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A RADIOACTIVE TRACER TECHNIQUE TO STUDY THE HYDRODYNAMIC BEHAVIOUR OF AN EFFLUENT DECONTAMINATION PLANT

by

R. LOPES CARDOZO, J. VACCAREZZA, C. MONFRINI and S. VANUZZI

1969

Joint Nuclear Research Center
Ispra Establishment — Italy

Chemistry Department
Organic Chemistry

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ABSTRACT

Some radioactive tracer experiments for the determination of the hydrodynamic behaviour of a plant used for decontamination of 2.5 m^3/h of radioactive effluent are described. I ^{131} has been used as tracer.

The equipment consists of a mixer and a flocculator. It is shown that the mixer behaves ideally and that the flocculator is functioning in a rather inefficient way. Some possible improvements of the equipment are indicated.

KEYWORDS

TRACER TECHNIQUES
DECONTAMINATION
RADIOACTIVE WASTES
IODINE 131
TESTING
MIXER-SETTLERS
FLUID FLOW

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A RADIOACTIVE TRACER TECHNIQUE TO STUDY THE HYDRODYNAMIC BEHAVIOUR OF AN EFFLUENT DECONTAMINATION PLANT*)

1. INTRODUCTION

In order to get acquintained with the use of radioactive tracers in the art of effluent treatment, some tests were executed to establish the hydrodynamic behaviour of a mixer and flocculator in use at the C.C.R. Ispra. The effluent decontamination plant, described elsewhere [1,2,3], treats radioactive effluent at a flow rate of 2.5 m^3/h by classical Ca^{2+} - Fe^{3+} - PO_4^{3-} flocculation-sedimentation at pH 11.

As tracer Iodine-131 (half-life 8.05 days, $\beta^- = 0.61$ MeV and $\gamma = 0.364$ MeV mainly) was chosen, since it has a sufficiently long half-life to permit easy counting. On the other hand, its half-life is short enough to permit a reasonable storage time before discharge. Furthermore, the iodine, present as KI, does not interfere markedly with the sludge, by sorption or reaction, so that it indicates the true water-path.

2. EQUIPMENT

The flocculation takes place in a small baffled mixer (Figure I), equipped with four equidistant baffles of 13 cm width, to which the effluent containing already the appropriate concentration of Ca^{2+}, Fe^{3+} and PO_4^{3-}-ions is feeded. In the mixer, the pH is adjusted by addition of sodium hydroxide. A polyelectrolytic flocculant is added at the outlet 1 of the mixer. The effluent enters the flocculator in the stirred mixing zone 2. The stirrer provides a certain recirculation (circuit 2-3-4-5-9-2). The effluent enters the sedimentation zone at 6 and leaves the flocculator at 8. The sludge settles mainly in the sludge settling zone (6-7) and leaves the flocculator at 7 towards the sludge centrifuge. The effluent from the centrifugal separator is normally recirculated (12-15), but during the experiments reported here, this effluent was stored in order not to influence the operation by recirculation of a part of the I^{131}-activity. Some of the sludge settles in the cone 10 and is also conveyed, if necessary, to the centrifugal separator.

The empty volumes of the various elements of the equipment are given in Table I.

The radioactivity was determined by a multichannel-analyzer equipped with a 1½" NaI-crystal. The activities given hereafter are expressed in arbitrary units.

3. EXPERIMENTAL

20-40 mC of I^{131} was added to the mixer before effluent flow started. After thorough mixing, the effluent flow was initiated and at time t = 0 the first liquid left the overflow. Samples were taken at regular intervals at various points, see Figure I.

In total three elution experiments were performed. The experimental conditions are given in Table II.

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*) Manuscript received on 5 September, 1969.

TABLE I

Empty volume of parts of the equipment.

Element	Volume (m^3)	Element	Volume (m^3)
Mixer	0.88	6-7	0.80
1-2	"empty tube"	7-$\underline{12}$	0.04
$\bar{2}$-3	0.10	5-$\bar{9}$	1.09
3-$\underline{4}$	4 x 0.003	9-2	0.39
$\underline{4}$-$\bar{5}$	1.20	14-15	0.01
$\bar{5}$-6	0.016	15-13	0.03
6-8'	4.65	14-13	0.13
6-$\underline{8}$	4.81		

TABLE II

Conditions for iodine elution experiments. The effluents B and C originate from mainly laundry operations, A is tap water.

Condition		A	B	C
Global nett flow rate	(m^3/h)	2.50	2.50	2.50
Flow to centrifuge	(m^3/h)	0.50	0.50	0.50
Recycle of centrifuge water to main line (circuit $\overline{12}$-13)		no	no	no
Mean sludge level $\sigma_S \pm 0.05$	(m)	-	-1.50	-1.25
No. of centrif. disch. per hour		-	1	5
Effluent before treatment	pH	6.5	4.0	5.5
$Ca^{2+} + Mg^{2+}$	(ppm)	25	120	20
$PO_4{}^{3-}$	(ppm)	-	310	50
Dry residue	(ppm)	low	530	450
Suspended matter	(ppm)	-	50	80
I^-	(ppm)	8	-	-
Treatment:	pH	6.5	11.0$\pm$0.2	11.0$\pm$0.2
+ $MnO_4{}^-$	(ppm)	-	30	40
+ Ca^{2+}	(ppm)	-	50	100
+ Fe^{3+}	(ppm)	-	50	100
+ $PO_4{}^{3-}$	(ppm)	-	50	50
+ Cationic polyelectrolyte	(ppm)	-	100	65

The experimental data are given in the Figures II, III and IV, where the activity is plotted against the time of sampling. Some numerical values obtained from the Figures are given in Table III.

In total three runs were performed:

RUN A : no sludge in the flocculator; tap water.

RUN B : the sludge blanket level was at -1.50 m from the level of the outlet of the effluent; the sludge production rate was low (about 1 centrifuge discharge of 3 l per hour); mainly laundry effluent.

RUN C : sludge blanket level at -1.25 m; 5 centrifuge discharges per hour; mainly laundry effluent.

Unfortunately it was not possible to measure quantitatively the density of the sludge blankets. However, it is accepted that the densities during the runs were qualitatively: zero - low - high.

4. RESULTS

4.1. Mixer

For an ideal mixer in case of elution:

$$\frac{dCV}{dt} = - \varnothing C \qquad \text{or}$$

$$C/C_o = e^{-\varnothing t/V} \qquad \ldots (1)$$

C = Concentration (-)
t = Time (h) or (min)
V = Volume (m^3)
$\varnothing$ = Flow rate (m^3/h)

Since the volume of the mixer is 0.88 m^3, it follows that at a flow rate of 3 m^3/h the slope of the elution curve is

$$- \varnothing/V = -0.0568 \ (\text{min})^{-1}$$

In the three cases this value was found to be respectively:

$$\begin{aligned} A &: -0.0576 \longrightarrow \varnothing = 3.04 \ m^3/h \\ B &: -0.0535 \longrightarrow \varnothing = 2.825 \ m^3/h \\ C &: -0.0625 \longrightarrow \varnothing = 3.30 \ m^3/h \end{aligned}$$

TABLE III

Numerical results obtained from Figures II-IV.

		RUN A no sludge	RUN B low sludge	RUN C high sludge
SAMPLING POINT 1, MIXER				
$-(\emptyset/V)_{exp.} \rightarrow \emptyset$	(m^3/h)	$-0.0576 \rightarrow \emptyset = 3.04$	$-0.0535 \rightarrow \emptyset = 2.825$	$-0.0625 \rightarrow \emptyset = 3.30$
$-(\emptyset/V)_{theor.}$ at $\emptyset = 3\ m^3/h$		-0.0568	-0.0568	-0.0568
C_o	(arbitrary units)	4.08×10^5	7.44×10^6	1.035×10^6
SAMPLING POINT 4, INLET DOUBLE-WALLED SECTION				
First maximum, t_{4-1}, from $t = 0$	(min)	6	12	6
$C_{t_{4-1}}/C_o \rightarrow \emptyset_R$	(m^3/h)	$0.465 \rightarrow \emptyset_R = 3.51$	$0.460 \rightarrow \emptyset_R = 3.58$	$0.453 \rightarrow \emptyset_R = 3.68$
Slope after t_{4-1}		-0.0636	?	?
Second maximum, t_{4-2}, from $t = 0$	(min)	32	16	10
$C_{t_{4-2}}/C_o$		0.175	0.44	0.45
Slope after t_{4-2}		-0.0227	-0.0458	-0.0592
SAMPLING POINT 8, EFFLUENT OUTLET				
First maximum, t_{8-1}, from $t = 0$	(min)	29	55	65
$C_{t_{8-1}}/C_o$		0.059	0.045	0.135
Second maximum, t_{8-2}, from $t = 0$	(min)	147	117	75
Ibid., from t_{4-2}	(min)	115	104	67
$C_{t_{8-2}}/C_o$		0.117	0.148	0.147
SAMPLING POINT 12, SLUDGE TO CENTRIFUGAL SEPARATOR				
Maximum, t_{12}, from $t = 0$	(min)	75	52	50
Ibid., from t_{4-2}	(min)	69	39	42
$C_{t_{12}}/C_o$		0.135	0.210	0.213
SAMPLING POINT 10, SLUDGE FROM CONICAL PART				
Maximum, t_{10}, from $t = 0$	(min)	29	-	-
Ibid., from t_{4-2}	(min)	23	-	-
$C_{t_{10}}/C_o$		0.185	-	-

As the real flows were obtained from rotameter readings, it is accepted that in all three cases the average of the above given values yields the most probable value:

$$\emptyset = 3.05 \pm 0.25 \ m^3/h$$

It is concluded that the mixer behaves almost ideally until $C \leqslant 3 \times 10^{-3} C_0$. Hereafter slight deviations can be observed, perhaps due to slow desorption of I^{131}, previously adsorbed on the walls of the mixer.

4.2. Flocculator

4.2.1. The mixing zone

In the mixing zone (9-3, Figure I), new effluent ($\emptyset$ m^3/h at a concentration C_1, with at $t = 0$, $C_1 = C_0$) enters at 2 and recirculating effluent ($\emptyset_R$) at 9. In the beginning, when the whole of the flocculator contains non-active*) effluent, the activity at 4 rises steeply to a certain value $C_{t_{4-1}}$ for which is valid:

$$C_{t_{4-1}} (\emptyset + \emptyset_R) = \emptyset \, C_0$$

For the three cases, $\emptyset_R$ showed to be respectively: 3.51, 3.58, and 3.68 m^3/h, from which follows $\emptyset_R = 3.59 \pm 0.09 \ m^3/h$.

The first maximum of sample point 4 appears after ± 6'. In theory, this should take place after about 1', the volume between 2 and 4 being 0.11 m^3 (see Table I) and the total flow rate 6.64 m^3/h. The difference may be attributed to the assumption that the whole of the mixing zone ($V = 0.49 \ m^3$) behaves as a mixer. This leads to a mean retention time of 4.5'. The slope of the decrease of the 4-concentration is 0.0636, reasonably close to the slope of the mixer-line, so that a fairly rapid dilution takes place in the mixing zone.

After having attained the first maximum, the activity of the recycle stream decreases parallel to the decrease of the activity in the mixer until at point 2, or at 9 if the mixing zone is considered as a whole, the effluent that passed the way 4-5-9 (-2) arrives.

This behaviour can be observed clearly only during run A (no sludge in flocculator). The volume of the part 4-5-9(-2) is 1.20 m^3 at a flow rate of 6.64 m^3/h and 1.48 (0.81) m^3 at 3.59 m^3/h. This gives 35 (29) min as mean flow time. Since the second maximum of the 4-line lies at 32 min, 26 min after the first, it is concluded that the whole of the volume 4-5-9(-2) is contributing to the flow, i.e. no stagnant parts are present.

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*) Referred to I^{131}.

For the other two runs, with sludge in the flocculator, this is no longer true. Indeed, the most probable second maximum of the 4-line shifts from 32' (run A) through 16' (B, low sludge production) to 10' (C, high sludge production), which indicates that part of the effluent in the circuit 4-5-9 is not circulating, especially in the lower part of the cone of the flocculator. This is proved by the fact that during runs B and C no I^{131}-activity was found in the lower part of the cone (sampling point 10), whereas in run A the activity at that point followed well the general trend. The effective cone-volume is thus much smaller than its empty volume indicates. In run C also part of the double-walled section should be ineffective.

Another observation which proves the above statement is the fact that the slope of the part of line 4 (case A) after the second maximum is much less than in the other cases. This means that more liquid present in the cone takes part in the flow than in the other cases. The ratio of this slope to that of the mixer is 0.39, 0.86 and 0.95 respectively for run A, B and C. This value increases with increasing amount of sludge present.

4.2.2. The settling zone

The effluent enters the settling zone at 6. Part of it goes towards the sludge bowl, where it leaves at 7, the rest rises towards the outlet 8.

The behaviour of the settling zone is quite different for the three cases. In ideal hydrodynamic conditions, a maximum at the outlet 8 should arrive 124' after a maximum of 4. For case A, a first maximum is observed after 23' from t_{4-1} and a second maximum after 115' from the second maximum of the 4-line, t_{4-2}. This behaviour proves that the flow in the settling zone is far from ideal. A substantial part of the effluent travels at a velocity much higher than indicated by theory. This is caused by the absence of baffles that should quiet down the "jet" of the liquid that enters the settling zone at point 6.

In order to compare directly the behaviour of the flocculator during the three runs, the 4- and 8-lines (respectively inlet double-walled section and outlet) are shown together in Figure V, where also the respective sludge-levels are indicated. In Table IV some relevant data are given.

TABLE IV

Data belonging to Figure V.

		Run A	Run B	Run C
$C_{t_{8-1}}/C_{t_{4-1}}$	(%)	13	10	30
$t_{8-1} - t_{4-1}$	(min)	23	43	59
$C_{t_{8-2}}/C_{t_{4-1}}$	(%)	25	32	32
$t_{8-2} - t_4$ *)	(min)	115	103	67
σ_F	(m)	(1.71)	1.52	0.97
σ_S	(m)	1.68	1.5	1.25

---

*) For Case A, t_{4-2} is taken. Since in cases B and C, t_{4-1} and t_{4-2} are close together, the mean time is taken.

In order to explain the observed phenomena, it is accepted that the concentration of the liquid arriving at point 6 equals that at 4. Furthermore, it is supposed that the settling zone is divided into two sub-zones:

- a lower turbulent sub-zone corresponding roughly to the sludge volume,
- an upper calm sub-zone, where the effluent is about sludge-free.

Now the following phenomena can be qualitatively understood:

- When no sludge is present (case A), the turbulency is not damped by sludge, about 13 % of the liquid as follows from the ratio of the concentration at t_{8-1} and t_{4-1}, is rapidly projected upwards with a velocity of about 8 m/h as follows from the time-lapse $t_{8-1} - t_{4-1}$.
- As soon as sludge is present and the effects become more pronounced with increasing sludge load, turbulency is damped and the time at which the first activity leaves at 8 increases from 10' (A) via 30' (B) to 40' (C). Furthermore, the ratio of the concentration of the main peaks at t_{8-2} and t_{4-1} increases.
- In the lower sub-zone turbulency makes mixing quite effective. For the calculation of the velocity from activity measurements, this zone should not be taken into consideration. The height of the upper sub-zone, σ_F, can be estimated from the flow rate, the free cross-section of the flocculator (2.76 m^2) and the time-lapse $t_{8-2} - t_4$ reduced with 4' for the stretch 8'-8. For the cases B and C it follows that σ_F equals respectively 1.52 and 0.97 m. These values should be compared with the observed sludge-levels of 1.50 and 1.25 m. The corresponding value for case A is 1.71 m. This equals approximately the distance between 6 and the water-level. In this case no distinction between σ_F and σ_S can be made.

4.2.3. The sludge settling cup

This part of the flocculator serves as a collector for settled sludge that is evacuated at 7. The liquid flow is from 1-2-3-4-5-6-7-12. Theoretically this takes 112' from 1 and 108'-111' from 4. In reality the liquid arrives at 12 after (resp. A, B, C) 69', 40' and 44' from 4 at a relative concentration of 29, 40 and 47 %.

It is accepted that even in the case of a cup only filled with water, a part of it is unactive. This part is becoming larger whenever sludge is present.

4.2.4. The sludge settling cone

A part of the sludge settles in the bottom part of the flocculator (4-5-10) and can be evacuated*). Theoretically this takes 29'. For run A this value showed to be 23'. In the other runs no I^{131}-activity was found at sampling point 10 throughout the experiments.

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*) In practice this is done occasionally.

It follows that when no sludge is present, this part of the flocculator behaves reasonably; if sludge is present, no liquid is circulating, the cone serving for sludge storage only.

4.3. I^{131} as water-path tracer

It was found that the activity associated with the water-phase amounted to more than 95 % of the activity of the water and sludge together. It is concluded that the choice of I^{131} as a water-path tracer is justifiable and that a separation of the water from the sludge is not necessary prior to counting.

5. CONCLUSIONS

The few experiments reported here lead to the conclusion that the mixer behaves well, but that the flocculator described is of unsatisfactory design. Its main defects are:

- Mixing zone and sludge cone: part of the double-walled section and of the bottom-cone of the flocculator are not effective. The circular motion in the double-walled section, caused by the four inlets, is apparently not perfect, the liquid being in a flaw-like motion. In order to improve the performance of the flocculator, zone I (Figure VI) could be omitted. Furthermore, the double-walled section should be made somewhat larger, in order to avoid compacting of the sludge with subsequent blockage of the rung.
- Settling zone: the velocity of the effluent that enters into the settling zone is too high. For decreasing the velocity the entrance should be made larger, by taking away a part of the sludge settling cup (Figure VI, zone II). Furthermore some kind of baffling of the flow seems necessary in zone III. Since this is the most important improvement, bench-scale experiments are necessary to determine the best size and place of the baffles.
- Sludge settling cup: this part of the flocculator is not totally effective. The removal of a part (zone II) will improve its effectiveness. Also here small-scale experiments seem necessary.

It is concluded that in order to optimize the existing flocculator, some changes that could lead to an important increase of its capacity have to be made.

It is quite clear that any flocculator of more modern design, flatter and broader, takes already into account the factors which cause the imperfectness of the described flocculator.

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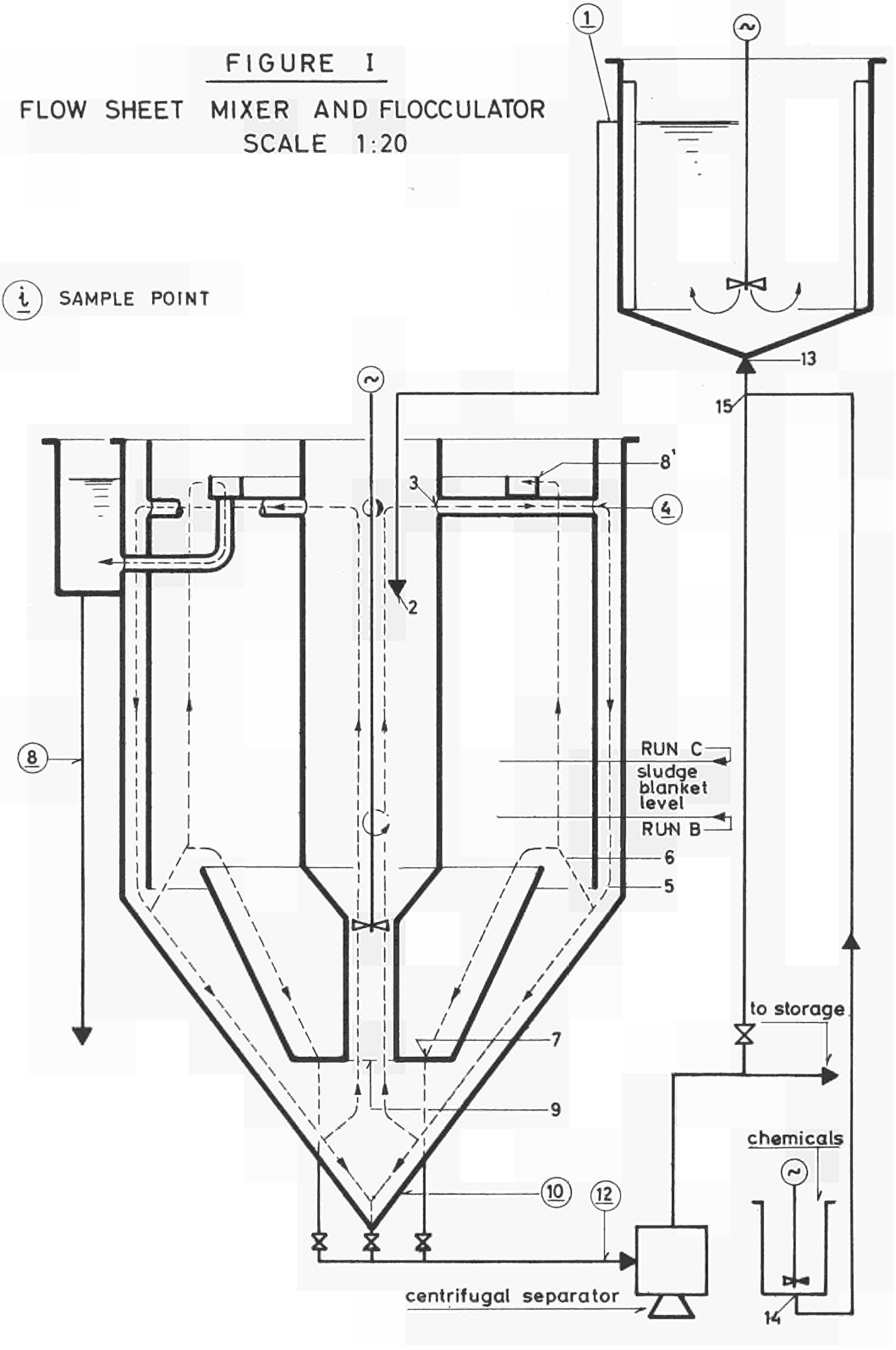


FIGURE I

FLOW SHEET MIXER AND FLOCCULATOR
SCALE 1:20

FIGURE II

I^{131}- ELUTION RUN A. NO SLUDGE IN FLOCCULATOR.

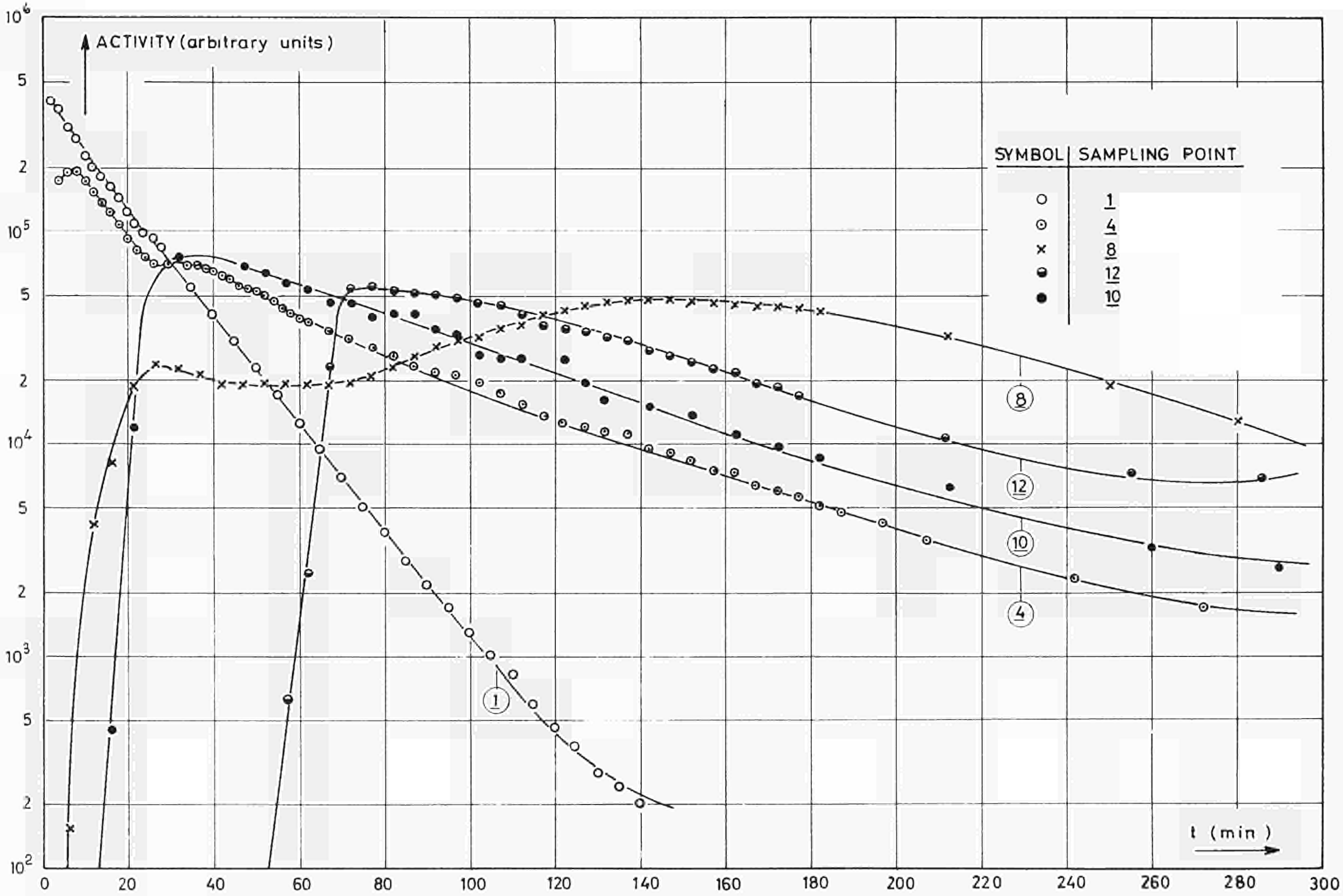


FIGURE III

I^{131}- ELUTION RUN B. LOW SLUDGE PRODUCTION, ∇_s = −1,50 m.

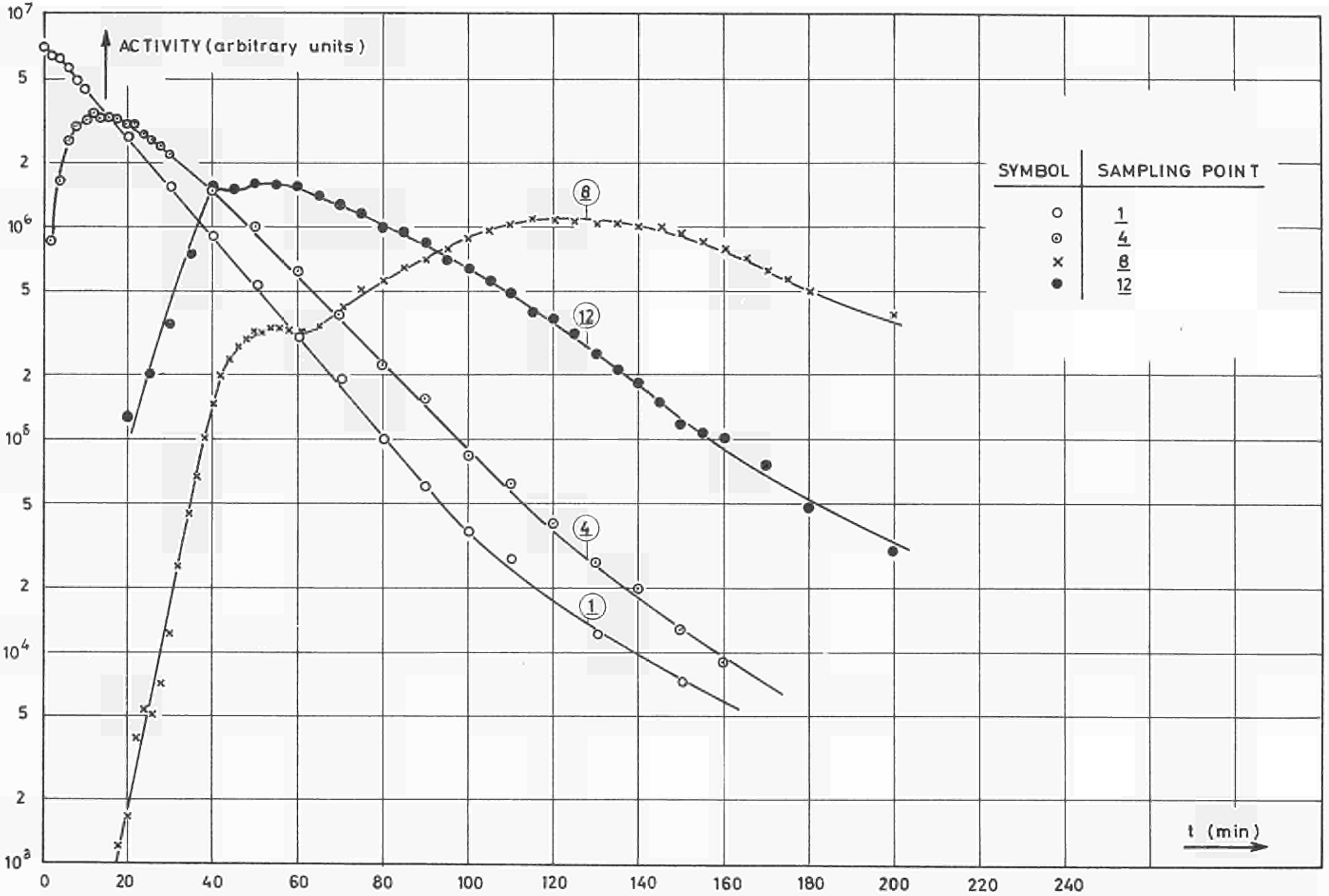
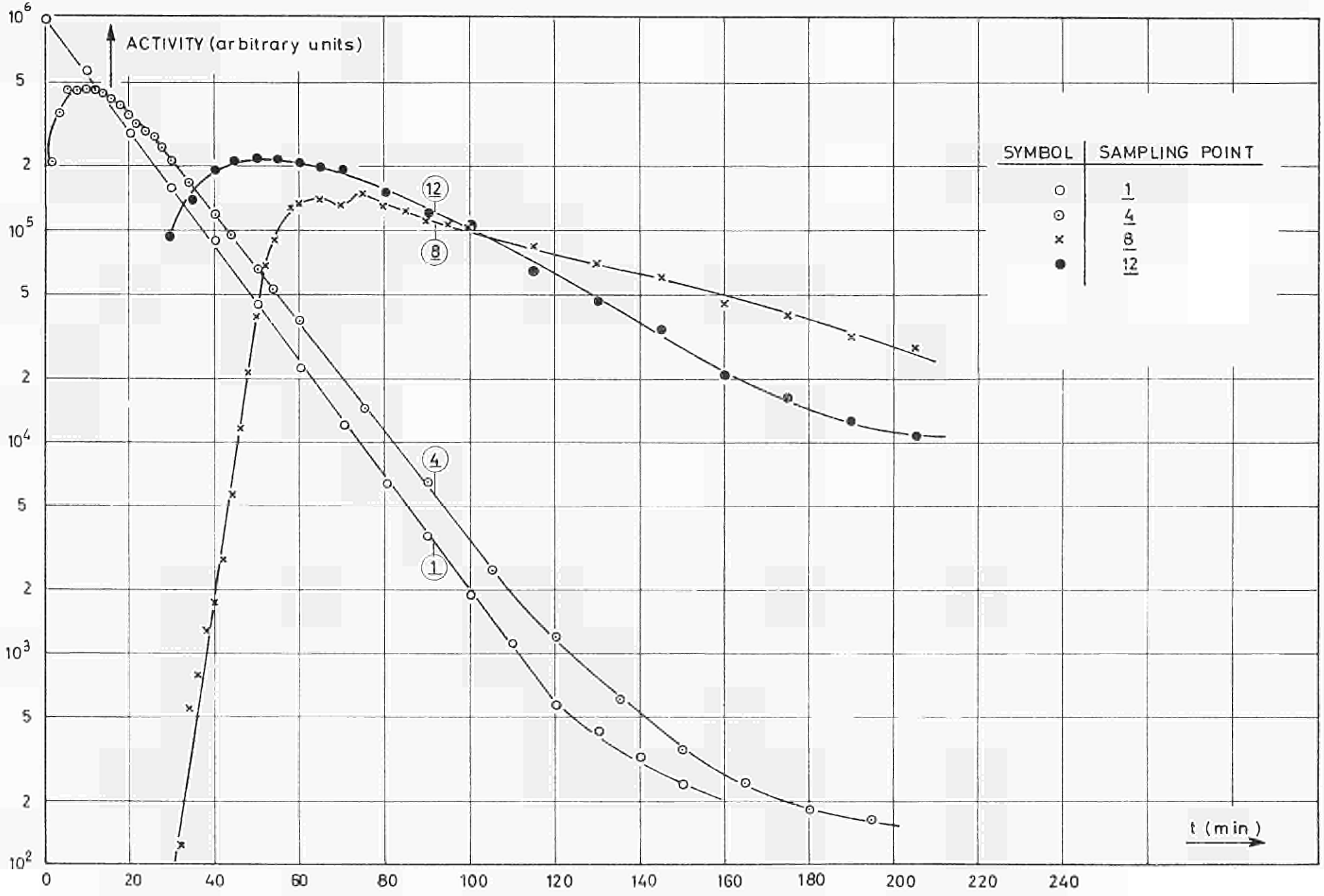


FIGURE IV

I^{131}- ELUTION RUN C. HIGH SLUDGE PRODUCTION, $\nabla s = -1.25$ m.



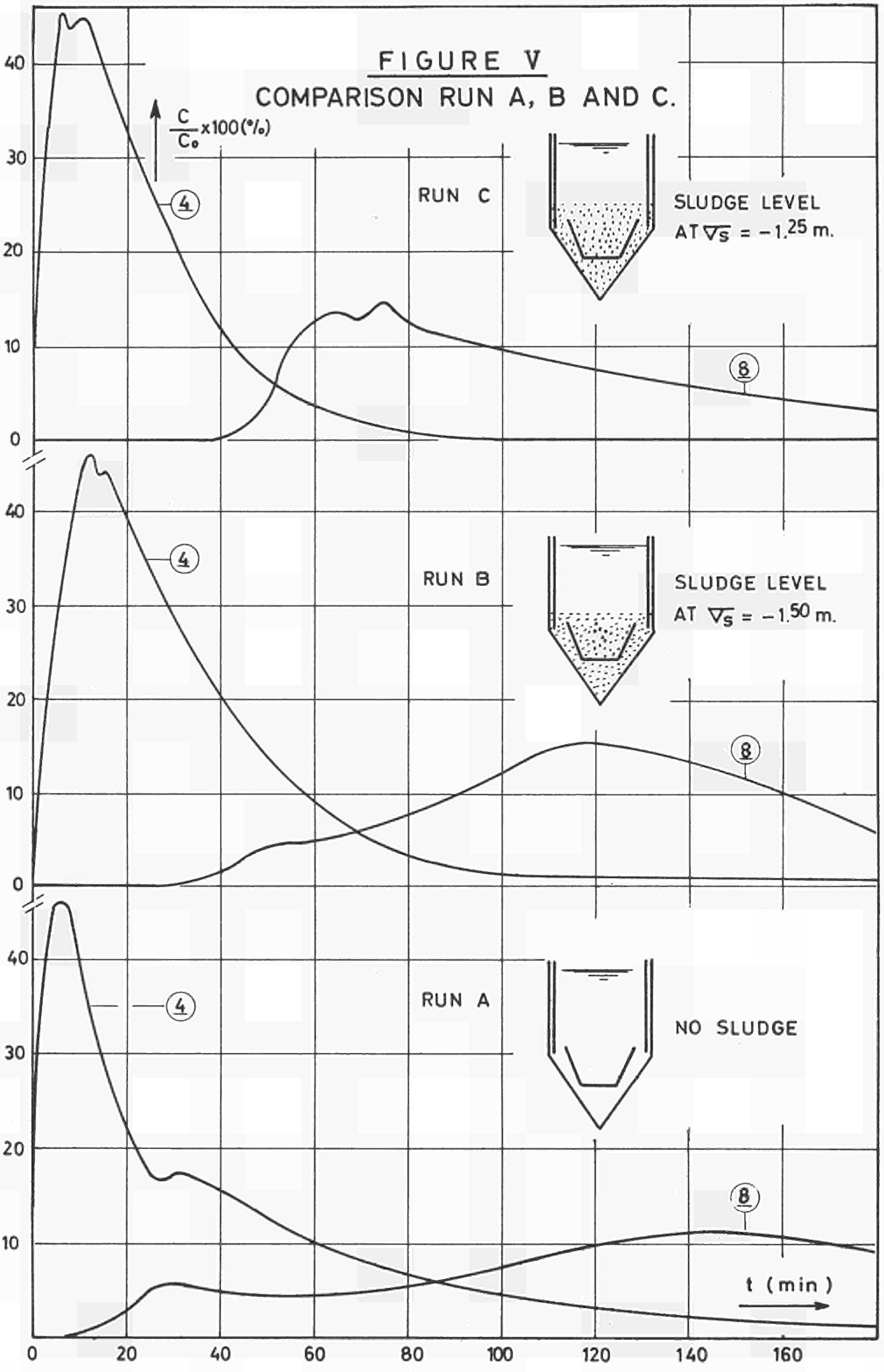
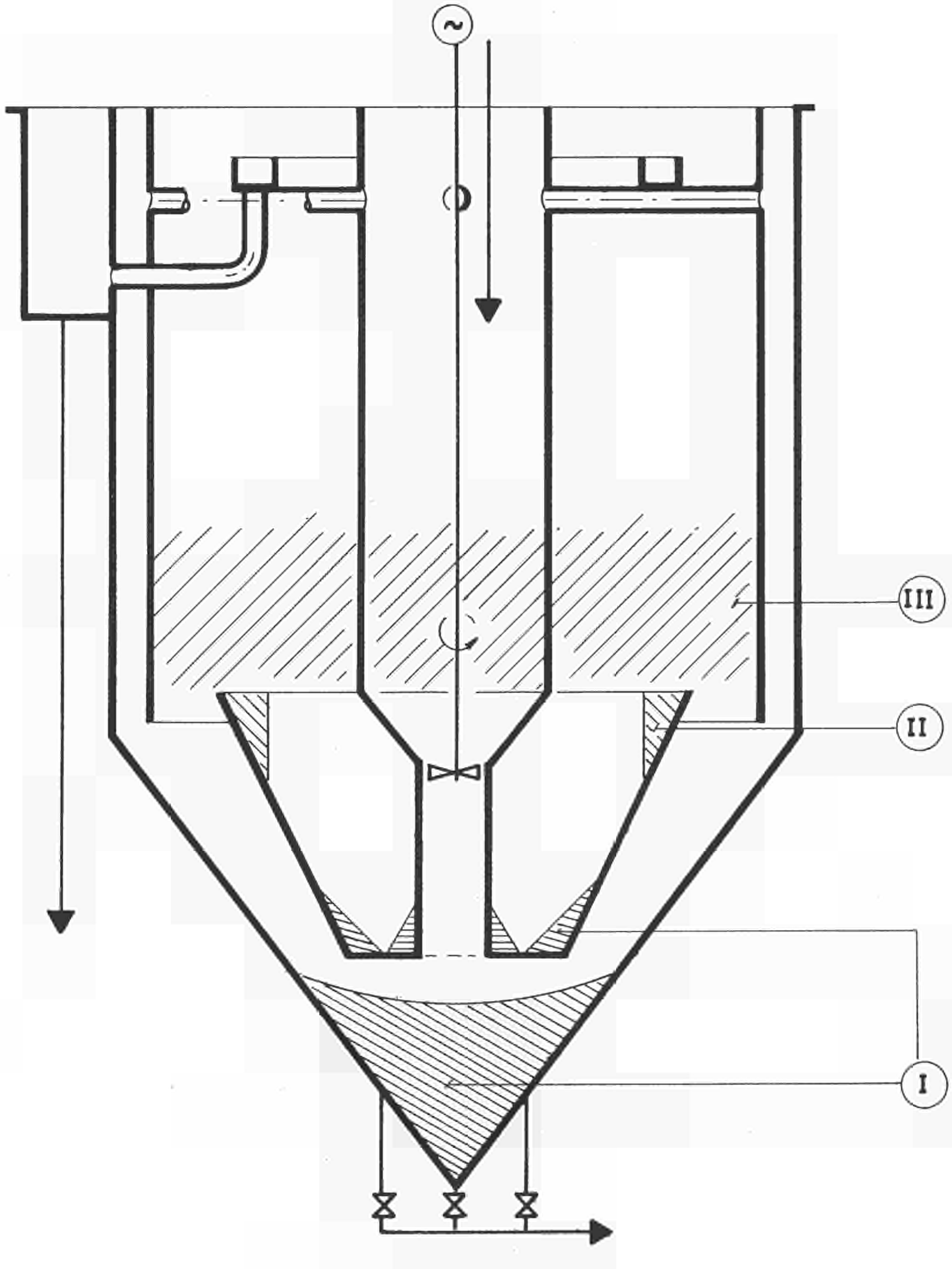


FIGURE V

COMPARISON RUN A, B AND C.

FIGURE VI

SUGGESTIONS FOR BETTER FUNCTIONNING OF THE FLOCCULATOR



> To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.
>
> Alfred Nobel

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