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Greenhouse Enclosed Aquaculture Pond Temperature Maintenance Using a Falling Droplet Heat Exchanger

N. Zamir, H. Pasternak, D. Cohen, R.A. Heckmann
L. Wallace

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TEMPERATURE MAINTENANCE USING A FALLING DROPLET HEAT EXCHANGER

Investigators' Names
(Principal listed first)

N. Zamir	
H. Pasternak	
D. Cohen	
L. Wallace	
R. Heckmann	בית החל

Investigators' Institutions

Agricultural Research Organisation
Agricultural Research Organisation
Hebrew University of Jerusalem
Brigham Young University
Brigham Young University

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Natur Zuriin

Signature
Principal Investigator

U. Laron

Signature
Institution's Authorizing Official

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Agricultural Research Organization, Israel
Institute of Agricultural Engineering
Department of Protected Crops

Brigham Young University, Utah, U.S.A.
Depts. of Civil Engineering & of Zoology

Hebrew University of Jerusalem, Israel
Life Science Institute

GREENHOUSE ENCLOSED AQUACULTURE POND, TEMPERATURE MAINTENANCE,
USING A FALLING DROPLETS HEAT EXCHANGER

Final Research Report

BARD Project I-905-85

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Nachum Zamir, Principal Investigator, ARO
Lynn P. Wallace, Cooperating Investigator, BYU
Dan Cohen, Cooperating Investigator, HU

Submitted to BARD, Bet Dagan 50250, Israel

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Bet Dagan, Provo and Jerusalem

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Authors' affiliations

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Authors' Affiliations

Anderson, A.	BYU, Utah, U.S.A
Arbel, A.	ARO, Israel
Cohen, D.	HU, Israel
Cristiansen, Y.	ARO, Israel
Geva, A.	ARO, Israel
Gilad, I.	HU, Israel
Haas, Elise	ARO, Israel
Heckman, R.	BYU, Utah, U.S.A.
Nilsen, B.	ARO, Israel
Pasternak, H.	ARO, Israel
Potter, G.	BYU, Utah, U.S.A.
Snir, R.	HU, Israel
Wallace, L.	BYU, Utah, U.S.A.
Zamir, N.	ARO, Israel
Zhao, L.	BYU, Utah, U.S.A.

GREENHOUSE ENCLOSED AQUACULTURE POND, TEMPERATURE MAINTENANCE,
USING A FALLING DROPLETS HEAT EXCHANGER

N. Zamir, H. Pasternak, D. Cohen, L. Wallace and R. Heckmann

ABSTRACT

Aquaculture pond temperature and water quality maintenance, as well as the feasibility of growing fish using very little nonrenewable energy and fresh water, were tested and discussed.

A series of experiments showed that falling droplets of a volumetric medium diameter of 0.65 mm, sprayed at a capacity of 1 kg/sm² from a height of 2.5 m, are capable of exchanging sensible and latent heat with an efficiency of ~50, when air wet bulb temperature is only 4 K above the temperature of the water supplied to the nozzles.

A series of energy-balance equations were derived that indicate the nocturnal heat loss from the upper surface of the water body, for single-skin and double-skin covered greenhouse enclosed ponds, under diverse climatic conditions. This heat losses calculated with these equations were in good agreement with the measured heat losses.

The heat losses from a biodisk with a bacteria area of 50m² was approx. 56 W/K. Mounting the biodisk under a nontransparent long-wave radiation cover reduced the loss by approximately 33%. The heat loss from a sprayed trickling biofilter for the same bacterial area was 20% higher.

Covering the pond with a greenhouse is a partial answer that is not sufficient to avoid the cooling of the water during cold seasons.

Installing a falling droplet heat exchanger reduced the daily heat losses from the greenhouse and increased the portion of energy used from the solar radiation.

The FDHE oxygenates the water to 0.8 of saturation after 0.5-m fall, and very near to saturation after a fall of 2.5 m. It may be recommended as an oxygen supplier, as a byproduct of heat transfer or as an inlet for fresh water, that is poor in DO or too rich in some other gases.

A constant of approximately 1.5 ug of ammonium was found to be oxidized per second at 25°C over 1 m² of a well bacteria covered film, with little effect of ammonium concentration.

Experiments were conducted to determine the suitability of the aquatic habitat for production of carp and channel catfish, in Provo, Utah and Carp and Tilapia in Israel.

In Utah, a hot-water-exchange system (heated effluent from power plant) was used. Two of the tanks were connected with a vertical trickling filter system, while the others were not filtered, requiring constant water exchange.

In Israel, four tanks were constructed inside a hydro solaric greenhouse located at Mevot Eiron. The temperature of the water was maintained by harvesting the extra heat from the greenhouse air. Submerged biofilters were used. Aeration of the water was mainly as a result of the FDHE.

The biofiltering system was efficient in lowering nitrite (NO₂) and ammonia (NH₃) levels and the filtered system supported much more biomass than the unfiltered.

I. INTRODUCTION

N. ZAMIR

The problem and the objectives:

The freshwater aquaculture systems in Israel and in the southern USA are successful agricultural branches, supplying a significant proportion of the freshwater fish consumed. In Israel, the industry has begun to export its products (prawns, Tilapia etc), while in the USA, catfish is gaining nationwide acceptance. Tropical organisms require a temperature range of 21-28°C for rapid growth and survival; such temperatures prevail in Israel and the USA in uncovered and/or unheated pond waters from May to November, permitting economic growth during 6-7 months of the year. This period is sufficient to achieve market size in one grow-out season, provided that post-nursery fry and juvenile prawns are stocked in the open ponds at the beginning of this season. The solution employed by the aquaculture industry therefore entails the division of the production line into two phases: (a) winter activities in the hatchery and nursery in which mating, fertilization and egg incubation occur and larval development is obtained; and (b) summer activities in the grow-out pond, in which post-nursery fry are stocked in ponds for grow-out to market size.

This procedure is predicated on the fact that during the initial stages of the larval development and nursing of juveniles, which last 3-4 months, the individual weights increase to approx. 1.0 g and can be achieved at high densities in relatively small production units. Such production units are becoming an integral part of an aquafarm in the temperate zone. Their state of development is low, and the notorious 'winter kill' is a major problem in these industries.

The main factor determining the economic viability and thus the price of the fry to the farmer, is the cost of the energy required to maintain a suitable temperature in the nursery, during the 3-4 months preceding stocking. Whether the energy source is geothermal, heat effluent or fossil fuel, high investments are needed, making the calory expensive. The use of solar energy in greenhouse-enclosed aquaculture pond (GEAP) is less expensive, but has not yet been developed for aquaculture purposes.

The tendency of the nursery operator is therefore to minimize the size of his facility in order to minimize heat losses and to avoid changing water, in which he invested energy to heat it, resulting in water pollution, which must be treated in order to avoid reduction in growth and survival.

Utilizing inexpensive energy for heating, may be antagonistic to maintaining water quality, if both technologies are not utilized in a complementary and economical manner.

The objectives of this project were two:

- (i) To evaluate the physical characteristics of the falling droplets heat exchanger and the heat balance of the greenhouse -

enclosed aquaculture pond in different climates (USA and Israel).

(ii) To evaluate the relationship between the environment and cost as affected by the solar and back-up heat supply, water mobilization, cover and bottom insulation, filtering and crop sources (salinity, temperature, cost), and the secondary use of the effluents.

The approach to achieving these objectives was to divide the project into several subprojects, each dealing with a different professional aspect, and joining them together only after some progress had been achieved. This led to numerous individual reports that are presented in this final report, covering most of the objectives suggested in the original proposal. Together with research engineers Arbel and Nilsen, the efficiency of the FDHE was evaluated and much is known about its heat and mass transfer as described in Chapter II.

The nocturnal heat losses from water were fully evaluated and the details are presented in Chapter III. The heating requirements of most kinds of greenhouse-enclosed ponds may now be defined.

Together with research biologists Gilad and Snir, the oxygen uptake properties of the FDHE were also evaluated, as described in Chapter VII, so that this tool may now be employed economically in aquaculture.

The heat losses induced by the biofilters were investigated by the late Elise Haas, as detailed in Chapter IV. This information provides us with a better tool to reduce heat loss in full-scale aquaculture.

The utilization of solar radiation, using the information given in the previous chapters, was evaluated experimentally and in commercial nurseries, together with H. Pasternack, and is presented in Chapter V. Using some previous formulations for the solar radiation penetration into various shapes of greenhouses, and the present heat loss formulation, it became possible to erect the ideal shape of greenhouse from the energy aspect and to calculate the optimal use of solar energy and the back-up needed, as described also in Chapter VI by L. Wallace and A. Anderson.

Water quality is discussed in Ch. VIII-IX by all the members of this research team. The most important finding was that if the water is rich in dissolved oxygen, the ammonia and nitrite decomposition is related mainly to the solid surface area available for the bacteria.

This knowledge served for the installing of the set up of the growing fish experiments as described in Chapter X.

II. EFFICIENCY FACTORS IN FALLING DROPLETS' HEAT EXCHANGE

N. Zamir, A. Arbel And B. Nilsen

ABSTRACT

A series of experiments showed that falling droplets of a volumetric median diameter of 0.65 μm sprayed at a capacity of 1 kg/sm^2 from a height of 2.5 m, are capable of exchanging heat and mass with an efficiency of 50, when air wet bulb temperature is only 4 K above the temperature of the water supplied to the nozzles.

The heat exchange parameter for 1 m^2 of cross section of this 2.5 m-high falling droplets heat exchanger (FDHE), is 170 $\text{w}/\text{m}^2\text{K}$ and 5 $\text{w}/\text{m}^2\text{Pa}$, the former for sensible heat and the latter for latent heat.

INTRODUCTION

General

In the literature, the spraying chamber heat exchanger is described as a tool for cooling and for air washing. Perhaps the reason for this is that this heat exchanger is known in two shapes: i) with very big droplets, or sheets, of water where the surface amount of water in relation to water capacity is small; ii) very small droplets, in which the evaporation is high.

If a big droplet or a sheet, exchanges heat with the surrounding air, all the droplets settle and no drift appears. In this case a high volume of water has to be raised and therefore a great amount of energy has to be used, in relation to surface area and therefore to the heat exchanged. Small droplets evaporate and may 'disappear' in the heat exchanger and in most cases a droplet washer has to be used. In order to produce small droplets, high pressure is needed and much energy has to be introduced in relation to the heat exchanged.

Using a spray in which droplets are of optimal size, takes advantage of the two good characteristics of the above mentioned systems. Choosing a droplet size which does not evaporate to a too small size in the heat exchanger, makes it possible, first, to exchange energy by heat and mass transfer and to collect this energy change in the settling droplets; and second to have the maximum surface area for the energy exchange.

A wide range of droplet sizes are normally produced by regular sprayers. Choosing a spraying nozzle with an adapted mean diameter and a narrow range of droplet sizes, optimizes the relation between the energy supplied, and that exchanged. In this case liquid that appears in small droplets and might evaporate, and that in big droplets in which the surface-area-to-volume ratio is small, are avoided. The main heat exchange occurs in the chosen droplet size.

Experiments were conducted to determine the volumetric mean diameter that gives the best heat transfer ^{1,2}. Measuring the change in the water temperature (the difference between water temperature when it leaves the nozzles and just before it reaches the sink) of variable volumetric mean diameter droplet sprays,

made it possible to find a prevailing droplet size that provides the best heat transfer. It was found that a droplet size of 0.7 mm gives the best heat transfer (Fig. 1). The experiment was carried out with approximately 1 kg/s of air and water circulating through an area of 1 m² and the falling distance of 2.5 m.

Calculations

1.2.1 Surface for heat exchange

It is possible to calculate the number of droplets for a specific volume and the surface of these droplets as given in Tables 1 and 2. In order to calculate the amount of heat transferred per unit area of the heat exchanger, it is necessary to know the number or surface area of droplets that are in the air at a certain time and the velocity of the droplets during their fall from the nozzle to the sink. The velocity distribution will give the droplets' falling time, and the heat and mass transfer between them and the air.

Velocities and duration

The velocity of the droplets is higher than that of the air. Knowing that the velocity of the air from continuity of mass, and the velocity of the droplets close to the nozzle v_n and just before the sink v_s , and assuming the deceleration of the droplets is constant, it is possible to calculate the time t , the droplets are in the air, along the path between the nozzle and the sink:

$$t = 2 l (v_n - v_s) / (v_n^2 - v_s^2) \quad (1)$$

Mechanical energy regenerated by the sucked air.

The mechanical energy E_v lost to the air by the droplets due to speed deceleration.

$$E_{vd} = (v_n^2 - v_s^2) / 2 \quad (2)$$

This energy is used to speed up the air through the heat exchanger.

Sensible heat transfer between spheres and air

To be able to distinguish which kind of heat is transferred in the falling droplet heat exchanger, it is necessary to investigate the heat transfer between the droplet and the air, which means between a sphere with a diameter 'D' and the air.

The Reynolds number 'Re':

$$Re = VD/\nu \quad (3)$$

v : velocity difference between air and sphere (max)

D : diameter of ball

The kinematic viscosity ' ν ' of air at 30°C is: 16×10^{-6} [m²/s] = 0.16 [cm²/s] and dealing with droplets in the range of diameter 'D' = 0.3 to 1 mm and relative velocities $v_d - v_a$ between the droplets and the air in the range of 10 to 1 m/s, the Reynolds number is in the range of 50-200. For a Reynolds number

of 25 to 10,000, the equation to calculate the average unit surface conductance 'h' for a sphere heated or cooled by air is:

$$h = 0.037 \text{ Re}^{0.6} k / D \text{ [W/m}^2\text{K]} \quad (4)$$

The thermal conductivity of air K is: 0.026 [w/m²K] and the sensible heat transfer is:

$$Q = h \cdot G \cdot A \cdot t \quad (5)$$

1.2.5. Latent heat transfer between spheres and air by mass transfer

Heat transfer between spheres and air by mass transfer means either evaporation of water from droplets or condensation of water from air. The specific latent heat is calculated by a similar formula, but instead of temperature difference, the pressure difference between the vapor pressure of the water in the air and that of the water surface:

$$Q_e = h_e \cdot G \cdot A \cdot t \quad (6)$$

EXPERIMENTAL PROCEDURE

The setup of the heat exchanger

Eighty-seven nozzles were placed at a height of 2.5 m above water level. The nozzles are specially designed so that they produce a narrow spectra of droplet sizes. The nozzles spray an area 'A_i' of 1.2 x 2.5 m totaling 3 m². The heat exchanger is open above nozzle level - where the air enters, and above water level - where the air escapes - no. 4 on Figure 2.

The water is pumped from a basin to the nozzles. With a valve, it is possible to by pass and regulate the pressure. The heat exchanger (H.E) is placed at the north end of a 3 x 22 m greenhouse, with a possibility of temperature and humidity regulation. It is possible to change the area of the air outlet 'A_o', in the H.E. by changing the size of the air-escape opening.

The setup of the measuring system

In order to measure the temperature of the droplets at different levels between the nozzles and water levels, four funnels for collecting the droplets were set up at distances of 0.6 m, the lowest one being 0.1 m above water level (see Fig. 3). Care was taken to ensure that there were no disturbances in any of the funnels, piles or funnel holders.

A copper-constantan thermocouple was placed at the bottom of each funnel. To ensure that the thermocouples were covered with the exact amount of water and to take precise temperature measurements of collected droplets, a pipe with a hole was placed on the funnel to draw away the water and maintain a specific water level in the funnel. The holes in the pile were made so that the pipe would not empty the funnel (see Fig. 4). The temperature of the water in the nozzle was measured by installing

a thermocouple in one of the nozzles, and that of the water in the basin under the spray was also measured by a thermocouple. All the thermocouples were protected from corrosion by covering them with thin epoxy with a high heat transfer coefficient.

The dry and wet bulb temperature measuring units were constructed so that they protect the thermocouple against radiation, and blow a certain air velocity at the dry and wet thermocouples (see Fig. 5). The thermocouples were connected to a Hewlett Packard data logger which translated the voltage to temperature values and recorded the measurements. The data logger was set to take a measurement every 2 minutes.

The experiment was run as follows: The H.E. was stopped. Heat from the sun was then trapped in the air. When a sufficient temperature was reached, the experiment was started. The data logger started measuring every other minute and the pump of the H.E. was started at a designed pressure. After approximately five to seven measurements, the door to the greenhouse was opened to change the conditions in the greenhouse. Again after five to seven measurements, the pump was stopped and the door was closed in order to collect and trap heat in the greenhouse. When sufficient temperatures were again reached, the pump was started at a different pressure. There were three chosen pressure levels to run the experiments: $P_n = 30, 50$ and 70 kPa.

The measurements were made with two different air outlet areas, A_o of 2 and 0.8 m^2 at the three spray capacities at three pressures, giving outlet-to-inlet ratios ' A_{ar} ' of 0.67 and 0.27 .

The amount of water, according to pressure was measured by installing a pressure-meter instead of a nozzle. The amount of water emitted from six different nozzles was measured with a stop-watch. The water quantity, time and pressure were recorded.

RESULTS AND DISCUSSION

Capacities, droplet size and surface area

The results are given in Table 2.

Heat exchange

Figure 6 shows the heating of the droplets ' dT_w ', as a function of the difference between the wet bulb temperature of the incoming air and that of the incoming sprayed water ' dT '.

The abscissa and the mantissa of the linear formulae that describe this phenomenon are given in Table 3. The abscissa may be explained by remembering that this difference ' dT ' describes only the inlet conditions and not the exact conditions throughout path by which heat and mass are transferred. These results are given as a rise in temperature droplets (Table 4).

The energy gain by this system is very efficient (Table 5). Taking for example a winter solar supply of 500 W/m^2 under a good greenhouse coverage, this may be collected by a 2.4 m high FDHE of 10% of greenhouse area when the air wet bulb is 3 K above the aquaculture water body, with an efficiency of about 40 , that means that only 12.5 W will have to be spent for electricity to pump the water up and through the nozzles and piping, etc, at a total mechanical and electrical efficiency of 0.7 , that was introduced in the calculation of Table 4.

Because every position of air condition, is defined by temperature and vapor pressure-as total pressure remains unchanged, a representative sample of lots of conditions, were chosen in order to describe more principle phenomena. These are given for a fall of 2.4 m in table 6. These values were used for the evaluation of tables 7 and 8.

From table 7, it can be seen that the heat transfer parameters 'hdT' are only similar to that given in table 4, under $dT = 1$, and for $l = 2,4$ m. This confusion is due to the deviation between the mean given in table 4 to only one condition described in tables 6, 7 and 8.

The second important information given in table 7 is the rate of air that is sucked and exchanges heat with the droplets. It can be seen that there is a small decrease in the air ratio, or as given in the table the enlarging of water capacity in order to move the air through the FDHE, as pressure and therefore water capacity increases, but lots of water are needed to move the air when the outlet of the air is decreased. Looking back to table 4 shows that this affects the heat exchange rate mainly when there is a high differences 'dT' between the air and the water.

Table 8 gives a more exact look on the effect of sensible and latent heat capacity of the FDHE. It can be seen that 'hs', the surface heat conductence, is not changing linearly according to the pressure. Smaller droplets of 0.58 mm dia, that are moving faster in the beginning 'Vn' and are slowing faster in the air and therefore reaching a slower 'Vs', gave similar values compared to the lower pressure of 50kPa, giving droplets of 0.65 mm.

For example, the velocity of a droplet that is advancing from the nozzle at 50 kPa is approximately 7 m/s at 45° to the horizon, and air is moving at 0.9 m/s (according to $1.086 \text{ Kg/m}^2\text{s}$) downward, it can be assumed that the velocity of the droplets of 0.00065 m (from table 2) is in the end of its way 3 m/s and because the path is more than $l = 2.5$ m, because of the small sideways, we can take a value of 2.7 m for this path. According to formula (1) we get that the time that takes from the droplet formation until reaching the sink is:

$$t = 2 \cdot 2.7 (7-3)/(7^2-3^2) = 0.54 \text{ [s]}$$

The Reynold number is calculated according to the relative velocity between the droplets and the air, which may be taken in this case as $V = 3 \text{ m/s}$ and according to equation (3):

$$\text{Re} = 3 \cdot 0.00065 / 0.000016 = 122$$

And therefore according to equation (4)

$$h = 0.037 \cdot 1220.6 \cdot 0.026 / 0.00065 = 26.4 \text{ W/m}^2\text{K}$$

and the specific heat transfer of the FDHE in this form of operation:

$$h_2 = h A C t = 26.4 \cdot 10.03 \cdot 1.086 \cdot 0.54 = 164.6 \text{ W/m}^2\text{K}$$

that is very near to the experimental results that was in table 8 for this case $169 \text{ W/m}^2\text{K}$.

In table 8 a parameter of mass transfer (a₁) is also given and its relation (c) to the parameter of sensible heat transfer (h₂). It can be seen that this value is almost twice the value submitted by Lewis. It is essentially a result of the comparatively high Reynold Numbers as described lately by Kincaid and Longley³.

CONCLUSIONS

The sensible and latent energy transfer were evaluated for several types of operation. The ratio between these parameters is in the range of 20 to 40 K/kPa and differ from the Lewis number that is only 15 K/kPa.

The efficiency of the FDHE is high. The heat exchanged is 50 times that of the actual energy for the pumping, when the inlet air wet bulb temperature is only 4 K above that of the water supplied to the nozzles.

There is an optimum for raising up the nozzles from the sink according to the pressure in the nozzles and the air to water rate.

Notation

A area, m²
a mantissa
b abscissa
c ratio between sensible and latent energy transfer parameters, K/Pa
D droplet diameter, m
d differential
E energy, J
G capacity, kg/s
h coefficient of surface heat transfer, W/m²s
K thermal conductivity, W/m²K
l length, m
P pressure, Pa
Re Reynolds number
r relative humidity
T temperature, K
t time, s
v velocity, m/s
kinematic viscosity of air, m²/s

Subscripts

a air
d droplet
i in-enter
l latent
n nozzle
o out-exit
r relative
s sink or sensible

w water
wb wet bulb, for temperature of air

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TABLE 1:
SOME USEFUL FORMULAE AND SPRCIFIC PARAMETERS.

Surfase area of a sphere:	$A_s = 3.14 D^2, m^2$
Volium of a sphere:	$V_s = 3.14 d^3/6, m^3$
Number of spheres per unit volium:	$N = 1/(3.14 D^3/6), /m^3$
Surface area of spheres per unit volium:	$A = 6 / D, m^2/m^3$
Capacity of a No. 3 ABCD nozzle at pressure P:	$Q = 2.8 p^{0.663}, g/s$
Volumetric Median Diameter of No. 3 ABCD nozzle:	$D_{v,50} = 3.97 / Q^{0.5}, mm$

TABLE 2:
CAPACITIES, CALCULATED VOLUMETRIC MEDIAN DIAMETERS ($D_{v,50}$) AND
HEAT TRANSFER AREA (A_{HT}), AT THE VARIOUS PRESSURES (P_n), USED.

P_n k Pa	Q_n g/s	Q g/s m^2	$D_{v,50}$ mm	A_{HT} m^2
70	46.8	1358	0.58	14.05
50	37.5	1086	0.65	10.03
30	26.7	774	0.77	6.03

TABLE 3:
THE MANTISSA AND ABSCISSA OF THE FORMULA: $(T_{\infty} - T_{\infty}) = a (T_{\infty} - T_{\infty})$
THAT DESCRIBES THE EXPERIMENTAL RESULTS.

A_{∞}	P_{∞}	1 = 2.4		1.8		1.2		0.6	
		a	b	a	b	a	b	a	b
		$m^2/m^2 \text{ kPa}$							
0.67	70	0.422	-0.265	0.446	-0.281	0.371	-0.269	0.264	-0.173
	50	0.45	-0.268	0.395	-0.143	0.327	-0.165	0.256	-0.127
	30	0.137	-0.099	0.119	-0.123	0.108	-0.109	0.005	-0.146
0.27	70	0.475	-0.305	0.364	-0.18	0.304	-0.241	0.268	-0.186
	50	0.377	-0.236	0.252	-0.041	0.18	-0.003	0.121	-0.037
	30	0.358	-0.357	0.379	-0.457	0.278	-0.237	0.241	-0.299

TABLE 4:
WARMING OF THE WATER DROPLETS dT_{∞} , AS THEY FELL ALONG '1' m,
AT A DIFFERENCE $dT = T_{\infty} - T_{\infty}$, OF 1, 2, 3 AND 4 K.

		dT = 1							
		2		3		4			
		1				1		2	
		3		4		1		3	
		4				2		4	
A_{∞}	P_{∞}	1 = 2.4 m				1 = 1.8 m			
m^2/m^2	kPa								
0.67	70	0.157	0.579	1.001	1.423	0.165	0.611	1.057	1.503
	50	0.182	0.632	1.082	1.532	0.252	0.647	1.042	1.437
	30	0.038	0.175	0.312	0.449	-0.004	0.115	0.234	0.353
0.27	70	0.17	0.645	1.12	1.595	0.184	0.548	0.912	1.276
	50	0.141	0.518	0.895	1.272	0.211	0.463	0.715	0.967
	30	0.001	0.359	0.717	1.075	-0.078	0.301	0.68	1.059
		1 = 1.2 m				1 = 0.6 m			
0.67	70	0.102	0.473	0.844	1.215	0.091	0.355	0.619	0.883
	50	0.162	0.489	0.816	1.143	0.129	0.385	0.641	0.897
	30	-0.001	0.107	0.215	0.323	-0.141	-0.136	-0.131	-0.126
0.27	70	0.063	0.367	0.671	0.975	0.082	0.35	0.618	0.886
	50	0.177	0.357	0.537	0.717	0.084	0.205	0.326	0.447
	30	0.041	0.319	0.597	0.875	-0.058	0.183	0.424	0.665

TABLE 5:
MECHANICAL ENERGY INPUT 'Me', HEAT ENERGY OUTPUT 'He' AND ENERGY
EFFICIENCY, $\epsilon = He/Me$, AT DIFFERENT TEMPERATURE GRADIANTS $dT = T_{\text{he}} - T_{\text{co}}$.

				dT = 1								
				2				3				
				4				1				
				2				3				
				4				1				
l	A _{ex}	P _o	Me	He				E				
m	m ² /m ²	kPa	W/m ²	W/m ²								
2.4	0.67	70	182	893	3292	5691	8090	4.9	18.1	31.2	44.4	
		50	115	828	2875	4922	6968	7.2	25.0	42.9	60.7	
		30	60	123	567	1011	1456	2.1	9.5	16.9	24.4	
	0.27	70	182	967	3667	6368	9068	5.3	20.1	34.9	49.7	
		50	115	641	2356	4071	5786	5.6	20.5	35.4	50.4	
		30	60	3	1164	2324	3485	0.1	19.5	38.9	58.3	
	1.8	0.67	70	171	938	3474	6009	8545	5.1	19.1	33.0	46.9
			50	106	1146	2943	4740	6536	6.3	16.1	26.0	35.8
			30	53		373	759	1144		2.0	4.2	6.3
0.27		70	171	1046	3116	5185	7255	5.7	17.1	28.4	39.8	
		50	106	960	2106	3252	4398	5.3	11.5	17.8	24.1	
		30	53		976	2204	3433		5.4	12.1	18.8	
1.2		0.67	70	159	580	2689	4798	6908	3.2	14.7	26.3	37.9
			50	96	737	2224	3712	5199	4.0	12.2	20.4	28.5
			30	46		347	697	1047		1.9	3.8	5.7
	0.27	70	159	358	2087	3815	5543	2.0	11.4	20.9	30.4	
		50	96	805	1624	2443	3261	4.4	8.9	13.4	17.9	
		30	46	133	1034	1935	2837	0.7	5.7	10.6	15.6	
	0.6	0.67	70	147	517	2018	3519	5020	2.8	11.1	19.3	27.5
			50	87	587	1751	2916	4080	3.2	9.6	16.0	22.4
			30	40								
0.27		70	147	466	1990	3514	5037	2.6	10.9	19.3	27.6	
		50	87	382	932	1483	2033	2.1	5.1	8.1	11.2	
		30	40		593	1375	2156		3.3	7.5	11.8	

A REPRESENTAL SAMPLE OF NUMERICAL RESULTS.

A _{s,r} m ² /m ²	P _a kPa	Water		Air in			Air out			T _{amb} -T _a K
		T _{wa} °C	T _{wo} °C	T _i °C	T _{wb} °C	r	T _o °C	T _{wbo} °C	r	
0.67	70	27.0	28.4	38.8	33.8	0.71	36.7	32.1	0.73	6.8
	50	27.0	28.3	37.1	32.7	0.74	35.4	31.5	0.76	5.7
	30	27.2	28.1	38.2	33.0	0.70	36.5	32.0	0.73	5.8
0.27	70	28.5	29.5	41.4	34.9	0.65	38.8	32.9	0.67	6.4
	50	28.6	29.6	41.8	34.9	0.63	38.9	33.0	0.67	6.4
	30	28.6	29.7	41.1	34.8	0.65	38.7	32.9	0.67	6.2

TABLE 7:
HEAT TRANSFERED PER UNIT WATER ' Q_w ', AIR ' Q_a ' AND FDHE ' Q_f ',
THE HEAT TRANSFER PARAMETER ' hd ' CALCULATED ACORDING TO ' dT ',
AND THE RELATION Q_w/Q_a .

$A_{s,r}$ m^2/m^2	P_n kPa	G_w $kg/m^2 s$	dT K	Q_w kJ/kg	Q kW/m^2	hd $w/m^2 K$	Q_s kJ/kg	Q_w/Q_s kg/kg
0.67	70	1.358	6.8	5.78	7.847	1154	9.40	1.63
	50	1.086	5.72	5.23	5.684	994	6.66	1.27
	30	0.774	5.79	3.60	2.787	481	5.52	1.53
Mean:								1.48
Stand. Error:								0.12975
0.27	70	1.358	6.38	4.19	5.686	891	11.49	2.74
	50	1.086	6.35	4.48	4.865	766	10.97	2.45
	30	0.774	6.21	4.52	3.500	564	10.97	2.43
Mean:								2.54
Stand. Error:								0.12573

TABLE 8:

[illegible]

Figure 1: The change in the temperature of the droplets as a function of their volumetric median diameter when the wet bulb temperature in the inlet air was 1 K above the inlet water temperature.

Figure 2: The falling droplets heat exchanger: 1. Spraying nozzles. 2. Water basin. 3. Incoming air. 4. Outcoming air. 5. Pump. 6. Bypass regulator. 7. Front cover.

Figure 3: A schematic cross section of the measuring system in the heat exchanger.

1. Spray nozzles	2. Water basin
3. Incoming air	4. Outgoing air
5. Pump	6. Bypass regulator
7. PVC	8. Funnel with thermocouple

Figure 4: The water droplet temperature measurement: 1. Funnel. 2. Funnel holder. 3. Hose. 4. Thermocouple. 5. Water level in the funnel. 6. The hole in the hose that disabled siphon effect. 7. Discharge hose.

Figure 5: The dry and wet bulb unit: 1. Bare thermocouple. 2. Wet cotton covered thermocouple. 3. Fan. 4. Distilled water container. 5. Cotton in conduit.

Figure 6a: The temperature changer of the falling water u_w jets (dt_w) as a function of the difference between the wet bulb temperature of incoming air and the water temperature in the nozzle (dt), when outlet-to-inlet ratio (Aar) = 0.67.

Figure 6b: The temperature changer of the falling water droplets (dt_w) as a function of the difference between the wet bulb temperature of incoming air and the water temperature in the nozzle (dt), when outlet-to-inlet ratio (Aar)=0.27.

III. CALCULATION OF NOCTURNAL HEAT LOSS FROM A GREENHOUSE-ENCLOSED AQUACULTURAL POND

N. Zamir, H. Pasternak and A. Arbel,

ABSTRACT

The rate of nocturnal heat loss from the surface of a covered aquacultural water body is high, due to water evaporation and covering surface condensation.

In order to predict the investment and operational costs required to maintain a desired water body temperature, an attempt was made to derive a series of energy-balance equations that would indicate the nocturnal heat loss from the upper surface of the water body, for single-skin and double-skin-covered greenhouse- enclosed ponds, under diverse climatic conditions. This was achieved by evaluating the ingredients of the heat transfer fluxes from the water surface through-the air and the greenhouse coverage. The calculated heat losses were in good agreement with the measured heat losses.

INTRODUCTION

One possibility of conserving energy in an aquacultural pond lies in surrounding the water body with a thinly glazed plastic structure (greenhouse). This method dispels in some climates the need for diurnal heating, because solar energy is captured during the day and energy losses are reduced during the night.

Although this system has been used for several years, the relationship between the fluxes of sensible and latent heat, and the effect wind velocity has on them, are still not fully understood.

The aim of this study was to adapt existing empirical formulas, that were useful for the calculation of the heat fluxes of greenhouse structures, to the case of a greenhouse-enclosed aquacultural pond, and to derive a model for the calculation of the heat losses from the surface of the water. The purpose was to give a tool to economise the investment and operating costs incurred as a result of water body temperature upkeep requirement and ambient conditions.

Notations

- A Area, m^2
- a coefficient for wind effect, s/m
- B " (formulas 30 through 36)
- b " for wind effect (power factor)
- c relation of energy transfer by vapor to that by sensible heat, K/Pa
- D length, m
- e emittance
- H sensible heat-flux, W/m^2
- h coefficient of surface heat transfer, W/m^2K
- k conduction, $W/m K$, or $W/m Pa$
- L latent heat-flux, W/m^2 , or specific, J/Kg

l coefficient of latent heat transfer, $W/m^2 Pa$
M molecular weight, g/mol
m transmissivity to long wave radiation
N number of covering layers
P pressure, Pa
q energy flux, W/m^2
R heat flux by radiation, W/m^2
r relative humidity ratio, Pa/Pa
S specific heat, J/kg K
T temperature, K
X ratio between open water surfaces and cover surface
y ratio between ground surface and open water surfaces
u coefficient of total heat transfer, $W/m^2 K$
v wind speed, m/s
 σ Stefan Boltzman factor = $5.67 \cdot 10^{-8}$, $W/m^2 K^4$

Subscripts

a air
c cover
d dividing film or distance
h specific heat
f inside
o outwards
s sky
u convection
v water vapor
w water
z measured during the experimental work
l..n serial no. of placement, coverings etc.

THEORETICAL CONSIDERATIONS

General

The heat loss from the surface of the water is caused by heating and humidifying the air above the surface and by radiating heat to the covering material or to the sky. Only as a secondary step does this air lose its heat to the covering material, and then through it, to the outside.

Heat flux by convection

Analytical formulas exist for the calculation of the sensible heat flux 'H', for simple geometrical shapes, but a water surface upset by fish and edge effects, etc., makes these calculations practically useless. Therefore, in this study a mean value for the surface heat convection 'h' was sought, where:

$$H = h (T_1 - T_2) \quad (1)$$

and because wind and evaporation has a major effect on the convected heat, the energy flux may be expressed as:

$$H + L = (1 + av^b) (h (T_w - T_a) + l (P_w - P_a)) \quad (2)$$

Garzoli & Blackwell¹, Seginer, et al.² and Zamir, et al.³ indicated 'h' values ranging from 2 to 10 W/m²K; the lowest value was for somewhat insulated materials¹, and the highest value included a measure of wind effect².

When dealing with very thin covering materials in the range of 100 μ m and heat conductance of 0.2 W/mK, a 0.1°C difference between two sides, is sufficient to enable the transfer of 200 W/m², which is almost the greatest heat flux measured in Israeli and in similar climates, greenhouses. Therefore, this temperature gradient shall be excluded from this study.

Effect of wind on heat and mass transfer

The parameters 'a' and 'b' in equation (2) are a result of the exact location of wind speed measurement, as well as the shape of the structure, its size, and the shape of the site from which the wind is blowing. In most published results this value is given for the wind effect on heat transfer from inside air to outside air. In previous field experiments³, 'a' was found to be an independent value of 1/5.6 for a 1000 m² greenhouse, when wind was measured at the top of a hill and the greenhouses were located on the slope below. For flat surfaces, it is commonly denoted in literature^{4,5} that 'a'=1 s/m and 'b'=1, and that wind affects mainly the outside of the cover. Measurements taken near the inner surface of a thin polyethylene cover showed an internal air velocity - in a similar direction - of approximately one-third of outside, above-roof measurements. These internal air movements were found also near the ground of the greenhouse, in the opposite direction.

From these data one may conclude that 'b'=1 and 'a'=1 for practical calculations, for heat convected from the outside surface, and 'a'=1/3 for the internal side of the cover.

For heat transfer from the internal wet surfaces to the air under windy conditions, eqa. 2 becomes:

$$H + L \approx (1+v/3) (h (T_w - T_a) + l(P_w - P_a)) \quad (3)$$

for heat transfer from dry internal surfaces:

$$H = (1+v/3) h (T_a - T_{ci}) \quad (4)$$

and from the outside of the cover:

$$H = (1 + v) h (T_{co} - T_o) \quad (5)$$

When there is no wind, equations 3-5 must be somewhat different, as the sensible heat transfer parameter 'h' is then smaller for the horizontal part of the ceiling, although there is no effect on vapor transfer, parameter 'l'.

Latent heat flux

Two phenomena are involved in a comparison of the latent heat flux by either evaporation or condensation^{6,7}: one - the result of the molecular concentration and specific heats, and the

other - the result of air thermal conductivity and vapor diffusivity in the air.

Grosman⁶ and Grosman & Heath⁷, by solving simultaneously the energy and the diffusion equations, found that the mass and heat transfer are related depending on the Peclet number ($Pe = RePr$) and the Lewis relation ($Le = (Rv/Mw Lw)/Ka/Ma Ta Sha$)).

These may be described as follows:

The molecular assumption:

$$c = 1/h = (Lh Mw (P_w - P_{wa})/P_a) / (Sh Ma (T_w - T_a)) \quad (6)$$

were

$$Lh = 2502.5 - 2.385 (T_a - 273), \quad [kJ/kg] \quad (7)$$

and

$$Sh = 1004.2 + 0.6 (T_a - 268), \quad [J/kg K] \quad (8)$$

$$Ma = 28.966 \quad [g/mol]$$

at:

$$Pa = 101325 \quad [Pa]$$

For the 15-25°C range, the result is:

$$c = 1/h = 0.015 \quad [K/Pa] \quad (9)$$

where 'l' is expressed in $W/m^2 Pa$

and 'h' is expressed in $W/m^2 K$

The diffusion assumption

$$c = 1/h = k_v/k_a \quad (10)$$

At 20°C, $k_v = 0.75 \cdot 10^{-3} \text{ w/m Pa}$, and $k_a = 25.7 \cdot 10^{-3} \text{ W/m K}$
The result for the 15-25°C range is:

$$c = 1/h = 0.03 \quad [K/Pa] \quad (11)$$

The proposed latent-to-sensible heat transfer relation

As mentioned previously with regard to sensible heat, none of the surfaces is shaped in a way that enables the designation of an exact weight of either phenomenon, so:

$$0.015 < c < 0.03 \quad (12)$$

0.015 refers mainly to an upward heating laminar flow, whereas these values increase with the velocity of the running water, but values of nearly 0.03 are rarely mentioned. For a fish pond, a value of 0.0166 is proposed as the most adaptable relation and eq.(3) becomes:

$$H + L = h (1+v/3) ((T_w - T_a) + 0.0166 (P_w - P_{wa})) \quad (13)$$

The water vapor pressure at saturation, and very near a wet surface, may be calculated as:

$$P_{wa} \approx 733 \exp (T_a - 273)/17, \quad [\text{Pa}] \quad (14)$$

By differentiation:

$$dP/dT \approx 43 \exp (T_a - 273)/17, \quad [\text{Pa/K}] \quad (15)$$

The differential vapor pressure may be given as a function of a temperature difference:

$$(P_w - P_a) \approx dP/dT (T_w - T_a) \quad (16)$$

where dP is calculated at the mean temperature.

When the water surface is at 25°C, the inside of the cover is at 10°C and the air is at 15°C, the corresponding value for dP is approximately 150 Pa/K, so that in this case

$$L = h (1+v/3) 0.0166 150 (T_w - T_a) = 2.5 h (1+v/3) (T_w - T_a) \quad (17)$$

and for a Greenhouse Enclosed Aquaculture Pond, where the air is very humid and near saturation, eq.(13) gives:

$$H + L = 3.5 h (1+v/3) (T_w - T_a) \quad (18)$$

Energy transfer by radiation as related to temperature

When the temperature of the two surfaces (e.g. water and cover) is similar, and considering:

$$h = 5.6 \text{ W/m}^2\text{K} \quad (19)$$

$$R_w = \sigma e_w e_{ci} (T_w^4 - T_{ci}^4) \approx 5.67 e_w e_{ci} (T_w - T_{ci}) \approx h e_w e_{ci} (T_w - T_{ci}) \quad (20)$$

In the greenhouse, when the heat flux from the water is by convection to the air and by radiation to the cover, one might consider the radiation to the air and its temperature as a simple mean between the water and the cover as related to the relevant areas, thus:

$$R_w = 4 h e_w e_{ci} (T_w - T_a) \quad (21)$$

The formulation for the energy radiated to the sky, in relation to outer surface and ambient air, is more complicated. Sky temperature was calculated by:

$$T_s = T_o / r^d \quad (22)$$

where 'd' ranges from 0.04 for a greenhouse located between buildings³, to 0.16 for a greenhouse located in an open field⁸.

For the temperature range of 0 to 20°C, and relative humidities in the range of 0.9 to 0.6, the best fit calculated formula is:

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$$R_{co} = \sigma e_{co} (T_{co}^4 - T_s^4) \approx 2 h e_{co} (T_{co} - T_o) \quad (23)$$

The simplified energy flux equations

The equation that defines the energy flux from the water surface, according to eqs.(18)and(21) is:

$$q_w = h (T_w - T_{ai}) ((3.5(1+v/3) + 4 e_w e_{ci})) \quad (24)$$

The energy flux to the internal wet surface by similar consideration:

$$q_c = h (T_{ai} - T_{ci}) ((3.5(1+v/3) + 4 e_w e_{ci})) \quad (25)$$

The energy flux equation defines heat movement from the cover to another layer above, from, or to any intermediate layer, by summarizing equ. (15) and (21):

$$q_d = h (T_c - T_d) ((1+v/3) + 4 e_c e_d) \quad (26)$$

The energy flux equation which defines heat movement from the outside of the cover to the open air and sky, is obtained from equ. (15) and (23):

$$q_{co} = h (T_{co} - T_{ao}) ((1+v) + 2 e_{co}/r) \quad (27)$$

For windy climates 'h' has the same value for all directions. This simplifies the further calculation of the individual temperatures of the covering layers.

It is worthwhile to note that the effective areas of the cover differ in most cases from that of the water. The effective covering area for convection will be according to its relation to the water area (1/x) and for radiation according to its relation to the water area and the greenhouse ground area (y/x).

Calculating the temperature of the enclosed air, the various coverings, and the heating demands

In order to simplify further, it is assumed that all covering layers transfer no long-wave radiation ($m = 0$), and $h = 5.6 \text{ W/m}^2\text{K}$ to and from air, to any material and in any direction.

On the basis of:
the energy conservation:

$$q_w = q_c = q_d = q_{co} \quad (28)$$

And the temperature steps:

$$T_w - T_{ao} = (T_w - T_{ai}) + (T_{ai} - T_{ci}) + (T_{ci} - T_{di}) + \dots \\ + (T_{di} - T_{co}) + (T_{co} - T_{ao}) \quad (29)$$

And deriving water temperature T_w from the water temperature requirement of the fish, the outside climatic parameters (e.g. temperature T_o , humidity r and wind velocity v) from the regional climatic references and writing:

$$B_w = h (3.5 (1+v/3) + 4 e_w e_{ci}) \quad (30)$$

$$B_c = h (3.5 (1+v/3) + 4 y e_w e_{ci})/x \quad (31)$$

$$B_d = h (1+v/3 + 4 y e_c e_d)/x \quad (32)$$

$$B_o = h (1+v + 2 y e_{co}/r)/x \quad (33)$$

Transposing these into eq. (29) gives:

$$T_{ai} = T_w - (T_w - T_o) / (1 + B_w/B_a + 2(n-1)B_w/B_c + B_w/B_o) \quad (34)$$

$$T_{ci} = T_{ai} - (T_w - T_o) / (B_a/B_w + 1 + 2(n-1)B_a/B_c + B_a/B_o) \quad (35)$$

$$T_{co} = T_o + (T_w - T_o) / (B_o/B_a + B_o/B_a + 2(n-1)B_o/B_c + 1) \quad (36)$$

When these temperatures and corresponding vapor pressure values are substituted back into eq.(3) and (20) the heat loss from the water surface of the pond may be derived.

EXPERIMENTAL PROCEDURE

A small tunnel-shaped greenhouse, situated on an experimental field of the ARO at Bet Dagan, was used for measurements. It is constructed of 200° arcs, 10 m long, with a radius of 2.5 m, with dimensions of 20 m length by 3.2 m bottom width by 3.5 m-height. A double layer and a single layer of 0.25-mm-thick polyethylene was installed on the arcs during 1987 and 1988, respectively. Both, end-walls were insulated. The pond (2.8 x 16 m and one m water deep) covered almost two-thirds of the ground of the greenhouse. Further details are given in Table 1. The soil around and below the water body was kept dry.

The water body was warmed during the day by the solar radiation, or cooled by means of air ventilation.

Wet and dry bulb temperatures of the inside and outside air were measured using two copper-constantan thermocouples - one dry and another wetted by a cotton wick from a connected distilled water bottle, both in boxes shaded against radiation and aspirated. The inside box was placed in the center of the air volume, 1.8 m above water level. The location of the outside measuring box was approximately 20 m away from the greenhouse, also 1.8 m above ground.

The temperature of the water body was measured at various locations, using the same type of thermocouples, which were introduced into a small insulated bottle filled with distilled water. This was done to avoid disturbances by fish, etc. The above mentioned temperature measuring gauges were checked periodically using a standard thermometer, and replaced if faulty. The water level was checked every day and water was added as required.

The wind velocity was measured using a standard meteorological vane-type, wind way gauge. The measured data were recorded automatically on a floppy disc every 30 minutes for further evaluation.

Each run continued from 10 p.m. to 4 a.m. during nights when the temperatures of the outside and the inside air and wind

velocity were sufficiently constant. The mean climatic condition was taken as a mathematical mean of the 13 readings taken during the night. These long periods were needed in as much as the change in temperature of the water body was slight, and the instrument resolution was accurate up to 0.1 K only.

RESULTS AND DISCUSSION

Table 2 shows the climatic conditions for each set of data. The measured heat loss, q_{wz} against that calculated, q_w by eq. 13 and 21 according to the calculated T_a and T_{ci} , and using $h = 5.6 \text{ W/m}^2\text{K}$.

Fig. 1 shows close agreement between the calculated and the actual measured heat loss values. The R^2 of the relation between the calculated and the actual heat loss was 0.98 for the one layer tests, and 0.97 for the double-layer tests, showing the appropriateness of the model, and that a value of $5.6 \text{ W/m}^2\text{K}$ for surface heat convection is reasonable.

CONCLUSIONS

An analysis of heat loss by convection, condensation and radiation from a greenhouse-enclosed aquacultural pond has led to the development of a method for determining the heating requirements for a pond covered with one or more thin layers under a range of climatic conditions.

The analysis and the experimental work show that the water body surface heat loss may be calculated according to outside climate parameters: temperature, humidity and wind velocity; and the aquaculture setup factors: area of water, solid ground and covering surfaces; covering material type; and the number of insulating cover layers.

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TABLE 1
CHARACTERISTICS OF A GREENHOUSE-ENCLOSED AQUACULTURAL POND

Ground area, m ²	64
Thin coverage, m ²	196.5
Water surface, m ²	44.8
x	0.228
y	1.43
m _{ci}	0.1
m _{co}	0.5
e _w	0.98
e _{ci}	0.9
e _{co}	0.8
N (until May 1988)	2
N (from Sept. 1988)	1

TABLE 2:

MEAN WATER BODY TEMPERATURE (T_w), CLIMATIC CONDITION (T_{ao} , r_o , v , T_{sky}), AND MEASURED (Q_{wme}) AND CALCULATED (Q_{wca}) HEAT LOSS.

Year and month	night	T_w °C	T_{ao} °C	r_o	v m/s	T_{sky} K	Q_{wme} W/m ²	Q_{wca} W/m ²
1988	I 24/25	19.7	11.1	0.80	8	279.1	207	203
	25/26	18.6	13.2	0.87	7	283.2	122	115
	28/29	19.9	12.4	0.94	10	284.3	207	207
	29/30	19.7	7.5	0.97	7	280.1	268	254
	30/31	19.6	7	0.97	9	279.6	305	308
	II 1/2	20.3	12.7	0.73	7	278.9	171	170
	2/3	16.5	9.7	0.95	6	281.7	122	120
	3/4	15.9	10.8	0.77	2	278.1	61	56
	4/5	17.1	7.7	0.96	4	280.0	134	133
	5/6	19	14.5	0.55	10	274.4	134	129
	6/7	19.2	12.3	0.89	4	282.8	110	108
	9/10	19.4	6.8	0.79	7	274.7	256	262
	10/11	19	7	0.83	6	276.0	232	224
	11/12	19.7	7.7	0.87	6	277.8	232	229
	12/13	18.4	13	0.81	3	281.3	73	74
	13/14	19.2	13.7	0.74	8	280.1	134	132
	14/15	20.2	13.3	0.60	8	275.1	171	171
	15/16	20.4	13.2	0.64	9	276.3	195	193
	III 1/2	21.2	17.2	0.98	7	289.9	98	93
	2/3	21.3	13.7	0.99	7	286.6	171	173
	3/4	22.4	14.6	1.00	8	287.8	171	201
	X 27/28	26.1	20.6	0.99	2	293.5	167	153
	29/30	24.6	16.2	0.98	1	288.9	167	176
	30/1	24.9	15.7	0.99	1	288.6	213	192
	XI 1/2	24.4	14.3	0.99	1	287.2	213	206
	2/3	24.7	14.1	1.00	2	287.3	258	263
	3/4	23.2	12.4	0.99	1	285.3	228	210
	4/5	22.3	16.1	0.97	1	288.6	137	124
	5/6	24.4	18.1	0.98	3	290.8	182	193
	XII 26/27	18.8	10.3	0.58	2	271.5	182	193
	27/28	15.8	7.1	0.96	0	279.3	122	110
	28/29	17.4	6.9	0.93	0	278.5	91	137
	29/30	17.1	15.6	0.99	2	288.5	30	32
	30/31	15.2	9.2	0.96	0	281.5	76	77
1989	I 31/1	15.9	8.7	0.94	5	280.4	213	213
	1/2	16	5.6	1.00	2	278.8	198	195
	2/3	15.8	10.7	1.00	2	283.9	106	101
	4/5	14.3	0.2	0.98	0	273.0	182	161
	5/6	15.1	3.9	0.97	1	276.4	167	169
	14/15	17.3	8.2	0.95	4	280.2	243	244
	15/16	17.6	5.3	0.99	3	278.1	274	278
	16/17	15.1	4.9	1.00	0	278.1	122	123
	17/18	15.3	3.7	1.00	2	276.9	213	210
	18/19	16.5	4.6	1.00	2	277.8	228	223
	20/21	15.6	10.2	0.95	1	282.3	91	89
	26/27	23.1	15.8	0.98	2	288.5	167	179
	II 26/27	24.3	10.1	0.95	4	282.1	441	451
	III 26/27	23.7	12.7	0.97	3	285.1	319	310
	27/28	21.6	8.8	0.99	3	281.7	304	328
	28/29	20.9	5.1	0.97	2	277.6	319	326

Fig. 1: The relation between calculated and measured water surface heat loss of a greenhouse-enclosed aquacultural pond: (a) Winter 1988-1989, single layer, (b) Jan.-March 1988, double layer.

IV. THE HEAT LOSSES FROM A DISK AND TRICKLING BIOFILTER

N. Zamir, Elise Haas and A. Arbel

ABSTRACT

A marked increase in the commercial culture of warm-water fish was registered in the U.S.A., Europe and Israel in the past few years. Since progress in this field is based on careful temperature monitoring of the water heat losses under different climatic conditions, two biological filters were evaluated.

The water flow through the biofilter tank did not have a significant influence on the heat losses of this apparatus. Reducing the biodisk rotation velocity from 13 to 6 rpm decreases the heat loss by 8%. Covering the biodisk with a black polyethylene (PE) film reduced the heat loss by 16%.

Mounting the biodisk under a nontransparent long wave radiation cover had a significant effect on the heat loss. The heat loss coefficient for an uncovered biodisk at 13 rpm was 55.8 W/K, such a cover reduced the loss by approximately 33% to 37.2 W/K; as a result of the decreasing of the heat radiated to the sky.

The heat loss coefficient from the nonrotating biodisk water surface was 30.2 W/K in the plastic house and only 10.3 W/K under a nontransparent long wave radiation cover.

The heat loss from the trickling biofilter for the same bacterial area was 20% higher than that from the biodisk.

INTRODUCTION

A marked increase in the commercial culture of warm water aquatic animals was registered in the U.S.A., Europe and Israel in recent years. However, during the winter months the water becomes cold and therefore growing of this type of fish is limited.

The heating of large amounts of water, as needed in through-flow culture, is limited to places where there are cheap hot water sources, such as geothermal wells. One of the procedures is to raise fishlets during the cold season in a warm water hatchery, and to place them in open ponds in the spring, when the water there reaches a sufficiently high temperature. Another procedure consists of rearing the fish all year round, in a body of closed-recirculation of water, and thereby minimize heat losses.

In Israel and in most industrial countries where only limited quantities of fresh water are available, it is necessary to recirculate most of the water used, after a mechanical and biological filtering process.

It is well known that fish and invertebrates produce ammonia (NH_3). This is synthesized by bacteria to nitrate (NO_2) and later to nitrogen gas (N_2). The NH_3 production rate and the biochemical O_2 demand were determined by several investigators^{1,2}. NH_3 and NO_2 have been shown to be toxic to fish. E.g. Smith and Williams³ found that salmonids are extremely sensitive to NO_2 . Kowaratani⁴

determined the maximum nonlethal level of NO_2 for fresh water prawns.

A compromise solution of NO_2 removal for industrial use was described in the Journal of Water Quality Institute⁵. This antoxic biological denitrification process depends on bacteria deprived of O_2 , which will break down NO_2 and reduce it to N_2 taking the O_2 for life support. In addition to the O_2 taken from the nitrates, the bacteria require a protein source and some nutrients. Adding organic chemicals to the water resolves the protein problem. In the U.K., methanol is used, but this solution is not recommended for fish. For this biofiltering, the water is flowed through surfaces on which the denitrification bacteria are settling.

Rogers and Klementson⁶ have tested four biofilters: a rotating biological disc contactor (BD) with 16 discs of 25.4 cm diameter, developed by Stern and Cohen⁷, a 30.5 cm diameter biodrum, an aerobic downflow submerged filter, and a trickling filter. They found that the biofilters can provide adequate removal of NH_3 and organics from aquaculture waste waters. Biodisks and biodrums in various sizes and shapes have become common lately in the aquacultural industry, providing acceptable water quality in recirculating systems.

In order to keep the water pond temperature suitably high when the ambient temperature is low and the surrounding soil is cold, one needs to insulate the pond walls and floor, cover the pond with some structure, and supply heat. Some mathematical models are available for calculating the heat losses through the pond walls and floor and from the uncovered water surface^{8,9}. These models deal with still water and are not suitable for calculating the heat losses of fast moving wet surfaces, such as those in some biofiltering devices.

To maintain water temperature in a recirculating system, it is important to know the heat losses caused (a) by direct heat transfer from the water surface, and (b) by the evaporation process as a result of the operation of the rotating biodisk and the trickling biofilters.

The main aim of this work was to determine the parameters of these heat losses.

METHODS

The biofilters, the fish pond and all the other systems were introduced into a plastic house. The pond water was heated during the day by direct contact with the enclosed air in the plastic house, which is heated by solar radiation¹⁰. The volume of the fish pond was 25 m^3 . The experimental biodisk had 42 corrugated fiberglass disks with an outside diameter of 0.70 m, mounted close to each other on a common axis, forming a 0.76-m-long drum. Twenty-four holes were provided in each disk. The total surface for the bacteria settling was approx. 40 m^2 . This drum was partially introduced into water tank. The total heat-transfer area of that portion of the peripheral of the disk which remains above the water level, was 1.83 m^2 . The specific area for bacteria on this biofilter was approx. 22 m^2 for a peripheral surface of 1 m^2 . The schematic design of the biodisk is shown in Fig. 1. The biodisk was also shaded with two coverings, one

consisting of black 0.1-mm-thick PE sheeting and the other of a radiation opaque and insulated roof. The rotating velocity of the biodisk was adjusted to 6 or 13 rpm by an electric "Parajast" variator. The water flowing rate through the tank of the biodisk was varied between 0.1 and 1 l/sec.

The trickling biofilter contained a 0.20-m layer of PVC chips. The water was sprayed at a pressure of 30 kPa using non-drift nozzles, spaced 0.15 x 0.20 m apart with droplets of 0.77 mm VMD, from a height of 0.15 m above this layer, supplying 0.8 l/m²s. The total area for bacteria on this biofilter was 50m² for a filter upper surface of 1m².

Thermocouples (copper constantan) were used to measure the dry and wet bulb air temperatures in the greenhouse and outdoors. Thermocouples were located also at the water inlets and outlets.

The solar radiation was measured with a Kip & Zonen pyranometer.

All these data were recorded by a data logger, during the cold seasons of 1986-1988. One change in the rpm or water flow rate only, was introduced into the biodisk every 24 h, and no changes were made in the trickling biofilter.

All data were evaluated automatically by the central computer of the Weizmann Institute of Science in Rehovot.

RESULTS AND DISCUSSION

Examples of two temperature and radiation regimes at extreme ambient climatic conditions are shown in Fig. 2.

Between the hours of 10 pm and the following 4 am, the heat loss from the pond and the filters water surfaces increased the air temperature in the plastic house; only a small portion was lost through the pond walls and bottom to the surrounding dry soil.

The temperature at the inlet of the biofilters was that of the pond as influenced by the ambient climatic conditions. When the amount of solar radiation was higher, the water temperature reached 24-26°C. In the test carried out later in the winter (on 16 December), the water temperature at the disk inlets was only 20-22°C, as a result of the preceding several cloudy days.

Influence of the water flow through the biodisk

The examples given in Figure 3 show that at similar climatic conditions, by decreasing the water flow through the biodisk from 0.84 l/s and to 0.14 l/s, the water temperature dropped but as shown in Fig. 4, the energy loss parameter was not influenced by this change.

The water temperature drop through the trickling biofilter changed from 0.6 to 1.5°C at a quasi-constant water flow of 0.8 l/m²s. The difference in temperature drop was determined by the difference between the water temperature and the climatic conditions in the plastic house.

Factors influencing heat loss from the biodisk

Heat loss was calculated by multiplying the water temperature drop by the water flow. This was put simultaneously

against temperature difference for sensible heat and against vapor pressure difference for latent heat transfer.

Figure 4 shows that the water flow rate through an uncovered biodisk in a plastic house did not have a significant influence on the heat losses. The correlation between the total heat losses (Q) and the temperature and vapor pressure difference (D) for an uncovered biodisk at 13 rpm (presented in Fig. 7) was found to be:

$$Q = 55.8 D, [W] \quad (1)$$

where: Q is the total heat loss of the biodisk, W.

$$D = (T_1 - T_2) + c (E_1 - E_2), [K] \quad (2)$$

T₁ = water temperature in the biodisk tank, K

T₂ = air temperature in the plastic house, K

E₁ = vapor pressure at the water surface, Pa

E₂ = vapor pressure in the plastic house air, Pa

c = the ratio between transfer of latent heat as a result of vapor pressure difference, and that transferred as sensible heat, as a result of temperature differences, K/Pa

The ratio of $c = 0.0275$ K/Pa was found to be the most adaptable relation and was used for the calculations where the wet surfaces were moving. For a non-moving wet surface, the ratio of 0.016 K/Pa was used.

The influence of a black PE cover is also shown in Figure 4. The most suitable correlation line for a covered biodisk at 13 rpm was given by:

$$Q = 47.1 D [W] \quad (3)$$

It is important to note that the heat loss coefficient is approximately 16% lower than that of an uncovered biodisk (Eq. 1). The influence of the disk rotation velocity on the heat loss is shown in Figure 4. At 6 rpm, the most suitable correlation line for a black-PE-covered biodisk was:

$$Q = 43.1 D [W] \quad (4)$$

By reducing the disk peripheral velocity from 0.46 m/s (13 rpm) to 0.22 m/s (6 rpm), the heat loss decreased by 8%. For a nonrotating biodisk the most suitable line was:

$$Q = 30.2 D [W] \quad (5)$$

This correlation shows the heat loss from the biodisk tank water surface.

Figure 5 shows the heat loss from biodisk to the air at 13 rpm and nonrotating at a flow rate of 0.1 l/sec under the insulated cover. In this case the most suitable correlation line for 13 rpm was:

$$Q = 37.2 D \text{ [W]} \quad (6)$$

Under the same insulated cover the heat loss from the water surface for a nonrotating biodisk was greatly reduced, and was:

$$Q = 10.3 D \text{ [W]} \quad (7)$$

The correlation lines between Q and D for all the experiments carried out with the biodisk are presented in Figure 6.

The heat loss from the trickling biofilter, for a surface of 1 m^2 , is given in Figure 7. The most suitable correlation line was:

$$Q = 96 D \text{ [W]} \quad (8)$$

This coefficient is high, probably as a result of the flow of the drops of water in the air and on the biofilter surface. This biofilter has a large bacterial surface of $56 \text{ m}^2/\text{m}^2$, in comparison with the 40 m^2 of the entire biodisk. The heat loss from the biodisk with the same bacterial area is only 80% of heat from the trickling biofilter.

The following example shows how to calculate the heat loss from an uncovered biodisk with a rotating velocity of 13 rpm when the water temperature (T_1) is 25°C , the air temperature in the plastic house (T_2) is 17°C , and the air RH is 100%. In this case the water vapor pressure at the water surface (E_1) is 3200 Pa and the water vapor pressure in the air (E_2) is 2000 Pa:

$$D = (25-17) + 0.0275 (3200-2000) = 41$$

$$Q = 55.8 \cdot 41 = 2288 \text{ W}$$

CONCLUSIONS

The water flow rate through the biodisk tank does not have a significant influence on the heat loss of this apparatus.

Reducing the biodisk rotation velocity from 13 to 6 rpm decreased the heat loss by 8%.

Covering the biodisk with black PE film, reduced the heat loss by 16%.

Mounting the biodisk under a radiation insulating cover had a significant effect in reducing heat loss. The heat loss coefficient for the biodisk at 13 rpm decreased from 55.8 W/K to approximately 37.2 W/K .

The heat loss coefficient from the nonrotating biodisk water surface only, was 30.2 W/K in the plastic house and only 10.3 W/K under the insulated cover. This coefficient is a result of the heat loss from the water surface only (1.3 m^2).

The heat loss from the trickling biofilter used in this experiment for the same bacterial area, was 20% higher than that from the biodisk.

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Fig. 1 - Schematic view of the tested biodisk. (dimensions are in meters).

Fig. 2 - A sample of climatic conditions in the experiment.

- +: air temperature in the greenhouse (°C)
- o: water temperature the pond (°C)
- Δ: outdoors air temperature (°C)
- *: solar radiation outdoors (W/m²)

Fig. 3 - Differences in temperature between the inlet water and outlet of biodisk (Δ), trickling biofilter ($\circ$), and air ($+$) and between the water vapor pressure at the water surface and in the air ($+$).

Heat losses, W

Fig. 4 - The biodisk heat losses

Fig. 5 - The biodisk heat losses under an insulated roof.

Fig. 6 - The biodisk heat losses

Fig. 7 - The trickling biofilter heat losses

V. UTILIZATION OF SOLAR RADIATION FOR AQUACULTURE

N. ZAMIR and H. PASTERNAK

ABSTRACT

The upkeep of the water body temperature, in aquacultural ponds during the cold season in Israel and other similar regions, necessitates supplementary heating. Covering the pond with a greenhouse is only a partial answer but is not sufficient to avoid the cooling of the water.

Installing a falling droplet heat exchanger reduces the daily heat losses from the greenhouse and increases the portion of energy used from the solar radiation, so that in climates similar to Israel and in other northern sunny regions, the water body's temperature may be kept sufficiently high without supplementary heating throughout the cold season.

INTRODUCTION

Heating of the water body of an aquaculture pond by direct solar radiation is limited, due to the limited transparency of the water. In such cases most of the absorbed radiated energy causes the heating up of the region near the surface and, as a result, most of this energy is lost to the air, causing heating and humidification of the air above the pond^{1,2}.

Under cold conditions, supplementary heating is necessary in order to keep the water body at an optimal temperature range for aquacultural needs. In an attempt to minimize the supplementary demands, a series of energy-balanced equations was used, to determine the quantity of energy that can be saved from the solar-heated air above the water by closing the greenhouse and exchanging the heat that is absorbed by the air back to the water body, by a falling droplet heat exchanger (FDHE).

The solar energy transmitted by the greenhouse cover was determined using the integrating techniques described by Manbeck & Aldrick³ and the solar radiation transmission equation derived by Fieler & Zamir⁴. The heat losses were determined using the model described in chapter III of this report.

EXPERIMENTAL PROCEDURES

The validation of these calculations was done in the same small tunnel-shaped greenhouse as described previously. The heat exchanger employed previously^{5,6} (and in chapter II of this report) had a 3m² air-through area. The droplets were produced by 100 nozzles of low range droplet diameter (Israel Pat. 51142) giving volumetric mean diameter droplets of 0.65 mm, supplying each 37.5 g/s at a water pressure of 50 kPa (0.5 kg/cm²). The height of the nozzles above sink was 2.5 m.

Temperatures were measured by copper-constantan thermocouples. The outdoors solar radiation was measured with a pyranometer, the wind velocity - by a standard meteorological vane-type anemometer, and the mean wind velocity was calculated.

The measured data were recorded on a floppy disk, for further evaluation.

RESULTS OF THE EXPERIMENTS TESTS AND PRELIMINARY DISCUSSION

The temperature and other recorded mean data of two consecutive sunny days, one without and the second with the FDHE, are presented in Figure 1. Climatic data and the calculated related data are given in Figures 2 and 3, showing the competence of these references for this energy balance definition.

Figure 3 shows the result of the calculated heat losses and the measured water body heat gain, with the solar radiation transmitted into the greenhouse.

In Figure 4 the outdoors measured solar radiation (R) is described by the equation:

$$R = (\cos K)^{1.5} R_c \quad (1)$$

where K is the angle of incidence (between the direction to the sun and zenite) and

$$R_c = 1000 \text{ W/m}^2 \quad (2)$$

This simplified the need for tables to derive the actual hourly solar radiation for the further evaluation that is presented later for clear sky winter days in Israel.

The temperature regimes of three greenhouse-enclosed ponds are described in Figures 5 to 8.

The ratio between daily heat gain-to the introduced mechanical energy, is given in Table 2.

PREDICTING WATER BODY TEMPERATURES

After the validation of the model for the energy fluxes to and from the water body, the greenhouse and the heat exchanger, it became possible to predict the mean and deviation of the water body temperature in the various climates and greenhouse structures. A sample of this estimation is given in Figure 9 for a triangular shaped greenhouse in which the roof is insulated to 0.5 W/Km^2 , and has a 50° slope, polyethylene double-skinned inflated southern wall, as described in Figure 10.

CONCLUSIONS

The experiments have shown that it is possible to calculate the energy balance of a greenhouse enclosed aquaculture pond with reasonable accuracy, using local climatic data including air temperature, humidity, winds and cloudiness.

The water temperature level and fluctuation is a result of greenhouse shape and covering material. The heat gain may be increased by lowering the internal air temperature by enlarging the capacity of the heat exchanger, and the fluctuation may be decreased by enlarging the water volume.

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TABLE 1
SPECIFIC VALUES OF THE BET DAGAN EXPERIMENTAL GEAP AND FDHE

Total nozzle capacity:	3.638	kg/s
Specific droplet capacity	0.0812	kg/s m ²
Net theoretical energy	364	W
Total electrical energy	520	W
Total specific electrical energy	11.6	W/m ²
Depth of water, 1988	1	m
Depth of water, 1989	0.84	m
Surface area of water:	44.8	m ²

TABLE 2
THE TEMPERATURE OF AMBIENT AIR (T_o), INDOORS AIR (T_i), AND WATER BODY (T_w), THE HEATING UP OF THE WATER BODY (dT_w), THE DURATION OF HEAT EXCHANGING (dt), THE MEAN ENRGY GAINED IN THE WATER (E_w), THE RATIO BETWEEN THE ENERGY GAINED TO THE ELECTRICAL ENERGY FOR PUMPING (E_w/E_e) AND THE MEAN OUTDOORS MEAN SOLAR RADIATION (R_s).

Year and day no.	T_o °C	T_i °C	T_w °C	dT_w K	dt s	E_w W/m ²	E_w/E_e -	R_s W/m ²
1988								
26	16.7	23.6	19.5	3.4	28800	494	43	315
27	16.4	25.9	20.2	4.2	32400	543	47	519
28	15.3	24.3	20.0	4.1	28800	596	51	527
56	13.2	23.7	20.0	3.2	28800	465	40	319
57	17.7	23.1	23.6	4.0	21600	775	67	420
58	20.2	22.8	21.1	1.4	29340	200	17	129
59	17.5	24.4	21.9	2.8	32400	362	31	320
60	18.3	26.5	23.0	3.5	28800	509	44	369
61	21.7	27.9	23.9	5.4	25200	897	77	525
62	17.6	24.8	23.3	2.0	18000	465	40	299
1989								
26	14.9	21.7	17.9	3.7	25200	578	50	451
27	12.3	19.2	16.9	1.6	10800	583	50	304
28	13.6	19.8	16.5	2.7	21600	492	42	365
29	15.5	20.9	16.7	4.1	28800	560	48	517
30	14.1	21.1	16.5	3.1	21600	565	49	523
31	13.4	20.3	15.8	2.3	14400	629	54	467
56	27.1	29.6	23.9	4.9	28800	670	58	555
57	17.6	26.7	23.1	2.1	25200	328	28	643
58	17.8	26.8	22.0	1.9	28800	260	22	640
59	17.8	26.9	21.9	3.2	28800	437	38	556
60	17.4	26.0	21.5	2.4	25200	375	32	388
61	18.7	27.4	22.2	3.6	25200	562	48	598

Fig. 1: Solar radiation (R_s) and temperatures of outdoors (T_o), indoors air (T_i) and water body (T_w), first day without FDHE and the second with the FDHE on from 9 a.m., showing the effect of the FDHE on water body heat uptake and inside air cooling.

Fig. 2: Solar radiation (R_s) and temperatures of outdoors air-wet bulb (T_{wbo}) and dry bulb (T_o), indoors air (T_i), and water body (T_w), on the 317th day of 1988.

Fig. 5: Solar radiation (Rs) and temperatures of outdoors air (To), indoors air (Ti) and water body (Tw) for several days, at the experimental small pond at Bet Dagan, during the winter of 1988 and 1989.

Fig. 3: cumulative energy values of solar radiation (—), water body heating up (+), calculated system heat loss (◇), and global solar energy utilization (Δ) from sunrise to sunset, on the 317th day of 1988.

Fig. 4: the measured (□) and the calculated (by Eqn. 1) (+) solar radiation, from sunrise to sunset, on the 317th day of 1988.

Fig. 7: Water body temperature regime measured during February and March 1990 (30 - 80 days after Jan. 1) at Mevoot Eron.

Fig. 6. The maximal (T_w max) and minimal (T_w min) water body temperature, as a function of the mean water body temperature and the corresponding day's outdoors mean temperature (T_o) is also

Fig. 8: Temperatures of outdoors air-wet bulb (T_{wbo}) and dry bulb (T_o), indoors air-wet bulb (T_{wbi}) and dry bulb (T_i), and water body (T_w), during 48 hours, march 17 to 19, 1990 at Reshafim nursery.

Fig. 9: A 24-hour energy gain or loss of a 26 °C water body, with insulated bottom and sides, when daytime ambient mean air temperature is 10 °C, as a function of ambient nocturnal mean temperature January 21, when the solar radiation's constant (R_c) in eq. 1 is 800 W/m², at winds of 1 (□), 5 (+) and 10 (◇) m/s; and 400 W/m², at winds of 1 (▽), 5 (x) and 10 (△) m/s, for a greenhouse enclosed aquaculture pond, constructed as shown in Figure 10.

Fig. 10. The theoretical most energy-economical shape for a greenhouse enclosed aquaculture pond: 1. insulated roof. 2. double transparent sloping southern wall. 3. pond (with falling droplet heat exchanger).

VI. UTILIZATION OF WASTE HEAT FROM ELECTRICAL POWER GENERATION FACILITIES FOR AQUACULTURE

L. Wallace and A. Anderson

Summary

Supplemental heating is required during cold seasons in many parts of the world such as Utah and Israel, in order to maintain adequate water temperatures for warm-water aquaculture projects. The amount of supplemental heat can be reduced by enclosing tanks or ponds in greenhouse-type structures and by insulating above-ground tanks.

Installing heat exchangers to utilize waste heat from an electrical power generating facility was the method used to obtain supplemental heat for this part of the combined US-Israel aquaculture project.

Introduction

In regions of the world where solar radiation is not sufficient to maintain year-round water temperatures conducive to successful warm-water aquaculture projects, some type of supplemental heating is generally required. Enclosed structures, such as greenhouses, are used in cooler climates to capture a portion of the available heat energy from the sun and to reduce that losses to the atmosphere. Methods such as the falling droplet heat exchanger, or passive heat sinks, are available to maximize the capture of solar energy. If that energy is stored for use during the night and during cloud cover, supplemental heating may not be required or will be significantly reduced.

The economic success of aquaculture projects in regions where supplemental heating is required will depend on the cost of obtaining the necessary heat energy. Fuel costs generally preclude the use of boilers that are used exclusively to heat the greenhouses or the tanks. Geothermal energy sources are commonly used where such sources are available. Waste heat from industrial power generation is sometimes available as a source of thermal energy. If the cost of obtaining such heat is within the economic capabilities of the aquaculture project, this opportunity would be available wherever such generation facilities are located.

Quantities of waste heat from an electrical power generating facility located near the university were measured in this part of the experiment. Calculations were made to learn more about the economics of using supplemented heat sources to extend the fish growing season in colder climates.

Experimental Equipment and Procedures

Six reinforced marine-plywood tanks were constructed to grow fish for this study. The size of each tank was 2.40 m long by 1.22 m wide by 1.20 m high. Four of the tanks were each lined with a 30 mil thick rubber liner and two tanks were each lined with a 8 mil polyethylene liner. The polyethylene liners failed and so only the four rubber-lined tanks were used during the course of the experiment. The tanks were placed on wooden railroad ties for support and a deck was constructed between the tanks to facilitate access.

The six tanks, two trickling filters, a work bench and small storage area were all housed in a tunnel-shaped greenhouse. The greenhouse was 12.2 meters long and semi-circular in cross section. It was 4.7 meters wide at the base and 2.8 meters high at the apex. The side and roof supports were made of 2.54 cm diameter PVC pipe bent into a semi-circle shape and placed 0.61 meters on center along the length of the structure. Three longitudinal braces of 2.54 cm diameter PVC pipe ran the length of the structure and were glued to each vertical pipe using cross-shaped fittings. In addition, a 7.62 cm X 24.1 cm support beam, constructed of timber, ran the length of the greenhouse. The beam was supported at the ends and at third points to carry the anticipated snow load on the roof. The ends of the greenhouse were constructed of 5 cm x 10 cm nominal lumber made into a frame 0.61m on center. A door was framed into each end of the greenhouse.

The greenhouse was covered with a single layer of clear, 8-mil, treated PVC to reduce UV rays and claimed a two-year guarantee life. The PVC was purchased in a roll wide enough to cover the semi-circle shaped greenhouse from ground to ground and long enough to cover the top and both ends. Folds were made in the ends to accommodate the curved roof. The same PVC material was used to cover the doors. The internal volume of the empty greenhouse was approximately 130 cu meters. The greenhouse was located adjacent to the municipal power plant in a residential area. The greenhouse was oriented with the 12.2 meter dimension facing south and north and the ends to the east and west. This orientation provided an unobstructed southern exposure for solar radiation during the day but there were trees to the west which blocked the sun in the late afternoon. During the summer months a layer of black PVC was placed over the top of the greenhouse to reduce solar input to an acceptable level. A 3.7 meter frame extension was constructed on the east end of the greenhouse during the final year of research to house four Rotating Biological Contactors (RBCs). The extension was covered with the same clear 8-mil treated PVC that was used for the greenhouse.

Individual heat exchangers were constructed for each fish tank. Each exchanger consisted of 15 meters of 1.27 cm diameter copper tubing in two large loops held approximately 4 cm above the bottom of the tank by the aeration lines. The heat controls were quite simple. A Penn Temperature Control Switch was used to open and close a Bell and Gossett, 24v hydroponic zone valve located on the heat line. The temperature control switch was sensitive enough to maintain tank water temperature within 2 degrees celsius. When the temperature dropped to 25 degrees celsius the switch would close and activate the zone valve to open, allowing 50 to 60 degrees celsius hot water to flow through the heating tube. When the water in the fish tank heated to 27 degrees celsius, the temperature switch would open causing the zone valve to close, shutting off the hot water to that tank. Tank water temperature was automatically kept within the desired range as long as there was power to the controls and available hot water.

During the time of this experiment, the power plant turbines were being re-built and auxiliary diesel-engine-driven generators were used for peaking power. The power plant has an on-going contract to supply hot water heat to a nearby school, hospital and several business so they operate auxiliary boilers to meet this commitment. Hot water for our project was supplied from the condensate return storage tank that supplied the auxiliary boilers at the power plant.

Since these boilers work more efficiently if the condensate water temperature is lowered, the municipality considered it waste heat and made this hot water available to us at no cost. Every power generating facility is faced with problems of reducing heat loads by cooling. Finding

beneficial uses for this waste heat is an on-going challenge and this project investigated one such use.

To transport the hot water from the condensate return storage tank to the fish tanks, a 4.14 cm inside diameter, galvanized steel pipe was connected to the bottom of the tank and ran to the inside of the greenhouse and then back to the top of the tank. The pipe was insulated with a 1.9 cm thick slip-on polyurethane insulated pipe sleeve. Both the insulated supply line and return line were enclosed in a plywood utiliduct from the power plant to the greenhouse for protection from the weather. The line was equipped with valves, drains, a pressure gage, water meter and centrifugal pump. The pump was a Bell and Gossett MRLT24JX pump powered by a 1/4 HP, 1725 RPM, single phase 60 Hz, electric motor. The water meter was a 5/8-inch Badger rotating disk type positive displacement brass water meter.

Each of the tank heat exchangers was connected to the supply line and to the return line. A zone valve was placed between the supply line and the return line which would close whenever any of the tanks called for hot water and would open to maintain flow through the system when the tanks required no hot water. This was done to insure water flow through the pipe at all times to prevent freezing. Hot water flow in the supply pipe ranged from 0.16 liters per second with one heat exchanger operating to 0.78 liters per second with six heat exchangers running. When no heat exchangers were operating, the supply was being returned through the safety zone valve at a flow rate of 0.25 liters per second. The pump maintained a water pressure that ranged from 64 kg/cm² with one heat exchanger operating to 56 kg/cm² with all heat exchangers operating. The static water pressure in the heat exchangers was 15 kg/cm² resulting from the height of the water in the condensate return tanks.

Experimental Results and Discussion

To measure the response capability of the heat exchangers, iron-constant thermocouples were attached to the copper heating loops. One was placed at a point 2 cm before the loop entered the water and one was placed 2 cm after the loop exited the water. A thermocouple was also lowered into the water to measure water temperature. Air temperatures were measured with a mercury thermometer at the same time as other readings were taken.

Flow measurements were recorded under the different loading conditions of one, two, three or four heat exchangers calling for hot water at the same time. Since the by-pass opened when all of the heat exchangers shut off, there was always hot water flowing through the supply pipe. Accumulated meter readings confirm the total amount of hot water pumped but do not represent the amount of heat required to keep the fish tanks at the proper temperature.

The following 1-4 figures represent recorded relationships between time and temperature with the supply of hot water flowing through one, two, three and four tank heat exchangers simultaneously. These data confirm that the supply pipe carried sufficient volumes of hot water to heat each tank in a timely manner. During the coldest time periods, the heat exchangers had no problem in maintaining constant tank temperatures.

These 1-4 figures show a very close relationship in heating capability. Once the zone valve opens to allow flow to occur, the incoming temperature from the supply line stabilizes in less than ten minutes. This occurs only when flow has been turned off and the supply line allowed to cool as was done in these tests. Normally there is some flow at all times and the response time is much shorter. The heating proceeded at a very constant rate until the water temperature reached the desired level and the zone valve closed. Under the conditions of the test it took approximately two hours to raise the volume of water in each tank (1.8 m^3) about 20 degrees celsius. Under operating conditions where the temperature change was $\pm 2^\circ\text{C}$, the zone valve would remain open for much shorter periods and cycle at the rate heat was lost from the tanks. The cycle time would vary not only with outside temperature, but also with the time of day and the amount of solar heat trapped in the greenhouse.

An additional test was run to compare temperatures of one tank being heated with the aeration system turned off while a another tank was not heated but the aeration system was left operating. The heated tank responded approximately the same as in the other tests and the unheated tank remained at a constant temperature. The air temperature dropped during the test because it was late afternoon and the sun went down. The dip in the incoming and outgoing heat was caused by a power failure which turned off the pump and closed the valves for a short time period.

The aquaculture pond temperature model developed by Klemetson and Rogers (1983) under a previous BARD research project (US-60-80) was modified for the conditions of this study. The energy budget equation $H = H_e + H_c + H_r - H_s - H_a$ was used as a basis for determining heat loss from the facility; where: H = net heat loss, H_e = heat loss by evaporation, H_c = heat loss by convection, H_r = heat loss by radiation, H_s = heat gain by solar radiation, and H_a = heat transfer by advection.

Since this model was developed using Imperial units, Imperial units were used to calculate the following data and the final results can be converted to SI units if desired. Since waste heat was utilized, there were no charges for the heated water. The cost values shown were based on the current rate charges for the municipal power generating facility that supplied the hot water to show what the market value for this amount of heat would be. There were costs associated with pumping, measuring and controlling the water at the desired temperature. Since these costs are site specific and vary for each facility, it was decided not to include operational costs, only the heat losses and their market value costs.

The calculated values for this model included heat-loss reductions for being in an enclosed greenhouse and some extra heat gain for the greenhouse effect. Considerations were also made for night-time losses from the greenhouse based on the work by Zamir, Pasternak & Arbel, Ch. III. The coefficients were adjusted to reflect that the tanks were constantly being aerated with low volume compressed air which agitated the surface, increased evaporation until saturation was achieved and added some heat because of the compression required to pump the air.

The calculated values also included consideration for heat losses from the two trickling filters located in the greenhouse and later for the four biological contactors located in the greenhouse extension. These adjustments were based on the work of Zamir, Haas & Arbel Ch. IV on heat losses of disk and trickling filters.

Conclusions

Waste heat from power generating facilities is a valuable resource that can be successfully used to provide heat energy for maintaining aquaculture facilities at optimum growth temperatures on a year-round basis. It can also be a source of back-up heat for solar collectors in areas where cloud cover may preclude solar systems only. The economic feasibility of any system will depend entirely on the total cost of obtaining the waste heat including operation and maintenance costs.

Where power generating facilities use boiler water that may be toxic to the aquatic organisms, heat exchangers can be purchased or constructed that successfully separate the heat-source water from the aquaculture water. Such heat exchangers provide a certain degree of flexibility of operation but require that aquaculture facilities be located in the close proximity of the heat source to minimize transmission heat losses.

A combination of solar heated facilities, using waste heat for back-up, could provide much larger growing capacities than using either system alone. This would also provide a needed risk reduction capability in case of adverse weather that could destroy an aquaculture crop if solar heating was the only source of heat.

In areas where summer temperatures are sufficient for aquaculture enterprises and waste heat would not be needed, some method of wasting excess heat from the power generation facility must be provided as part of the waste heat recovery system or the capability of using existing cooling systems at the power plant must be employed during summer months.

It is mandatory that a good working relationship be maintained with the power generating facility personnel. A waste heat utilization system must be a cooperative endeavor if it is to achieve success.

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TABLE 1 Monthly Heat Losses (BTU h⁻¹ ft⁻²)

<u>Item</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>
Avg. Temp. F	67.0	56.9	44.2	28.9	32.6	37.2	50.0	62.0	65.9
H _e	163	163	163	163	163	163	163	163	163
H _c	20	35	54	77	71	64	45	27	21
H _r	13	23	36	51	47	43	30	18	14
H _s	66	47	31	22	25	38	52	71	84
H _a Assumed = 0	0	0	0	0	0	0	0	0	0
H	130	174	222	269	256	232	186	137	114
Million BTU/tank	3.37	4.51	5.75	6.97	6.63	6.01	4.82	3.55	2.95
\$/Tank in US Dollars (@ \$3.50/Million BTU)	11.80	16.80	20.00	24.40	23.20	21.00	16.90	12.44	10.35
\$ for 4 tanks	47.20	67.20	80.00	96.00	92.80	84.00	67.60	49.76	41.40
\$ for 4 tanks (Including supply line BTU losses)	51.82	73.90	92.00	110.4	111.4	100.8	77.74	57.22	45.54

Figure 1 Single Tank Heating

Figure 2 Double Tank Heating

Figure 3 Three Tanks Heating

Figure 4 Four Tanks Heating

Figure 5 Comparison of Heated Tank to Unheated Tank

VII. THE OXYGENATION CHARACTERISTICS OF FALLING DROPLETS

N. Zamir, I. Gilad and R. Snir

ABSTRACT

In two sets of experiments a small falling droplets heat exchanger (FDHE) was used, with a total area approximately 0.3m^2 , and 11 nozzles supplying approximately one kg/s m^2 . A container was filled with 70 kg of water taken from a nearby fish pond. In the first experiment approximately 7 kg of fish (carp) reduced most of the dissolved oxygen (DO) from the water; in the second, nitrogen gas was bubbled into the water to decrease DO concentration.

The results showed that the FDHE is a very strong tool for aerating water. It oxygenates the water to 0.8 of saturation after a 0.5 m fall, and very near to saturation after a fall of 2.5 m.

The mechanical efficiency of the FDHE as an aerator is comparatively low - only 15% to 50% of commercial equipment. Therefore it may be recommended as an oxygen supplier, only as a byproduct of heat transfer or as an inlet for fresh water that is poor in DO or too rich in some other gases, cases in which this high diffusion exchange with the air is of importance.

INTRODUCTION

Oxygen is required in fish production for two main consumers: the fish, for their metabolism, and the bacteria, for the ammonia reduction. The metabolism requirement for bodies of 0.1 to 0.2 kg, is approximately one mg/s Kg of O_2 per biomass of the fish. This value is reduced to range of 0.25 to 0.1 mg for fish of 1 kg body weight and above.

If food is added artificially and is to be decomposed by bacteria at the end of the cycle, more O_2 is required. In some cases this might rise to about 3 mg/s kg and even more for small fishlets.

If alga are growing in the water, what is called "green water", they will add O_2 during the hours of sunshine but will be an additional consumer for dissolved oxygen at night.

The rate of the demand for DO can be summarized in the formula:

$$\text{DOD} = \text{CF} \text{ FG} \quad (1)$$

where: DOD = dissolved oxygen demands, in kg of DO per kg of fish per second, kg/kg s .

CF = farm constant, depending on culture, temperature and water quality.

FG = feed rate, in kg of food per kg of biomass per day, kg/kg d .

The constant CF value changes with the age of the fish and it rises, as long as the feeding rate is optimal.

Oxygen transfer between the water surface and the surrounding air is related to the difference in the partial

pressures ('dp') of the O₂ in the water body and the air and measured in pressure units (Pascal, etc.). Because the partial pressure is related almost linearly to the mass concentration, and the measuring instruments are regularly calibrated to mass, ppm is used instead of the partial pressure.

The equilibrium - or saturation point - of O₂ concentration in water, according to temperature and salinity, as kg of O₂ to kg of water, is given mainly in ppm, for 21000 pascal of O₂ above the water, which is the regular partial pressure of oxygen, when the atmospheric pressure is 101325 pascal (1 atm). The transfer parameter 'U' changes according to the same physical laws as other vapor transfer parameters: mainly velocity, shape, size and viscosity on both sides of the dividing film, between the liquid and the gas phases.

$$q = dp \ U \quad (2)$$

$$q = dp \ f \ (V_w, V_a, s, l, w, a) \quad (3)$$

where:

q - O₂ transfer, kg/s-m²

dp - pressure difference, Pa

V_w - velocity of water body related to the film, m/s

V_a - velocity of air body related to the film, m/s

s - a shape constant

l - bubble or droplet diameter, or distance between sides of layer, m.

w - viscosity of the water (mainly of droplets), Pa/s

a - viscosity of the air, Pa/s

In practice the O₂ capacity is calculated as:

$$q = (C_s - C_t) \cdot U \quad (4)$$

where:

C_s - concentration at saturation (according to water temperature and salinity), kg/kg or ppm.

C_t - concentration at time t, kg/kg or ppm

U - O₂ transfer parameter (kg/m² s)/(kg/kg) or (mg/m² s)/ppm

For a given instrument, U' is given as (kg/s) and the appropriate concentration gradient in ppm has to be included also. The effectiveness, e is in %:

$$e = 100 \ (C_{to} - C_{ti}) / (C_m - C_{ti}) \quad (5)$$

Oxygen-enriching systems

Two principles are used: the air to water contact and the pressurized O₂ supply. The former is related to the DO deficit against the saturated DO. With pressurized O₂, no relation exist between the DO content in the water body and the supply. Therefore, there is a tendency for the fishermen who want a high and reliable O₂ supply, to use pressurized O₂.

From eq. (4) it is understood that in cases where O₂ concentration has to be near saturation, the mechanical

efficiency of the regular aerators is very low, as the difference $C_s - C_t$ in eq. 4 becomes small.

The mechanical efficiency (Me) is the relation between DO gained to the energy (E) input, at a specified dp :

$$Me = Q/E = (C_s - C_t) (U/E) \quad (6)$$

EXPERIMENTAL PROCEDURE

A small FDHE was used for this experiment. Its total area is approx. 0.3 m^2 , and 11 nozzles supply 1 kg/s m^2 . A container was filled with about 70 kg of water taken from a nearby fish pond. Two sets of experiments were conducted: in the first, 7 kg of fish (carp) biomass reduced the DO in the water and in the second, nitrogen (N_2) gas was bubbled into the water to decrease DO concentration. After the DO concentration was sufficiently low, the pump was started and measurement of DO were taken.

The sprayed water was collected by a trap, placed 0.5 m below the nozzles, and the outflow from it was collected in bottles that were filled, one after the other and immediately checked for DO concentration. Every 30 seconds another bottle was started until it was filled up. Simultaneously with filling the bottles, the DO concentration in the water supply tank was also determined, using the same detector in order to eliminate instrument errors.

Air and water temperatures were recorded every second minute during the experiments.

RESULTS AND DISCUSSION

The temperature of the water in both experiments was $25-26^\circ\text{C}$ and that of the air was 27°C dry bulb and 23°C wet bulb; (relative humidity 72%).

The DO concentrations are given in Table 1, which shows the readings of the instrument used and the two others which are differences: one between the concentrations measured in the inlet to the nozzle and that in the water after it has been as a spray and falling 0.5 m, and the other between the concentration in the nozzle and saturated concentration. The exact saturation concentration for every experiment was evaluated by calculating and minimizing the abscissa of the best linear formula that describes the results according to eq. (4):

$$e = -(C_b - C_t) / (C_s - C_t) [\text{mg kg/mg kg}] \quad (7)$$

and according to the experimental result for this system:

$$e = 0.8 \text{ mg kg/mg kg} = 80\%.$$

In Figure 1 these results are presented together with the line $(C_b - C_t) = 0.8(C_s - C_t)$. The results of the two replicates are almost identical and the regression fitness is very high ($R^2 = 0.99$).

Because this FDHE may be used also for O_2 enrichment, it was interesting to derive its mechanical efficiency.

In order to spray the water in droplets with a mean diameter of 0.77 mm, the pressure in the nozzle (P_n) has to be at a minimal pressure of 30 kPa. The 'total height' has to be approximately 1 m or a pressure of 10 kPa. That raises the pressure of the water body surface to 40 kPa. Taking the sum of pump, screen and piping total efficiency as 0.7 gives an input total pressure of:

$$P_t = (P_n + P_e) / \epsilon \quad (8)$$

$$P_t = (30 + 10) / 0.7 = 57, \text{ kPa}$$

and for 1 kg of water the energy input is:

$$E = P_t \cdot G = 57 \text{ J/kg} \quad (9)$$

and, according to eq. 6:

$$Me = Q / E = 3.2 / 57 = 0.056 \text{ g/kgJ} = 200 \text{ g/kWh}$$

and if the height 'l' of the nozzles is 2.5 m above the water body surface, 'Me' will obtain a value of approximately 140g/kWh and if $l = 0.15$ m then $Me = 100\text{g/kWh}$.

Comparing these results with those from aerators on the market, as given in Table 2, it is seen that the efficiency of the FDHE covers 15-50% of that of the commercial aerators, as compared with electrical consumption. This allows the users of the FDHE to save between 15% and 50% of the electricity of the aerators when the FDHE is on for the collection of solar energy as heat by day, and serve as a somewhat expensive tool for emergency O_2 supply.

CONCLUSIONS

The FDHE is a very strong device for aerating water. It oxygenates the water to 80% of saturation after a 0.5-m fall and very near to saturation after a fall of 2.5 m.

The mechanical efficiency of the FDHE as an aerator is comparatively low, between 15% and 50% of commercial devices and therefore should be recommended as an oxygen supplier only as a byproduct of heat transfer or as an inlet for fresh water that is poor in DO or too rich with some other gases, cases in which this high diffusion exchange with the air is also of importance.

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TABLE 1:
THE CONCENTRATION OF THE DISULVED OXYGEN (DO), MEASURED IN THE WATER:
BEFORE THE SPRAYING NOZZLES (DO_i), IN THE SINK 0.5 m BELOW THE
NOZZLES (DO_o), THE ADDED DO ($DO_e = DO_o - DO_i$), AND THE OXYGENATION
POTENTIAL ($DO_p = DO_s - DO_i$).

TIME s	DO_i ppm	DO_o ppm	DO_e ppm	DO_p ppm
Exp. 1				
0			4.80	6.00
30	2.60	6.50	3.90	4.98
60	2.99	6.80	3.81	4.59
90	3.60	6.80	3.20	3.98
120	4.03	6.85	2.82	3.55
150	4.50	6.96	2.46	3.08
180	4.95	7.02	2.07	2.63
210	5.20	7.07	1.87	2.38
240	5.50	7.24	1.74	2.08
270	5.90	7.25	1.35	1.68
300	6.27	7.37	1.10	1.31
330	6.60	7.37	0.77	0.98
360	6.80	7.36	0.56	0.78
390	7.20	7.68	0.48	0.38
420	7.57	7.47	-0.10	0.01
450	7.62	7.59	-0.03	-0.04
Exp. 2				
0	1.60			
30	2.15	6.45	4.30	5.35
60	3.19	6.60	3.41	4.31
90	3.75	6.72	2.97	3.75
120	4.35	6.92	2.57	3.15
150	4.84	6.92	2.08	2.66
180	5.25	7.08	1.83	2.25
210	5.64	7.14	1.50	1.86
360	7.49	7.43	-0.06	0.01
390	7.44	7.56	0.12	0.06

TABLE 2

The specific oxygenation factor ('e') and mechanical efficiency ('Me') of the falling droplets heat exchanger and various other, commercial oxygenators.

	e	Me at T = 25°C dC = 4ppm g/kWh
	%	
Sprayed at 30 kPa		
0.15 m drop	60	100
0.5 m drop	80	200
2.5 m drop	96	140
Riser with perforated aprons 1		
0.3 m drop	30	315
0.6 m drop	50	280
Paddle 2	-	800
Bubble air lift ^{3,4}	-	480

Fig. 1: The added dissolved oxygen (DO_e) as a function of the potential oxygen dissolving (DO_p), in an exchanger of 0.5-m-high droplet fall.

Regression Output

Exp. 1

Constant	0.0046622956
S. E. of Y Est	0.0802754105
R ²	0.9964938111
No. of Observations	15
Degrees of Freedom	13

X Coefficient(s)	0.8010523808
Std Err of Coef.	0.0131786097

Exp. 2

Constant	0.0046097514
S. E. of Y Est	0.0511558443
R ²	0.9988931187
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	0.7982270187
Std Err of Coef.	0.0100431146

VIII. BIOFILTER EFFICIENCY

L.P. Wallace, A. Anderson, G. Potter D. Cohen, J. Gilad, R. Snir
and N. Zamir

ABSTRACT

Several biofilters has been tested. The results show that when oxygen is available a constant of about 1.5 microgram of amonium is oxidized per second over one square meter, at about 25°C, by a well bacteria covered film, with little effect of amonium concentration. This gives the possibility to use any of the biofilter types like rotating, trickling or submerged, as long as efficiency of amonification does not exceed 70% and desolved oxygen is supplied to the bacteria.

When low amonia concentration is desired and high desolved oxygen in the fish pond is also desired than the submerged biofilter is the most economic and reliable amonia and nitrite biofilter.

INTRODUCTION

Where limited quantities of fresh water are available, or where the fresh water are very cold or very hot, the use of running water becomes unpractical.

In order to eliminate the use of fresh water it is necessary to filter out from the water in which the fish are growing, the amonium (NH_3) that is produced by the fish.

In nature there are several bacteria that are amonium syntesizers. Some of these bacteria syntesize the amonium (NH_3) to nitrate (NO_2) and some other bacteria syntesize the NO_2 to O_2 and N_2 . Most of these bacteria need a solid surfacr on which to live and develop and oxygen (O_2).

The purpose of these tests was to determine the capacity of denitrification of these bacteria satled surfaces. Rogers and Klementsonl came to a conclusion that there is a maximal rate of water from that above it the removal of NH_3 per bacteria substrate drops down.

From the DO values mentioned in their report it is obtained that DO concentrations were much below saturation (only 40 to 70%). This gave the previlage to biofilters that were capable to supply oxygen during the flow of the water through them, like the biodisk, somewhat less the biodrum and the closed box of the trickling biofilter. Obviously bad results were received using any submerged biofilter.

As a result, some questions arose; first: is it economic to supply oxygen by moving the layers of bacteria surfaces? second, what happens if part of this areas dries out? Therefore tests were carried out in Provo and Bet Dagan in order to get some answers.

METHODS

A. Provo tests

Two trickling filters were constructed using biodek plastic filter media. One filter was made with low density media ($100 \text{ m}^2 / 1 \text{ m}^3$) and one made with a higher density media ($140 \text{ m}^2 / 1 \text{ m}^3$). The filter sizes were 0.61 m^2 by 2.44 m high having a filter volume of 1.48 m^3 , which resulted in a filter surface of 148 m^2 for the low density filter and 207 m^2 for the higher density filter. The second filter had also a recirculation pump.

Four rotating biological contractors (RBC) contained 39 m² of media each, were also tested. The rate of flow was different in each of this RBC.

The results are given in table 1. It can be seen that by recirculation of the water in the trickling biofilter there is a reduction in the total oxidation of amonium. This is mainly a result of the very low concentration of amonium in some of the areas of the biofilter. It can be seen also, that the removal of amonium was between 1.54 and 1.8 mg/s m² with no relation to shape or flow rate.

B. Bet Dagan tests

Three types were examined, in the greenhouse enclosed ponds:

1) Submerged. Two types of surface substrate were used: gravel (ca. 5 cm in diam.), and plastic strips. Both substrates were placed in 130-liter tanks. The water was supplied from below and the bed height was 0.2 m, giving 56 m²/m² surface for the bacteria.

2) Biodisk. A 40 m² surface area unit having plates of corrugated fiberglass disks of 0.7 m diam was used. The unit was placed on a ca m³ tank of water. The water was introduced on one side and overflowed through an outlet in the other side.

3) trickling. The same PVC strips and bed height as in the submerged biofilter were used, but due to the fact that the spraying water distribution system was designed to be equal to that of the EDHE, only one flow rate was studied.

The three biofilters represent three modes of elimination of the toxic NH₃ and NO₂. According to the literature, they differ in their biofiltering efficiency as related to bacteria surface area and in their exposure to the surrounding air and therefore heat exchange capacity, as shown in chapter .

The results are given in Table 1. It can be seen that under high levels of dissolved oxygen (as caused by the F.D.H.E.), in the supplied water, similar biofiltering efficiencies were obtained.

CONCLUSIONS

From tables 1 it can be seen that the biodek media used in provo for both filters is somewhat superior to the corugated media used in Bet Dagan. The strips as a submerged biofilter gave poorer results, mainly because its non regularity that enables blocking and shortways, it was somewhat better when used as a trickling biofilter when the water was sprayed and evenly distributed.

The value of about 1.5 mg/s m² of oxidized amonium was obtained for all biofilter types, and is a very important parameter for biofilter area calculation. For example: if for every 5% of food, amonium is produced, and for small fish 10% of biomass weight food is served per day, than the mean amonium production per fish biomass is 1:

$$1000 \cdot 0.05 \cdot 0.1 = 5 \text{ g/d kg}$$

$$5/86400 = 58 \text{ } \mu\text{g/s kg}$$

and the area of biofilter needed is:

$$58/1.5 = 39 \text{ m}^2/\text{kg}.$$

Since nitrosomonas consumes about 3 kg of oxygen to oxidize NH_3 to NO_2 , and nitrobacter consumes about 1 kg of oxygen to oxidize NO_2 to NO_3 , about 0.24 $\mu\text{g/s}$ of desolved oxygen must also be supplied simultaneously in the RBC, or by the water.

The flow rate is for a RBC is only a result of the removal percent and amonium concentration. If amonium concentration is planned to be 0.25 ppm and the efficie4ncy 50% then the water flow rate has to be:

$$58/(0.25 \cdot 0.5) = 470 \text{ g/s kg}$$

or

$$470/39 = 12 \text{ g/s m}^2 \text{ kg}$$

but if the 0.24 mg/s of oxygen have to be supplied with the water as in a submerged film and only 1 ppm of oxygen is available, then the minimal rate of water has to be:

$$0.24/0.001 = 240 \text{ g/s kg}$$

It can be seen that in this example there is sufficient suply of oxygen, but if amonium concentration is to be more than twice, then the water rate has to be calculated again in order to suply the oxygen

A simple calculation shows that as long as the energy for raising the water for trickling, or for the rotating of the bio disk is less than the extra pumping needed for oxygen suply, these tools are superior. This is the case only when amonium concentration may be high (appr. 1 ppm) and or the desolved oxygen in the water is low (appr. 5 ppm).

In low amonium concentration (< 0.25 ppm) and high desolved oxygen concentration (>6), the submerged biofilm is significantly more economic as its price is low and the hazard of water suply stop does not exist.

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TABLE 1: BIOFILTER TESTS RESULTS.

Water rate	Ammon, (NH ₃)					Nitrate, (NO ₂)				
	in	out	removal			in	out	removal		
g/sm ²	ppb	ppb	ppb	%	µg/sm ²	ppb	ppb	ppb	%	µg/sm ²
Provo										
Trickling with recirculation										
4	625	180	445	71	1.76	175	141	34	19	0.07
Trickling										
12	415	274	141	34	1.69					
Rotating contractor										
1.94	1398	580	818	59	1.59					
2.13	1398	675	723	52	1.54					
2.73	1398	796	602	43	1.64					
3.48	1398	882	516	37	1.80					
Bet Dagan										
Rotating contractor (Biodisk)										
6.1	255	70	185	73	1.13	61	30	31	51	0.19
12.2	245	149	96	39	1.17	77	51	26	34	0.32
18.4	228	157	71	31	1.31	75	52	23	31	0.42
25.0	200	145	55	28	1.37	66	57	9	14	0.23
Submerged gravel										
7.0	200	120	80	40	0.56	70	20	50	71	0.35
23.0	240	180	60	25	1.38	70	25	45	64	1.04
Submerged strips										
7.4	210	120	90	43	0.67	70	30	40	57	0.30
24.0	240	200	40	17	0.96	70	42	28	40	0.67
Trickling										
14.3	240	145	95	40	1.35	70	30	40	57	0.57

IX. FEASIBILITY OF GROWING FISH IN COLD WEATHER

A. Using heat from electrical power generating facilities
R. Heckmann, Li Zhuo

B. Using solar energy
A. Geva, Y. Christiansen, N. Zamir, D. Cohen

ABSTRACT

Experiments were conducted to determine the suitability of the aquatic habitat for production of carp, *Cyprinus carpio* and channel catfish, *Ictalurus punctatus* and *Tilapia*

Fish weight, total length, body condition and mortality were recorded. For the fish tanks, dissolved oxygen (DO), pH, water temperature, nitrites, ammonia and ambient temperature were monitored. Many of these water quality factors were recorded daily for correlation with fish condition and growth.

In Utah, six tanks each 2.39 x 1.18 x 1.18 m, were constructed in a greenhouse located inside the Provo Power Plant Compound. A hot-water-heat-exchange system (heated effluent from the power plant) and aerators were set at the bottom of the tank. Two of the tanks (#3 and #4) were connected with a vertical trickling filter system, while the others were not filtered and therefore required constant water exchange.

Channel catfish and common carp were obtained in two batches (March 5 and September 7, 1989). The fish were fed twice a day.

Both carp and catfish survived and grew normally within the aquatic systems. Filtered water (tank #3) supported twice the biomass as compared with unfiltered water (tank #5).

Algal growth in the tanks contributes to DO and to pH values which are usually detrimental to the fish.

The filter system was efficient in lowering nitrite (NO_2) and ammonia (NH_3) levels. The filtered system supported double the biomass in relation to the unfiltered system. The size and other features that influence the efficiency of the filter must be considered to meet the maximum stocking density requirements.

In Israel, four tanks were constructed inside a hydro solaric greenhouse located at Mevot Eiron. The temperature of the water was maintained by harvesting the extra heat from the greenhouse air. Evening out the temperature fluctuations, between day and night, in the water was achieved by the circulation through the main water reservoir of the greenhouse. Submerged biofilters were used. Aeration of the water was mainly as a result of the FDHE.

A. USING HEAT FROM ELECTRICAL POWER GENERATING FACILITIES

R. Heckman, Li Zhuo

INTRODUCTION

Experiments were conducted to determine the suitability of the aquatic habitat for production of carp, *Cyprinus carpio* and channel catfish, *Ictalurus punctatus* to state regulations we were not allowed to use Tilapia in our system. The carp and catfish were obtained from a fish farm in California which had certified disease-free stock. The farm was recommended by the Utah State Natural Resources Division.

Fish weight, total length, body condition and mortality were recorded. For the fish tanks, dissolved oxygen (DO), pH, water temperature, nitrites, ammonia and ambient temperature were monitored. Many of these water quality factors were recorded daily for correlation with fish condition and growth.

Six tanks, each 2.39x1.18x1.18 m, were constructed in a greenhouse located inside the Provo Power Plant Compound. The water level was maintained at 0.6 m depth and the approximate capacity was 1.69 m. A hot-water-heat-exchange system (heated effluent from the power plant) and aerators were set at the bottom of the tank. Two of the tanks (#3 and #4) were connected with a vertical trickling filter system, while the others were not filtered and therefore required constant water exchange.

Channel catfish and common carp were obtained in two batches (March 5 and September 7, 1989). The fish were fed twice a day with trout pellets containing 40% crude protein. During the period between March 5 and December 9, 1989, tanks containing fish were cleaned and the water was changed once a week. One-third to one-half of the volume of water in the tank was changed three times a week during the period between December 9, 1989 to February 23, 1990. Temperature, DO, and pH were monitored daily. Ammonia and nitrogen were measured at certain times as recorded in the data.

RESULTS

Water Quality

Temperature: For the growing season of this study, the results could be separated into three phases:

A-First phase: (March 5 to April 24, 1989). The water temperature was maintained automatically at 27°C (80.6°F) by a thermostat-controlled-hot-water-heat exchange system.

B-Second phase: (April 25 to September 5, 1989)
Because the ambient temperature was quite high, the water temperature was higher than desired. The heat-exchange system was turned off during the summer time. During this period, water temperature ranged between 21.7 and 27.2°C (71-81°F).

C-Third phase: (September 6, 1989 to February 23, 1990)
The temperature was maintained automatically at 22°C (71.6°F) by a thermostat-controlled

hot-water-heat-exchange system (power plant effluent was the source of hot water).

The results are given in Table 1.

pH: The pH in the tanks containing fish had a wide range during the summer time (March 5 to September e, 1989). The reasons for this include higher water temperatures and algae. Due to these problems, we maintained the pH at a higher level (average, 8.69). During the autumn and winter, the pH dropped to an average of 7.6. The results are given in Table 2.

Dissolved oxygen:

Oxygen was provided by an aerator, and part from the trickling filter. The average DO was maintained above 5.4 ppm (64% of saturation) in tanks #3 and #4 which were connected to a trickling filter. The average DO in the other two tanks, without filters, was maintained above 4.6 ppm (48% of saturation) throughout the experiment. There was an apparent relation between DO concentration and water temperature. The results are given in Table 3.

Nitrite:

Nitrite (NO_2) was measured daily between August 23 and 29, 1989 to determine the efficiency of the filter in tanks #3 and without a filter in tank 5. The results are given in Table 4 and figures 1 and 2.

NO_2 was measured daily also during the period between October 24, and 30, in tank #3 as shown in Figure 3. The results of the statistical analysis demonstrated there is no significant difference between NO_2 concentrations at the different water levels in the tanks, as given in Table 5.

Nitrite concentration

The results are given in figures 1, 2 and 3.

Note: For the nitrite data measured between August 23 and 29, 1989, the first water sample was collected one day after tanks were cleaned and the water was changed, and for the nitrite data measured between October 24 and 30, 1989, the first water sample was collected one hour after the tank was cleaned and the water was changed.

There is no apparent relationship between the pH and NO_2 concentration, but there is between DO and NO_2 concentration.

Ammonia:

Ammonia (NH_3) data were obtained between January 3 and 23, 1990. According to the statistical analysis, there was no significant difference for ammonia concentration in tanks #2, #3, #4 and #5 ($P < 0.05$), but there was one for ammonia concentration in tank #3 and the water sample collected at the outlet of the filter as given in Table 6.

Fish Growth

During the first growing period, with the exception of a slightly high pH, water quality factors met the requirements for optimum catfish growth and the fish grew well as given in Table 7 and figures 4 and 5. Water temperature dropped when the hot water heater was cut off during the second growing period. The water temperature was influenced by the environmental temperature, the range of which was great (IQR 6-9.3). During this period the pH varied over a wide range (IQR 0.6-0.8), due mainly to algae growth. Lower temperatures and varying pH levels tend to reduce fish growth. Growth reduction can be attributed to low temperatures and a varying pH during the third growing period. For the last period, the temperature was still below the optimum, but higher than during the third period (195 GP - 254 GP) and thus the growth rate was accelerated.

In this experiment the main factors which influenced fish growth were temperature and pH, but not DO or stocking density. High mortality was caused by bacterial disease and shut-down of the aeration system. One problem was the short period during which nitrite and ammonia data were measured, but the data now available indicate that nitrite and ammonia may be other important factors that influenced fish growth.

Catfish grew better in experiment II as compared with experiment I (from September 7, 1989 to February 3, 1989). The total growing period was 142 days for experiment II.

In this second experiment, temperature was still one of the main factors influencing growth of fish. During the first stage, the temperature was low (22°C/71°F). Then the heat exchange system was turned on and the variation in temperature was therefore not great. DO and density did not become a problem during this period. In the second stage, the temperature did not increase. Fish density increased one fold, DO decreased but the pH dropped and was more stable (IQR 0.2). One-third to one-half of the tank of water was changed every 2-3 days. The fish were left in the tanks during water changing, which should be less traumatic than removing them. The growth rate increased. During the cleaning and water changes, the temperature varied widely and the aerator was turned off, which may have caused the high mortality in this experiment. The same reason mentioned for catfish in experiment I, nitrite and ammonia, may be a severe problem causing growth restriction. The development of the catfish is given in Table 8 and figure 6.

Carp possess the ability to tolerate low DO, variable temperatures, poor water quality, and other stress environmental conditions with better growth than catfish. In the first stage of this experiment, although the temperature was lower, carp grew well. During the second stage of the experiment, the density of fish increased and more oxygen was required to maintain the DO. The DO level in the tank dropped below 50% of saturation, and the concentration of ammonia increased. These water quality factors all influence the growth of fish. During the second phase, the growth rate of carp was lower than in the first phases. In this experiment ammonia may have been a limiting factor for fish growth. The development of the carps is given in Table 8 and figure 7.

DISCUSSION

Optimum Growth and Restrictive Conditions of Channel Catfish

Optimum temperature

When DO is maintained at above 77% of saturation, catfish make the best weight gains and food conversion in water temperature of 28-30°C (82.4-86.0°F). There is less growth^{1,4}, between 26°C and 18°C.

Dissolved oxygen

When the experiments were conducted under conditions of 1 kg/m³ of biomass, 26.6°C (79°F), 3% of biomass fed daily, and 3.8 l/min of fresh water added, fish grew well ($I = .016$) when the DO level was > 60% of saturation, and less well at 36% of saturation. A low DO is reported to create reduced food consumption³.

Density

For fingerlings stocked, 141 fish/m³ (2.82 kg/m³), fish had a better growth rate ($I = .020$, with 58 g gained per fish within 10 weeks) and food conversion (1.5) under the experimental conditions of fresh water that was added at a rate of 2.5 gal/min (5 turnover/d), 26.5°C (80°F), and 3% of biomass fed daily.

For bigger fish, 211 fish/m³, the growth rate ($I = .028$, and an average of 169.6 g gained by an individual fish within 16 weeks) was better than for fingerlings. The culture system had a biomass capacity of 52.8 kg/m³ under experimental conditions of a 2-h water exchange and 26.5°C (80°F) (2).

Nitrite and ammonia

The short-term (96 h) toxicity (LC₅₀) for nitrogenous compounds to channel catfish, at 30°C was 3.8 ppm and 44 ppm for un-ionized ammonia and nitrite, respectively. (5).

For chronic exposure of channel catfish to ammonia, at 28°C (82.4°F) water temperature and 7.6 ppm DO in the cultural water, growth was reduced by 50% at 0.517 ppm NH₃-N and no growth occurred at 0.967 ppm. Mortality was increased significantly at 0.989 ppm NH₃-N and above (6).

SUMMARY AND RECOMMENDATIONS

1. The heat-exchange systems for the six tanks in the greenhouse using heated effluent from the power plant, were capable of producing a constant water temperature.
2. Results represent pilot studies and additional experiments should be conducted to test density levels for the tanks in relation to the filtered and unfiltered water. Most of the problems with the system were corrected by the time the trials were completed.
3. Both carp and catfish survived and grew normally within the aquatic systems. Filtered water (tank #3) supported twice the biomass as did unfiltered water (tank #5).
4. The temperature had to be lowered (from 27°C to 22°C) due to bacterial diseases and marginal DO during the fish trials. The fish were given an antibiotic-enriched food during one critical

bacterial outbreak; otherwise they were fed a high-supplement fish food.

5. The maximum biomass density for the tanks was not attained during any of the three trials. It is recommended that additional trials be conducted to achieve maximum density values.

6. Algal growth in the tanks contributes to DO and to pH values which are usually detrimental to the fish.

7. The filter system was efficient in lowering nitrite (NO_2) and ammonia (NH_3) levels. The filtered system supported double the biomass in relation to the unfiltered system. The size and other features that influence the efficiency of the filter must be considered to meet the maximum stocking density requirements.

8. Unexpected events (power outage, oxygen pipe leaks and constriction) contributed to fish mortality and to termination of the trials. A backup system could be installed to eliminate some of these problems. It would also be advisable to install an alarm system to warn of failures.

B. USING SOLAR ENERGY

A. Geva, Y. Christiansen, N. Zamir and D. Cohen

INTRODUCTION

Fish were raised to determine weak points in the growing system, during two seasons. During February-May 1988 carps *Cyprinus carpio* were raised in one pond and during February-May 1989, tilapia *Oreochromis niloticus* were raised in four ponds at three biomass densities.

The "ponds" were constructed in a greenhouse equipped with a FDHE and submerged gravel biofilters.

Each pond was 20 m long, 1 m wide and the water level was maintained on 0.7 m, giving an approximate capacity of 14 m³. The water of this ponds was recirculated through the main water reservoir of the hydro solaric greenhouse that had the volume of approx. 140 m³, at a rate of approx. 2.8 m³/h giving one exchange every 5 hours.

Carp were put in one pond on 25th February 1988, and tilapia were put in 14th February 1989 in the other three ponds. The fish were fed through a stick feeder so that only small quantities of food reached the bottom of the water.

RESULTS

The temperature of the water during the growing period of the fish was 23±0.5°C. This wide range was caused by several following clouded or sunny days as no artificial heating auxiliary was used. A detailed hourly temperature is given in Figure 7 of Chapter V.

The dissolved oxygen concentration was almost saturated during the first season but in the next season it was fluctuating between 2 to 7 ppm as a result of the time the falling dropelt heat exchanger was on or off.

The pH, ammonia (NH₃) and Nitrite (NO₂) during the first season (1988) is given in Table 9. During the second season (1989) the water quality was less good. From 36 samples of water taken during this season, six times the ammonia concentration reached 1.0 ppm, the pH was 7.6±0.4 and the nitrite concentration reached several times 10 ppm.

Checking the reason for this fast change in the oxygen concentration gave also some answer to the poorer water quality; In the end of the season it was found that the carps of previous season's experiment were introduced into the main 140 m³ pond, and reached each a mass of between 2 and 5 kg, giving a total biomass of about 2500 kg of fish. As the total water content in circuit was of about 200 m³ we get that the mean biomass was approximately 10 kg of fish per 1 m³ of water and as the mean water height was 0.75 m we got that the system was bearing a mean of about 13 kg/m² of biomass.

Table 10 shows the fattening of the carps during 1988. It can be seen that the fish doubled their weight during every month. In Table 11 the results of the fish growing during 1989 is given. It shows that although feeding to growth ratio was higher

than suggested as economical, the fish were healthy and grew in all the densities.

CONCLUSIONS

1. The use of the FDHE and the GEAP gave a good crop of carps during the cold winter (February 88 - June 88).
2. The growing of tilapia was interrupted during these experiments by the effect of the high biomass in the recirculated water and the absence of sufficient dissolved oxygen and biofilters.
3. IT is recommended that additional trials be conducted to achieve maximum density values.

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Table 1 - Variations in Water Temperature in the Tanks

Tank no.	Mean	Q1	Q3	Q3-Q1
5.III - 24.IV.1989				
2	80.55	80.0	82.0	2
3	79.80	80.0	81.0	1
4	80.67	79.0	82.0	3
5	81.96	80.0	83.8	3.8
25.IV-5.IX.1989				
2	75.45	71.0	80.0	9
3	74.33	71.0	78.0	7
4	75.90	73.0	79.0	6
5	76.44	72.0	81.3	9.3
6.IX-29.XII.1989				
2	71.08	70.0	72.0	2
3	71.41	70.0	73.0	3
4	70.30	69.0	72.0	3
5	71.86	70.0	73.0	3
30.XII.1989-23.II.1990				
2	71.41	70.0	73.0	3
3	71.49	70.0	73.0	3
4	72.95	71.0	76.0	5
5	73.73	70.3	77.0	6.8

Q1: Bottom quartile

Q3: Top quartile

Q3-Q1: Interquartile Range (IQR); 50% of the data fall into this range.

Table 2 - Variations in the pH of the Tank Water

Tank no.	Mean	Q1	Q3	Q3-Q1
5.III-24.IV.1989				
2	8.65	8.60	8.70	0.1
3	8.74a	8.70	8.80	0.1
4	8.75a	8.60	8.90	0.3
5	8.72A	8.60	8.90	0.3
25.iv.-5.ix.1989				
2	8.67	8.40	9.00	0.6
3	8.70b	8.30	9.10	0.8
4	8.76B	8.40	9.00	0.6
5	8.52C	8.20	8.90	0.7
6.IX-29.XII.1989				
2	7.85	7.60	8.08	0.5
3	7.86d	7.50	8.30	0.8
4	7.82d	7.50	8.30	0.8
5	7.73d	7.40	8.05	0.7
30.XII.1989-23.II.1990				
2	7.37	7.20	7.40	0.2
3	7.29e	7.20	7.40	0.2
4	7.45f	7.20	7.70	0.5
5	7.42f	7.20	7.60	0.4

Within the period values followed by a common letter do not differ significantly ($P>0.05$).

Table 3 - Variations in the Level of Dissolved Oxygen in the fish tanks

Tank no.	Mean	M%	Q1	Q1%	IQR	MIN	MI%
5.III-24.IV.1989							
2	5.84	74	5.4	69	0.9	3.7	47
3	6.06a	76	5.7	71	0.6	4.9	61
4	6.22a	79	5.9	75	0.7	4.0	52
5	5.81b	75	5.5	71	0.7	4.0	52
25.IV-5.IX.1989							
2	6.01	72	5.5	65	1.3	3.2	38
3	6.26c	75	5.7	68	1.0	4.5	54
4	6.45d	78	6.0	73	0.8	4.8	58
5	5.60e	68	5.0	61	1.1	2.4	29
6.IX-29.XII.1989							
2	6.01	70	5.6	66	1.0	2.6	30
3	6.00f	70	5.6	66	0.8	3.7	43
4	9.29g	72	5.6	65	1.2	4.7	54
5	5.32h	62	4.8	56	1.0	2.1	25
30.XII.1989-23.II.1990							
2	4.93	58	4.0	47	2.0	2.8	33
3	5.56i	65	5.3	62	0.6	3.6	42
4	5.39i	64	4.8	57	1.3	2.6	31
5	4.61j	48	3.9	47	1.6	1.8	21

Within the same period, values followed by a common letter do not differ significantly ($P < 0.05$)

M%: Percentile (%) of saturation of average DO.

Q1: 75% of the data fell above this point (ppm).

Q1%: Percentile (%) of saturation of average DO at this point.

IQR: Interquartile range.

MIN: Lowest DO.

MI%: Percentile (%) of saturation of lowest DO.

Table 4 - Average pH, DO and NO₂ between August 23 and 29.

Location of water sample		Avg. pH	Avg. DO	Avg. NO ₂
Tank #3	Outlet of the filter	8.46	6.1a	0.148d
	Bottom of the filter	8.51	6.5a	0.183d
	Top of the tank	8.47	7.0b	0.154d
Tank #5	Top of the tank	8.24	5.6c	0.086e

Notes: (1) Within columns values followed by a common letter do not differ significantly ($P < 0.05$).

(2) Biomass in tank #3 was 3.44 kg/m'; in tank #5, 5.71 kg/m'.

Table 5 - Average pH, DO and NO₂ between October 24 and 30 in tank 3.

Location of water sample		Avg. pH	Avg. DO	Avg. NO ₂
Top of the tank		7.77	4.8a	0.363b
Bottom of the tank		7.74	4.6a	0.369b

Within columns values followed by a common letter do not differ significantly ($P < 0.05$).

Table 6 - Ammonia concentration.

Location of water sample		Avg. conc. of NH ₃ (ppm)
Tank #2		0.489a
Tank #3		0.625a
Outlet of filter of tank #3		0.180b
Tank #4		0.415a
Outlet of filter of tank #4		0.274a
Tank #5		0.984a

Notes:

(1) When the water samples were measured, the biomass was in kg/m') as follows: in tank #2 0.64, in tank #3, 11.93; in tank #4 10.16 and in tank #5 9.75.

(2) The trickling filter in tank #3 worked with a recirculating path, and the trickling filter in tank #4 worked without a recirculating path.

(3) The water in tank #2 was not changed for 2 weeks.

Table 7 - Development of Catfish in Experiment I.
(5.III.1989 to 23.II.1990; growing period, 356 days)

GP	T(oF)	DO%	Q1%	MIN%	pH	pH-IQR	D	I
0-14	80.8	>70	69	47	8.72	.1-.3	Low	.021
15-194	76.0	>68	61	29	8.7	.6-.8	2.86	.010
195-254	70.0	>70	65	54	7.8	.8	3.77	.0078
255-356	73.0	>64	57	31	7.5	.5	10.16	.010

GP%: Growing period (Cumulative days)

DO%: Percentile of saturation of average DO.

Q1%: Percentile of saturation of DO at Q1.

MIN%: Percentile of saturation of lowest DO level.

pH-IQR: IQR of pH.

D: Density (kg/m).

I: Average growth rate $[I=(Y/P)-1]$.

Table 8 - Development of Catfish and Carp in Experiment II.
0-60 Days (14.IX-13.XI.1989)

FISH	PW	B	I	ToF	T	pH	P	DO%	D%	M%
Catfish I	56.4	3.77	.0078	70.3a	3	7.82	.8	72	65	54
Catfish II	36.4	5.71	.0097	71.4b	3	7.86	.8	70	66	43
Carp II	25.5	3.44	.0183	71.1	2	7.85	.5	70	66	30
61-162 Days (11.IV.89-2.III.90)										
Catfish I	89.9	10.16	.010	73.0g	5	7.45	.5	64	57	31
Catfish II	64.8	11.93	.0096	71.5h	3	7.29	.2	65	62	42
Carp II	75.6	9.75	.0126	73.7i	6.8	7.42	.4	48	47	21

Note:

(1) PW: Primary weight.

B: Biomass, kg/m.

I: Average growth rate.

ToF: Average temperature (fahrenheit).

T: IQR of the temperature.

P: IQR of the pH.

DO%: Percentile of saturation of DO.

D%: Percentile of saturation at 25th of IQR of DO.

M%: Percentile of saturation of lowest DO level.

(2) Within columns, values followed by a common letter do not differ significantly ($P>0.05$). There is a 95% confidence that $a>b$, $d>e>f$, $g>h$, $i>h$, $J>k$, $m>n$.

Table 9 - Water quality during the 1988 experiment

Date	pH	NH ₃ ppm	NO ₂ ppm
15.II	7.45	10	0
25.II	7.15	10	0
29.II	7.45	10	0.05
3.III	7.2	0	0.05
7.III	7	0	0.1
10.III	7	5	0.1
14.III	7.2	5	0.1
17.III	7	0.1	0.05
21.III	6.7	0	0.5
24.III	7	5	0.1
28.III	7.2	5	0.25
31.III	7.2	10	0.25
4.IV	7	0	0.35
18.IV	7.2	0	0.75
22.IV	7.2	0	0.3
5.V	-	-	0.5
9.V	-	0	0.6
12.V		1	1
19.V		0	0.5
23.V		0.5	1
25.V		0	0.35
30.V		0.5	0.6
2.VI		0.5	0.5
6.VI		0.5	0.25
10.VI		0.5	0.25
13.VI		0.5	1
16.VI		0	0.7

Table 10 - The weight of *Cyprinus carpio* during the 1988 experiment

Date	No. of fish	Mean weight (g)	Remarks
25.II.88	410	16	
8.III.88	407	18.6	3 dead
23.III.88	405	24.3	2 dead
24.IV.88	233	70	Small fish removed
19.V.88	232	164	1 dead
2.VI.88	232	200	
15.VI.88	232	358	

Table 11 - The growth of tilapia in Mevoot Eiron in 1989

Pond		B	C	D
Population,	fish/pond	500	1000	2000
"	fish/m ²	20	40	80
Biomass 26 I,	kg/m ²	1.192	2.384	4.768
2 V,	kg/m ²	2.945	5.449	9.560
Biomass growth	kg/m ² season	1.753	3.065	4.892
Weight of each,	kg/fish	0.147	0.136	0.119
food,	kg/season	4.128	6.820	13.020
feeding rate,	kg/kg	2.35	2.22	2.66

Fig. 1 - The ammonia concentration in tank no. 3 (with a filter) Aug. 23-29, 1989.

TANK #5 WITHOUT A FILTER
8/23/89 to 8/29/89

Fig. 2 - The ammonia concentration in tank no. 5 (without a filter) Aug. 23-29, 1989.

Fig. 3 - The ammonia concentration in tank no. 3 (with a filter) Oct. 24-30, 1989.

Fig. 4 - The development of channel carfish in experiment I (tank 6). March 5, 1989 to Feb. 23, 1990.

Fig. 5 - The development of channel catfish in experiment I (tank 4). Sept. 14, 1989 to Feb. 23, 1990.

Fig. 6 - The development of channel catfish in experiment II (Tank 3). Sept. 14, 1989 to Feb. 3, 1990.

Fig. 7 - The development of carp in experiment II (tank 5). Sept. 14, 1989 to Feb. 23, 1990.

X. SUMMARY

Cooperation

The research scientists at the HU and the ARO worked together most of the time as one group, sharing technical and human resources. This enabled us to investigate heat, mass and oxygen transfer in parallel, and the same applied to fish and biofilter culturing, data accumulation and evaluation.

The two faculties of BYU also worked together as one group. The meeting of the groups from the two countries made it possible to understand better the heat losses phenomena, both in the more moderate climate of Israel and the more severe one of Utah. Using similar but different materials for biofiltering led to better and more reliable of ammonia oxidation in practice.

Research Achievements

The harvesting of solar energy and employing this energy, better insulation or, vice versa, heating of aquaculture ponds, is the most important economic and engineering achievement.

Of no less importance is the new concept of combining the heat, mass and oxygen transfer, between air and water into one model.

In addition to the known impact of temperature, the effect of dissolved oxygen was also demonstrated.

New methodology was developed to measure heat uptake by droplets, to evaluate a greenhouse-enclosed aquacultural pond (GEAP) and the oxygenation of the water as it passes through the aerator.

New data were obtained on the mean convective heat transfer parameter; on the relation between outdoors and indoors air velocity and its effect on heat transfer; on the relation between latent heat transfer (evaporation or condensation) and sensible heat transfer for in-greenhouse surfaces and for various moving surfaces like droplets and rotating biofilters; and on the bacterial area denitrification.

A better understanding of the nature of the relationship between fish feeding, oxygen enrichment and biofiltering as a combined group was achieved, but more work still has to be done.

Comparison with Original Goals

Physical characteristics of the FDHE were fully investigated (Chapters II, V, and VI). The heat balance of the GEAP in different climates was modeled in Israel and the same simulation was also checked in Utah.

The evaluation of the relationship between the environment and costs as affected by the solar and back up heat supply, cover and bottom insulation, filtering and fish growth are dealt with in Chapters IV, V, VII and VIII, in relation to local components

such as climate and water sources. Secondary use of effluents was dealt with, only as a source of water for the biofilters.

The principle shape of a GEAP that outcame this project, is given in Fig. 1.

Benefits and Agriculture

1) The possibility described in Chapter II, to make use of winter solar energy with the aid of a relatively simple heat exchanger that might also be used, as described in Chapter VI, as a back up oxidizer - saves expensive fuel and lowers the smoke hazard.

2) The energy transfer model that is described in Chapter III, makes it possible to design better the appropriate aquaculture pond.

Publications

Chapter III was submitted to the Journal of Agric. Enging. Res. Chapters II, IV, V and VI are in preparation for submission.

Fig. 1a - A schematic drawing of the planned GEAP.
 (1) fish pond (2) biofilter (3) mechanical filter (4) spraying
 nozzles (5) feeder (6) harvesting chamber (7) sewer

Fig. 1b - Top view of the planned GEAP.