Plankton going down slowly - always

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Problem

With time phytoplankton will sink into the deeper layers of the lake, where most of it dies due to the lack of light:

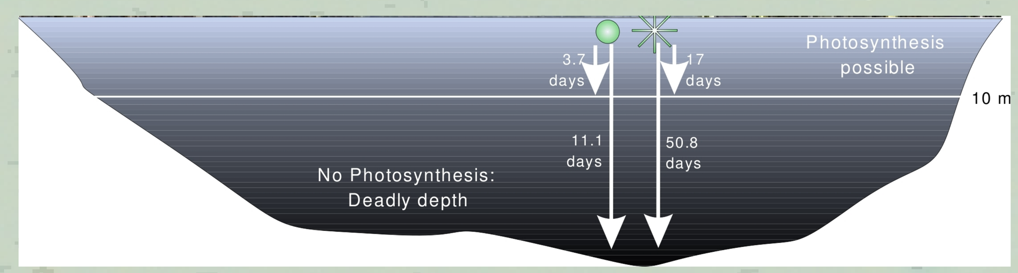

Fig. 1: Sinking of plankton

A small sphere with a radius of 10 μm would need about 4 days[1] to reach the compensational depth (at about 10 m) of Sorpe Reservoir, where light is so low, that photosynthesis is impossible. But algae need time to reproduce and grow! Microscopy of plankton reveals that most organisms are not shaped like a sphere:

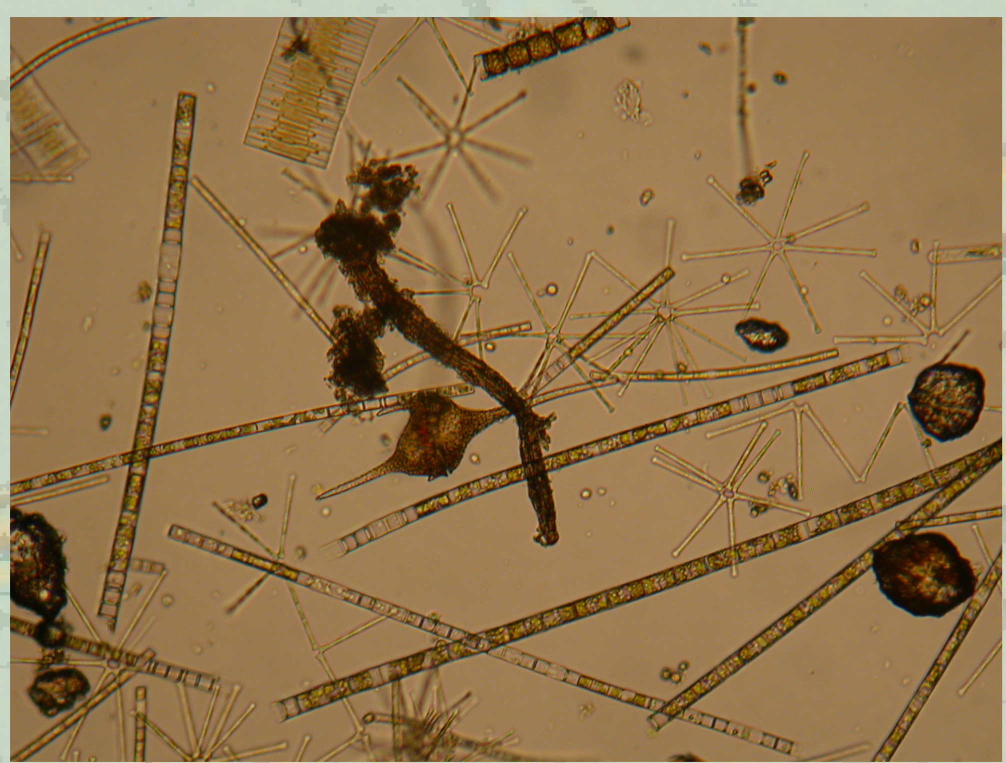

Fig. 2: Phytoplankton from Sorpe Reservoir: Asterionella, Melosira, Ceratium, and Peridinium

Asterionella, for example, mostly is shaped like a star with 8 arms. It needs about 17 days to travel 10 m downwards.

Does the bizarre shape of most plankton help preventing it from an early decay in the deathly depths?

Experiments described in school textbooks shall help to find out the reasons for the slower movement of plankton compared to spheres and to measure the expected delay:

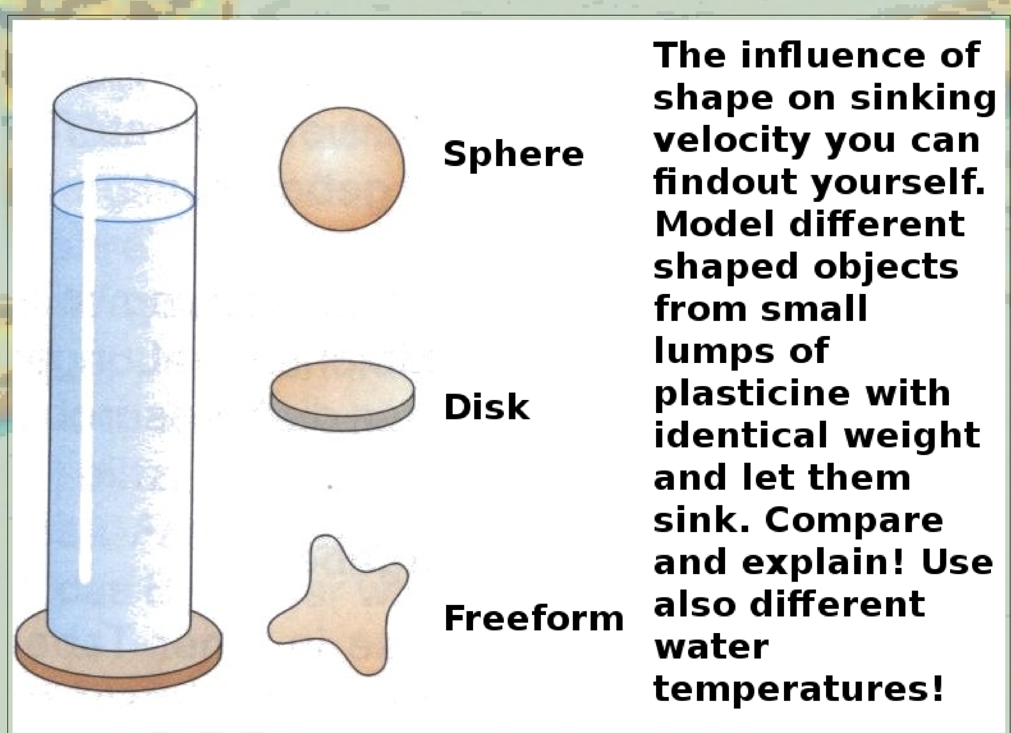

Fig. 3: Experiment from school book [1], translated

Mostly it is recommended, e.g. at [1], to let fall plasticine models of plankton into water. With this experimental layout it is intended to find out the influence of shape on sinking velocity V. Model algae are formed according to microscopic observation from the same amount of plasticine as a reference sphere. The ratio $\frac{V_{model\ alga}}{V_{reference\ sphere}}$ should give the sinking quotient c. It describes how slower the alga falls than the sphere. But this sketched approach results in quite high sinking velocities, which are difficult to measure by a hand stop watch. The outcome lies in the range of fractions of a second. The sinking quotient is nearly undeterminable. The questions can not be answered.

Most described experiments do not help solving this question.

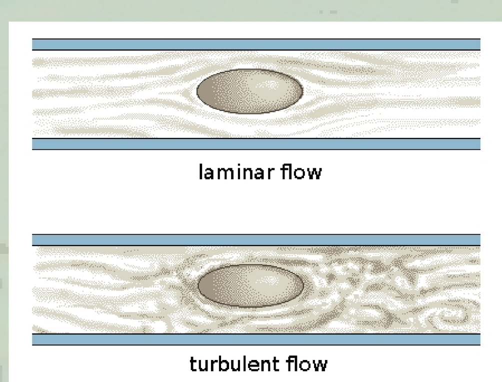

Fig. 4: Types of flow, from [4]

It is not considered that one can not make small objects larger without altering their hydrodynamics. While laminar flow prevails with small objects, turbulent flow is dominating with large objects. Laminar flow produces friction, turbulent flow influences displacement.

Solution

To describe the type of flow REYNOLDS' number is used. It is defined as follows:

$$Re = V \times l \times \nu^{-1},$$

with sinking velocity V measured in m/s, l is the reference length, e.g. diameter in m, and ν is the kinematic viscosity in m^2/s. For **water** at 20 ℃ ν is 1.01 $\times$ 10^{-6} m^2/s [3]. A small REYNOLDS' number ($Re \leq 1$) means laminar flow, high numbers turbulent flow (a swimming human in a swimming pool has a Re of about 2 millions, so friction is of nearly no importance, but force is needed to displace the water in front of the swimmer).

To achieve the same hydrodynamics with large objects as with small objects the viscosity of the fluid has to be increased. Best option is **glycerol** (w = 98 %) [5], which has a viscosity of $\nu = 768.6 \times 10^{-6}$ m^2/s. In this liquid, our plasticine model alga needed about 2.5 min for a sinking distance of 18 cm. That means a sinking velocity of about $V = 0.0012$ m/s and a REYNOLDS number of $Re = 0.02$ and therefore the model is in the range of laminar flow.

The drawbacks of glycerol are its price, which means a certain challenge for some schools' budgets. Second, glycerol is very hygroscopic and even small amounts of water absorption have considerable effects on its viscosity. But there are alternatives. In principle every liquid is usable, as long as it is viscous enough. Concentrated saccharose solution or motor oil are recommended.

Fig. 5: Media for model experiments: sugar, motor oil, strawberry syrup

Saccharose solution (w = 66 %) has a viscosity of $\nu = 165{,}3 \times 10^{-6}$ m^2/s and a density of $\rho \approx 1300$ kg/m^3. For our model algae that means a REYNOLD's number of $\approx$ 705, meaning a certain part of turbulent flow, but the sinking velocity is three to four times less than in water and therefore becomes more easily measurable.

The use of **motor oil** (Calpam Multifleet SAE15W40) is even better. The viscosity ν of this oil is at 20 ℃ about 230 $\times$ 10^{-6} m^2/s and the density ρ measures about 883 kg/m^3. Using the same sphere as with the experiments in saccharose, a REYNOLDS number of only 9.1 is resulting; with a model of *Asterionella* Re rises to 43.7. These values are still not perfect, but nearer to the values which are decisive with real plankton in water. Laminar flow plays a dominant role.

With these liquids and with different plasticine models sinking velocities and sinking quotients were determined:

		sphere	*Asterionella* (8 cells)
saccharose	sinking time t (s)	1.13	3.46
	sinking velocity V (m/s)	0.27	0.09
	sinking quotient c	1	3.06
motor oil	sinking time t (s)	2.5	8.9
	sinking velocity V (m/s)	0.12	0.033
	sinking quotient c	1	3.64

Table 1: Model experiment using saccharose (w = 66%) and motor oil (Calpam Multifleet SAE15W60). Measuring distance 30 cm, plasticine models 2.2 g

Real Asterionella 8-cell colonies have a sinking quotient of c = 4.63 [6], and PADISÁK et.al [5] found in a model experiment in glycerol $c \approx 5$. **Our results of 3.06 in saccharose and 3.64 in motor oil are lower than reality, due to the still too high REYNOLDS' number. But it is a quite good approximation.**

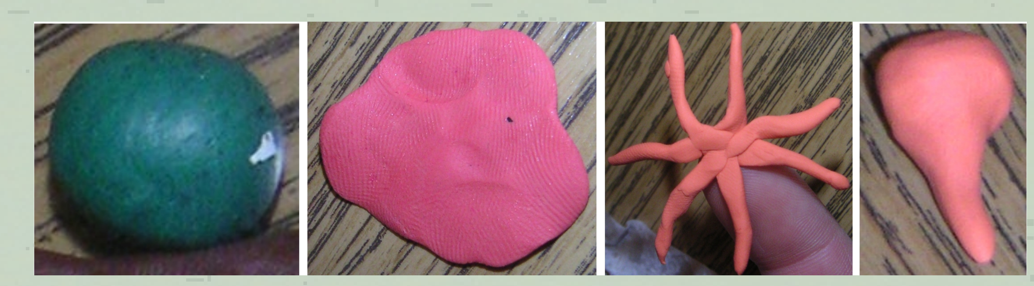

Fig. 6: Plasticine models of plankton algae

Appliance

Temperature in lakes influences sinking behaviour:

It is often noticed, that in lakes during the summer the oxygen concentration rises when entering the thermocline. Sinking plankton gets under the influence of cold water, which posesses a higher viscosity. Hence the sinking velocity slows down and a 'plankton jam' develops. This 'jam' produces additional oxygen, if it gets enough light [2]. This supplemental oxygen can be monitored measuring an oxygen profile (arrow).

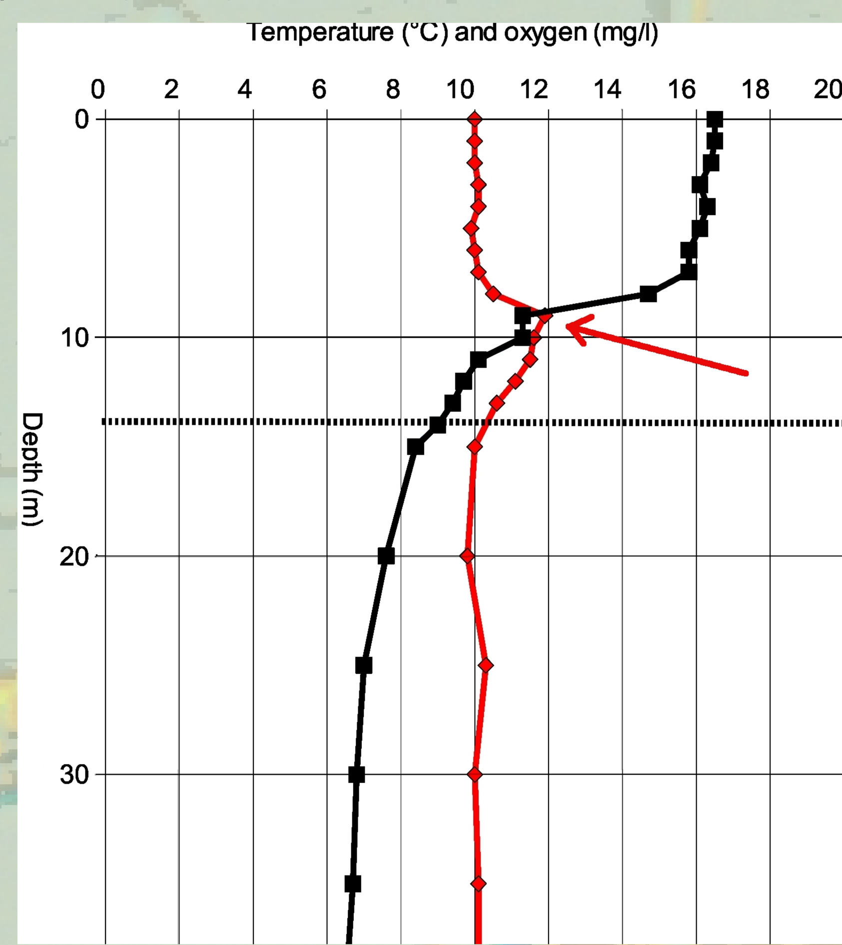

Fig. 7: Oxygen concentration and temperature of Sorpe Reservoir at 3 June 2002. Squares: temperature, diamonds: oxygen, horizontally dotted: depth of euphotic zone

Heating the test fluid[2] allows to reproduce this phenomenon in our model experiment. Increasing the temperature of motor oil from 20 to 45 ℃ increments the sinking velocity of our models by a velocity factor of about 2.2 (table 2). With real plankton the factor is roughly 1.6.

		sphere	*Asterionella* 8 cells	*Asterionella* 4 cells
20 ℃	v (m/s)	0,12	0,033	0,049
	c	1	3,64	2,45
45 ℃	v (m/s)	0,256	0,079	0,112
	c	1	3,24	2,23
velocity factor		2,13	2,39	2,28

Table 2: Sinking velocity v and sinking quotient c at different temperatures in motor oil SAE15W40

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[1] Conditions: density 1.05 g/cm^3, temperature: 20 ℃, no circulation, no turbulence

[2] For safety reasons to max. 45 ℃

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