Chapter 39

A GUIDE TO THE DESIGN OF AIR BUBBLERS FOR MELTING ICE

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INTRODUCTION

The use of air bubblers for maintaining ice-free areas in lakes and in the sea has been reported abundantly in the technical literature. This author (1962) reported his observations on two air bubbler installations in the Canadian Arctic to the Eighth International Conference on Coastal Engineering.

The results of these investigations were, at that time, still inconclusive. Today, some of the mystery is resolved and it is the author's opinion that the existence of a heat reserve is the answer to the problem. Based on this premise, an attempt is made here to develop some guide lines for the proper utilization of this thermal reserve.

AIR BUBBLER SYSTEMS

A review of the literature and evaluation of experiments and observations bring out the following salient points.

1. PREVENTION OF ICE-COVER FORMATION

To prevent ice formation the operation of the air bubbler must begin before freeze-up. If a large thermal reserve due to stratification exists, then the upward transport and mixing of the warmer strata supplies to the surface layers water above its freezing point and compensates for the heat losses to the atmosphere. The size of the ice-free area depends - aside from atmospheric conditions - upon the temperature structure of the water, the quantity of water transported to the surface, the mixing in the vertical plume and the temperature and velocity decay of the surface current.

If there is insufficient thermal reserve to compensate for heat losses, the system may still work to a limited extent, provided there is enough turbulence created on the surface to prevent the formation of a solid ice cover. The heat losses in this case are compensated by the formation of frazil ice, each gram of which liberates upon freezing its latent heat of fusion. The frazil particles are carried away by the currents and deposited on the underside of the adjacent ice sheets. The principles involved in this process are the same in fresh or sea water.

2. MELTING OF AN EXISTING ICE COVER

The melting of an ice cover when a large thernal reserve exists is a function of the flow factors outlined in the previous section. If there is insufficient thermal reserve within the range of influence of the air bubblers, only a limited amount of ice can be removed from the underside of the cover. There are reports, however, that by using underwater purps, under certain conditions it is possible to "erode" the sea ice by the mechanical action of abrasion rather than melt it by thermal energy. The disturbing part of these claims is that the efficiency of the system is reported to be much greater than 100 percent, i.e. the energy input is smaller than that required to melt the volume of ice. This is undoubtedly an area which will require more research. Based on reports of the operation of this pump, it is the opinion of this author that two factors might have contributed to the success of the operation.

- (a) There must have been in the region a small thermal reserve not detected by conventional oceanographic instruments. With the very large amounts of water circulated by the pump this may have been sufficient to honeycomb the ice cover and cause its disintegration.
- (b) The experiments were conducted in relatively mild weather (about 0°C) at which time the strength of sea ice had decreased considerably, thus contributing to the rapid decay.

SOME APPROXIMATE RULES FOR THE DESIGN OF AIR-BUBBLER SYSTEMS

On the premise that ice removal is due to thermal effects, an attempt will be made to give simple working rules for the practicing engineer, to guide him in the efficient design of air bubbler installations.

The hydrodynamics of bubble curtains in homogeneous water has been studied quite extensively. For the practicing engineer the results of Bulson (1961) and Abraham and Burgh (1964) are most useful.

In summary and referring to Figure 1, the following relationships are found to be valid within reasonable limits.

(a)	The maximum horizontal velocity mately at a distance $x = d/2$	vo	occurs approxi- (1)
(b)	$v_o = 1.2 (g \cdot q_g)^{1/3}$		(2)
(c)	b = d/4		(3)

where



d = depth of water

- q_a = rate of air flow per unit length of manifold measured at atmospheric pressure
- g = acceleration of gravity
- b = thickness of horizontal jet at $x = \frac{d}{2}$.

The author has plotted the decay of the surface velocity, given by Bulson and Abraham, in dimensionless form in Figure 2, and has obtained the relationship

$$\frac{\mathbf{v}}{\mathbf{v}_{o}} = 1.5 \left(\frac{\mathbf{x}}{\mathbf{b}}\right)^{-0.50} \tag{4}$$

In view of the scatter of the experimental points and because in stratified fluids the surface jet tends to plunge and be effective only up to a limited distance, this simple relationship seems for the present sufficiently accurate.

The horizontal jet under an ice cover has, of course, the velocity distribution shown in Figure 3, but it can be reasonably assumed that the decay of the maximum velocity follows the same law.

The effect of the bubbler's orifice size on the maximum velocity has also been investigated and found to have no significant influence. Porous pipes do increase V_O by about 10 percent but are impracticable because of the higher air pressures required. For practical purposes simple squareedged orifices of 1/8" to 1/16" diameter are recommended.

The effect of orifice spacing has not been studied extensively but it was observed that for the same air flow a large number of smaller orifices spaced closely together were more effective than larger orifices spaced widely apart.

HEAT TRANSFER THROUGH THE ICE

The transfer of heat from the horizontal jet to the ice cover is at best a most complicated problem. By making some very rough assumptions, however, it may be possible to arrive at conclusions which may be of help in designing air bubbler installations.

As a first approximation, it is possible to consider the horizontal flow induced by the air bubbler as a form of two-dimensional wall-jet, where the jet velocity V_j is replaced by V_o , and jet thickness a by b.





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Comparing the horizontal velocity decay function of air bubblers with that of wall-jets,

$$\frac{\mathbf{v}}{\mathbf{v}_{j}} = 3\left(\frac{\mathbf{x}}{\mathbf{a}}\right)^{-0.5} \tag{5}$$

given by Sigalla (1958), it is seen that the analogy does not appear far-fetched.

In the absence of further experimental data on air bubblers, it seems reasonable for a first approximation to use for our application temperature variation and shear distribution functions obtained experimentally for wall-jets.

Sigalla (1958) reports
$$\theta = 3 \cdot \left(\frac{a}{x}\right)^{1/2}$$
 (6)
Here $\theta = (T_1 - T_0)/(T_j - T_0)$

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where $T_1 = maximum$ temperature at any position along the wall,

 $T_o =$ ambient temperature, $T_j =$ temperature at nozzle exit.

In the case of air bubblers, T_i would correspond to the temperature of the horizontal current at x = d/2.

For the skin friction, Sigalla reports the relation-

$$C_{f} = \tau_{o} / \frac{1}{2} \rho v^{2} = 0.0865 / \left(\frac{Vx}{v}\right)^{0.2}$$
 for $\frac{x}{a} > 30$. (7)

Assuming for our case,

$$C_{f} = 0.1 / \left(\frac{Vx}{v}\right)^{0.2}$$
 for $\frac{x}{b} > 2$, (8)

we can make use of the relationship derived by Sidorov (1957) for heat transfer by the turbulent horizontal jet to the lower surface of the ice,

$$\mathbf{N} = \frac{1}{2} \mathbf{C}_{f} \mathbf{R} \mathbf{P}_{r}^{1/3} \tag{9}$$

Here,

N = Nusselt number = $q x/k (T_1 - T_s)$ R = Reynolds number = $\frac{Vx}{v}$ P_r = Prandtl number = C_p^{μ}/k

where

q = local rate of heat transfer

k = thermal conductivity of water evaluated at a temperature of $\frac{1}{2}$ (T₁ + T_s)

 $T_s =$ temperature of wall surface

v = kinematic viscosity of water

- μ = dynamic viscosity of water
- $C_{\rm p}$ = specific heat of water
- V = maximum velocity at point x.

The Prandtl number for water at $32^{\circ}F$ is 13.6. It is convenient to assume it constant for all applications where the temperatures are close to this value.

Substituting into equation (9) the value of C_{f} from (8) and that of V from (4), we get

$$N = 0.94 \left(\frac{V_0 x}{v}\right)^{0.8} \left(\frac{b}{x}\right)^{0.4}$$
(10)

and hence,

$$\frac{q x}{k (T_1 - T_s)} = 0.94 \left(\frac{V_0 x}{v}\right)^{0.8} \left(\frac{b}{x}\right)^{0.4}$$
(11)

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With the help of the relationships (1), (2), (3), (6) and (11), a more rational design of air bubblers can be accomplished than has been possible up to now.

A very simple example may illustrate the new approach.

Consider the water-temperature structure in a lake, shown in Figure 4.

It is desired to melt the ice at x = 20 m. within 24 hours after installation of the air bubbler. This requires, on the average, a heat supply

 $q_1 = 0.05 \text{ cal/cm}^2/\text{sec.}$

Assuming the heat losses to the atmosphere to be,

$$q_2 = 0.0112 \text{ cal/cm}^2/\text{sec.} (3600 \text{ BTU/ft}^2/\text{day})$$

the total heat to be supplied is,

$$q = q_1 + q_2 = 0.0612 \text{ cal/cm}^2/\text{sec.}$$



If the bubbler is to be installed at the bottom (d = 20 m.), it seems reasonable to assume that the temperature of the horizontal jet at x = d/2 will be spproximately $T_1 = 1^{\circ}C$. Conveniently, $T_s = 0$.

With q = $0.0612 \text{ cal/cm}^2/\text{sec.}$ x = 2000 cm. k = 0.00133 cal/sec. cm/°C.T₁ - T_s = 1° C. v = $1.86 \cdot 10^{-2} \text{ cm}^2/\text{sec.}$ b = $\frac{d}{4}$ = 500 cm. equation (11) yields V₀ = 32 cm/sec.

From equation (2), $q_p = 1920 \text{ cm}^3/\text{sec/m}$.

The energy per second available in the air leaving the manifold, assuming isothermal conditions and an air pressure just sufficient to overcome the static head, is given by

$$E_{A} = \gamma_{W} H_{O} q_{a} \ln \left(1 + \frac{d}{H_{O}}\right)$$

where

 γw = specific weight of water

 $H_o = atmospheric pressure in cm. of water.$

Substitution of velues yields,

$$E_A = 207 \text{ watts/m}.$$

For the same conditions, if the manifold is suspended at a depth of 10 m, b = $\frac{d}{L}$ = 250 cm,

and we get

 $V_0 = 45 \text{ cm/sec.}, q_a = 5460 \frac{\text{cm}^3}{\text{sec}}/\text{m},$

and $E_{A} = 373$ watts/m.

CONCLUSIONS

The paper is an attempt to put on a more rational basis the design of air bubblers for melting the ice cover and maintaining ice-free areas in lakes and in the sea. Since there is not sufficient experimental data to support the validity of some of the relationships used from the wall-jet analogy, caution should be exercised in putting too much

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faith in exact numerical results. Nevertheless, it is believed that the procedure outlined above might be useful in estimating the order of magnitude of the air supply and power requirements, once information is available about the atmospheric and oceanic or limnologic environment.

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