MODERN AERATION BLOWER SELECTION – FROM AN ENERGY EFFICIENCY PERPECTIVE

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ABSTRACT

Gas transfer is a vital part of a number of modern water and wastewater treatment processes. The most common application of gas transfer in the field of modern wastewater treatment processes is in the transfer of oxygen in the biological treatment – blower air aeration.

In wastewater treatment plants, the blowers are typically expected to supply a wide range of air flows with a relatively narrow pressure range under varied environmental conditions. With the increasing need for energy conservation, the design, selection of an energy efficient blower system and optimum life time cost to meet current and future demand is becoming a common challenge for the designers and owners.

This paper discusses various types of common aeration blower technologies available on the market, flow and load applications, noise treatment, operation and maintenance requirements. The advanced high speed turbo centrifugal blower technology and its associated benefits are also discussed.

KEYWORDS

Wastewater Treatment, Aeration, Blower, Efficiency.

1 INTRODUCTION

Experiments on aeration in the history went back to as early as 1882 and the first porous plates (diffusers) became available in 1915 in UK (EPA, 1989). The transfer of oxygen is an essential key requirement for the treatment processes within a water or wastewater treatment plant; those being (and not limited to);

Water (AWWA & ASCE, 1998)

- To reduce the concentration of taste/odour causing substances and to a limited extent for oxidation of organic matter.
- To remove substances that may in some way interfere the water treatment processes. E.g removal of carbon dioxide from water before lime softening.
- To remove radon gas.
- To remove VOCs considered hazardous to public health.

Wastewater (WEF & ASCE, 1998)

- To function aerobic processes such as activated sludge biological filtration and digestion.
- To remove nutrient compounds. E.g nitrification and de-nitrification.

This paper will focus on the wastewater application of blower for aeration purposes. The goal of the paper is to provide an overview of common aeration blower technologies available on the market and suggested selection processes. Several comparisons will be carried out using the data provided by the equipment vendors.

2 BLOWER TYPES

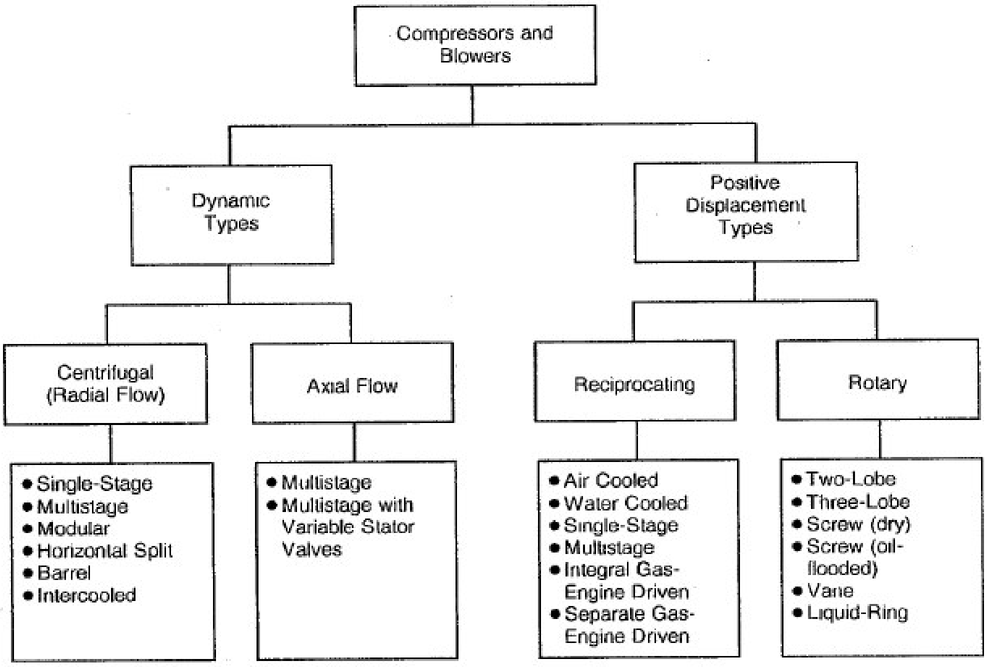

Figure 1: Types of Blowers and Compressors (EPA, 1989)

The term "blower" generally applies to the unit that delivery pressures between 14kPa and 100kPa. There are many different types of blowers available as shown in figure 1. The two common types of blowers in New Zealand wastewater treatment plants are centrifugal and rotary positive displacement types which generally operate between 30 – 70 kPa (gauge).

Table 1 below provides an overall view of pros and cons between centrifugal and rotary positive displacement types of blowers.

	Centrifugal	Rotary positive displacement
Pros	• Constant pressure over a range of volume. • Quieter • Relatively smaller footprint.	• Constant volume over a wide range of discharge pressures • Low initial cost and relative simple control requirements
Cons	• Limited operating pressure range. Flow rate can be reduced with any build up in the aeration system.	• Less efficient and limited flow capacity. • Relatively more maintenance Noisier

Table 1: Pros and cons between centrifugal and rotary positive displacement blowers

3 NEW TECHNOLOGY – HIGH SPEED TURBO COMPRESSOR (MARC-LAURILLARD, 2008)

The innovation of magnetic bearing technology accompanied by advanced control hardware and software has provided a break-through in blower aeration market. The high speed turbo compressor (HST) makes use of this new bearing technology and incorporates a high-speed motor up to 16 times the normal frequency with integrated variable speed control.

The impeller is coupled directly onto the motor shaft which is supported by the magnetic bearings. The apparent benefits are no wearing parts, oil lubrication and minimal vibration. The compressor typically comes with a local control unit which is programmed to operate the HST so as to achieve maximum electrical consumption/air demand overall efficiency via the feedbacks from the plant automation system.

3.1 MAGNETIC BEARING FEATURES

All traditional bearings have a predicable lifetime and will need replacement on regular basis. They all generate waste heat and friction and require lubrication at regular intervals.

Magnetic bearings support load using magnetic levitation. The rotating shaft can levitate and permit relative motion without friction or wear. Compared to conventional machinery, they have the following advantages;

- Light weight
- Compact structure
- Safe operation. i.e less likely to fail.
- Higher efficiency through a large range of operational parameter.

The magnetic bearing consists of an electromagnet assembly, in which the magnetic field is produced by the flow of an electric current. The physical arrangement of the magnetic bearing is not much more than high school science.

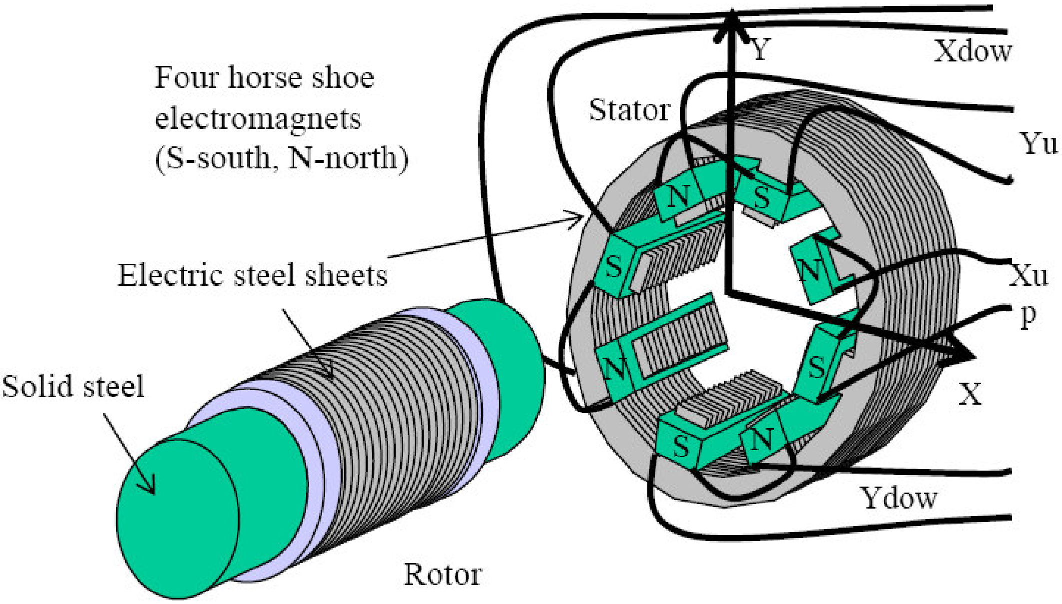

Figure 2: Magnetic bearing general arrangement

3.2 MAGNETIC BEARING CONTROLLER

By far the most complex part of a magnetic bearing is the control system, the Magnetic Bearing Controller (MBC). The magnetic bearing controller includes a signal processor, power supply, controller; amplifiers in order to control radial and axial bearings. Three protection measures are typically provided to prevent the bearings from failure during the power cut;

- Auxiliary power
- Backup battery
- The motor itself can act as a generator till the speed is decreased to 300RPM.

The complete magnetic bearing assembly includes position sensor, rpm sensor and safety bearings (also called touchdown bearings). As soon as the power is turned ON, the shaft is levitating in between the magnetic bearings. The power amplifiers supply equal bias current to two pairs of electromagnets on opposite sides of the rotor. The position sensors provide a feed back to the PID about the exact location of the shaft. The PID will then adjust the attractive power of each magnet in order to keep the shaft in the predefined optimum position by adding or reducing the amount of current going through the magnet.

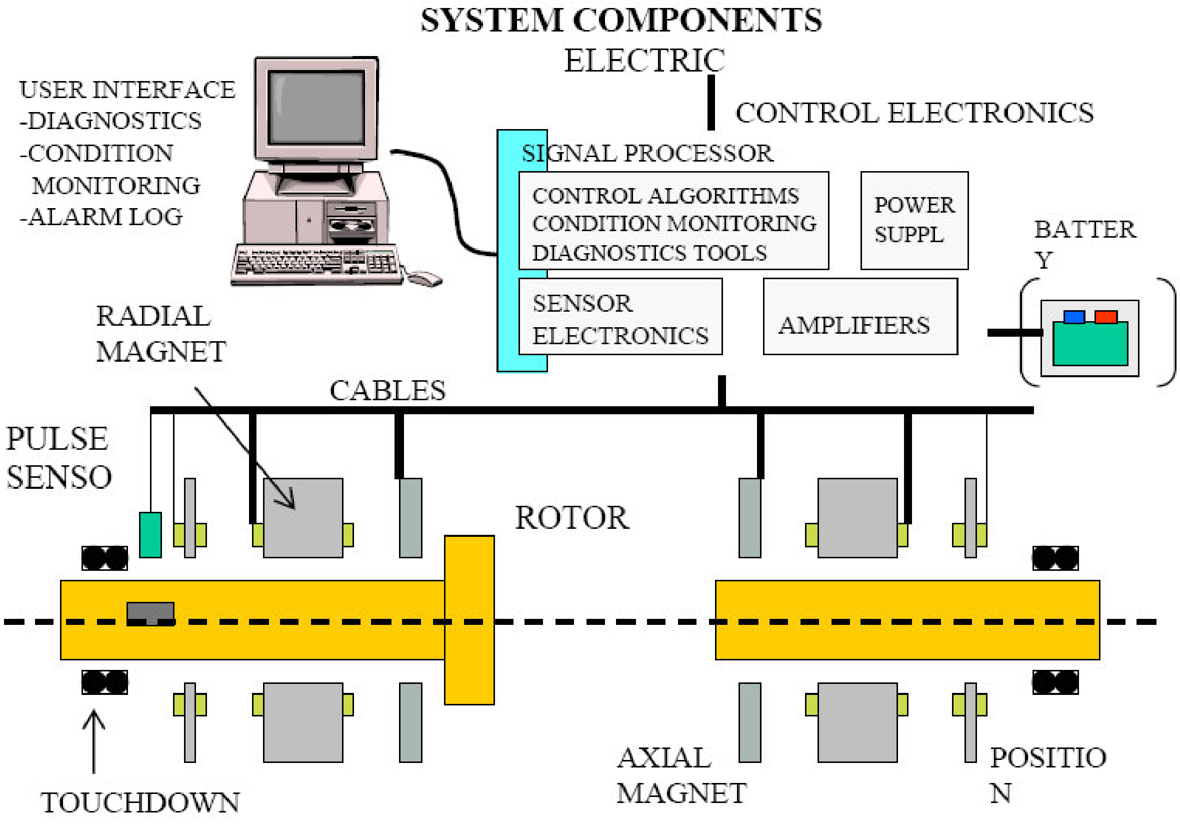

Figure 3: Magnetic bearing schematic

4 DESIGN SELECTIONS AND CONSIDERATIONS

In wastewater treatment plants, there are expectations for the blowers to supply a wide range of air flows and a pressures under varied environmental conditions. Due to mechanical limitation, a blower in most instances can only meet on particular set of operating conditions efficiency.

4.1 AIR CLEANING (TREATMENT)

The degree of air cleaning depends on supply air quality, blower installed and the services downstream. For protecting blowers, a typical minimum requirement for inlet air cleaning is 95% removal of particles with diameters of 10 micron and larger. There are three basic types of air treatment systems, namely viscous impingement, dry barrier and electrostatic precipitation. Of the air-cleaning systems available, the dry barrier type in form of replaceable filter units are the most common, due to its simplicity to construct and operate. (WEF & ASCE, 1998).

4.2 TURN DOWN

The selection of blower should take into account the following;

- Initial (or Today's) minimum and maximum air requirements based on the actual BOD loadings.

- Future minimum and maximum air requirements based on design. The reputable and calibrated computer process modelling software is expected to provide comprehensive prediction.

- Initial and future air requirements for mixing in the aeration tank.

- Energy efficiency of combination of blowers (WEF & ASCE, 1998). In certain applications, the centrifugal blower can be turned down to 40% without much loss in total efficiency.

The turndown is up to 33% for rotary lobe blower and 40% for centrifugal blower. The control of air flow on a rotary positive displacement blower is normally carried out by the variable speed drive. The performance of centrifugal blower can be controlled efficiently via inlet throttling and or a variable speed drive. When varying the air flow rate, it is important to note the flow shall not be decreased to a point where surge occurs.

If the design or actual flow range fails outside the turndown capability of the equipment, multiple operating units perhaps shall be considered. If the risk profile permits, the full time standby may be shared as an assist unit.

4.3 EFFICIENCY

For the centrifugal blower, the efficiency is typically measured and represented as polytropic efficiency where it can be achieved as high as 80%. For the rotary positive displacement blower, the efficiency is regarded in two forms, namely adiabatic and volumetric efficiencies. The adiabatic efficiency can reach 70% at a pressure ratio of about 1.2. The volumetric efficiency is a measurement of all clearance between the lobes/rotors and the end of the wall or the rotor and the casing when they are subjected to the total pressure difference. It drops rapidly from about 100% to 70% as the pressure ratio is increased from one to two (Davidson & Bertele, 1996).

The aeration blower(s) is the one of largest energy consumer at a modern wastewater treatment, thus the efficiency of the selected blower shall be considered carefully. It is highly recommended to obtain the wire power drawn for each blower which complies with the relevant ISO testing standards and use the information to calculate its total efficiency for comparison purposes. E.g ISO 1217 for positive displacement compressor and ISO 5389 for turbo compressor.

4.4 TEMPERATURE

The relationship between isentropic compression and discharge temperature is described as follows (Cengel, 1997);

$(T_2 / T_1) \approx (P_2 / P_1)^{(k-1)/k}$ (1)

Where k is the specific heat ratio which does varies mildly with the temperature. In general case, it stays contant at 1.667.

The high discharge air temperature can be a concern considering majority of the aeration diffusers are made out of PVC plastic materials. The operating temperature ratings are 60°C for PVC material and 70°C for ABS material (reduced design life). The selection of the blower should take into account the seasonal worst case ambient temperature and ensure the maximum discharge air temperature does not exceed the downstream equipment temperature rating after discounting any positive heat losses.

4.5 HUMIDITY

The humidity at the inlet condition does often not get considered. The isentropic work of compression of humid air is greater than of dry air, consequently the power required is greater.

Sherstyuk et al, 1997 states the efficiency of the equipment can be reduced due to higher humidity as follows;

$n = n_a (1 - 1.56 * \text{alpha})$ (2)

where n = efficiency humid air, n_a = efficiency dry air, alpha = humidity ratio (0.015 at relative humidity 100%, 20°C)

4.6 NOISE

The noise is generated by the blower generally via the movement of the air, air pulsation and vibration. It typically exceeds the level acceptable to the human being working or living around it and worse if the plant is located in an urban area.

Table 2 outlines the typical methods available to reduce the noise transmission;

Methods	Materials	Performance	Data Source
Blower(s) in building.	GIB Noiseline® plastic boards on both sides of the wall	STC rating Up to 55	Gib Noise control system brochure.
		Typical STC ratings	CCANZ's website
	100 mm concrete wall	44	
	150 mm concrete wall	55	
	200 mm concrete wall	58	
	Sealing the wall	Increase by 3	
Blower(s) in acoustic enclosure.	Purposely designed acoustic enclosure	18-22 dBa reduction	Noise control product vendor.
Pipework	Pipe lagging or installing pipe	Approx. 10 dBa	Noise control product

treatment	silencer	reduction	vendor.
Operation	Operate blower in quiet band.	Approx. 5-10 dBa reduction	Blower Vendor.

Table 2: Typical Noise Treatment Methods

A submersible rotary lobe blower has been developed. It is available between 20 and 600 Nm^3/hr with discharge pressure rating up to 60 kPa(g). The average noise level across the range is approx. 60 dBa at 1m free field. This could be the excellent choice if the application suits.

4.7 MAINTENANCE

Except for the proprietary parts such as magnetic bearing system and motor control unit, majority of the blowers utilise standard couplings, bearings (and lubrication), air filters, shaft seals, belts and motors as its materials of construction. These parts all each have a definite life thus the equipment will require servicing or replacement within its design life. The labour requirements for servicing depend on the design and physical characteristics of the equipment.

4.8 COST

A group of reputable blower vendors have been invited to participate in the following cost comparison. The data are grouped in generally four common types of blowers, namely side channel, rotary lobe, conventional centrifugal and high speed centrifugal (turbo). The main purpose is to demonstrate in general terms the magnitude of costs between different types of blowers.

To narrow the wide spread of the data, the common set of aeration and environmental parameters have been utilised to generate the comparisons. i.e discharge pressure of 30, 40 and 60 kPa gauge and air flows are in Nm^3/hr unit.

The following sections will also discuss several key costs to be considered when it comes to the estimation of life costs.

4.8.1 CAPITAL COST

The capital cost estimation is often one of critical stages during the design and equipment selection process. The build up of capital cost shall be considered not only the equipment unit cost; the installation related costs can be significant (Davidson & Bertele, 1996). To protect commercial advantages and interests among the vendors, the illustration of the cost is in a price index scale; where the price index is the actual cost in New Zealand dollars divided by a nominal constant.

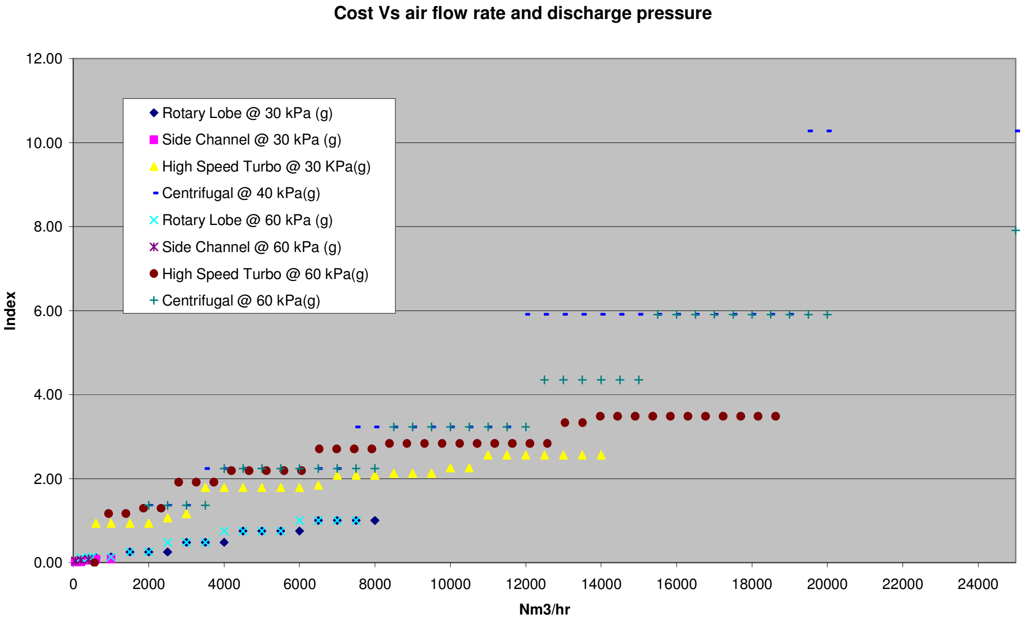

Figure 4: Blower unit cost Vs. Air flow rate and discharge pressure

The unit cost comparison is illustrated in figure 4 and it is based on the standard package unit supply without external or non factory standard ancillary electrical drives, automation, instrumentation(s) and duty performance testing. From the figure, it is concluded that;

- The available of centrifugal blowers are limited at the low end flow range, i.e below 1000 Nm^3/hr. The side channel and rotary lobe blowers are the main types to be considered.
- The rotary lobe blowers are cost competitive up to high 7000 Nm^3/hr across different discharge pressures.
- The flow capacity of centrifugal blowers (both conventional and high speed centrifugal) is significantly affected by the discharge pressure.
- The availability of high speed turbo blower is not as wide as the conventional centrifugal.
- The unit cost of blower increases exponentially as the air flow rate increases.

The installation related costs are to be considered in there general categories, namely foundation & housing, area classification and noise control. The footprint and unit weight are the major contributors to the foundation and housing costs. Comparisons have been carried out and the results are illustrated in figure 5 and 6 as follows;

- Being positive displacement equipment, the rotary lobe blowers increase in footprint & unit weight significantly as the air flow capacity increases. The footprint and unit weight appears to be competitive against the respective centrifugal blowers up to 4000 Nm^3/hr. At beyond 6000 Nm^3/hr, it can be 3 times larger and heavier than the respective centrifugal blowers.
- The side channel blowers are the best choice for the foot print and weight below 1000 Nm^3/hr.
- At beyond 1000 Nm^3/hr, the high speed centrifugal blowers are the best choice across the board within its air capacity limit.

- At between 6000 and 8000 Nm^3/hr, the conventional centrifugal blower can be as heavy as the rotary lobe blower. At this air flow range onwards, the motor size and its weight starts to contribute significantly to the overall weight of the unit.

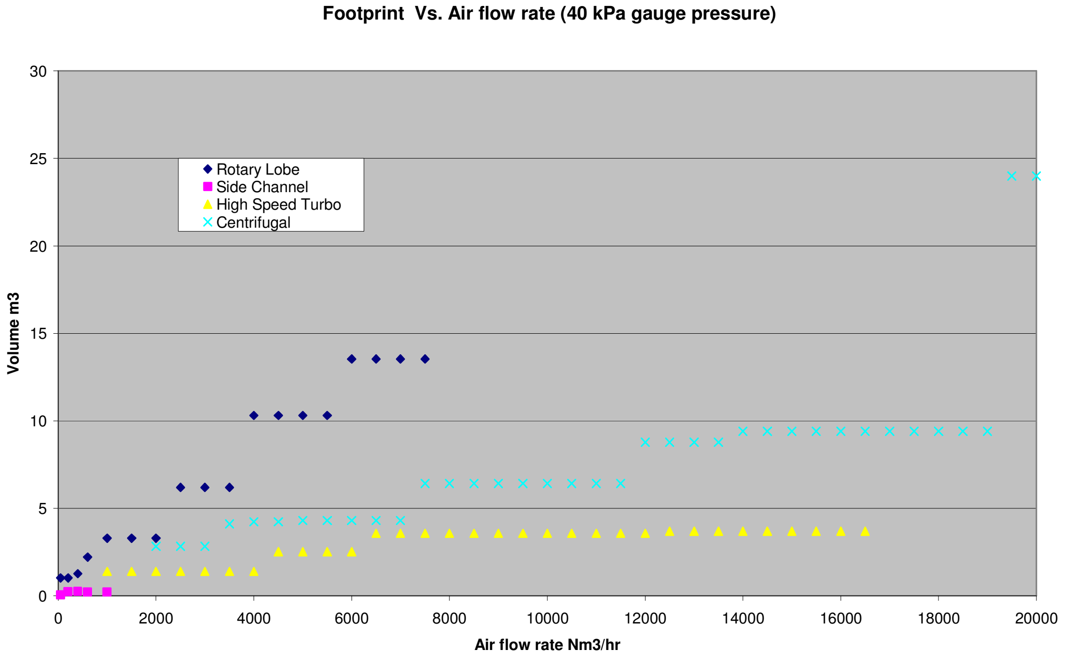

Figure 5: Foot Print Vs. Air flow capacity

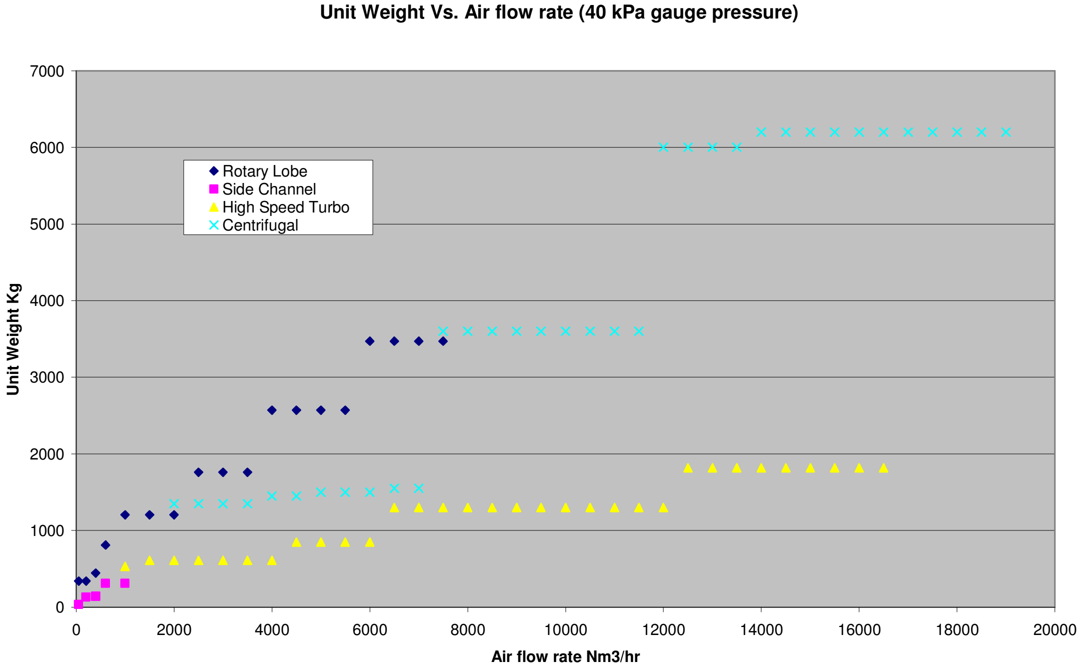

Figure 6: Unit Weight Vs. Air flow capacity

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Noise control cost is difficult to be established at the time of authoring this paper. The noise control requirements are subject to local government regulations and the locality of the blowers within the treatment plant. There are also various noise treatment methods depending on the degree of the noise level (table 3) and type (or characteristics). This paper has not considered the different area classifications, as the standard blower packages are generally acceptable in wastewater treatment plant environment.

Blower Types	40 kPa (g)		60 kPa (g)	
	<= 4000 Nm^3/hr	> 4000 Nm^3/hr	<= 4000 Nm^3/hr	> 4000 Nm^3/hr
Side Channel	63.5 - 79	-	76 - 79	-
Rotary Lobe	73.3- 76.3	74.5-76.3	72.8-78.2	76.5-78.2
High Speed Turbo	69-79	74-85	69-79	74-85
Centrifugal	66-71	71-77	69-70	70-80

Table 2: Noise Range (dBA in 1m free field)

4.8.2 OPERATING COST

Operating cost is a long term cost which covers (is not limited to) the electricity, replacement parts, and preventative maintenance. The operation cost in generally can exceed the initial unit cost of the blower within first few years of operation. To generate a comparison of the efficiency between different types of blower, the wire power drawn data (tested to relevant ISO standards) is populated. The efficiency is derived from dividing the isentropic power by the wire power drawn.

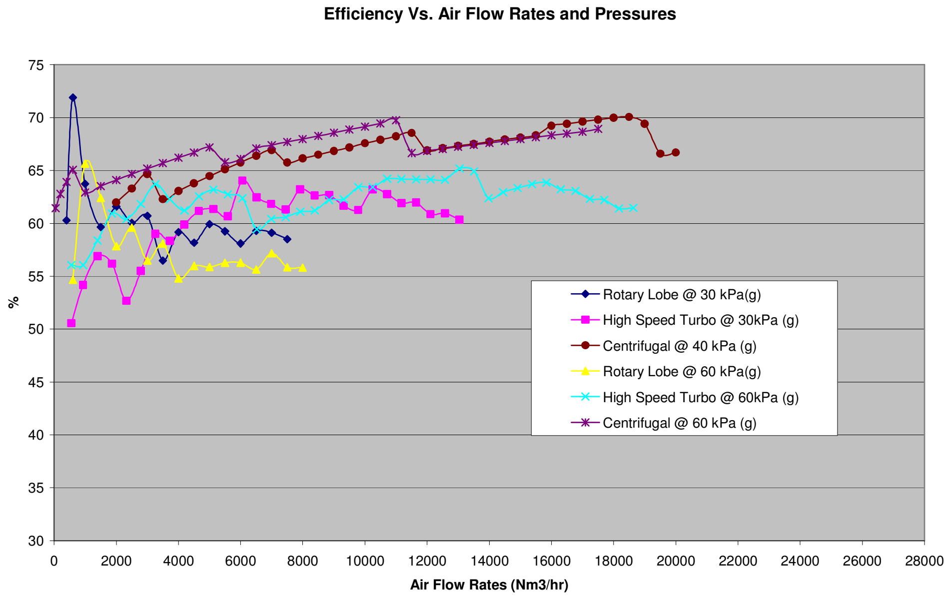

Figure 7: Total efficiency Vs. Air flow capacity & discharge pressure (101 kPa absolute pressure, 20oC & 60% Relative Humidity at Inlet)

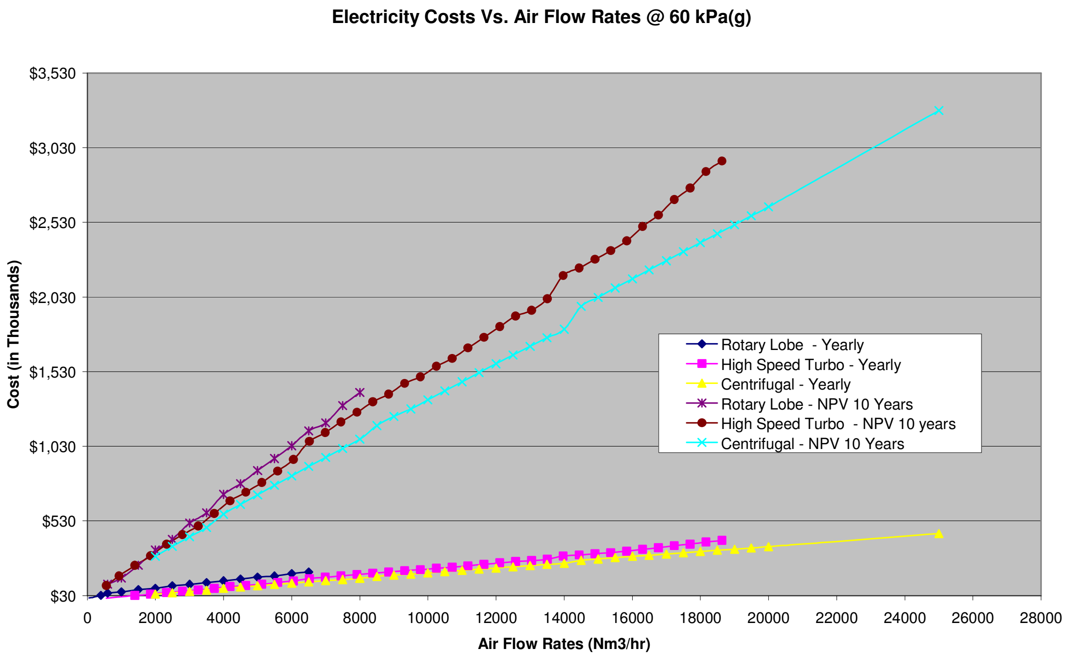

Figure 8: Electricity Costs (in NZD) Vs. Air flow capacity @ 60 kPa (g) (101 kPa absolute pressure, 20oC & 60% Relative Humidity at Inlet, 6% Cash Discount Rate)

The annual electricity cost is derived from multiplying the electrical power drawn at the wire by electricity unit rate of $0.2 per kWhr and 12 hours per day operation (365 days per year).

It is noted from figure 7 & 8 that;

- The rotary lobe blowers are the most efficient below 2000 Nm^3/hr air flow capacity and the efficiency does increase with the decrease of discharge pressure.

- The conventional centrifugal type blower can be the most efficient from 2000 Nm^3/hr air flow capacity onwards. It is possible for the high speed turbo to be more efficient at certain duty points.

- The difference in unit cost between different blower types and potentially the installation related costs could be paid back within 10 years of operation from 6000 Nm^3/hr air flow capacity onwards.

To populate the 10 years maintenance cost comparison, the vendor is requested to provide the annual cost which consists of both the preventative maintenance and replacement parts including labour. The costs are generally insignificant in comparison with the respective annual electricity cost. The high speed turbo blower surprisingly has the highest maintenance cost generally across the board, even there is hardly any mechanical part to be maintained within the blower itself as discussed in earlier section. The rotary lobe blower has the lowest maintenance cost below 4000 Nm^3/hr air flow capacity (Figure 9).

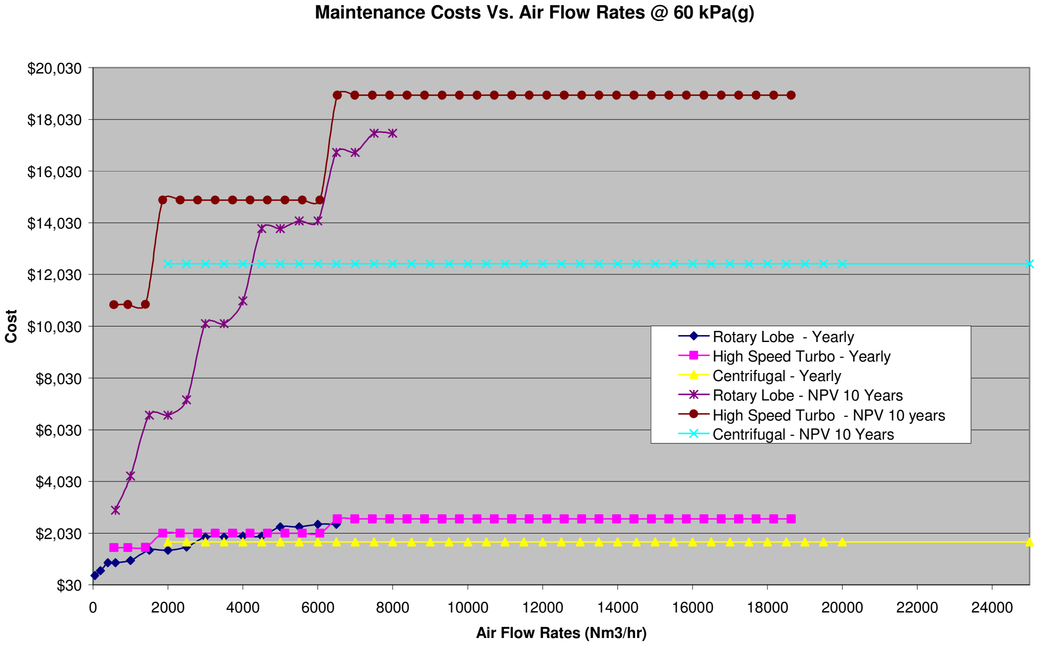

Figure 9 : Maintenance Cost Vs. Air flow capacity @ 60 kPa (g)(6% Cash Discount Rate)

5 CONCLUSIONS & DISCUSSIONS

As a summary of this paper and conclusions from the results;

- The mechanical technology for air compression has existed for more than a century. The breakthrough nowadays is on the minimisation of transmission losses hence the improvement of efficiency. The degree of maintenance is also improved as the result.
- To select or enquire for a blower, the wider issues such as air cleaning, turndown, efficiency, air temperature & humidity, noise and key cost contributors shall be considered.
- The rotary lobe blower is the strong contender for application below 2000 Nm^3/hr provided the turndown is achievable.
- The high speed turbo blower offers the smallest footprint for majority of air flow rates.
- The unit cost of blower increases exponentially as the air flow rate increases. The difference in unit cost between different blower types and installation related costs could be paid back within 10 years of operation.
- The maintenance cost which consists of both the preventative maintenance and replacement parts including labour is minimal in comparison with the electricity cost in the long run.
- The conventional centrifugal blower remains the technology which covers the widest range of air flow duty.

This paper and the associated results are subject to the following limitations;

- The equipment data is based on the information provided by the selected reputable vendors and may not represent all the blowers available on the market. It is strongly encouraged that the designer or asset owner carries out own assessments during the design or procurement processes.

- No external or third party verification has been carried out on the data given.

- The comparisons in this paper have focussed on single operating blower unit. The results may not be applicable to multiple units in operation.

- The maintenance cost data provided by the vendors can subject to interpretation errors and potentially commercial bias. For better and more accurate results, the cost is to be studied at "skeleton" levels.

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