Studies in Environmental Science 5

INDUSTRIAL WASTE WATER MANAGEMENT

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INTRODUCTION

All over the industrial world legislation with regard to the discharge of industrial waste water is being sharpened. Many industries, which have not previously considered waste water as any problem at all, are now being forced to think along new lines, such as: Which waste water treatment methods are available? Is it feasible to change the quality and/or the quantity of the waste water? Will it be profitable to consider complete or partial recirculation and recovery?

Generally, industrial waste water plants must be tailored. Only in very few cases can standard solutions be applied or are even available at all.

The best solution to waste water problems can only be found by teamwork between the industrial engineer and the industrial waste water specialist. It is the aim of this book to serve as a bridge between the two, since no fruitful dialogue is possible unless all participants have a survey of the problems and the solutions available.

Billions of dollars will be invested in industrial waste water plants in the coming decade, and for many industries the right choice of the waste water treatment methods available might be a matter of life or death. The problem is very complex, as not only the cost of the treatment, but also the increasing cost of water supply and raw materials, the change of manufacturing methods and the discharge criteria influence the final selection of waste water management. Consequently, industries cannot simply give the problem to a waste water specialist, but must with their own engineers be involved in selection of the right method.

The first part of the book is devoted to unit processes of industrial waste water treatment. Here the industrial engineer can find the theory, the characteristics, the design data, the application area and the advantages and disadvantages of the most used treatment methods of to-day.

The second part of the book provides a survey of industrial waste water problems. For the different industries, the basic questions of what is the characteristic of the waste water and which methods have been used to treat the different types of waste water are answered.

It is of course not possible to give all details about the different processes applied to all types of waste water, because of the limited space, but the many references make it feasible to find further details for each present-day case.

The comprehensive index will hopefully make it possible for the book also to be used as a handbook in industrial waste water management.

CONTENTS

CHAPTER 31

CHAPTER 1

SEDIMENTATION

SEDIMENTATION PROCESSES

Sedimentation is used to remove suspended solids from waste water. The settling tank has three main functions:

(1) It must provide for effective removal of suspended solids so that its effluent is clear.

(2) It must collect and discharge the subnatant stream of sludge.

(3) It must thicken the sludge to a certain concentration of solid.

Three distinct types of sedimentation may be considered:

(1) Discrete settling. This is the settling of a dilute suspension of particles which have little or no tendency to flocculate.

(2) Flocculent settling, which occurs when the settling velocity of the particles increases as they fall to the bottom of the tank, due to coalescence with other particles.

(3) Zone settling, which happens when interparticle forces are able to hold the particles in a fixed position relative to each other. In this case the particles sink as a large mass rather than as discrete particles.

Mathematical descriptions of the three cases must be treated separately.

Discrete settling

The settling of a discrete non-flocculating particle in a dilute suspension can be described by means of classical mechanics. Such a particle is not affected by the presence of other particles, and settling is therefore a function only of the properties of the fluid and the characteristics of the particles. As shown in Fig. 1.1, the particle is affected by three forces:

(1) Gravity, F_g, (2) the buoyant force, F_b and (3) the frictional force, F_f.

In accordance with Newton's second law of motion, we can set up the following equation:

$$m\frac{dv_s}{dt} = F_g - F_b - F_f \qquad (1.1)$$

where v_s = the linear settling velocity of the particles, m = the mass of the particles and t = time.

Gravity is given by:

$$F_g = \rho \cdot V \cdot g \tag{1.2}$$

where ρ = the particle density, V = the particle volume and g = the acceleration due to gravity.
The buoyant force is:

$$F_b = \rho_e \cdot V \cdot g \tag{1.3}$$

where ρ_e = the fluid density.

The frictional force is a function of different particle parameters, such as roughness, size, shape and velocity of the particle, and of the density and viscosity of the fluid. It can be described by the following relationship:

$$F_f = \frac{C_d \cdot A \cdot \rho_e \cdot v_s^2}{2} \tag{1.4}$$

where C_d = Newton's dimensionless drag coefficient and A = the projected particle area in the direction of the flow. C_d varies with Reynolds number.

By substituting the equations (1.2),(1.3) and (1.4) in equation (1.1), an expression for the dynamic behaviour of the particles is obtained:

$$m \cdot \frac{dv_s}{dt} = g(\rho - \rho_e)V - \frac{C_d \cdot A \cdot \rho_e \cdot v_s^2}{2} \tag{1.5}$$

After an initial transient period the acceleration becomes zero and the velocity is constant. This velocity can be obtained from equation (1.5):

$$v_s = \left(\frac{2g(\rho - \rho_e) \cdot V}{C_d \cdot \rho_e \cdot A}\right)^{1/2} \tag{1.6}$$

If the particles are spherical and the diameter is d, the V/A is equal to 2/3·d and equation (1.6) becomes:

$$v_s = \left(\frac{4g(\rho - \rho_e)d}{3C_d \cdot \rho_e}\right)^{1/2} \tag{1.7}$$

Newton's drag coefficient C_d is, as mentioned, a function of Reynolds number and of the shape of the particle. The relationship between C_d and Reynolds number for spheres and cylinders is given in Fig. 1.2.

When Reynolds number is below 1, the relationship between C_d and Re can be approximated by $C_d = \frac{24}{Re}$, where Re = Reynolds number defined as:

$\frac{d \cdot \rho_e \cdot v_s}{\mu}$, where μ = the viscosity.

In this case (1.7) conforms with Stokes law:

$$v_s = \frac{g}{18\mu}(\rho - \rho_e) \cdot d^2 \qquad (1.8)$$

From Fig. 1.2 it can be seen that C_d is approximately constant for turbulent flow in the range for Reynolds number between 1000 and 250,000. For this region the velocity v_s is given by:

$$v_s = 1.82 \left(\frac{(\rho - \rho_e) \cdot d \cdot g}{\rho_e} \right)^{1/2} \quad \text{(for spheres only)} \qquad (1.9)$$

If we consider a section of an ideal settling tank, the particles and velocity vectors are equally distributed, the liquid moves as an ideal slug and all particles reaching the bottom are effectively removed. We can then set up the following equation (Camp, 1946):

$$v_s = \frac{Q}{A} \qquad (1.10)$$

where Q = the rate of flow through the tank and A = the tank surface area. All particles with settling velocities greater than v_s will be completely removed, and particles with settling velocities v less than v_s, will be removed in the ratio v/v_s.

If clear water is drawn off at a surface rate Q/A, the particles should settle at a velocity just opposed by the velocity of the rising liquid. Under such circumstances the top particles will of course be stationary and never reach the bottom, so the overflow rate in equation (1.10) must be considered as a critical minimum value for clarification.

Example 1.1

100 m^3/h of waste water must be treated. Discrete settling can be considered of spherial particles with a diameter of approximately 0.1 mm and specific gravity of 1.01 g/ml. Calculate the necessary surface area.

Solution

Assuming that Re < 1, then

$$v_s = \frac{10}{18\cdot 10^{-3}}(1010 - 1000)\cdot(10^{-4})^2 = 5.56\cdot 10^{-5} \text{ m/s, as } \mu = 10^{-3} \text{ Pa/s.}$$

For water:

$$Re = \frac{10^{-4}\cdot 1000\cdot 5.56\cdot 10^{-5}}{10^{-3}} = \ll 1$$

The assumption was right, and:

$$A = \frac{Q}{v_s} = \frac{100/3600}{5.56\cdot 10^{-5}} \cong 500 \text{ m}^2.$$

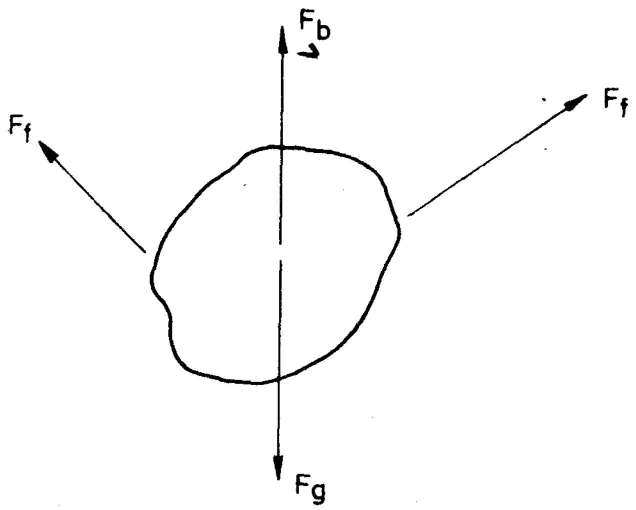

Fig. 1.1. The settling particle is affected by three forces: The gravity, F_g, the buoyant force, F_b and the frictional force, F_f.

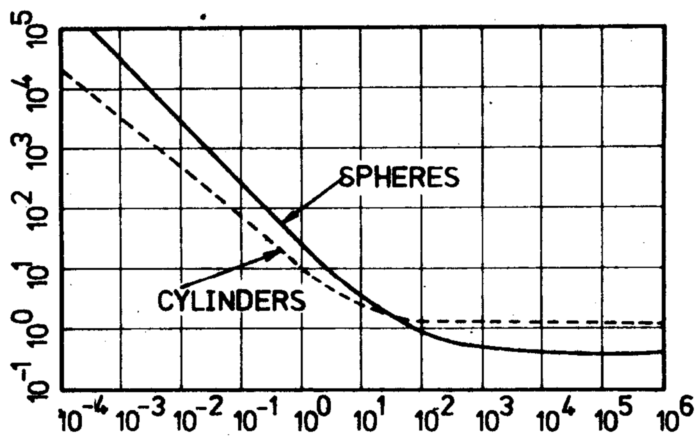

Fig. 1.2. Experimental variation of the drag coefficient with Reynolds number. After Fair et al. (1968).

Flocculent settling

Suspended solid in industrial waters cannot usually be described as discrete particles. If any of the interacting particles have characteristics which might cause agglomeration, growth of individual particles to larger sizes is a natural consequence. Hence, the greater the tank depth, the greater is the opportunity for contact among particles and so sedimentation depends on the depth as well as on the properties of the fluid and the particles.

As yet, there is no satisfactory formulation for predicting the effect of flocculation on the settling rate. Thus flocculent settling requires extensive testing to define the characteristics of the waste water.

Evaluation of the sedimentation characteristics of flocculent settling can be accomplished by placing a quantity of the waste water in a column similar to the one shown in Fig. 1.3. The suspension is settled and the concentration of the particles is determined on samples withdrawn at the different sampling points. The fraction of the particles removed at each step is used to construct lines showing equal fraction or equal per cent removal as illustrated in Fig. 1.4. The lines are called isoconcentration lines: The per cent maximum settling path for the indicated per cent removal.

If the tank has an overflow rate of $v_1 = H_4/t_2$ all particles having a settling velocity $\geq v_1$ will be removed from the tank and particles with a velocity $v < v_1$ will be removed in proportion to v/v_1.

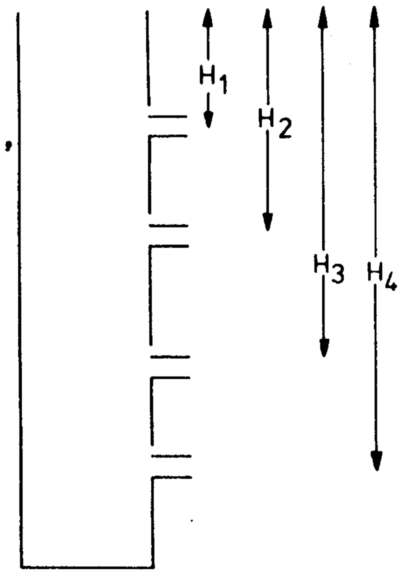

Fig. 1.3. Column with four sampling points for settling tests.

Fig. 1.4 shows that the remaining solid between R_a and R_b has settled with an average velocity of $v = H'/t_2$ and the solid between R_c and R_d has settled with an average velocity of H''/t_2. An approximation for the total overall removal, R, by the chosen overflow is given by:

$$R = R_c + \frac{H'}{t_2 \cdot v_1}(R_b - R_c) + \frac{H''}{t_2 \cdot v_1}(R_a - R_b) \qquad (1.10)$$

This approximation can be improved by adding more terms and increasing the interval between the isoconcentration lines.

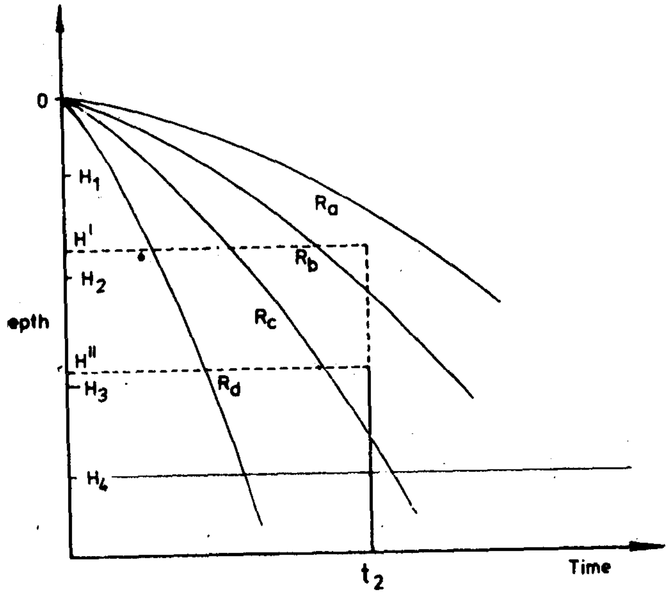

Fig. 1.4. The result of a settling test illustrated with isoconcentration lines: R_a, R_b, R_c and R_d.

Zone settling

Zone settling of activated sludge and flocculated chemical suspension occurs when the concentration of solids exceeds approximately 0.5 g/l. The particles form a mass, which settles as a blanket with a distinct interface between the settling sludge and the clarified effluent. The interface can be observed in a batch settling test. Initially all the suspension is at a uniform concentration and the height of the interface as Z_o (see Fig. 1.5 which shows the height of the interface plotted against time). In the region A-B, settling is hindered, but proceeds at a constant rate. The region B-C shows a transition into the compression zone, represented by C-D. The zones are further illustrated in Fig. 1.6.