The Effect of Temperature on the Cruising Speed Performance of Golden Shiners

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I. Introduction

The seriousness of many water pollution problems is just becoming evident to many people today in the United States. Many factors which contribute to pollution are just now being assessed as to their dangerousness. This assessment in many cases is coming after they have become a threat to aquatic life and to man's use of certain bodies of water. Our purpose in this report is to anticipate how much damage a specific pollutant, heat, does to a specific form of aquatic life, the golden shiner (Notemingonous crysoleucas).

At present thermal pollution is not a serious threat to aquatic life. However, as nuclear power plants are constructed, the problem will become portentious. In the next 30 years the power needs of the United States are likely to increase on the order of nine fold.[1] Nuclear plants are expected to handle a large part of this increase. Nuclear plants need large amounts of water to cool the reactor cores. John Clark has estimated that with such a large number of nuclear plants, up to one-third of the average daily freshwater run-off in the United States would be required to cool the reactor cores.[2] In the summer months of low flow this average figure of one-third could go up to virtually 100% of the run-off.[3] In the summer months many rivers reach a natural temperature of 90 degrees (F) which is already close to many fish's lethal level. The reactors would raise the temperature of the water used for cooling about 10 degrees (F) which in the summer, with temperatures already perilously high, would be fatal.

Our project attempts to analyze the effect of certain temperature levels on the performance of a certain common fish, the golden shiner. A fish's performance is measured by its cruising speed. The cruising speed of fish is that swimming speed which it can maintain for long (greater than one minute) periods of time. An apparatus was constructed in which a group of temperatures could be maintained while the fish's maximum cruising speeds could be measured at any given time. The group of temperatures correspond to those that the fish are likely to encounter in rivers of both normal and abnormal temperatures. The oxygen content of the water was kept maximal for each temperature.

II. Procedure and Apparatus

The fish, golden shiners, were purchased from a bait store. They had been taken from their natural habitat only a short time before purchase. The fish then were allowed to acclimate themselves to a higher temperature existence in the storage aquarium for three to four days before testing. They naturally lived in water around 12°C. Acclimation to higher temperatures was said by Jones[15] to occur in a few hours. We felt that several days acclimation would be more than adequate for the fish. Water tests were run both on the aquarium storage water and on the test water in the apparatus to insure that no significant chemical differences existed. Of the tests (calcium hardness, chlorides, pH, copper, and carbon dioxide) only the chloride content varied significantly between the two. The chloride content was 80 p.p.m. in the storage tank and only 30 p.p.m. in the test water.

Before each test, each fish was weighed and measured (length) to insure that there were no great deviations in size. As can be seen from data sheet 2.1, the average deviations in size fell within the measurement error ranges for both length and weight. The extreme measurements deviated only 5% from the total average length and weight.

If the test temperature was more than three to four degrees away from the aquarium temperature, the fish were given a special acclimation period where they were allowed to float in a beaker of storage water in a tub of test water. The temperature in the beaker was thus slowly brought to that of the test water. The time period of this acclimation varied from five to fifteen minutes. All fish were then acclimated in the test apparatus for ten minutes while the apparatus ran at very low speed (less than 0.05 m.p.h.) to provide sufficient oxygen for the fish.

The apparatus itself was constructed from plastic and rubber hosing (1½ inch internal diameter), plastic garden hose, copper tubing, various condensers and adapters, valves, and a large plastic tube (of 1 7/8 inch internal diameter). A head tank of 150 gallon capacity was used along with a pump capable of pumping 49 gallons per minute to a height of five feet. The head tank was aerated at an extremely fast rate by two large air pumps working in opposition to each other. The entire apparatus excluding the head tank and air pumps was attached to a large wooden backboard.

Refer to diagram No. 1. The head tank (7) is aerated by the opposing air pumps (A.P.). A rubber hose (9) was filled with pinholes allowing air in large quantities to aerate the water to maximum oxygen content (tests with an oxygen meter established that we had indeed maximum oxygen content). A thermometer (8) was placed in the tank to monitor temperatures there which had to be constant for the water in the fish tube (10) to be constant. The pump (P) pumped the water down into a large horizontal tube (12) from whence it flowed down through several manifolds (11). The flow through these manifolds was controlled by valves (V). The water then flowed through several copper coils in buckets (1-6). Here the water was heated or cooled. When heat was desired, hot water ran into the buckets from a faucet and was siphoned off by a siphoning system. Both the connections to the faucet and the siphons were made out of garden hose. Ice baths were used to attain lower temperatures. We found that once the head tank water reached the desired temperature, very little alteration of temperature was necessary during the hour and twenty minutes that a test took. Temperatures for the test were taken from a thermometer (13) located in the tube (10) where the fish (14) swam during the test.

Refer to diagram No. 2. Water, after being heated and/or cooled, was collected in the large horizontal tube (16). The water was then forced to flow past two screens (18, 19) (made out of household screen) and a columnator (17). The columnator was constructed out of twenty inch long pieces of glass tubing attached with electrician's tape. The columnator and screens served the purpose of causing turbulent rather than laminar (slow on edges, fast in middle) flow in the fish swimming tube (10). The flow was seen to be turbulent by the insertion of many small air bubbles into the system. As long as the air bubbles traveled the same speed in

DIAGRAM #1

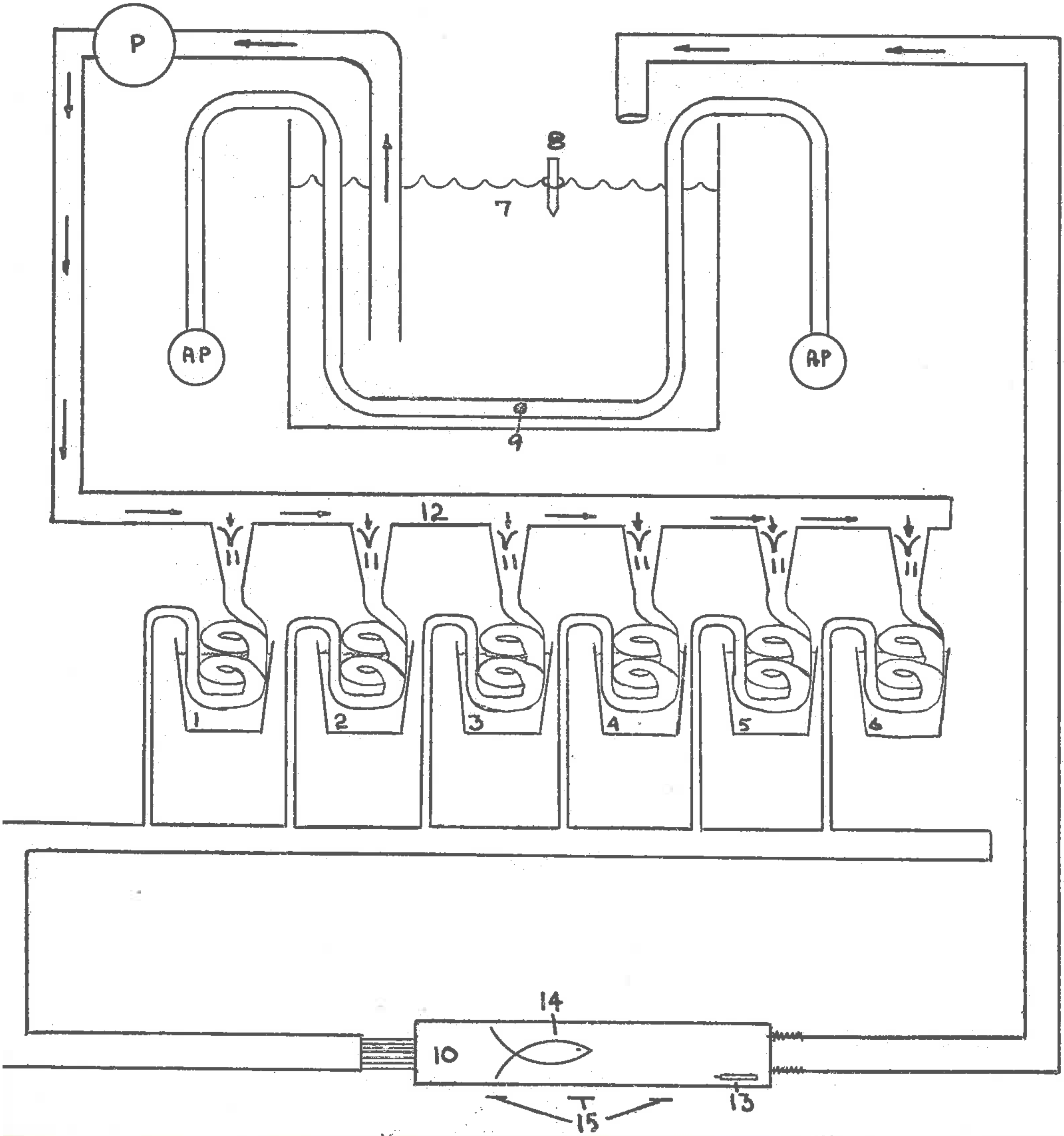
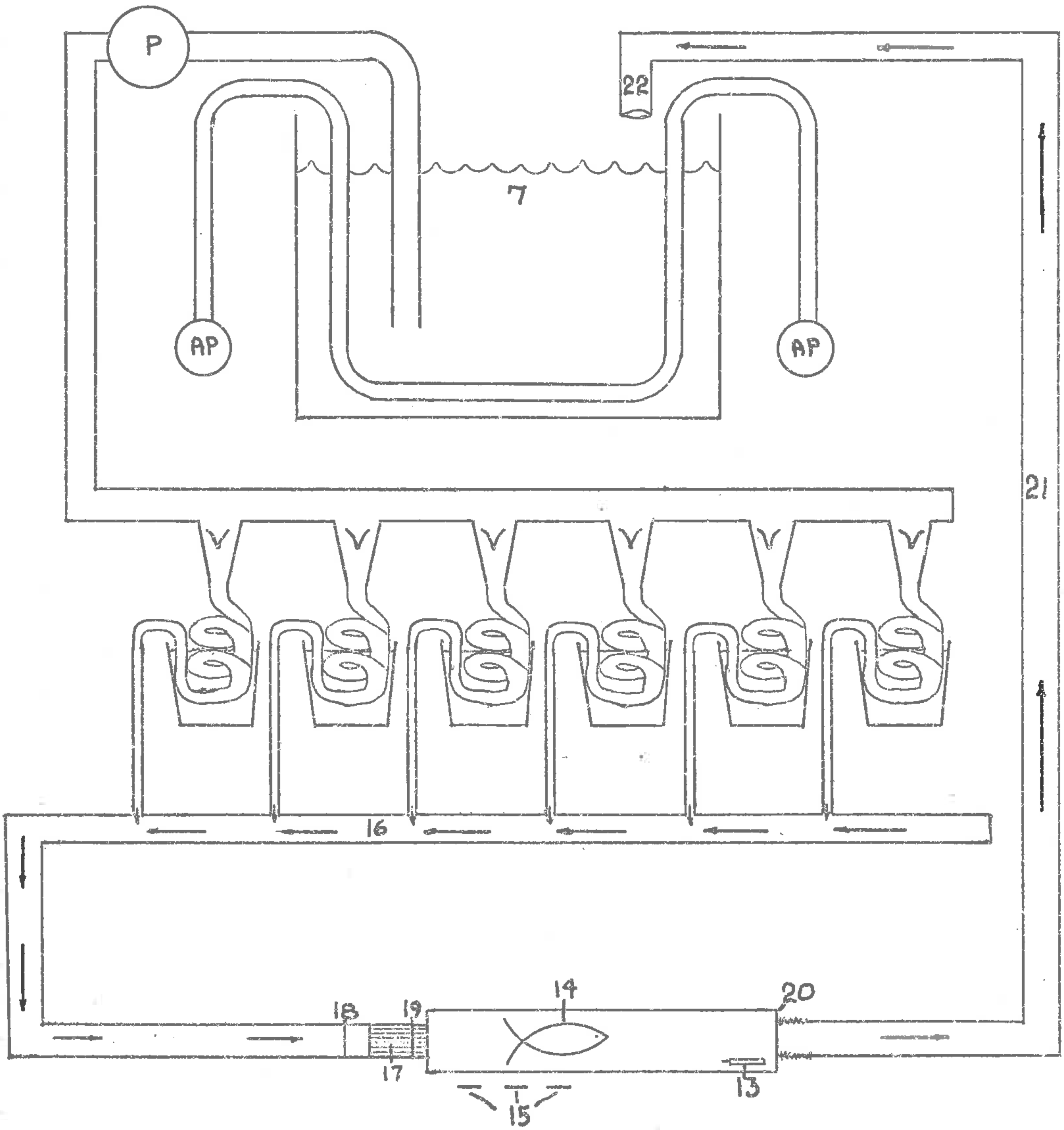


DIAGRAM #2



all parts of the tube, we could be assured that the flow was turbulent. The screens also trapped any particles of debris that went through the system. They were cleaned periodically. Several colored slats (15) were placed under the tube to give the fish orientation references. The thermometer (13) inside the tube also aided the fish in this respect. A screen was also placed at the end of the tube (20) to prevent the fish from simply floating with the flow. The screen also caused irritation to the fish when the apparatus was in operation thus motivating it to swim against the current. The water then flowed up a vertical pipe (21) and back into the head tank through the entry point (22).

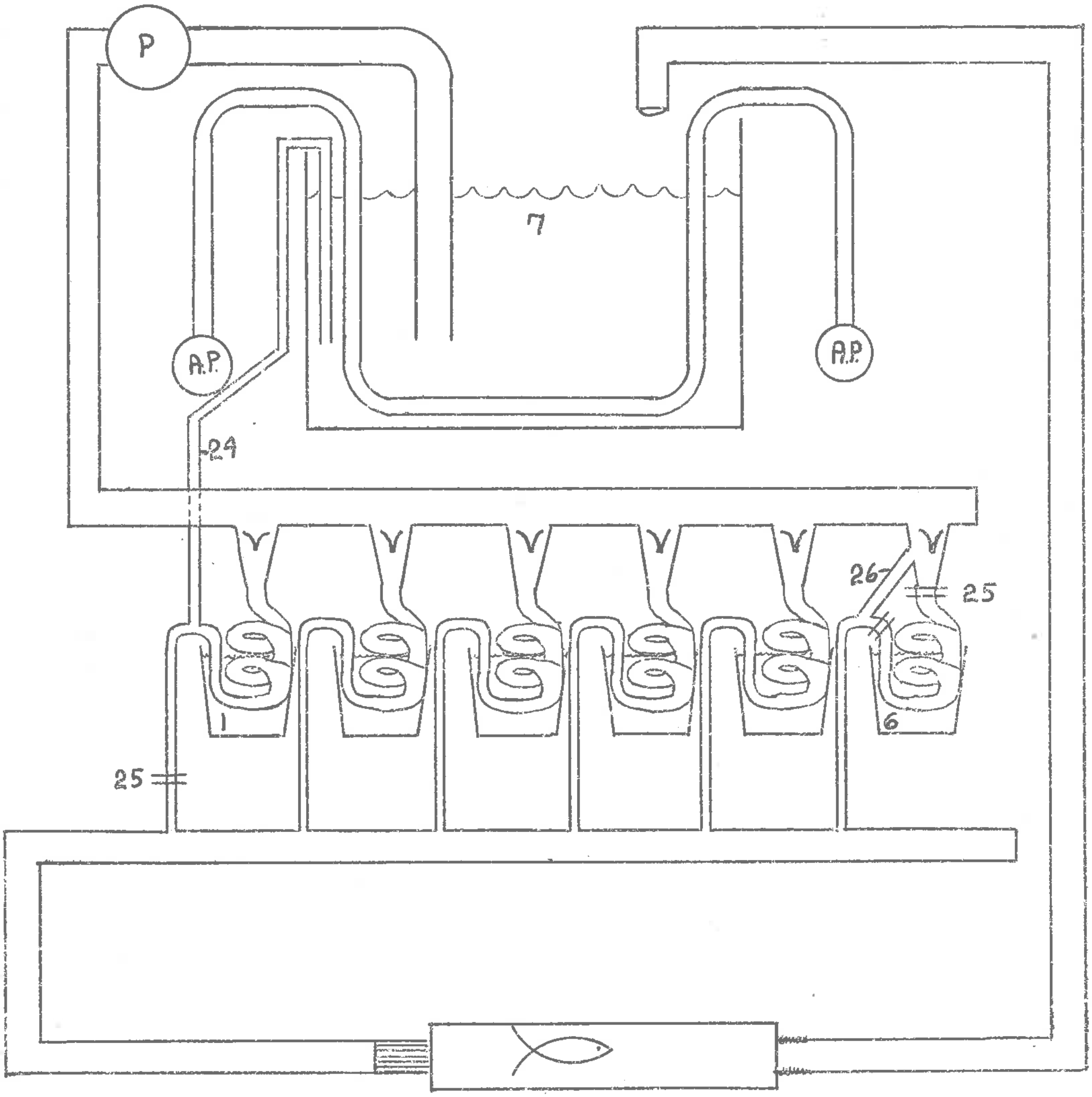
At the entry point (22), the flow of water was determined by measuring the time a liter jar took to fill up at this point (22). We considered a fish to be cruising if it could stay within a small distance (3 inches either way) of one of the colored slats. We adjusted the flow to the maximum at which each fish could cruise, every 10 minutes during the test. After adjusting the flow at the ten minute interval, we measured the time that a liter jar required to fill. A stopwatch accurate to tenths of a second was used and two or three fillings were usually timed to assure accuracy.

Refer to diagram No. 3. Several alterations were made in the apparatus. An altermate path (24) was made, by-passing the first bucket and going directly back into the head tank (7). There were two reasons for doing this. First, a constant strong flow of water through the pump could be maintained thus preventing overheating. Second, extremely low flow could then be maintained through the rest of the apparatus for the purpose of acclimating the fish. Bucket (6) was also bypassed allowing water to go directly to the horizontal collection tube (16). This allowed water to go through the apparatus without being heated or cooled in the coils. We found that we rarely used more than two of the buckets except in the cold water tests where temperature proved the hardest to maintain. All in all, we feel that the apparatus was highly successful in maintaining both speed and temperature levels.

III. Data and Results Section

This section involves the tabulation and graphical interpretation of results

DIAGRAM #3



obtained from the tests. Ten data sheets and ten graphs were made for the data obtained for the ten different testing temperatures. These ten graphs and ten data sheets were not included in this report for reasons of length. However, the graphs were transposed onto two graphs, 1.0 and 1.1. Average data of both performance and biological characteristics were recorded on data sheet 2.1. From the performance data on that sheet a graph was made showing average and maximum cruising speed graphed as a function of temperature. This graph was labeled 1.2.

IV. Conclusions and Discussion

In past studies of the effect of thermal pollution on fishes temperature tolerance levels were stressed. Little effort was made to determine the precise effect of temperature on the performances of fish and thus the effect of temperature on the longer range ability of fish to survive is unknown. As Jones states:

> "Furthermore it must be emphasized that death-point temperatures determined experimentally represent the extreme limits of existence, and the temperature zone within which the life of the fish, in every way, can be said to be normal, may be very much more limited."[4]

Thus, we felt that measuring performance in the form of cruising speed for the period of an hour would give us an indication of the effect of temperature on the endurance as well as the maximum speed of fish. One would expect that the activity of fishes measured by the cruising speed would increase for two reasons. First, the metabolic rate of fishes as well as almost all other organisms increases with an increase in temperature. As John Clark states:

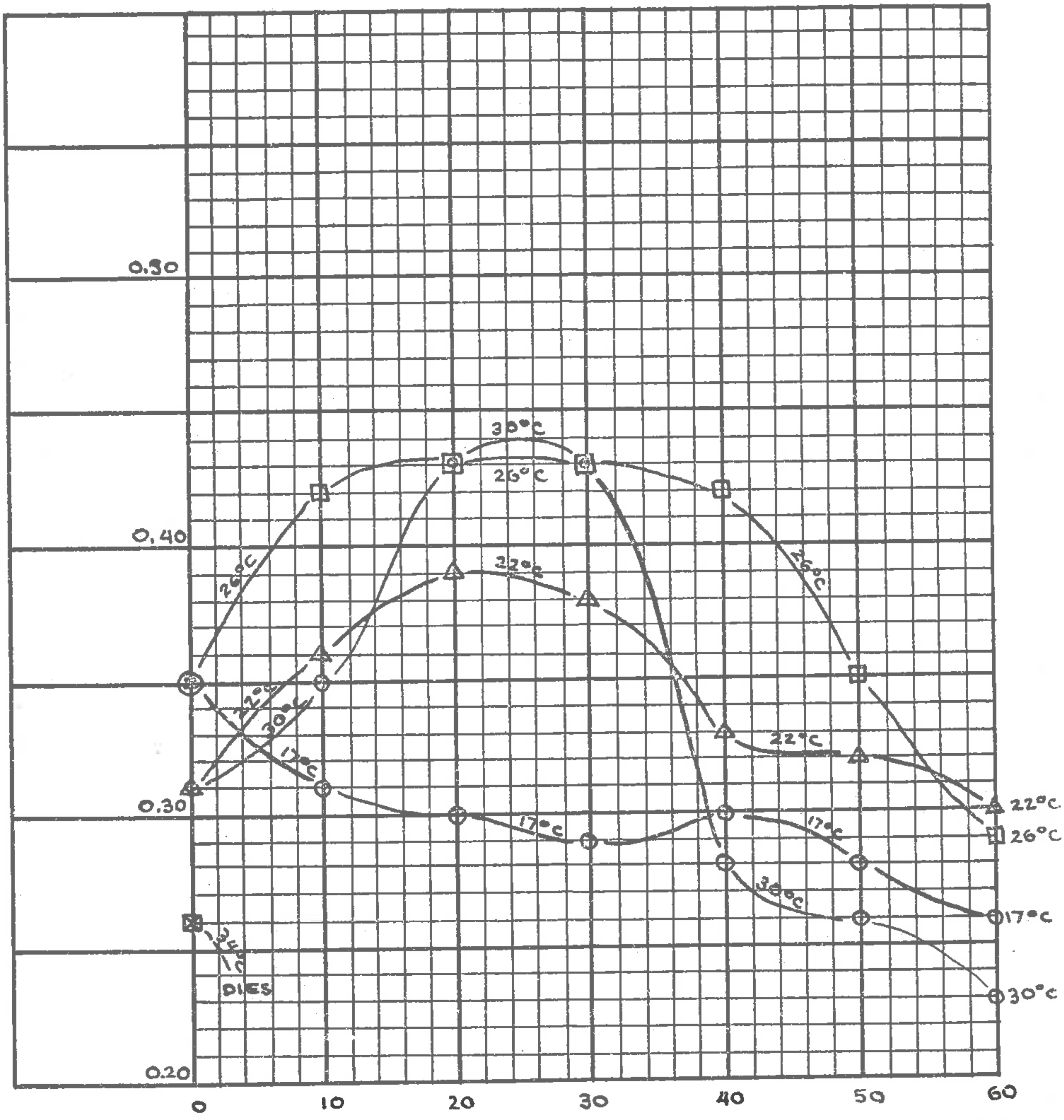
> "Most of the effects (on life processes) stem from the impact of temperature on the rate of metabolism, which is speeded up by heat in accordance with the van't Hoff principle that the rate of chemical reaction increases with rising temperature."[5]

second, as the temperature of water rises, the solubility of oxygen in the water decreases. Fish operating at a faster metabolic rate must swim more quickly to get more water and thus more oxygen through their gills. The change in oxygen level itself does not affect the fish adversely for as Dr. Jones states:

> ". . . provided that the river water and the cooling water discharged are reasonably pure, thermal pollution is not likely to be fatal to fish as a result of changes in the oxygen supply."[6]

GRAPH NO. 1.0

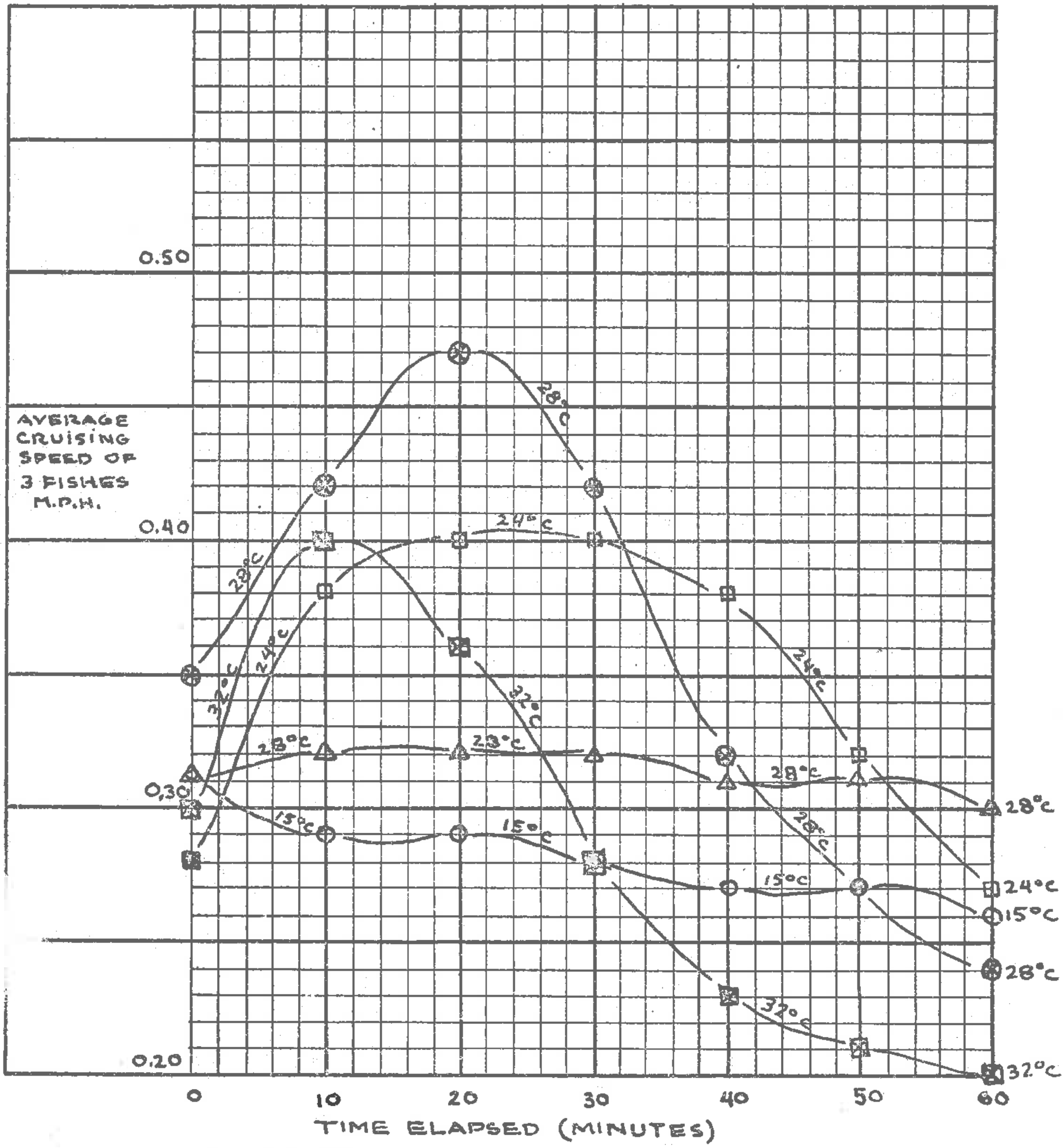
GRAPH OF CRUISING SPEEDS AT SEVERAL TEMPERATURES AS A FUNCTION OF TIME ELAPSED IN TESTS.



KEY AT 17°C ○
" 22°C △
" 26°C □
" 30°C ⊕
" 34°C ⊠

GRAPH NO. 1.1

GRAPH OF CRUISING SPEEDS AT SEVERAL TEMPERATURES AS A FUNCTION OF TIME ELAPSED IN TESTS.



KEY AT 15°C ○
" 20°C △
" 24°C □
" 28°C ⊗
" 32°C ⊠

Data Sheet Number: 2.1

Taxonomic Data Comparison Table

Temperature (degrees C) (±0.2 C)[1]	Average Weight of the 3 fish[1] (g.±.2)	Deviation from Total Average	Average Length of the 3 fish[1] (cm.±.5)	Deviation from Total Average
15.1	14.2	0.0	11.2	+0.2
17.0	14.1	-0.1	11.0	0.0
20.0	13.6	-0.5	10.4	-0.6
22.1	14.1	-0.1	10.9	-0.1
24.1	14.3	+0.1	11.1	+0.1
26.1	14.5	+0.3	11.0	0.0
28.1	14.3	+0.1	11.0	0.0
30.1	13.9	-0.3	10.7	-0.3
32.0	14.7	+0.5	11.2	+0.2
34.0	14.2	0.0	11.0	0.0
Average of the 10	14.2	±0.2	11.0	±0.2

Average Speeds Table

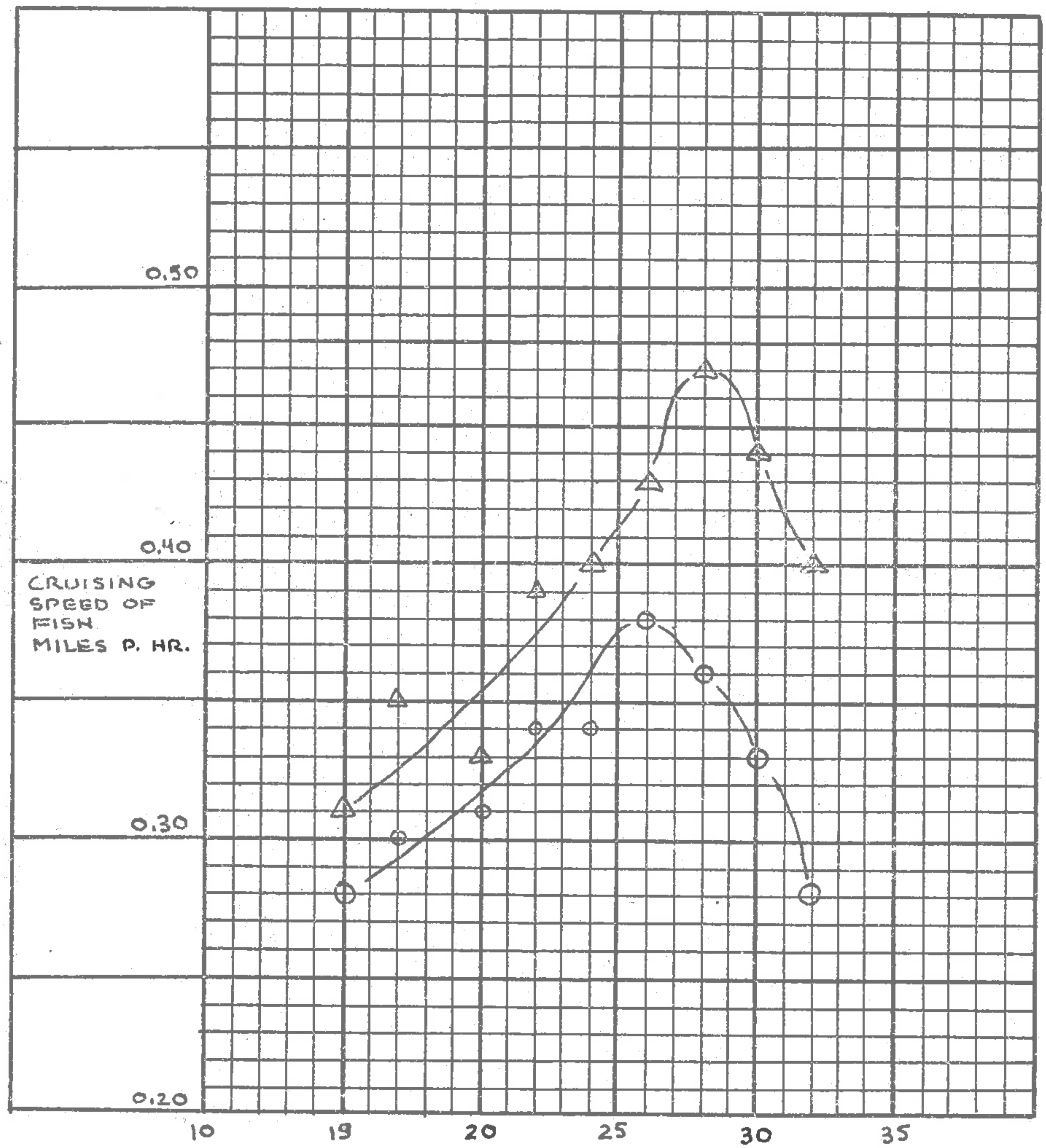
Temperature (degrees C ±0.2 C)[1]	Average Speed of 3 fish during entire test[1] (m.p.h.±0.01)	Average Maximum Speed of 3 fish during test[2] (m.p.h.±0.01)
15.1	0.28	0.31
17.0	0.30	0.35
20.0	0.31	0.33
22.1	0.34	0.39
24.1	0.34	0.40
26.1	0.38	0.43
28.1	0.36	0.47
30.1	0.33	0.44
32.0	0.28	0.40
34.0	—	—

[1]Taken from or averaged from data tables 1–10. (not included in final report)

[2]Average maximum Speed is the average of the maximum speeds which each fish attains during the test.

GRAPH NO. 1.2

GRAPH OF AVERAGE CRUISING SPEED AND MAXIMUM CRUISING SPEED AS A FUNCTION OF TEMPERATURE.



KEY: AVERAGE CRUISING SPEED FOR 3 FISH : O

AVERAGE MAXIMUM SPEED FOR 3 FISH : Δ

Thus, because of falling oxygen levels and an increased metabolic rate one would expect fish to increase their cruising speed as the temperature of water increases.

By looking at graph number 1.2, one can see that both the maximum and average cruising speeds increase with the temperature in equal amounts from 15°C to 26°C. However, after 26°C, the average cruising speed falls off sharply. After 28°C. the maximum cruising speed also begins a sharp decline. One would conclude from the graph that after 26°C a golden shiner's ability to maintain a high average (high enough to cope with decreased oxygen and increased metabolism) speed is seriously affected by any additional rise in temperature. Thus, a fish loses endurance after 26°C. After 28°C, one would conclude that any rise in temperature will affect a fishes maximum speed adversely as it will no longer be able to accelerate to cope with increasing metabolism and decreasing oxygen content. Death occurred at 34°C.

The effects of temperature on endurance can also be observed by looking at performance graphs (1-10) at individual temperatures. Graphs 1.0 and 1.1 were specially prepared for the comparison of individual graphs. Performances at various temperatures fall roughly into three catagories. At 15°C, 17°C, and 20°C the graphs fall into the first category. Here, the cruising speed of the fish remains almost constant (a slight drop is observed) from the beginning to the end of the test. The fishes ability to endure at these temperatures is thus considerable.

A second type of graph is seen at 22°C, 24°C, and 26°C. The fish increases speed during the first half of the test and decreases speed during the second half. The fishes ability to endure is lessened but still present as his performance tends to level out at the end of the test (this leveling tendency is particularly visible at 22°C, less visible at 24°C, and almost absent at 26°C as the graph tends toward the third type).

The third type of graph is represented by those at 28°C, 30°C, and 32°C. Here, the fish reaches a peak speed early in the test. The speed then drops off very sharply and levels off at a very slow speed (both the slowest and fastest speeds recorded were at this temperature). The fact that these fish cannot maintain any sort of higher speed during the entire test indicates that they cannot cope with the decrease in oxygen and increase in metabolic rate brought about by these high temperatures for along period of time. They show an ability to reach a certain top speed, but the ability to maintain speed for a period of time is almost entirely lost. Above 28°C, the height of the early peak in the graph itself falls off showing that even the ability to reach a top speed is affected (because of increasing metabolism, one would expect further rises in maximum speed at 30°C and 32°C, these rises do not occur as maximum speed actually drops off sharply). Death at 34°C was thus not as important as decreases in performance ability which become evident after 26°C and severe after 28°C.

The progression of the graphs can be easily seen on graph 11. Here, at 15°C and 20°C the more or less constant graph can be seen. At 24°C, the fish shows strain as it rises to a maximum speed in the middle of the test. The fish still, however, maintains a fairly fast speed throughout the test. At 28°C and 32°C the fish shows a lack of ability to endure over any long period of time. This effect is more pronounced at 32°C than 28°C as can be seen from a lower final speed and a lower maximum speed and an earlier peak speed. Thus, we would conclude that a golden shiner's endurance is adversely affected by temperatures over 20°C. This effect becomes severe with temperatures over 26°C. Top speed rises as one would expect until 28°C when this too drops off sharply showing the adverse effects of temperature increase. Thus, golden shiners can perform adequately in water up to 26°C although under strain between 20°C and 26°C. Any higher temperature results first in loss of endurance ability, then in loss of maximum speed ability, and finally in death.

The evidence we have obtained compares favorably with that found by other researchers on the effect of temperature on the activity of other species of fish (no work that we know of has been done on the golden shiner). Dr. Jones in his book, Fish and River Pollution, in the chapter on thermal pollution listed some of the body of evidence on the adverse effects of below lethal temperature on the activity of fishes:

> "Evidence is accumulating to show that temperatures which are not so high as to cause death may have very adverse effects on the life

> of fish. The activity of cold-blooded animals usually increases with a rise in the temperature, but the relation is complicated; it has been shown that in certain fish maximum activity is displayed at comparatively low temperatures, and that at higher temperatures it declines. Thus Gibson and Fry have shown that whereas lake trout have an ultimate lethal temperature of 23.5°C their maximum maintained swimming speed is displayed at 16°C. Similarly the goldfish has a cruising speed which rises with the temperature up to about 28°C and then drops sharply, though acclimation to 41°C is possible."[7]

Our findings also show the drop off in maximum cruising speed as temperature increases above a certain level (28°C). However, in addition, we found that the endurance of the fish was strained at 6°C below this turning point for maximum cruising speed and that the endurance began to fall off before (2°C before) the turning point was reached where maximum speed decreased. Dr. Jones states:

> "It is probable that further research will show that for most fish the temperature zone within which the animal lives in comfort and success occupies a comparatively small trapezium inside that indicating the extreme limits of thermal tolerance."[8]

We believe that the range within which a fish's endurance is not diminished by the temperature constitutes the range in which a fish can live with "success and comfort." Studies of the speckled trout[9] indicate that it is "comparatively slow" at catching minnows at 17°C which is close to the temperature at which trout exhibit their maximum cruising speed (the lake trout for example exhibits its maximum at 16°C[7]). Thus, endurance performance might well be a more valid criterion for the determination of the range of temperatures at which a fish lives with "comfort and success." Maximum cruising speed certainly is not a valid criterion for success if fish experience difficulty catching minnows at this temperature. Also, the strain which fish show in enduring test temperatures above 20°C (the strain can be seen as the fish's lack of ability to maintain a constant speed) indicates that the fish is not comfortable at such temperatures.

Our findings for the death point of the golden shiner seemed to match earlier findings. The fishes survived the test at 32°C but died during acclimation or early in the test at 34°C. The thermal death-point for the golden shiner was found to be 30.5°C by an earlier researcher using an acclimation temperature of 15°C.[10] A rise in acclimation temperature of 3°C is known to cause a rise of 1°C in the death-point temperature (as long as the acclimation temperature is well below that death-point).[11] Since our acclimation temperature (the temperature of the storage aquarium) was about 22°C (±1.0°C), one would expect a rise in death-point temperature of about 2°C putting it at 32.5°C. This temperature is between the 32°C where our fish lived and the 34°C where our fish died. Thus it would seem that our results agreed with those of the earlier researcher.

Brett[12] stated "that the upper limit of required temperature for any species of fish should not exceed that which would curtail activity below three-quarters of optimum." This rule clearly does not hold for golden shiners. If activity is meant to be maximum cruising speed, then the fish would die before they reached the point where activity was ¾ of maximum. At 32°C, which was the highest temperature that the fish survived at, the activity, if measured by the maximum cruising speed, was greater than ¾ of the maximum activity. If average cruising speed is taken to measure activity, then 32°C would be the point that was considered the upper limit. However, the fish's lack of endurance at this temperature would certainly make it inadequate as an upper limit. We would set the temperature at which endurance begins to falter seriously as the upper limit for any requirements. This is the temperature at which the average speed curve begins to fall away from the maximum speed curve. Looking at graph 1.2 one can see that this occurs at about 25°C for the golden shiner. The point at which the maximum cruising speed occurs (28°C) certainly cannot be used as a limit since fish have been observed to have difficulty catching minnows at this temperature. We would set the temperature limit where fish can live a "successful and comfortable" life at the greatest temperature at which fish's endurance remains unaffected by the temperature. This would be 20°C for the golden shiner. At this temperature the fish were able to maintain an almost constant speed during the test (see graph 1.1).

Nuclear power plants have been known to warm rivers as much as 8°C in an area extending two miles downstream of the discharge point.[13] This figure was given for the late fall months, but there is no reason to believe that the change in the summer months would be less than 4°C as a maximum. Many streams can reach a temperature of 28°C naturally during the summer (some go as high as 31°C).[14]

Increasing such a temperature even 2°C would clearly be detrimental to any golden shiners exposed to the water. A rise of 4°C would clearly be fatal as the temperature would approach the death level for the golden shiner.

V. Summary

The endurance (constancy of cruising speed) of the golden shiner is lessened by temperatures above 20°C. This effect becomes adversely severe after 26°C. The maximum cruising speed of the golden shiner reaches an optimum at 28°C and thereafter diminishes sharply. The divergence (in the form of lessening more quickly) of the average speed curve from the maximum speed curve indicates the loss of endurance. Our results on the maximum speed curve and on the death point of the golden shiner are supported by other researchers working on it or other fishes. Our results, however, do not support Brett's criterion for the establishment of upper thermal limits. Either our fish is not typical or the criterion is invalid. Endurance capability seems to be a good criterion for establishing both "safe" upper limits and upper limits below which a fish (if it follows the model of the golden shiner) can live with "success and comfort." The effluent of nuclear power plants clearly would endanger the golden shiner during summer low-flow months.

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