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TECHNICAL MEMO

To	From
Joe Jewel, Utilities Supervisor District of Port Hardy	Dragan Rokic, P.Eng. McElhanney Ltd. (Victoria)
Re	**Date**
Port Hardy Airport WWTF Aeration System Upgrade	January 5, 2024

1. Background

The District of Port Hardy (the District) operates a Wastewater Treatment Facility (WWTF) at the Port Hardy airport serving the airport and the adjacent residential areas (Figure 1). The WWTF is located adjacent to the Transport Canada airport facility approximately 10 km south east of Port Hardy. Treated effluent from the WWTF is discharged into the Queen Charlotte Strait. There are three sewage lift stations (LS) located in the collection system transferring sewage to the WWTF - Fort Rupert School LS, Fort Rupert Village LS, and Peel Street LS.

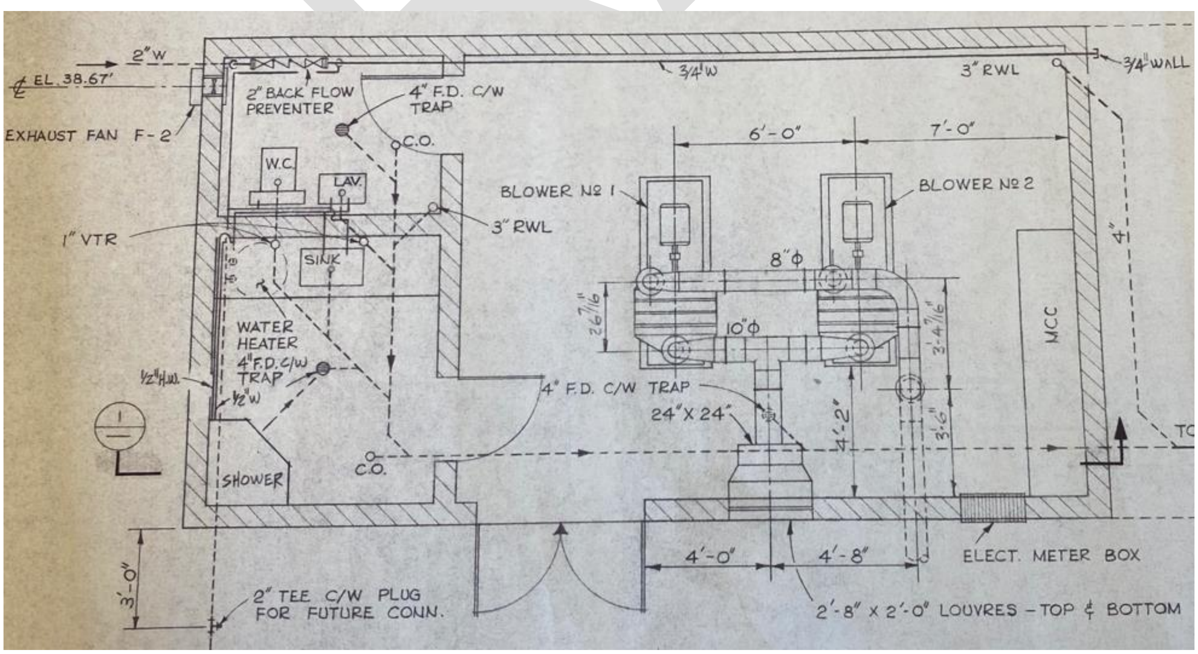
The existing WWTF, originally built in 1975, has been operating for about 48 years with two centrifugal blowers. The facility was originally designed for future expansion and full build-out with two parallel treatment trains. However, the second train has never been added as the community growth had been overestimated at the time and never materialized. According to District operations, no significant growth is expected in the WWTF catchment at the current time with the exception of a potential addition of approximately 80 additional units in the adjacent First Nation Community (*District Operations, 2023*).

The plant features a secondary treatment process consisting of raw sewage screening, grit removal, and aerobic biological treatment. The aerobic treatment is an Extended-Aeration Activated Sludge (EAAS) process. Currently, there is no effluent disinfection in place. The WWTF is classified as the Class II facility under the Environmental Operators Certification Program (EOCP).

Figure 1 Port Hardy Airport WWTF

The process aeration needs are provided by two blowers (1 duty, 1 stand-by) located in the blower room (Figure 2). The existing blowers are Hoffman, centrifugal blowers – model 4206A with Toshiba motors rated for 40 hp (30 kW), 230/460 V, 60 Hz, 3 ph, 3525 RPM. Each blower has a nominal capacity of 20 m^3/min (700 cfm). The blowers are equipped with hard starts and operate continuously without variable frequency drives (VFDs) or a dissolved oxygen (DO) set point and/or control loop.

Figure 2 Blower Room (Record Drawing)



The blowers are complemented with coarse bubble diffusers in the aeration tank supplying oxygen required for biological oxidation and tank mixing. According to record drawings, there are 15 duplex coarse bubble diffusers, installed on vertical drop pipes, in the EAAS tank. Air supplied by blowers is also used for mixing of a sludge storage tank prior to sludge pump-out.

Waste Activated Sludge (WAS), generated in the treatment process, is stored in a sludge holding tank, located next to the EAAS tankage, and pumped out every two weeks for dewatering at the Port Hardy Tsulquate WWTF (*District Operations, 2023*). The sludge generation is estimated at 6,000 gal (23 m^3) every two weeks or 1.6 m^3/day. The sludge holding tank volume is 55 m^3 (4.2 m dia. x 4.0 m high).

2. Objective

As the existing Hoffman blowers operate continuously without VFDs or dissolved oxygen (DO) set point and/or control loop, the District is looking to replace them with more efficient blowers and have more flexibility over the aeration control and energy optimization resulting in long-term O&M cost savings.

The District has a preference for Roots blowers that are also employed at the Port Hardy Tsulquate WWTF for redundancy purposes and to optimize O&M procedures/operations. The WWTF operations' preference is to install three of these blowers within the existing blower room to replace the existing two Hoffman blowers.

3. Scope

The work scope that was undertaken for the purposes of this report is summarized below and included:

- Site visit and review of options and constraints with the WWTF operations.
- Background data review and processing of wastewater influent characterization data, including historical flow records, solids and organic loadings, effluent quality data, and facility mass balance to determine process and sludge aeration requirements.
- Establishment of the WWTF design criteria and prediction of projected hydraulic and organic loadings based on existing conditions and potential future connections.
- Hydraulic verification of the aeration system including blowers, air distribution piping, and diffuser capacity.
- Conceptual design showing the proposed layouts of the new replacement blowers and aeration headers with technical specifications.
- Evaluation of blower replacement options including CAPEX, OPEX, and life-cycle costs and potential savings that can be realized compared to existing configuration.
- Feasibility level (Class C) cost estimates to provide indicative costs of the WWTF improvements. An accuracy range of Class C capital cost estimate is expected to be within +/- 25-40% with a confidence interval of 90%, in accordance with *Budget Guidelines for Consulting Engineering Services, Consulting Engineers of British Columbia, 2009*.

- Summary of assessment findings with recommendations for upgrade requirements.
- A letter-style, brief technical memo (draft and final) outlining recommendations for blower replacement and costing assumptions for review and comments as well recommendations for future work.

4. Operational Certificate

In BC, the *Municipal Wastewater Regulation* (*MWR, 2012*) is a comprehensive regulation that governs all aspects of municipal wastewater management. The BC MWR has set minimum standards for effluent discharges exceeding 22.7 m^3/day (5,000 Igpd) into different receiving bodies (environment), as well as minimum requirements for WWTF effluent quality monitoring, design and construction standards, and management and operations of WWTFs.

The Port Hardy airport WWTF currently operates under the Operational Certificate (OC) ME-105299, issued under the provisions of the Environmental Management Act in 2012. The annual average and maximum authorized rates of discharge are 650 m^3/day and 1,254 m^3/day, respectively. According to the OC, the effluent quality must meet the requirements outlined in Table 1.

Table 1 Permitted Effluent Quality Criteria (OC, ME-105299)

Parameter	Effluent
BOD_5 (mg/L) (Note 1)	Max. ≤ 45
TSS (mg/L) (Note 2)	Max. ≤ 45
pH	6 - 9

Notes:
Note 1: BOD – Biochemical Oxygen Demand
Note 2: TSS – Total Suspended Solids

The authorized treatment works are based on the secondary sewage treatment consisting of screening, grit removal, aerobic biological treatment, back-up power generation, operations building, and a 550 m long outfall discharging through a diffuser at a depth of 20 m below chart datum.

According to the WWTF operational data from 2018 to 2023, the facility has been consistently meeting effluent quality criteria outlined in Table 1 (*District Operations, 2023*).

5. Original and Current WWTF Design Data

The original WWTF design data are summarized in Table 2 under “Initial” and “Ultimate Conditions” columns (*Associated Engineering, 1997*).

Values in the “Current Conditions” column were used to assess the process oxidation requirements under current and projected operational conditions beyond Yr 2023. A safety factor of 25% was applied to 1975 population to provide some extra capacity for potential future connections and/or service area expansion.

Table 2 – WWTF Design Data

Year	Initial Conditions (Note 1)	Ultimate Conditions (Note 1)	Current Conditions (Note 2)
Year	1975	1990	2023
Population Served by Sewerage System (people)	975	2,300	1,219
Average Wastewater Generation Rate (L/capita/day) (Note 3)	380	380	380
Sewerage Flow (Average Dry Weather Flow)	370 m^3/day 4.3 L/sec	870 m^3/day 10 L/sec	460 m^3/day 5.3 L/sec
Sewerage Flow (Peak)	61 m^3/hr 17 L/sec	126 m^3/hr 35 L/sec	76 m^3/hr 21 L/sec
Biochemical Oxygen Demand (BOD) (Note 3)	204 mg/L 76 kg/day	204 mg/L 178 kg/day	204 mg/L 94 kg/day
Total Suspended Solids (TSS) (Note 3)	240 mg/L 89 kg/day	240 mg/L 209 kg/day	240 mg/L 110 kg/day
Total Kjeldahl Nitrogen (TKN) (Note 4)	35 mg/L 13 kg/day	35 mg/L 30 kg/day	35 mg/L 16 kg/day

Notes:

Note 1: Per original WWTF design.

Note 2: Conditions used for the assessment of the aeration system and process oxidation requirements under current and projected operational conditions beyond Yr 2023.

Note 3: Values used in the original WWTF design criteria

Note 4: Design concentrations and organic loadings used for Total Kjeldahl Nitrogen (TKN) are unknown as they are not provided in the original design data. Values indicated in the table are assumed concentrations and loadings at average dry weather operational conditions for estimation of the process oxidation requirements required for nitrification. These values are typical for week to medium strength sewage (*Metcalf & Eddy, 1991, 2003, 2014*).

Values in this table are rounded up when compared to the same values in Table 6.

6. Historical WWTF Flow Records

Historical flow records from 2018 to 2023, obtained from the WWTF operations, have been processed and are summarized in Table 3. The flow records in Table 3 are averaged over the entire year.

Table 3 – Historical Flow Records Averaged over the Entire Year (District Operations, 2023)

Year	Qmin. (m^3/day)	Qaverage (m^3/day)	Qmax. (m^3/day)
2018	271	552	1,331
2019	288	482	1,041
2020	256	496	1,715
2021	192	432	913
2022	198	454	1,006
2023	261	471	928

Note: Flow data for 2023 were incomplete and provided up to July 2023.

The average annual flows show a slight decline after 2018. Observed annual flow variations are in the 5% to 15% range between 2019 and 2023. In general, average annual flows are consistently below the OC limit of 650 m^3/day.

The maximum to annual average flow ratio is typically between 2.0 and 2.5 with the exception of 2020 when the ratio was 3.5. The maximum month to average month flow ratio typically varies between 1.2 and 1.25.

Seasonal dry and wet weather flows are summarized in Table 4 and Table 5, respectively.

Table 4 – Dry Weather (May to September) Flow Records (District Operations, 2023)

Year	Qmin. (m^3/day)	Qaverage (m^3/day)	Qmax. (m^3/day)
2018	271	474	1,331
2019	288	423	933
2020	256	399	726
2021	192	355	559
2022	198	404	903
2023	261	391	529

Note: Flow data for 2023 were incomplete and provided up to July 2023.

The average dry weather flows also show a slight decline after 2018. Observed annual flow variations are typically within 10 % between 2019 and 2023.

After 2019, the observed average dry weather flow has been within 10% of the original design criteria (i.e., 370 m^3/day per Table 2). The maximum dry weather flow exceeded the OC limit of 1,254 m^3/day in 2018.

Table 5 – Wet Weather (October to April) Flow Records (District Operations, 2023)

Year	Qmin. (m^3/day)	Qaverage (m^3/day)	Qmax. (m^3/day)
2018	527	693	890
2019	430	591	1,041
2020	447	680	1,715
2021	384	533	913
2022	399	546	1,006
2023	388	584	928

Note: Flow data for 2023 were incomplete and provided up to July 2023.

In general, peak wet weather flows have been below the OC limit of 1,254 m^3/day with the exception of 2020 when the OC limit was exceeded. After 2018, the maximum to average dry weather flow ratio is typically around 2.5 with the exception of 2020 when the ratio was 4.3.

7. Organic Loadings

Influent wastewater characterization data outlined in Table 2 was considered to estimate WWTF organic mass loads and process aeration requirements.

The BOD and TSS load calculations in Table 6 are based on average per capita BOD and TSS mass loads of 78 gr/capita/day and 90 gr/capita/day, respectively. These are back calculated values based on the BOD and TSS design concentrations of 204 mg/L and 240 mg/L, respectively, at average dry weather flows, per Table 2.

The Total Kjeldahl Nitrogen (TKN) load calculations are based on the average per capita TKN mass load of 13 gr/capita/day yielding the TKN concentration of 35 mg/L at average dry weather flow conditions.

A maximum day mass loading factor of 1.5, typically used for mechanical treatment systems, was assumed as an allowance for peak mass loading conditions for estimation of aeration requirements. These peak mass loading conditions are highlighted in orange in Table 6.

Influent BOD, TSS, and TKN are expected to be diluted during wet weather flow periods.

Table 6 – Organic Load Estimates

Parameter	Symbol	Units	1975	1990	Year 2023
Population / Houses					
Projected Population	P	people	975	2,300	1,219
Flow					
Average Day (Dry Weather) Flow	ADWF	m^3/day	369	871	461
Per Capita Hydraulic Loading at ADWF (ADWF/P)	Lcd	L/capita/day	379	379	379
Maximum Day Flow (f_{MDF}xADWF)	MDF	m^3/day	1,472	3,025	1,840
Maximum Day Flow Factor	f_{MDF}	-	4.0	3.5	4.0
Biochemical Oxygen Demand (BOD_5)					
Average Day (Dry Weather) per Capita Loading	grcd	gr/capita/day	78	78	78
Average Day (Dry Weather) Loading (Pxgrcd)	ADWL	kg/day	76.1	179.4	95.1
Average Day (Dry Weather) Concentration (ADWL/ADWF)	C_{ADWF}	mg/L	206	206	206
Max. Day Loading Factor	f_{MDL}	-	1.5	1.5	1.5
Max. Day Loading (f_{MDL}xADWL)	MDL	kg/day	114.1	269.1	142.6
Max. Day Flow Concentration (MDL/MDF) (est.)	C_{MDF}	mg/L	78	89	78
Total Suspended Solids (TSS)					
Average Day (Dry Weather) per Capita Loading	grcd	gr/capita/day	90	90	90
Average Day (Dry Weather) Loading (Pxgrcd)	ADWL	kg/day	87.8	207.0	109.7
Average Day (Dry Weather) Concentration (ADWL/ADWF)	C_{ADWF}	mg/L	238	238	238
Max. Day Loading Factor	f_{MDL}	-	1.5	1.5	1.5
Max. Day Loading (f_{MDL}xADWL)	MDL	kg/day	131.6	310.5	164.5
Max. Day Flow Concentration (MDL/MDF) (est.)	C_{MDF}	mg/L	89	103	89
Total Kjeldahl Nitrogen (TKN)					
Average Day (Dry Weather) per Capita Loading	grcd	gr/capita/day	13.0	13.0	13.0
Average Day (Dry Weather) Loading (Pxgrcd)	ADWL	kg/day-N	12.7	29.9	15.8
Average Day (Dry Weather) Concentration (ADWL/ADWF)	C_{ADWF}	mg/L	34	34	34
Max. Day Loading Factor	f_{MDL}	-	1.5	1.5	1.5
Max. Day Loading (f_{MDL}xADWL)	MDL	kg/day	19.0	44.9	23.8
Max. Day Flow Concentration (MDL/MDF) (est.)	C_{MDF}	mg/L	13	15	13
Total Phosphorus (TP)					
Average Day (Dry Weather) per Capita Loading	grcd	gr/capita/day	2.0	2.0	2.0
Average Day (Dry Weather) Loading (Pxgrcd)	ADWL	kg/day-P	2.0	4.6	2.4
Average Day (Dry Weather) Concentration (ADWL/ADWF)	C_{ADWF}	mg/L	5	5	5
Max. Day Loading Factor	f_{MDL}	-	1.5	1.5	1.5
Max. Day Loading (f_{MDL}xADWL)	MDL	kg/day	2.9	6.9	3.7
Max. Day Flow Concentration (MDL/MDF) (est.)	C_{MDF}	mg/L	2	2	2

8. Aeration Requirements

Air supplied by blowers at the Port Hardy Airport WWTF is used for biological oxidation of BOD and TKN as well as for the EAAS bioreactor and sludge tank mixing. Each existing blower has a nominal capacity of 20 m^3/min (700 cfm). Based on the WWTF operational data from 2018 to 2023, an average dissolved oxygen concentration in the EAAS bioreactor is typically between 6 mg/L and 7 mg/L.

8.1. PROCESS AIR

Process air calculations are provided in Appendix A. The calculations are provided for average and peak organic mass loading conditions. Some of the key calculation assumptions are provided in Table 7.

Table 7 – Key Air Calculation Assumptions

Parameter	Value
Bioreactor Average Dissolved Oxygen Concentration	min. 2.0 mg/L
Air Required for BOD Oxidation	1.25 kg O_2/kg BOD/day
Air Required for TKN Oxidation (Nitrification)	4.6 kg O_2/kg TKN/day
Fouling Factor for Coarse Bubble Diffusers (Safety Factor)	0.9
Fouling Factor for Fine Bubble Diffusers (Safety Factor)	0.7
Coarse Bubble Diffusers Oxygen Transfer Efficiency	2.5 %/m
Fine Bubble Diffusers Oxygen Transfer Efficiency	6.5 %/m
Wastewater (Field) Operating Temperature (Critical for Summer Operation)	20ºC
Ambient Air Temperature (Critical for Summer Operation)	25ºC

The summary air requirements under summer operational conditions are provided in Table 8.

Table 8 – Process Air Requirements under Summer Operational Conditions

Design Condition	Initial Conditions		Current Conditions		Current Conditions		Ultimate Conditions	
Year	1975	1975	2023+	2023+	2023+	2023+	1990	1990
Population (people)	975	975	1,219	1,219	1,219	1,219	2,300	2,300
Average Dry Weather Flow (m^3/day)	369	369	461	461	461	461	871	871
Organic Loading (BOD and TKN)	Average Load	Peak Load	Average Load	Peak Load	Average Load	Peak Load	Average Load	Peak Load
Diffuser Type	Coarse	Coarse	Coarse	Coarse	Fine	Fine	Coarse	Coarse
Air Volume (m^3/min)	11.0	16.5	13.8	20.7	6.8	10.2	26.0	39.0
Air Volume (cfm)	389	583	486	730	240	361	918	1,377

Note: The + sign in 2023+ indicates anticipated operational conditions beyond Yr 2023

Estimates indicate that up to 13.8 m^3/min (486 cfm) of air is required to meet current and projected process requirements under average organic load operational conditions. This estimate is based on coarse bubble diffusers (refer to “Current Conditions” column and coarse bubble diffusers). Peak organic load operational conditions would require up to 20.7 m^3/min (730 cfm) of air. These process requirements could be met with a single (duty), VFD-controlled blower operating under average loading conditions and most of the time while the second (standby) blower would be operating only during peak loads (refer to Section 9.1 for blower specifications).

Estimates also indicate that up to 6.8 m^3/min (240 cfm) of air is required to meet current and projected process requirements under average organic load operational conditions based on fine bubble diffusers (refer to "Current Conditions" column and fine bubble diffusers). Peak organic load operational conditions would require up to 10.2 m^3/min (361 cfm) of air.

Air requirements for Initial and Ultimate Conditions in Table 8 are provided for comparison with the original WWTF design criteria.

8.2. BIOREACTOR MIXING AIR

Bioreactor mixing air requirements are estimated based on the bioreactor geometry provided in Table 9.

Table 9 – Bioreactor Geometry

Parameter	Symbol	Value	Units
BIOREACTOR			
Bioreactor Volume (Total)	V_{Bio}	926	m^3
Bioreactor Depth (Total)	H_{total}	4.4	m
Diffuser Elevation from Bottom	$H_{diffuser}$	0.3	m
Diffuser to Water Level	H_{wl}	3.2	m
Bioreactor Depth (Active)	H_{active}	3.5	m
Bioreactor Volume (Active)	V_{Bio}	737	m^3

References indicate that 0.01 to 0.015 m^3_{air}/m^3_{tank}/min is required for tank mixing for diffused aeration in the activated sludge process (*Metcalf & Eddy, 1991, 2003, 2014*). That would require between 7.4 and 11 m^3/min (260 to 390 cfm) of air for tank mixing.

References also indicate that 0.02 to 0.03 m^3_{air}/m^3_{tank}/min is required for tank mixing for spiral roll aeration in the activated sludge process (*Metcalf & Eddy, 1991, 2003, 2014*). That would require between 14.7 and 22.1 m^3/min (520 to 780 cfm) of air for tank mixing.

Aeration requirements for bioreactor tank mixing are expected to be within the ranges indicated above.

For coarse bubble diffusers, process air requirements are more critical than mixing air requirements. For fine bubble diffusers, mixing air requirements may be more critical than process air requirements as the mixing pattern in the EAAS bioreactor is a single spiral roll. However, the replacement blowers will be adequate for operation with either coarse or fine bubble diffusers (refer to Section 9).

8.3. SLUDGE TANK MIXING AIR

Sludge tank mixing air requirements are estimated based on the sludge geometry provided in Table 10.

Table 10 – Sludge Tank Geometry

SLUDGE HOLDING TANK			
SHT Volume (Total)	V_{SHT}	55	m^3
SHT Depth (Total)	H_{total}	4.0	m
Diffuser Elevation from Bottom	$H_{diffuser}$	0.3	m
Diffuser to Water Level	H_{wl}	3.4	m
SHT Depth (Active)	H_{active}	3.7	m
SHT Volume (Active)		51	m^3

Note: SHT – Sludge Holding Tank

References indicate that up to 1.2 to 1.8 m^3_{air}/m^3_{tank}/min may be required for sludge tank mixing wherein sludge builds up and concentrates at the tank bottom (*Metcalf & Eddy, 1991, 2003, 2014*). That would require approximately 1.3 m^3/min (45 cfm) of air for tank mixing at 1.5 m^3_{air}/m^3_{tank}/min. The existing sludge holding tank is not currently operated as an aerobic digestor.

9. Blower Design and Operational Strategy

The District has a preference for the Roots 56 URAI blower model to consolidate operations with the Port Hardy Tsulquate WWTF and optimize O&M procedures and procurement of spare parts. The District is looking at adding three replacement blowers in the existing blower room (2 duty, 1 stand-by).

9.1. BLOWER SPECIFICATIONS

The detailed Roots 56 URAI blower model specifications are provided herein.

- Roots 56 URAI Positive Displacement Rotary Blower
- VersaBase 567 with Integral Belt Guard and associated brackets for accessory mounting
- Motor, 30 HP (22.4 kW), TEFC, Inverter Duty, 1800 RPM, 1.15 SF, 208-230/460 Volts, 3 Phase, 60 Hz
- Motor Slide Base, Double Adjusting
- Drive, V-Belt, minimum service factor of 1.4
- Inlet Filter, 5", Paper Element, Universal CF-5
- Inlet Silencer, 5", Chamber-Absorptive Type, Universal SD-5
- Discharge Silencer, 4", Chamber-Absorptive Type, Universal SD-4
- Discharge Flex Connector, 4", Silicone Impregnated Fiberglass
- Relief Valve, Pressure, Spring Type, Kunkle 337, 2", Set at 8 PSI
- Check Valve, 4" MNPT, EPDM Seal
- Pressure Gauge, 2.5" Dia., 0-15 PSI, Liquid Filled, Snubber & Gauge Cock

- Enclosure, Acoustical, Galvanized Steel, Removable Roof & Doors, 120V Exhaust Fan (optional)
- Fabricated Steel Sub-base for common mounting of package and enclosure, Forklift Slots (optional)
- Thermostat for Enclosure Interior Temperature (optional)
- Mechanical Run Test at Design Conditions
- VFD, Invertek Optidrive, Shipped Loose

9.2. OPERATING CONDITIONS

- Inlet Volume: 523 ACFM (500 SCFM)
- Site Elevation: up to 500' (150 m)
- Barometric Pressure: 14.4 PSIA (10.1 m)
- Inlet Temperature: 100 °F (38°C)
- Inlet Pressure Drop: 0.3 PSI (0.2 m)
- Blower Inlet Pressure: 14.1 PSIA (10.1 m)
- Discharge Pressure Drop: 0.2 PSI (0.14 m)
- Discharge Pressure: 6.0 PSIG (4.2 m)
- Blower Differential Pressure: 6.5 PSI (4.6 m) (70% of maximum)

9.3. PERFORMANCE DATA

- Design Speed: 2100 RPM (74% of maximum)
- Shaft Power: 21.9 BHP (16.3 kW)
- Discharge Temperature: 293 °F (145°C)
- Differential Temperature: 193 °F (90°C) (76% of maximum)
- Discharge Volume: 362 ACFM
- Estimated Noise Level: 90 dB at 3 feet

9.4. OPERATIONAL STRATEGY

The blowers (2 duty, 1 stand-by) will be controlled by VFDs based on a new dissolved oxygen (DO) set point and/or control loop. The blower nominal flow rate is 10 m^3/min (350 cfm); however, will be able to operate in the range from 5 m^3/min (200 cfm) to 15 m^3/min (500 cfm). A single blower will be operating most of the time while the second blower can be used occasionally to adapt to peak organic loading conditions. Two blowers can also operate in parallel at a reduced frequency to optimize power consumption. The Roots 56 URAI blower curves are provided in Figure 3. The proposed blower room layout with three replacement blowers is shown in Figure 4.

Figure 3 Roots 56 URAI Blower Curves

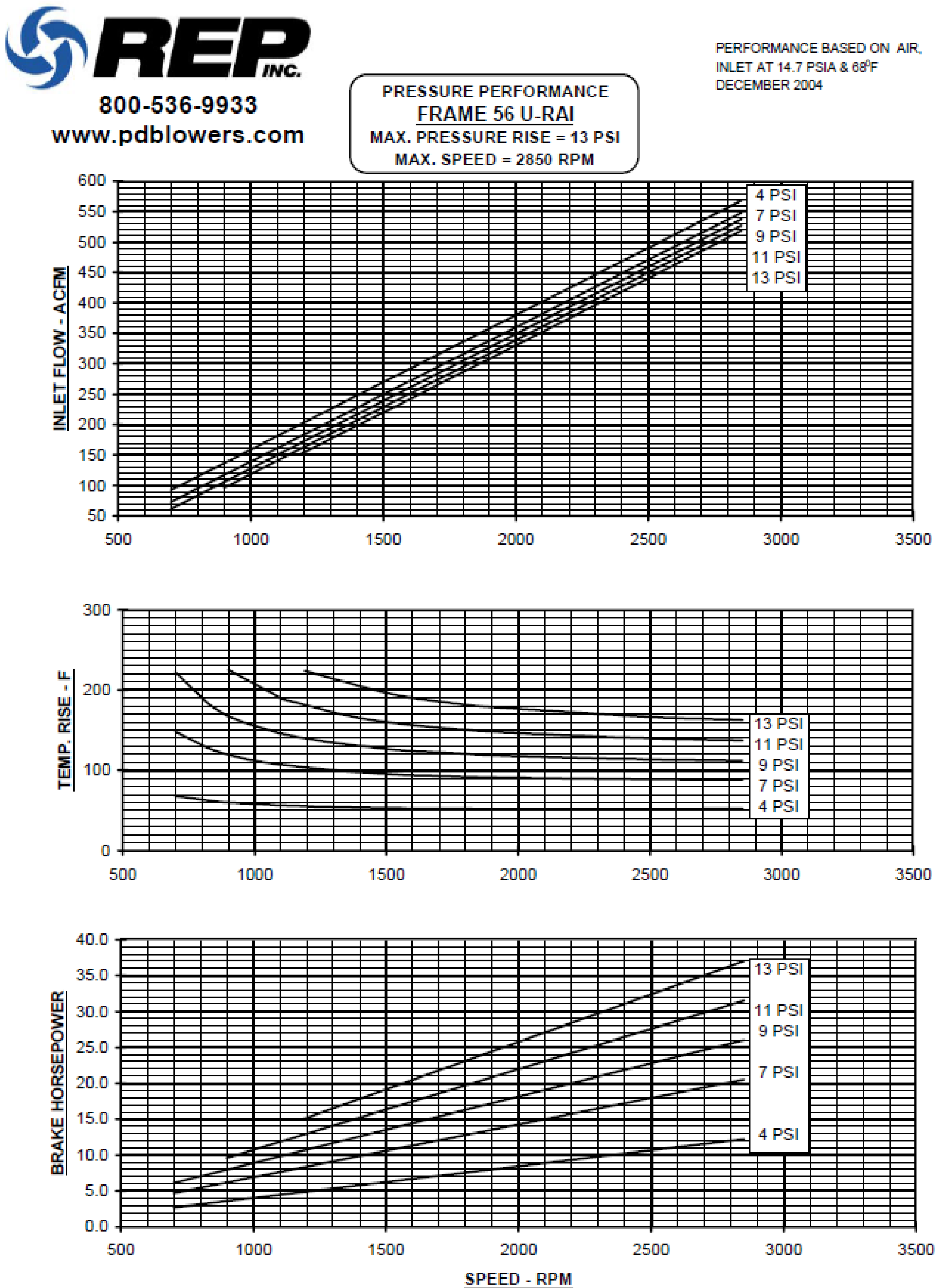
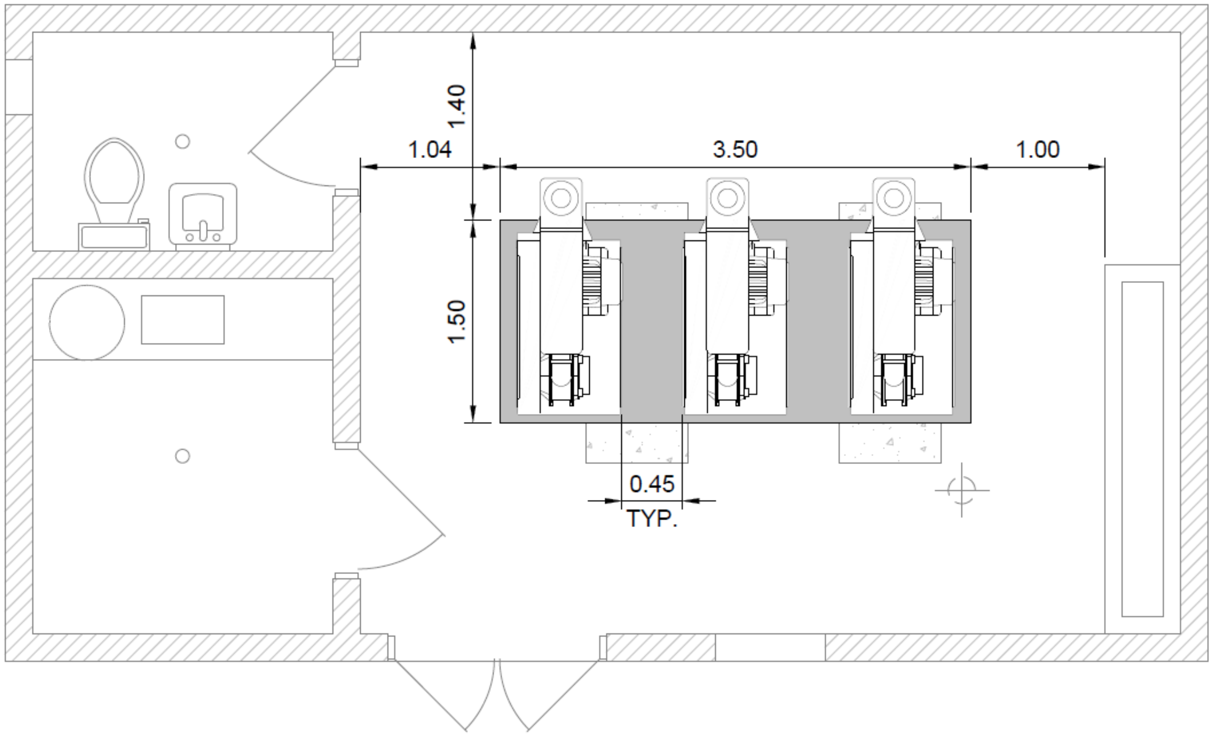


Figure 4 Proposed Blower Room Layout



Further layout optimization is possible and can be finalized during detailed design.

A typical Roots 56 URAI blower package with a fully enclosed blower is shown in Figure 5. However, the blower configuration can be customized due to space constraints in the existing blower room, as shown in Figure 6.

Figure 5 Typical Roots 56 URAI Fully Enclosed Blower Package

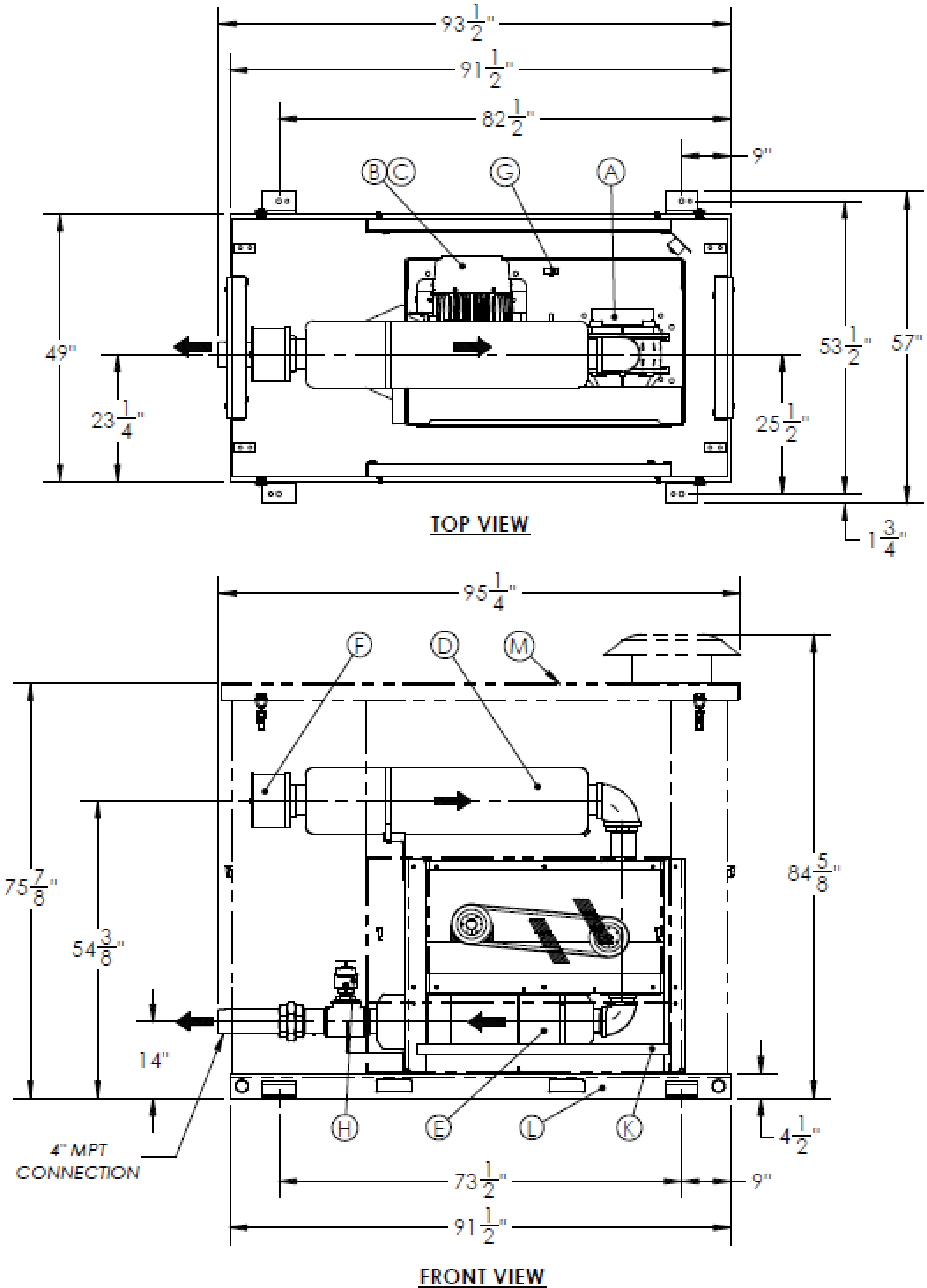
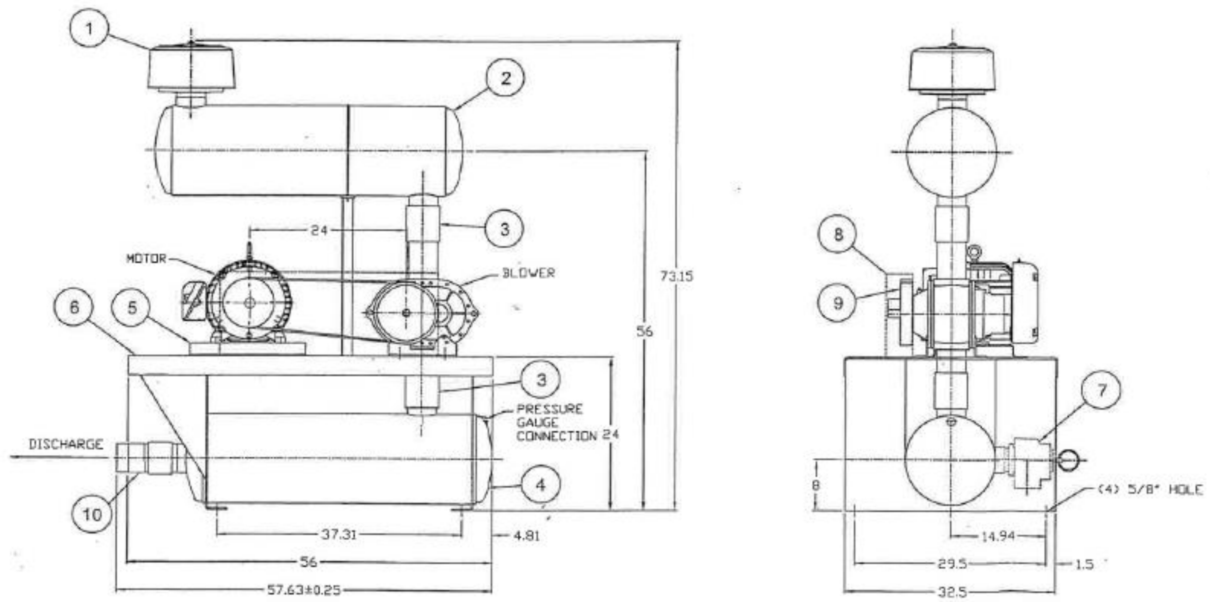


Figure 6 Customized Roots 56 URAI Blower Configuration



10. Diffusers

10.1. EXISTING CONDITIONS/CONFIGURATION

Currently, coarse bubble diffusers are used to supply air to the EAAS bioreactor for process requirements and tank mixing. According to record drawings, there are 15 duplex coarse bubble diffusers (Figure 7), installed on vertical drop pipes (Figure 8), in the EAAS tank. Diffusers create a single spiral roll mixing pattern in the bioreactor. The diffuser model is unknown.

Figure 7 Diffuser Configuration in the EAAS Tank

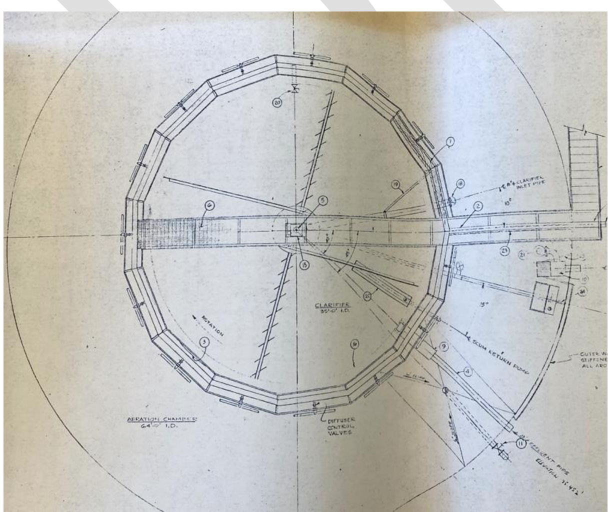
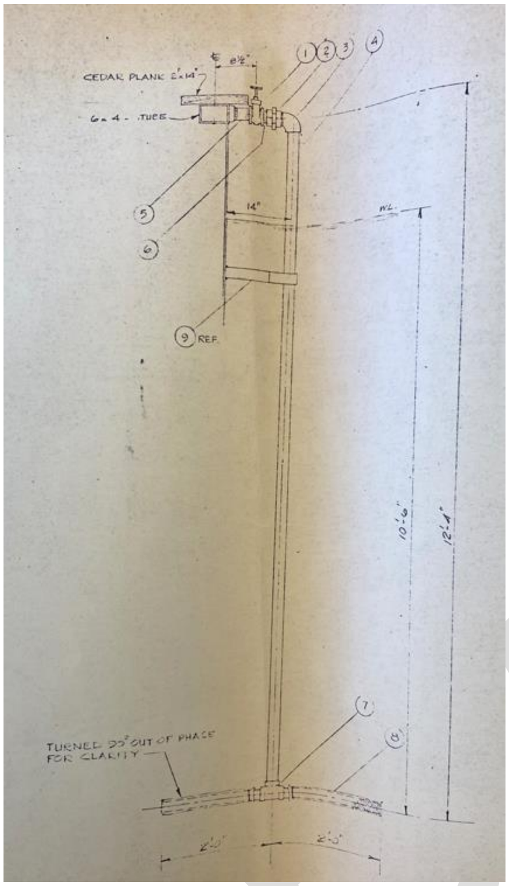


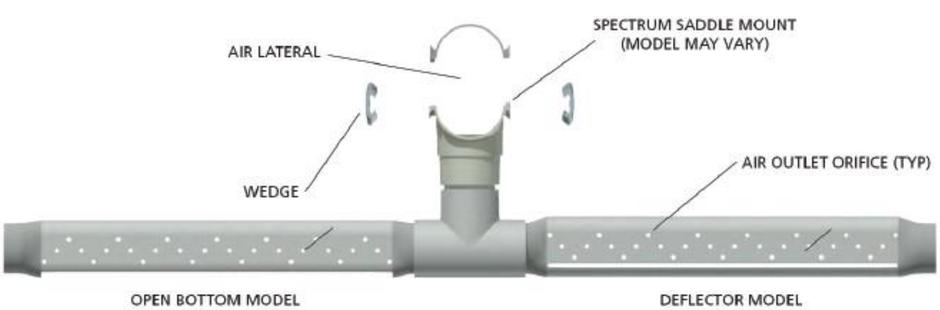
Figure 8 Duplex Coarse Bubble Diffuser on Vertical Drop Pipe



10.2. REPLACEMENT COARSE BUBBLE DIFFUSERS

The existing diffusers can be retained in service or, depending on the condition, replaced with either new coarse bubble diffusers of the same design or an alternate model, such as, for example, with the EDI duplex diffusers (Figure 9).

Figure 9 EDI CoarsAir MaxAir PVC Diffuser (Environmental Dynamics International)



The EDI CoarsAir MaxAir PVC diffuser specifications are provided in Table 11.

Table 11 – EDI CoarsAir MaxAir PVC Diffuser Specifications (Environmental Dynamics International)

Model / Parameter	Value
Diffuser Type	Duplex
Diffuser Model	EDI CoarsAir MaxAir PVC
Design Air Flow	0 - 2.6 m^3/min/diffuser 0 - 100 cfm/diffuser
Diffuser Length	1.63 m
Total Diffuser Capacity Based on 15 Diffusers	0 - 39 m^3/min 0 – 1,500 cfm
Anticipated Operational Conditions Based on Process Air Requirements per Table 8.	Typically, and most of the time, 25% - 35% of max. diffuser capacity considering the blower turndown ratio; Occasionally up to 49% of max. diffuser capacity at peak organic loadings

The replacement diffusers would provide adequate air flow for process needs and bioreactor tank mixing. Diffusers would operate in the optimum range as, according to EDI, the optimum oxygen transfer efficiency is achieved when diffusers are operating in the middle to low end of the air flow range.

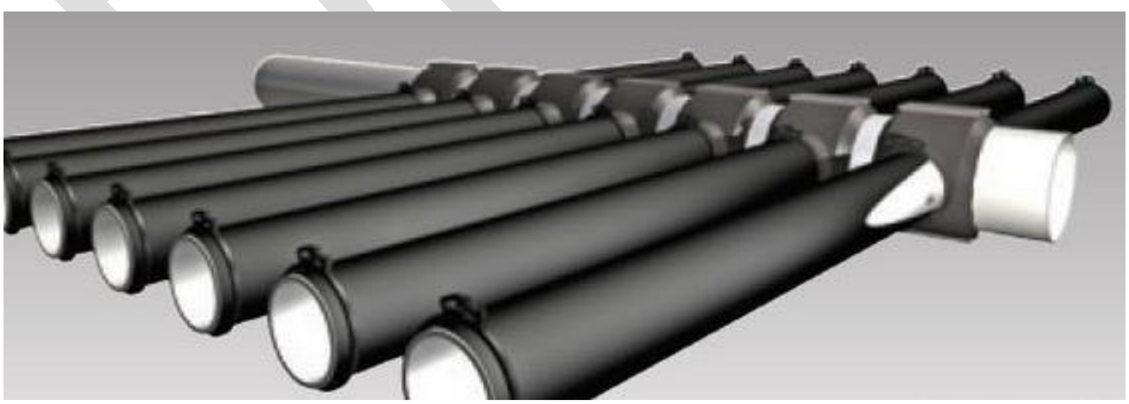
10.3. REPLACEMENT FINE BUBBLE DIFFUSERS

Replacement of coarse bubble diffusers with fine bubble diffusers is a process configuration modification option the District is willing to evaluate. Two potential options are presented herein - EDI FlexAir MiniPanel Diffuser and EDI FlexAir Pro Magnum Diffuser.

10.3.1. EDI FlexAir MiniPanel Diffuser

The diffuser look and a typical installation is shown in Figure 10.

Figure 10 EDI FlexAir MiniPanel Diffuser (Environmental Dynamics International)



The EDI FlexAir MiniPanel diffuser specifications are provided in Table 12.

Table 12 – EDI FlexAir MiniPanel Diffuser Specifications (Environmental Dynamics International)

Model / Parameter	Value
Diffuser Type	Duplex Micropore
Diffuser Model	EDI FlexAir MiniPanel
Design Air Flow	0 – 1.3 m^3/min/diffuser 0 - 50 cfm/diffuser
Diffuser Length	2.97 m
Total Diffuser Capacity Based on 15 Diffusers (i.e., single duplex diffuser on each vertical drop pipe)	0 - 20 m^3/min 0 – 750 cfm
Anticipated Operational Conditions Based on Process Air Requirements per Table 8 and in consideration of tank mixing requirements.	Typically, 45% - 70% of max. diffuser capacity
Potential Upgrade	
Total Diffuser Capacity Based on 15 Dual Diffusers (i.e., two duplex diffusers on each vertical drop pipe)	0 - 40 m^3/min 0 – 1,500 cfm
Anticipated Operational Conditions Based on Process Air Requirements per Table 8 and in consideration of tank mixing requirements.	Typically, 25% - 35% of max. diffuser capacity

Considering anticipated typical operational conditions, single EDI FlexAir MiniPanel diffusers would not operate in the optimum range and would require two duplex diffusers on each vertical drop pipe for optimum oxygen transfer efficiency. Alternatively, the addition of more drop pipes inside the EAAS tank does not seem to be a practical approach.

10.3.2. EDI FlexAir Pro Magnum Diffuser

This diffuser model is similar to the EDI FlexAir MiniPanel diffuser model, shown in Figure 10. The EDI FlexAir Pro Magnum diffuser specifications are provided in Table 13.

Table 13 – EDI FlexAir Pro Magnum Diffuser Specifications (Environmental Dynamics International)

Model / Parameter	Value
Diffuser Type	Duplex
Diffuser Model	EDI FlexAir Pro Magnum
Design Air Flow	0 – 0.9 m^3/min/diffuser 0 - 35 cfm/diffuser
Diffuser Length	2.4 m
Total Diffuser Capacity Based on 15 Diffusers (i.e., single duplex diffuser on each vertical drop pipe)	0 - 14 m^3/min 0 – 525 cfm
Anticipated Operational Conditions Based on Process Air Requirements per Table 8 and in consideration of tank mixing requirements.	Typically, 70% - 100% of max. diffuser capacity
Potential Upgrade	
Total Diffuser Capacity Based on 15 Dual Diffusers (i.e., two duplex diffusers on each vertical drop pipe)	0 - 28 m^3/min 0 – 1,050 cfm
Anticipated Operational Conditions Based on Process Air Requirements per Table 8 and in consideration of tank mixing requirements.	Typically, 35% - 50% of max. diffuser capacity

As in the previous case and considering typical operational conditions, single EDI FlexAir Pro Magnum diffusers would not operate in the optimum range and would require two duplex diffusers on each vertical drop pipe for optimum oxygen transfer efficiency.

11. Estimate of Probable Costs

11.1. CAPITAL COST ESTIMATE

The system component upgrade/replacement costs for options with coarse and fine bubble diffusers are provided in Table 14 and Table 15, respectively. An indicative Class C capital cost estimated herein is based on the combination of technology/material quotes, parametric estimates, and analogous pricing (i.e., historical costs) from previous experience with similar past projects. An accuracy range of Class C capital cost estimate is expected to be within ±25-40% with a confidence interval of 90% in accordance with *Budget Guidelines for Consulting Engineering Services, Consulting Engineers of British Columbia, 2009*.

Table 14 – Estimated System Component Upgrade/Replacement Costs with Coarse Bubble Diffusers

System Components	Cost
Roots 56 URAI Blower Package per Section 9; Qty: 3 blower packages (based on quote received from Roots); 14-16 Week Delivery	$195,000
Blower Manifold Reconfiguration incl. 3 Shut-off Valves and 100 mm 316 SS Sch 10 Discharge Piping (est.)	$25,000
Blower Concrete Base (est.); Qty: 1 continuous	$5,000
Replacement of Coarse Bubble Diffusers with Coarse Bubble Diffusers; Qty: 15 duplex diffusers	$15,000
Dissolved Oxygen Probe and Control Loop, Transmitter, Cabling and Wiring; Qty: 1	$15,000
Contingency at 25%	$63,750
Subtotal	**$318,750**
Electrical Review, Upgrades, and Programming for Integration of New Blowers, VFDs, and DO Probe/Control Loop (est.)	$30,000
Process/Mechanical Engineering (est.)	$25,000
Total with Coarse Bubble Diffusers	**$373,750**

Note: Based on McElhanney experience with the past projects, other blower options (e.g., Aerzen) are expected to be more cost effective. The Aerzen blowers have a larger footprint; however, the anticipated cost of a 2-blower Aerzen configuration (1 duty, 1 stand-by), equipped with VFDs, is expected to be less than $100,000 resulting in a potential saving of about $100,000 in capital cost upgrades.

Provided estimates are based on the assumption that District operations may be actively involved with the upgrades and complete the blower/base installation, discharge manifold reconfiguration, diffuser replacement, and some electrical works with their own staff.

Table 15 – Estimated System Component Upgrade/Replacement Costs with Fine Bubble Diffusers

System Components	Cost
Roots 56 URAI Blower Package per Section 9; Qty: 3 blower packages (based on quote received from Roots); 14-16 Week Delivery	$195,000
Blower Manifold Reconfiguration incl. 3 Shut-off Valves and 100 mm 316 SS Sch 10 Discharge Piping (est.)	$25,000
Blower Concrete Base (est.); Qty: 1 continuous	$5,000
Replacement of Coarse Bubble Diffusers with Fine Bubble Diffusers; Qty: 30 duplex diffusers	$45,000
Dissolved Oxygen Probe and Control Loop, Transmitter, Cabling and Wiring; Qty: 1	$15,000
Contingency at 25%	$71,250
Subtotal	**$356,250**
Electrical Review, Upgrades, and Programming for Integration of New Blowers, VFDs, and DO Probe/Control Loop (est.)	$30,000
Process/Mechanical Engineering (est.)	$25,000
Total with Fine Bubble Diffusers	**$411,250**

11.2. POTENTIAL OPERATIONAL COST SAVINGS

11.2.1. Current (2023) Operational Conditions

The BC Hydro electricity rate for commercial users is currently $0.1134/kW-hr. For comparison, BC Hydro charges residential users $0.0975/kW-hr up to 1,350 kW-hr and $0.1408/kW-hr thereafter.

The District's monthly bill for blower operation is about $2,400/month in 2023 (*District Operations, 2023*). Based on the back calculation, the BC Hydro commercial rate of $0.1134/kW-hr is applicable assuming a continuous operation of a single Hoffman blower.

Potential initial operational, specifically electricity, cost savings after blower replacement under average operating conditions are estimated in Table 16.

An initial saving in the electricity bill is estimated at approximately $13,410 annually.

Table 16 – Potential Initial Electricity Cost Savings

System Components	Value
Existing Hoffman 4206A Blower Rating	40 HP (29.8 kW)
Roots 56 URAI Blower Rating (Installed Power)	30 HP (22.4 kW)
Roots 56 URAI Blower Power Draw at Nominal Flow of 350 cfm	21.9 HP (16.3 kW)
Initial Operational Saving - Delta Power (29.8 kW – 16.3 kW)	Delta Power = 18 HP (13.5 kW) Saving = 324 kW-hr/day Saving = 118,260 kW-hr/year
Current BC Hydro Electricity Rate for Commercial Users	$0.1134/kW-hr
Annual Electricity Cost Saving (Current Conditions)	appr. $13,410/year

11.2.2. Potential Long-Term Operational Cost Savings

Potential operational, specifically electricity, cost savings under long-term average operating conditions are estimated in Table 17. These savings are calculated based on the assumption that a single blower will be operating continuously most of the time at the nominal flow rate of 350 cfm. As BC Hydro applies regularly for annual electricity rate increases, potential long-term electricity cost savings are calculated assuming an average BC Hydro rate of $0.15/kW-hr (potentially higher) over the next 20 to 25 years and beyond.

Table 17 – Potential Long-Term Average Electricity Cost Savings

System Components	Value
Existing Hoffman 4206A Blower Rating	40 HP (29.8 kW)
Roots 56 URAI Blower Rating (Installed Power)	30 HP (22.4 kW)
Roots 56 URAI Blower Power Draw at Nominal Flow of 350 cfm	21.9 HP (16.3 kW)
Potential Operational Saving - Delta Power (29.8 kW – 16.3 kW)	Delta Power = 18 HP (13.5 kW) Saving = 324 kW-hr/day Saving = 118,260 kW-hr/year
Long-Term Average Electricity Rate	$0.15/kW-hr
Potential Long-Term Annual Electricity Cost Saving (est.)	appr. $17,740/year

A potential long-term saving in the electricity bill is estimated at approximately $17,740 annually.

Additional O&M savings are possible and can be realized as the same blower model is used at the Port Hardy Tsulquate WWTF, due to the same spare parts, oil, grease, and other consumables as well as optimization of servicing procedures. However, this cost cannot be quantified at this time.

12. Conclusions

Replacement of the two existing Hoffman 4206A blowers with the three Roots 56 URAI blowers (2 duty, 1 stand-by) is a feasible option. The blower room layout will be optimized during detailed design.

The blowers will be controlled by VFDs based on the dissolved oxygen (DO) set point in the bioreactor and/or control loop. Addition of VFDs and DO set point and control loop will provide operational flexibility and result in long-term, cumulative O&M cost savings.

The Roots 56 URAI blower nominal flow rate is 10 m^3/min (350 cfm); however, will be able to operate in the range from 5 m^3/min (200 cfm) to 15 m^3/min (500 cfm). Two blowers in parallel operation will be able to deliver up to 30 m^3/min (1,000 cfm) of air.

A single blower will be operating most of the time while the second blower can be used occasionally to adapt to peak organic loading conditions. Two blowers can also operate in parallel at a reduced frequency to optimize power consumption.

The existing coarse bubble diffusers in the EAAS tank can be replaced with either new coarse bubble diffusers or retrofitted with new fine bubble diffusers. This will be District operations' decision although replacement with new coarse bubble diffusers is expected to be more cost effective. Either option will provide adequate treatment and bioreactor mixing.

For coarse bubble diffusers, process air requirements are more critical than mixing air requirements. For fine bubble diffusers, mixing air requirements may be more critical than process air requirements as the mixing pattern in the EAAS bioreactor is a single spiral roll. The replacement Roots blowers will be adequate for operation with either coarse or fine bubble diffusers.

A potential saving in the electricity bill after blower replacement is estimated at approximately $13,410 annually initially and at $17,740 per year as a long-term average.

Additional O&M savings can be realized as the same blower model is used at the Port Hardy Tsulquate WWTF, due to the same spare parts, oil, grease, and other consumables as well as optimization of servicing procedures. This cost cannot be quantified at this time.

13. Closure

Please do not hesitate to call the undersigned at your earliest convenience should you have any questions or require additional information.

Sincerely,

McELHANNEY LTD.

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Appendix A - Process Calculations

YEAR 1975					
Process Air - Summer Operating Conditions (BOD+NH_3)					
Parameter	**Symbol**	**Value**	**Value**	**Units**	**Comment**
Actual Oxygen Rate (AOR)		**Average**	**Peak**		
Design Flow	Q	369.0	369.0	m^3/day	ADWF
Design BOD	BOD	76.1	114.1	kg BOD/day	Average and Peak day load
Design NH_3-N	NH_3-N	12.7	19.0	kg NH_3-N/day	Average and Peak day load
Air for BOD Oxidation		1.25	1.25	kg O_2/kg BOD/day	
Air for NH_3-N Oxidation		4.6	4.6	kg O_2/kg NH_3-N/day	
Air for BOD Oxidation		95.1	142.6	kg O_2/day	
Air for NH_3-N Oxidation		58.4	87.4	kg O_2/day	
Field Oxygen Transfer Rate	OTR	153.5	230.0	kg O_2/day	
Standard Oxygen Rate (SOR)					
DO Surface Saturation Concentration	C^*_{st}	9.092	9.092	mg/L	at wastewater operating temperature t
DO Surface Saturation Concentration	C^*_{s20}	9.092	9.092	mg/L	at standard temperature (20^{o}C)
Temperature Correction Factor	τ	1.000	1.000		$\tau = C^*_{st}/C^*_{s20}$
Relative DO Saturation to Clean Water	β	0.95	0.95	-	Typically 0.95 - 0.98
Standard Barometric Pressure	P_s	101.325	101.325	kPa	at sea level
Barometric Pressure at Test Site	P_b	101.151	101.151	kPa	at elevation h; $P_b = P_s * \Omega$
Acceleration due to Gravity	g	9.810	9.810	m/s^2	
Air Molecular Weight	M	28.97	28.97	g/mole air	
Elevation	h	15.0	15.0	masl	in meters
Universal Gas Constant	R	8,314	8,314	Nm/(mole air * K)	
Air Temperature	$T_{C,air}$	25	25	^{o}C	summer/winter; summer is critical
Temperature	T_{air}	298.15	298.15	K	T_{air} = 273.15 + ^{o}C
Pressure Corection Factor	Ω	0.998	0.998		$\Omega = P_b/P_{s;}\ exp(-gMh/RT_{air})$)
Diffuser Depth	D_f	3.20	3.20	m	in bioreactor
Mid-Depth Correction Factor	d_e	0.40	0.40	-	Typically 0.25 - 0.45 (0.40)
Saturated DO Value at Sea Level	$C^*_{\infty 20}$	10.22	10.22	mg/L	$C^*_{\infty 20} = C^*_{s20}\ [1+d_e(D_f/P_s)]$ at standard temperature (20^{o}C)
Average DO Concentration	C	2.0	2.0	mg/L	in bioreactor
Empirical Temperature Correction Factor	θ	1.024	1.024	-	typically 1.024
Wastewater Field (Operating) Temperature	t	20	20	^{o}C	summer/winter; summer is critical
Standard Temperature	T_s	20	20	^{o}C	
Relative Oxygen Transfer Rate	α	0.65	0.65	-	in process water versus clean water; typically 0.4 - 0.8 for diffused aeration
Fouling Factor	F	0.90	0.90		typically 0.65 - 0.9 for diffused aeration
OTR/SOTR		0.44	0.44	-	OTR/SOTR = $[(\tau\beta\Omega C^*_{\infty 20}-C)/C^*_{\infty 20}]*[\theta^{t-Ts}]\alpha F$
Oxygen Transfer Rate under Standard Conditions	SOTR	348.73	522.44	kg O_2/day	
Air Mass and Volume					
Percent of Oxygen by Weight	$O_{2\ by\ weight}$	23.18	23.18	%	in air
Diffuser Oxygen Transfer Efficiency	OTE	2.5	2.5	%/m	of tank depth (coarse bubble diffusers)
Total Oxygen Transfer Efficiency	OTE_{tot}	8.0	8.0	%	OTE_{tot} = OTE * D_f
Mass Air Flow	Q_{mass}	18,806	28,173	kg/day air	Q_{mass} = SOTR/($O_{2\ by\ weight}$ * OTE_{tot})
Air Density	ρ_{air}	1.184	1.184	kg/m^3	$\rho_{air} = P_sM/RT_{air}$
Air Volume	$Q_{air,d}$	15,881	23,791	m^3/day	of air; $Q_{air,d} = Q_{mass}/\rho_{air}$
Air Volume	$Q_{air,hr}$	662	991	m^3/hour	of air; $Q_{air,hr} = Q_{air,d}/24$
Air Volume (PROCESS AIR)	$Q_{air,min}$	11.0	16.5	m^3/min	of process air; $Q_{air,min} = Q_{air,d}/1440$

YEAR 1990					
Process Air - Summer Operating Conditions (BOD+NH_3)					
Parameter	**Symbol**	**Value**	**Value**	**Units**	**Comment**
Actual Oxygen Rate (AOR)		**Average**	**Peak**		
Design Flow	Q	871.0	871.0	m^3/day	ADWF
Design BOD	BOD	179.4	269.1	kg BOD/day	Average and Peak day load
Design NH_3-N	NH_3-N	29.9	44.9	kg NH_3-N/day	Average and Peak day load
Air for BOD Oxidation		1.25	1.25	kg O_2/kg BOD/day	
Air for NH_3-N Oxidation		4.6	4.6	kg O_2/kg NH_3-N/day	
Air for BOD Oxidation		224.3	336.4	kg O_2/day	
Air for NH_3-N Oxidation		137.5	206.5	kg O_2/day	
Field Oxygen Transfer Rate	OTR	361.8	542.9	kg O_2/day	
Standard Oxygen Rate (SOR)					
DO Surface Saturation Concentration	C^*_{st}	9.092	9.092	mg/L	at wastewater operating temperature t
DO Surface Saturation Concentration	C^*_{s20}	9.092	9.092	mg/L	at standard temperature (20^{o}C)
Temperature Correction Factor	τ	1.000	1.000		$\tau = C^*_{st}/C^*_{s20}$
Relative DO Saturation to Clean Water	β	0.95	0.95	-	Typically 0.95 - 0.98
Standard Barometric Pressure	P_s	101.325	101.325	kPa	at sea level
Barometric Pressure at Test Site	P_b	101.151	101.151	kPa	at elevation h; $P_b = P_s * \Omega$
Acceleration due to Gravity	g	9.810	9.810	m/s^2	
Air Molecular Weight	M	28.97	28.97	g/mole air	
Elevation	h	15.0	15.0	masl	in meters
Universal Gas Constant	R	8,314	8,314	Nm/(mole air * K)	
Air Temperature	$T_{C,air}$	25	25	^{o}C	summer/winter; summer is critical
Temperature	T_{air}	298.15	298.15	K	$T_{air} = 273.15 + {}^oC$
Pressure Corection Factor	Ω	0.998	0.998		$\Omega = P_b/P_{s;}\ exp(-gMh/RT_{air}))$
Diffuser Depth	D_f	3.20	3.20	m	in bioreactor
Mid-Depth Correction Factor	d_e	0.40	0.40	-	Typically 0.25 - 0.45 (0.40)
Saturated DO Value at Sea Level	$C^*_{\infty 20}$	10.22	10.22	mg/L	$C^*_{\infty 20} = C^*_{s20}\ [1+d_e(D_f/P_s)]$ at standard temperature (20^{o}C)
Average DO Concentration	C	2.0	2.0	mg/L	in bioreactor
Empirical Temperature Correction Factor	θ	1.024	1.024	-	typically 1.024
Wastewater Field (Operating) Temperature	t	20	20	^{o}C	summer/winter; summer is critical
Standard Temperature	T_s	20	20	^{o}C	
Relative Oxygen Transfer Rate	α	0.65	0.65	-	in process water versus clean water; typically 0.4 - 0.8 for diffused aeration
Fouling Factor	F	0.90	0.90		typically 0.65 - 0.9 for diffused aeration
OTR/SOTR		0.44	0.44	-	OTR/SOTR = $[(\tau\beta\Omega C^*_{\infty 20}-C)/C^*_{\infty 20}]*[\theta^{t-Ts}]\alpha F$
Oxygen Transfer Rate under Standard Conditions	SOTR	821.70	1233.08	kg O_2/day	
Air Mass and Volume					
Percent of Oxygen by Weight	$O_{2\ by\ weight}$	23.18	23.18	%	in air
Diffuser Oxygen Transfer Efficiency	OTE	2.5	2.5	%/m	of tank depth (coarse bubble diffusers)
Total Oxygen Transfer Efficiency	OTE_{tot}	8.0	8.0	%	$OTE_{tot} = OTE * D_f$
Mass Air Flow	Q_{mass}	44,311	66,495	kg/day air	$Q_{mass} = SOTR/(O_{2\ by\ weight} * OTE_{tot})$
Air Density	ρ_{air}	1.184	1.184	kg/m^3	$\rho_{air} = P_sM/RT_{air}$
Air Volume	$Q_{air,d}$	37,419	56,152	m^3/day	of air; $Q_{air,d} = Q_{mass}/\rho_{air}$
Air Volume	$Q_{air,hr}$	1559	2340	m^3/hour	of air; $Q_{air,hr} = Q_{air,d}/24$
Air Volume (PROCESS AIR)	$Q_{air,min}$	26.0	39.0	m^3/min	of process air; $Q_{air,min} = Q_{air,d}/1440$

YEAR 2023 w/Contingency					
Process Air - Summer Operating Conditions (BOD+NH_3)					
Parameter	**Symbol**	**Value**	**Value**	**Units**	**Comment**
Actual Oxygen Rate (AOR)		**Average**	**Peak**		
Design Flow	Q	461.0	461.0	m^3/day	ADWF
Design BOD	BOD	95.1	142.6	kg BOD/day	Average and Peak day load
Design NH_3-N	NH_3-N	15.8	23.8	kg NH_3-N/day	Average and Peak day load
Air for BOD Oxidation		1.25	1.25	kg O_2/kg BOD/day	
Air for NH_3-N Oxidation		4.6	4.6	kg O_2/kg NH_3-N/day	
Air for BOD Oxidation		118.9	178.3	kg O_2/day	
Air for NH_3-N Oxidation		72.7	109.5	kg O_2/day	
Field Oxygen Transfer Rate	OTR	191.6	287.7	kg O_2/day	
Standard Oxygen Rate (SOR)					
DO Surface Saturation Concentration	C^*_{st}	9.092	9.092	mg/L	at wastewater operating temperature t
DO Surface Saturation Concentration	C^*_{s20}	9.092	9.092	mg/L	at standard temperature (20^{o}C)
Temperature Correction Factor	τ	1.000	1.000		$\tau = C^*_{st}/C^*_{s20}$
Relative DO Saturation to Clean Water	β	0.95	0.95	-	Typically 0.95 - 0.98
Standard Barometric Pressure	P_s	101.325	101.325	kPa	at sea level
Barometric Pressure at Test Site	P_b	101.151	101.151	kPa	at elevation h; $P_b = P_s * \Omega$
Acceleration due to Gravity	g	9.810	9.810	m/s^2	
Air Molecular Weight	M	28.97	28.97	g/mole air	
Elevation	h	15.0	15.0	masl	in meters
Universal Gas Constant	R	8,314	8,314	Nm/(mole air * K)	
Air Temperature	$T_{C,air}$	25	25	^{o}C	summer/winter; summer is critical
Temperature	T_{air}	298.15	298.15	K	T_{air} = 273.15 + ^{o}C
Pressure Corection Factor	Ω	0.998	0.998		$\Omega = P_b/P_{s;}$ exp(-gMh/RT$_{air}$))
Diffuser Depth	D_f	3.20	3.20	m	in bioreactor
Mid-Depth Correction Factor	d_e	0.40	0.40	-	Typically 0.25 - 0.45 (0.40)
Saturated DO Value at Sea Level	$C^*_{\infty 20}$	10.22	10.22	mg/L	$C^*_{\infty 20} = C^*_{s20}\,[1+d_e(D_f/P_s)]$ at standard temperature (20^{o}C)
Average DO Concentration	C	2.0	2.0	mg/L	in bioreactor
Empirical Temperature Correction Factor	θ	1.024	1.024	-	typically 1.024
Wastewater Field (Operating) Temperature	t	20	20	^{o}C	summer/winter; summer is critical
Standard Temperature	T_s	20	20	^{o}C	
Relative Oxygen Transfer Rate	α	0.65	0.65	-	in process water versus clean water; typically 0.4 - 0.8 for diffused aeration
Fouling Factor	F	0.90	0.90		typically 0.65 - 0.9 for diffused aeration
OTR/SOTR		0.44	0.44	-	OTR/SOTR = $[(\tau\beta\Omega C^*_{\infty 20}-C)/C^*_{\infty 20}]*[\theta^{t-Ts}]\alpha F$
Oxygen Transfer Rate under Standard Conditions	SOTR	435.06	653.50	kg O_2/day	
Air Mass and Volume					
Percent of Oxygen by Weight	$O_{2\ by\ weight}$	23.18	23.18	%	in air
Diffuser Oxygen Transfer Efficiency	OTE	2.5	2.5	%/m	of tank depth (coarse bubble diffusers)
Total Oxygen Transfer Efficiency	OTE_{tot}	8.0	8.0	%	$OTE_{tot} = OTE * D_f$
Mass Air Flow	Q_{mass}	23,461	35,240	kg/day air	$Q_{mass} = SOTR/(O_{2\ by\ weight} * OTE_{tot})$
Air Density	ρ_{air}	1.184	1.184	kg/m^3	$\rho_{air} = P_sM/RT_{air}$
Air Volume	$Q_{air,d}$	19,812	29,759	m^3/day	of air; $Q_{air,d} = Q_{mass}/\rho_{air}$
Air Volume	$Q_{air,hr}$	826	1240	m^3/hour	of air; $Q_{air,hr} = Q_{air,d}/24$
Air Volume (PROCESS AIR)	$Q_{air,min}$	13.8	20.7	m^3/min	of process air; $Q_{air,min} = Q_{air,d}/1440$

YEAR 2023 w/Contingency					
Process Air - Summer Operating Conditions (BOD+NH_3)					
Parameter	**Symbol**	**Value**	**Value**	**Units**	**Comment**
Actual Oxygen Rate (AOR)		**Average**	**Peak**		
Design Flow	Q	461.0	461.0	m^3/day	ADWF
Design BOD	BOD	95.1	142.6	kg BOD/day	Average and Peak day load
Design NH_3-N	NH_3-N	15.8	23.8	kg NH_3-N/day	Average and Peak day load
Air for BOD Oxidation		1.25	1.25	kg O_2/kg BOD/day	
Air for NH_3-N Oxidation		4.6	4.6	kg O_2/kg NH_3-N/day	
Air for BOD Oxidation		118.9	178.3	kg O_2/day	
Air for NH_3-N Oxidation		72.7	109.5	kg O_2/day	
Field Oxygen Transfer Rate	OTR	191.6	287.7	kg O_2/day	
Standard Oxygen Rate (SOR)					
DO Surface Saturation Concentration	C^*_{st}	9.092	9.092	mg/L	at wastewater operating temperature t
DO Surface Saturation Concentration	C^*_{s20}	9.092	9.092	mg/L	at standard temperature (20^{o}C)
Temperature Correction Factor	τ	1.000	1.000		$\tau = C^*_{st}/C^*_{s20}$
Relative DO Saturation to Clean Water	β	0.95	0.95	-	Typically 0.95 - 0.98
Standard Barometric Pressure	P_s	101.325	101.325	kPa	at sea level
Barometric Pressure at Test Site	P_b	101.151	101.151	kPa	at elevation h; $P_b = P_s * \Omega$
Acceleration due to Gravity	g	9.810	9.810	m/s^2	
Air Molecular Weight	M	28.97	28.97	g/mole air	
Elevation	h	15.0	15.0	masl	in meters
Universal Gas Constant	R	8,314	8,314	Nm/(mole air * K)	
Air Temperature	$T_{C,air}$	25	25	^{o}C	summer/winter; summer is critical
Temperature	T_{air}	298.15	298.15	K	T_{air} = 273.15 + ^{o}C
Pressure Corection Factor	Ω	0.998	0.998		$\Omega = P_b/P_s$; $\exp(-gMh/RT_{air})$)
Diffuser Depth	D_f	3.20	3.20	m	in bioreactor
Mid-Depth Correction Factor	d_e	0.40	0.40	-	Typically 0.25 - 0.45 (0.40)
Saturated DO Value at Sea Level	$C^*_{\infty 20}$	10.22	10.22	mg/L	$C^*_{\infty 20} = C^*_{s20}\,[1+d_e(D_f/P_s)]$ at standard temperature (20^{o}C)
Average DO Concentration	C	2.0	2.0	mg/L	in bioreactor
Empirical Temperature Correction Factor	θ	1.024	1.024	-	typically 1.024
Wastewater Field (Operating) Temperature	t	20	20	^{o}C	summer/winter; summer is critical
Standard Temperature	T_s	20	20	^{o}C	
Relative Oxygen Transfer Rate	α	0.65	0.65	-	in process water versus clean water; typically 0.4 - 0.8 for diffused aeration
Fouling Factor	F	0.70	0.70		typically 0.65 - 0.9 for diffused aeration
OTR/SOTR		0.34	0.34	-	$OTR/SOTR = [(\tau\beta\Omega C^*_{\infty 20}-C)/C^*_{\infty 20}]*[\theta^{t-Ts}]\alpha F$
Oxygen Transfer Rate under Standard Conditions	SOTR	559.37	840.21	kg O_2/day	
Air Mass and Volume					
Percent of Oxygen by Weight	$O_{2\ by\ weight}$	23.18	23.18	%	in air
Diffuser Oxygen Transfer Efficiency	OTE	6.5	6.5	%/m	of tank depth (fine bubble diffusers)
Total Oxygen Transfer Efficiency	OTE_{tot}	20.8	20.8	%	$OTE_{tot} = OTE * D_f$
Mass Air Flow	Q_{mass}	11,602	17,427	kg/day air	$Q_{mass} = SOTR/(O_{2\ by\ weight} * OTE_{tot})$
Air Density	ρ_{air}	1.184	1.184	kg/m^3	$\rho_{air} = P_sM/RT_{air}$
Air Volume	$Q_{air,d}$	9,797	14,716	m^3/day	of air; $Q_{air,d} = Q_{mass}/\rho_{air}$
Air Volume	$Q_{air,hr}$	408	613	m^3/hour	of air; $Q_{air,hr} = Q_{air,d}/24$
Air Volume (PROCESS AIR)	$Q_{air,min}$	6.8	10.2	m^3/min	of process air; $Q_{air,min} = Q_{air,d}/1440$