THE EFFECT OF TEMPERATURE ON THE SETTLING VELOCITIES OF AN ESTUARY MUD

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JULY 1972

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Report No
INT 106

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1. Effect of temperature on settling velocity

2. Typical settling velocity grading curves with varying temperature.

SUMMARY

The report describes an extension of the studies discussed in a previous report "A detailed study of the settling velocities of an estuary mud", Report No INT 78, September 1970.

Further detailed tests on a mud obtained from Avonmouth in the Severn Estuary were carried out in a bottom withdrawal tube 2 metres high to determine the effect of temperature on settling velocities.

After allowing for changes in the viscosity of the suspension due to the variation in temperature, the settling velocities were found to vary little with temperature, with only a slight tendency towards greater flocculation and higher settling velocities at increasing temperatures.

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INTRODUCTION

This brief report forms an extension of the previous report "A detailed study of the settling velocities of an estuary mud", Report No INT 78, September 1970, and should be read in conjunction with that report.

The previous tests were designed to study the effect on the settling velocity of salinity, suspended concentration, and depth of settling. The tests described in this report extend this list of variables by studying the effect of temperature on the settling velocity.

In the section of the previous report which dealt with the theory of flocculation, it was pointed out that the probability of collision due to Brownian motion depends on the temperature of the suspension. There is a small direct influence of temperature on the actual Brownian motion, and a larger effect due to the variation of viscosity with temperature, as reflected in Equation I of the previous report. At the same time, once the floc has been formed, the variations of viscosity with temperature affect the settling velocity, by altering the drag coefficient of the floc settling through the suspension. In all these above mentioned effects one would expect to obtain higher settling velocities at increased temperatures.

SCOPE OF TESTS

In order to cover a range of temperatures likely to be experienced in estuaries, tests were carried out at fixed temperatures of 5, 15 and 25^{o}C. At each temperature, tests were carried out at all combinations of salinities of 2, 8 and 32 g/l, and suspended concentrations of 0.25, 1.0 and 4.0 g/l. For all tests, a 2.0 metre depth of settling was adopted.

The mud used in these tests was obtained at a later date than those used in the previous studies, and although obtained from the same location during a similar tide, gave slightly higher settling velocities. The results of these tests cannot therefore be directly combined with those of the previous studies, although the influence of the different variables, such as salinity and concentration, will be similar for both sets of tests.

DESCRIPTION OF APPARATUS

A bottom withdrawal sedimentation tube of length 2.0 metres, as used in the previous studies, was enclosed in a perspex tube, through which was circulated water at a constant temperature. The temperature was controlled by equipment capable of maintaining the prescribed temperature to within $\pm$0.5^{o}C. In all other respects the tests were conducted in exactly the same manner as these described in the previous report.

RESULTS AND DISCUSSION

The complete results of the tests carried out to determine the effect of temperature on settling velocity are given in Table I. This gives the salinity, concentration, and temperature of each test, and the values obtained for the median settling velocity, the upper deviation, i.e. w_{84}/w_{50}, and the lower deviation, w_{50}/w_{16}. In order to try to eliminate the effect of temperature on viscosity, the measured settling velocities were corrected to a standard temperature of 20°C by multiplying by the ratio of the viscosity at 20°C to that at the test temperature. For particles in the Stokes range, this operation gives the truly correct settling velocity. However, mud flocs in all probability fall slightly outside the Stokes range because of their relatively large diameter and high settling velocity, so that the correction applied is only approximately true, although the deviation will be small. The corrected median settling velocities are included in Table I, and are plotted against temperature in Fig 1 for each combination of salinity and suspended concentration. The standard deviation of settling velocities obtained for each test is also plotted on this figure. Typical settling velocity grading curves at the different temperatures are shown in Fig 2, in this case for a suspended concentration of about 1 g/l and a salinity of about 8 g/l. The settling velocities in each case have been corrected for viscosity changes, and brought to a standard temperature of 20°C.

In comparison with Fig 8, 9 or 11 of the previous report, Fig 2 indicates that the effect of temperature on settling velocities, after allowing for changes in viscosity, is very small compared with the effect of salinity, concentration or depth of settling. This is confirmed by comparison of Fig 1 with Fig 6, 7 or 10 of the previous report.

As the temperature increases from 5°C to 15°C, Fig 1 shows that the corrected median settling velocities are either virtually unchanged or increase slightly for seven of the tests, and decrease for the other two. These two tests appeared to be distributed randomly among the various combinations of salinity and concentration, and no discernible pattern emerges. In general the corrected settling velocities increase by about 10% as the temperature changes from 5°C to 15°C, although it must be pointed out that the accuracy of the settling velocity measurements is considerably worse than this, because of the great difficulty of reproducing exactly all the conditions in each test. Changes in the viscosity of the suspension would cause an additional 33% increase in settling velocity over this temperature range.

Examination of the standard deviations on Fig 1 shows that there is very little overall change in the spread of the settling velocities over the temperature range of 5°C to 15°C, with possibly a slight tendency to lower standard deviations indicating a greater degree of flocculation.

As the temperature is increased further, from 15°C to 25°C, the corrected median settling velocities appear to increase slightly for some of the tests, with an almost equal number having decreased values. All the tests carried out at the salinity of 2 g/l, and that at a salinity of 8 g/l, concentration 0.25 g/l have reductions in corrected settling velocity of the order of 50%, whereas the other tests show an increase of about 25% over this temperature range. Changes in the viscosity of the suspension would lead to an additional increase of about 28%, so that the low salinity tests have reductions in actual, rather than corrected, settling velocities of about 20%. However the standard deviations on Fig 1 show a tendency to decrease in most of the tests, including those showing reductions in settling velocity, indicating further enhancement of flocculation.

It is not very common for enhanced flocculation to result in reduced median settling velocities, as appears to happen at low salinities as the temperature increases from 15°C to 25°C. As flocculation occurs, two processes take place which have an opposing effect on the settling velocity. Firstly, flocculation causes an increase in the floc diameter, which tends to raise the settling velocity. However the water trapped between the particles or groups of particles forming the flocs generally leads to a reduced floc density with increasing size, and hence to a decrease in the settling velocity. Normally the increased diameter effect outweighs the reduced density, and flocculation results in higher settling velocities. In these particular tests however the reduced density appears to outweigh the increased diameter.

CONCLUSIONS

Further studies of Avonmouth mud have shown that the effect of temperature on the settling velocities of flocs formed in suspensions of varying salinity and concentration is largely limited to the effect temperature changes have on the viscosity of the suspension. After correcting the measured settling velocities for this variation in viscosity, there appeared to be a slight tendency to increased flocculation at higher temperatures, generally accompanied by slightly greater median settling velocities. However, at temperatures above 15°C the settling velocities of flocs formed in low salinity suspensions decreased.

Over the normal range of temperatures, the effect on median settling velocities is small in comparison to the effect of concentration, salinity, or depth of settling.

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TABLE

TABLE I

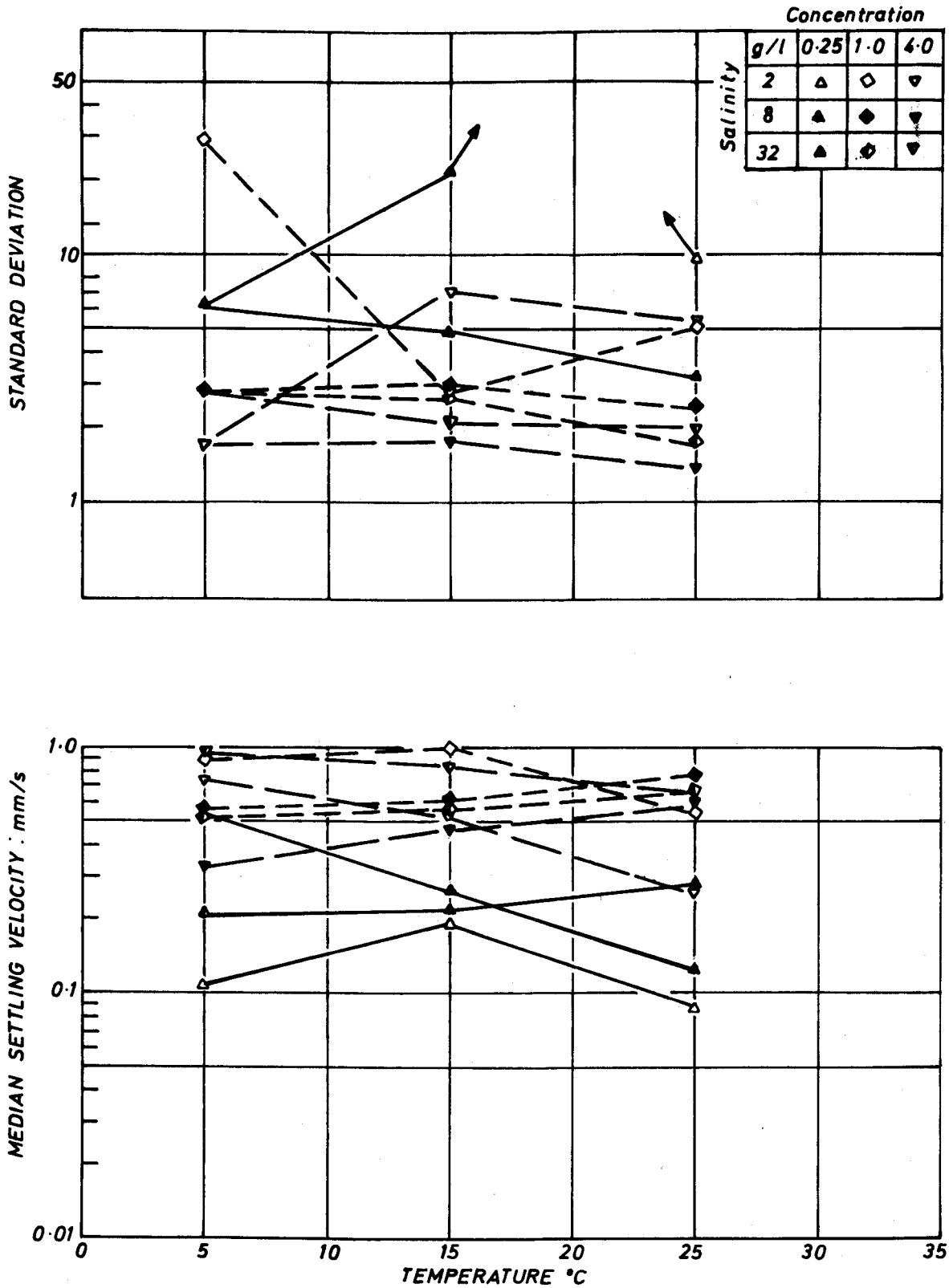
Results of temperature tests

Test Number	Concentration g/l	Salinity g/l	Median settling velocity w_{50} mm/s	Corrected median velocity† mm/s	Upper deviation w_{84}/w_{50}	Lower deviation w_{50}/w_{16}
			Temperature 5°C			
Aa	0.215	2.37	0.075	0.11	3.5	*
Ac	0.216	8.14	0.36	0.54	2.5	17
Ae	0.240	29.5	0.14	0.21	2.4	17
Ca	0.763	2.54	0.59	0.89	2.2	390
Cc	1.618	8.31	0.37	0.56	1.5	5.1
Ce	1.240	30.2	0.34	0.52	1.6	5.0
Ea	3.52	2.37	0.49	0.74	1.4	2.1
Ec	4.00	8.31	0.22	0.33	1.9	1.5
Ee	3.50	32.4	0.62	0.94	1.6	4.8
			Temperature 15°C			
Aa	0.214	2.21	0.17	0.19	2.6	*
Ac	0.209	8.31	0.23	0.26	2.5	190
Ae	0.228	29.8	0.19	0.22	2.2	11
Ca	0.944	2.54	0.86	0.98	1.5	5.4
Cc	0.920	7.97	0.54	0.61	1.4	6.5
Ce	1.083	30.2	0.49	0.56	1.5	4.9
Ea	3.45	2.20	0.46	0.52	1.5	35
Ec	4.08	8.14	0.41	0.47	1.7	1.8
Ee	3.35	31.7	0.73	0.83	1.5	3.0
			Temperature 25°C			
Aa	0.197	2.20	0.10	0.089	3.2	30
Ac	0.195	7.81	0.14	0.125	2.8	*
Ae	0.224	30.2	0.32	0.28	1.8	6.0
Ca	0.864	2.37	0.62	0.55	1.6	17
Cc	0.917	7.97	0.88	0.78	1.4	4.0
Ce	1.060	31.2	0.75	0.67	1.4	2.0
Ea	3.53	2.37	0.29	0.26	1.7	17
Ec	3.87	8.14	0.68	0.60	1.3	1.4
Ee	3.43	31.4	0.74	0.66	1.5	2.6

* w_{16} too low to be accurately determined.

† Median settling velocity corrected for viscosity variations to standard temperature of 20°C.

FIGURES



EFFECT OF TEMPERATURE ON SETTLING VELOCITY

FIG 1

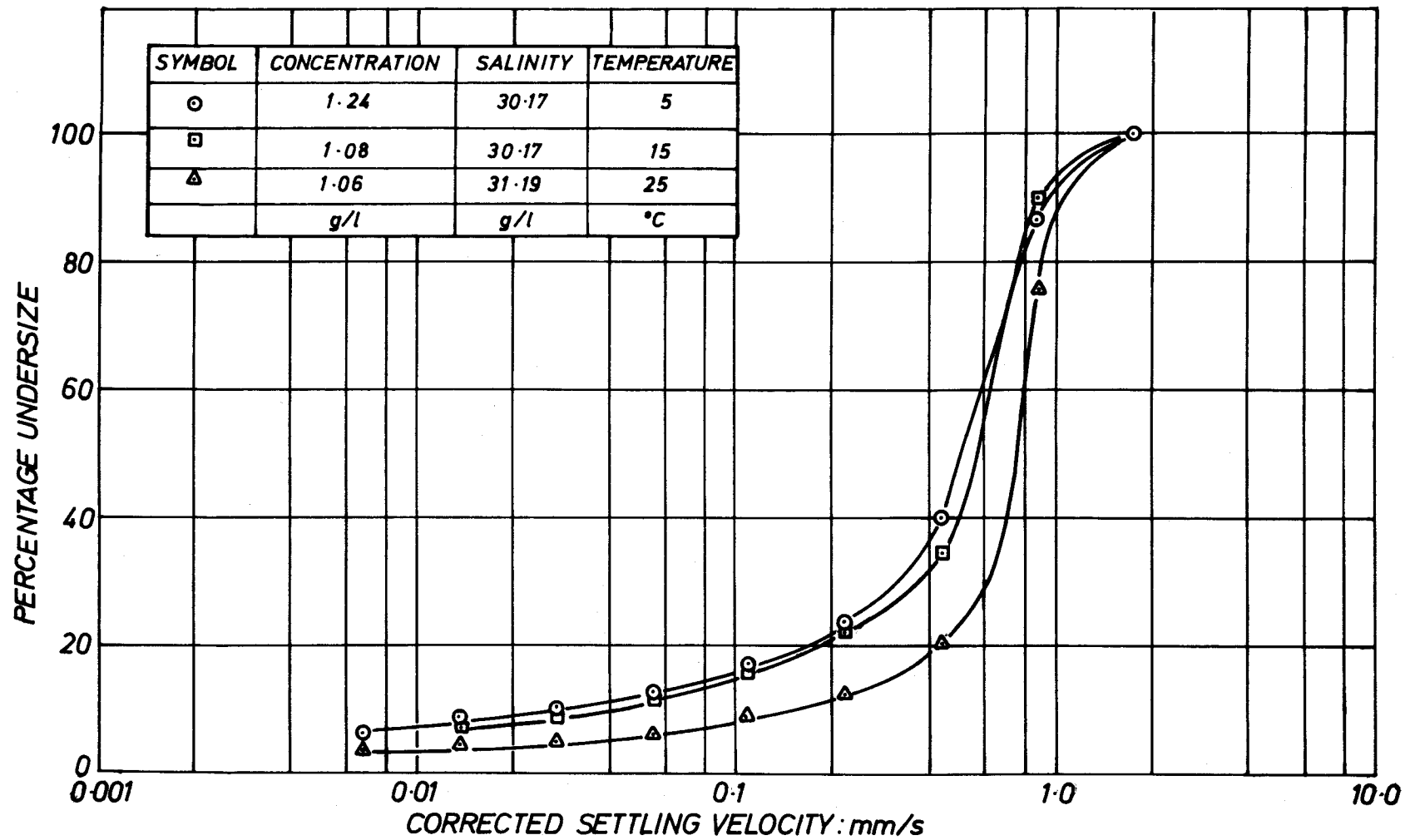


FIG 2

TYPICAL SETTLING VELOCITY GRADING CURVES WITH VARYING TEMPERATURE