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by V. V. Blinov

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On the problem of counting and transporting fingerlings

V.V. Blinov

The problem of releasing raised juvenile fish has both biological and technical aspects [6]. By the technical aspects we understand the construction of apparatuses, mechanisms, and devices used in counting and transporting juvenile fish to the water reservoir which should be stocked with fish. Such apparatuses should be cheap, simple in maintenance, reliable in operation, and the time spent by the juvenile fish passing through them should be kept at a minimum. Apparatuses of such kind give opportunity to any fishery to count raised juvenile fish at certain stages of the biotechnical process. The simplest way is by passing water with fingerlings through a specially constructed system of channels.

Since grown fingerlings and, especially, raised juveniles possess a great motor activity, the velocity of their motion becomes equal or greater than the possible rate of the water discharge at a laminar regimen, i.e. $|V_M| \geqslant V_b$ (1)

Construction of the apparatus in paper 1 was based on the principle of inactivation and swimming of the fry. However, although the free embryo is naturally passive, it may be possible to inactivate the fingerling artificially (we shall call this process the inactivation of motor activity of fingerlings) and use the same principles in constructing a counting device.

The basic ecological factor, available and suitable for control is, in this case, water temperature t_b. If the selection of t_b may paralyze the motor activity of fingerlings without damaging physiological processes in their organisms, then the scheme of counting may be represented as follows. (158)

Water from the reservoir or fattening pond with fingerlings is decanted (with filtering) into an intermediate container and carefully heated to the inactivating temperature $t_b = t_{pass.}$. Then the water with fingerlings is decanted into another container through a counting device. After the water in the other reservoir has reached the ambient temperature (temperature of the medium), it is poured into the reservoir which should be stocked with fish (or into the water reservoir of the next stage of the biotechnical process).

Dependence of the fingerling's mobility rate of various species and dimensions on t_b has not appeared in literature. To obtain such data it is necessary to realize a large program of experimental work, comprising measurements of the motor activity of fingerlings at various t_b and certain physiological conditions and also determinations of the reaction of fingerlings on the flow rate V_b. The experimental program, evidently, needs a special elaboration.

Similarly to paper [1] we shall limit the mean flow rate of the water in the channel by the rate at which the laminar flow becomes turbulent [5], i.e. at Re 1700 ÷ 2200; we shall designate it $V_{b\ max.}$. In this way, in agreement with this instruction, the range of the mean rates of water in the channels will be $0 \div V_{b\ max.}$. In the transport of inactivated fingerlings evidently the upper part of this range will be used:

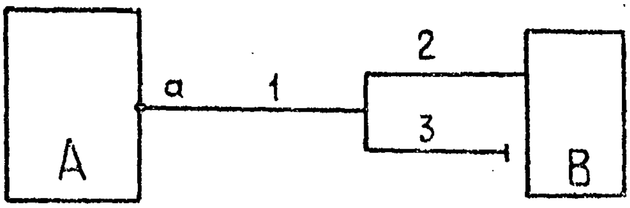
$$V_M \ll V_b < V_{b\ max.} \qquad (2)$$

A formula for counting the fingerlings has been published [1] :

(3)

The condition of swimming ceases to be true with large fingerlings. However, at $V_{otn.} \neq 0$ the per second differences in formulas (2) and (3) from paper [1] are changed. ($V_{otn.}$ means the relative rate ($V_{rel.}$) - translator's note). Formula (3) from this paper does not depend on V and V_i and remains invariant at the changed relative velocity of the fingerling. Experimental measuring of the relative velocity of the moving inactivated fingerling in the stream would be very valuable. However, (159)
from now on we shall assume that the relative velocity of the fingerling centre of gravity will be zero.

The scheme described above was intended to be used for the transportation of fingerlings to a distant water reservoir. The scheme of the stationary part of the installation consists of tank A and a system of channels 1, 2, and 3 (see diagram).



The scheme of the installation for transportation and counting of fingerlings: A = tank for the inactivation of fingerlings; B = transport tank; 1 = inlet channel of the counting device; 2 = main channel, and 3 = measuring channel.

In contrast to the scheme of inclined drainage (flow) considered in [1] , this suggested scheme has a pump in point A. Water proceeds from channel 2 into tank B where it gradually reaches the temperature of the environment. The construction of tanks must ensure oxygen regimen needed by the fingerlings. Even cans may take over the function of the transport tank.

When projecting the scheme, either a laminar flow regimen or a certain regimen of a developed turbulent flow may be selected. It is not advisable to work in the transitional region because of the effect of hydrodynamical instability, which is difficult to incorporate in the calculation.

To shorten the time of decantation it would be necessary to permit higher flow rates, corresponding to a turbulent flow. However, the value of rate pulsation (and, consequently, impulse pulsation) must be limited in order not to disturb the motion of the fingerlings in the stream. This restricts the scale of pulsation (spectrum of the flow turbulence), the forms and dimensions of the channel and, also, the selection of Re and F_z (160)

(Frud) numbers. The state of the turbulence theory in limited flow regions and insufficient knowledge of the effects of walls on the turbulence characteristics do not allow to carry out the necessary calculations. Therefore this consideration will be confined to laminar flow.

A stream of water with suspended fingerlings may be considered as a suspension of particles of a certain shape. It is necessary to select an acceptable shape for the particle and a model of the body of the fingerling to study the motion of such a particle in the stream and to evaluate the apparent viscosity μ^* of the suspension.

It should be noted that the value μ^* allows to introduce a correction into the calculation presented in paper [1] , if the size of the fry cannot be assumed infinitely small (e.g., the fry of Acipenseridae has considerable dimensions, i.e. 9-10 mm on the average). Therefore μ^* should be substituted for η in formula (19) in the article [1] . The scheme accepted in this paper (see the diagram) is calculated by means of ordinary methods of hydraulics, also using μ^*.

The body surface of the fingerling (fins excepted) should approximately be considered as the surface of a rotational ellipsoid. It follows from the classical paper by J e f f e r e y [7], experimentally confirmed by G. T a y l o r [8] that ellipsoidal particles (prolate spheroids) in laminar shear flow will be oriented by their axes in directions parallel to vortex lines, and perform stable oscillations around such directions in two planes perpendicular to one another, passing through the particle axis. At the same time the particle axis will circumscribe a mantle of an elliptical cone with the major axis of its base perpendicular to the free-stream velocity gradient.

The shape of the channels and the channel system is assumed to be the same as in the paper [1] . The stationary field of velocities in the channel cross-section has the following profile:

$$V=\frac{1}{2\mu^*}\left(-\frac{dp}{dz}\right)\left\{\left(\frac{h^2}{4}-x^2\right)-\frac{8h^2}{\pi^3}\sum\frac{(-1)^n\cos\left[(2n+1)\frac{\pi x}{h}\right]\mathrm{ch}\left[(2n+1)\frac{\pi y}{h}\right]}{(2n+1)^3\,\mathrm{ch}\left[(2n+1)\frac{\pi b}{h}\right]}\right\} \qquad (4)$$

The velocity vortex is entered:

$$\vec{\Omega}=\frac{\partial V}{\partial y}\vec{i}-\frac{\partial V}{\partial x}\vec{j}\,, \qquad (5)$$

where $\vec{i}$ and $\vec{j}$ are unit vectors of the axes x and y, respectively.

Differentiation (4) determines the constituent vortices:

$$\frac{\partial V}{\partial y}=\frac{dp}{dz}\;\frac{4h^2}{8\mu^*\pi^2}\sum\frac{(-1)^n\cos\left[(2n+1)\frac{\pi x}{h}\right]\,\mathrm{sh}\left[(2n+1)\frac{\pi y}{b}\right]}{(2n+1)^2\;\mathrm{ch}\left[(2n+1)\frac{\pi b}{h}\right]} \qquad (6)$$

$$\frac{\partial V}{\partial x}=\left(-\frac{dp}{dz}\right)\frac{1}{2\mu^*}\left\{-2x+\frac{8h}{\pi^2}\sum\frac{(-1)^n\sin\left[(2n+1)\frac{\pi x}{h}\right]\mathrm{ch}\left[(2n+1)\frac{\pi y}{b}\right]}{(2n+1)^2\,\mathrm{ch}\left[(2n+1)\frac{\pi b}{h}\right]}\right\} \qquad (7)$$

The scalar field of the slope angles γ between the vortex line and the axis y is entered:

$$\gamma=\mathrm{arctg}\left(\frac{\Omega_x}{\Omega_y}\right). \qquad (8)$$

In this way inactivated fingerlings will be oriented in the direction of the lines γ = const., passing through the fingerling centres of inertia.

The particle oscillations described above, however, do not affect the entry of the fingerling into the measuring channel. Only those fingerlings will enter the channel, whose coordinates of the centres of mass will meet the requirements for the relation

$$y_c > -\left(\frac{b}{2} - b_2 \cos \varphi_2 + \Delta y\right). \tag{9}$$

A Δy value of the order of magnitude of 2-3 mm is needed to ensure that a negative moment vector would act upon the fingerling on its coming into contact with the branching of channels; as a result, the fingerling becomes orientated along the stream and falls into the measuring channel.

The apparent viscosity μ^* of a dilute suspension under the assumption of a very slow flow is usually evaluated according to a formula of the Einstein type:

$$\mu^* = \mu(1 + \Psi C), \tag{10}$$ (162)

where C = volume concentration of the suspension and

Ψ = coefficient characterizing dissipation energy when a viscous fluid flows around the particles.

Definition of the principle of swimming. A particle is swimming ("sailing" in the original text - translator's note), if the field of velocities of the points of the particle is homogeneous and the velocity factor is identical with the free-stream velocity vector of a homogeneous stream. A moving sphere is swimming in case that it does not rotate forward.

A particle is called quasi-swimming if the velocity vector of its mass centre is identical with the free-stream velocity vector. Consequently, the quasi-swimming particle may rotate and oscillate around its mass centre.

A small sphere moving forward in a shearing stream is quasi-swimming. Quasi-swimming is also any other small particle of other than spherical shape. Evidently, only particles of homogeneous density which is the same as the density of the fluid, meet one of the two definitions given above.

In this way the motion of the stream with fingerlings is considered as a motion of a low concentration suspension of quasi-swimming prolate pheroids. The movement of such a suspension in the channel will have the characteristic signs of its movement in a homogeneous shearing stream.

We shall call the motion of a prolate spheroid in a shearing stream the Jefferey motion (a spheroid appears quasi-swimming according to our definition). The Jefferey motion may be considered as an important particular class of movements of prolate spheroids in a shearing stream [7] . A suspension should naturally be called a Jefferey suspension if each particle of such suspension performs an independent Jefferey motion.

We do not know papers on measuring apparent viscosity of Jefferey suspensions except in the qualitative experiment by G. Taylor [8] . We shall endeavour, therefore, to obtain the value ψ in the equation (10) by calculation.

The rate of energy dissipation in a particle performing (163)
the Jefferey motion is given [7] by a formula:

$$D=\frac{4}{3}\pi K^2\mu\left[\frac{2a^2b^2}{(a^2-b^2)}\left\{\frac{a^2+b^2+2K^2}{(a^2+K^2)(b^2+K^2)}-2\right\}\left\{\frac{\alpha_0''}{2b^2\alpha_0'\beta_0''}+\frac{1}{2b^2\alpha_0'}-\frac{2}{\beta_0'(a^2+b^2)}\right\}+\frac{K^2}{\sqrt{(a^2+K^2)(b^2+K^2)}}\left\{\frac{1}{b^2\alpha_0'}-\frac{2}{\beta_0'(a^2+b^2)}\right\}+\frac{2}{\beta_0'(a^2+b^2)}\right] \tag{11}$$

where a = the major semiaxis and b = the minor semiaxis of a prolate spheroid;

$$\alpha_0'=\int_0^\infty\frac{d\lambda}{(b^2+\lambda)^3\sqrt{a^2+\lambda}};\quad \alpha_0''=\int_0^\infty\frac{\lambda\, d\lambda}{(b^2+\lambda)^3\sqrt{a^2+\lambda}};$$

$$\beta_0'=\int_0^\infty\frac{d\lambda}{(b^2+\lambda)^2(a^2+\lambda)\sqrt{a^2+\lambda}};\quad \beta_0''=\int_0^\infty\frac{\lambda\, d\lambda}{(b^2+\lambda)^2(a^2+\lambda)\sqrt{a^2+\lambda}} \tag{12}$$

μ = dynamic viscosity of the fluid, K = undetermined constant, characterizing the motion within a fixed class of particle movements.

The integrals α_0' and β_0' in formulas (12) may be evaluated by means of tables [2] but the integrals α_0'' and β_0'' may be converted by a simple transformation into the tabulated integrals and verified for convergence.

Finally we obtain:

$$\alpha_0'=\frac{3a}{4b^2(a^2-b^2)^2}-\frac{a}{2b^4(a^2-b^2)}+\frac{3A}{8(a^2-b^2)^2\sqrt{a^2-b^2}}, \tag{13a}$$

$$\beta_0'=-\frac{1}{ab^2(a^2-b^2)}-\frac{3}{a(a^2-b^2)^2}-\frac{3A}{2(a^2-b^2)^2\sqrt{a^2-b^2}}, \tag{13b}$$

$$\alpha_0''=-\frac{a^3}{(a^2-b^2)^2b^2}-\frac{a}{4(a^2-b^2)^2}-\frac{(4a^2-b^2)A}{8(a^2-b^2)^2\sqrt{a^2-b^2}}, \tag{13c}$$

$$\beta_0''=\frac{3a}{(a^2-b^2)^2}+\frac{(4a^2-b^2)A}{2(a^2-b^2)^2\sqrt{a^2-b^2}}, \tag{13d}$$

where

$$A = \ln\left(\frac{a - \sqrt{a^2 - b^2}}{a - \sqrt{a^2 - b^2}}\right) . \quad (14)$$

The value D may also be written [7] in the form:

$$D = \Psi V \mu K^2 , \quad (15)$$

where V = the volume of the prolate spheroid: $V = \frac{4}{3}\pi a b^2$

Jefferey showed that the value of the constant K 0 and may widely fluctuate (from 0 to ∞); higher K values are characteristic of prolate spheroids. Within the range $K \to \infty$ the value of Ψ may be expressed:

$$\Psi = \frac{1}{a b^4 \alpha_0'} , \quad (16)$$

where α_0' has been given (13a).

Considering that $K \gg 1$, the formula (11) may be transformed:

$$D = \frac{4}{3}\pi\mu K^2 \left[\frac{2a^2b^2}{(a^2-b^2)^2}\left(\frac{2}{K^2} - 2\right)\left\{\frac{\alpha_0''}{2b^2\alpha_0'\beta_0''} + \frac{1}{2b^2\alpha_0'} - \frac{2}{\beta_0'(a^2+b^2)}\right\} + \frac{1}{b^2\alpha_0'}\right] . \quad (17)$$

Formally, the equations (15) and (17) contain three unknown quantities (we assume that μ_1, a, and b have been preset). Virtual calculations showed, however, that for very small particles the formula (17) is reduced into a form $D \sim CK^2 + d$ and at the same time $d \ll CK^2$ so that d may be abandoned. Comparing (15) to (17) we notice that the constant K has disappeared and for Ψ we obtain the following relationship:

$$\Psi = -\frac{4a}{(a^2-b^2)^2}\left\{\frac{\alpha_0''}{2b^2\alpha_0'\beta_0''} + \frac{1}{2b^2\alpha_0'} - \frac{2}{\beta_0'(a^2+b^2)}\right\} + \frac{1}{ab^4\alpha_0'} . \quad (18)$$

In the deduction (18) we used the relation $CK^2 \gg d$

instead of K $\rightarrow \infty$. Thus the equation (18) is also correct for some intervals of high K. The following inequality may be drawn (165)
from the Jefferey calculations:

$$2 < \Psi < \infty \tag{19}$$

The quantity Ψ may be expressed by means of $\varepsilon = \frac{\sqrt{a^2 - b^2}}{a}$ i.e. the ellipticity of the particle meridian cross-section. As matter of fact, substituting $a^2 (1 - \varepsilon^2)$ for b^2 in the equation (18) convinces us that a becomes eliminated here and we obtain a universal function $\Psi = \Psi(\varepsilon)$.

$$\Psi = -\frac{16\varepsilon(1-\varepsilon^2)}{4\varepsilon^2 - 6\varepsilon(1-\varepsilon^2) - 3(1-\varepsilon^2)\ln\frac{1-\varepsilon}{1+\varepsilon}} -$$

$$- \frac{40\varepsilon^2 - 8\varepsilon^4 + 4\varepsilon(3+\varepsilon^2)(1-\varepsilon^2)\ln[(1-\varepsilon):(1+\varepsilon)]}{\left[10\varepsilon^3 - 6\varepsilon - 3(1-\varepsilon^2)\ln\frac{1-\varepsilon}{1+\varepsilon}\right]\left[6\varepsilon + (3+\varepsilon^2)\ln\frac{1-\varepsilon}{1-\varepsilon}\right]} -$$

$$- \frac{16\varepsilon(1-\varepsilon^2)}{(2-\varepsilon^2)\left[2\varepsilon^3 + 6\varepsilon(1-\varepsilon^2) + 3(1-\varepsilon^2)\ln\frac{1-\varepsilon}{1+\varepsilon}\right]} -$$

$$- \frac{8\varepsilon^5}{4\varepsilon^3 - 6\varepsilon(1-\varepsilon^2) - 3(1-\varepsilon^2)^2\ln\frac{1-\varepsilon}{1+\varepsilon}} \tag{20}$$

Calculations accomplished by means of the formula (20) are presented in the following table:

ε	Ψ	ε	Ψ	ε	Ψ
0,50	264	0,75	I4,800	0,96	2,0I6
0,55	I4I	0,80	8,540	0,97	2,097
0,60	78	0,85	4,9I6	0,98	2,094
0,65	44	0,90	2,98I	0,99	2,097
0,70	25,7	0,95	2,I78	I,00	2,000

The inequality (19) has been confirmed. Extremely large Ψ quantities at average and small ε values have no physical meaning. It may be assumed that the approximation, which has been developed, is true for all $I > \varepsilon \geqslant 0.8$.

As a rule, the largest body height is not equal to the largest body width in fingerlings of the majority of species. In this case b may be determined as a radius of a circle, the area of which is equal to the maximum area of the fingerling cross- (166)
section. If b' is the maximum body height and C the maximum body width, then

$$b = \sqrt{Cb'} \qquad (21)$$

After having determined ε we find ψ and, knowing the concentration of fingerlings, we may determine the apparent viscosity μ^* of the suspension; the apparent viscosity μ^* is necessary for technical calculation of the transport channel.

As a simple example we shall present evaluation of the quantity ψ for pike perch fingerlings. We shall use morphometrical data by E.N. D m i t r i e v a [3] and consider the body of the fingerling as a rotational ellipsoid with the major axis equal to l, i.e. to the length of the fingerling less the length of its tail fin; the width of the fingerling will be equal to the tallest height of the trunk. Incidentally we shall notice that the morphometrical data are lacking cross-section dimensions of fish. These are needed to accomplish hydrodynamical and energetical calculations in rigorously and properly established mathematical-ecological problems. At the developmental stage E the length $l = 2.1$ mm and the ratio $H/l = 20.4\%$. Consequently the semiaxes a and b will be equal to 1.05 and 0.214 cm, respectively;

$$\varepsilon = 0.98 \quad \text{and} \quad \psi \approx 2.094 \text{ (see the table).}$$

The following conclusions may be drawn from this presentation:

1. To count inactivated fingerlings, i.e. fingerlings with diminished mobility, the same principles and elements may be used in the construction of a device, which was suggested by us earlier for counting fish fry.

2. A hydraulic line for transporting inactivated fingerlings may be calculated using the magnitudes of the coefficient of the apparent viscosity of the water-fingerling mixture obtained in this paper.

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On the problem of counting and transporting fry.

V.V.Blinov

S u m m a r y

Simple and reliable methods and designs of computers should be developed to control the number of fry in various stages of the biotechnical process. Canal systems are most suitable to count the young by bypassing them from one artificial or natural reservoir to another.

The layout of the device, considered earlier, is suggested for relatively large but inactive fry. In the theory of the device, use is made of the transport medium (water) viscosity value. The water - fry mixture is regarded as a suspension of ellipsoidal particles. The probable types of motion in the suspension are investigated, and the coefficient of apparent viscosity is calculated for the most probable motion called here the Jefferey motion.

A hypothesis is advanced as to the possibility of reducing the swimming activity of the fry by raising the water temperature. In this case, the results obtained may be also used for transporting and counting active fry.