January 19, 1951

Memorandum on Growing Photosynthetic Organisms in Sunlight and Daylight.

This memorandum concerns an apparatus and method for growing photosynthetic organisms. If a suspension of synthetic micro-organisms, for instance algae in a nutrient solution, is exposed to sunlight, the sunlight is not efficiently utilized since itsix intensity is too strong and photosynthesis cannot keep pace with the energy supplied. If a concentrated suspension of algae is used and if it is very vigorously stirred, the utilization of sunlight can be improved up to a certain point. Because for every single micro-organism which reaches the surface and is then removed from the surface by the motion of the nutrient liquid in which it is suspended, the intense light acts only for a short period of time between two longer periods of darkness, and under these conditions, the utilization of light is better. This method of improvement, the utilization of light xx has its limitations, however, both in the mechanical damage which the micro-organism suffers as the solution is too vigorously stirred and also in the expense which too vigorous stirring would involve.

The present memorandum describes a method which permits the utilization of sunlight fxr and daylight by photosynthetic organisms and which give an improved utilization both in the absnece and with artificial stirring of the nutrient liquid in which the micro-organisms are suspended. The method can be applied both to continuous and the batch processes to grow an algae or photosynthetic micro-organism.

Figure I shows the principle of the method. In Figure IA, number 1 is a supporting stand which holds two transparent tubes made of glass or some pliable transparent pastic material. Two tubes, 2 and 3, made of some pliable material. These two tubes are placed flat against the stand by the wires, 4 and 5, at a number of intervals along the axis of the arrangement. As can be seen in Figure IB, the axis of the arrangement is set in a east-west and a north-south arrangement and the V-shape can either be as shown in Figure I, or can be dexit tilted toward the west as shown in Figure II. Iinthe In the latter case it might possible be tilted so that the symetrical axis of the V is parallel to the daily orbit of the sun.

One feature of this arrangement consists in the following: Let us assume for the sake of argument that the plane of symetry of the supporting stand is parallel to the orbit of the sun and let us consi er the movement when the sun stands high. The rays of the sun which then fall directly on the slanted surface of either of the tubes will in part only

these tubes and in particular they will be reflected and fall on the opposite tube. The small the angle α is which makes the opening of the V, the larger is the fraction which will thus be reflected and the the smaller is the fraction which are penetrated upon the first impact. The reflected light which will then hit the flat surface of the other tube will do so at an angle which is larger than the angle of incidence at the first direct impact of sunlight, and therefore a larger chance of impact. This second reflection is followed by a return reflection and so on and fina ly a large fraction of the total incident sunlight will absorb will penetrate into the tubes and will be absorbed by the photosynthetic microorganisms suspended in the nutrient liquid in the tubes. The pertinent fact is that while the intensity of the direct sunlight impinging on a micro-organism set in the surface of the flat wall of the tube (on the inner side of the V) is reduced by the fraction which is reflected on the first impact. The total amount of the once or several times reflected light

The intensity of the reflected light, once or several times reflected, which hits the micro-organism mentioned before, will be lower than the intensity of the direct sunlight for geometric reasons by a factor represented by $\tan \alpha$.

Another feature of this arrangement consist in the following:

The direct rays of the sun which penetrate without reflection the side of the flat tube containing the micro-organisms in suspension will at noon strike the flat wall of the tube at an angle which is the smaller the smaller is. If this angle is kept small and if we have a dense suspension of algae, the light intensity within the suspension will fall off very rapidly with the depth measured vertically to the tube wall. For a given state of turbulent flow of the suspension, the time spent by any individual cell in the lighted region near the flat wall of the tube will therefore be all the smaller the smaller is made. This effect again tends to increase efficiency of photosynthesis in the tube in case of direct sunlight.

We have therefore two features both tending to increase the efficiency of photosynthesis in sunlight.

Depending on the time of the year toward sunset and toward sunrise either the exposed side of the flat tube which faces north or else the exposed side of the other tube which faces south will get more sunlight. In order to have in both tubes about equal amounts of photosynthesis going on, it might therefore be preferable to adjust the inclination of the V-shaped holder so that the plane of symmetry be ~~in~~ not paralell. to the daily orbit of the sun, but rather deviate from it. And the deviation may be so chosen that the tube which gets more sun it sunrise and sunset, get somewhat less sun toward noon time, and vice versa. Figure III chows another example, particularly suitable if instead of a continuous flow system, a batch process is desired. In Figure IIIA and B, we see a tray, 10, which is ~~set~~ fitted with a transparent cover 11. The cover forms a series of V-shaped deep grooves and the space between these V's which descent into the liquid in the tray. The space between these adjacent V's inside the tray is filled with liquid and the tray is so oriented that the grooves run east-west.

January 20, 1951

Memorandum on the growing of photosynthetic organisms in sunlight and daylight.

by Leo Szilard

This memorandum concerns an apparatus and method for growing photosynthetic organisms. If a suspension of photosynthetic micro-organisms in a nutrient solution, for instance a suspension of algae, is exposed in a tray to sunlight, the sunlight is not efficiently utilized since the micro-organisms close to the surface of the nutrient solution are exposed to light intensity which is too strong and their photosynthetic activity cannot keep pace with the rate at which they absorb radiant energy.

The utilization of sunlight can be improved up to a certain point by using a concentrated suspension of algae and by vigorously stirring the suspension. In that case a micro-organism moving with the liquid which reaches the strongly illuminated layer close to the surface, will stay in that layer only for a short period of time, and is thus exposed to intense light only for a short period of time between two longer periods of comparative darkness. As a result of this, the light is utilized with greater efficiency in the process of photosynthesis by the suspended algae. This method of improving the utilization of sunlight has its limitations, however, because to approach maximum efficiency it would be necessary to stir the suspension very vigorously, and the cost which the operation of equipment necessary for such stirring would involve becomes from an economic point of view a limiting factor. Moreover, some algae might not be able to stand such vigorous stirring.

The present memorandum describes a method which permits an increase in efficiency of the utilization of sunlight and daylight by photosynthetic organisms. The method is applicable whether or not the suspension is stirred and leads to an increase in efficiency whether or not the suspension is stirred. The method can be applied both to continuous and to batch processes for growing algae or for the photosynthetic micro-organisms in general. Figure I shows an example which illustrates a principle of the method. In Figure IA, number (1) is a V-shaped holder which carries two flat transparent tubes (2) and (3), made, for instance, of glass or some pliable transparent plastic material. Each of these two tubes is pressed flat against one side of the V-shaped holder by wires or straps (4) and (5), respectively, at a number of sites placed at intervals all along the axis of the V-shaped holder.

As can be seen in Figure IB, the axis of the V-shaped holder is set east-west rather than north-south. The V-shaped holder can be so oriented as shown in Figure I that its plane of symmetry is vertical or else it can be so oriented that its plane of symmetry can be tilted toward the south (in the Northern Hemisphere). In particular it may be so tilted that the plane of symmetry becomes parallel to the daily orbit of the sun. In that case the arrow in Figure II will point towards the sun when the sun stands at its highest at noon.

In order to explain one of the features of this arrangement as it effects the efficiency of photosynthesis in sunlight at about noon time, we may now consider the following (see Figure IIA):

The rays of the sun which fall at noon time on the flat side of the left tube which faces south, will only partly penetrate into the tube and in part these rays will be reflected and hit the flat side of the right side of the flat tube, which faces north. The angle at which the sun rays reflect from the flat side of the left tube hit the flat side of the right tube, will depend on the angle which characterizes the V-shaped holder. The angle of incidence of the reflected rays at the light tube will in any case be greater than the angle of incidence of the sun on the left tube, and therefore a larger fraction of the reflected rays will penetrate into the right tube than the fraction of the direct sun rays which penetrate into the left tube. If we choose the angle to be, for instance 60°, the rays reflected from the flat surface of the left tube will hit the flat surface of the right tube perpendicularly. In that case a large fraction of the rays will penetrate the right tube and will be absorbed in the suspension inside the right tube. If we assume for the sake of argument that all the light impinging on the flat surface of the left tube is reflected and then hits the flat surface of the right tube and is absorbed, then a micro-organism close to the illuminated surface of the right tube would be exposed to a light intensity given by

October 25, 1951

Mr. M. C. Coulter — BSD Dean's Office

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Changeover from 4E Contract to 3Q Contract.

I wish to go on record as seriously considering transferring from the 4E type contract to the 3Q type contract, but I am unable at this time to say what reduction of salary I might find acceptable.

LS/sds