A Field Study of Energy Savings Realized By Replacing Rotary Lobe Blowers With Integrally Geared Centrifugal Blowers

Executive Summary: Replacement of 2 of the 4 originally active rotary lobe blowers with integrally geared turbo blowers in a nitrification-denitrification process resulted in over 35% less energy used by the integrally geared centrifugal blowers along with improved process control. Phase 2 replaced the 2 remaining active rotary lobe blowers with an additional pair of integrally geared turbo blowers, this pair having about 7% higher flow capacity relative to the first pair, and resulted in over 40% energy savings relative to the rotary lobe blowers. This total energy savings can be broken into 2 components: energy saved due to increased wire to air efficiency of the blower package and energy saved due to process improvements. It is estimated that wire to air efficiency accounts for approximately three-quarters of the savings while process improvement accounts for one-quarter of the total savings. This blower replacement was partially funded through an Energy Conservation Grant and the energy savings were independently verified by a third-party.

Introduction: This paper will look at the energy savings and other benefits experienced by replacing rotary lobe blowers with integrally geared centrifugal blowers in a 10 MGD municipal wastewater treatment plant.

Challenge: Aeration blowers used within the activated sludge process of wastewater treatment are well understood to be the single largest user of energy within an activated sludge wastewater treatment process, making up more than 50% of the electrical energy usage of a typical plant[1]. With electricity comprising 25%-40% of a typical wastewater treatment plant's operating costs[2], the opportunities for savings are significant. Reliability, serviceability, & maintainability are also areas where the plant is unwilling to compromise.

Overview: The Sni-A-Bar Wastewater Treatment Plant is a 10 MGD plant serving the cities of Blue Springs and Grain Valley Missouri and is part of the greater Kansas City metro area, home to Inovair's design, engineering, and manufacturing facilities. The Sni-A-Bar Plant utilizes a nitrification-denitrification cycle where each of 2 basins are aerated for 5 hours and unaerated for 1 hour. Within the plant, Basins 2 and 3 are twins, the product flow is continuously divided between them, in as much as possible, these flows are equal in volume and composition, providing an excellent opportunity for direct comparison between old and new aeration blower technologies. Throughout this paper, we will assume the basins to have substantially equal aeration needs.

Figure 1: Aerial view of Sni-A-Bar municipal wastewater treatment plant

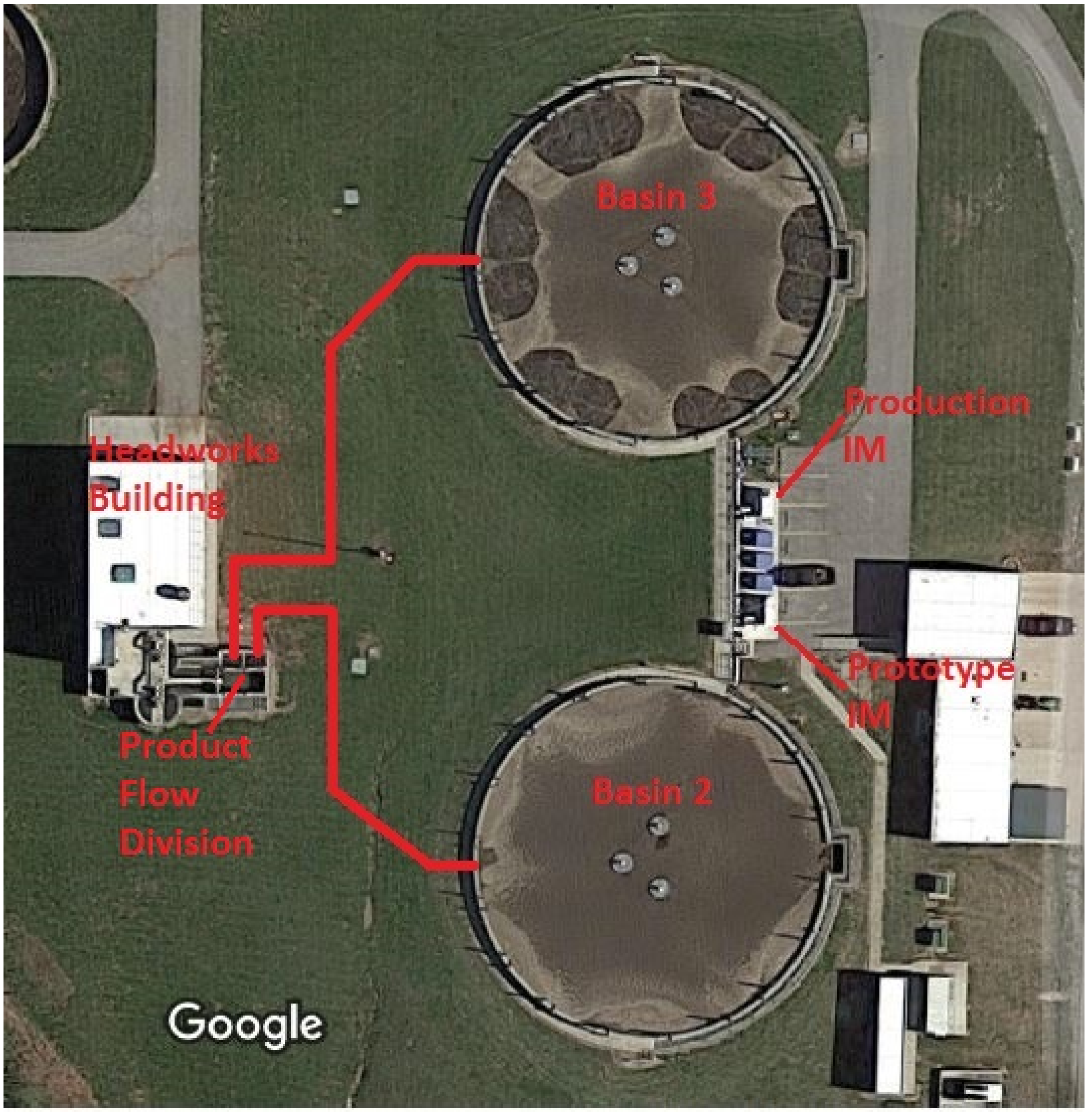

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Figure 2: Plant aerial showing Headworks Building where the Product Flow is divided, Aeration Basins 2 and 3, and the aeration blowers. The 3 remaining rotary lobe blowers are visible between the 2 Inovair Modular integrally geared centrifugal compressor stacks. The 30" pipe feeding the Aeration Basins from the Headworks Building is sketched in.

Figure 3: Product flow division between Basin 2 and Basin 3 at the Headworks Building

Equipment and process descriptions:

- **Pre-existing rotary lobe blowers**: 150hp belt driven rotary lobe blowers capable of 1875 scfm at 9.7 psig. They are run across the line with a softstart to reduce inrush current during motor starup.
- **Pre-existing aeration control**: Basins 2 and 3 operate on a 6 hour cycle, 5 hours of aeration followed by a 1 hour denitrification cycle with no aeration. At the start of an aeration period the lead rotary lobe blower is brought online for 10 minutes after which upper and lower DO levels are used to bring the lag blower on and offline. The lag blower will be turned on if DO level is below 1 mg/l and shut off when DO exceeds 2 mg/l. This causes a fluctuation in DO level between roughly 1 mg/l and 2 mg/l, although there is some overshoot. A typical cycle will start the lag blower 6-10 times during the 5 hour period.
- **2200 Gearbox**: The 2200 gearbox has been in service in various Inovair products since 2010 and specifically wastewater aeration applications since 2013. It utilizes oil film journal bearings on the high speed shaft and rolling element bearings on the low and intermediate speed shafts to yield an L10 life in excess of 10 years. Additionally, a lift-off style aerospace grade face seal combined with a labyrinth ensures both oil free air and no contamination within the gearbox oil system.
- **Production Inovair Modular unit (IM)**: Inovair's modular integrally geared centrifugal compressor system. The modular design allows 2 of these units to be stacked vertically for a reduced footprint, if desired. The gearbox is directly driven by an industry standard electric motor, typically TEFC although ODP motors are used as well. Inovair's Local Control System utilizes an industry standard AB PLC, which allows integration of virtually any industry standard Variable Frequency Drive. The first production IMs went into service in 2017.
- **Prototype Inovair Modular unit (IM)**: This is the prototype unit of Inovair's IM. It first ran in 2015 and was extensively lab tested prior to being placed into service at the Blue Springs facility in November of 2016.
- **Inovair DO control system**: The Master Control panel controls blower sequencing and flow based on DO or other process parameters. It can control 1 to 8 blowers.

This blower replacement project was executed in 2 phases:

Phase 1: Replaced Basin 2's rotary lobe blowers with a pair of prototype Inovair Modular (IM) integrally geared centrifugal blower units. Comparisons were made between energy used in the 2 identical aeration basins, Basin 2 running the prototype IM integrally geared centrifugal blowers and Basin 3 running the rotary lobe blowers.

Phase 2: Replaced Basin 3's rotary lobe blowers with a pair of production Inovair Modular (IM) integrally geared centrifugal blowers. Comparisons were again made between the 2 aeration basins, Basin 2 continuing to run the prototype IM integrally geared centrifugal compressors with no changes made from Phase 1 and Basin 3 now running a production stack of Inovair IM integrally geared centrifugal blowers of slightly higher capacity with an updated DO control system. This comparison will show gains from blower and control improvements as well as highlight any significant differences between the product flow through the twin basins.

Figure 4: Prototype Inovair IM stack during installation, customer specified Variable Frequency Drives are visible in this outdoor installation.

Project Results:

Phase 1 Blower Replacement: The pre-existing Basin 2 rotary lobe blowers were replaced by a single prototype Inovair IM stack. Each of the 2 modules in this package is comprised of a 100hp motor, VFD, directly coupled gearbox, aero package, & Local Control PLC. Each module is capable of delivering 1000 - 1875 scfm at 9.7 psi in all expected ambient conditions. Additionally, there is a Master Control PLC which controls blower flow and sequencing based on DO feedback.

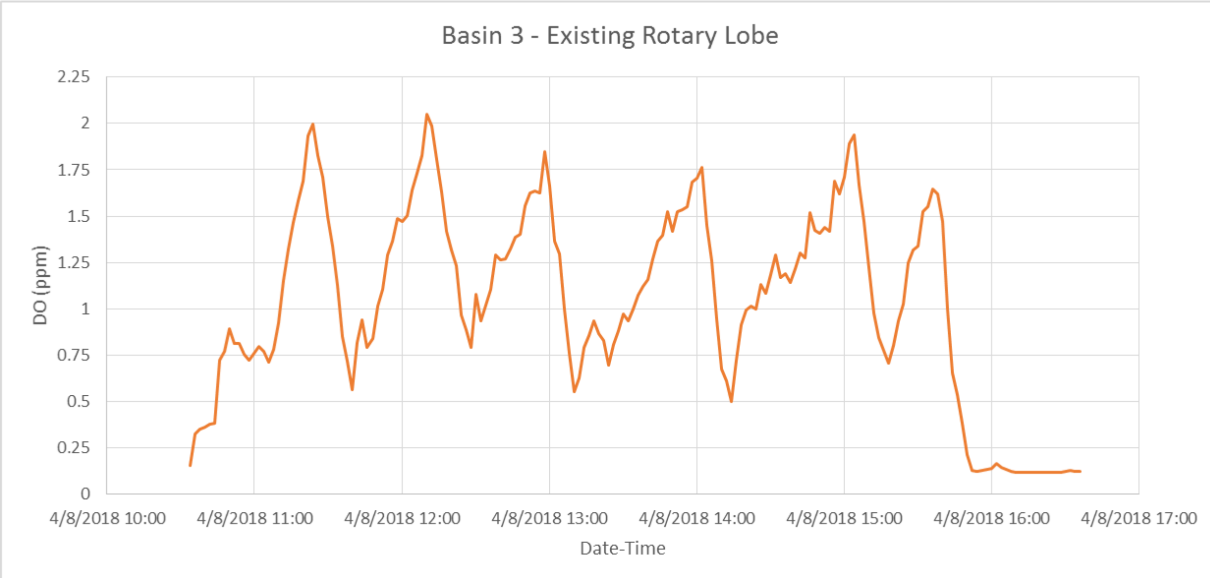

Figure 5: Typical DO levels during aeration cycle of Basin 3, using existing rotary lobe blowers. Dissolved Oxygen level generally swung between 1 mg/l and 2 mg/l with this particular example showing 6 starts of the lag blower during this 5 hour cycle. Average DO level during this aeration period was 1.18 mg/l.

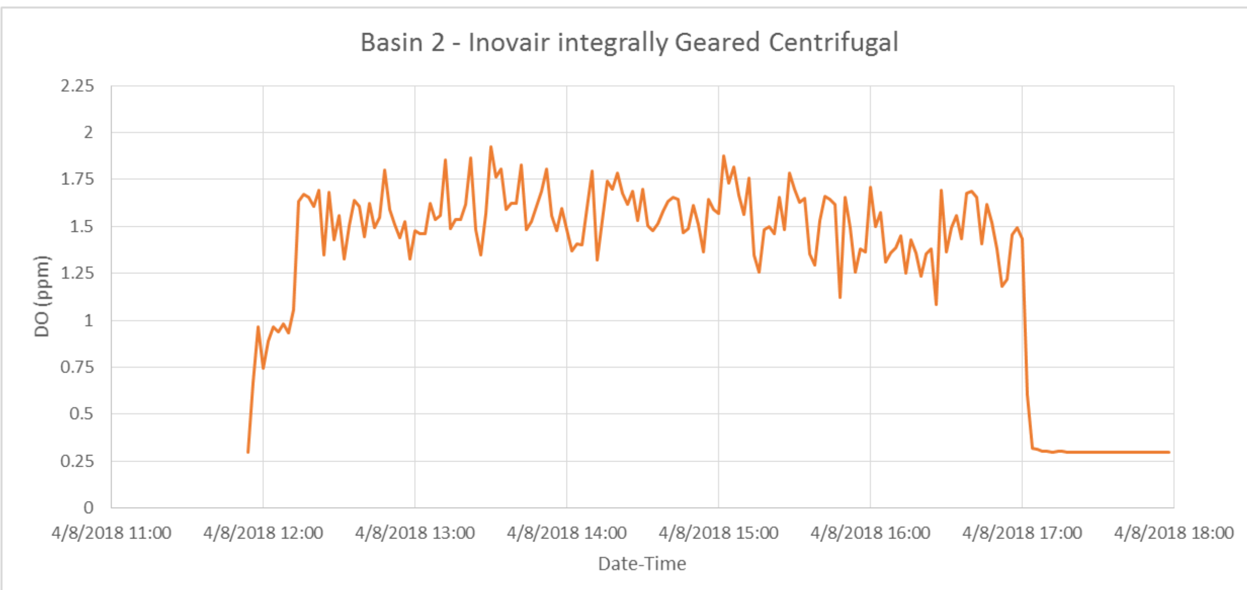

Figure 6: Typical DO level during aeration cycle of Basin 2, DO controlled Inovair integrally geared centrifugal blowers. Average DO level was 1.49 mg/l during the 5 hour aeration cycle.

As part of the Energy Conservation Grant, an independent verification of the energy consumption was performed for several months shortly after the rotary lobe blowers were replaced.

Monitoring Period Start	1/20/2017	6/27/2017	7/11/2017
Monitoring Duration, hr	721.2	479.0	487.4
Basin 3: 2 x 150hp Rotary Lobe Blowers, kW-hr	77,924	39,689	55,272
Basin 2: 2 x 100hp Integrally Geared Centrifugal Blowers, kW-hr	56,777	26,799	44,607
Integrally Geared Savings, kW-hr/hr	29.3	26.9	21.9
Integrally Geared Savings, %	27%	32%	19%

Figure 7: Energy savings comparison between rotary lobe blowers on basin 3 and integrally geared centrifugal blowers on basin 2.

During this initial monitoring phase the DO level in Basin 2 (integrally geared centrifugal blowers) was set to 2 mg/l while Basin 3 (rotary lobe blowers) was set to cycle between 1 mg/l and 2 mg/l.

In the second half of 2017, as the plant operators gained confidence in the ability of Inovair's DO control system to operate within their process, they began lowering the DO setpoint to achieve further energy savings. DO setpoint was eventually lowered to 1.5 mg/l. It should be noted that this is still higher than the resulting average DO level obtained with the rotary lobe blowers cycling between 1 mg/l and 2 mg/l (figure 5).

In March and April of 2018, Inovair ran a more comprehensive energy audit of the plant.

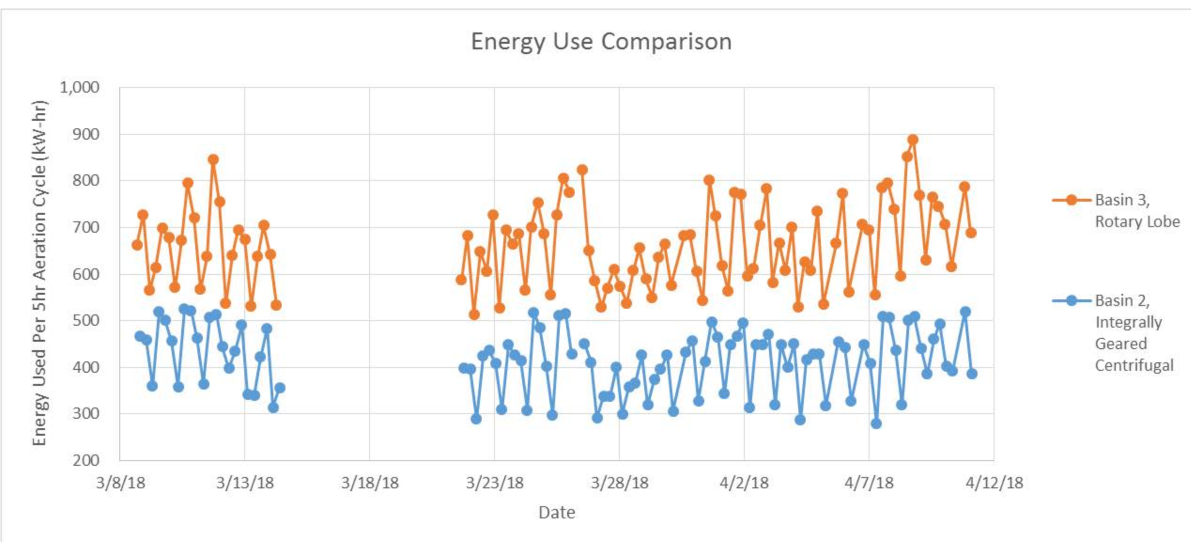

Figure 8: Energy used by each basin during individual aeration cycles.

Timing of aeration cycles between Basins 2 and 3 are staggered by 3 hours so that both basins are not denitrifying at the same time. It is thus not correct to do an exact comparison between basins on a single cycle but the trends are very clear. Summing the energy used over each continuously monitored period and using electrical input power while running to account for slight differences in run time caught during the monitored period shows the following savings:

Monitoring Start	Monitoring End	Inovair Energy Used, ekW-hr	Inovair running hrs	Rotary Lobe Energy Used, ekW-hr	Rotary Lobe running hrs	Inovair avg running input power, ekW	Rotary Lobe avg running input power, ekW	Inovair Energy Savings (based on running power)
3/8/18 11:10 AM	3/14/18 2:22 PM	10,052	118.0	15,112	118.6	85.2	127.5	33%
3/21/18 12:44 PM	3/26/18 6:20 AM	7,483	93.1	12,267	96.3	80.4	127.4	37%
3/26/18 6:53 AM	3/30/18 10:07 AM	5,505	77.0	9,163	77.2	71.5	118.7	40%
3/30/18 10:38 AM	4/5/18 11:20 AM	9,536	118.1	15,062	118.5	80.8	127.1	36%
4/5/18 11:50 AM	4/11/18 1:22 PM	8,629	102.7	14,330	103.2	84.0	138.9	39%

Figure 9: Energy use comparison over multi-day monitoring periods.

Total energy used by the integrally geared centrifugal compressor was 36.9% less than that of the rotary lobe blowers over the entire test period, when accounting for run time differences.

Phase 2: The remaining active rotary lobe blowers on Basin 3 were replaced by a stack of 100 hp production Inovair Modular units. Differences between the production units and the prototype unit used in phase 1 are mainly limited to the frame and enclosure resulting in a smaller footprint but the core components were unchanged. In this case, however, it was determined that the process would benefit from a slightly larger capacity aero stage, design flow was unchanged at 1875 scfm but the wire to air efficiency is increased at higher flows. There were no changes made to the prototype IM unit on Basin 2.

Figure 10: Inovair integrally geared centrifugal blowers installed alongside rotary lobe blowers. Production IM is nearest, prototype IM is visible in the background, 3 remaining rotary lobe blowers visible in the middle are unused, but fulfil the need for a redundant unit. There were initially 5 rotary lobe blowers, 2 per basin with 1 shared redundant unit. The Inovair Modular integrally geared centrifugal blowers physically replaced 2 rotary lobe blowers while functionally replacing 4 of them.

Protytpe IM, Basin 2			Production IM, Basin 3				Energy (kW-hr)		Power (kW-hr/day)		Energy
Monitor Start	Monitor End	Average Input Power (kW)	Monitor Start	Monitor End	Average Input Power (kW)		Prototype	Production	Prototype	Production	Production IM Savings
7/3/2018 14:46	7/9/2018 6:30	86.2	7/3/2018 14:47	7/9/2018 6:31	75.4		11,696	10,232	2,068	1,809	13%
7/9/2018 8:39	7/16/2018 0:27	90.0	7/9/2018 8:37	7/16/2018 0:23	77.1		14,389	12,319	2,161	1,851	14%
7/16/2018 9:09	7/23/2018 0:57	93.5	7/16/2018 9:07	7/23/2018 0:53	82.2		14,941	13,130	2,244	1,972	12%

Figure 11: Summary of energy use between the Production Inovair IM unit on Basin 3 and the Prototype Inovair IM unit on Basin 2

The higher capacity stage used on the production unit was expected to yield an 8-10% improvement in efficiency at higher airflow rates, thus an additional savings of 13% over the already significant 36.9% savings exceeded expectations. There are a couple of likely sources of the increased savings but it was not investigated in any significant detail:

1. It is possible that the 2 basins are not operating identically, the flow dividing structure could be yielding a slight difference in the quantity and/or quality of product delivered to the 2 basins. If this were the case, it would indicate that Basin 3 actually requires less aeration than Basin 2 and, since we assumed identical process flow to the 2 basins, Phase 1 energy savings would have been even greater than the 36.9% that was observed.
2. While no changes were made to the Basin 2 process controller from Phase 1 to Phase 2, the Basin 3 DO controller likely benefitted from further refinement of the DO controller logic, which should result in fewer and smaller airflow fluctuations experienced while maintaining DO setpoint.

Additionally, it is interesting to estimate how much of the total energy savings was due to process improvement and how much was due to the higher wire to air efficiency of the Inovair integrally geared centrifugal blowers. While Inovair eagerly awaits the release and implementation of ASME PTC-13 Wire-To-Air Performance Test Code for Blower Systems, no attempts were made to audit the existing wire to air efficiency of the rotary lobe blowers as in-field measurements are notoriously difficult. Rotary lobe blower efficiency is understood to peak at relatively low pressure and decrease with increasing pressure ratio, a reasonable estimate of the isentropic efficiency at 9psi pressure differential is 55%[3], while a centrifugal compressor should have at least 75% isentropic efficiency[3], if not exceeding 80%[4]. This suggests that a centrifugal blower should offer 27% to 31% energy savings over a rotary lobe blower. Another approach to getting a rough estimation of the energy savings due to efficiency is a simple look at the motor size required for each blower package, the rotary lobe blowers utilized 150hp motors and the integrally geared centrifugal blowers utilize 100hp motors, indicating that the integrally geared centrifugal blowers could offer ~33% energy savings based on efficiency alone but it is unlikely that both manufactures have their motors loaded to the same percentage of nameplate. Another approach would be to look at the initial Phase 1 energy audit results, when the Inovair process control was far from optimized, those results indicated an average savings of 26%. During the initial part of Phase 1 testing, the Inovair units were maintaining DO at 2 mg/l while the rotary lobe blowers were cycling between 1 mg/l and 2mg/l, thus the Inovair units were certainly delivering more air and it is likely that the wire to air efficiency difference is greater than 26%. An estimate of 30% energy savings due to the wire to air efficiency seems reasonable. Thus, with a total energy savings of approximately 40%, it is estimated the blower efficiency compromised approximately 75% of the total energy savings and the process improvement comprised approximately 25% of the total energy savings.

To find out how Inovair integrally geared turbo blowers and process control can reduce your plant's operating costs, please contact Inovair at:

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