A DIGITAL CONTROL SYSTEM FOR OPTIMAL OXYGEN TRANSFER EFFICIENCY

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APPENDIX C: BLOWERS ASSESSMENT

PIER FINAL PROJECT REPORT

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Blowers Assessment

Introduction

Blowers are low pressure compressors and are needed for subsurface aeration systems, including turbines. There is a class of aeration device that avoids using blowers by inducing air suction, but these devices are rarely used and beyond the scope of this report.

Blowers, because of their limited “turn-up” or “turn-down” capabilities often restrict energy conservation at treatment plants. Blowers are classified into two broad types: positive displacement and centrifugal. Positive displacement (PD) blowers are generally considered as constant flow, variable pressure devices, while centrifugal blowers are often considered constant pressure, variable flow devices.

There are advantages and disadvantages of the two types, which can be summarized as follows:

Positive Displacement	Centrifugal
More economical at small scale	Economical at all scales but especially for large installations
Noisy – the low frequency “thud” associated with the rotary lobes is harder to dampen. Three lobe blowers partially overcome this objection, but experience with three lobe blowers is limited.	Also noisy but the continuous, higher frequency spinning sounds are easier to dampen.
Vibration transmissions to piping and supports sometimes problematic	Operation at excessive flow overloads the motor, and operation at excessive pressure causes surge, which may result in destruction of the blower. Over current and vibration detection controls required for safe operation
Motor overloads with excessive discharge pressure, requiring current protection on motors	
Higher discharge pressures possible	Multistage centrifugals are used for medium size plants, while single stage centrifugals, which require higher RPM (~ 10,000 to 14,000) are used for the largest installations. Single-stage blowers have most often been fitted with outlet diffusers as well as inlet guide vanes to provide more turn up or turn down.

For all practical purposes, smaller plants use PD blowers or centrifugals and all larger plants use centrifugal blowers, with the largest plants most often using single-stage blowers.

Before the advent of efficient variable frequency drives (VFDs), there was little opportunity to modulate the flow of a PD blower, without using expensive, low efficiency variable ratio gearboxes. Some energy could be consumed by throttling the suction or in other cases, excessive discharge flow could be vented at reduced pressure. Neither situation was very satisfactory. With VFDs, the flow is proportional to blower RPM (less a small fraction due to slippage), and a wide range of turn up or turn down is possible.

State of the art blowers

Centrifugal blowers

Centrifugal blowers have intake air along the axis of rotation of the shaft, and impart velocity to the air with an impeller attached to the main shaft. The air is continuously discharged radially and its increased kinetic energy is converted to a pressure increase by reducing the air velocity through a diffuser. The figure below illustrates the concept. Also, traditional centrifugal blowers do not have turn-up or turn-down capability, and have to be operated at constant rotational speed.

Figure 1. Blower Examples: a) An older single stage centrifugal, typically found in older plants with coarse bubble diffusers. This is the type of blower often reused in an upgrading project; b) A new single stage centrifugal, equipped with inlet guide vanes and exit diffusers; c) a large, multistage centrifugal, circa 1957, still in good condition; d) a medium size, multistage centrifugal, found in many current, medium size treatment plants; e & f; Two examples of small PD blowers.

Newer technologies include centrifugal blowers with guide vanes, either or both on the stator and the rotor, and with distribution vanes on the stator (Fig.2). By varying the angle of the guide vanes, the air flow rate can be varied and the blower acquires tuning capability. Nevertheless, centrifugal blowers have an optimum operating region, and outside that region may have severe efficiency drops.

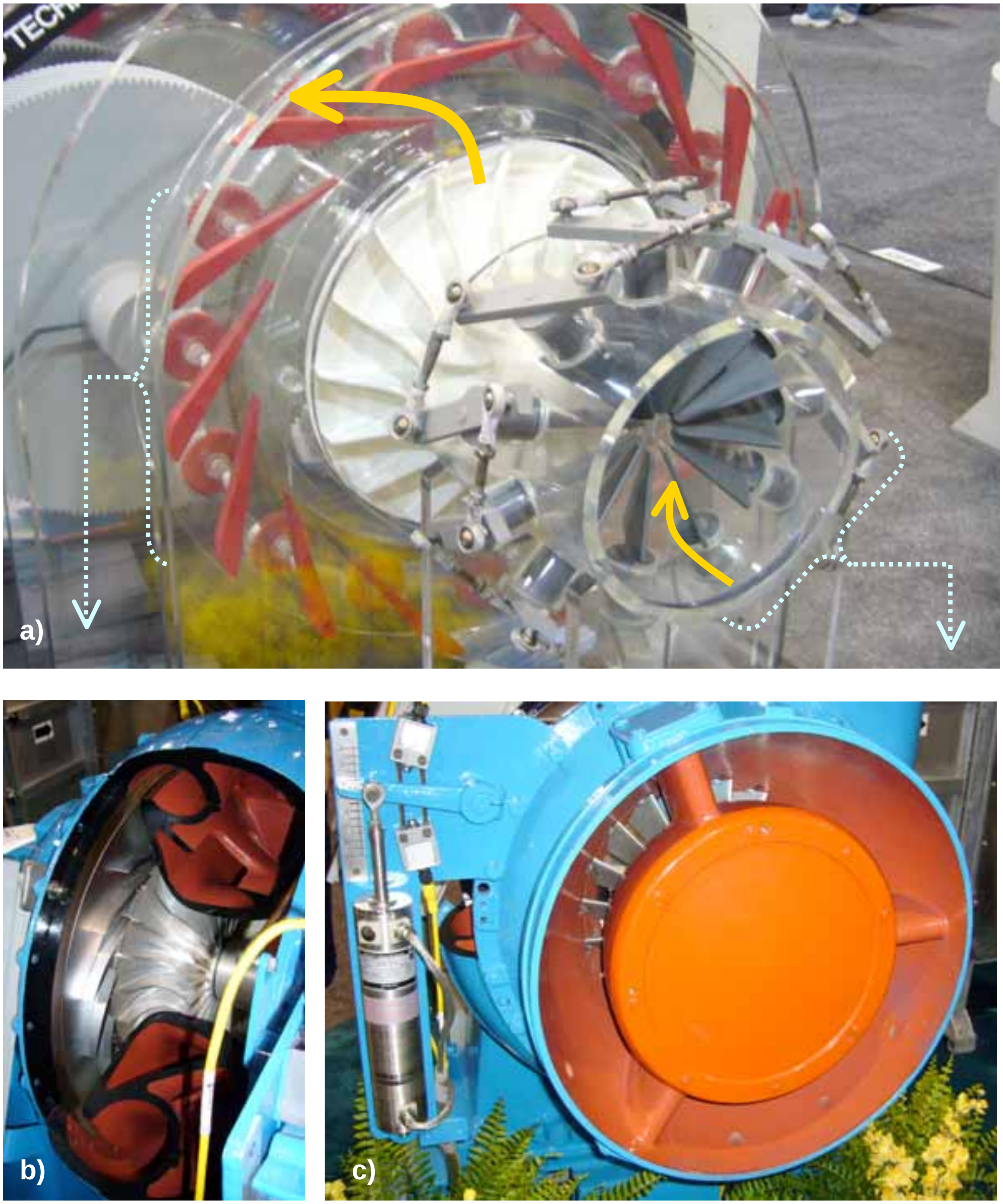

Figure 2. Single-stage centrifugal blower (model in Fig. 2a) with variable distribution vanes (b) and variable inlet guide vanes (c). The yellow lines in Fig. 2a show the air flow pattern.

Positive displacement blowers

Positive displacement (PD) blowers use a different approach. Instead of continuously imparting air velocity with a rotor and then converting that kinetic energy into pressure, the PD blower compresses discrete "packets" of air by pushing the air with two bi- or tri-lobed gears. Figure 3 illustrates the concept.

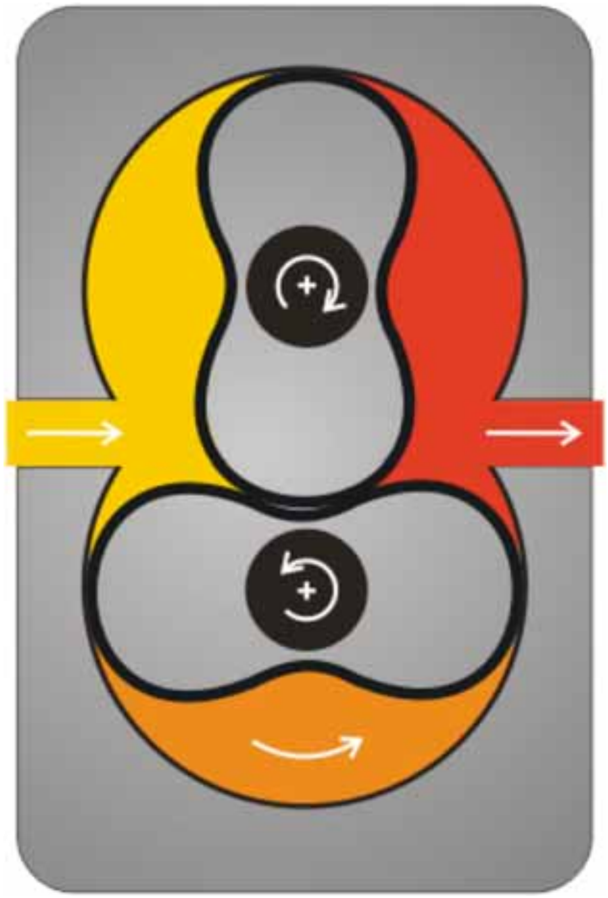

Figure 3. Schematic of a two-lobes positive displacement blower

Due to the discrete nature of the process, PD compression is not as efficient as the centrifugal flow, but can achieve higher output pressure for same air flow rates. Also, the air flow can be varied by varying the speed of the PD blower. A disadvantage of PD blowers is the noise produced by the compression, typically recognizable as a frequent low-pitched sound.

Variable frequency drives

A variable-frequency drive (VFD) is an electronic system that modifies the frequency of alternating current (AC), therefore controlling the rotational speed of the electric motor connected. As an example, if an electrical motor has a speed of 1800 rpm with a electrical frequency of 60 Hz (same as in the grid in the US), its speed can be reduced to 1200 rpm by reducing the frequency to 40 Hz. By applying a VFD to an electric motor, the motor can be run at higher or lower speed than its nominal rating, and can be started and stopped with less overheating. When traditional motors are started, about 300% of the rated current is initially drawn to bring the motor to speed. This overheats the motor and in certain cases may reduce the ability for the motor to be started more than once in an extended period of time (e.g., not more than once per hour or work shift). At the same time the increased initial current burdens the blower energy cost, especially if drawn during peak power rate periods. Diurnal cycles in wastewater treatment typically result in highest treatment requirements during daytime, when power has higher cost. Therefore, reducing the power drawn of motors during normal operation as well as for motor startup is very important.

Existing control systems

Current control techniques for aeration systems are typically based on feedback signals provided by dissolved oxygen (DO) probes immersed in the aeration tanks. Dissolved oxygen concentration is an effect of oxygen transfer. DO is an important indicator of proper process conditions. When the DO is too low, bacterial metabolism can be inhibited. When that happens, the sludge composition may change, thus reducing treatment efficiency or even causing process failures (i.e., sludge bulking). Conversely, high DO may pose problems for denitrification (which requires anoxic conditions) and consumes excessive energy (Ferrer, 1998; Serralta et. al., 2002). Many studies have focused on the improvement of the DO control system (Ferrer, 1998, Ma et. al., 2004).

Unfortunately, most activated sludge plants have blowers that can meet only a portion of the required combinations of flow and pressure before surging, overloading the motors, or operating in an extremely inefficient region. The dynamic wet pressure (DWP) required by fouled diffusers may be too high causing some diffusers not to release air, resulting in uneven bubble distribution throughout the tank. In other facilities, blowers may be able to overcome the required DWP by the fouled diffusers only when working outside their optimum efficiency region, resulting in increased power costs and possible damage to the blower.

To optimize the energy consumption of aeration systems, the best blower control strategy is to supply the minimum amount of process air to the wastewater treatment, yet meeting substrate removal and DO requirements. The adoption of a low-cost on-line off-gas measurement should be considered. Off-gas testing measures the exact mass transfer, not only an effect of it, therefore offering a new tool for accurate energy calculations. In addition, a time-series of off-gas measurements offers a tool for monitoring the decline in SOTE with diffuser fouling.

Blower upgrades

When converting from coarse to fine pore diffusers, or when converting to second or third generation fine pore diffusers, a blower upgrade or modification may be needed. When evaluating blower upgrades, several factors should be taken into consideration.

Blower units must be chosen, accounting for redundancy, to allow scheduling shifts and operations and maintenance requirements. In order to avoid sudden increases in air flow rates (therefore of energy demand), blowers with tuning capability are always recommended (i.e., positive displacement blowers with variable frequency drives, or centrifugal blowers equipped guide vanes and/or variable frequency drives, etc.). These blower systems allow the variation in air flowrate within their operating range, which accommodates the variations of load in the treatment plant. When the variation exceeds the blowers' operating range, one more blower is activated, as in traditional systems. The benefit of tuning systems is a smoother transition within the range of air flowrates, which is reflected in increased ease of management in terms of energy costs.

A classical problem that haunts operators and process control engineers is "hunting" that occurs with DO control systems. The basic problem is that the blower is treated as an "infinite" source by the control algorithm. An example explains it best.

A treatment plant is composed of several, parallel aeration tanks. When one tank has low DO, caused by a flow imbalance or random effect, the controller calls for more air and opens an air valve, which provides more air to the affected tank. Ideally, the additional air should be provided by the blower, but in reality it is not. Instead it robs the supply air from an adjacent tank. This occurs because of pressure drops in the air distribution system as well as the nature of the blower. The loss of air in the adjacent tank causes the DO to drop, and the controller calls for even more air, which robs air from other tanks. Eventually all tanks are calling for more air and the control system finally responds by turning on an additional blower. Because the blowers have pre-set ranges of flow, and not a continuous distribution of flow rates, the air to all tanks increases and the DOs begin to increase. One tank will be first to reach excessively high DO and the control system will reduce the air flow. This does not reduce blower output, but only forces more air into other tanks. Very quickly all the tanks begin to have excessive DO, and the control system finally turns off the additional blower. Now the cycle starts over again and the DOs will decline until a blower is turned back on again, when all tanks will have excessive DO, yet again.

The impact of "hunting" is excessive energy consumption for starting and stopping of blower motors as well as an increase in wear and tear on the blowers. In cases where the operators become concerned about the impacts on plant performance, they may disable the DO control system altogether and causes over- or under- aeration. Usually operators choose over-aeration to avoid effluent permit violations or other operational problems.

Conclusions and Recommendations

- Conclusions:
  - The choice of air blowers and air distribution systems is a substantial capital investment and has consequences on operating costs throughout the lifespan of the wastewater treatment plant.

- Blowers with turn-up turn-down capability are available on the market. Newer technologies include centrifugal blowers with variable guide vanes and variable frequency drives, or positive displacement blowers.
- Control systems oftentimes incur in “hunting”, which is the continuous search for an optimum set point. It results in increased wear and tear on the aeration system. In many cases, operators set the aeration system at an arbitrary high operating point to bypass hunting, with consequent over-aeration and excessive energy usage.

- Recommendations
  - Care must be used when choosing air blowers. Blowers with turn-up turn-down capability should always be evaluated as an alternative. This should be considered for both new designs and retrofits of existing installations.
  - The possible higher cost of these newer blowers should be compared in a net present worth analysis with the increased operating cost of traditional blowers. Also, in this analysis, potentially increasing air demand should be considered, and the limitations of conventional air blowers should be accounted for. These limitations may entail a decreased blower operating efficiency (i.e., increased energy costs) or the inability for the blower to operate at the increased air flow rate.
  - To mitigate hunting, several changes are needed. The first is to provide blowers with larger turn-up and turn-down capabilities by providing VFDs or guide vanes, or to provide a greater number of smaller units. The second is to provide a “smart” control system that would not consider the blower as an infinite source. This requires that the control system be equipped with a model for the blower (essentially the flow versus pressure curve and a time lag) that can be solved for each new state so that the new system pressure can be predicted and the air valves on all tanks can be adjusted appropriately.
  - A general recommendation is to have at least three blowers for any installation and to provide each blower with 50% turn down capability.
  - Blower manufacturers are gaining experience with VFDs and centrifugal multistage blowers. At present there are few demonstrable success stories using VFDs and multistage blowers. This should rapidly change and the technology will find its niche.

References

1. Ferrer, J., (1998) Energy saving in the aeration process by fuzzy logic control. Water Sci. Technol. 38(3): 255-263.
2. Ma, Y., Peng, Y, Wang, S. (2004) Feedforward-feedback control of dissolved oxygen concentration in a predenitrification system, Bioprocess Biosyst Eng. 27, 223.
3. Metcalf and Eddy, Inc. (2003) Wastewater engineering: treatment and reuse, 4th ed., McGraw-Hill, New York.
4. Serralta, J., Ribess, J., Seco, A., Ferrer, J. (2002) A supervisory control system for optimizing nitrogen removal and aeration energy consumption in wastewater treatment plants. Wat. Sci. Technol., 45 (4-5), 309.