Prairie Farm Rehabilitation Administration Paper

Performance Characteristics of Aeration Devices

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ABSTRACT

The aeration efficiency of two types of aeration devices, air injection and mechanical surface aerators was evaluated in farm dugouts in the Peace River Region of Alberta. The air injection systems were tested using three types of diffusers; open-ended tubing, linear fine bubble diffusers and a membrane diffuser.

Our results indicate that without aeration, anoxia can develop in the bottom of dugouts in both summer and winter. This can be prevented by good aeration. The aeration devices we examined circulate and aerate all the water in the dugout at all depths shallower than the location of the air injector. Water which was below the level of the air injector was not aerated or circulated and tended to become anoxic. **Fine bubble diffusers were more efficient at circulating and aerating the water than the large bubbles produced by open-ended tubing or by tubing with 3.2 mm holes drilled in the end.**

Preliminary results indicate that year round aeration improves a number of parameters of water quality in addition to alleviating taste and odour problems.

INTRODUCTION

In rural situations where domestic water is obtained from dugouts, winter aeration is widely practiced to overcome problems associated with taste and odours during periods of anoxia. Air is generally injected, either through an open-ended tube or via some sort of diffuser, near the water intake. The underlying hypothesis is that the air injection will improve water quality in the area of the water intake.

The use of aeration in the management of dugout water quality is highly variable across the prairies. This appears to be as a result of practices which have developed as a result of practical experience in different regions. In the Peace River Region, aeration is generally practiced mainly in winter when dugout oxygen levels drop to near zero resulting in taste and odour problems. The traditional aeration method used is air injection in the region of the water intake, the air coming out the end of tubing connected to a compressor.

Generally the tubing used is nominally 1.27 cm inside diameter. This type of aeration results in a large area of open water, a polynya, around the site of air injection.

Anoxic conditions may occur both in summer and in winter but they are most pronounced in winter when dugouts may be ice covered for many months. Anoxic conditions result in a shift from oxidizing to reducing environments in dugouts. Under reducing (anoxic) conditions, hydrogen sulphide and other objectionable compounds are produced. Aeration serves to both strip out these gases and to create an oxidizing environment which prevents further formation of the offending gases.

Air injection has been used on lakes and large reservoirs to circulate (destratify) them in summer and on shallow temperate lakes to prevent fish kills during the winter (Ashley, 1987). In the former case, the goal is circulation of water in the lake or reservoir (Patriache, 1961); in the later case the objective is the addition of oxygen. Destratification requires considerable energy input since the deep, cold (4 °C) hypolimnetic water has a much higher density than the warm overlying water of the epilimnion (Ashley, 1983). Winter aeration is generally done in shallow lakes or reservoirs to prevent winter kill (Fast, 1994). Under these conditions water density is fairly uniform since water temperature generally varies by < 4 °C.

Mechanical aeration devices in the form of pumps which float on the surface have also been used as aeration devices to prevent winterkill.

In this study we set out to test the hypothesis that effective aeration required complete water circulation through out the dugout. We also hypothesized that the depth to which water is circulated will be related to the location of the surface aerator or diffuser in the dugout.

METHODS

This study was conducted on farm dugouts within a 10 km radius of the town of Falher, Alberta. Falher is located in the Peace River Region of Alberta, approximately 70 km south of the town of Peace River (Figure 1). The geographic coordinates of Falher are 55° 29' N, 117° 9' W. The area is flat and used for the production of cereal and forage crops. Dugouts were at or near full supply level through out the study.

Ten of the eleven dugouts we studied were used as domestic water supplies. All except two, Control-1 and Open-ended-2 were constructed according to PFRA guidelines and were partially funded by PFRA. The other two were highway borrow pits, one of which was used as a domestic water supply. The study dugouts varied somewhat in size and depth (Table 1). Volumes were calculated from the surface dimensions and depth assuming an end slope of 4:1 and a side slope of 3:1 (Figure 2).

In most cases the air compressors in this study were supplied by the dugout owners. Given the differing sizes of the dugouts involved and the differing sizes of air compressors, there was some variation between dugouts in the air input and energy expenditure (Table 2).

Table 1. Description of dugouts used for aeration study. Control dugouts received no aeration, open-ended were aerated with air injection through an open-ended tube, surface were aerated mechanically with spray pumps floating on the water surface, linear were aerated using a linear diffuser with 5 to 6.5 mm slits every 7.6 cm which produced fine bubbles; membrane was a point source diffuser using a rubber membrane with 2 mm slits which produced fine bubbles.

Treatment	Length m	Width m	Depth m	Surface Area, m^2	Volume m^3
Control-1	107.0	58.4	4.00	6,249	19,202
Control-2	70.0	31.0	4.25	2,170	5,700
Control-3	54.0	18.2	3.10	983	1,807
Open-end-1	65.2	31.0	5.5	2,021	5,738
Open-end-2	87.2	55.6	5.0	4,848	16,412
Surface-1	78.4	33.8	3.5	2,650	6,521
Surface-2	67.4	27.0	3.25	1,820	3,980
Linear-A1	61.0	39.2	4.3	2,391	6,327
Linear-R1	61.1	22.5	3.5	1,374	3,170
Linear-R2	63.6	24.9	3.75	1,581	3,293
Membrane	61.0	20.4	3.75	1,244	2,654

A variety of diffusers were tested. The most common type of 'diffuser' in the study region is the open end of the nominally 1.27 cm inside diameter black plastic tubing which brings the air to the dugout. We also tested three fine bubble, linear diffusers. These were made of black plastic tubing of approximately 1.27 cm inside diameter with a 1 mm thick wall and fine slits approximately 5 to 6.5 mm long every 7.6 cm along the upper surface of the tubing. One of the linear diffusers, **Linear-A1, was manufactured by Air Diffusion Systems, Lake Bluff, IL.** It was 10.7 m long, had an inside diameter of 1.27 cm, a wall thickness of 1 mm, and a weighted keel so that it lay on the bottom of the dugout. The other two diffusers, Linear-R1 and Linear-R2, were manufactured by one of the authors of this paper, R. Woelcke, from black PE tubing with a 15 mm inside diameter and 1 mm thick wall. Slits were cut every 7.62 cm with a number 11 X-ACTO™ knife blade (Figure 3). Diffuser R1 was 30.48 m long and R2 was 15.24 m long. Both of these diffusers floated about 50 cm above the bottom of the dugout. They were held in place with weights attached to the diffuser by rope every 1.2 m. The membrane diffuser was manufactured by Air Aqua Inc., Glenview, IL. It consisted of a cylindrical rubber tube 28 cm long and 7.5 cm in diameter with rows of slits 2 mm long spaced approximately 2.0 - 2.5 mm apart.

Table 2. Comparison of energy expenditure and amount of aeration of study dugouts. Treatments are described in Table 1. Air flow is given in litres per minute.

Treatment	Area m^2	Volume m^3	Air Flow	Watts	L/min/m^2	watts/m^2
Open-end-1	2,021	5,738	18.4	65	0.0091	0.032
Open-end-2	4,848	16,412	38.2	327	0.0079	0.067
Surface-1	2,650	6,521	-	155	-	0.058
Surface-2	1,820	3,980	-	178	-	0.098
Linear-A1	**2,391**	**6,327**	**11.0**	**50**	**0.0045**	**0.021**
Linear-R1	1,374	3,170	56.6	-	0.0413	-
Linear-R2	1,581	3,293	24.6	513	0.0156	0.324
Membrane	1,244	2,654	16.7	50	0.0133	0.040

The location of the aeration device in the dugout varied somewhat. The open-ended tubes were located near the water intakes which in both cases were located away from the centre of the dugout. The surface aerator and the membrane diffuser were located in the middle of the dugout while the linear aerators were located in the centre of the dugout oriented parallel to the long axis of the dugout (Figure 2).

Two surface aerators were also tested. Both of these consisted of a small electric motor oriented vertically in the dugout and supported by a float. A small propeller was attached to the shaft of the motor and which forced a plume of water into the air. One of these, Little Titan (1/6 HP, 1.51 Amps @118 volts) was manufactured by Otterbine/Barebo Inc, Emmaus, PA. The other, a nominally 1/20 HP (1.34 Amps @ 116 volts) aerator was manufactured by The Power House, Owings Mills, Maryland.

Dugouts were sampled biweekly during the open water season and monthly in winter. During sampling, oxygen and temperature profiles were measured at 1 m intervals from surface to 50 cm above the sediment using a Yellow Springs Instruments, Model 55 Oxygen Meter. Temperature was recorded to 0.1 °C and oxygen levels to 0.1 mg/L. During the open water season profiles were measured in three equally spaced locations. These locations were perpendicular to the linear diffusers and in all other cases were parallel to the long axis of the dugout. Since there was no spatial difference in oxygen profiles during the summer, profiles were done in one location near the centre of the dugout during the winter.

RESULTS

Dugouts which were unaerated showed some horizontal heterogeneity in vertical profiles for oxygen and temperature (Table 3a) but this was not the case for aerated dugouts (Table 3b).

Table 3. Vertical profiles for oxygen and temperature at three stations on: (a) upper panel, an unaerated control (Control-1) dugout on August 21, 1996 (upper and (b) lower panel, an aerated (membrane diffuser) dugout on August 22, 1996.

a.

Depth m	**Station 1**		**Station 2**		**Station 3**		
		°C	**O_2**	**°C**	**O_2**	**°C**	**O_2**
surface	17.4	8.7	17.0	8.3	16.7	7.7	
1	17.3	8.8	17.0	8.3	16.7	7.8	
2	16.9	8.7	16.7	8.5	16.3	7.5	
3	16.3	8.6	16.2	8.1	16.2	7.4	
3.5			16.0	7.9	16.1	7.4	
b.							
Surface	18.1	9.6	18.0	9.2	18.9	9.2	
1	18.1	9.5	18.1	9.3	18.2	9.3	
2	18.0	9.4	18.1	9.2	18.1	9.3	
3	17.9	9.2	17.5	9.2			
3.5			17.1	9.2			

Dugouts which were not aerated often showed marked vertical stratification of both temperature and dissolved oxygen during the open water months and were strongly stratified during winter (Table 4). On occasion however, unaerated dugouts became well mixed as a result of strong winds in the period preceding sampling. Such a situation is shown in Table 4 for the October 2 data.

Aerators circulate and aerate water to some fixed depth which is determined by the location of the aerator relative to the bottom of the dugout. In the case of surface aerators, the body of water is mixed and aerated to the depth of the bottom underlying the aerator (Table 5). The surface aerator in this had a cord which was 7.62 m long necessitating a location of the aerator approximately 6.1m from shore in about 2 m of water. The open-ended tubing in dugout Open-ended-1 was located at depth of about 2 m. The water throughout the dugout at and above that depth was well aerated while the water below 2 m often had very low oxygen levels, even during the open water season. ***The linear aerator in dugout Linear-A1 was weighted with a plastic coated lead keel so that it was on the bottom of the deepest part of the dugout. This resulted in the whole dugout being well aerated during both summer and winter even though the area weighted energy and volume of air input was the lowest of all the dugouts in the study.***

In dugouts with linear aerators (R1 and R2) which were floating off the bottom the oxygen levels below the diffuser were low indicating that the water below the diffuser was not mixed or aerated. In dugout Linear R2 on August 9, 1996 oxygen levels were homogenous at 9.4 mg/L from the surface to 4.0 m which was the depth of the diffuser and 1.1 mg/L below the diffuser. Temperature went from >18.3 above the aerator to 10.1 °C below it.

Summer oxygen profiles do not accurately reflect oxygen profiles (Table 5). This is particularly evident in the control dugout in Table 5. Oxygen levels varied from one dugout to another, even at the surface.

In winter, water temperatures and always stratified in unaerated dugouts (Table 6). By early January unaerated dugouts are effectively anoxic throughout the water column. The different aeration systems tested provided adequate dissolved oxygen levels to maintain acceptable taste and odour of the water. However the level of dissolved oxygen varied substantially between aeration devices. None of the data shown in Table 6 represent water which is saturated with oxygen (14.2 mg/L @ 1°C). Saturation levels (14.3 mg/L @ 0.2°C) were achieved at one dugout (Linear-R2) on January 7, 1997 but the energy and air input on an aerial basis was much greater than in the dugouts reported in Table 6.

Table 4. Oxygen and temperature profiles in an unaerated dugout during the open water season (August 15, 1996) and during the winter.

Depth m	**August 15, 1996**		**October 2, 1996**		**December 3, 1996**	
	°C	**O_2 mg/L**	**°C**	**O_2 mg/L**	**°C**	**O_2 mg/L**
Surface	21.2	7.7	5.8	10.8	6.4	1.9
1	19.8	8.3	5.9	11.1	3.4	3.9
2	17.3	8.2	5.9	11.2	1.9	4.1
3	14.6	4.3	5.9	11.5	2.1	4.1
4	12.1	4.3	5.8	11.0	1.6	4.1

There was no detectable difference in ice thickness in the aerated and unaerated dugouts. There was however a difference in the area of open water maintained by the different aeration devices. Dugouts aerated with open-ended tubing had polynyas which varied from approximately 1.5 to 3 m in diameter throughout the winter months. Dugouts with more efficient aeration were cooled more substantially (Table 6) and in these dugouts no open water was observed throughout the winter. An ice cone which resembled a small volcano formed over one of the surface aerators which created a spray in the air. Oxygen levels were adequate but not particularly high (Table 6) in this situation. The other surface aerator became slightly depressed during the winter so that it did not spray water into the air but it continued to circulate water. This resulted in a polynya of 1 to 2 m in diameter throughout the winter. Oxygen levels in this dugout were 7.7 mg/L on January 7, 1997.

Table 5. Relationship between temperature and oxygen profiles for dugouts with different aeration regimes in open water. Control is dugout Control-1, Surface aerator is dugout

Surface-2, open-ended is dugout Open-ended-1 and linear diffuser is dugout Linear-A1. Data were obtained on September 17, 1996. 1997.

Depth m	Temperature, °C			
	Control	Surface aerator	Open-ended tubing	Linear diffuser
Surface	13.6.	15.0	12.4	13.9
1	13.2	14.5	12.4	13.9
2	12.5	13.7	12.3	13.9
3	12.2	12.4	11.2	13.8
4	11.5	12.0	10.8	13.7
5			10.2	13.6
5.75			9.8	
Dissolved Oxygen, mg/L				
Surface	10.7	10.7	11.8	9.4
1	9.8	10.9	12.2	9.6
2	7.6	10.2	12.1	9.8
3	2.6	4.5	9.4	9.9
4	2.4	4.4	6.5	9.9
5			1.2	9.4
5.75			0.5	

Table 6. Relationship between temperature and oxygen profiles for dugouts with different aeration regimes under ice cover. Control is dugout Control-1, Surface aerator is dugout Surface-2, open-ended is dugout Open-ended-1 and linear diffuser is dugout Linear-A1. Data were obtained on January 7, 1997.

Depth m	Temperature, °C			
	Control	Surface Aerator	Open-ended tubing	Linear diffuser
Surface	0.6	0.2	0.3	0.1
1	1.0	0.3	0.3	0.2
2	1.7	0.3	0.3	0.2
3	2.0	0.3	2.3	0.2
4	3.1		2.5	0.2
5			2.8	

Dissolved oxygen, mg/L				
Surface	0.4	5.9	4.5	10.6
1	0.3	5.9	4.3	10.6
2	0.3	5.8	4.2	10.6
3	0.2	5.8	1.1	10.6
4	0.2		0.6	10.6
5			0.2	

DISCUSSION

Our results indicate that good aeration is accompanied by complete mixing of the water in a dugout. All of the systems we tested were effective in aerating the water above them in the case of air injection and all of the water down to the depth of the bottom underlying them in the case of surface aerators. We therefore conclude that in order to aerate all the water in a dugout the site of air injection should be at the bottom of the deepest part of the dugout. Similarly if a mechanical aerator is used it should be located over the deepest water in the dugout.

The most effective and efficient method of aeration appears to be air injection in combination with a diffuser which produces fine bubbles. Although open-ended air lines did provide aeration to the depth at which they were located, they maintained lower oxygen levels than similar air compressors when used in conjunction with a fine bubble diffuser. Open-ended tubing also appear to provide less efficient circulation of the water in the dugouts than a fine bubble diffuser on a similar air compressor. In order to maintain saturated oxygen conditions in the water bodies, the amount of air injection required was three to ten times that required to maintain adequate oxygen levels. We define adequate oxygen levels as being in the range of 4 to 5 mg/L oxygen.

One of the potential problems with diffusers is fouling associated with algal and bacterial growth and also mineral precipitates on and around the sites of bubble formation. All of the diffusers we tested were thin-walled and flexible and hence had some capacity to self clean, particularly with regard to mineral precipitates.

In the region where this study was conducted, the present practice is to aerate dugouts for domestic use with open-ended tubing during the winter months. This system creates an area of open water which can pose a hazard for pets and people. People have also come to associate open water with adequate aeration. Our results clearly show that better aeration is achieved using a fine bubble diffuser and that the cooling of the water associated with the use of such diffusers allows a complete ice cover to form on the dugout without any significant increase in overall ice thickness.

Adequate aeration in the water bodies we studied can be achieved at air injection rates of 0.0057 to 0.0142 L/m^2 and a power cost of 0.02 to 0.04 watts/m^2 of dugout surface area.

A dugout with a volume of 3,000 m^3 requires about 14 L/min of air which can be obtained from a compressor using from 50 to 75 watts of electricity.

ACKNOWLEDGEMENTS

This project was supported by a contract from PFRA to Sweet Water Supplies. We gratefully acknowledge the vision of Dave Kiely for initiating it and Brad Fairly for his continuing interest and support along the way. Denis Belisle provided valued help in the field setting up the sampling regime. We also thank Jennifer Dobbelaere and Bryan Kemper for assistance with field sampling.

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Reviewed: 1999-08-10
http://www.agr.ca/pfra/pub/aerat51b.htm

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