rise through a centrifugal blower is reduced at lower air density. Centrifugal blower discharge pressure should be specified at the highest anticipated ambient temperature and lowest barometric pressure. Positive displacement (PD) blowers can create any pressure needed in overcoming the resistance to flow – up to the point a relief valve opens or system damage occurs – regardless of density variations.

The system curve and the blower characteristic curve must be plotted together to determine the operating point of the blower system. An example is shown in Figure 4. The intersection of the two curves establishes the flow rate. Note that the curve for the centrifugal blower is only applicable at one set of inlet conditions.

Summary

Blowers for wastewater aeration are part of a complex treatment system. The process demand for air is constantly changing. Supplying one blower operating at a single flow rate and discharge pressure is unlikely to meet the system requirements.

A good design will include considerations of variable process demand, current and future loadings, and the impact of ambient conditions on performance. The resulting specification should identify the range of operation the blower system must cover.

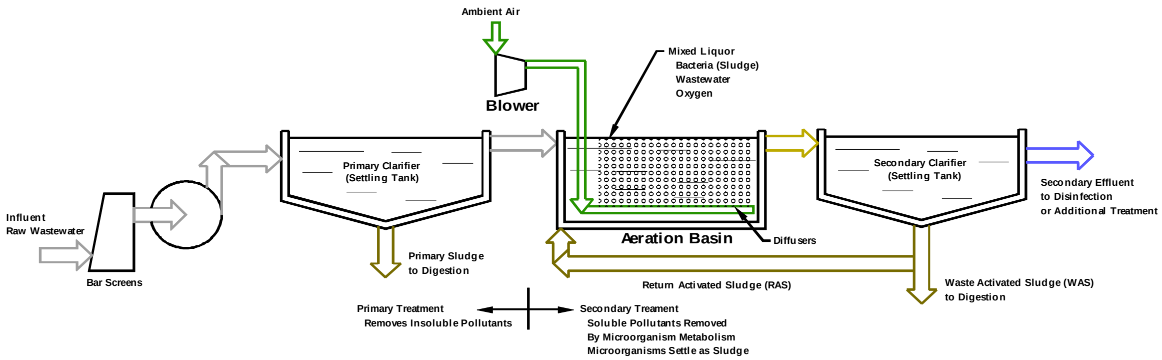

Figure 1: Typical WWTP Process

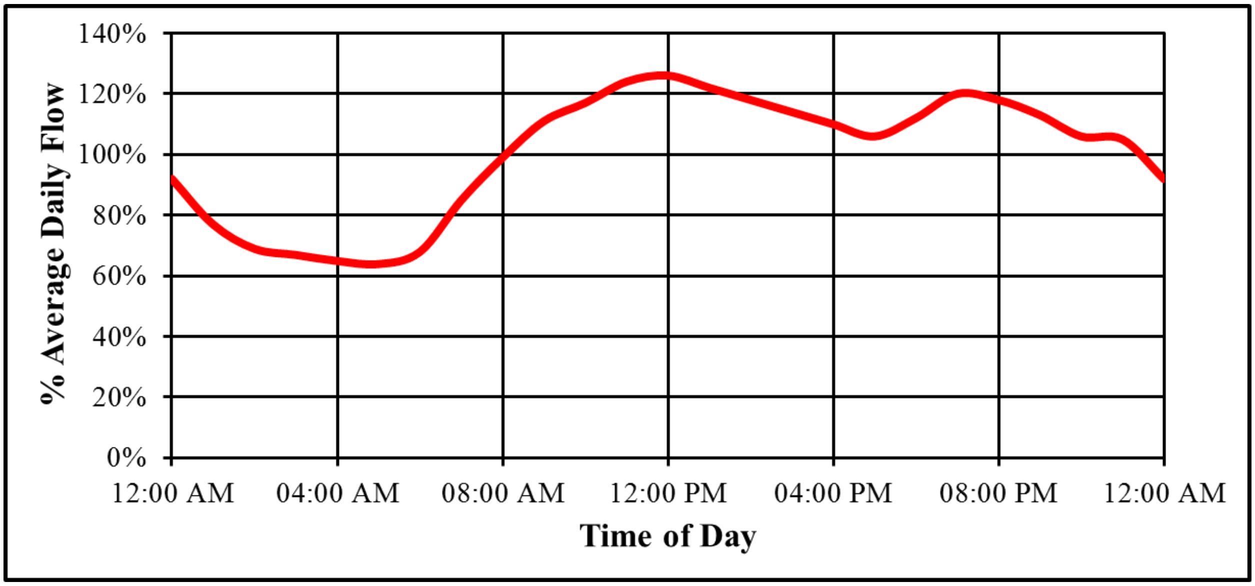

Figure 2: Typical Diurnal Loading Pattern

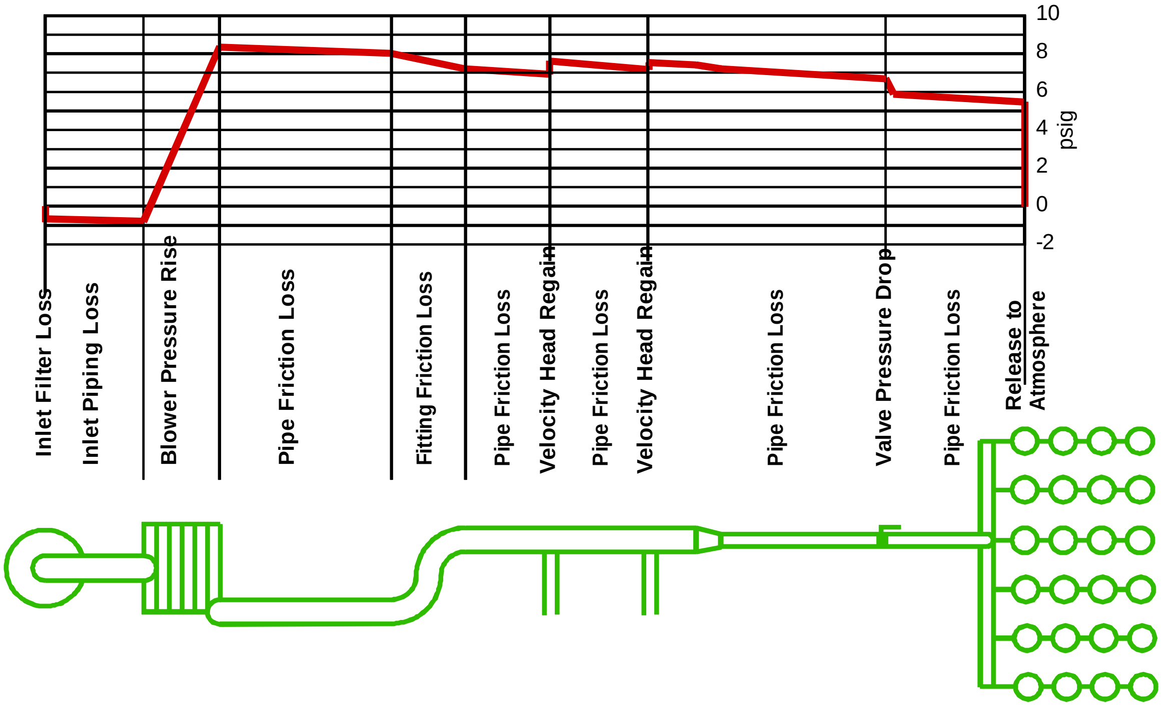

Figure 3: System Pressure Grade Line

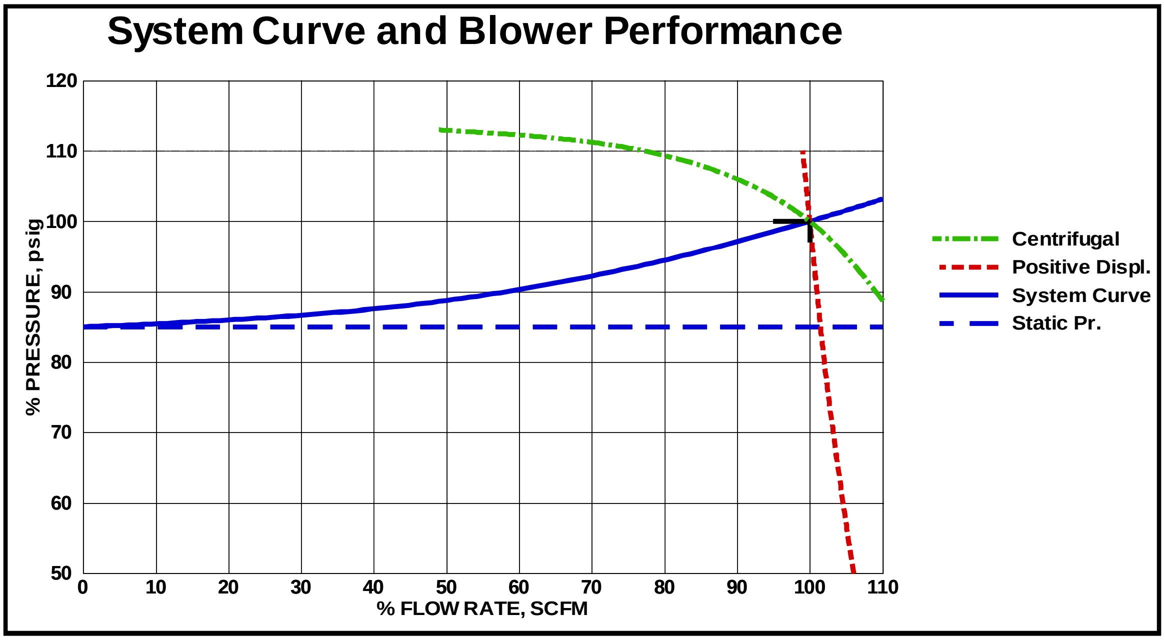

Figure 4: System Curves and Blower Performance