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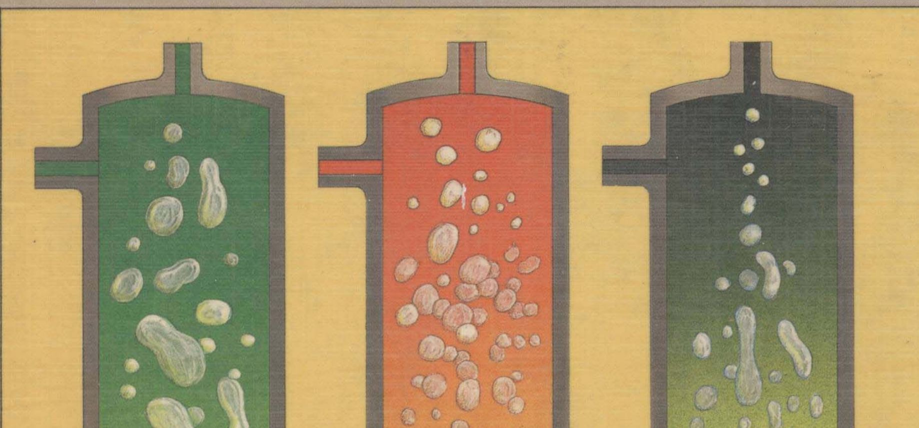

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PREFACE

The increasing importance of solvent extraction is demonstrated by the rapidly growing number of national and international meetings. ISEC, the main world forum on this subject, is held alternately in different continents, attracting thousands of enthusiastic participants. However, its scope is so broad that there is a need for more intimate meetings where specific problems can be discussed in detail. The present conference, with its tradition of previous meetings organised by Professor John Thornton at the University of Newcastle-upon-Tyne and at Dounreay in 1984, is providing such a focus for British and other scientists, interested both in specific processes and in extracting generally. Being held in a nuclear establishment with the recovery of high value materials as its main topics, enables workers in hydrometallurgy and the reprocessing of nuclear fuel to present specialised contributions in their fields of interest. However, by also including general papers in equipment design, operation and modelling, its scope is sufficiently broad to be attractive for everybody interested in liquid-liquid extraction, both in industry and the universities. The result presented in this proceedings is a balanced contribution of valuable scientific work from 10 countries throughout the world, showing that Dounreay has established itself as a permanent event for those concerned with some of the still unsolved problems in liquid-liquid extraction.

This success would not be posssible without the enthusiastic work of the organisation committee and its chairman Mr. Mike Walker, the valuable contributions of the authors of the scientific papers collected in this volume and the efficient and exhaustive work of Mrs. Gillian Nelson, who managed the practical organisation so well. They and everybody else who contributed to the success of this meeting deserve the appreciation of all participants of Extraction '87.

S. Hartland

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PREDICTION OF JET BREAK-UP LENGTH IN LIQUID-LIQUID SYSTEMS UNDER THE INFLUENCE OF EXTERNALLY APPLIED MECHANICAL VIBRATIONS

Anwar M M, Khan S A and Pritchard D W**

ABSTRACT

A laminar liquid jet in another immiscible liquid can either expand or contract depending on the physical properties of the system. The diameter of the drops produced as a result of the disintegration of the jet are a function of the jet diameter at the point of break-up.

The present work shows that Rayleigh's equation can be modified to predict the jet break-up length. Experimental techniques are also described which are capable of measuring jet break-up length under the influence of externally applied mechanical vibrations.

INTRODUCTION

When one liquid is injected into a second immiscible liquid, a jet is formed. The jet attains a length which is characteristic of nozzle diameter, nozzle velocity and physical properties of the system.

Rayleigh[1] suggested that when the length of the liquid jet exceeds the circumference of the jet, it becomes unstable and a standing wave is formed at the surface of the jet. The amplitude of the wave grows exponentially and when it becomes equal to or greater than the radius of the jet, the jet breaks-up into droplets. He presented an analytical treatment of the phenomenon which gave an equation:

$$L = \frac{U_n}{\alpha} \ln \frac{a}{\eta_o} \qquad \text{—— 1}$$

A number of previous workers [2,3,4] have developed equations to predict drop diameter as a function of the jet diameter. In their calculations they assumed that the jet diameter is equal to the nozzle diameter.

Das[5] and Anwar et al[6] reported that the jet diameter is a function of the jet length and cannot always be taken as equal to the nozzle diameter. They concluded that depending on the physical properties of the system and nozzle diameter, the jet could either expand or contract. Thus in order to calculate the drop diameter and interfacial area, it is essential to have a knowledge of jet break-up length.

This paper attempts to extend the work of Anwar et al[6] in this field and to study the effect of various parameters on the jet break-up length.

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An experimental programme has been devised to enhance the understanding of the effect of applied vibrations and flowrate of the dispersed phase on the jet break-up length.

EXPERIMENTAL

The apparatus used is shown in Figure 1. In the early part of the work, a Kerosine/Paraffin mixture was used as the continuous phase. For later experiments the continuous phase was n-decane. Water is used as a dispersed phase throughout. The temperature was maintained at 20°C. A pressure of 2 bar was applied to the feed tank via Valve A. The required flowrate was achieved by the adjustment of Valves B and C. The indicated flowrate on the rotameter was confirmed by weighing the collected sample of dispersed phase over a fixed time. To maintain a constant flow of the dispersed phase, over extended periods, a gas-liquid chromatographic flow control system was modified and incorporated into the system.

The jet was subjected to externally applied vibrations at a chosen frequency and amplitude using a vibrator 407L made by L T V Ling Altec Ltd. A PO-20 type frequency generator was used to activate the vibrator. The signals from the generator were amplified using an amplifier supplied by L T V Ling Altic Ltd.

The variation in the jet length was studied and recorded using a video camera and a 35 mm still camera. Measurements of the jet length and drop diameter were taken from still photographs and the process of jet disintegration was studied by replaying the recorded films in slow motion.

Two types of nozzles were used for injection of the dispersed phase.

(a) Hypodermic Needles: These needles were provided by Coopers Needle Works Ltd. The length of each needle was 6.5 cm. Needle tips were machined flat and smooth to reduce the rough surface effect of the nozzle on the liquid jet.

(b) Spinnerettes: These spinnerettes were made up of stainless steel plate of 1 mm thickness. Spinnerettes with four different hole sizes (250, 200, 150 and 100 μm) were employed. An aluminium chamber was designed and constructed to hold these spinnerettes.

The needles and spinnerettes were mounted on the extension bar of the vibrator. Physical properties of the two phases were measured under mutually saturated conditions. A synchro-lectric viscometer was used for the measurement of viscosity. Density was measured using Gravity bottle. The surface tension was determined using Harkins-Brown's drop volume technique. A listing of the physical properties for liquid pairs used is given in Table 1.

RESULTS AND DISCUSSION

Experimental results for the jet break-up length without external vibrations against nozzle velocity for a spinnerette (250 μm) are given in Figure 2. In the initial region A-B the jet length increases linearly with nozzle velocity. Subsequently, there is an abrupt lengthening of the jet from B-C, without any noticeable change in the nozzle velocity. The jet length reaches a maximum along C-D. After the critical velocity at which the maximum jet length occurs, the jet length starts to decrease with increase in the nozzle velocity D-E.

Most previous workers restricted their investigations to the region A-B for a low dispersed phase flowrate. For contacting equipment, higher dispersed phase flowrates are desirable. Therefore, initially the experiments were conducted at a flowrate in the region D-E in Figure 2. The data obtained under the influence of externally applied mechanical vibrations in this region are plotted in Figure 3. The results show that the jet length decreases with the increase in the applied amplitude. There is also evidence of jet length variation with the change in the applied frequency. This is contrary to previous reports(2,3,4) where workers have taken

$$\ln \frac{a}{\eta_o}$$ as a constant in Equation 1.

To take into account this variation in jet length due to applied amplitude, η_o is replaced by value of applied amplitude η in Equation 1. Thus equation 1 can be written as:

$$L = \frac{U_n}{\alpha} \ln \frac{a}{\eta} \qquad \text{—— 2}$$

From this equation a plot of L vs $\ln a/\eta$ for a constant nozzle velocity should give a straight line. Results are plotted in Figure 4 and show that the value of Un/α is constant for all frequencies and amplitudes but the intercept changes with the change in the applied frequency. Therefore, Equation 2 needs to be modified to allow for this behaviour ie., we can write Equation 2 as:

$$L = \frac{U_n}{\alpha} \ln \frac{a}{\eta} + C \qquad \text{—— 3}$$

Where intercept C is a function of the applied frequency.

To take into account the effect of frequency on η and develop a relationship to correlate the experimental data without generating a series of intercept values for different frequencies we can write:

$$C = \frac{U_n}{\alpha} \ln K$$

Hence:

$$L = \frac{U_n}{\alpha} \ln \frac{ak}{\eta} = \frac{U_n}{\alpha} \ln \frac{a}{\eta K} \qquad \text{—— 4}$$

Where K is a function of applied frequency which can be related in terms of a polynomial function as:

$$\frac{K}{\eta} \text{ or } \frac{1}{\eta K} = \frac{1}{\eta(POL)}$$

Where $POL = A_1 + A_2F + A_3F^2$ —— 5

Where F is the frequency of the applied vibration. The final equation can be written as:

$$L = \frac{U_n}{\alpha} \ln \frac{a}{\eta(POL)} \qquad 6$$

The values of the constants (A_1, A_2 and A_3) in equation 5 were determined by using an optimising technique proposed by Nelder and Mead[7].

These constants were employed to predict the jet length using Equation 6. Figure 5 shows the plot of jet length vs ln a/η(POL). The experimental points were calculated using the intercept values in Figure 4. The line indicates the predicted values using calculated constants. The agreement between experimental and calculated values is very good.

The results reported in Figure 5 were obtained without producing monosized droplets. The drops actually produced varied in diameter from 0.2 to 1.2 mm. The still photographic technique was used and this could not accurately capture the exact point of break-up. The jet length measurements varied with the size of the drop and its point of detachment. This introduced an error in the measurement of jet length, which at maximum, is equal to the drop diameter as shown in Figure 5 (standard deviation - 0.072).

In view of this error the second part of the present work was carried out with monosize droplets.

To help in the determination of the exact point of break-up, still photography was supplemented by a video film technique. A nozzle of 0.61 mm diameter was used and the continuous phase was changed to a single component (n-decane) instead of kerosene. It was observed by trial and error that it was easier to locate the frequency of the applied vibrations for the production of monosize droplets in the region A-B in Figure 2. Therefore the work was limited to this region. The frequency was varied from 200 to 350 Hz and the amplitude was adjusted to produce monosize droplets. The data obtained were used to produce plots of jet length Vs ln a/η shown in Figures 6, 7 and 8.

The plots in these figures are parallel lines with different intercepts at different applied frequencies. This confirmed the conclusions drawn earlier that although the jet break-up length is affected by applied vibrations the growth rate of disturbances on the surface of the jet is constant. The only parameter in equation 1 which can vary is η.

Assuming that there is more than one wave responsible for the break-up of the jet, then the combined effect of these waves should produce a composite wave. The frequency and amplitude of the resultant wave will be determined by the frequency and amplitude of the original waves. Considering two waves to be responsible for the formation of the resultant wave, one being the natural wave that predominates in the absence of any applied vibration and the other occurring as a result of the applied vibration. The amplitude of the resultant wave will be equal to the difference of the amplitudes of these waves at the point of interference, and equal to the sum of their amplitudes at a point of resonance. According to the accepted theory, the liquid jet breaks-up when the amplitude of the wave becomes equal to or greater than the radius of the jet. In this case it will be the amplitude of the resultant wave. Thus equations 1 can be written as:

$$L = \frac{U_n}{\alpha} \ln \frac{a}{\eta_a} \qquad \text{——— 7}$$

Where η_a is the amplitude of the resultant wave and can be measured experimentally by the video film technique at constant applied amplitude. The results are plotted in Figure 9. These results show that the ratio of measured amplitude and applied amplitude ($\eta_m/\eta = R_f$) changes with change in the applied frequency, for example, at a frequency of 200 Hz the R_f is 2.7 while at 300 Hz the value is 0.66. This leads to the conclusion that at 200 Hz frequency resonance is occurring and at 300 Hz frequency interference is taking place. This is also evident in the experimental data for jet break-up length which show that with the applied vibration at 200 Hz, the jet length was shorter than the jet length at 300 Hz frequency.

For any system R_f values can be determined experimentally by using the technique employed in the present work. These values can be used to evaluate the amplitude of the resultant wave. According to equation 8 the plot of jet length vs ln $a/\eta R_f$ should give a straight line with zero intercept. The appropriate results are plotted in Figures 10, 11 and 12. The plots gave the expected straight lines with zero intercepts, and confirmed the validity of the equation 7.

CONCLUSIONS

The work on the disintegration of laminar liquid jets under the influence of an externally applied vibration has shown that the growth rate of the resultant wave is constant. Rayleigh's equation can be modified to predict the jet break-up length if the frequency and amplitude of the applied vibration are known.

LIST OF SYMBOLS

a - nozzle radius cm
L - jet length cm
R_f - Resonance Correction Factor
U_n - nozzle velocity cm/s
α - growth rate of disturbance cm/s
η_o - initial amplitude of the wave at the nozzle cm
η - applied amplitude of the vibration cm
η_m - measured amplitude of the vibration cm
η_a - actual amplitude of the resultant wave cm

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TABLE 1

AVERAGE PHYSICAL PROPERTIES OF MUTUALLY SATURATED LIQUIDS USED IN THE PRESENT INVESTIGATION

S. No	SYSTEMS	DISPERSED PHASE DENSITY	CONTINUOUS PHASE DENSITY	DISPERSED PHASE VISCOSITY	CONTINUOUS PHASE VISCOSITY	INTER FACIAL TENSION
		gm^{-3}	gm^{-3}	mpas	mpas	mN
1.	Water-Kerosene	1.0	0.78	1.0	1.6	44.20
2.	Water-Kerosene (75%) + Paraffin (25%)	1.0	0.82	1.0	2.27	42.48
3.	Water-Kerosene (50%) + Paraffin (50%)	1.0	0.83	1.0	8.04	41.50
4.	Water-Kerosene (25%) + Paraffin (75%)	1.0	0.84	1.0	15.2	40.10
5.	Water-Paraffin	1.0	0.86	1.0	28.0	39.11
6.	Water-Decane	1.0	0.73	1.0	1.25	25.00

Note : Above mentioned mixing percentages by volume are approximated.

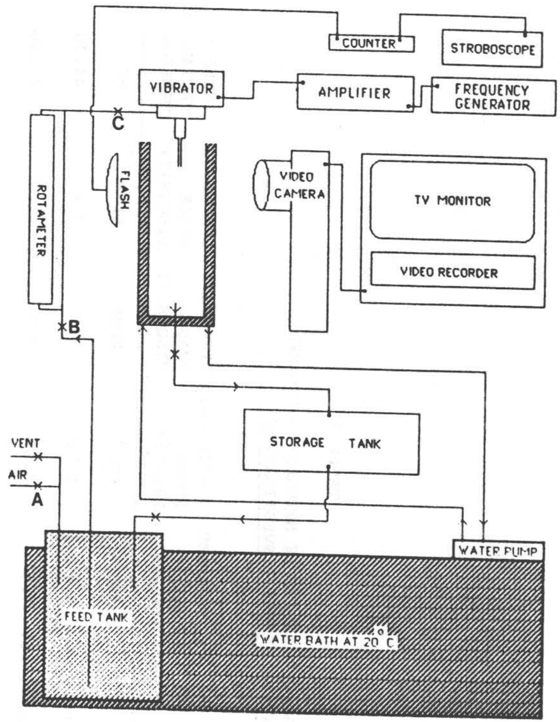
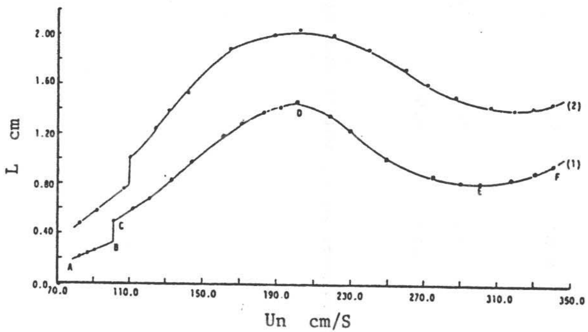


FIGURE 1

SCHEMATIC DIAGRAM OF EXPERIMENTAL APPARATUS



(1) Water/Kerosine
(2) Water/Liquid Paraffin

Nozzle Diameter - 0.025 cm

Figure 2 Jet Break-up Length Against Nozzle Velocities

Figure 3 Plot of experimental jet length and applied amplitude

System - Water/Kerosine
N. Dia - 0.020 cm

- ▼ 200 Hz
- + 250 Hz
- ⊙ 300 Hz
- ◆ 350 Hz
- ✱

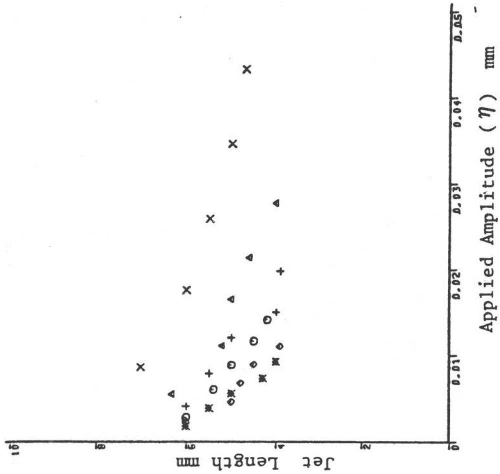


Figure 4 Plot of experimental jet length and applied amplitude

System - Water/Kerosine
N. Dia - 0.020 cm

- ■ - 200 Hz
- ▼ - 250 Hz
- ◆ - 300 Hz
- □ - 350 Hz
- △ - 400 Hz
- ○ - 450 Hz

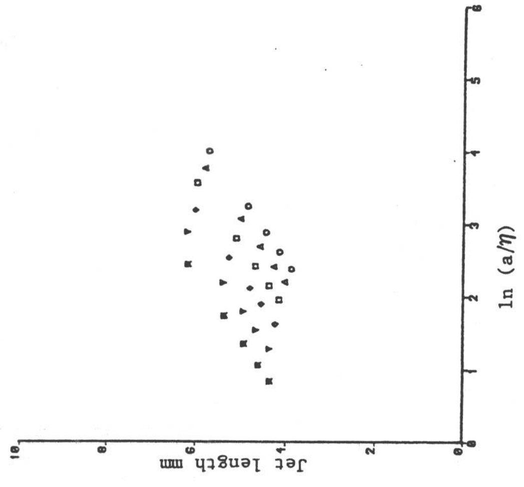


Figure 5 Experimental and Predicted jet length using equation (6)

System - Water/Kerosine
N. Dia - 0.020 cm

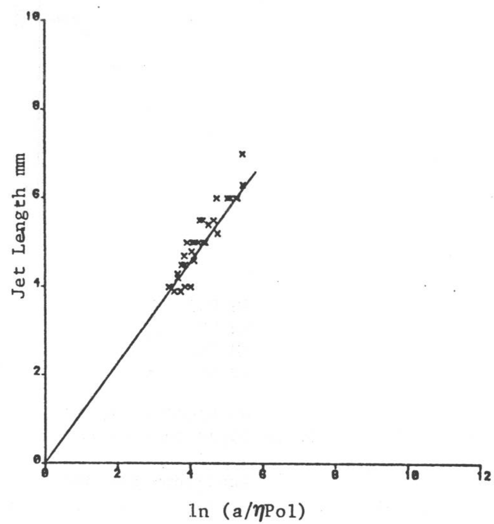


Figure 6 : Plot of jet breakup length agaist applied amplitude.
Nozzle velocity - 562 mm /sec.
nozzle Diameter - 0.61 mm.
System - Water / Decane

• - 200 Hz.
▲ - 275 Hz.
+ - 300 Hz.
■ - 350 Hz.