

The Passive Vacuum Degasser; Research Test Setup and Preliminary Observations

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ABSTRACT

Some form of vacuum-assisted degassing is often required in both production and research facilities to bring the total pressure of dissolved gasses in the culture water below the saturation value. One form of vacuum degasser is the passive vacuum degasser, a device that consists of a column, packed or unpacked, that has its tailpipe exiting below the surface of the water in the receiving vessel. Such an arrangement causes a vacuum to self-form in the column. The strength of this vacuum appears to correlate to both geometric and operational parameters in relationships that have not yet been clearly defined.

An elaborate recirculating apparatus, with degassing columns equivalent in size to a commercial system, has been set up to explore the various physical parameters of passive degassers. Initially, to observe the degassing process, the column being used is a 10 ft (3 m) long, 1 ft (0.3 m) diameter clear plastic pipe into which water, supersaturated with air, is introduced at its upper end. The pump has been selected to operate at rates adjustable up to 210 USGPM (800 Lpm). A chiller is used to maintain a constant temperature. The re-saturation of the water is accomplished by means of a separate pressurized packed column. The geometric parameters that will be investigated are: column diameter to length ratio, distribution plate design, tailpiece diameter and length,

and packing/no packing. The operational parameters include water flow rate, air saturation rate, water temperature, and column water height. Instrumentation includes a paddle wheel flowmeter, ultrasonic flowmeter, total gas pressure, oxygen level, temperature sensors before and after the column, column vacuum probe, column height differential pressure transducer, cross-over pipe pressure and pump pressure.

The entire setup is linked to a computer for data logging. The aim of this paper is to describe the apparatus and its instrumentation, and report some preliminary findings.

INTRODUCTION

It has been well established that gas-supersaturated supply water causes gas bubble disease in aquatic animals, as the gas comes out of solution in conditions of reduced pressure or solubility. (e.g. Colt and Bouck 1984, Bouck et al. 1984, Westers et al. 1991) Ideally the unsaturated level should be -5 to -10% to ensure that further conditioning, such as warming, will not cause the water to again become saturated or even supersaturated.

One device in common use to achieve desaturation of supply water is the passive vacuum degasser (PVD). This device, essentially a vertical column, packed or unpacked, with a restricting tailpipe exiting below the surface of the receiving tank, creates a vacuum in the column merely from the characteristics of the water flow through the column and tailpipe. Exactly how that vacuum is created and what range of system characteristics can optimize the transfer is largely unreported.

Background

A paper by Westers et al. (1991) based on the sealed columns at a Michigan state hatchery (Figure 1) initiated this investigation. Their primary focus was gas transfer, but flow rate, column height and vacuum data were also recorded. Regretfully, the length of the tailpipe to the receiving tank water surface was not noted.

When one plots Westers et al. (1991) column water level data against the vacuum created in the same terms, a straight line relationship emerges (Figure 2, solid line).

Figure 1: Michigan state hatchery degasser diagram (from Westers et al. (1991).

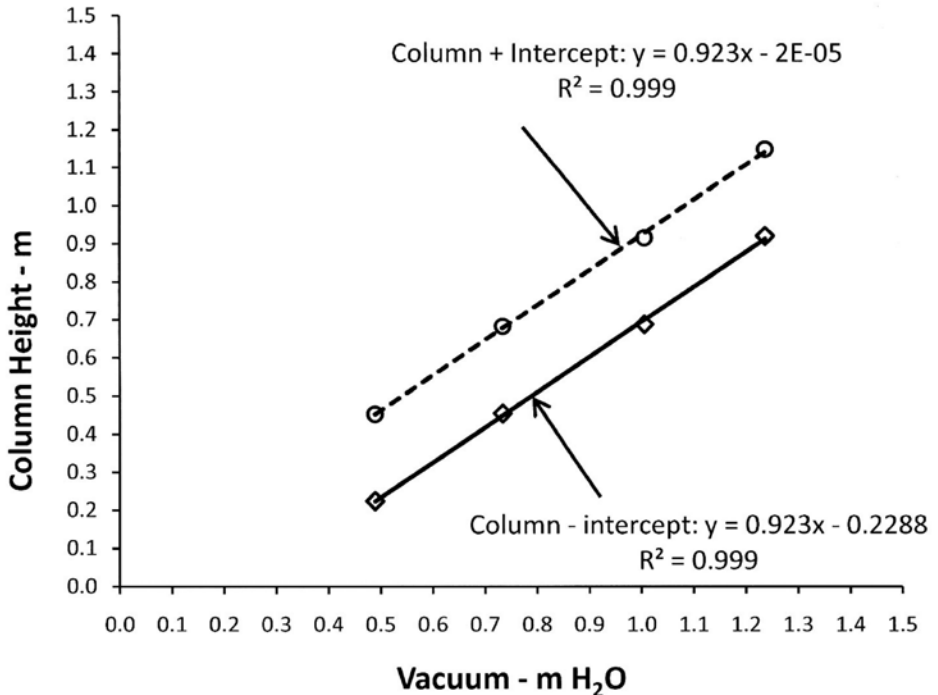
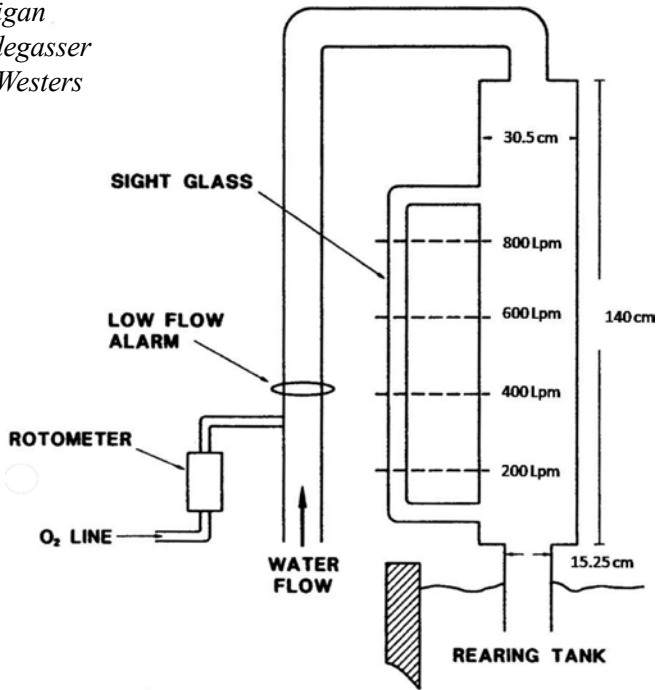


Figure 2: Water column height vs. vacuum measured, with column bottom as datum (solid line) and the data with the intercept removed (dotted line). From Westers et al. (1991)

As noted above, the datum for the water column height measurements in Figure 1 is the bottom of the column. If it is assumed that the intercept reflects the height of this datum above the surface of the receiving tank, and if that value is added to the column values to reflect the total height of the column above the tank water surface, Figure 2 (dashed line) emerges which suggests a very close relationship between the height of the water column (with the tank surface as datum) and the vacuum produced.

The data also show a relationship between the vacuum and column height and the flow rate (Figure 3), applying the tailpipe length/intercept assumption suggested above.

Purpose of the Study

This study was initiated to examine the physical parameters that cause the passive degasser to function. The aim is to develop guidelines and a model to assist the engineer in designing a device given the water parameters (temperature and salinity), flow rate, and degree of desaturation required. Thus a test bed was required to examine a whole range of factors that might influence gas transfer; e.g. degree of input

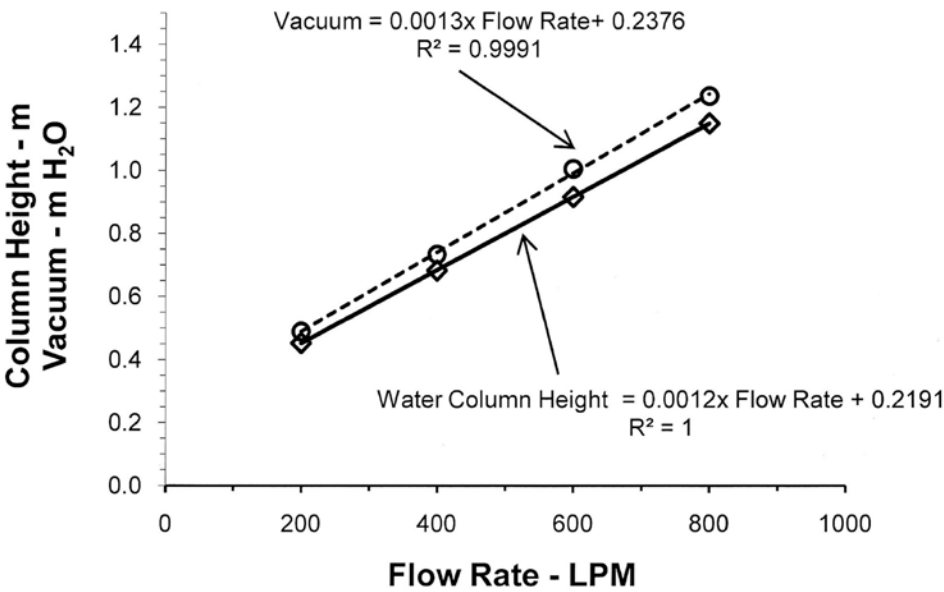


Figure 3: Water column height, assuming that the intercept in Figure 2 is the distance from the bottom of the column to the tank surface, and the vacuum recorded versus the flow rate. From Westers et al. (1991)

supersaturation, flow rate, residency time, the vacuum created, and dimensional effects of the column and tailpipe.

Initially, the study examines the questions: what causes the vacuum and can a design model based on flow rate and desired vacuum be developed? The experimental set-up at Dalhousie University is still being commissioned and so this is a report on the design and construction of the system with some preliminary results.

MATERIALS AND METHODS

The Dalhousie Engineering Test Setup (Figure 4)

The Main Flow Route

The water flow route from the holding tank, 1.9 m (6.23 ft) diameter by 1.4 m (4.5 ft) deep, begins with a 2 hp sump pump (Hydromatic SB3S, 5.69 inch impeller, Hydromatic, Kitchener, ON, Canada) pumping up to a tee fitting. Using baffles, the holding tank is divided into three parts: tailpipe section, underflow to a probe section and overflow to the pump section. This arrangement is to present the probes with the deepest (least amount of entrained air) water.

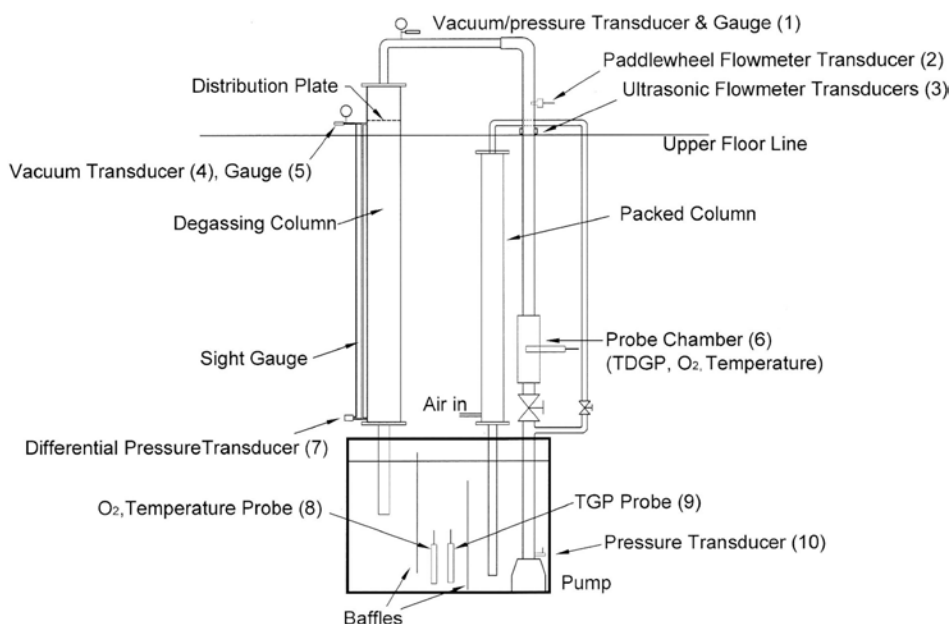


Figure 4: Dalhousie Engineering Research test setup for passive vacuum degasser studies. The numbered sensors are referred to in the text.

The main flow rises past a nominal 4 inch gate valve through a Probe Chamber (6) [basically a section of 0.2 m (nominal 8 in Schedule 40) PVC with ports], followed by a section of clear nominal 0.102 m (4 in) Schedule 40 PVC pipe. The crossover to the top of the degassing column is nominal 0.075 m (3 in) PVC pipe which also has a section of clear pipe.

The present column is a 3.05 m (10 ft) long, 0.305 m (nominal 12 inch Schedule 40) clear PVC tube. There is a distribution plate at the top and the flow exits through a 0.075 m (nominal 3 inch Schedule 40) clear PVC tailpipe with tattle tails (clear pipe was used in four locations in order to visually inspect the flow for any entrained air.) It is intended that the dimensions of these last two items will be changed to vary the test parameters as noted previously.

In order to re-saturate the water, a side stream is diverted from below the main gate valve to the top of a pressurized packed column of 0.203 m (nominal 8 inch) Schedule 40 PVC, 2.44 m (8 ft) tall. The packing is 1.27 cm diameter by 0.95 cm polypropylene wheels from Coffin World Water Systems (Irvine, CA, USA). The laboratory air supply is not detailed, but pressurized air is fed to the bottom of this column through a manifold.

Instrumentation

Flow rate

As this parameter is thought to be very important, flow is measured by three methods: an Omega PX482A-030 pressure transducer (Omega, Laval, QC, Canada) on the pump outlet (10) (to be compared with the pump operating curve), an FLS F3.3 paddlewheel flow sensor with K330 4-20 mA transmitter (2) (Northeast Equipment Co., Dartmouth, NS, Canada) and the transducers from the Omega F7000 ultrasonic flowmeter (Omega, Laval, QC, Canada) (3).

Vacuum/pressure

The main degasser vacuum is sensed by a vacuum transducer [Winters PT30HGV (4) CTH Instruments, Dartmouth, NS, Canada] and a vacuum gauge [Winters P304 V 100 inches of water (5) CTH Instruments, Dartmouth, NS, Canada] tapped in just below the distribution plate. There is a second Omega PX1 82B-01 5CI (-14.7 to +15 psi) (Omega, Laval, QC, Canada) transducer with a Winters P861 (30" Hg - 15 psi,

CTH Instruments, Dartmouth, NS, Canada) tapped into the end of the crossover nearest the degassing column.

Column height

Running up the degassing column is a clear plastic sight gauge (Figure 5). Tape measures run along the column by the sight gauge and down into the tank for measuring column height with respect to the water surface. The clear column showed that the degassing action in the column created considerable foaming. The sight gauge gives a clearer indication of the height of the water alone. However, there is an undulation in the rate of flow from the pump (detailed later). Thus while the flow rate was being averaged electronically, the column height reading was essentially a snapshot. Consequently, an Omega PX2300-10 DI (0-10 psid) differential pressure transducer (Omega, Laval, QC, Canada) was paralleled to the sight gauge.

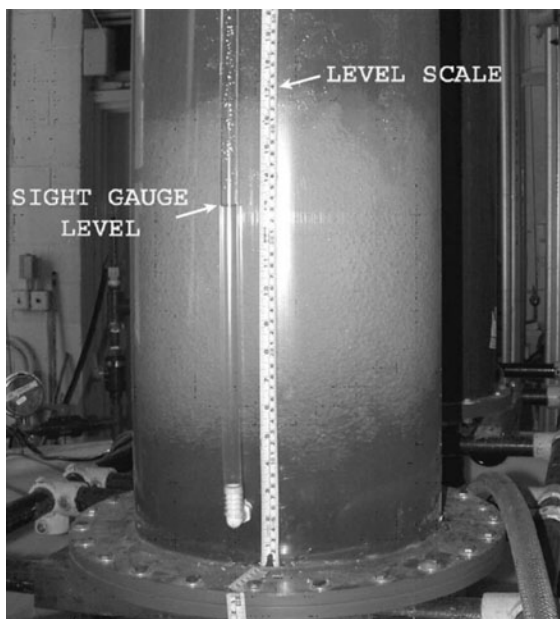


Figure 5: Lower end of the degassing column showing the sight gauge and height tape.

Total dissolved gas pressure (TDGP), dissolved oxygen (DO), and water temperature

For the in-flow to the degassing column, these parameters are sensed in the Probe Chamber (6) by the probe of a TBO-DL6F (6) (Common Sensing, Inc. Clark Fork, ID, USA). This probe senses total dissolved gas pressure, dissolved oxygen and temperature. The TBO box itself reads barometric pressure and water vapor pressure. After the column, these parameters are sensed in the mid division of the tank by a dissolved gas probe [Alpha 300c (8) Alpha Designs, Ltd., Victoria, BC, Canada] and a dissolved oxygen/temperature probe [Royce 900 (7) Royce Instrument Corp., New Orleans, LA, USA].

Re-saturation air

Laboratory air is supplied to the bottom of the packed column through a manifold with variable area flow meters. A pressure gauge and a humidity/temperature probe (Omegaette HH3 14, Omega, Laval, QC, Canada), are included in the air supply line.

Ancillaries

There is an external 1/2 hp recirculating chiller (Aquanetics Systems, San Diego, CA, USA) plumbed into the system should temperature become a factor. If testing uses other than freshwater, salinity will be measured with a Hach Sension5 conductivity meter (Northeast Equipment Co., Dartmouth, NS, Canada).

Data recording

While the TBO-6DLF and the Omegaette HH3 14 have on-board logging, the remainder of the electronic inputs are logged on two LabJack U12 data loggers in parallel (LabJack Corp., Lakewood, CO, USA) with the data being sent to a notebook computer using the program DAQFactory Express (Azeotech, Inc., Ashland, OR, USA).

Flowrate determination

As some of the expected parameters of the flow are directly affected by the velocity of flow, primarily to the second power, considerable effort has been expended in assuring that an accurate flow rate could be obtained. Three methods were examined and reported in Table 1: the paddle wheel flowmeter (PWFM), the pump head pressure transducer (PTD) against a digitized version of the published pump curve and the ultrasonic flowmeter (USFM).

Initially, while the paddlewheel flow meter (PWFM) and the ultrasonic flow meter (USFM) were in 0.5 to 7% accordance, the pump pressure transducer (PTD) differed considerably, up to 37%. The original pump order was for a 5.69 inch impeller. Back plotting the pressure head vs. PWFM flow rate data on the manufacturer's set of curves (Figure 6), the plot came out along the 5.88 inch impeller line. Either there is about a 1.5 m (5 ft) of water head difference error or the impeller is really 5.88 inch.

Manual Data - Ultrasonic				Lablack-DAQ Averaged VDC Data					Derived Data	
Run	Time	Avg GPM	LPM	Run	Time	PWFM	Ultrasonic	PTD	PWFM	PTD
1	9:23:15	31.83	120.48	1	9:22:16	2.449265	2.608109	6.442795		
2	9:26:40	47.05	178.10	2	9:26:41	3.092936	2.912435	6.319824	56.1	125.10
3	9:30:10	77.22	292.32	3	9:30:12	3.954791	3.502844	5.887667	139.7	165.86
4	9:33:56	125.34	474.45	4	9:33:51	5.138672	4.44401	5.719076	251.6	315.82
5	9:36:30	134.80	510.29	5	9:36:32	5.503267	4.617289	5.740504	405.2	377.17
6	9:39:50	144.06	545.33	6	9:39:51	5.736202	4.818864	5.478673	452.5	369.29
7	9:42:20	156.95	594.13	7	9:42:31	6.162705	5.066573	5.435523	482.8	467.42
8	9:44:50	169.28	640.80	8	9:44:31	6.460612	5.303385	5.379557	538.1	483.97
9	0:46:50	181.72	687.87	9	9:46:51	6.786784	5.546712	5.261393	576.8	505.58
10	9:51:40	196.21	742.73	19	9:51:42	7.302857	5.832214	5.059509	619.1	551.79
11	9:54:00	208.96	790.99	11	9:54:01	7.516113	6.076823	4.977376	686.1	632.56
12	9:56:30	221.68	839.16	12	9:56:31	8.001302	6.32959	4.831543	713.8	666.07
13	9:58:50	237.37	898.55	13	9:58:51	8.385522	6.63968	4.626544	776.8	726.51
14	10:01:00	243.21	920.65	14	10:01:01	8.583287	6.740897	4.638672	826.7	813.50
									852.3	808.29

Table 1: Consolidated Flow Rate Test Data

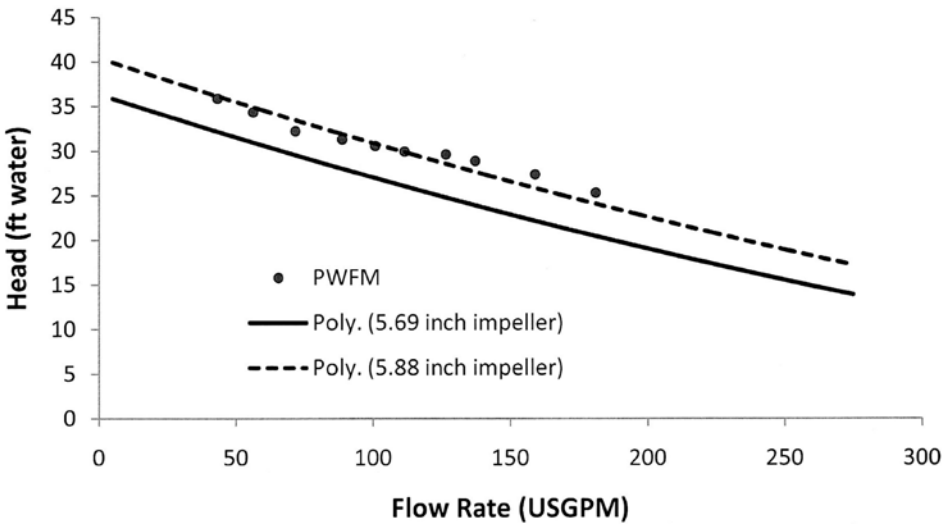


Figure 6: Reproduced Hydrostatic S3SD pump curves for 5.69 inch and 5.88 inch impellers with the paddlewheel flowmeter (PWFM) data vs. pump head pressure data (PTD)

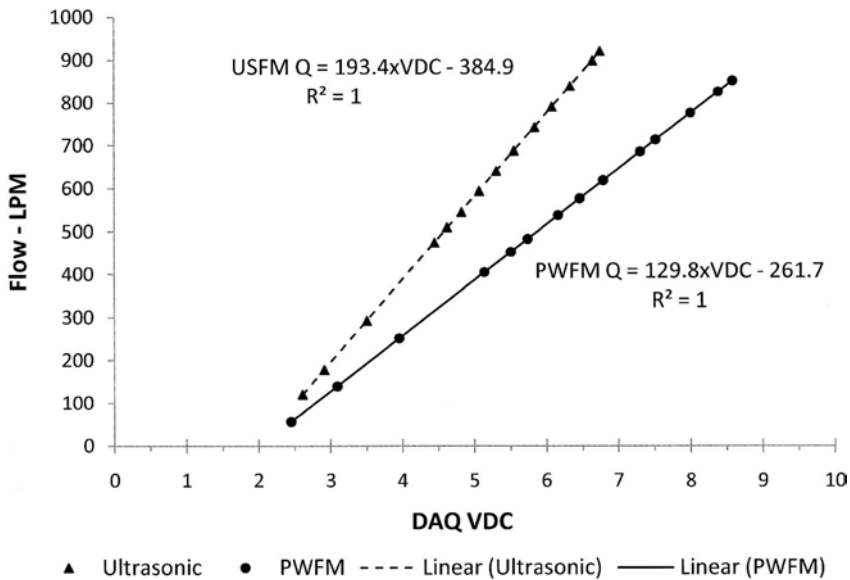


Figure 7: Plots from calibration data of the paddlewheel flowmeter (PWFM) and the ultrasonic flowmeter (USFM).

Note in Figure 7 that the ultrasonic flowmeter calibration (F7000 panel reading vs. voltage on the LabJack/DAQFactory Express) was linear but with a different slope and intercept from the paddlewheel flowmeter (paddlewheel flow values were derived from the LabJack recorded voltages according to the manufacturer’s setup directions).

Figure 8 compares methods with each other. The pump head PTD supports neither the USFM nor the PWFm and its scatter is still evident despite the averaging. This is further discussed later in the paper.

The ultimate question is: which of the flowmeter outputs, the paddlewheel flowmeter or the ultrasonic flowmeter is most accurate? The probe chamber represents a reducer in the line and the recommended distance is 15 diameters, or about 1.5 m (5 ft). As the present distance is over 1.8 m (6 ft), this sensor is in a valid location.

For the ultrasonic flowmeter transducers, there is less certainty about the location and the fluid echo quality of the ultrasonic signal. There are three conditional cases:

1. Liquid with suspended solids or aeration bubbles 25 to 10,000 PPM of 30 μm in size, or larger.
2. Liquid with suspended solids or aeration bubbles greater than 10,000 PPM 30 μm size, or larger.

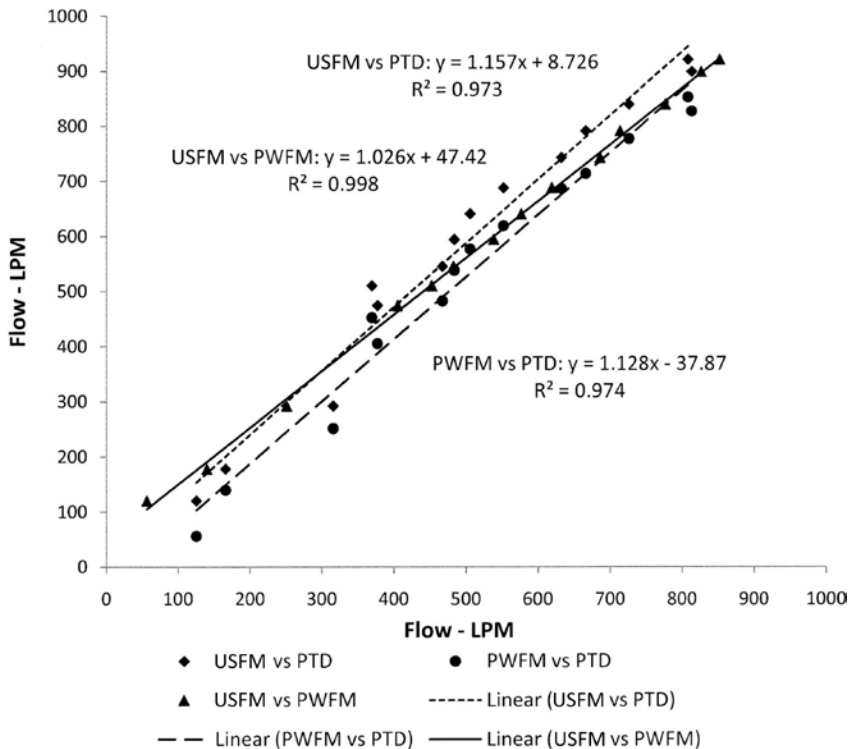


Figure 8: Cross-comparison of the three methods, paddlewheel flowmeter (PWFm), ultrasonic flow meter (USFM), and pump outlet pressure (PTD).

- 3. Liquid with less than 25 PPM suspended solids or aeration of 30 μm or larger and suspended solids or aeration content smaller than 30 μm (clean water).

All three cases require different mounting arrangements. Being unsure of the liquid condition and hence the mounting of the ultrasonic transducers in this case, it was decided to use the paddlewheel as the standard. However, the ultrasonic voltage output is a valid calibration line if compared to the paddlewheel output, and a good check on the paddlewheel.

The paddlewheel flowmeter indicated that there is a slight undulating character to the flow with a period of about 45 seconds as shown in an expanded form in Figure 9. This undulation can also be seen in Figures 6 and 8.

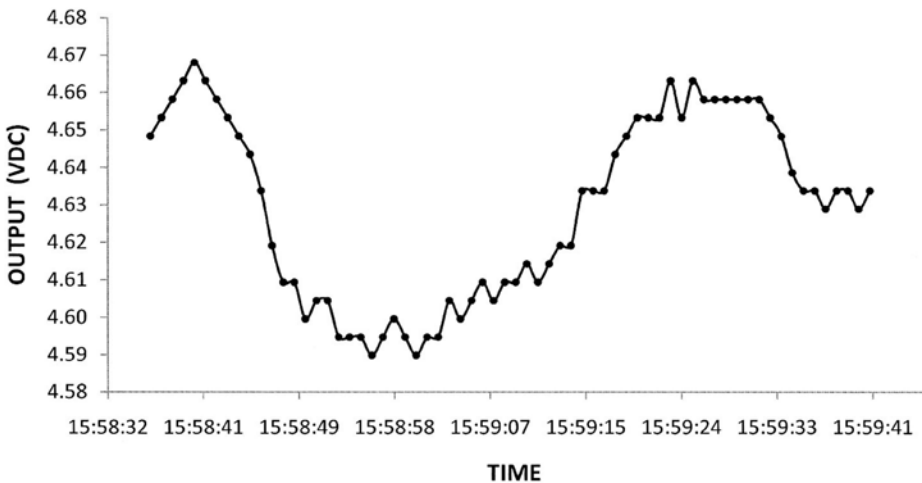


Figure 9: Paddlewheel flowmeter (PWF) voltage readings over approximately one minute.

The pulse of the two-bladed impeller is clear in the upper plot of Figure 10. The averaging of the results tends to smooth out the data as shown in the derived flows for the paddlewheel and ultrasonic flowmeters (Figure 10, lower plots).

For the pressure transducer on the pump outlet, while the flow rate data is of the same order as that for the paddlewheel flowmeter, it does not line up with the paddlewheel data (Figure 10), despite the close adherence to the 5.88 inch impeller curve published by the manufacturer referred to

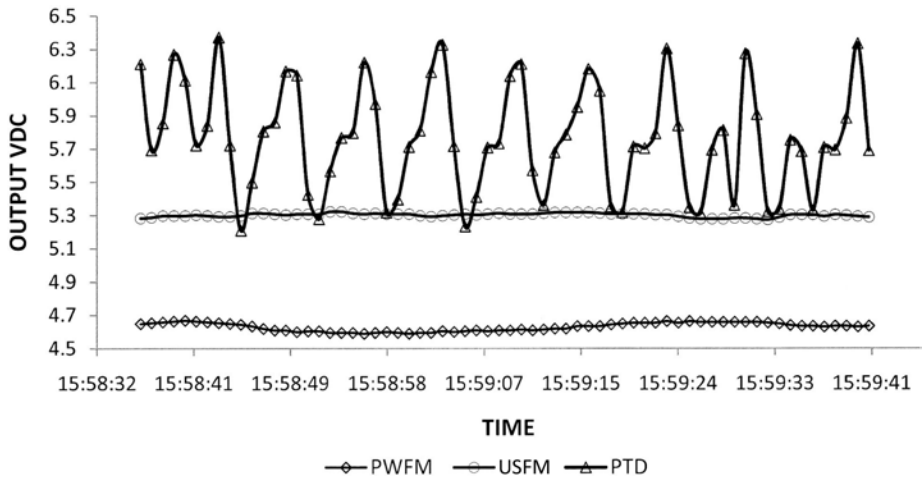


Figure 10: Comparison of recorded voltages of the three flow rate transducers with time.

earlier. The pressure transducer must be considered the third best method of determining flow rate in part because it depends so much on having an accurate characteristic curve for this particular pump.

Re-supersaturating the flow

These columns, normally used on flow-through water supplies, are very efficient at removing the dissolved gasses. The challenge in this recirculating system is to re-supersaturate the flow for the next cycle. Both a side-stream venturi and air stones were tried without sufficient success. The packed column is much more efficient and supersaturates the water, as would be expected. Trial and error is used to determine the correct mix of air/water flows. Even at maximum re-aeration flow rates, the degasser eventually removes more gasses than can be replaced in the cycle. It is expected that, instead of a continuous series of runs in a trial, the method will be to supersaturate the water, do a run, re-supersaturate the water, do a run, etc. This methodology is expected to be valid, as depending on conditions (degree of supersaturation, flow rate), the desaturation rate is about 0.1% per minute.

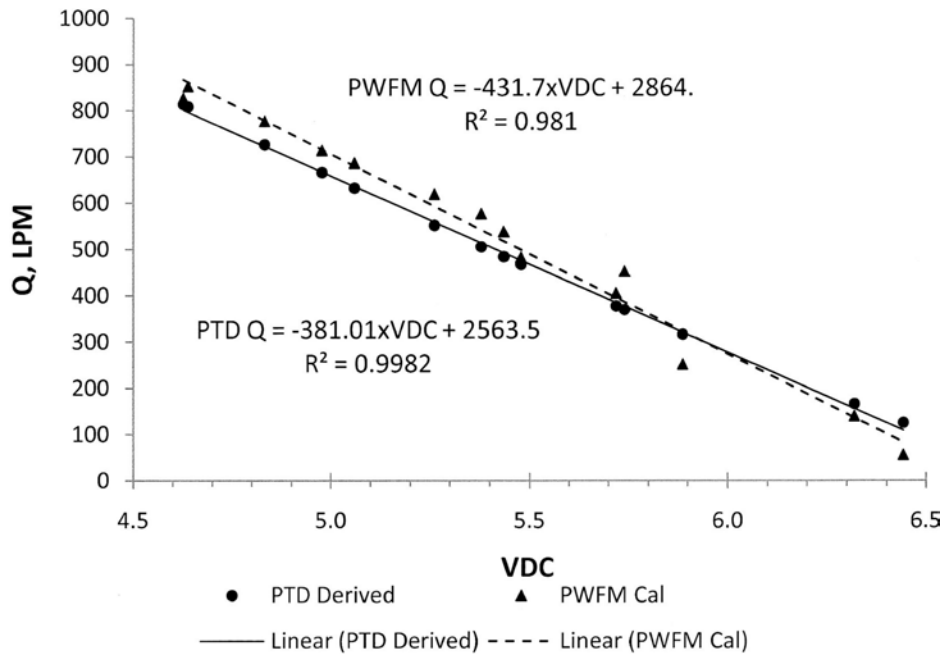


Figure 11: Derived flow rates (Q) for the pump pressure transducer (PTD) vs. voltage compared to the paddlewheel data (PWFm).

RESULTS AND DISCUSSION

Static tests

The column can be locked at any column height by closing the main valve. A static test to prove vacuum tightness was performed by running the column up to about 2/3rds full, closing the main valve (and shutting off the pump) waiting for settling, taking readings, venting in a little air to allow the height to drop a little, taking readings, etc. A typical result is shown in Figure 12. The strong correlation between the column height (top of tank water datum) and the vacuum created is evident.

Nature of the column flow

The clear column and tailpipe allow a view of the activity in these sections not observable in commercial systems. The water head in the column is a two-phase mixture of water and extracted gases in the form of bubbles (Figure 5). Whereas the foam head is churning, the sight gauge is virtually bubble free. Its water level is lower than the foam head height, depending on flow and the amount of air being extracted. This gauge gives a truer indication of the height of water.

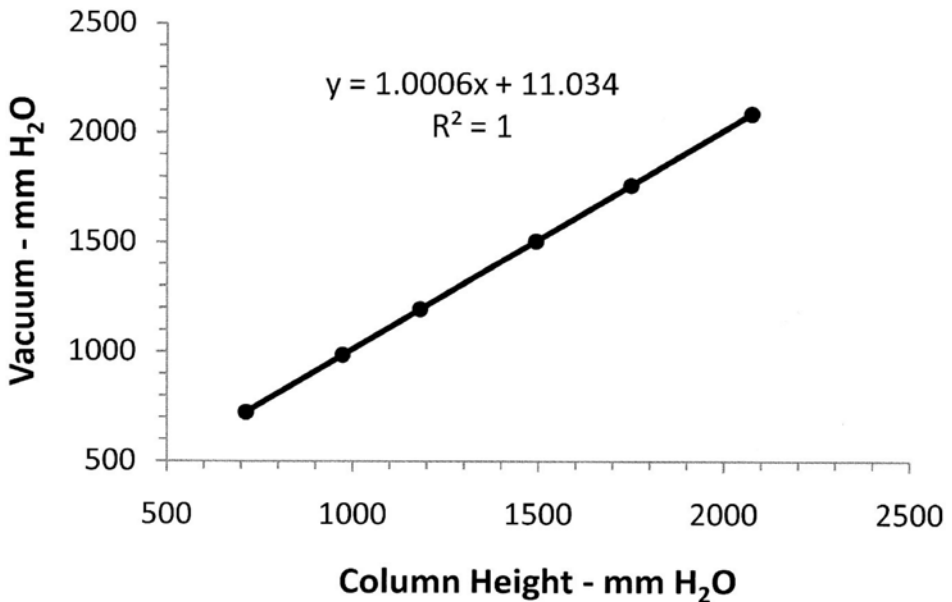


Figure 12: Static test data.

While the sight gauge level varies about 1 to 5 cm ($\frac{1}{2}$ to 2 in) with the flow, this is nearly stable compared to the foam head. Even so, as mentioned in the system description, a differential pressure transducer was installed across this sight gauge so that a reading can be recorded electronically and multi-sampling and averaging used as for the other data streams.

System gas removal is by bubble transport in the flow down through the tail piece. The entrained gas bubbles then float up to the tank surface. Cotton thread tattle tails were mounted in the clear PVC tailpipe to observe if vorticity existed through this section. None was observed.

Dynamic tests

A dynamic test is performed by adjusting the flow rate and allowing the column to stabilize before readings are taken. Early results of such tests gave a very different correlation between vacuum and column height. An example is shown in Figure 13.

The column vacuum is much less than the column height would indicate. The variation increases with greater column height, from 11% at the lowest point to 28% at the highest value for this data set. This result differs widely from that reported by Westers et al. (1991). A parabolic correlation fits the data better, as the R^2 value is greater.

Several more test runs will be needed to confirm these observations. The theoretical basis for the phenomenon shown in Figure 14 has not yet been established.

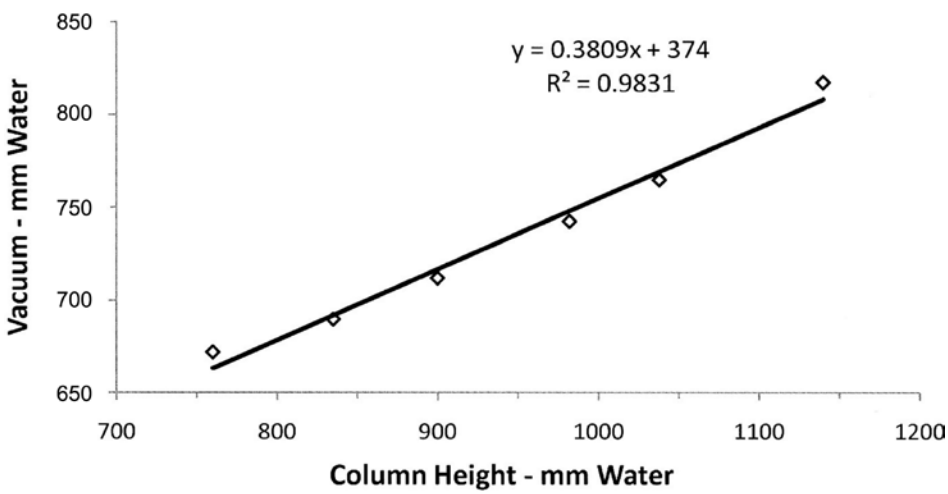


Figure 13: Vacuum produced vs. column height (tank surface datum) for one dynamic test.

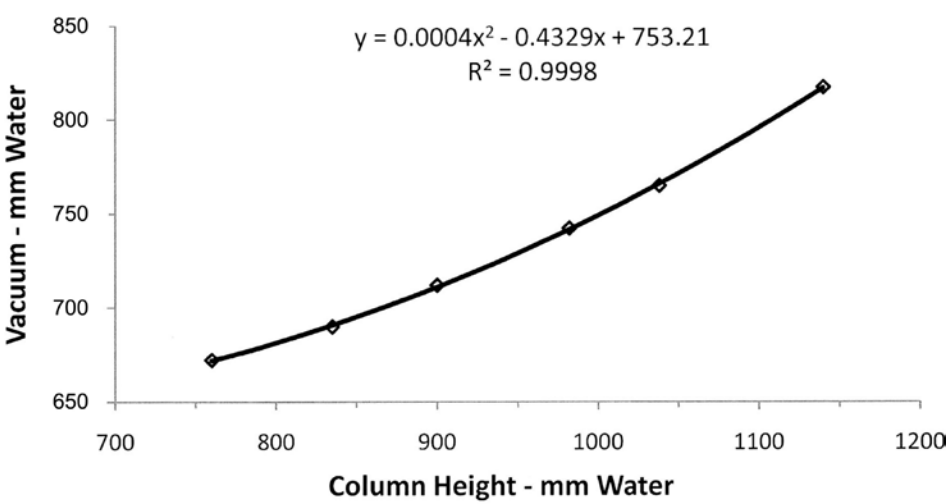


Figure 14: Figure 13 with parabolic curve fitting

CONCLUSION

The ultimate aim of this study is the production of a model or models to assist the engineer in designing a column to specifications of flow rate and degassing capability. The set-up has the capability of testing, at flow rates from 100 to 800 LPM, various combinations of column length, column diameter, tailpiece diameter, length and depth submerged, and water supersaturation versus desaturation. The purpose is to look for optimal combinations. That work is ongoing, but the simple premises that spawned it are being rethought.

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