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PABLO A. SANCHEZ PODLECH and WALTER BORZANI

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INSTITUTO DE ENERGIA ATÔMICA
Caixa Postal 11049 (Pinheiros)
CIDADE UNIVERSITÁRIA "ARMANDO DE SALLES OLIVEIRA"
SÃO PAULO — BRASIL

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Pablo A. Sanchez Podlech[1] and Walter Borzani[2]

Departamento de Radiobiologia
Instituto de Energia Atômica
São Paulo - Brasil

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1 Departamento de Radiobiologia - Instituto de Energia Atômica.
2 Departamento de Engenharia Química - Escola Politécnica da Universidade de São Paulo.

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Summary

In this work, a radiometric method is used for the determination of the oil drop size distribution in agitated hydrocarbon-water systems. The influence of the counter position, the oil concentration, and the rotation speed of impeller were studied. An experimental parameter is proposed for the definition of the drop size distribution. It was observed that an unsymmetrical distribution represents the drop size distribution better than the normal distribution law.

INTRODUCTION

The size distribution of the oil droplets must be regarded as one of the most important parameters in the kinetic study of hydrocarbon fermentations, and until now the distribution of hydrocarbon drop diameters has not been readily measured to establish the real situation within agitated liquid in fermenters.

It seems really difficult to propose a complete kinetic model, that is, a correlation between the fermentation rate and the physical and geometrical conditions of the fermenter, without precise determination of the oil droplets size distribution.

If it was possible to relate the size distribution of the hydrocarbon droplets to fermentation conditions such as the oil concentration, the rotation speed of impeller, the physico-chemical characteristics of the hydrocarbon and the aqueous medium, the power consumption for agitation, and the number and size of baffles, one of the major problems, from a biochemical engineering standpoint, in the understanding of the kinetic of hydrocarbon fermentations could be conveniently studied.

With the purpose of contributing to the study of the problem, the present paper shows the results obtained by the application of a radiometric method[1] to the measurement of the oil drop size distribution in agitated hydrocarbon-water systems.

DROP SIZE DISTRIBUTION

The following equation was proposed and tested previously:[1]

$$F = 100(1 - 10^{-\alpha AH/r^2}) \quad (1)$$

where F is the oil fraction (in mass per cent) in the form of oil droplets with radius equal to or larger than r.

MATERIALS AND METHODS

Equipment

All the experiments were carried out in a 14-liter fermenter (New Brunswick Scientific) represented schematically in Figure 1.

The activity measurements were made by means of a Geiger-Müller (Amperex Electron Tube) model 90 NB-3.

The Geiger-Müller tube was connected to an amplifier, a scaler, a count rate meter, and a recorder.

Figure 2 shows the lead shield and the collimating slit used in order to assure good activity measurements.

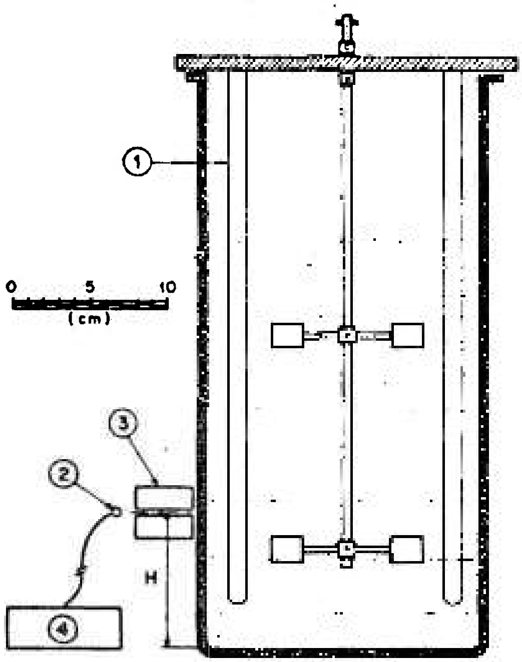


Fig. 1. Schematic representation of the fermenter. 1: Four baffles at 90° position. 2: Geiger-Müller counter. 3: Lead shield and collimating slit. 4: Recorder.

Materials

Diesel oil, obtained from Brazilian crude oil, kindly supplied by the Refinaria Presidente Bernardes (Cubatão, São Paulo, Brazil), was used in all the experiments.

Distilled water was used as the continuous liquid phase.

The oil was labeled[2] with iodine-131 produced by the Radiochemistry Division (Radioactive Material Processing Service) of the Instituto de Energia Atômica (São Paulo, Brazil).

Oil Characteristics

The following oil characteristics were measured at 30°C: density (Mohr balance), viscosity (Ostwald viscosimeter), surface tension, and water-oil interfacial tension (Du-Nouy tensiometer).

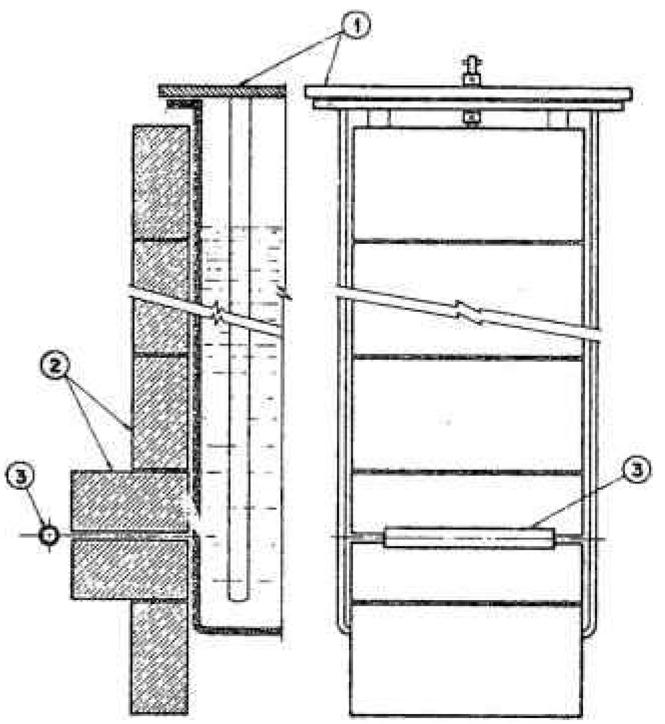


Fig. 2. Lead shield and collimating slit used in the experiments. 1: Fermenter. 2: Lead shield and collimating slit. 3: Geiger-Müller counter.

Experimental Conditions

The following were the experimental conditions:

a) volume of distilled water in the fermenter = 10 liters
b) temperature = 30.0 ± 0.3°C
c) oil concentrations = 8.2, 16.3, 24.2, 32.0, 39.6, 61.6, and 75.6 g/liter
d) rotation speed of impeller = 190, 285, 385, 480, 570, and 670, rpm
e) approximate total activity in each experiment = 5 mCi.

It must be mentioned that in order to facilitate the experiments with the radioactive material, the different oil concentrations were obtained only by adding labeled oil to the fermenter, without removing an equivalent volume of water. As a consequence, the liquid height in the tank increased about 8.9% when the oil concentration increased from 8.2 to 75.6 g/liter. This fact, however, did not affect the purpose of the present report.

RESULTS

Oil Characteristics at 30°C

The characteristics of the oil at 30°C were:

a) density = 0.8316 g/cm^3
b) viscosity = 5.031 g/cm sec
c) surface tension = 27.26 dyne/cm
d) water-oil interfacial tension = 29.00 dyne/cm.

Sensitivity of the Measuring Equipment

In order to evaluate the sensitivity of the measuring equipment, the following experiment was carried out. Labeled oil was added, drop by drop, to the fermenter containing 10 liters of distilled water until an activity significantly different from the background level was attained. It was observed that at this point the oil concentration was 0.06 g/liter. This oil concentration is negligible when compared with the total oil concentrations used in this work.

Influence of the Counter Position

During the rise of the oil droplets towards the liquid surface, the effect of coalescence could significantly influence the experimental results obtained with the method used in this paper. Such an influence was studied by carrying out experiments with the radiation detector placed at two different distances from the fermenter bottom (8 cm and 13 cm). Figures 3 and 4 clearly show that, under our experimental conditions, droplet coalescence is not a significant factor during drop rise.

Influence of the Oil Concentration and of the Rotation Speed of Impeller

Figures 5 to 11 present the distribution curves obtained by varying the oil concentration and the rotation speed of impeller. The corresponding values of α are represented in Table I.

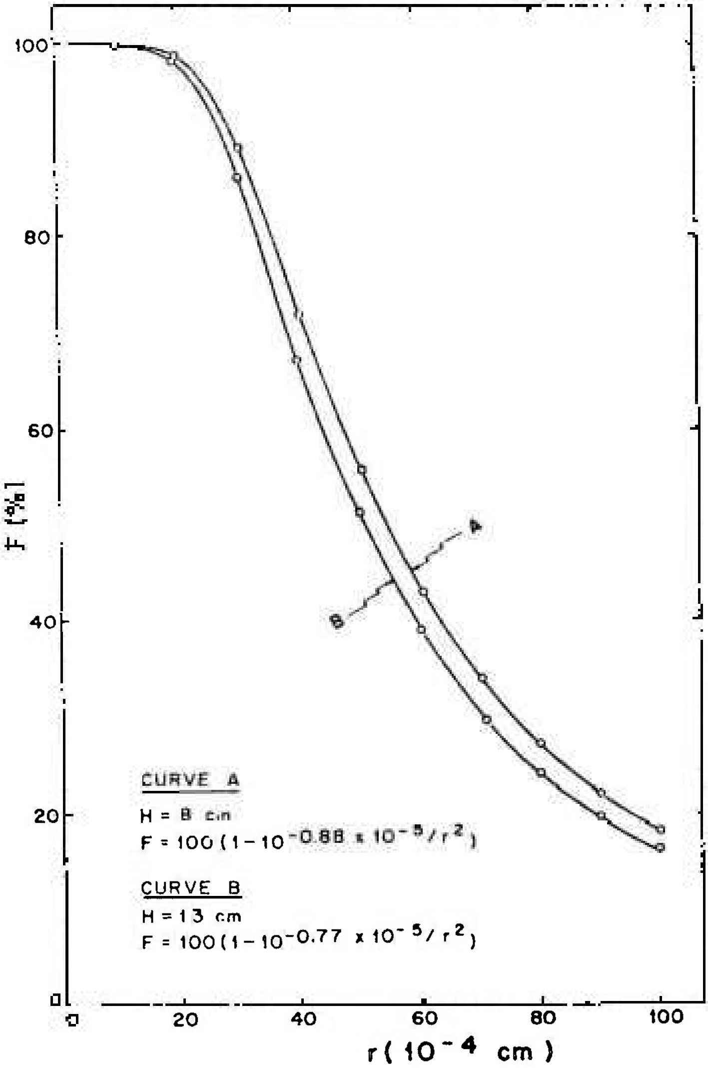


Fig. 3. Influence of the Geiger-Müller counter position. Oil concentration = 16.3 g/liter. Rotation speed of impeller = 570 rpm.

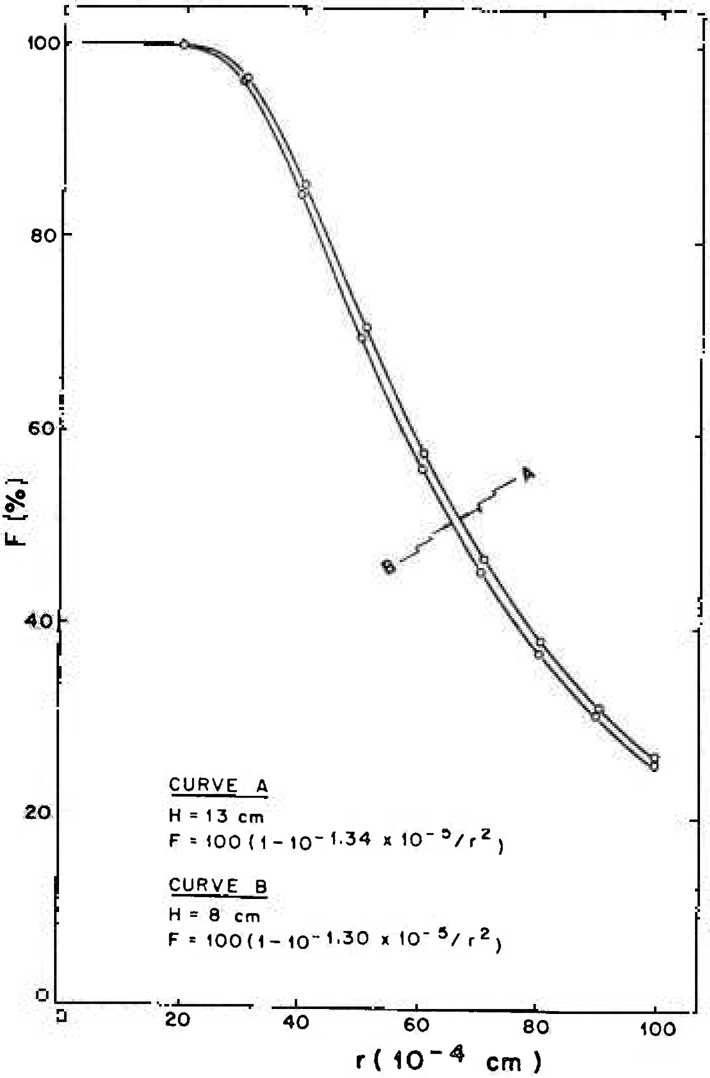


Fig. 4. Influence of the Geiger-Müller counter position. Oil concentration = 16.3 g/liter. Rotation speed of impeller = 385 rpm.

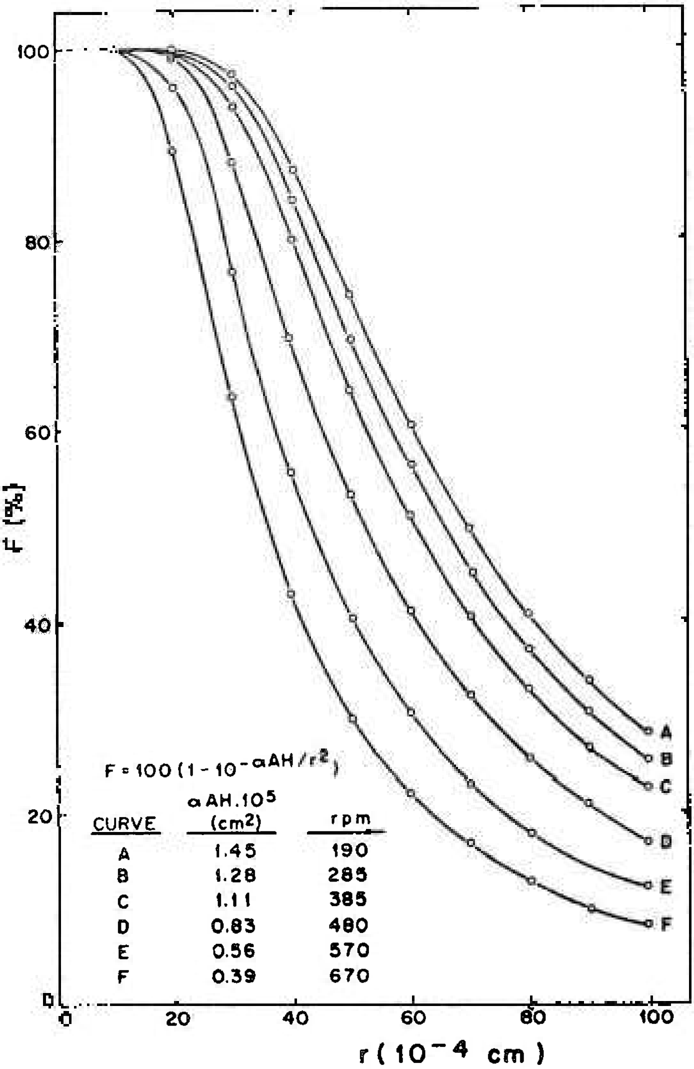


Fig. 5. Distribution curves. Oil concentration = 8.2 g/liter.

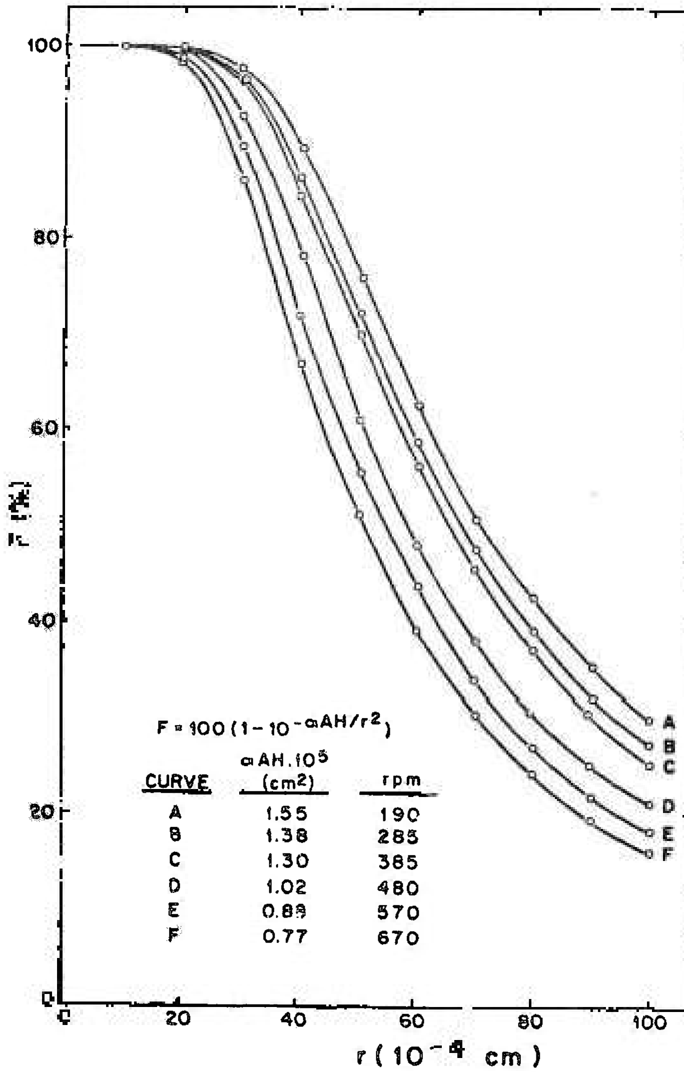


Fig. 6. Distribution curves. Oil concentration = 16.3 g/liter.

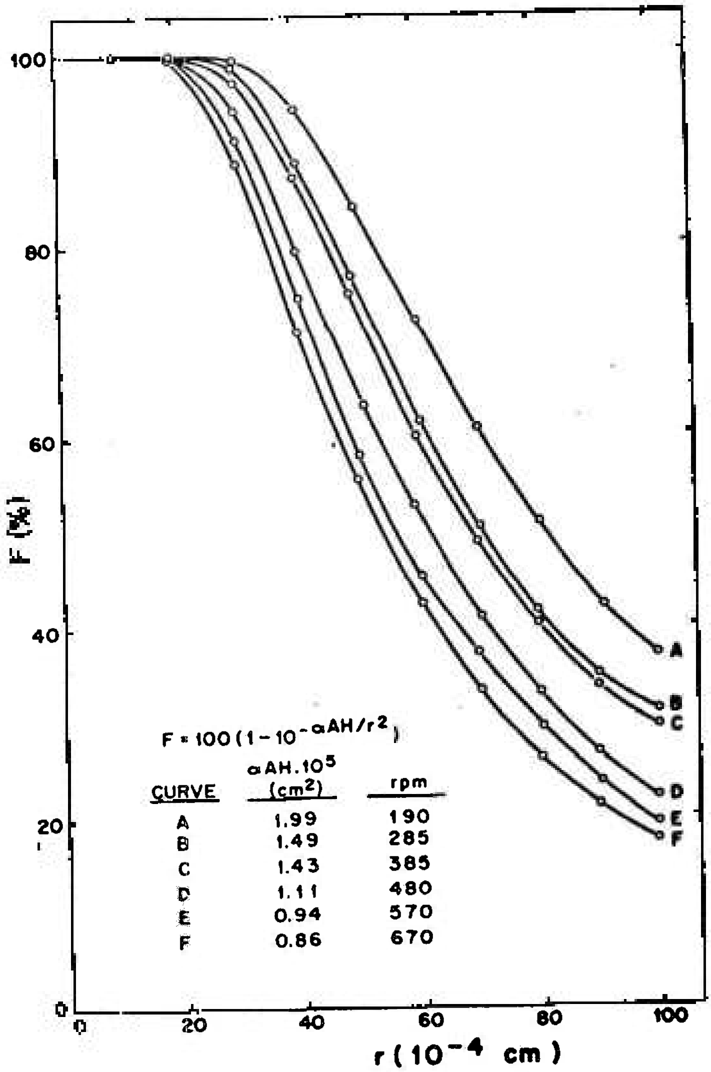


Fig. 7. Distribution curves. Oil concentration = 24.2 g/liter.

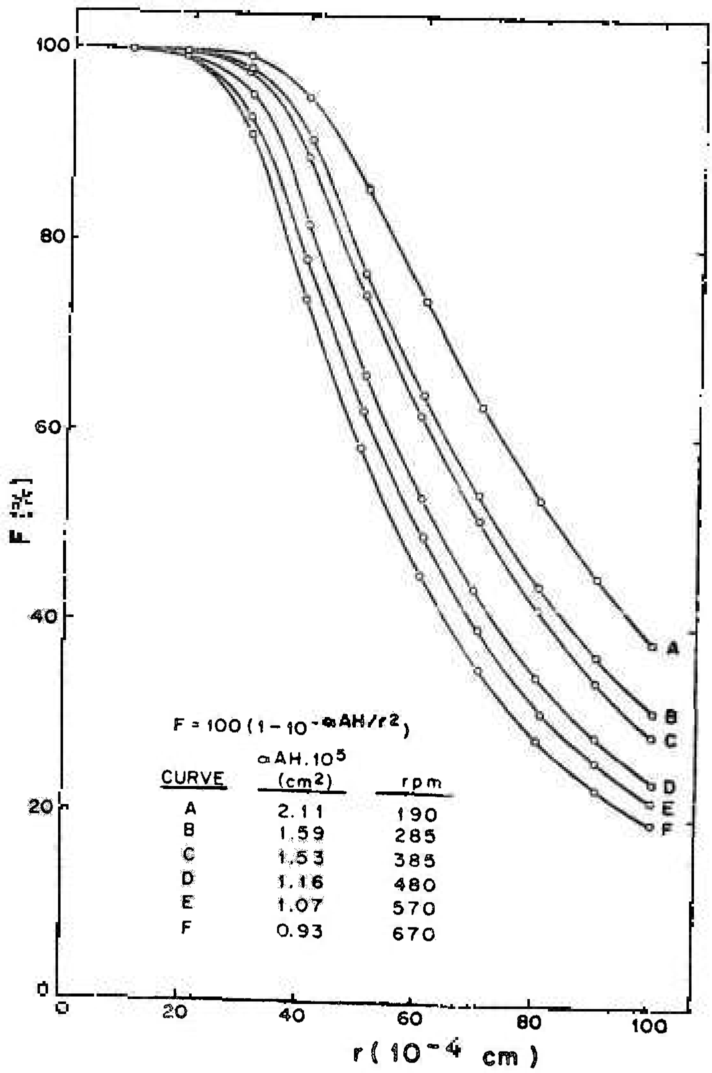


Fig. 8. Distribution curves. Oil concentration = 32.0 g/liter.

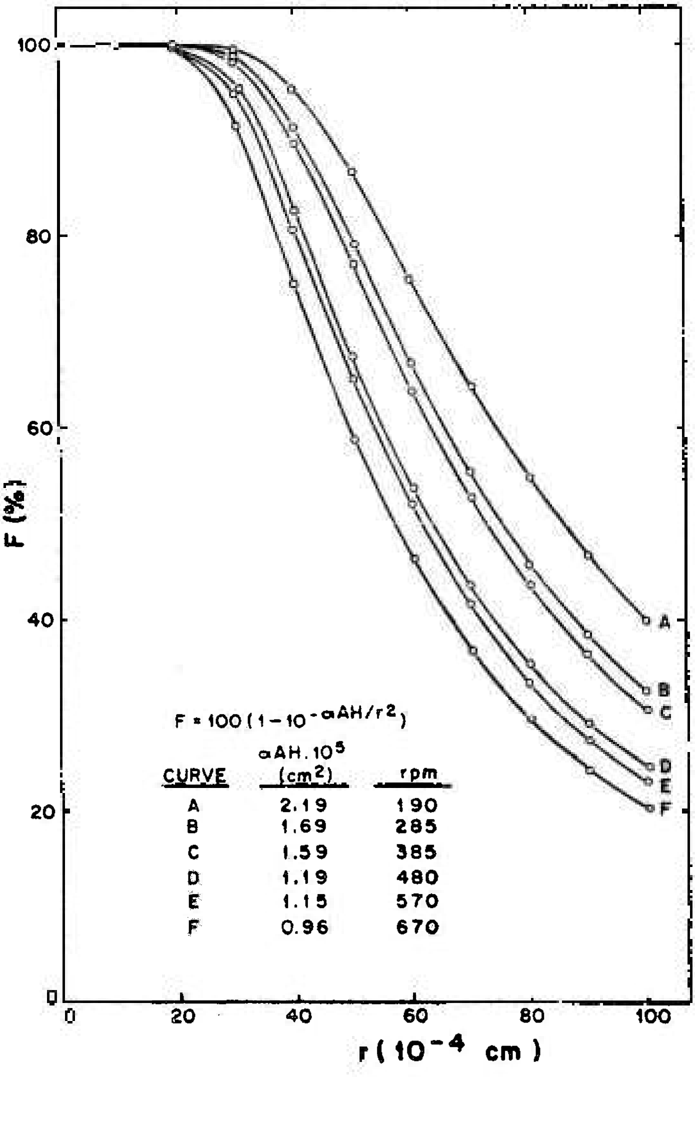


Fig. 9. Distribution curves. Oil concentration = 39.6 g/liter.

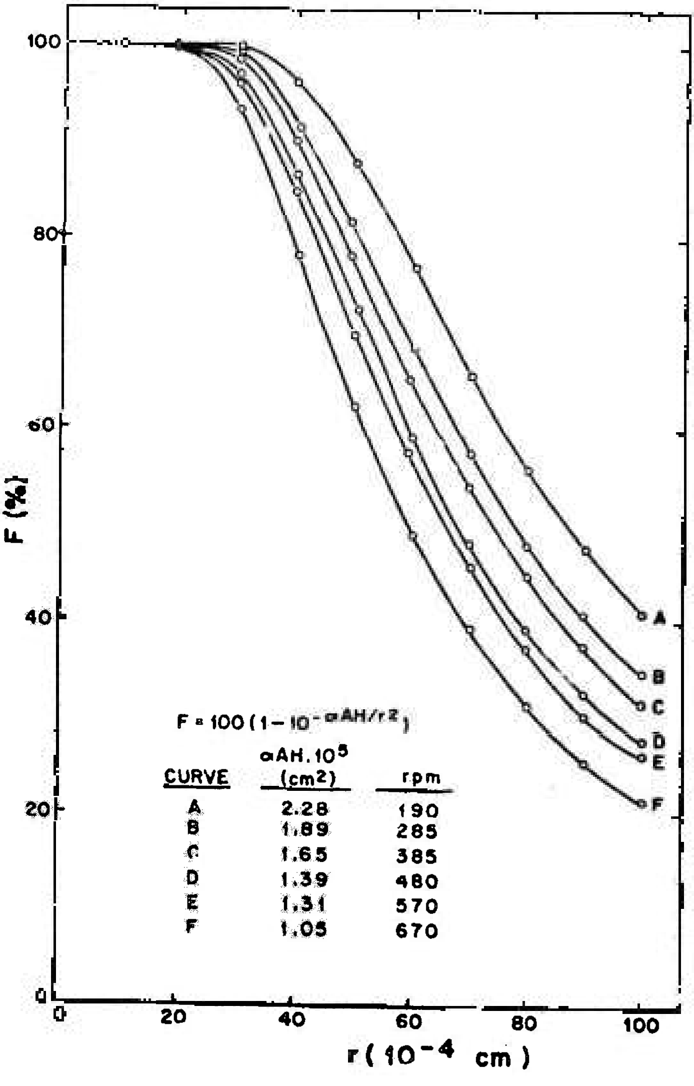


Fig. 10. Distribution curves. Oil concentration = 61.6 g/liter.

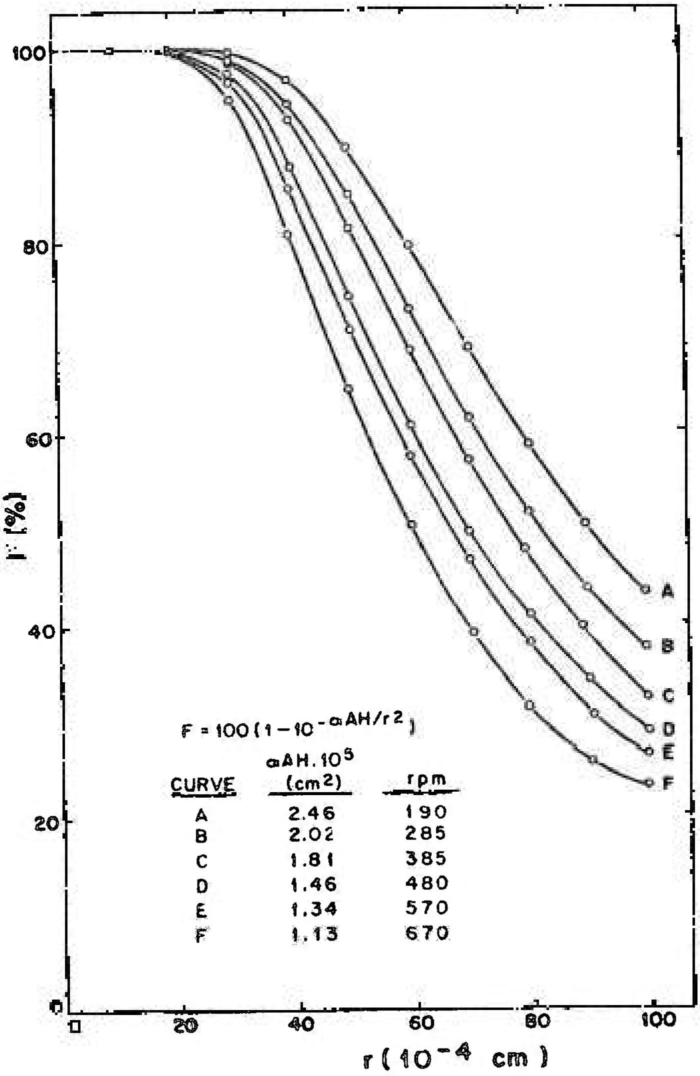


Fig. 11. Distribution curves. Oil concentration = 75.6 g/liter.

TABLE I

Influence of the Oil Concentration and of the Rotation Speed of Impeller on the Value of α

Rotation speed of impeller, rpm	$10^3\,\alpha\,(sec^{-1})$ Oil concentration, g/liter						
	8.2	16.3	24.2	32.0	39.6	61.6	75.6
190	8.04	8.55	11.03	11.65	12.13	12.62	13.59
285	7.11	7.66	8.26	8.80	9.33	10.09	11.19
385	6.17	7.19	7.92	8.49	8.82	9.15	10.00
480	4.59	5.65	6.13	6.44	6.62	7.68	8.09
570	3.12	4.87	5.23	5.94	6.34	7.26	7.40
670	2.16	4.29	4.74	5.16	5.31	5.81	6.27

DISCUSSION

Applicability of Equation (1)

It was already shown[1] that the applicability of eq. (1) is valid only when the Reynolds number[3] is smaller than 1, that is, in our experimental conditions, when $r \leqslant 95 \times 10^{-4}$ cm.

The Parameter α

The experimental results presented in this paper lead to the conclusion that α can be adopted as a parameter that defines the drop size distribution. It is possible, from the values of Table I, to find the experimental conditions in order to assure a given droplet size distribution in an oil-water system. If we desire, for instance, to work with 75.6 g/liter of oil, and to reproduce the same drop size distribution observed when the oil concentration is 8.2 g/liter and the rotation speed is 190 rpm, a speed of about 480 rpm must be used.

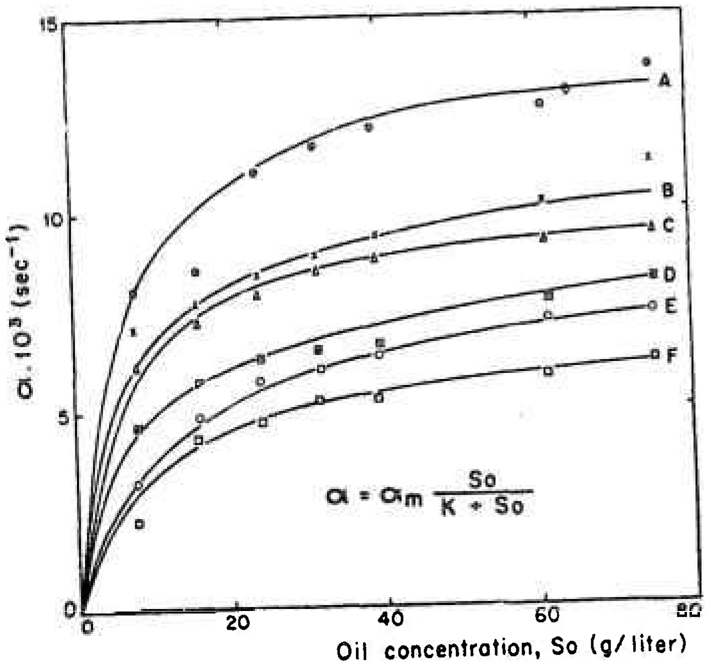
The results indicate that it seems reasonable to correlate α with the oil concentration as shown in Figure 12.

Distribution Curves

The curves represented in Figures 5 to 11 provide information concerning the corresponding distribution functions. The approximate graphical representation presented in Figure 13 permits us to state that an unsymmetrical distribution law represents the oil dispersion better than the normal distribution.[4]

Nomenclature

$$A = \frac{9\eta}{2(\rho_a - \rho_o)g}, \text{ cm sec}$$



Curve	rpm	$\alpha_m \cdot 10^3$ sec^{-1}	K, g/lite
A	190	14.26	6.39
B	285	11.12	7.62
C	385	10.02	5.42
D	480	8.08	6.49
E	570	8.84	14.83
F	670	6.78	9.72

Fig. 12. Variation of α with the oil concentration and the rotation speed of impeller.

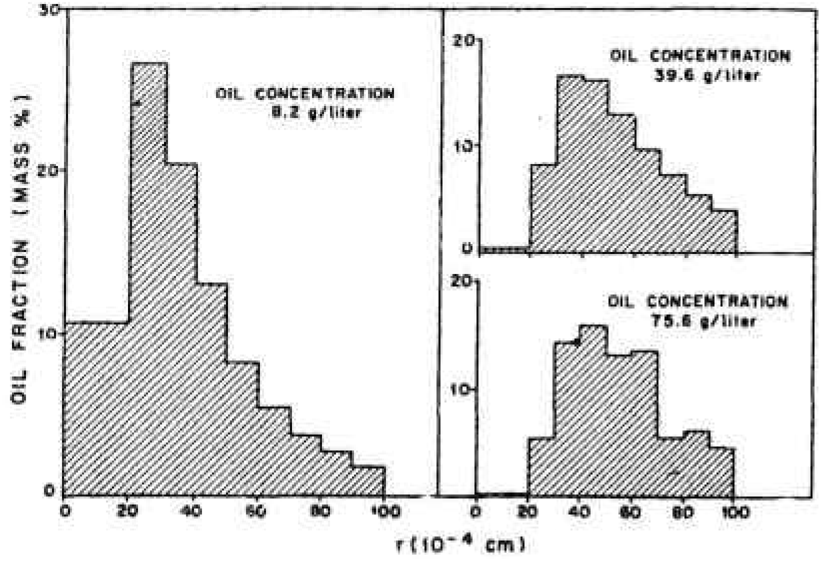


Fig. 13. Approximate distribution law. Rotation speed of impeller = 670 rpm.

F = oil fraction, in mass per cent, in the form of oil droplets with radius equal to or larger than r

g = acceleration due to gravity, cm/sec^2

H = distance from the radiation detector to the tank bottom, cm

r = oil drop radius, cm

α = empirical parameter, function of the experimental conditions, sec^{-1}

η = water viscosity, g/cm sec

ρ_a = water density, g/cm^3

ρ_o = oil density, g/cm^3

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RESUMO

Usa-se um método radiométrico para determinação da distribuição de diâmetros de gotas de óleo, em sistemas hidrocarboneto-água agitados. Foram estudadas a influência da posição do detetor, a concentração de óleo e a freqüência de agitação. Propõe-se um parâmetro experimental para a definição da distribuição dos diâmetros de gotas de óleo. Foi observado que a distribuição dos diâmetros de gotas era melhor representada por uma lei de distribuição assimétrica, do que por uma distribuição normal.

RÉSUMÉ

Une méthode radiométrique, pour la détermination de la distribution des diamètres des gouttes d'huile dans des systèmes hydrocarbure-eau agités, est employée. L'influence de la position du détecteur, de la concentration en huile et de la fréquence d'agitation ont été étudiées. Nous proposons un paramètre expérimental pour la définition de la distribution des diamètres des gouttes d'huile. On a observé que la distribution des diamètres des gouttes était mieux représentée par une lai de distribution asymétrique que ne l'était par une lai de distribution normale.