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MASS TRANSFER COEFFICIENTS IN THE EXTRACTION AND RECOVERY OF COBALT AND NICKEL

by

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A Thesis
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ABSTRACT

Overall mass transfer coefficients ($\bar{K}_{org}$) values, were determined for the extraction and separation of cobalt and nickel from aqueous sulphate solutions. A modified Lewis cell was used to study the three distinct contacting steps that are required to effect the separation. In the first an aqueous solution containing both metals is extracted using a solution of 10% D2EHPA in kerosene with tri-butyl phosphate added as a phase modifier. The equilibrium in this stage is such that the loaded solvent contains both cobalt and nickel. In the second stage the loaded solvent is scrubbed with an aqueous cobalt solution where the equilibrium is displaced so that nickel is transferred from the organic to the aqueous phase. Finally, in the third stage the scrubbed solvent is stripped with aqueous sulphuric or nitric acid solutions to produce a concentrated cobalt solution. The Reynolds number of the aqueous and organic phases in the cell was varied from 1000 to 3000 and the response of $\bar{K}_{org}$ to these variations was evaluated.

$\bar{K}_{org}$ values varied in value from 0.9×10^{-3} to 1.4×10^{-2} cm/s for co-extraction and scrubbing and depended on the direction of mass transfer, organic phase loading and stirrer Reynolds number. $\bar{K}_{org}$ values for stripping were found to be lower than those observed in the other contacting regions and were not greatly affected by change in Reynolds number.

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Finally, the author would like to dedicate this thesis to his beloved parents whose understanding and encouragement made the study possible and to my future wife, Marjorie, goes my deepest appreciation for the patience and moral support given me throughout this work.

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NOMENCLATURE

A: Area (cm^2)

C: Metal concentration (g/L)

C^*: Equilibrium metal concentration (g/L)

D: Diffusion coefficient (cm^2/sec)

k: Individual mass transfer coefficient (cm/sec)

R_{org}: Overall mass transfer coefficient faced on organic phase (cm/sec)

L: Length of stirrer (cm)

M: Equilibrium coefficient, C_{org}/C_{aq}

N: Rate of rotation (revolution/sec)

dN: Rate of mass trnasfer (gm/sec)

S: Cross-sectional area (cm^2)

t: time (sec)

V: Volume (cm^3)

ρ: Density (gm/cm^3)

ν: Kinematic viscosity (cm^2/sec)

η: Viscosity (gm/cm sec)

σ: Surface tension

Subscripts

org.: organic

aq: aqueous

i: Interfacial

1: Location 1

2: Location 2

Dimensionless Groups

Re: Reynolds number, $\frac{L^2 N}{\nu}$

Sc: Schmidt number, $\frac{\eta}{\rho D}$

A. INTRODUCTION

Liquid-liquid extraction is a method encountered in the chemical processing industry for the separation of the constituents of a homogeneous liquid mixture. The solvent used in the extraction process should be immiscible with one of the components of the mixture in order to facilitate the separation of the liquid phases.

The liquid-liquid extraction operation consists of the following steps: (a) intimate contacting of the solvent with the solution containing the component to be extracted (extractant or solute) so that the solute will be transferred from the solution to the solvent and (b) separation of the two immiscible phases. This unit operation is used when a separation cannot be achieved by other means such as distillation, evaporation and crystallization or effecting the separation more economically. [1 , 2]

The initial success of liquid-liquid extraction (also called solvent extraction) for both the separation of uranium from its ore and the subsequent treatment of spent reactor fuel to separate plutonium from uranium and its fission products [3] has led to the use of solvent extraction to isolating metals in the metallurgical industries, especially in the field of hydrometallurgy.

Publications on the principles of these operations became available in the early 1950s. Soon, other reagents were being considered for uranium, so that the alkyl phosphoric acids were screened [4]. It was realized that these derivatives had a wider use, in that other valuable cationic metal-species could be extracted, e.g. vanadium [5]. Indeed, the value of the metal recovered was a primary driving force in developing the earliest solvent-extraction units, such as the rare-earths [6,7]. Gradually attention turned toward the less-valuable, but nevertheless important, transition metals such as cobalt and nickel [8,9] which the present work is concerned with.

The Phosphorous-based acid, Di (2-ethyl hexyl) phosphoric acid (D2EHPA) has been used for the extraction and separation of cobalt and nickel from aqueous sulphate solutions [10-12]. Three distinct contacting steps are required. In the first an aqueous solution containing both metals is extracted using a solution of D2EHPA in kerosene with tri-butyl phosphate added as a phase modifier. The equilibrium in this stage is such that the loaded solvent contains both cobalt and nickel. In the second stage the loaded solvent is scrubbed with an aqueous cobalt solution where the equilibrium is displaced so that nickel is transferred from the organic to the aqueous phase. Finally, in the third stage the scrubbed solvent is stripped with aqueous sulphuric or nitric acid solutions to produce a concentrated cobalt solution. The stripped organic phase is pre-equilibrated before being recycled. Little work, however, has been carried out to determine the mass transfer characteristics for the extraction and separation of cobalt from nickel from aqueous solutions of their sulphates by D2EHPA [13-16].

Bench scale shake-up tests can be used to give rough information on the mass transfer characterisitcs of a separation process but are only suitable for obtaining equilibrium data. A more precise means for the study of extraction kinetics is the widely used Lewis [17] cell and its modifications, [17,26-32] in which an essentially flat liquid-liquid interface of known area is agitated by two counter-rotating impellers, one in each phase.

In this work, a Lewis type cell was utilized to investigate the extraction rate kinetics of cobalt from nickel. The stirred transfer cell was chosen, because each phase can be stirred at speeds low enough to avoid disruption of the known interfacial area but high enough to ensure complete mixing in the main body of the phases.

B. LITERATURE SURVEY

Many solvent extraction processes involve a chemical interaction between the solute and an extractant present in the solvent phase. A classic example is the extraction of uranium from an aqueous solution into a solvent comprising a solution of tri-n-butyl phosphate (TBP) in a suitable diluent. For nitrate media the reaction may be represented by:

$$\underset{\text{Aq.}}{UO_2^{++}} + \underset{\text{Aq.}}{2NO_3^-} + \underset{\text{Org.}}{2TBP} \longrightarrow \underset{\text{Org.}}{UO_2(NO_3)_2.2TBP} \qquad ...(1)$$

The distribution coefficient is determined by the position of this reaction equilibrium. This can be adjusted by control of the nitrate ion concentration, taking advantage of the common ion effect, thus making possible both forward and back-extraction. However, being an equilibrium process, it gives no guidance as to the overall rate of the mass transfer process from one phase to the other, a factor of key importance in determining the design and performance of continuous industrial solvent extraction units. The chemical reaction can possibly indicate those solutes which could determine the kinetics of the chemical interaction.

In most cases the overall mass transfer rate will be a function of both the kinetics of the chemical interaction and the rates of diffusion of one or more of the species involved between the two phases, except when the reaction or the mass transfer is instantaneous. A process can be classified as either kinetic or mass transfer controlled if one rate virtually determines the transfer resistance.

Equipment of solvent extraction processes designed from equilibrium isotherms automatically neglects kinetic effects. However, new processes used for the extraction of metals from solutions, involve reagents where chemical reaction kinetics can be important. Their neglect could introduce serious errors, particularly with the design of differential contactors. In addition, differences in kinetic rates can be expected to influence the separations achieved between solutes in a finite time of contact, giving separation factors either greater or less than would be predicted from distribution coefficients measured under equilibrium conditions. Such effects could be the cause of some anomalous separation performances.

I The Separation Process

Extensive research effort has been devoted to the problem of separating cobalt and nickel, with high separation factors being obtained when using a mixture of Kelex 100 and Versatic 911 [18]. These extractants were reported to exhibit a synergistic effect. Kinetic synergism was also successfully made use of for the separation of these two metals in acid sulphate systems using a mixture of hydroxyoxime and tertiary carboxylic acid [19]. Cobalt and nickel can also be extracted from aqueous solution with D2EHPA [10] and this is the basis of a proposed process for the separation of these two metals [10, 11]. Briefly, in this process nickel and cobalt were first co-extracted at a pH of 5.0-5.5. The loaded solvent was then scrubbed with an aqueous cobalt solution up to 20 g/l. The cobalt then extracted into the organic phase, the nickel being recovered in the raffinate solution. A dilute mineral acid was used to recover the cobalt.

In view of the interest in separation of cobalt and nickel (using D2EHPA), work was carried out to determine mass transfer coefficients and provide data which could assist in design of liquid-liquid extraction equipment for separation of cobalt and nickel.

II Chemistry of the Extraction Process

Ashbrook and Ritcey [12] reported that during the separation and extraction of cobalt from nickel using the acid form of D2EHPA, hydrogen ions are liberated from the solvent. The exchange of the hydrogen ions lowers the pH of the aqueous phase and since the co-extraction of the metals is pH dependent, equilibration of D2EHPA with ammonium hydroxide is necessitated for optimum extraction.

The mechanism of the process may be represented in simple terms as:

Equilibration

$$RH + NH_4OH \longrightarrow RNH_4 + H_2O \qquad \ldots(2)$$

Co-extraction

$$2(RNH_4)_{org} + Co^{2+}_{aq} \longrightarrow R_2Co + (NH_4)_2\,SO_4 \qquad \ldots(3)$$

$$2(RNH_4)_{org} + Ni^{2+}_{aq} \longrightarrow R_2Ni + (NH_4)_2\,SO_4 \qquad \ldots(4)$$

Scrubbing

$$R_2Ni_{org} + Co^{2+}_{aq} \longrightarrow R_2Co_{org} + Ni^{2+}_{aq} \qquad \ldots(5)$$

Stripping

$$R_2Co_{org} + H_2SO_4 \longrightarrow CoSO_4 + 2RH \qquad \ldots(6)$$

The stripped solvent is then equilibrated with ammonium hydroxide and recycled to extraction.

Although the metal complex is represented in the above equations as a 2:1 organic:metal complex, Madigan [20] showed that the complex is a coordination compound in which the chelated metal is surrounded by organic radicals. Baes and Baker [21] noted that polymeric complexes are present in the organic phases in which D2EHPA acts as a bridging ligand. The degree of polymerization depends on both the metal concentration and the temperature. Barnes and et al [22] correlated between the selectivity of D2EHPA and the structure of the complex.

These observations pose the question as to whether the formation of these organometalic complexes, or their large molecular structure control the overall mass transfer.

III Equipment and Correlation for Interphase Mass Transfer

The study of mass transfer accompanied by chemical reaction and involving two fluid phases is rather complex conceptually. In general, the overall rate of such a process is influenced by the relative magnitudes of the rates of interphase mass transfer and the reaction. The number of variables which affect the two processes is large, some of them influence the rate of one, whereas others affect both. Levenspiel and Godfrey [23] outlined an action response plot of how to possibly distinguish between kinetic regimes for interphase mass transfer with/without reaction.

In theoretical treatments, analytical solutions have been obtained for several cases of mass transfer with chemical reaction. However, approximate solutions and results of numerical solutions are available for quite a number of cases. Some of the equipment used in mass transfer in a two phase system and the empirical correlations are presented below while other aspects of the topic are extensively dealt with in special monographs [24, 25].

Equipment

Stirred cells, well established in mass transfer studies, have been used in several instances for studying gas-liquid and liquid-liquid reaction systems. Such cells have been designed specifically for application to gas-liquid systems [23] and liquid-liquid systems [17, 26-32]. The uncertainties and consequent limitations of this technique are known; Hanson [33] has given a comprehensive discussion.

Empirical Correlations

An empirical correlation for the mass transfer coefficient was developed by J.B. Lewis [17]. The resulting equation obeyed the relation.

$$k_1 = 1.13 \times 10^{-7} \nu_1 (Re_1 + Re_2 . \eta_2/\eta_1)^{1.65} + 0.0167 \nu_1 \quad \ldots(7)$$

where K_1 refers to any one phase and k_2 the second phase. Various objections have been raised to equation (7) and as written was found numerically satisfactory ±40%. A criticism of the correlation is detailed by Sherwood [34]. A different empirical correlation of the transfer across a clean interface in a stirred cell comes from Davies and Mayers [30].

$$k_2 = 0.00316 \, (D_2/L)(Re_2 \; Re_1)^{0.5} \, (\eta_1/\eta_2)^{1.9} \, (0.6 + \eta_1/\eta_2)^{-2.4} \, (Sc_2)^{5/6} \quad \ldots(8)$$

where k_2 varies with $D_2^{1/6}$, this dependence lying between that of Danckwerts [35] equation and that of equation (7) of J.B. Lewis. This correlation is accurate in predicting k_2 to ±40% for different systems. It suggests that the replacement of elements of liquid in the surface by turbulent flow is very important, so that molecular diffusion from these elements has then to occur over a very short distance.

Another empirical correlation is that proposed by McManamey [32].

$$k_2 = 6.4 \times 10^{-4} \nu_2 (Sc_2)^{-0.3} (Re_2)^{0.9} \left[1 + \frac{\eta_1 Re_1}{\eta_1 Re_2} \right] \quad \ldots(9)$$

This equation correlates k_2 with $D_2^{0.3}$, and the fit to the data of Lewis is somewhat better than that of equation (7).

An investigation by Gordon and Sherwood [31] indicated that for isobutonal and water

$$k_1 \; \alpha \; D_1^{0.5} \, (Re_1)^{1.3} \quad \text{when } N_1 = N_2 \quad \ldots(10)$$

Olander and Benedict [27] found that

$$k_1 \propto D_1^{0.44} N^{0.67} \qquad \ldots(11)$$

where the rate of stirring N was again the same in both phases. Yet another investigation gave power of N between 0.9 and 1.5 (Prochazka and Bulicka) [26]. The results of Austin and Sawistowski [29] for stirring in both phases are reasonably well correlated by

$$k_1 \propto D_1^{0.5} \nu_1 Re_1 \left\{1 + \left[\nu_2^2 (Re_2)^2 / \nu_1^2 (Re_1)^2\right]\right\}^{0.5} \qquad \ldots(12)$$

There is, however, considerable scatter of the experimental points, while at high stirring rates, this expression gives values which are rather higher than experimental.

In general, all correlations proposed are empirical and therefore uncertain when extrapolated beyond the range of the original data especially when the data shows very considerable scatter.

Because each correlation incorporates certain fundamental assumptions and limitations which are than inherent in the final solution, then it is necessary to study the kinetics of each individual system. Using the "Equilibrium Extraction" technique, Brisk and McManamey [36] studied the kinetics for the transfer of copper and cobalt between aqueous solutions of their sulphates and organic phases consisting of solutions of D2EHPA in kerosene. The authors reported that the total resistance to mass transfer was found to be greater than that predicted from the mass transfer resistances of the aqueous and organic phases. The additional resistance to mass transfer being between 30 and 75% of the total resistance. But the mechanism for the separation of cobalt from nickel depends on preferential extraction between the two metals, on the other present metal concentration, and involves three different stages in the process separations. Hence it was necessary that an indepth study of the process kinetics be investigated to better understand the separation of cobalt from nickel. Due to the time limitations, only experimental measurements of the overall mass transfer coefficients of the system were undertaken.

IV Theory

In processes involving mass transfer in liquid-liquid extraction the equation relating the rate of transfer to the area available for transfer and a driving force, i.e. solute concentration difference, may be written as:

$$\begin{aligned} dN &= k_{aq}\, ds\, (C_{aq} - C_{aq,i}) = \\ &= k_{org}\, ds\, (C_{org,i} - C_{org}) \end{aligned} \qquad \ldots(13)$$

This equation assumes that the transfer rate is proportional to driving force, steady state diffusion exists, and that equilibrium conditions exist at the interface. i.e. there is no resistance at the interface. This model was developed by Whitman [37] and known as the two film theory. From equation (13) the ratio of the individual film coefficients may be expressed.

$$\frac{k_{aq}}{k_{org}} = \frac{C_{org,i} - C_{org}}{C_{aq} - C_{aq,i}} = \frac{\Delta C_{org}}{\Delta C_{aq}} \qquad \ldots(14)$$

In practice, it is ordinarily impossible to determine the exact interfacial concentration $C_{aq,i}$ and $C_{org,i}$ and thus the ratio of the individual film coefficients cannot be obtained. It is more usual to express the rates of mass transfer in terms of overall mass transfer coefficients for the aqueous and organic, $\overline{K}$.aq and $\overline{K}$.org respectively. If the equilibrium curve is assumed to be a straight line, i.e. $C_{org,i} = M.C_{aq,i}$, we may define a concentration C^{*}_{org} which would be in equilibrium with C_{aq} as:

$$C^{*}_{org} = MC_{aq} \qquad ...(15)$$

and similarly

$$C_{org} = MC^{*}_{aq} \qquad ...(16)$$

On the basis of the overall mass transfer coefficients, equation (13) becomes:

$$dN = \overline{K}.aq\ ds\ (C_{aq} - C^{*}_{aq}) = \overline{K}.org\ ds\ (C^{*}_{org} - C_{org}) \qquad ...(17)$$

and similarly

$$\frac{\overline{K}.aq}{\overline{K}.org} = \frac{(C^{*}_{org} - C_{org})}{(C_{aq} - C_{aq}^{*})} \qquad ...(18)$$

By suitable elimination between equations (13), (15), (16) and comparison with equation (14)

$$\frac{1}{\overline{K}.org} = \frac{1}{k_{org}} + \frac{M}{k_{aq}} \qquad ...(19)$$

and similarly

$$\frac{1}{\overline{K}.aq} = \frac{1}{k_{aq}} + \frac{1}{M\ k_{org}} \qquad ...(20)$$

If the equilibrium line is not linear i.e. M varies, a graphical method of analysis is used to evaluate M. Treybal [38] has detailed the method of analysis. Pratt [39, 40] has suggested introducing an extra term into equations (19) and (20) to allow for the interfacial resistance to mass transfer due to any chemical reaction at the interface between phases. The mass transfer coefficient relationships then are:

$$\frac{1}{\overline{K}.aq} = \frac{1}{k_{aq}} + \frac{1}{M\ k_{org}} + \frac{1}{k_{R,aq.}} \qquad ...(21)$$

$$\frac{1}{\overline{K}.org} = \frac{1}{k_{org}} + \frac{M}{k_{aq}} + \frac{1}{k_{R,org.}} \qquad ...(22)$$

The overall coefficients, $\overline{K}.aq$ and $\overline{K}.org$ were obtained experimentally; from extraction data.

V Determination of Mass Transfer Coefficients

At any time the transfer rate is given by

$$dN = V_{org} \frac{d\,C_{org}}{dt} \qquad \ldots(23)$$

hence from equation (5) and for transfer of solute from the aqueous phase to the organic phase

$$V_{org} \frac{d\,C_{org}}{dt} = \overline{K}.org\ ds\ (C^{*}_{org} - C_{org}) \qquad \ldots(24)$$

for constant interfacial area.

$$V_{org} \frac{d\,C_{org}}{dt} = \overline{K}.org\ A\ (C_{org}{}^{*} - C_{org}) \qquad \ldots(25)$$

$$\therefore \overline{K}.org = \frac{V_{org}}{A} \frac{1}{dt} \cdot \frac{d\,C_{org}}{(C_{org}{}^{*} - C_{org})} \qquad \ldots(26)$$

integrating over the time interval t:

$$\overline{K}.org \frac{A\ t}{V_{org}} = \int \frac{d\,C_{org}}{(C_{org}{}^{*} - C_{org})} \qquad \ldots(27)$$

The right hand integral is evaluated by plotting $\frac{1}{(C^{*}_{org} - C_{org})}$ against C_{org} and measuring the area under the curve. Thus, mean values of $\overline{K}$.org relating to successive values of t or C_{org} can be obtained.

For transfer from organic to aqueous an exactly analogous equation can be derived thus:

$$\overline{K}.org \frac{A\ t}{V_{org}} = -\int \frac{d\,C_{org}}{(C_{org} - C_{org}{}^{*})} \qquad \ldots(28)$$

and $\overline{K}$.org can be obtained by graphical integration as before.

Where the concentration difference in the integral is the difference between the actual concentration in the organic phase and the concentration the organic phase would have if it were in equilibrium with the existing concentration in the aqueous phase at the same instant.

C. EXPERIMENTAL

The work to be described was confined to the measurement of mass transfer rates for cobalt and nickel passing from one to another of two immiscible liquids.

I Apparatus

The experiments were carried out with a cylindrical transfer cell in which each phase was independently stirred by a central paddle. The interface was restricted by an annular gap between a central circular baffle and a circumferential wall baffle, the central baffle preventing cavitation and the outer baffle reducing irregular wall effects to a minimum. Both baffles were bevelled to enable drops of either phase accidentlly introduced into the other to roll to the interface.

The cell (shown in figure 1) consisted essentially of two pieces of glass pipe 15.24 cm I.D., cut such that the volume of the upper cell was 1,010 ml and the lower cell 1,730 ml. The two glass sections were separated by the circumferential baffle. The contacting interface area was 30.5 sq. cm and the two phases were mixed by turbine, twin blade stirrers. The stirrers were mounted independently and were driven co-currently by Zeromax model D-1 variable speed motors, 0-50 R.P.M. range, corresponding to a Reynolds Number range of 0 to 4500. This equipment was used for both the extraction and scrubbing experiments. In the stripping and the Acetic Acid systems the cell compartments were reversed, such that the upper volume was 1,735 ml and the lower volume 1,085 ml.

II Systems

In the extraction and separation of cobalt and nickel using D2EHPA there are three distinct areas of interest:

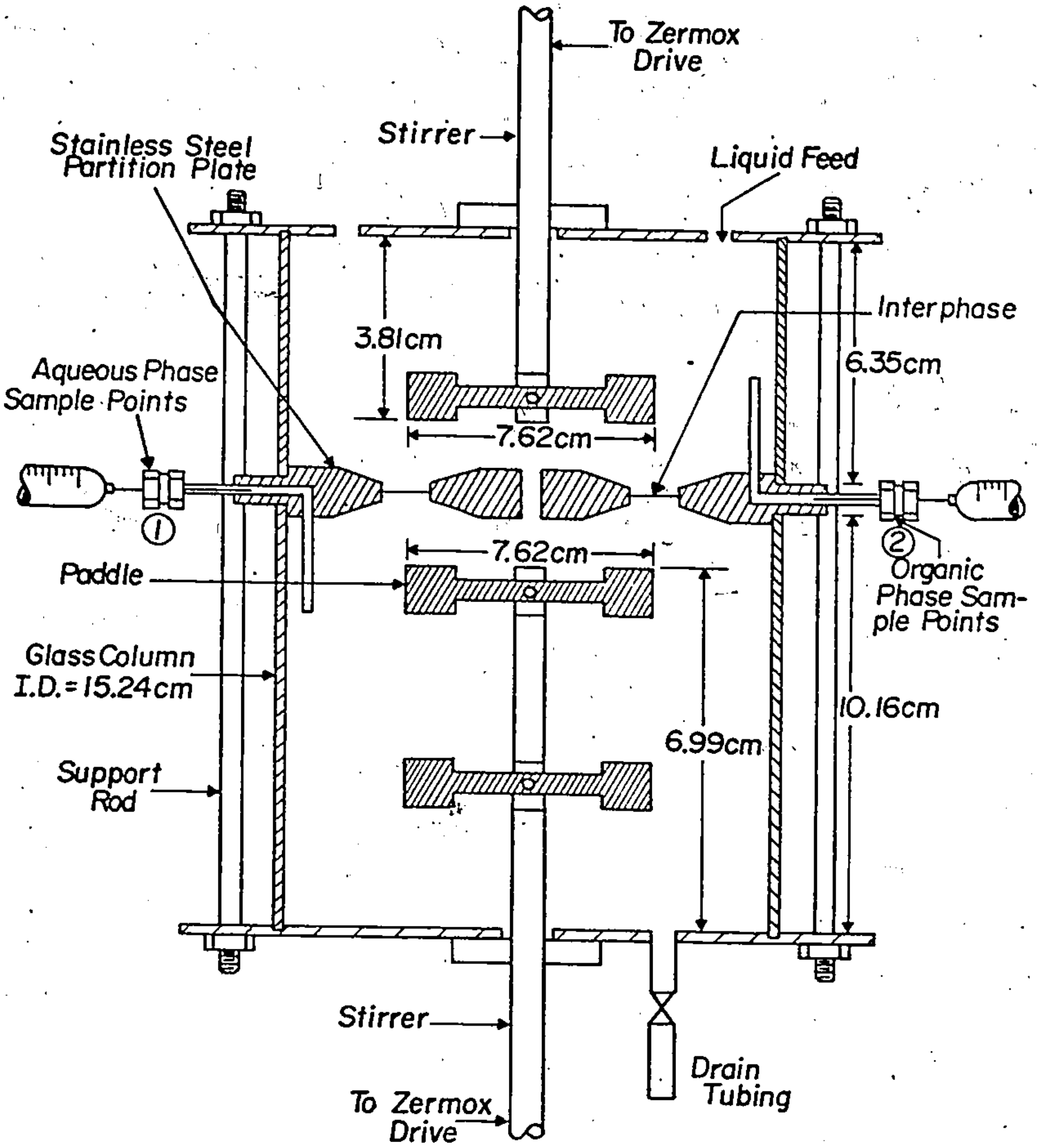


Figure 1. DETAILS OF EXTRACTION CELL

1) The co-extraction of cobalt and nickel.
2) The scrubbing of the loaded solvent as cobalt preferentially concentrates in the organic phase.
3) Acid stripping of the organic phase.

These three distinct stages in the separation of cobalt and nickel were investigated. In addition, for comparison, two other systems were studied. These were, Acetic Acid in benzene-water and Acetic Acid in Kerosene-water systems.

In all experimental runs, the organic phase always contained 10% volume of D2EHPA, 5% volume of T.B.P. modifier, and 85% volume of Kerosene diluent. Synthetic aqueous solutions were prepared by disolving nickel and cobalt sulphate crystals in distilled water.

The important physical properties of these systems are presented in table (1). Chemicals used and their properties are given in table (2).

III Procedure

Technique

Before loading the cell for an experiment it was carefully cleaned with acetone. Great care was taken to avoid contaminating the cell with grease or surface active agents. The heavier phase was run in until the top surface was above the mid-point of the annulus so that on taking the initial sample from this phase the interface fell to the correct level. The lighter phase was then poured into the top compartment to fill it completely. The stirring rates necessary to give the correct Reynolds Numbers had been previously calculated and the controllers set at this speed. Both phases were sampled at pre-determined Time intervals, initially by inserting long hypodermic needles through the

Table 1

Physical Properties of The System at 25°

	ρ (k_g M^{-3})	μ (k_g M^{-1} S^{-1}) X10^{-4}
10% D2EHPA + 5% T.B.P. + Kerosene	0.815	1.541
2g/l Co^{++} + 5 g/l N_i^{++} Aqueous Solution	1.026	0.945
Acetic Acid in Benzene	0.87865	1.608
Acetic Acid in Kerosene	0.799	1.181
10% H_2SO_4 Solution	1.068	1.232
25% HNO_3 Solution	1.1471	1.216
Distilled H_2O	0.9977	0.9548

N.B. Assumed no appreciable change in physical properties of organic solution due to organo metallic complex formation. Due to the low concentration of D2EHPA.

Table 2

Summary of Chemicals Used

Chemical	Supplier	Grade
T.B.P.	Anachemia Chemicals Ltd.	Technical
D2EHPA	Denison Co., Ltd.	Technical
Kerosene	Shell Oil Co., Ltd.	#140 Solvent
Sulphuric Acid	Fisher Scientific Co., Ltd.	Reagent 98% H_2SO_4
Ammonium Hydroxide	McArthur Chemical Co., Ltd.	Reagent 28-30% NH_3
Nickel Sulphate	Fisher Scientific Co., Ltd.	C.P.
Cobaltous Sulphate	Fisher Scientific Co., Ltd.	C.P.

filling hole and drawing samples from the middle of each phase. Later this procedure was altered. Sampling ports were installed in the circumferential baffle and again hypodermic needles were used (see figure 1). This change was incorporated so as to eliminate the interfacial disturbance that took place with the former technique, and to permit the withdrawing of a sample at a fixed position from the bulk phases. In order to compensate for the changes in the lower phase volume and to maintain the interface area unchanged in position, volumes equal to the samples removed were added.

The experiments were carried out over a period of three to four hours, and while samples were taken, the stirrers in both phases were stopped. This was done so as to obtain, as much as possible, instantaneous samples for analysis and possibly inhibit the mass transfer.

Also, during the extraction experiments the pH of the aqueous phase was monitered. This was accomplished by measuring the pH of the aqueous samples.

Operating Equilibrium Isotherms

Operating equilibrium loci data were obtained by batch shake-out tests, in separating funnels, at room temperature for all systems. The starting solutions of the systems were used and were contacted, at several different aqueous to organic volume ratios. After shaking, the samples were left over a 24 hour period to separate and settle. Samples from each phase were then analysed.

Preparation of Solutions

All solutions for the experiments were freshly prepared so as to avoid possible decomposition due to aging, such as pH change of aqueous solutions and the evaporation of the ammonia that is added to the organic solutions. The initial metal concentrations in these systems are presented in table (3).

1. Organic Solutions

(a) Extraction:

The solution comprised of 10% v/v D2EHPA and 5% v/v T.B.P., the third phase inhibitor, dissolved in kerosene diluent. In order to maintain the pH of the aqueous solution in the range of pH 4.00 to pH 5.5 during the experiment, the organic solution was equilibrated with ammonia to form the ammonium salt of D2EHPA. A 5% excess of the stoichiometric amount was found to be necessary.

(b) Scrubbing:

In preparation for scrubbing, the organic solution had to be loaded with cobalt and nickel. This was accomplished by similarly preparing the organic extraction solution, then contacting it with the same salt solution of cobalt and nickel used in the extraction stage. The same phase volume ratio as in the experimental unit cell i.e. 1,725:1 was used.

(c) Stripping:

The solvent was obtained in a two step procedure. Initially, the organic extraction solvent was prepared, then the organic scrubbing solvent. After separating the phases, the organic scrubbing solvent was contacted with the same salt solution of cobalt used in the scrubbing stage, in the ratio of 1.725:1.

2. Aqueous Solution

All aqueous metal solutions were synthetically prepared as metal sulphates. The initial pH of the solutions was adjusted using sulphuric acid.

Table 3

Initial Experimental Concentrations

Extraction

		Aqueous		Organic	
Experiment	pH	Cobalt Conc. g/l	Nickel Conc. g/l	Cobalt Conc. g/l	Nickel Conc. g/l
Run #1	3.92	2.00	4.9	0	0
Run #2	3.79	2.03	4.9	0	0
Run #3	4.0	1.973	4.9	0	0

Scrubbing

Run #1	5.0	14.75	0	1.745	3.6
Run #2	5.6	15	0	2.35	4.475
Run #3	5.4	15	0	2.186	4.246
Run #4	5.00	5	0	1.8	3.85

Stripping

Run #1	10% H_2SO_4 By weight	0.000	0.000	7.45	0.383
Run #2	"	0.000	0.000	7.303	0.466
Run #3	"	0.000	0.000	7.355	0.397
Run #4	25% HNO_3 By weight	0.000	0.000	6.000	0.000

Extraction

Experiment	Organic	Aqueous
AC-Ben-W	5% by weight of Acetic Acid in Benzene	Distilled Water
AC-Kero-W	5% by weight of Acetic Acid in Kerosene	Distilled Water

The initial metal concentration of the aqueous solution in the system are presented in table (3).

3. Acetic Acid System

Using glacial Acetic Acid, a 5% by weight of acetic acid disolved in benzene was prepared. Similarly, 5% by weight of acetic acid was used in the Kerosene system.

Analysis

A Unicam SP90 Atomic Absorption Spectrophotometer was used to analyse the metal concentrations.

1. Aqueous Concentration Determination

(a) Standard Solution Preparation:

Prepurchased standard solutions of 1,000 ppm of nickel and of cobalt were diluted with distilled water to the concentrations necessary to generate the desired absorbance mode calibration curve for the Atomic Absorption Spectrometry.

In order to correct for background chemical interference and loss in sensitivity due to the presence of the other metal in the experimental samples, the standards had to be matched as closely as to the samples. This matrix adjustment to the standard solutions was achieved by adding the appropriate concentration of the metal to the standards.

(b) Sample Preparations:

Initially, the samples were filtered with phase separating paper, (silicone treated "Whatman 1PS") then subdivided to prepare two dilutions. These were diluted to the optimum range concentration and detection limit of each respective metal on the A.A., which were different in dilution magnitude.

(c) Analysis:

The A.A. had to be calibrated before each metal analysis and repeatedly recalibrated during analysis. For details refer to "Atomic Absorption Spectrophotometry" by Peter Cooke, published by Unicam Instruments Lt

2. Organic Concentration Determination

Initially, the metals in the samples were stripped from the organic phase with nitric acid, diluted and then the same aqueous mode of analysis as described previously was used. This was found not to be very satisfactory. Specifically, because there was entrapment of metal loaded acid in the organic phase, and also due to the multiple dilutions of the acid that were needed for analysis.

The above mentioned difficulties and because of the small incremental concentration changes in the aqueous phase it was imperative that a direct method for organic analysis be used. After a long search, a method was achieved and is here described.

(a) Standard Solution Preparation:

The chemicals used to prepare the standards and their properties are here shown.

Available From Eastman Organic Chemicals	Nickel Cyclohexane Butyrate	Cobalt Cyclohexane Butyrate
Structural Formula	$(C_6 H_{11} (CH_2)_3 COO)_2 Ni$	$(C_6 H_{11} (CH_2)_3 COO)_2 Co$
Empirical Formula	$C_{20} H_{34} O_4 Ni$	$C_{20} H_{34} O_4 Co$
Molecular Weight	397.20	397.42
Metal Content	13.5%	15.0%
Grams of dried salt necessary to make 100 ml at 500 ppm concentration	0.371 gm	0.333 gm

Since the salt as supplied was not anhydrous, it was necessary to dry to constant weight before use. Approximately 0.4 gm of the salt was dried over fresh phosphorus pentoxide in a desiccator for 72 hours. A 0.371 gms of nickel salt and 0.333 gm of cobalt dried salt were quickly and accurately each transferred to 100 ml volumetric flanks. Kerosene was added with swirling. The solutions were brought to 100 ml and thoroughly mixed. This produced solutions having concentrations of 500 ppm nickel and 500 ppm cobalt. Again, matrix adjustment to the standard was achieved in the same manner as outlined in the aqueous section. Fresh dilutions were prepared before each analysis.

The procedure for sample preparation and analysis was the same as in the aqueous technique for the exception that care had to be exercised so as not to produce a sooty flame in the atomic absorption machine. For operating details of machine see Appendix III.

3. Acetic Acid Analysis

The concentration of acetic acid in the aqueous phase was determined by titration with sodium hydroxide and phenol phtalein as the indicator. The organic phase was analysed by adding water to extract the acetic acid from the organic phase and then titrating with NaOH. It was found that care had to be taken in determining the end point and ensure all the acetic acid has been extracted from the organic phase.

Calculation of Mass Transfer Coefficients

The overall solvent phase mass transfer coefficient are defined by equations (27) and (28).

Since samples were taken from each phase during an experiment, the variation of C_{org} and C_{aq} with time was known. For each value of C_{aq} the corresponding equilibrium solvent phase concentration C^*_{org} was obtained from the equilibrium curve. Thus $1/(C^*_{org} - C_{org})$ could be tabulated for various values of t enabling $\overline{K}.org$ to be evaluated by graphical integration of equations (27) and (28) for each time interval. Also the transfer coefficient was evaluated by plotting the log $(C^*_{org} - C_{org})$ against time. Assuming $\overline{K}.org$ and C^* does not vary appreciably at Δt intervals, then the slope of the graph at Δt intervals gives direct measure of the overall mass transfer coefficient.

A computer program was used to fit a polynomial to the concentration time and equilibrium data. Then a computer program was written to compute coefficients of mass transfer by both graphical and numerical techniques. In this way the process was followed as accurately as possible.

IV Variables

The temperature of the experiments was room temperature. The contacting surface area and the volumes in the cells were kept constant. The variables investigated were the solute concentration and the Reynolds Number effects on the three different stages of the metal separation. The various combinations of Reynolds Number that were used in the experiments are presented in table (4).

Table 4

Parametres of Operating System

	Extraction		Scrubbing		Stripping	
	Reynolds Number*		Reynolds Number*		Reynolds Number*	
Experiment	Organic Phase	Aqueous Phase	Organic Phase	Aqueous Phase	Organic Phase	Aqueous Phase
Run #1	1000	1500	1000	1500	1000	1500
Run #2	2000	1500	2000	1500	2000	1500
Run #3	1000	3000	1000	3000	1000	3000
Run #4	-	-	1000	1500	1500	1500
Acetic Acid-Benzene-Water	1500	1000	-	-	-	-
Acetic Acid-Kerosene-Water	1500	1000	-	-	-	-

*Characteristic length is impeller diameter.

D. RESULTS

Overall mass transfer coefficients based on the organic phase ($\overline{K}_{org}$) were evaluated from experimental data for co-extraction, scrubbing and stripping. The experimental data are presented in Appendix II. A computer program was used to fit experimental data, equilibrium data and to calculate $\overline{K}_{org}$ values (i) either by numerical integration or from the slope of $\ell n\ (C^*_{org} - C_{org})$ data. Typical data obtained from the computer printout is given in table (5) while the remainder of the data is given in Appendix I. For the purpose of comparison, the results are arranged in three groups according to the direction of mass transfer. The coefficients in each group for each metal are plotted against the organic phase concentration taking the Reynolds number as a parameter. The variation was changing the magnitude of N_{Re} by a factor of two in each phase. In the scrubbing stage, the effect of concentration was evaluated in Run #4, and in the stripping stage, nitric acid was evaluated in Run #4.

Co-extraction:

Overall mass transfer coefficients for co-extraction were found for cobalt to be in the 1.20×10^{-3} to 2.78×10^{-3} cm s^{-1} range. They were observed to depend on Reynolds number and on organic phase metal concentration. Thus $\overline{K}_{org}$ values for both metals increased with increase in Reynolds number in either the organic and aqueous phases, see figure (2). It can also be seen from figure (2) that $\overline{K}_{org}$ values for cobalt increased with increase in metal concentration in the organic phase.

Similar results were obtained for nickel with $\overline{K}_{org}$ values for nickel being higher than those observed for cobalt. The range of the $\overline{K}_{org}$ values for nickel were in the 2.3×10^{-3} cm s^{-1} to 1.0×10^{-2} cm s^{-1} range, see figure (3).

Scrubbing:

In this contacting region $\overline{K}_{org}$ values were of the same order of magnitude being in the 0.5×10^{-3} to 7.5×10^{-3} cm s^{-1} range for cobalt and the 0.5×10^{-3} to 5.0×10^{-3} cm s^{-1} range for nickel. These latter values were lower than was observed for extraction of nickel indicating an effect of the direction of mass transfer on the value of mass transfer coefficient. Increase in Reynolds number in either phase again resulted in an increase in $\overline{K}_{org}$ values for both metals, see figure (4). Also, an increase of the Reynolds number, by the same order of magnitude in each respective phase resulted with higher $\overline{K}_{org}$ values when the organic Reynolds number was changed than when the aqueous Reynolds number was doubled. An effect of metal concentration in the organic phase was noted when the agitation in the organic phase was raised, $\overline{K}_{org}$ values increasing with an increase in the metal concentrations in the organic phase for cobalt. However, the nickel $\overline{K}_{org}$ values increased with decrease in nickel organic concentration. See figure (5).

Stripping:

In this contacting region C* values for stripping were approximately equal to zero and $\overline{K}_{org}$ values could be obtained from plots of $\ln(C^* - C)$ versus the contacting time. (See figure 6, 7) $\overline{K}_{org}$ values were considerably lower than the values found for co-extraction and scrubbing; the values for cobalt were in the 2.46×10^{-4} to 3.0×10^{-4} cm s^{-1} range while for nickel values varied from 2.55×10^{-4} to 2.15×10^{-4} cm s^{-1}. The $\overline{K}_{org}$ values in this contacting region were not dependent

Table 5

```
N I C K E L

E X T R A C T I O N: RE-ORGANIC = 1000    RE-AQUEOUS = 1500

TIME                AQ                  ORG                   ORG EQU
 0                   4.8996             -.093813              3.73336
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 .26129              .150947             2.77699E-3           1.34212
ORG MED .17333      C*-C 3.82717        SLP-K.00-2.77032E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 30                  4.60342             .440473              3.73262
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 .303753             .159355             2.93167E-3           1.19154
ORG MED .681983                         C*-C 3.29214          SLP-K.00-2.92384E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 60                  4.34223             .923492              3.78188
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 .356076             .167728             3.08571E-3           1.03261
ORG MED 1.13937                         C*-C 2.80839          SLP-K.00-3.07639E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 90                  4.11603             1.35524              3.73117
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 .420889             .175442             3.22761E-3           .865387
ORG MED 1.54549                         C*-C 2.37592          SLP-K.00-3.21693E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 120                 3.92483             1.73573              3.7305
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
.50131               .181385             3.33695E-3           .690526
ORG MED 1.90034                         C*-C 1.99477          SLP-K.00-3.32481E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 150                 3.76862             2.06494              3.72991
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 .600614             .183705             3.37964E-3           .509801
ORG MED 2.20392                         C*-C 1.66496          SLP-K.00-3.36684E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 180                 3.6474              2.3429               3.72941
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 .721233             .179498             3.30224E-3           .326792
ORG MED 2.45624                         C*C 1.38651           SLP-K.00-3.29008E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 210                 3.56118            2.56958               3.72904
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 .862471             .164801             3.03186E-3           .147955
ORG MED 2.65729                         C*-C 1.15946          SLP-K.00-3.02228E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TIME                AQ                  ORG                   ORG EQU
 240                 3.50995            2.745                 3.72881
1/C*-C              AREA                ARE-K.00              LOG(C*-C)
 1.01646             .135311            2.48934E-3            -1.63255E-2
ORG MED 2.80707                         C*-C .983809          SLP-K.00-2.48329E-3
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
NOTATION
TIME = Minutes
AQ = Aqueous Concentration (g/l)
ORG = Organic Concentration (g/l),C
ORG EQU = Organic Equilibrium Concentration (g/l),C*
AREA = Area from graphical integration of  (dc/(C-C*)
ARE-K.00 = Mass Transfer Coefficient, (cm/sec), using graphical integration
ORG MED = Organic Medium Concentration
SLP-K.00 = Mass Transfer Coefficient, cm/sec, evaluated from a plot of
           ln(C*-C) vs t
```

Figure 2. Overall Mass Transfer Coefficients for Cobalt - Co-extraction

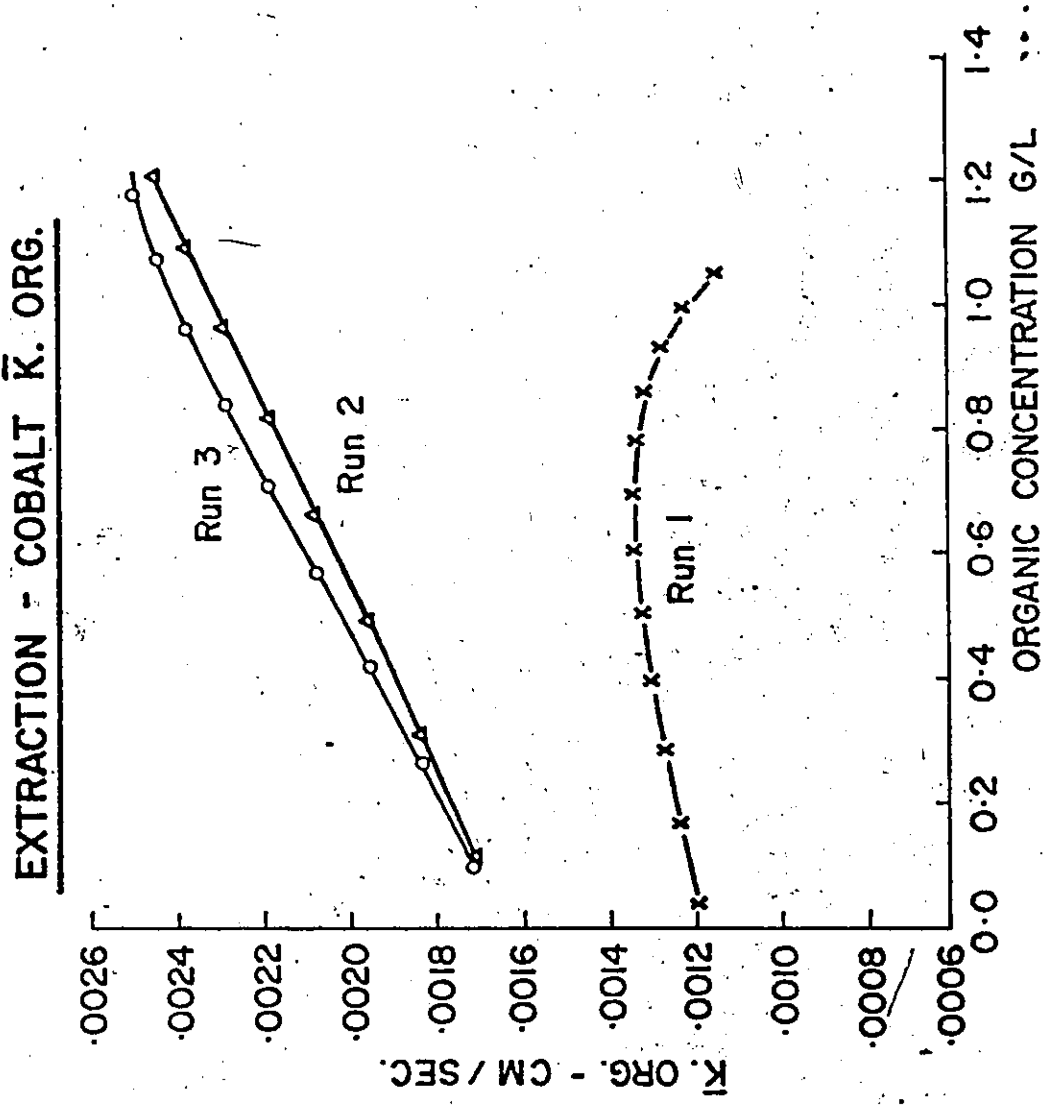


Figure 3. Overall Mass Transfer Coefficients for Nickel - Co-extraction

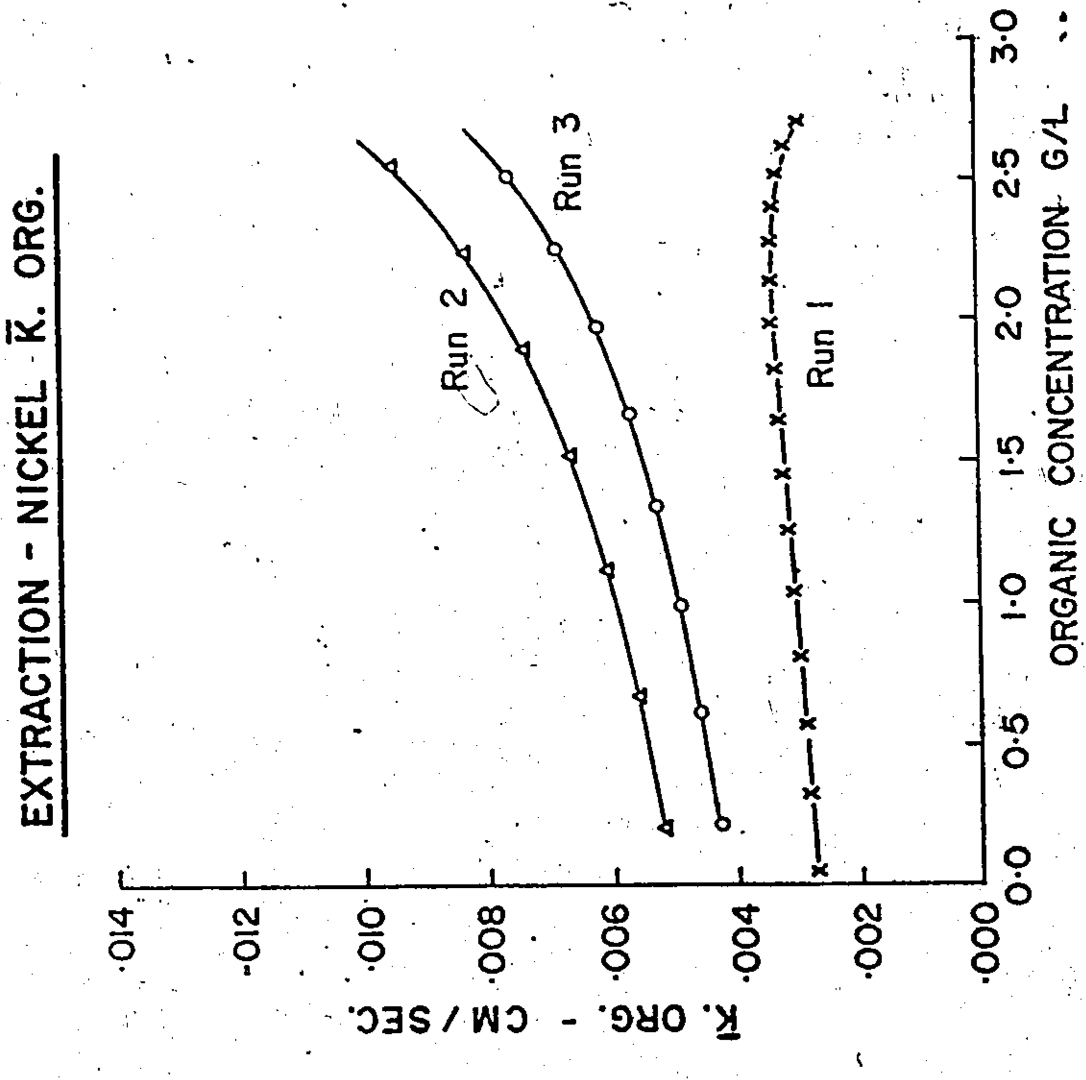


Figure 4. Overall Mass Transfer Coefficients for Cobalt - Scrubbing

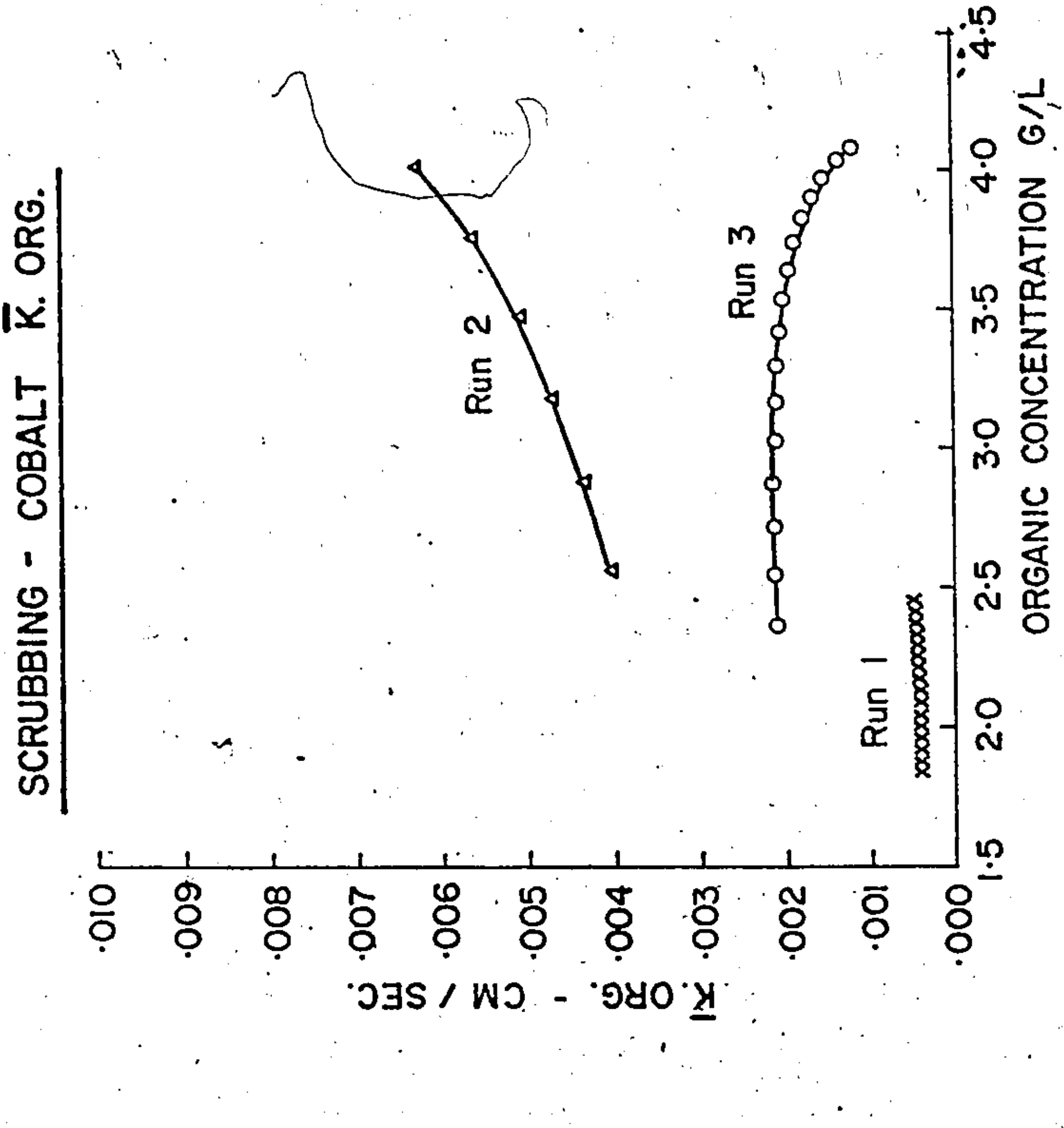


Figure 5. Overall Mass Transfer Coefficients for Nickel - Scrubbing

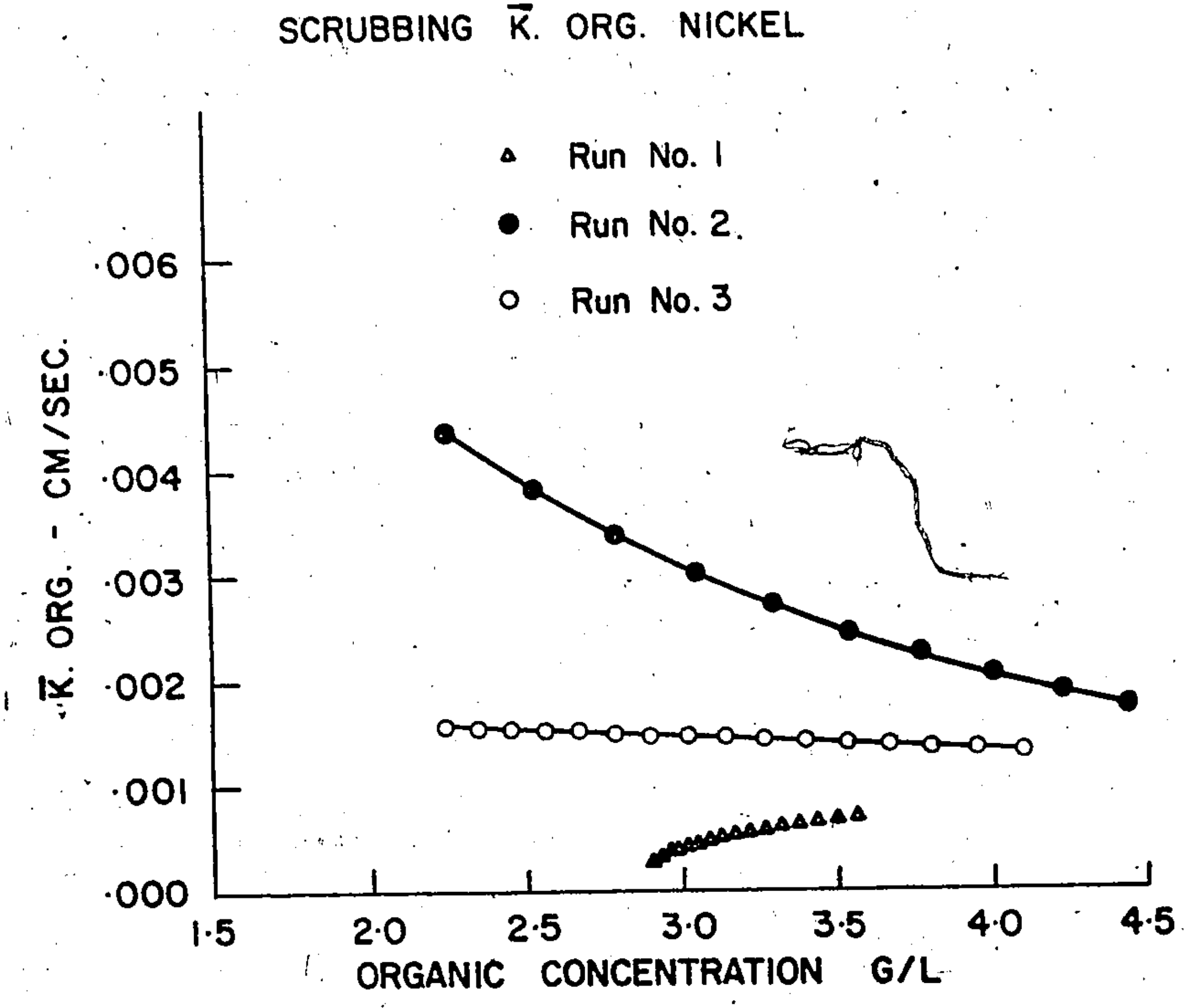


Figure 6. Mass Transfer Driving Force for Nickel - Stripping

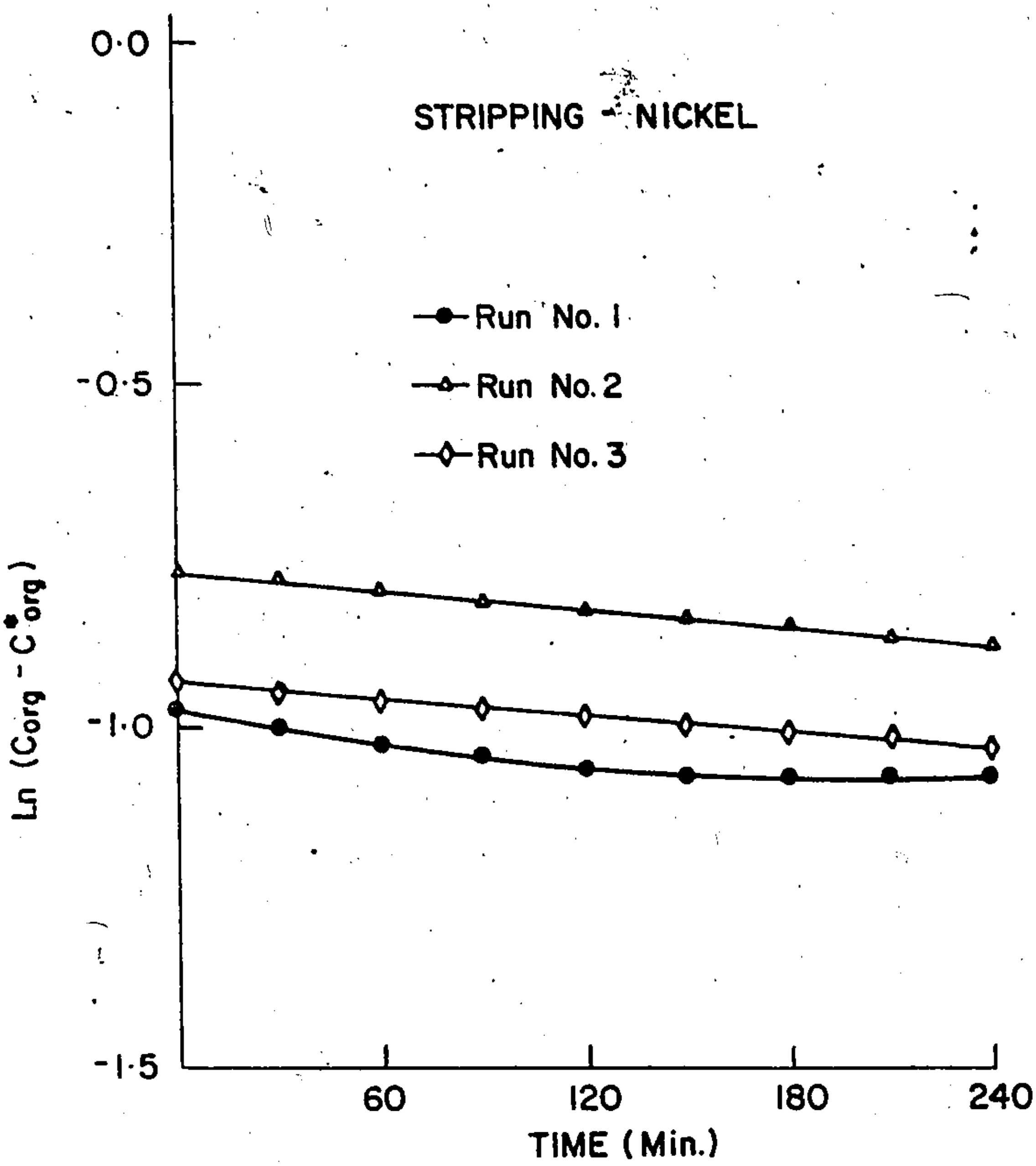


Figure 7. Mass Transfer Driving Force for Cobalt - Stripping

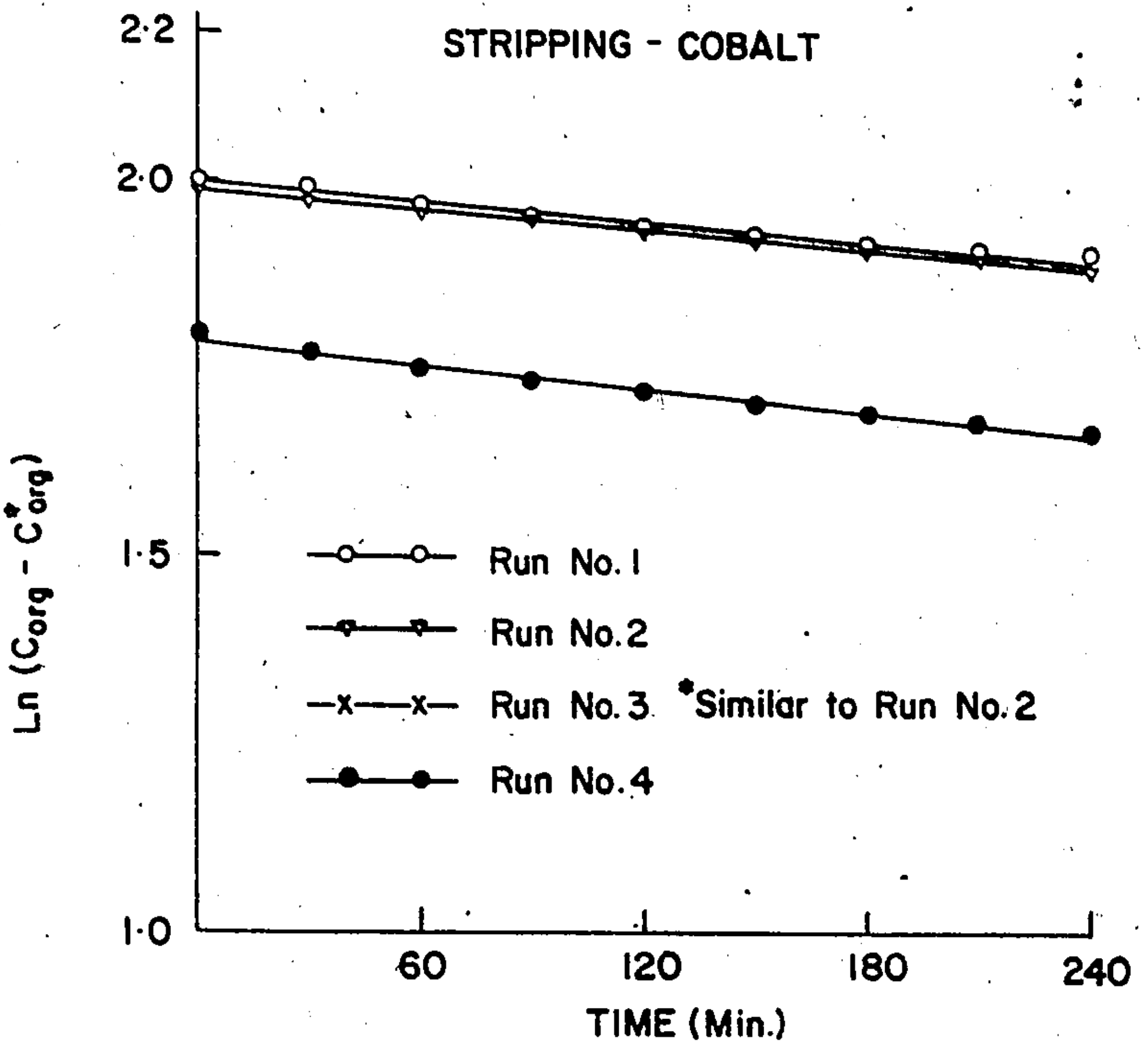


Table 6

Stripping

Overall Mass Transfer Coefficients

Run No.	Reynolds Number Aqueous Phase	Reynolds Number Organic Phase	Cobalt Overall Mass Transfer Coefficient cm/sec	Nickel Overall Mass Transfer Coefficient cm/sec
1	1500	1000	2.466×10^{-4}	2.558×10^{-4}
2	1500	2000	2.675×10^{-4}	2.476×10^{-4}
3	3000	1000	4.842×10^{-4}	2.160×10^{-4}
4*	1500	1500	3.014×10^{-4}	- -

*25% HNO_3 Stripping Solution.

on the metal concentration in the aqueous and there was only a slight increase in $\overline{K}_{org}$ values with increase in Reynolds Number for cobalt while the opposite observation for nickel. See Table (6).

The experimental error in the results is mainly from the measurement of concentration. The sensitivity of the atomic absorption spectrophotometer used was 1 ppm for cobalt and 2 ppm for nickel. On dilution of samples, this deviation is amplified. The error in the metal mass balance was taken as the difference between the mass of metal in initial solutions and the mass found in the final solutions. The range of error for nickel was ±2% to ±5% and for cobalt ±1% to ±2.5%, if all the error were in one phase composition.

The reproducibility of the experimental results were tested and were found to produce a 20 to 30 percent deviation, which is not very satisfactory. (See figure 12, experiment 1B is a repeated Run #1.)

Means to enhance reproducibility are put forward in the Recommendation Section.

E. DISCUSSION OF RESULTS

The results indicated that mass transfer coefficient values depended not only on Reynolds number and organic phase loading but also the contacting region. Thus, in co-extraction and scrubbing, $\overline{K}_{org}$ values were affected by change in either the aqueous or organic phase Reynolds number indicating that there was resistance to mass transfer in both phases [41]. In addition, the results suggest that the mass transfer rate was diffusion controlled [22]. The values of $\overline{K}_{org}$ obtained in these contacting regions are the same order of magnitude as values found for the extraction of acetic acid into benzene or Kerosene systems, which are known to be diffusion controlled. The integral average $\overline{K}_{org}$ values for the systems were evaluated in the stirred transfer cell and are reported in Appendix I. The $\overline{K}_{org}$ values for the benzene and Kerosene systems were 3.31×10^{-3} cm s^{-1} and 2.33×10^{-3} cm s^{-1} respectively.

The variation of $\overline{K}_{org}$ values with organic phase loading in these regions was, however, inconsistent firstly with the two-film theory [41] and secondly with the report that metal polymers are formed in D2EHPA [20-22]. The data indicated that during co-extraction $\overline{K}_{org}$ values increased with increase in metal loading. However, from the equilibrium line and operating line data (figures 8 and 9), the slope of the equilibrium line, m, would have increased slightly as the run progressed which should have resulted in a small decrease in $\overline{K}_{org}$ values. Polymer formation would also be favoured by increased metal loading and a decrease in $\overline{K}_{org}$ values should have been observed. In scrubbing the total metal concentration was approximately the same throughout the run so that any polymer formation would be constant. Also there was very little variation if any in the slope of the equilibrium line figure (10).

The $\overline{K}_{org}$ values then would have been expected to be independent of the individual metal concentration in this contacting region as was observed in a pulsed sieve tray column [14]. However, when the organic phase Reynolds number was increased $\overline{K}_{org}$ values increased with increase in the individual metal concentration for cobalt and for nickel.

These anomalies may be considered to be due to the following circumstances which are examined herein after.

Interfacial Turbulance

This is a spontaneous activity at the interface that occurs when two liquids, not at equilibrium, are in contact, such as this process. Some effects that have been reported are spontaneous emulsification, rippling, and twitching of the interface [43, 29]. Such activity increases the rate of mass transfer by increasing the value of $\overline{K}_{org}$ over and above that is anticipated from the hydrodynamic situation, and also by increasing the measured surface area. Increases of as much as tenfold and more of the mass transfer rate have been observed. [43, 44, 17, 42]

The effect is produced by gradients in interfacial tension resulting from concentration gradients along the surface, the so-called Marangoni effect which has been demonstrated to be one of the causes. [45, 46]

Studies of interfacial turbulence in the D2EHPA cobalt nickel system should be pursued as these effects could influence the mass transfer rate of the systems.

Equilibrium Concentration

The C* values shown in figures (8, 9, 10) are "operating" equilibrium lines and are the locus of the points on the true equilibrium isotherms which are dependent on the individual metal concentration in both phases and the pH. It is considered, therefore, that runs on this system be carried out under steady state contacting conditions [23]. Under these conditions C* could be estimated much more accurately while eliminating the errors found at the end of unsteady state data when concentration changes are small, see table (5).

pH

Metal loading in the organic phase is dependent on the pH of the system, see figure (11). The initial pH of the experiment was fixed for all aqueous solutions and no attempt was made to control the experiments at a constant pH value. While the equilibrium concentration C* was evaluated at an equilibrium pH of 6.0 - 6.5 [47], much higher than the unsteady state pH of the extraction experiments.

This discrepency in the pH values effected the metal loading in the organic phase and should be considered in future studies of the system, that is, constant pH values should be adhered to for all aspects of the studies.

In the stripping region, mass transfer would be expected to be organic phase controlled, figure (12). Thus as would be expected $\overline{K}_{org}$ values were independent of organic phase loading but only varied slightly with increase in organic phase Reynolds number. This is in contrast with the results obtained in the other contacting region. This could be a result of resistance due to chemical reaction or perhaps of an interfacial resistance as suggested by Murdoch & Pratt [39] and further work is required to determine the controlling kinetic region in stripping.

Figure 8. Operating Lines for Cobalt-Extraction

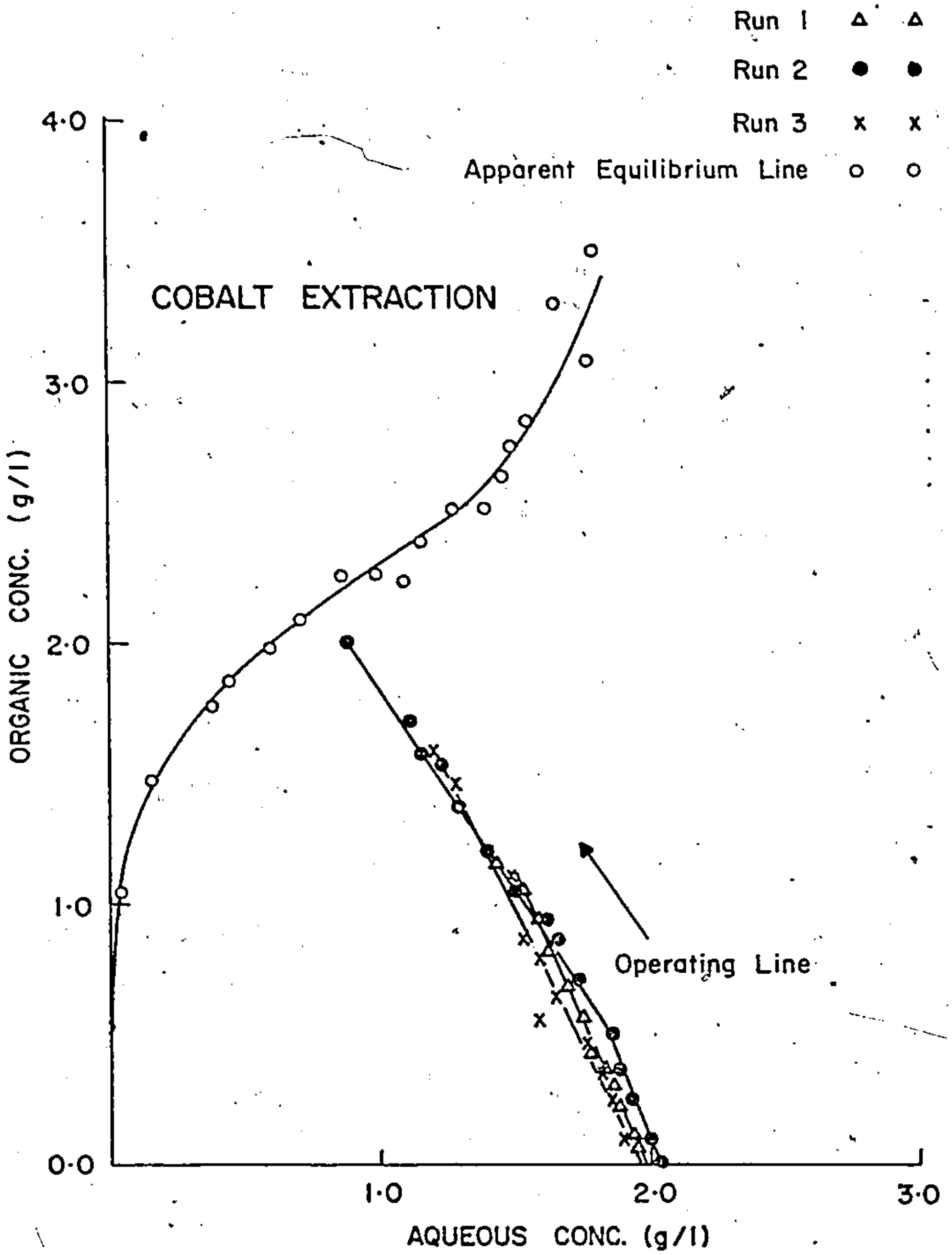


Figure 9. Operating Lines for Nickel-Extraction

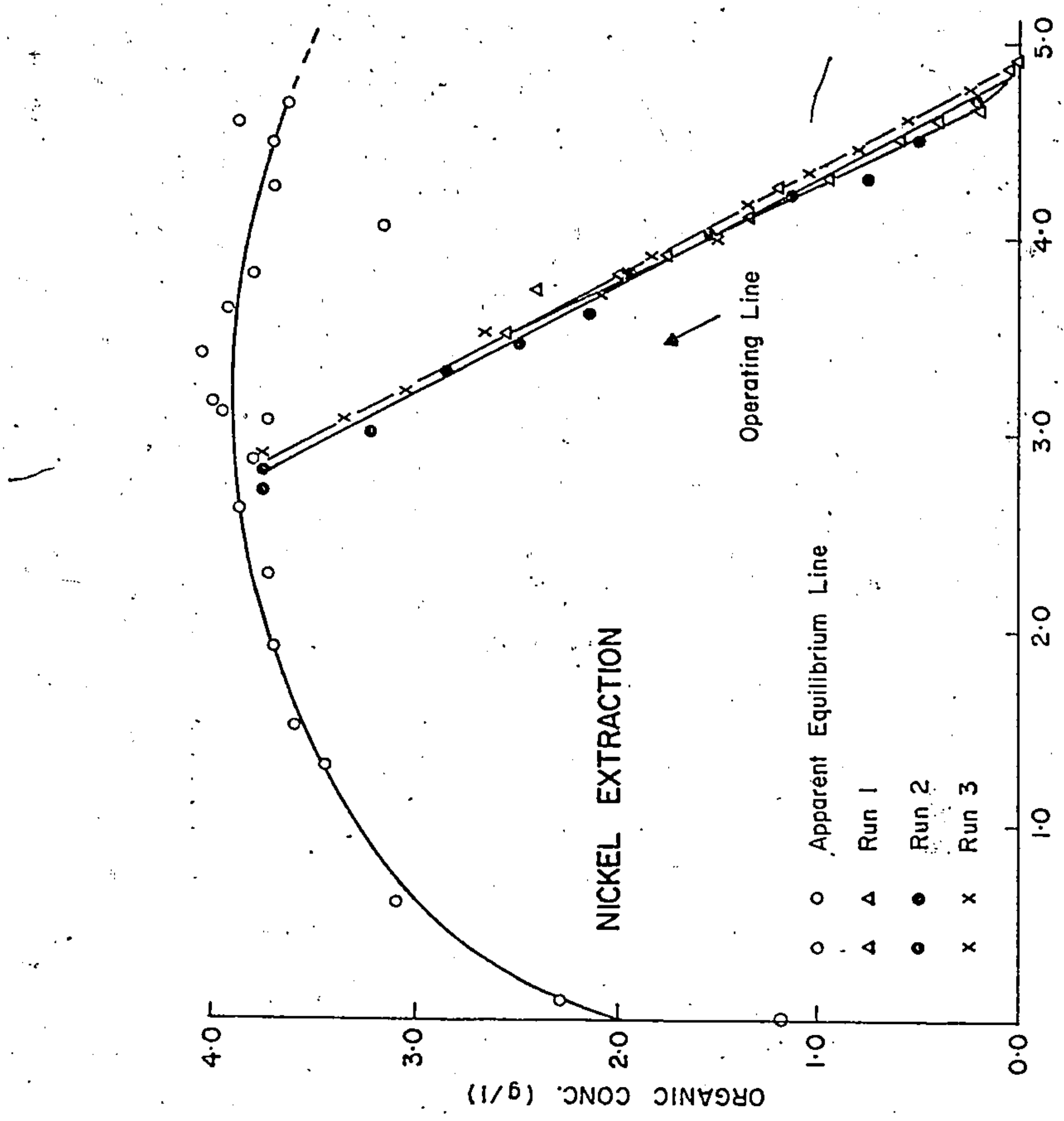


Figure 10. Operating Lines for Cobalt-Scrubbing

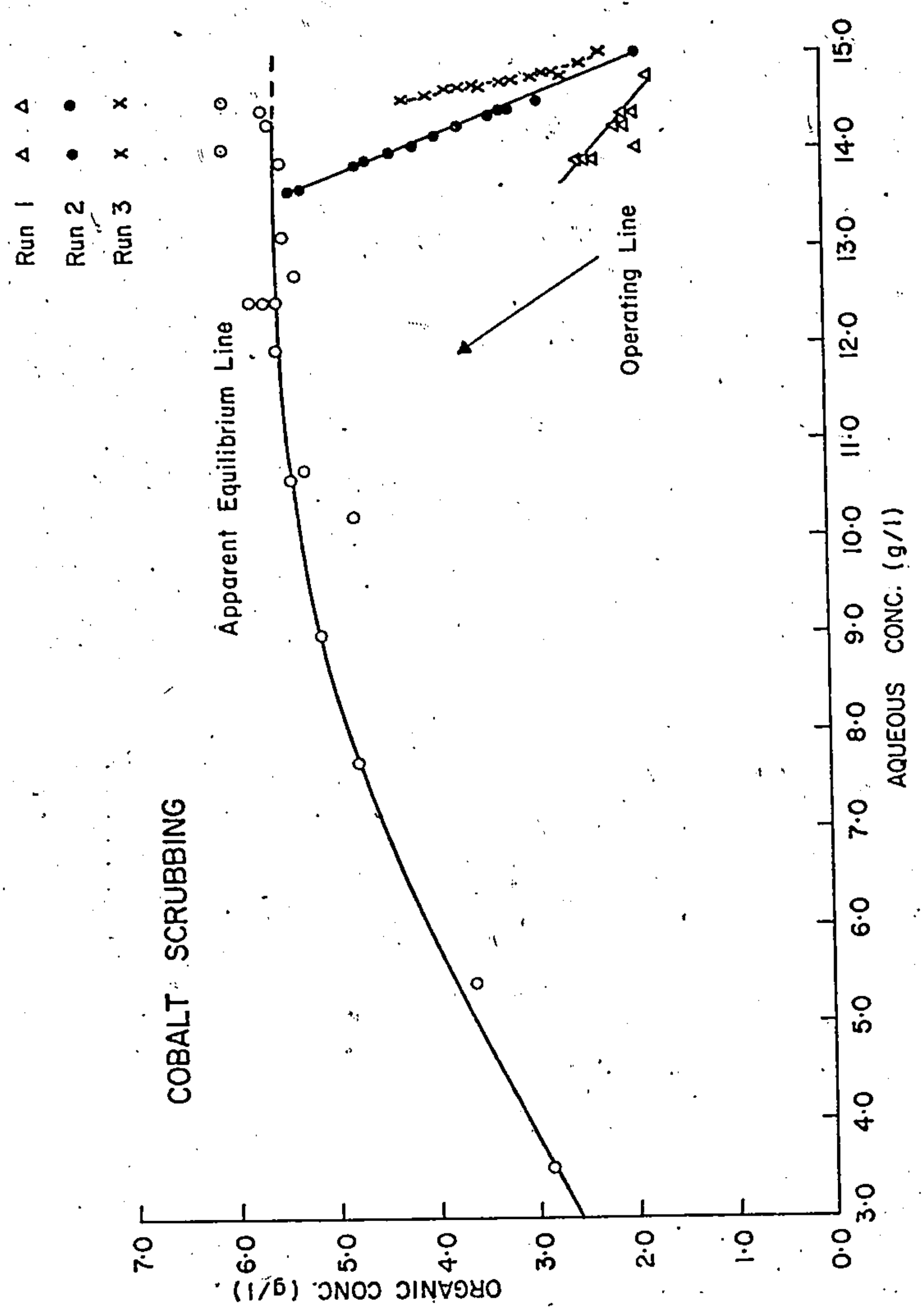
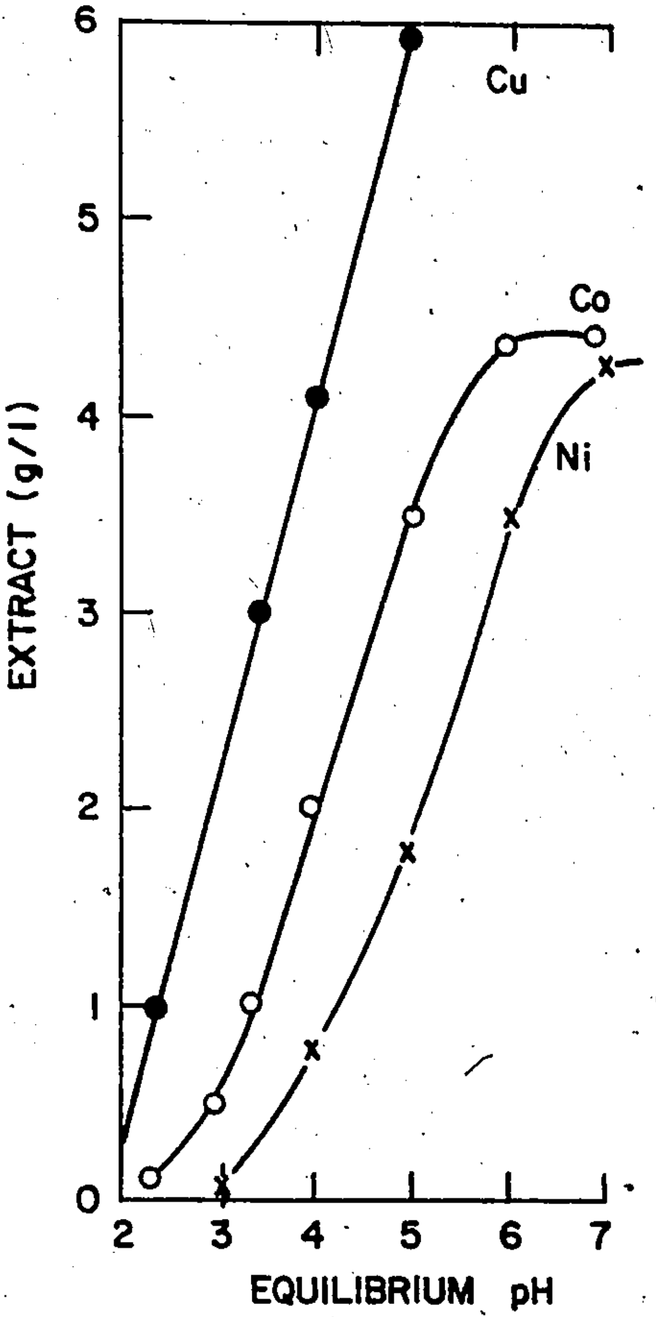
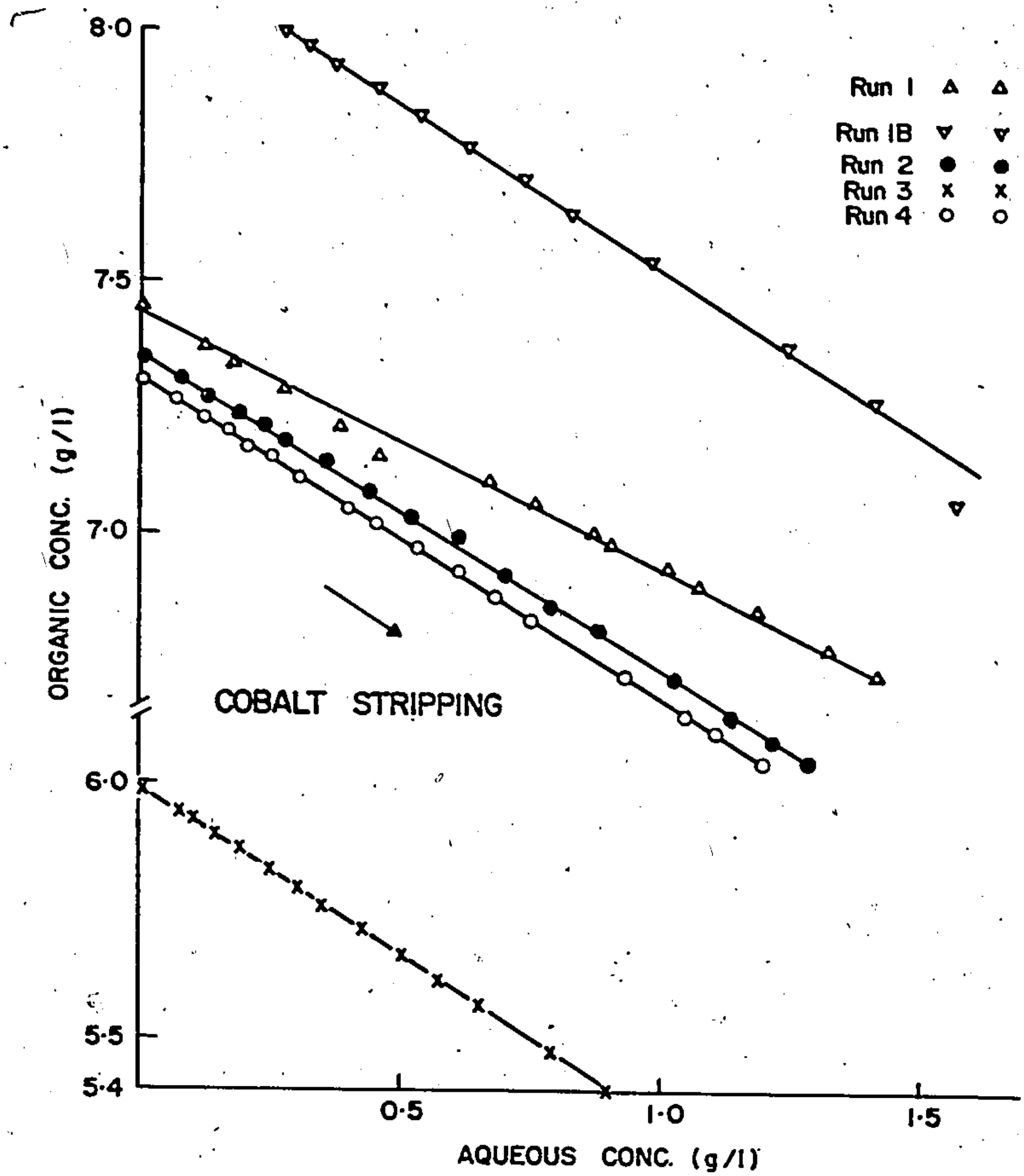


Figure 11. Variation of Metal Loading in Organic Phase With Equilibrium pH



(from E.G. Joe, et el 47)

Figure 12. Operating Line for Cobalt - Stripping



G. CONCLUSIONS AND RECOMMENDATIONS

The study has identified some of the controlling factors influencing the D2EHPA-cobalt-nickel system. These factors include the following:

1. cobalt and nickel concentrations
2. D2EHPA concentration
3. pH
4. Interfacial area
5. volume ratio
6. organic and aqueous phase Reynolds Number
7. temperature
8. reaction rate
9. contacting region

Of the above listed factors, only the effect of the hydrodynamic on the mass transfer was investigated while the other factors were held constant. The magnitude of the overall mass transfer coefficients obtained in the study were the same as that of the acetic acid-benzene-water system.

Although previous investigations have been successful in using a liquid-liquid stirred cell for studying mass transfer, the results of this work show that for hydrometallurgical system unsteady state experiments are not entirely satisfactory. The difficulties associated with determinating the constantly changing equilibrium values, lead to considerable experimental error. As a result it was not possible to do a complete mechanistic study in evaluating the controlling kinetic regime.

However the results did show the magnitude of the mass transfer coefficient values and their dependence on the contacting region. In the co-extraction and scrubbing, mass transfer could be considered to be a diffusion controlled process, although further work is required to determine the controlling resistance. In addition, the effect of metal up-take in the organic phase on $\bar{K}_{org}$ values has to be more fully investigated particularly at higher D2EHPA concentrations.

In the stripping region, mass transfer rates can be expected to be much slower than in extraction and scrubbing. However, further study is required to determine the kinetic region controlling mass transfer in this region.

Based on the results of this work, the following recommendations for further studies are made:

a) More precise data on equilibrium studies and specifically a possible correlation for these two component systems.

b) Examine the other factors affecting the overall rate of absorption-reaction by evaluating their effect on the overall mass transfer coefficient:

1. Variation in initial metal concentration in the extraction and scrubbing aqueous solution.
2. Variation of interfacial contacting area,
3. Variation of the volume phase ratio.
4. Higher concentration of D2EHPA in the organic phase.
5. The effects of interfacial tension on mass transfer.

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H. APPENDIX I

EVALUATION OF OVERALL MASS TRANSFER COEFFICIENTS

$\overline{K}_{org.}$

NOTATION

TIME = Minutes

AQ = Aqueous Concentration (g/l)

ORG = Organic Concentration (g/l), C

ORG EQU = Organic Equilibrium Concentration (g/l), C^*

AREA = Area from graphical integration of $(dc/(C-C^*))$

ARE-K.00 = Mass Transfer Coefficient, (cm/sec), using graphical integration

ORG MED = Organic Medium Concentration

SLP-K.00 = Mass Transfer Coefficient, cm/sec, evaluated from a plot of $\ln(C^*-C)$ vs t

Computer Program to Evaluate R_{org} Using Equations 27 in Theory Section

```
LIST
1   INPUT C
2   PRINT
3   PRINT "   C    O  B    A    L     T"
4   PRINT "   ========================="
5   PRINT
6   PRINT "E X T R A C T I O N:  RE-ORGANIC=        RE-AQUEOUS=   [illegible]

7   PRINT "....................."
8   PRINT
11   DIM A[250]
12   DIM G[250]
13   DIM F[250]
14   DIM D[250]
15   READ Q,W,E,Z,X,Y
19   DIM S[250]
20   FOR I= 0 TO 30 STEP C
25     LET T=I*10
30     LET A[I]=(Q*T↑2)+(W*T)+E
40     LET G[I]=(Z*T↑2)+(X*T)+Y
50     LET F[I]=.75578+3.7667*A[I]-3.4529*(A[I]↑2)+1.2135*(A[I]↑3)
60     LET D[I]=1/(F[I]-G[I])
62   NEXT I
63   READ V
64   LET T= 0
65   FOR I= 0 TO 30 STEP C
70     LET S[I]=((G[I+C]-G[I])*(D[I]+(.5*(D[I+C]-D[I]))))
75     IF S[I]> 0 GOTO  80
76     LET S[I]=-1*S[I]
77     GOTO  80
80     LET L=V*S[I]/(32.5*C*60)
85     LET L=L/10
90     LET T=I*10
95     LET M=(((G[I+C]-G[I])/2)+G[I])
96     LET K=((( LOG (1/D[I+C]))-( LOG (1/D[I])))/(C*10*60))*(M/32.5)
98     LET R=1/D[I]
99     LET B= LOG (R)
100     PRINT "TIME","AQ","ORG","ORG EQU"
110     PRINT T,A[I],G[I],F[I]
120     PRINT "1/C*-C","AREA","ARE-K.00","LOG(C*-C)"
130     PRINT D[I],S[I],L,B
131     PRINT "ORG MED"M,"C*-C"T,"SLP-K.00"K
135     PRINT "***********************************************************"
136     IF T=240 GOTO  160
140   NEXT I
160   END
161   END
200   DATA  7.9139E-6,-5.1194E-3, 1.9428,-2.0343-5, .011726, .010712
210   DATA  1010
```

Table 7

Overall Mass Transfer Coefficients - K_{org}

```
 C     O     B     L     T
 =====================

E X T R A C T I O N: PE-ORGANIC=60A    PE-AQUEOUS=1500  RUN NO. 1
......................

TIME              AQ                ORG                ORG EQU
 0                 1.999            -.22756             4.17377
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .238054           6.61657E-2        1.21726E-3         1.43526
ORG MED 9.91826E-2                  C*-C 4.20073       SLP-K.00-3.21956E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 30                1.89632           .226226            3.75255
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .283581           6.98341E-2        1.25566E-3         1.26025
ORG MED .338384                     C*-C 3.52632       SLP-K.00-3.12444E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 60                1.80235           .451583            3.4271
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .336076           7.22238E-2        1.32871E-3         1.09042
ORG MED .552293                     C*-C 2.97552       SLP-K.00-2.99343E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 90                1.71539           .649312            3.17723
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .395527           7.25419E-2        1.33455E-3         .927534
ORG MED .733662                     C*-C 2.52832       SLP-K.00-2.83134E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 120               1.636             .813313            2.98587
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .461392           7.01069E-2        1.28976E-3         .773505
ORG MED .889598                     C*-C 2.16735       SLP-K.00-2.61367E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 150               1.56419           .959434            2.83979
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .531829           6.41341E-2        1.15033E-3         .631429
ORG MED 1.01631                     C*-C 1.8803        SLP-K.00-2.33251E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 180               1.49995           1.07253            2.72892
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .603722           5.41756E-2        9.96673E-4         .504641
ORG MED 1.11499                     C*-C 1.65639       SLP-K.00-1.97381E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 210               1.44329           1.15744            2.64492
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .672279           3.93561E-2        7.33336E-4         .39709
ORG MED 1.18584                     C*-C 1.48748       SLP-K.00-1.54995E-3
******************************************************************
TIME              AQ                ORG                ORG EQU
 240               1.39421           1.21423            2.58152
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .731373           2.15792E-2        3.96994E-4         .312829
ORG MED 1.22656                     C*-C 1.36729       SLP-K.00-1.35426E-3
******************************************************************
```

Table 8

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
 N   I   C   K   E   L
 ============================

E X T R A C T I O N:  RE-ORGANIC= 1000 ,RE-AQUEOUS= 1500 RUN NO, 1
......................

TIME               AQ                ORG               ORG EQU
 3                  4.8996           -.093513           3.73336
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .26129             .150947           2.77699E-3        1.34212
ORG MED .17333 C*-C 3.82717     SLP-K.00-2.77038E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 30                 4.60342           .442473           3.73262
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .303753            .159355           2.93167E-3        1.19154
ORG MED .681933                      C*-C 3.29214    SLP-K.00-2.92384E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 60                 4.34223           .923492           3.73133
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .356076            .167728           3.08571E-3        1.03261
ORG MED 1.13937                      C*-C 2.80839    SLP-K.00-3.07639E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 90                 4.11523           1.35524           3.73117
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .420889            .175442           3.22751E-3        .865337
ORG MED 1.54549                      C*-C 2.37593    SLP-K.00-3.21692E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 120                3.92433           1.73573           3.7305
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .50131             .181365           3.33695E-3        .690526
ORG MED 1.90034                      C*-C 1.99477    SLP-K.00-3.32451E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 150                3.76362           2.06494           3.72991
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .600614            .183725           3.37964E-3        .509801
ORG MED 2.20392                      C*-C 1.66496    SLP-K.00-3.35584E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 180                3.6474            2.3429            3.72941
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .721233            .179493           3.38224E-3        .326792
ORG MED 2.45624                      C*-C 1.38651    SLP-K.00-3.27003E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 210                3.56115           2.56959           3.72904
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 .862471            .164531           3.03136E-3        .147955
ORG MED 2.65729                      C*-C 1.15945    SLP-K.00-3.22823E-3
**********************************************************
TIME               AQ                ORG               ORG EQU
 240                3.50995           2.745             3.72331
1/C*-C             AREA              ARE-K.00          LOG(C*-C)
 1.01646            .135611           2.45934E-3        -1.63255E-2
ORG MED 2.80727                      C*-C .983809    SLP-K.00-2.45329E-3
**********************************************************
```

Table 9

Overall Mass Transfer Coefficients - $\bar{K}_{org}$

```
C    O    B    L    T
=====================

E X T R A C T I O N:  RE-ORGANIC= 2000  RE-AQUEOUS= 1500 RUN NO. 2
......................

TIME             AQ               ORG              ORG EQU
 0                2.0631           .811203          4.50243
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .222654          .104257          1.91803E-3       1.50214
ORG MED .227413                   C*-C 4.49126     SLP-K.00-6.81137E-3
***************************************************************
TIME             AQ               ORG              ORG EQU
 30               1.56696          .423624          3.643
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .308731          .123331          2.27353E-3       1.17533
ORG MED .572736                   C*-C 3.23938     SLP-K.00-5.75435E-3
***************************************************************
TIME             AQ               ORG              ORG EQU
 60               1.65958          .741348          3.11115
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .422065          .143437          2.58455E-3       .862595
ORG MED .83386 C*-C 2.3693        SLP-K.00-5.43699E-3
***************************************************************
TIME             AQ               ORG              ORG EQU
 90               1.53599          1.02537          2.73895
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .56719           .152923          2.77617E-3       .56736
ORG MED 1.14279                   C*-C 1.76303     SLP-K.00-5.84103E-3
***************************************************************
TIME             AQ               ORG              ORG EQU
 120              1.40616          1.2557           2.59621
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .745995          .149162          2.74414E-3       .293847
ORG MED 1.34352                   C*-C 1.34051     SLP-K.00-4.49844E-3
***************************************************************
TIME             AQ               ORG              ORG EQU
 150              1.30211          1.43133          2.43106
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .952629          .128512          2.36424E-3       4.35281E-2
ORG MED 1.49205                   C*-C 1.24973     SLP-K.00-3.66535E-3
***************************************************************
TIME             AQ               ORG              ORG EQU
 180              1.21782          1.55277          2.41193
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 1.16392          8.33871E-2       1.54323E-3       -.151794
ORG MED 1.53635                   C*-C .859167     SLP-K.00-2.4735E-3
***************************************************************
TIME             AQ               ORG              ORG EQU
 210              1.15932          1.62             2.37107
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 1.33144          1.77059E-2       3.27209E-4       -.286262
ORG MED 1.62652                   C*-C .751067     SLP-K.00-3.71066E-4
***************************************************************
TIME             AQ               ORG              ORG EQU
 240              1.12453          1.63334          2.34935
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 1.396            .055131          1.23265E-3       -.33361
ORG MED 1.61246                   C*-C .716334     SLP-K.00 8.63934E-4
***************************************************************
```

Table 10

Overall Mass Transfer Coefficients - K_{org}

```
N   I   C   K   E   L
=============================

E X T R A C T I O N:  RE-ORGANIC=2000   RE-AQUEOUS=1000  RUN NO. 2
....................

TIME               AQ                 ORG                ORG EQU
 3                  4.5529            -.25779             3.73335
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 .26375             .292423            5.37931E-3         1.33254
ORG MED .417015                       C*-C 3.79134       SLP-K.00-5.31353E-3
****************************************************************
TIME               AQ                 ORG                ORG EQU
 30                 4.32934            .59132             3.73134
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 .35211             .347781            6.39655E-3         1.04381
ORG MED 1.38203                       C*-C 2.84002       SLP-K.00-6.85547E-3
****************************************************************
TIME               AQ                 ORG                ORG EQU
 60                 3.37719            1.71223            3.73233
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 .495517            .432023            7.94906E-3         .702154
ORG MED 2.05784                       C*-C 2.01809       SLP-K.00-7.73625E-3
****************************************************************
TIME               AQ                 ORG                ORG EQU
 90                 3.49544            2.40344            3.72374
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 .754545            .583933            1.06376E-2         .281639
ORG MED 2.63445                       C*-C 1.3253        SLP-K.00-1.01534E-2
****************************************************************
TIME               AQ                 ORG                ORG EQU
 120                3.1871             2.96546            3.72718
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 1.3128             .944358            1.73526E-2        -.272165
ORG MED 3.18156                       C*-C .761729       SLP-K.00-1.55239E-2
****************************************************************
TIME               AQ                 ORG                ORG EQU
 150                2.94917            3.39826            3.72576
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 3.05341            7.13791            .131317           -1.11526
ORG MED 3.55307                       C*-C .327503       SLP-K.00-4.93677E-2
****************************************************************

ERR 16  0 96
TIME               AQ                 ORG                ORG EQU
 180                2.73264            3.70186            3.72462
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 43.9654            3.26172            6.00061E-2        -3.7834
ORG MED 3.79908                       C*-C 2.27451E-2                      SLP-K.00-33
 336
****************************************************************

ERR 16  0 96

ERR 16  0 99
TIME               AQ                 ORG                ORG EQU
 212                2.65752            3.87629            3.72391
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
-6.5626             .262718            4.83325E-3        -1.78141E+33
ORG MED 3.3909 C*-C-.152379   SLP-K.00 0
****************************************************************
```

Table 11

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
C   O   B   A   L   T
========================

E X T R A C T I O N:  RE-ORGANIC= 1000  RE-AQUEOUS= 3000  RUN NO. 3
....................

TIME              AQ               ORG              ORG EQU
 0                 1.9408           .010712          3.92402
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 .255539           9.73758E-2       1.73593E-3       1.36438
ORG MED .177359                    C*-C 3.9133      SLP-K.00-4.53597E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 30                1.79434          .344036          3.40219
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 .326991           .110361          2.02479E-3       1.11783
ORG MED .498167                    C*-C 3.05819     SLP-K.00-4.42261E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 60                1.66214          .640323          3.04502
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 .415853           .122043          2.24524E-3       .877424
ORG MED .773004                    C*-C 2.4047      SLP-K.00-4.29795E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 90                1.5442           .899679          2.80339
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 .525289           .131634          2.42113E-3       .643803
ORG MED 1.01087                    C*-C 1.90371     SLP-K.00-4.15274E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 120               1.4405           1.12235          2.64139
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 .658312           .136715          2.51515E-3       .418074
ORG MED 1.21476                    C*-C 1.51904     SLP-K.00-3.96376E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 150               1.35106          1.30746          2.53227
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 .816457           .134579          2.47555E-3       .202732
ORG MED 1.38169                    C*-C 1.2245      SLP-K.00-3.67195E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 180               1.27583          1.4559           2.45909
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 .996818           .121711          2.23912E-3       3.18754E-3
ORG MED 1.51163                    C*-C 1.00319     SLP-K.00-3.21346E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 210               1.21495          1.56736          2.40973
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 1.18736           9.48861E-2       1.74563E-3       -.171735
ORG MED 1.63461                    C*-C .842214     SLP-K.00-2.50719E-3
***********************************************************************
TIME              AQ               ORG              ORG EQU
 240               1.16827          1.64136          2.37639
1/C*-C            AREA             ARE-K.00         LOG(C*-C)
 1.36033           5.32393E-2       9.79443E-4       -.307837
ORG MED 1.65062                    C*-C .735035     SLP-K.00-1.51552E-3
***********************************************************************
```

Table 12

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
N   I   C   K   E   L
==========================

E X T R A C T I O N   RE-ORGANIC= 1,000   RE-AQUEOUS= 3000  RUN NO. 3
......................

TIME            AQ              ORG             ORG EQU
 0               4.8971          5.5653E-3       3.73335
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .268256         .243454         4.47934E-3      1.31581
ORG MED .404519                 C*-C 3.72779    SLP-K.00-4.44295E-3
********************************************************
TIME            AQ              ORG             ORG EQU
 30              4.44779         .804072         3.73219
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .341517         .2791           5.13462E-3      1.07435
ORG MED 1.15664                 C*-C 2.92812    SLP-K.00-5.07577E-3
********************************************************
TIME            AQ              ORG             ORG EQU
 63              4.05502         1.50921         3.73096
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .450096         .327824         .006031         .798293
ORG MED 1.5151 C*-C 2.22175   SLP-K.00-5.93965E-3
********************************************************
TIME            AQ              ORG             ORG EQU
 90              3.71875         2.12099         3.72971
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .621614         .399133         7.34233E-3      .475434
ORG MED 2.3982 C*-C 1.60872   SLP-K.00-7.17634E-3
********************************************************
TIME            AQ              ORG             ORG EQU
 120             3.43936         2.6394          3.72848
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .918212         .515731         9.45794E-3      8.53251E-2
ORG MED 2.85192                 C*-C 1.08907    SLP-K.00-9.13345E-3
********************************************************
TIME            AQ              ORG             ORG EQU
 150             3.21583         3.06444         3.72734
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 1.50853         .752336         1.35403E-2      -.411135
ORG MED 3.23329                 C*-C .662905    SLP-K.00-1.28131E-2
********************************************************
TIME            AQ              ORG             ORG EQU
 180             3.04923         3.39613         3.72639
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 3.02793         1.66656         3.55593E-2      -1.10785
ORG MED 3.51529                 C*-C .330259    SLP-K.00-2.36327E-2
********************************************************

ERR 16  @ 96
TIME            AQ              ORG             ORG EQU
 210             2.93911         3.63444         3.7257
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 10.9583         .546524         1.00544E-2      -2.3941
ORG MED 3.70692                 C*-C 9.12547E-2               SLP-K.00-33
 B36
********************************************************
```

Table 13

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
A C E T I C   A C I D   B E N Z E N E   W A T E R
==================================================

E X T R A C T I O N:  RE-ORGANIC= 1500  RE-AQUEOUS= 1000 RUN NO.
......................

TIME            AQ              ORG             ORG EQU
 0               0               42.844          0
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 2.33435E-2      .137861         4.29403E-3      3.75755
ORG MED 43.3972                 C*-C 42.844     SLP-K.00-4.05133E-3
*************************************************************
TIME            AQ              ORG             ORG EQU
 30              7.50239         37.3503         .12455
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 2.68487E-2      .131939         4.10965E-3      3.61754
ORG MED 35.0592                 C*-C 37.2455    SLP-K.00-4.19976E-3
*************************************************************
TIME            AQ              ORG             ORG EQU
 60              13.7868         32.763          .22031
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 3.37242E-2      .120207         3.74416E-3      3.4527
ORG MED 33.9325                 C*-C 32.5477    SLP-K.00-3.34336E-3
*************************************************************
TIME            AQ              ORG             ORG EQU
 90              15.8531         29.0969         .332341
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .034765         .131331         3.1531E-3       3.35914
ORG MED 27.717 C*-C 28.7645    SLP-K.00-3.25712E-3
*************************************************************
TIME            AQ              ORG             ORG EQU
 120             22.7315         26.3372         .423598
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 3.85973E-2      7.41735E-2      2.3111E-3       3.25437
ORG MED 25.413 C*-C 25.9236    SLP-K.00-2.39795E-3
*************************************************************
TIME            AQ              ORG             ORG EQU
 150             25.3313         24.4353         .499932
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 4.16361E-2      3.93976E-2      1.24272E-3      3.17759
ORG MED 24.3231                 C*-C 23.9363    SLP-K.00-1.29554E-3
*************************************************************
TIME            AQ              ORG             ORG EQU
 180             26.7441         23.5513         .543093
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 4.34566E-2      1.12405E-3      3.50115E-5      3.13599
ORG MED 23.5336                 C*-C 23.0115    SLP-K.00-4.2641E-5
*************************************************************
TIME            AQ              ORG             ORG EQU
 210             26.9384         23.5257         .545718
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 4.35161E-2      .03779          1.17707E-3      3.13462
ORG MED 23.9684                 C*-C 22.98      SLP-K.00 1.21584E-3
*************************************************************
TIME            AQ              ORG             ORG EQU
 240             25.9143         24.4111         .516353
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 4.15533E-2      .072479         2.25754E-3      3.17366
ORG MED 25.3394                 C*-C 23.9947    SLP-K.00 2.33316E-3
*************************************************************
```

Table 14

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
 A C E T I C   A C I D   -  K E R O S E N E   -  W A T E R
 ============================================================

E X T R A C T I O N:  RE-ORGANIC= 1520   RE-AQUEOUS= 1000  RUN NO.
....................

TIME              AQ                ORG               ORG EQU
 0                 0                 39.359            0
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.50591E-2        .114297           3.56306E-3        3.68532
ORG MED 37.7105                     C*-C 39.855      SLP-K.00-3.56731E-3
************************************************************
TIME              AQ                ORG               ORG EQU
 30                .749296           35.563            1.37324E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .028134           .104604           3.25316E-3        3.57079
ORG MED 33.8014                     C*-C 35.5442      SLP-K.00-3.26781E-3
************************************************************
TIME              AQ                ORG               ORG EQU
 60                1.41468           32.0397           3.53571E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 3.12457E-2        9.00375E-2        2.824455E-3       3.45567
ORG MED 30.664 C*-C 32.0044     SLP-K.00-2.81555E-3
************************************************************
TIME              AQ                ORG               ORG EQU
 90                1.99616           29.2833           4.99841E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 3.42016E-2        7.01833E-2        2.15624E-3        3.37543
ORG MED 28.2955                     C*-C 29.2334      SLP-K.00-2.19700E-3
************************************************************
TIME              AQ                ORG               ORG EQU
 120               2.49374           27.3355           6.23434E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 3.67023E-2        .045368           1.4131E-3         3.30491
ORG MED 26.7047                     C*-C 27.2483      SLP-K.00-1.42469E-3
************************************************************
TIME              AQ                ORG               ORG EQU
 150               2.96739           26.1003           7.25343E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .03342            1.69321E-2        5.26459E-4        3.25917
ORG MED 25.9327                     C*-C 26.0231      SLP-K.00-5.36361E-4
************************************************************
TIME              AQ                ORG               ORG EQU
 180               3.23715           25.6646           8.29285E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 3.90874E-2        1.32379E-2        4.361E-4          3.24195
ORG MED 25.8325                     C*-C 25.5837      SLP-K.00 3.93636E-4
************************************************************
TIME              AQ                ORG               ORG EQU
 210               3.483             26.0003           8.78749E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 3.85903E-2        4.13618E-2        1.33339E-3        3.25475
ORG MED 26.554 C*-C 25.9133     SLP-K.00 1.29576E-3
************************************************************
TIME              AQ                ORG               ORG EQU
 240               3.64494           27.1077           9.11236E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 3.72143E-2        .367293           2.09617E-3        3.29645
ORG MED 23.0473                     C*-C 27.2165      SLP-K.00 2.09229E-3
************************************************************
```

Table 15

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
     C   O   B   A   L   T.
     =====================

S C R U B B I N G :  RE-ORGANIC= 1500   RE-AQUEOUS= 1300 RUN NO. 1
.................

TIME              AQ                ORG               ORG EQU
 0                 14.502            1.8187            5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .271643           2.25081E-2        4.14034E-4        1.30326
ORG MED 1.85966                     C*-C 3.6813       SLP-K.00-4.14093E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 30                14.3942           1.90063           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .277826           2.30266E-2        4.23621E-4        1.28076
ORG MED 1.94159                     C*-C 3.59937      SLP-K.00-4.23555E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 60                14.2863           1.98255           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .284297           2.35693E-2        4.33537E-4        1.25773
ORG MED 2.02352                     C*-C 3.51745      SLP-K.00-4.33539E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 90                14.1785           2.06448           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .291077           2.41383E-2        4.44074E-4        1.23417
ORG MED 2.10544                     C*-C 3.43552      SLP-K.00-4.44024E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 120               14.0707           2.14641           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .298188           2.47354E-2        4.5506E-4         1.21033
ORG MED 2.18737                     C*-C 3.35359      SLP-K.00-4.54792E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 150               13.9623           2.22333           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .305655           2.53631E-2        4.66606E-4        1.1853
ORG MED 2.2693 C*-C 3.27167         SLP-K.00-4.66526E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 180               13.855            2.31026           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .313505           .026023           4.73743E-4        1.15994
ORG MED 2.35122                     C*-C 3.18974      SLP-K.00-4.73719E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 210               13.7472           2.39219           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .32177            2.67134E-2        4.91541E-4        1.13392
ORG MED 2.43315                     C*-C 3.10781      SLP-K.00-4.91433E-4
*********************************************************************
TIME              AQ                ORG               ORG EQU
 240               13.6393           2.47412           5.5
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .330482           2.74522E-2        5.05041E-4        1.1072
ORG MED 2.51508                     C*-C 3.02588      SLP-K.00-5.04975E-4
*********************************************************************
```

Table 16

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
   N   I   C   K   E   L
   =====================

S C R U B B I N G :  RE-ORGANIC= 1000   RE-AQUEOUS= 1500 RUN NO. 1
.................

TIME              AQ                ORG               ORG EQU
 0                 .01339            3.5932            2.72135E-4
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .278325           3.66655E-2        6.74538E-4        1.27896
ORG MED 3.52355                     C*-C 3.59293      SLP-K.00-5.33327E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 30                8.52281E-2        3.46391           1.98561E-3
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .288857           3.45413E-2        6.35459E-4        1.24182
ORG MED 3.40817                     C*-C 3.46192      SLP-K.00-5.45731E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 60                .152887           3.34643           3.92254E-3
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .299177           3.21405E-2        5.91291E-4        1.20672
ORG MED 3.29359                     C*-C 3.34251      SLP-K.00-6.08851E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 90                .218365           3.24075           5.95141E-3
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .309138           2.94594E-2        5.41966E-4        1.17397
ORG MED 3.19383                     C*-C 3.2348       SLP-K.00-5.53732E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 120               .263664           3.1469            8.00993E-3
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .318584           2.64996E-2        4.37515E-4        1.14387
ORG MED 3.10857                     C*-C 3.13889      SLP-K.00-4.99283E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 150               .310733           3.06485           9.98838E-3
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .327347           2.32713E-2        4.28125E-4        1.11673
ORG MED 3.02973                     C*-C 3.05486      SLP-K.00-4.39296E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 180               .351723           2.9946            1.18291E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .335259           .019791           3.64897E-4        1.09285
ORG MED 2.96539                     C*-C 2.98276      SLP-K.00-3.74371E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 210               .386483           2.93617           1.34785E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .34215            1.60853E-2        2.95922E-4        1.0725
ORG MED 2.91286                     C*-C 2.92269      SLP-K.00-3.04375E-4
**************************************************************
TIME              AQ                ORG               ORG EQU
 240               .415063           2.88955           1.48924E-2
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 .347867           .012187           2.24225E-4        1.05593
ORG MED 2.87214                     C*-C 2.87466      SLP-K.00-2.31574E-4
**************************************************************
```

Table 17

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
C   O   B   A   L   T
=====================

S C R U B B I N G :  RE-ORGANIC= 2000  RE-AQUEOUS= 1500 RUN NO.2
..................

TIME              AQ                  ORG                 ORG EQU
 0                 14.349              2.3987              5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
 .322445           .23                 4.23133E-3          1.13152
ORG MED 2.71486                       C*-C 3.1013         SLP-K.00-4.19486E-3
*************************************************************
TIME              AQ                  ORG                 ORG EQU
 30                14.5434             3.03103             5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
 .405227           .271034             4.93568E-3          .933302
ORG MED 3.32105                       C*-C 2.46897        SLP-K.00-4.92565E-3
*************************************************************
TIME              AQ                  ORG                 ORG EQU
 60                14.4365             3.61107             5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
 .5294             .33355              6.13654E-3          .636007
ORG MED 3.87495                       C*-C 1.55893        SLP-K.00-6.32836E-3
*************************************************************
TIME              AQ                  ORG                 ORG EQU
 93                14.2372             4.13583             5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
 .734662           .443376             8.15131E-3          .308342
ORG MED 4.37657                       C*-C 1.36117        SLP-K.00-7.98576E-3
*************************************************************
TIME              AQ                  ORG                 ORG EQU
 120               14.0425             4.51431             5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
 1.12986           .696395             1.25117E-2          -.121337
ORG MED 4.8259 C*-C .885695           SLP-K.00-1.19525E-2
*************************************************************
TIME              AQ                  ORG                 ORG EQU
 150               13.8525             5.03749             5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
 2.16213           2.42564             4.45247E-2          -.771093
ORG MED 5.22295                       C*-C .462526        SLP-K.00-2.97396E-2
*************************************************************

ERR 16   0 96
TIME              AQ                  ORG                 ORG EQU
 180               13.6671             5.4334              5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
 12.9173           1.03751             1.98372E-2          -2.39335
ORG MED 5.56771                       C*-C 9.15976E-2                        SLP-K.00-3
 9-36
*************************************************************

ERR 16   0 96

ERR 16   0 99
TIME              AQ                  ORG                 ORG EQU
 210               13.4864             5.72732             5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
-4.42482           .856513             1.57574E-2          -1.72141E+38
ORG MED 5.3602 C*-C-.227024           SLP-K.00 0
*************************************************************

ERR 16   0 96

ERR 16   0 99
TIME              AQ                  ORG                 ORG EQU
 240               13.3103             5.99357             5.5
1/C*-C            AREA                ARE-K.00            LOG(C*-C)
-2.22539           .363227             5.7743E-3           -1.70141E+38
ORG MED 6.10539                       C*-C-.493366        SLP-K.00 0
*************************************************************

*READY
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Table 18

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
    N   I   C   K   E   L
    =====================

S C R U B B I N G :  RE-ORGANIC= 2000    RE-AQUEOUS= 1530  RUN NO. 2
.................

TIME              AQ                 ORG                ORG EQU
 0                 1.5715E-3          4.5436             3.1144E-5
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .219849           9.89336E-2         1.31954E-3         1.51431
ORG MED 4.33494                      C*-C 4.54357       SLP-K.00-1.34541E-3
**********************************************************
TIME              AQ                 ORG                ORG EQU
 30                .234751            4.12188            6.57322E-3
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .243049           .11777             2.16663E-3         1.41449
ORG MED 3.99354                      C*-C 4.1144        SLP-K.00-2.21131E-3
**********************************************************
TIME              AQ                 ORG                ORG EQU
 60                .462952            3.66531            1.73737E-2
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .27439            .143383            2.53035E-3         1.29429
ORG MED 3.424   C*-C 3.64343   SLP-K.00-2.69323E-3
**********************************************************
TIME              AQ                 ORG                ORG EQU
 90                .686176            3.18219            3.26259E-2
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .317303           .178655            3.28727E-3         1.1479
ORG MED 2.92631                      C*-C 3.15156       SLP-K.00-3.36634E-3
**********************************************************
TIME              AQ                 ORG                ORG EQU
 120               .904428            2.67343            4.53145E-2
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .381028           .233375            4.29348E-3         .964932
ORG MED 2.43047                      C*-C 2.62461       SLP-K.00-4.33083E-3
**********************************************************
TIME              AQ                 ORG                ORG EQU
 150               1.11769            2.13352            6.22119E-2
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .483457           .328807            6.04909E-3         .726729
ORG MED 1.84649                      C*-C 2.06831       SLP-K.00-6.11633E-3
**********************************************************
TIME              AQ                 ORG                ORG EQU
 180               1.32598            1.56247            .079172
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .674176           .543564            9.99999E-3         .394264
ORG MED 1.26436                      C*-C 1.48329       SLP-K.00-9.31251E-3
**********************************************************
TIME              AQ                 ORG                ORG EQU
 210               1.52929            .966263            9.61272E-2
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 1.14925           1.71997            3.16425E-2         -.139139
ORG MED .65409 C*-C .870136    SLP-K.00-2.45319E-2
**********************************************************

ERR 16  9 96
TIME              AQ                 ORG                ORG EQU
 240               1.72763            .341913            .112584
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 4.36044           .673898            1.24597E-2         -1.47258
ORG MED 1.56713E-2                   C*-C .229334       SLP-K.00-3.1301E+36
**********************************************************
```

Table 19

Overall Mass Transfer Coefficients - $\bar{K}_{org}$

```
C O B A L T
====================

S C R U B B I N G :  RE-ORGANIC= 1000    RE-AQUEOUS= 3000  RUN NO. 3
..................

TIME              AQ              ORG            ORG EQU
 0                 14.919          2.2775         5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .310318           .116271        2.13985E-3      1.17016
ORG MED 2.45399                   C*-C 3.2225    SLP-K.00-2.13423E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 30                14.8419         2.63047        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .34849            .117432         2.16132E-3     1.05415
ORG MED 2.78916                   C*-C 2.86953   SLP-K.00-2.15535E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 60                14.7723         2.94786        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .391827           .117265         2.15734E-3     .936933
ORG MED 3.08875                   C*-C 2.55214   SLP-K.00-2.15241E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 90                14.7117         3.22965        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .44046            .115036         2.11633E-3     .819936
ORG MED 3.35275                   C*-C 2.27035   SLP-K.00-2.1117E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 120               14.6535         3.47585        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .494034           .110037         2.02529E-3     .705151
ORG MED 3.58115                   C*-C 2.02415   SLP-K.00-2.02127E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 150               14.6132         3.68645        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .551405           .101659         1.87224E-3     .595231
ORG MED 3.77396                   C*-C 1.81355   SLP-K.00-1.86695E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 180               14.5759         3.86147        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .610303           .089847         1.6332E-3      .4938
ORG MED 3.93118                   C*-C 1.63853   SLP-K.00-1.63637E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 210               14.5466         4.00089        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .667063           7.18419E-2      1.32163E-3     .404869
ORG MED 4.05281                   C*-C 1.49911   SLP-K.00-1.32055E-3
**************************************************************
TIME              AQ              ORG            ORG EQU
 240               14.5252         4.10473        5.5
1/C*-C            AREA            ARE-K.00       LOG(C*-C)
 .716705           .053167         9.22927E-4     .333088
ORG MED 4.13335                   C*-C 1.39527   SLP-K.00-9.22533E-4
**************************************************************
```

Table 20

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
    N   I   C   K   E   L
    =====================

S C R U B B I N G :  RE-ORGANIC= 1000   RE-AQUEOUS= 3000  RUN NO. 3
..................

TIME             AQ               ORG              ORG EQU
 0                .015425          4.1733           3.1453E-4
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .23975           7.27251E-2       1.33793E-3       1.42883
ORG MED 4.02477                   C*-C 4.17045     SLP-K.00-1.36334E-3
*************************************************************
TIME             AQ               ORG              ORG EQU
 30               .21806           3.37374          6.24443E-3
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .253232          7.48893E-2       1.37773E-3       1.3539
ORG MED 3.73931                   C*-C 3.57249     SLP-K.00-1.4161E-3
*************************************************************
TIME             AQ               ORG              ORG EQU
 60               .402977          3.59989          1.42083E-2
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .278593          7.71531E-2       1.41949E-3       1.27692
ORG MED 3.46707                   C*-C 3.5356      SLP-K.00-1.46663E-3
*************************************************************
TIME             AQ               ORG              ORG EQU
 90               .578177          3.33425          2.34115E-2
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .302838          7.95151E-2       1.46255E-3       1.1978
ORG MED 3.20804                   C*-C 3.31084     SLP-K.00-1.51569E-3
*************************************************************
TIME             AQ               ORG              ORG EQU
 120              .719658          3.23153          .032523
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .327976          8.19334E-2       1.50734E-3       1.11491
ORG MED 2.96222                   C*-C 3.049       SLP-K.00-.001563
*************************************************************
TIME             AQ               ORG              ORG EQU
 150              .851421          2.34262          4.19557E-2
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .357058          .38438           1.55235E-3       1.02935
ORG MED 2.72962                   C*-C 2.80066     SLP-K.00-1.60311E-3
*************************************************************
TIME             AQ               ORG              ORG EQU
 180              .965469          2.61662          .050376
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .339674          8.68081E-2       1.59702E-3       .942443
ORG MED 2.51023                   C*-C 2.56625     SLP-K.00-1.65046E-3
*************************************************************
TIME             AQ               ORG              ORG EQU
 210              1.0618           2.43384          5.77973E-2
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .42625           8.91573E-2       1.64024E-3       .352729
ORG MED 2.30425                   C*-C 2.34604     SLP-K.00-1.68909E-3
*************************************************************
TIME             AQ               ORG              ORG EQU
 240              1.14041          2.20425          6.40253E-2
1/C*-C           AREA             ARE-K.00         LOG(C*-C)
 .467238          9.13488E-2       1.68251E-3       .760916
ORG MED 2.11183                   C*-C 2.14084     SLP-K.00-1.72831E-3
*************************************************************
```

Table 21

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
N   I   C   K   E   L
=====================

S C R U B B I N G :  FE-ORGANIC=          FE-AQUEOUS=       RUN NO. 4
.................

ERR 16 @ 50
TIME              AQ                ORG                ORG EQU
 0                -.021946           3.8696            -4.33477E-4
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .258396           4.31504E-3        3.85535E-3         1.35326
ORG MED 3.87393                     C*-C 3.87003       SLP-K.00 5.54592E-5
*****************************************************************
TIME              AQ                ORG                ORG EQU
 30                .225959           3.88826            6.53948E-3
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .257613           8.97015E-3        1.65023E-4         1.35625
ORG MED 3.87096                     C*-C 3.88172       SLP-K.00-2.22214E-4
*****************************************************************
TIME              AQ                ORG                ORG EQU
 60                .475833           3.85365            1.81136E-2
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .26072            2.32305E-2        4.27374E-4         1.34431
ORG MED 3.80971                     C*-C 3.83553       SLP-K.00-5.02422E-4
*****************************************************************
TIME              AQ                ORG                ORG EQU
 90                .730677           3.76577            3.35537E-2
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .267933           3.86671E-2        7.11362E-4         1.317
ORG MED 3.69519                     C*-C 3.7322        SLP-K.00-9.04299E-4
*****************************************************************
TIME              AQ                ORG                ORG EQU
 120               .987491           3.62461            5.20497E-2
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .279912           5.61634E-2        1.03333E-3         1.27333
ORG MED 3.52739                     C*-C 3.57256       SLP-K.00-1.14822E-3
*****************************************************************
TIME              AQ                ORG                ORG EQU
 150               1.24727           3.43017            7.27369E-2
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .297842           7.69971E-2        1.41652E-3         1.21119
ORG MED 3.30632                     C*-C 3.35743       SLP-K.00-1.53956E-3
*****************************************************************
TIME              AQ                ORG                ORG EQU
 180               1.51003           3.18246            9.45133E-2
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .32384            .103163           1.39792E-3         1.1275
ORG MED 3.03197                     C*-C 3.08795       SLP-K.00-2.03243E-3
*****************************************************************
TIME              AQ                ORG                ORG EQU
 210               1.77575           2.88148            .116512
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .361666           .133153           2.54216E-3         1.01703
ORG MED 2.73435                     C*-C 2.76497       SLP-K.00-2.63372E-3
*****************************************************************
TIME              AQ                ORG                ORG EQU
 240               2.04444           2.52723            .137575
1/C*-C            AREA              ARE-K.00           LOG(C*-C)
 .418471           .189863           3.47821E-3         .871149
ORG MED 2.32346                     C*-C 2.38965       SLP-K.00-3.31671E-3
*****************************************************************


*READY
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Table 22

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
C  O  B  A  L  T
*********************

S T R I P I N G :  RE-ORGANIC= 2000    RE-AQUEOUS= 1500    RUN NO. 1
.................

TIME              AQ                 ORG                ORG EQU
 0                 0                  7.41513            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .134914           1.51803E-2         5.6627E-4          2.00311
ORG MED 7.34936                      C*-C 7.41213       SLP-K.00-5.66244E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 30                .279694            7.2825             .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .137389           1.66369E-2         5.19757E-4         1.98453
ORG MED 7.22235                      C*-C 7.2785        SLP-K.00-5.19712E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 60                .531386            7.16215            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .139701           1.51122E-2         4.70707E-4         1.96825
ORG MED 7.10843                      C*-C 7.15815       SLP-K.00-4.70714E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 90                .754335            7.0545             .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .141829           1.34611E-2         4.1923E-4          1.95314
ORG MED 7.00766                      C*-C 7.0505        SLP-K.00-4.19236E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 120               .952281            6.96052            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .14375            1.17394E-2         3.65654E-4         1.93965
ORG MED 6.91993                      C*-C 6.95652       SLP-K.00-3.65693E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 150               1.11764            6.87934            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .145447           9.95493E-3         3.12071E-4         1.92794
ORG MED 6.84529                      C*-C 6.87534       SLP-K.00-3.10012E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 180               1.25692            6.81124            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .146903           8.11499E-3         2.52762E-4         1.91793
ORG MED 6.78373                      C*-C 6.80724       SLP-K.00-2.52727E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 210               1.36312            6.75622            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .148099           6.22938E-3         1.9433E-4          1.90987
ORG MED 6.73525                      C*-C 6.75222       SLP-K.00-1.94345E-4
****************************************************************
TIME              AQ                 ORG                ORG EQU
 240               1.45124            6.71429            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .149025           4.38802E-3         1.34134E-4         1.90364
ORG MED 6.69936                      C*-C 6.71029       SLP-K.00-1.34145E-4
****************************************************************
```

Table 23

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
    N  I  C  K  E  L
    ====================

S T R I P I N G :  PE-ORGANIC= 1000    PE-AQUEOUS= 1500    RUN NO. 1
.................

TIME              AQ                ORG               ORG EQU
 0                 0                .38334             .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.63324           2.92585E-2        8.83183E-4       -.970115
ORG MED .37776 C*-C .37924          SLP-K.00-8.83383E-4
*****************************************************************
TIME              AQ                ORG               ORG EQU
 33                .017223          .37248             .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.71335           2.43465E-2        7.53334E-4       -.99837
ORG MED .368349                     C*-C .36849       SLP-K.00-7.53236E-4
*****************************************************************
TIME              AQ                ORG               ORG EQU
 62                3.16326E-2       .363618            .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.73073           2.01241E-2        6.26816E-4       -1.02271
ORG MED .362236                     C*-C .359613      SLP-K.00-6.26758E-4
*****************************************************************
TIME              AQ                ORG               ORG EQU
 93                4.32259E-2       .356454            .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.83725           1.56317E-2        4.86839E-4       -1.04284
ORG MED .353721                     C*-C .352454      SLP-K.00-4.86839E-4
*****************************************************************
TIME              AQ                ORG               ORG EQU
 122               5.28113E-2       .350938            .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.88195           1.39223E-2        3.48139E-4       -1.05847
ORG MED .349103                     C*-C .346938      SLP-K.00-3.48133E-4
*****************************************************************
TIME              AQ                ORG               ORG EQU
 152               5.79311E-2       .347219            .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.91359           6.3519E-3         1.85522E-4       -1.06939
ORG MED .346134                     C*-C .343219      SLP-K.00-1.85525E-4
*****************************************************************
TIME              AQ                ORG               ORG EQU
 183               6.11374E-2       .345148            .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.93128           1.29363E-3        3.42539E-5       -1.07544
ORG MED .344962                     C*-C .341148      SLP-K.00-3.42553E-5
*****************************************************************
TIME              AQ                ORG               ORG EQU
 213               .06148           .344775            .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.93443           3.97982E-3        1.20347E-4       -1.07653
ORG MED .345438                     C*-C .340775      SLP-K.00 1.20353E-4
*****************************************************************
TIME              AQ                ORG               ORG EQU
 242               5.92295E-2       .3461              .024
1/C*-C            AREA              ARE-K.00          LOG(C*-C)
 2.92312           8.7966E-3         2.73992E-4       -1.07265
ORG MED .347611                     C*-C .3421        SLP-K.00 2.7393E-4
*****************************************************************
```

Table 24

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
    C   O   B   A   L   T
    ====================

S T R I P I N G :  RE-ORGANIC= 2000   RE-AQUEOUS=1500    RUN NO. 2
.................

TIME            A0             ORG            ORG EQU
 0               0              7.3335         .334
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .137052         .013435        4.13453E-4     1.93739
ORG MED 7.25181                C*-C 7.2935    SLP-K.00-4.13473E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 30              .157522        7,22313        .334
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .138926         1.34665E-2     4.19443E-4     1.97396
ORG MED 7.15498                C*-C 7.19913   SLP-K.00-4.19474E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 60              .312935        7.10664        .334
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .142789         1.34965E-2     4.20394E-4     1.96049
ORG MED 7.05923                C*-C 7.10233   SLP-K.00-4.2035E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 90              .456238        7.01162        .334
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .142792         1.35257E-2     4.21292E-4     1.94699
ORG MED 6.96455                C*-C 7.00762   SLP-K.00-4.21226E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 120             .617431        6.91745        .334
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .144645         1.35533E-2     4.22151E-4     1.93347
ORG MED 6.87894                C*-C 6.91343   SLP-K.00-4.22147E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 150             .766515        6.82441        .334
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .146519         1.35794E-2     4.22966E-4     1.91992
ORG MED 6.77342                C*-C 6.82041   SLP-K.00-4.22904E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 182             .913499        6.73242        .224
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .143623         1.36043E-2     4.2374E-4      1.93634
ORG MED 6.68697                C*-C 6.72342   SLP-K.00-4.23751E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 212             1.05835        6.64131        .334
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .150659         1.36276E-2     4.24466E-4     1.89273
ORG MED 6.59659                C*-C 6.63751   SLP-K.00-4.24419E-4
*************************************************************
TIME            A0             ORG            ORG EQU
 240             1.22111        6.55167        .224
1/C*-C          AREA           ARE-K.00       LOG(C*-C)
 .152726         1.36493E-2     4.25133E-4     1.37911
ORG MED 6.50729                C*-C 6.54737   SLP-K.00-4.25147E-4
*************************************************************
```

Table 25

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
N  I  C  K  E  L
====================

S T R I P P I N G :  RE-ORGANIC= 2220  RE-AQUEOUS= 1530    RUN NO. 2
.................

TIME               AQ                 ORG                ORG EQU
 3                  3                  .46469             .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.17066            1.39572E-2         4.34733E-4        -.775232
ORG MED .461497                       C*-C .46069        SLP-K.00-4.34677E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 30                 1.13229E-2         .455305            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.20116            1.39525E-2         4.3552E-4         -.753938
ORG MED .455151                       C*-C .454335       SLP-K.00-4.35633E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 62                 2.17549E-2         .451997            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.23216            1.42361E-2         4.36257E-4        -.802974
ORG MED .443882                       C*-C .447997       SLP-K.00-4.36242E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 90                 .332196            .445766            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.26364            .014328            4.36935E-4        -.816979
ORG MED .442639                       C*-C .441766       SLP-K.00-4.36531E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 123                4.23451E-2         .439613            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.29562            1.42479E-2         4.37557E-4        -.831225
ORG MED .436574                       C*-C .435613       SLP-K.00-4.37534E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 153                5.22053E-2         .433536            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.32879            .014066            4.39123E-4        -.845052
ORG MED .432536                       C*-C .429536       SLP-K.00-4.38793E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 180                6.17736E-2         .427537            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.36127            .014232            4.3862E-4         -.859117
ORG MED .424575                       C*-C .423537       SLP-K.00-4.38623E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 210                7.12509E-2         .421614            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.39[illegible]    1.42955E-2         4.3983E-4         -.873193
ORG MED .418692                       C*-C .417515       SLP-K.00-4.39019E-4
*****************************************************************
TIME               AQ                 ORG                ORG EQU
 240                8.30374E-2         .415769            .224
1/C*-C             AREA               ARE-K.00           LOG(C*-C)
 2.42554            1.41873E-2         4.39429E-4        -.887293
ORG MED .412395                       C*-C .411769       SLP-K.00-4.39403E-4
*****************************************************************
```

Table 26

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
C  O  B  A  L  T
====================

S T R I P P I N G :  FE-ORGANIC= 1000   FE-AQUEOUS= 3000   RUN NO.3
................

TIME              AQ                 ORG                ORG EQU
 0                 0                  7.3499             .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .13613            1.49613E-2         4.56208E-4         1.99414
ORG MED 7.29536                      C*-C 7.3459        SLP-K.00-4.65991E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 30                .184294            7.24082            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .138182           .014553            4.52635E-4         1.97919
ORG MED 7.18747                      C*-C 7.23682       SLP-K.00-4.52649E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 60                .362061            7.13413            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .14025            1.47366E-2         4.59208E-4         1.96432
ORG MED 7.08198                      C*-C 7.13013       SLP-K.00-4.58936E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 90                .533381            7.02953            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .142332           1.46116E-2         4.55116E-4         1.94959
ORG MED 6.97857                      C*-C 7.02553       SLP-K.00-4.55289E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 120               .698315            6.92792            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .144427           1.44773E-2         4.52949E-4         1.93498
ORG MED 6.87316                      C*-C 6.92392       SLP-K.00-4.52901E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 150               .856202            6.8284             .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .146533           .014335            4.46531E-4         1.9205
ORG MED 6.77934                      C*-C 6.8244        SLP-K.00-4.4649E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 180               1.00786            6.73127            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .148649           .014183            4.41764E-4         1.90617
ORG MED 6.68391                      C*-C 6.72727       SLP-K.00-4.41752E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 210               1.153              6.63654            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .150772           1.40214E-2         4.36731E-4         1.89199
ORG MED 6.59036                      C*-C 6.63254       SLP-K.00-4.33672E-4
***************************************************************
TIME              AQ                 ORG                ORG EQU
 240               1.29161            6.54419            .004
1/C*-C            AREA               ARE-K.00           LOG(C*-C)
 .152901           .01335             4.31393E-4         1.87797
ORG MED 6.49922                      C*-C 6.54019       SLP-K.00-4.31333E-4
***************************************************************
```

Table 27

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

```
    N   I   C   K   E   L   =
    ====================

STRIPING :  RE-ORGANIC= 1000    RE-AQUEOUS= 3000   RUN NO. 3
.................

TIME             AO              ORG              ORG EQU
 0                0               .39696           .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.54479          1.19476E-2      3.72137E-4      -.934049
ORG MED .394626                  C*-C .39296      SLP-K.00-3.72134E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 30               1.32403E-2      .392293          .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.57537          1.20325E-2      3.74753E-4      -.945996
ORG MED .389971                  C*-C .388293     SLP-K.00-3.74753E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 60               2.01774E-2      .387649          .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.60655          1.21191E-2      3.77432E-4      -.958028
ORG MED .385338                  C*-C .383649     SLP-K.00-3.77436E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 90               2.93112E-2      .383025          .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.63835          1.22272E-2      3.82223E-4      -.970147
ORG MED .380728                  C*-C .379025     SLP-K.00-3.82204E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 120              3.91416E-2      .378429          .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.67073          1.22963E-2      3.83333E-4      -.982354
ORG MED .376141                  C*-C .374429     SLP-K.00-3.82981E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 150              4.31633E-2      .373853          .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.70377          1.23872E-2      3.85831E-4      -.994649
ORG MED .371577                  C*-C .369853     SLP-K.00-3.85315E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 180              5.65926E-2      .3693            .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.73747          1.24795E-2      3.88725E-4      -1.00704
ORG MED .367035                  C*-C .3653       SLP-K.00-3.85729E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 210              6.53130E-2      .36477           .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.77185          1.25734E-2      3.91631E-4      -1.01952
ORG MED .362516                  C*-C .36077      SLP-K.00-3.91611E-4
***************************************************************
TIME             AO              ORG              ORG EQU
 240              7.34305E-2      .360262          .004
1/C*-C           AREA            ARE-K.00         LOG(C*-C)
 2.80692          1.25558E-2      3.94622E-4      -1.03229
ORG MED .35822 C*-C .356262      SLP-K.00-3.94611E-4
***************************************************************
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Table 28

Overall Mass Transfer Coefficients - $\overline{K}_{org}$

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C  O  B  A  L  T
====================

S T R I P I N G :  RE-ORGANIC=  1500   RE-AQUEOUS= 1500    RUN NO. 4
.................

TIME            AQ              ORG             ORG EQU
 0               0               6.0001          .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .156775         2.03925E-2      6.53751E-4      1.79111
ORG MED 5.93312                 C*-C 5.9761     SLP-K.00-6.50729E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 30              .174744         5.87613         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .170295         .019442         6.05569E-4      1.77002
ORG MED 5.81961                 C*-C 5.87213    SLP-K.00-6.05558E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 60              .332977         5.76303         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .173639         1.73967E-2      5.57437E-4      1.75377
ORG MED 5.712   C*-C 5.75933   SLP-K.00-5.57407E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 90              .474698         5.66093         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .176774         1.62606E-2      5.26476E-4      1.73235
ORG MED 5.61531                 C*-C 5.65693    SLP-K.00-5.26449E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 120             .599907         5.56959         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .179672         .014535         4.52524E-4      1.71652
ORG MED 5.52953                 C*-C 5.56569    SLP-K.00-4.52317E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 150             .708604         5.48937         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .182333         1.27362E-2      3.96702E-4      1.70233
ORG MED 5.45466                 C*-C 5.48537    SLP-K.00-3.9669E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 180             .83079          5.41995         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .18464          1.08619E-2      3.33321E-4      1.68935
ORG MED 5.3907  C*-C 5.41595    SLP-K.00-3.33336E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 210             .976464         5.36144         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .186656         8.92444E-3      2.77974E-4      1.67348
ORG MED 5.33764                 C*-C 5.35744    SLP-K.00-2.77961E-4
**************************************************************
TIME            AQ              ORG             ORG EQU
 240             .935628         5.31334         .334
1/C*-C          AREA            ARE-K.00        LOG(C*-C)
 .188329         6.9338E-3       2.15971E-4      1.66956
ORG MED 5.2955  C*-C 5.32934    SLP-K.00-2.15932E-4
**************************************************************
```

I. APPENDIX II

EXPERIMENTAL DATA

Table 29

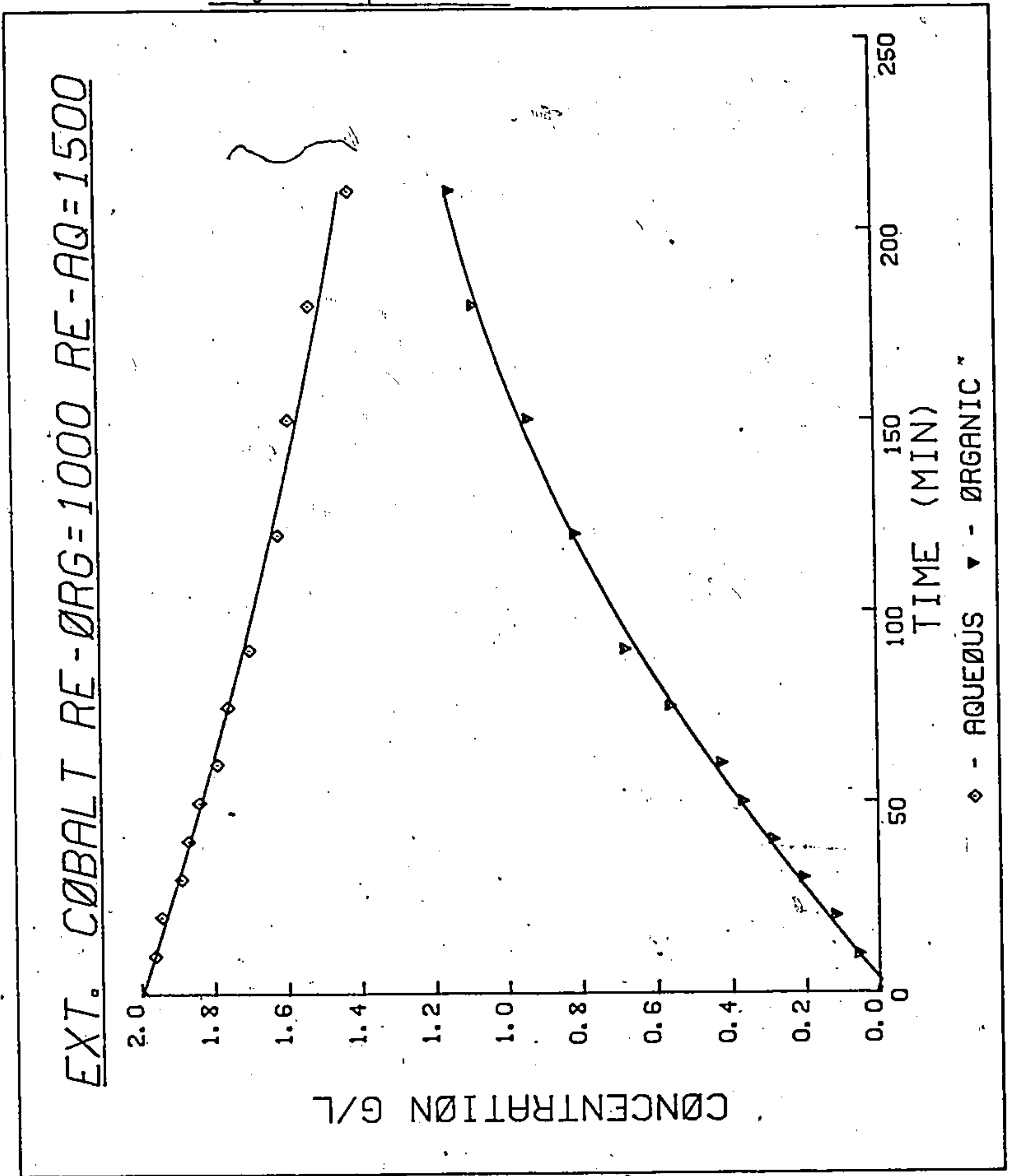
EXTRACTION

Run #1

N_{Re} Org = 1000
N_{Re} Aqu = 1500

		Cobalt		Nickel	
pH	Time (min.)	Organic Conc. g/l	Aqueous Conc. g/l	Organic Conc. g/l	Aqueous Conc. g/l
3.92	0	0	2.000	0	4.90
4.5	10	0.062	1.964	0.05	4.87
4.81	20	0.125	1.945	0.20	4.65
4.70	30	0.213	1.890	0.40	4.60
4.8	40	0.294	1.870	0.60	4.50
4.85	50	0.375	1.85	0.80	-
4.9	60	0.432	1.79	0.95	4.3
5.15	75	0.567	1.76	1.20	4.25
5.17	90	0.684	1.70	1.35	4.10
5.39	120	0.817	1.62	1.75	3.9
5.42	150	0.942	1.59	2.0	3.8
5.61	180	1.088	1.53	2.4	3.73
5.60	210	1.150	1.42	2.55	3.5
-	240	-	-	-	-
5.93	∞	2.30	0.90	4.7	2.5

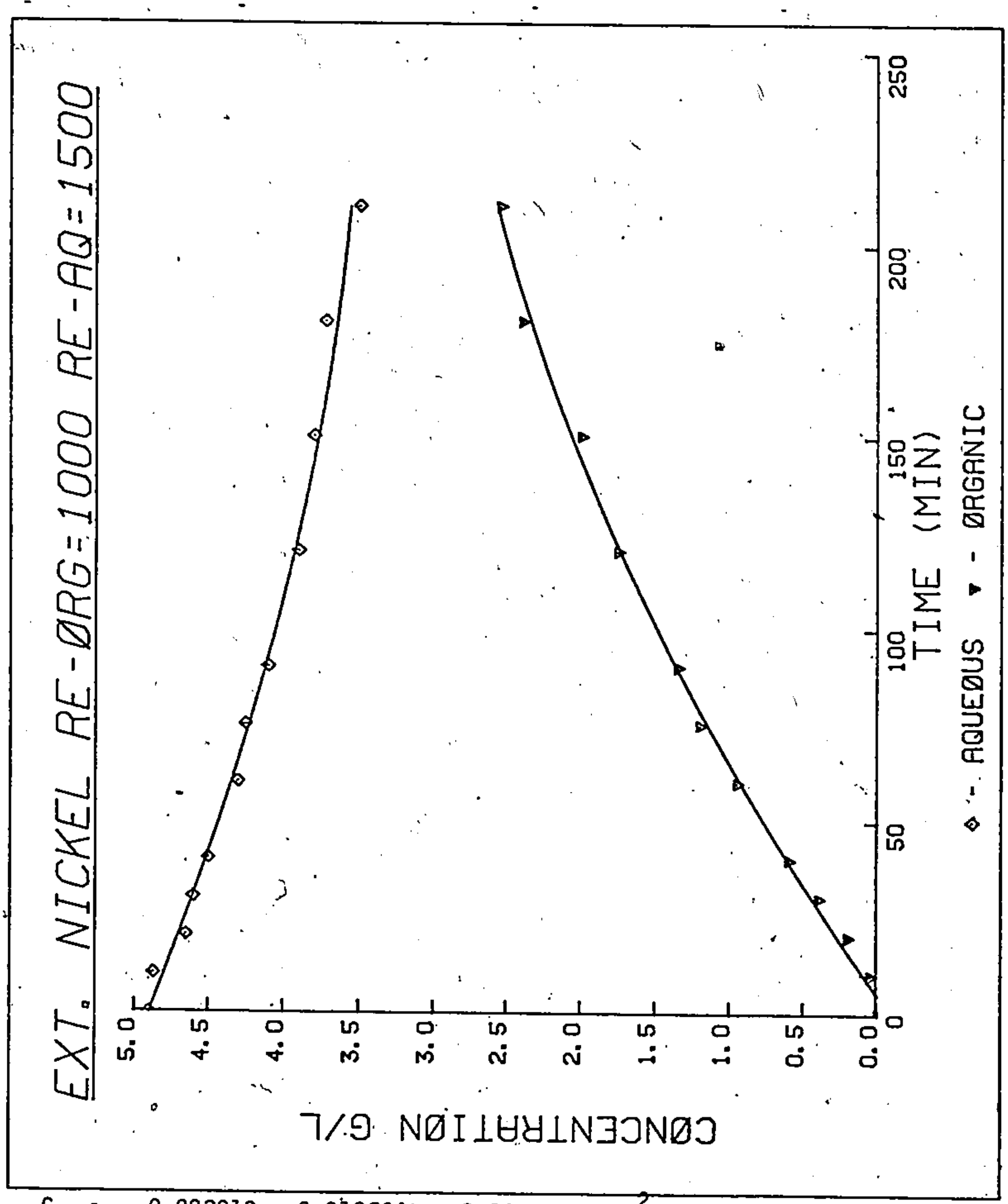
Figure 13. Run No. 1 Cobalt - Extraction Variation of C_{org} and C_{aq} With Time



$C_{org} = -0.02766 + 0.008925t - 1.5627\ \ E\text{-}5.t^2$

$C_{aq} = 1.999 - 0.00353t + 4.2085\ \ E\text{-}6.t^2$

Figure 14. Run No. 1. Nickel - Extraction Variation of C_{org} and C_{aq} With Time



$C_{org} = -0.093813 + 0.018664t - 2.848 \quad E\text{-}5.t^2$

$C_{aq} = 4.8996 - 0.010456t + 1.9441 \quad E\text{-}5.t^2$

Table 30

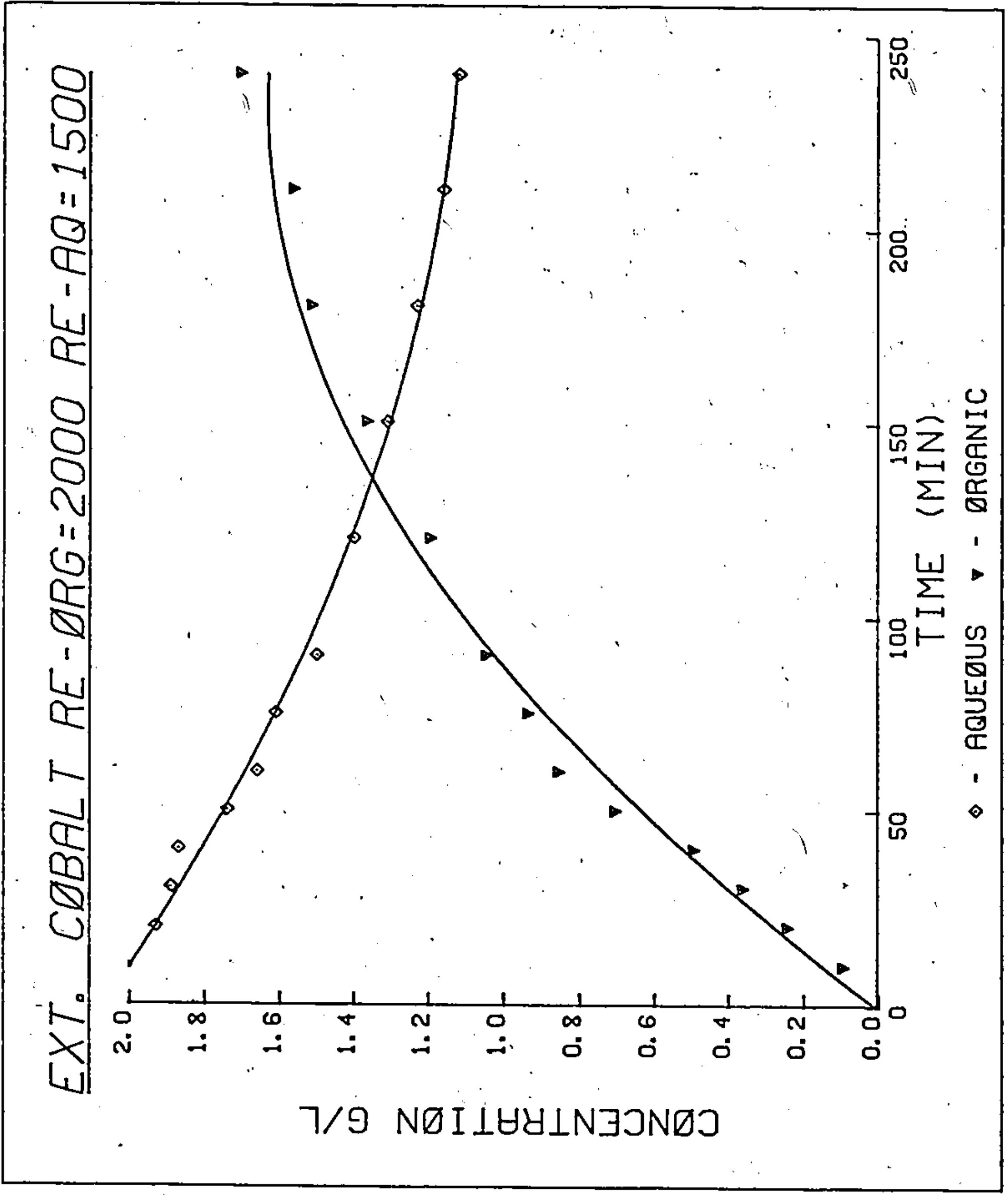
EXTRACTION

Run #2

N_{Re} Org = 2000
N_{Re} Aqu = 1500

pH	Time (min.)	Cobalt		Nickel	
		Organic Conc. g/l	Aqueous Conc. g/l	Organic Conc. g/l	Aqueous Conc. g/l
3.79	0	0.00	2.03	0	4.9
3.87	10	0.10	2.01	0.2	4.7
4.11	20	0.25	1.93	0.5	4.5
4.21	30	0.37	1.89	0.75	4.3
4.43	40	0.50	1.87	1.15	4.2
4.84	50	0.71	1.74	1.55	4.0
4.96	60	0.86	1.66	1.95	3.8
5.11	75	0.94	1.61	2.15	3.6
5.22	90	1.05	1.50	2.5	3.45
5.33	120	1.20	1.40	2.85	3.3
5.42	150	1.37	1.31	3.23	2.98
5.45	180	1.52	1.23	3.75	2.8
5.54	225	1.57	1.16	3.75	2.7
5.56	240	1.71	1.12	4.1	2.6
5.74	∞	2.0	0.91	4.425	2.35

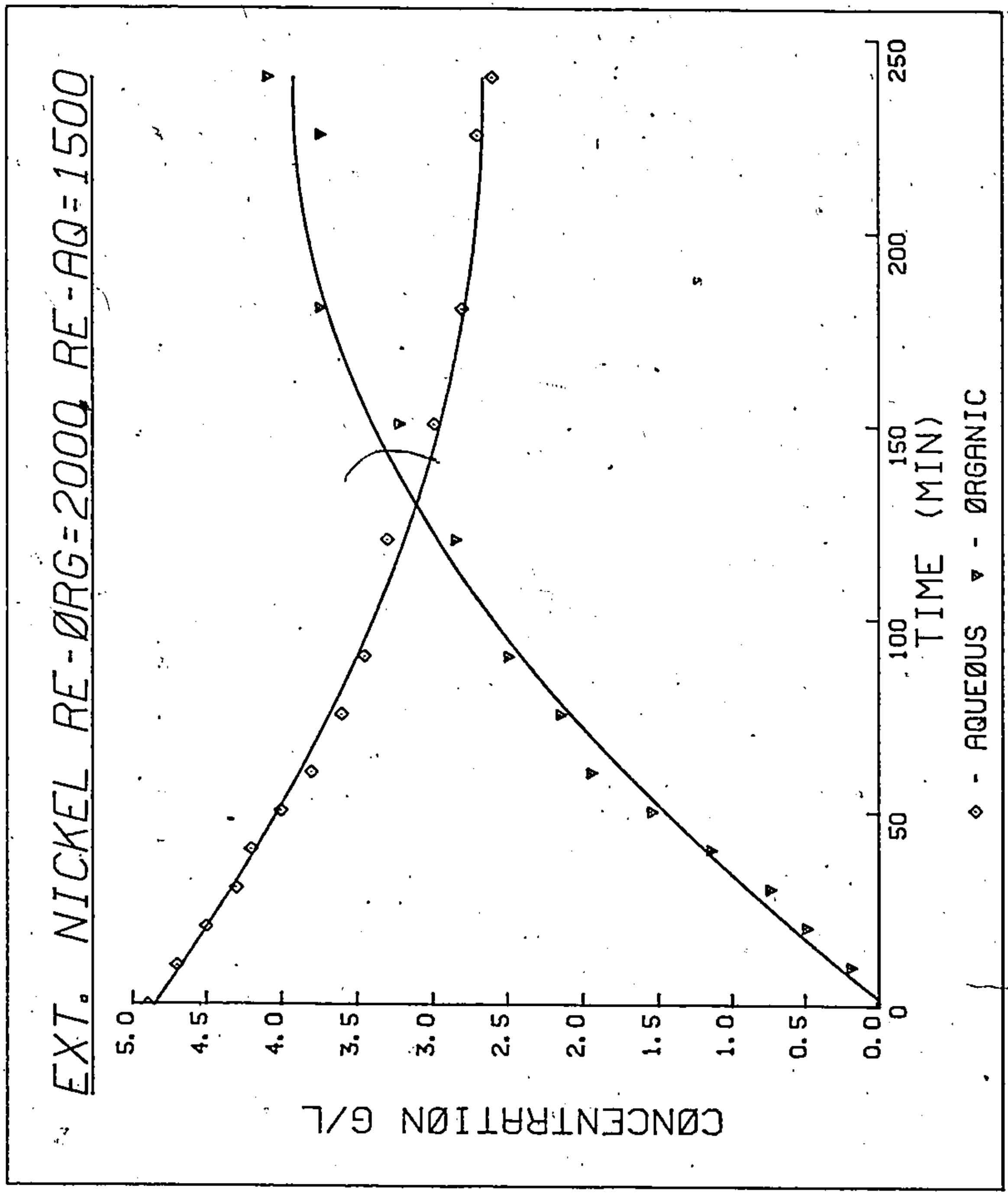
Figure 15. Run No. 2. Cobalt - Extraction Variation of C_{org} and C_{aq} With Time



$C_{org} = 0.011203 + 0.013984t - 3.011 \text{ E-5}.t^2$

$C_{aq} = 2.0681 - 0.007101t + 1.3207 \text{ E-5}.t^2$

Figure 16. Run No. 2. Nickel - Extraction Variation of C_{org} and C_{aq} With Time



$C_{org} = 3.967\ E\text{-}5\ t^2 - 0.018642\ t + 4.8529$

$C_{aq} = -7.1778\ E\text{-}5\ t^2 + 0.033807\ t - 0.05774$

Table 31

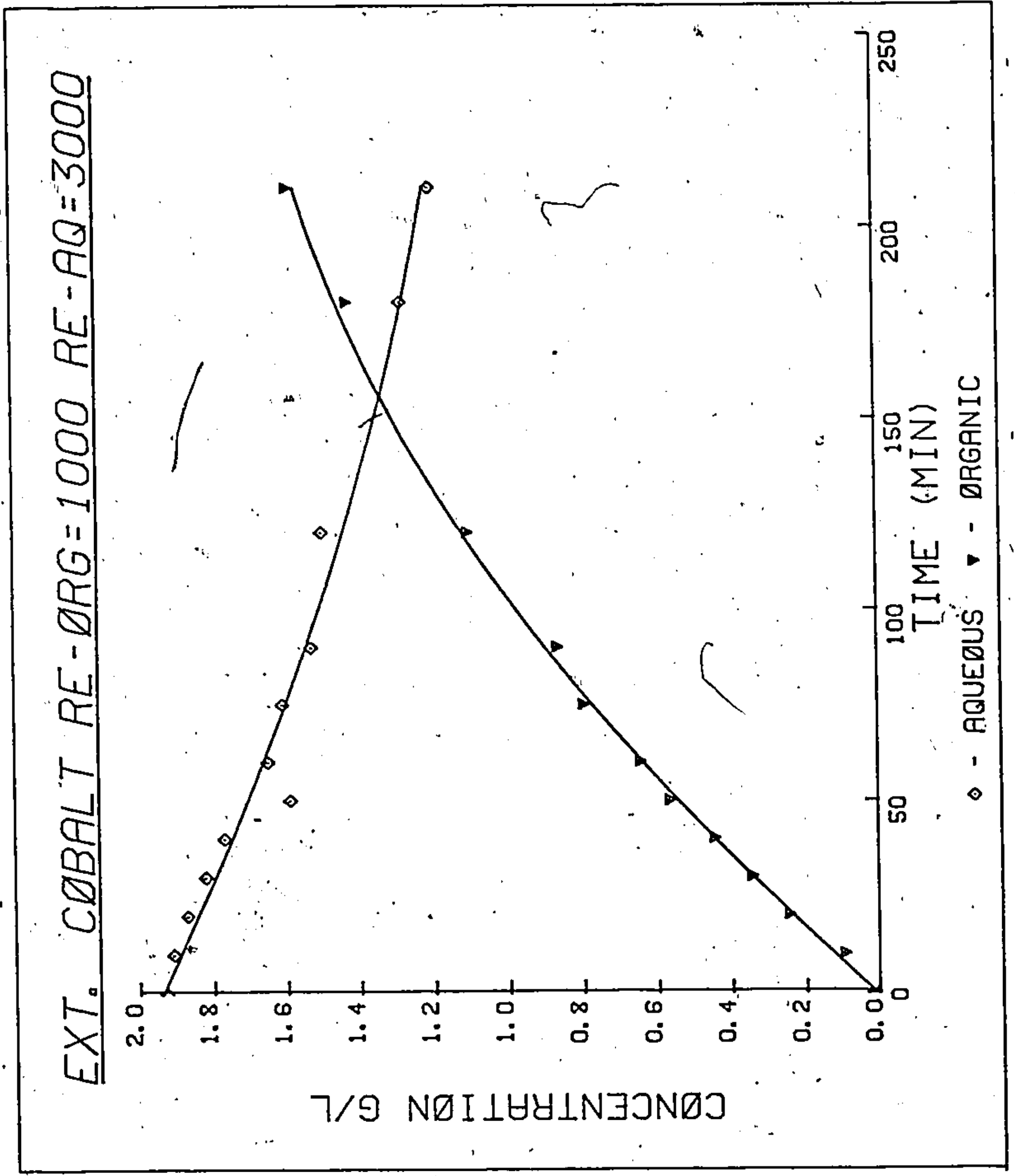
EXTRACTION

Run #3

N_{Re} Org = 1000
N_{Re} Aqu = 3000

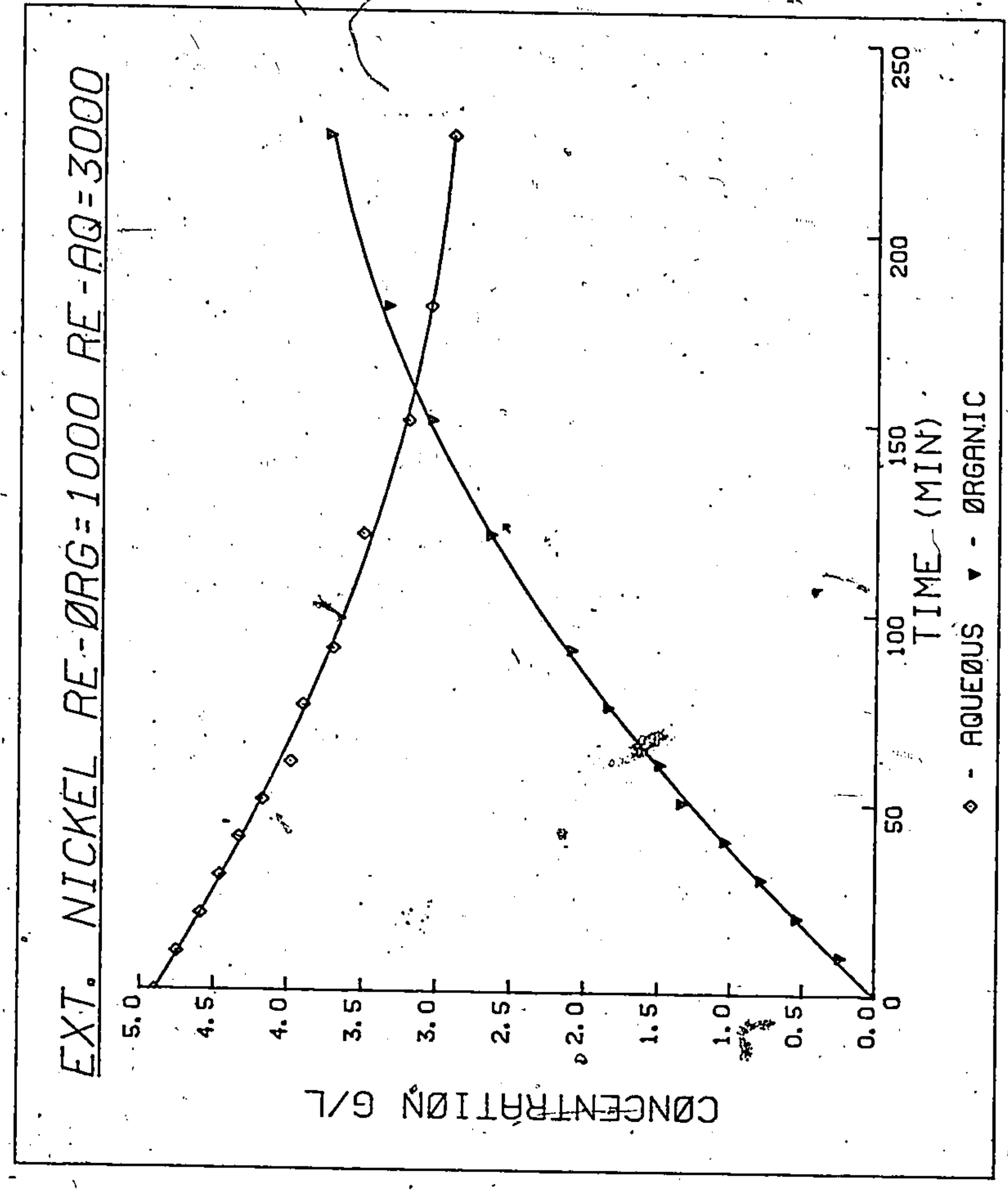
		Cobalt		Nickel	
pH	Time (min.)	Organic Conc. g/l	Aqueous Conc. g/l	Organic Conc. g/l	Aqueous Conc. g/l
4.1	0	0	1.97	0	4.9
-	10	0.1	1.91	0.25	4.75
4.6	20	0.25	1.87	0.55	4.59
4.75	30	0.35	1.82	0.80	4.46
4.88	40	0.45	1.77	1.05	4.33
5.00	50	0.57	1.59	1.35	4.17
5.10	60	0.65	1.65	1.5	3.98
5.18	75	0.80	1.61	1.85	3.90
5.2	90	0.87	1.53	2.1	3.70
5.3	120	1.11	1.50	2.65	3.50
-	150	1.28	-	3.05	3.20
5.45	180	1.43	1.28	3.35	3.05
5.5	210	1.59	1.20	3.75	2.9
-	240	-	-	-	-
5.7	∞	2.8	0.89	-	2.45

Figure 17. Run No. 3 Cobalt - Extraction Variation of C_{org} and C_{aq} With Time



$$C_{org} = 0.010712 + 0.011726\ t - 2.054\ \mathrm{E}{-5}\ t^2$$
$$C_{aq} = 1.9408 - 0.0051194\ t + 7.9189\ \mathrm{E}{-5}\ t^2$$

Figure 18. Run No. 3 Nickel - Extraction Variation of C_{org} and C_{aq} With Time



$$C_{org} = 3.1406\ E\text{-}5\ t^2 - 0.015919\ t + 4.8971$$

$$C_{aq} = -5.187\ E\text{-}5\ t^2 + 0.028173\ t + 0.0055653$$

Table 32

EXTRACTION

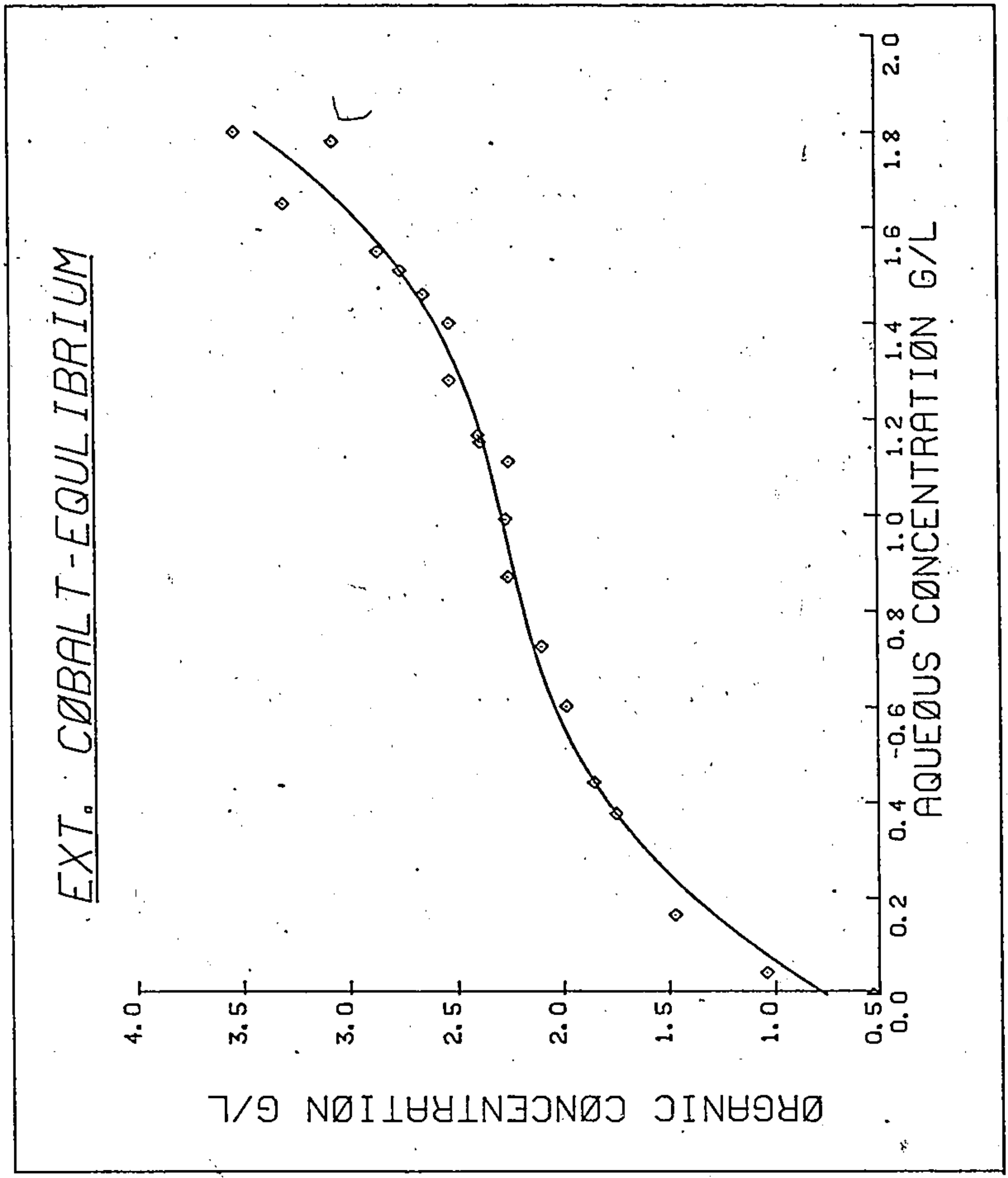
Equilibrium Loci

Aqueous/organic Volume Ratio	COBALT		NICKEL	
	Aqueous Concentration g/L	Organic Concentration g/L	Aqueous Concentration g/L	Organic Concentration g/L
0.25	0.004	0.53	0.004	1.1875
0.5	0.04375	1.038	0.09375	2.328
0.75	0.1625	1.468	0.6	3.1125
1.00	0.375	1.745	1.3	3.45
1.1	0.44	1.848	1.49	3.586
1.3	0.60	1.976	1.9	3.705
1.5	0.725	2.0925	2.27	3.72
1.8	0.87	2.25	2.6	3.87
2.0	0.99	2.26	2.84	3.82
2.2	1.11	2.244	3.06	3.718
2.4	1.15	2.38	3.11	3.936
2.5	1.165	2.3875	3.15	4.00
3.0	1.28	2.52	3.4	4.05
3.5	1.40	2.52	3.63	3.92
4.0	1.46	2.64	3.8	3.80
4.5	1.51	2.745	4.06	3.15
5.0	1.55	2.85	4.26	3.70
7.0	1.65	3.29	4.47	3.71
9.0	1.78	3.06	4.57	3.87
11.0	1.8	3.52	4.67	3.63

initial aqueous conc: cobalt = 2.12
nickel = 4.75

organic conc. 10% D2EHPA

Figure 19. Cobalt - Extraction
Apparent Equilibrium Isotherm



$$C_{org} = 0.75578 + 3.7667\, C_{aq} - 3.4529\, (C._{aq})^2 + 1.2125\, (C._{aq})^3$$

Figure 20: Nickel - Extraction
Apparent Equilibrium Isotherm

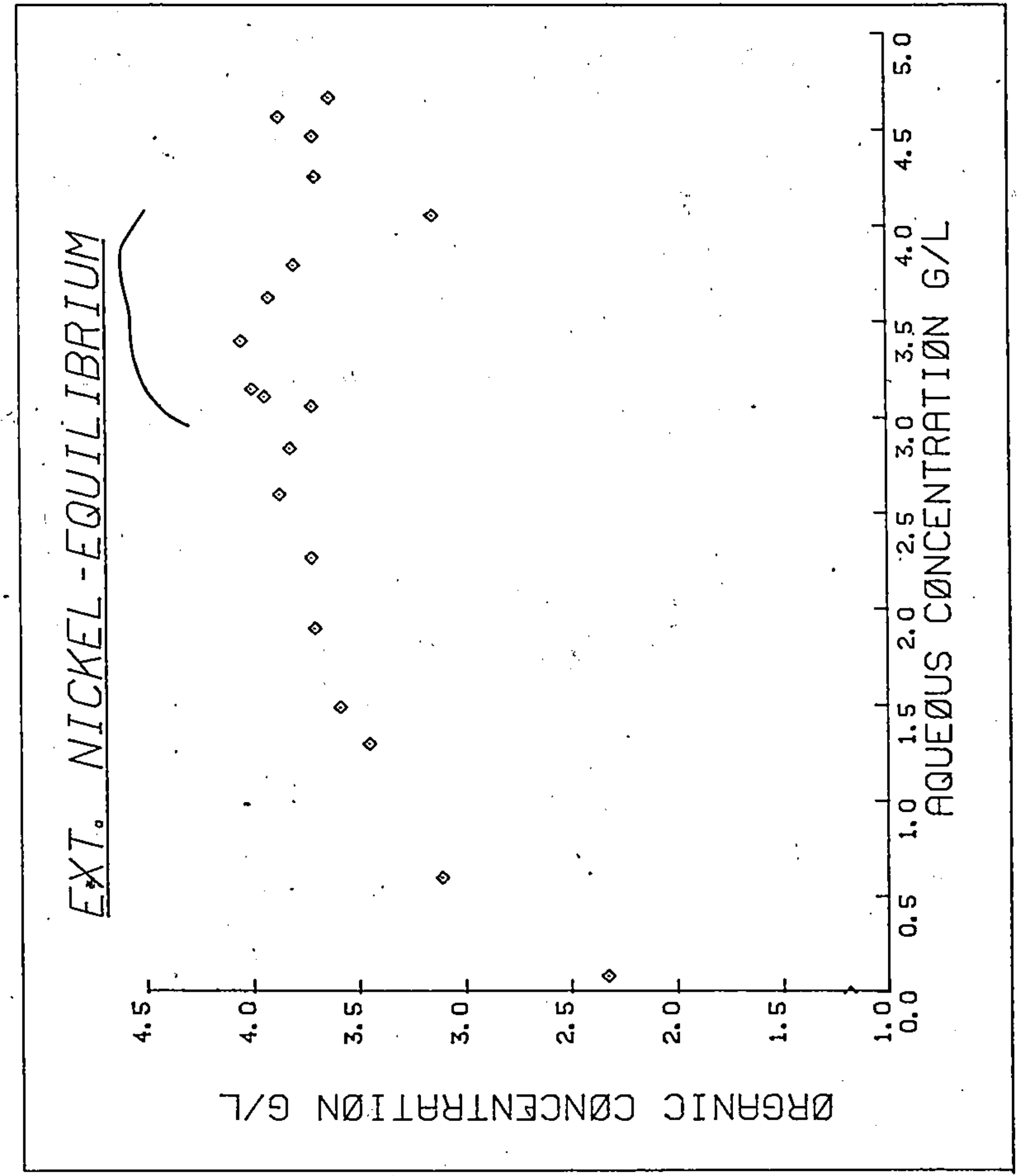
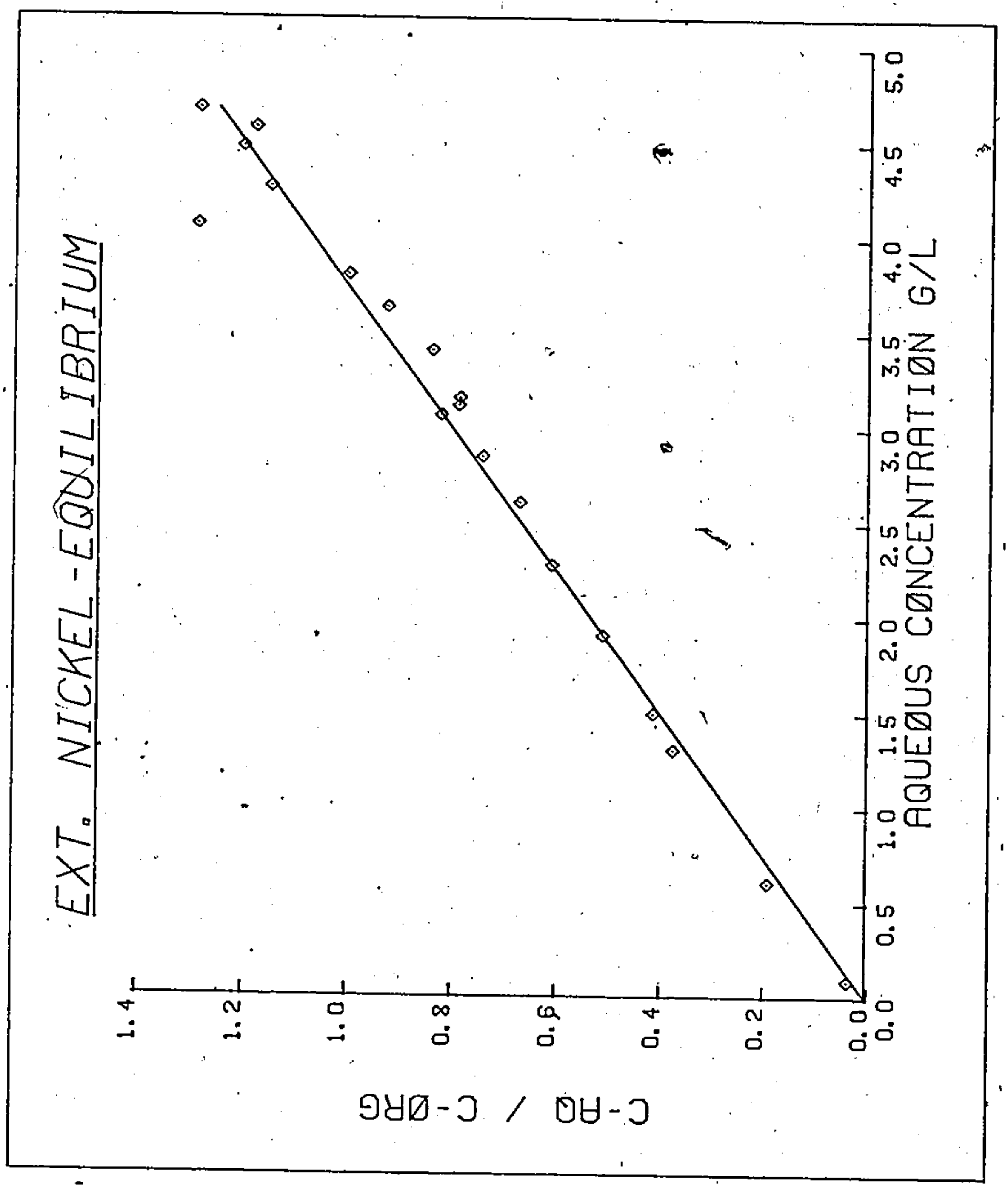


Figure 21. Nickel - Extraction
Variation of Equilibrium Isotherm



$$C_{org} = \frac{C_{aq}}{0.26703\, C_{aq} + 0.01185}$$

Table 33

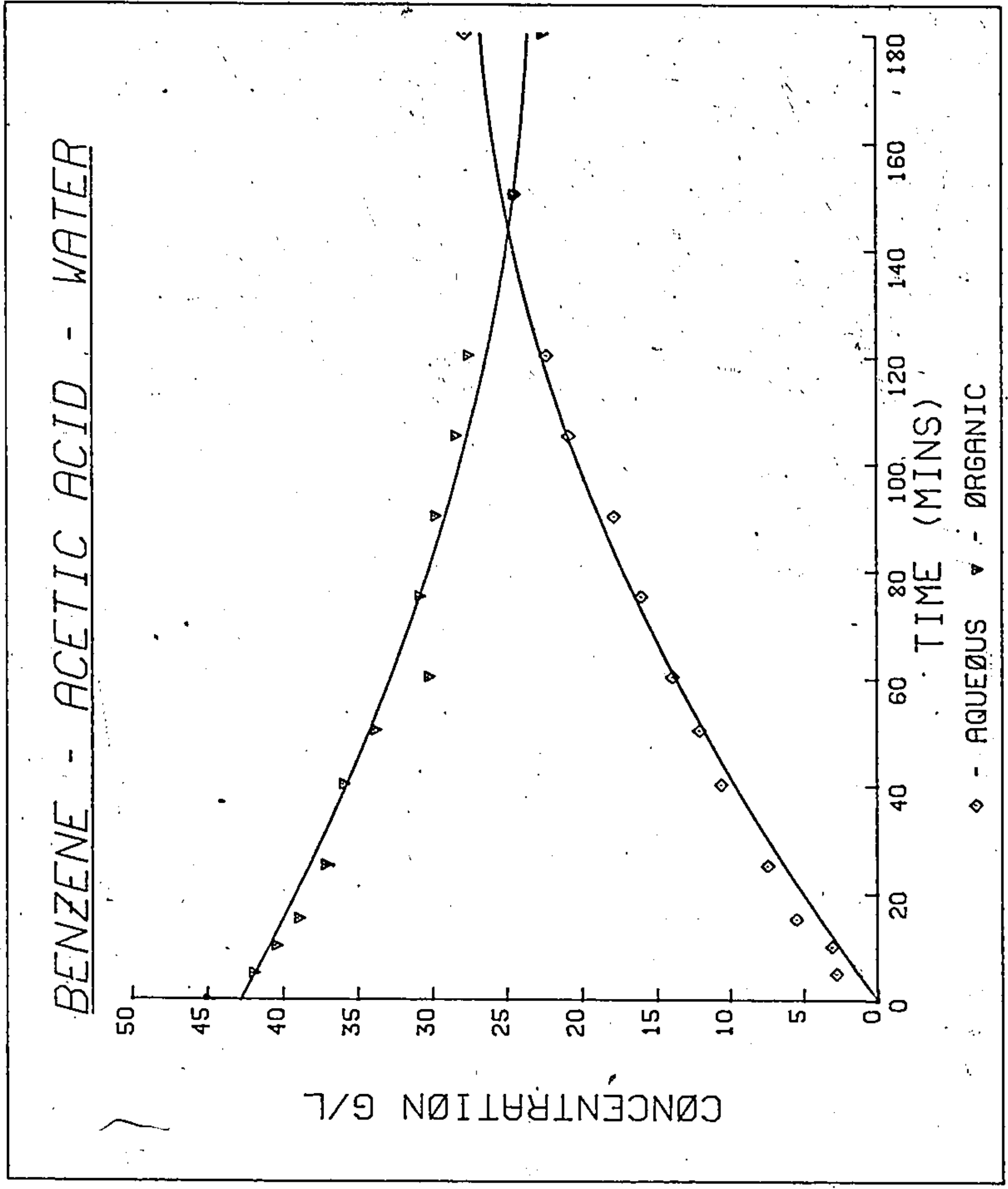
EXTRACTION

Acetic Acid - Benzene - Water

N_{Re} Organic = 1500
N_{Re} Aqueous = 1000

Time (min.)	Organic Conc. g/l	Aqueous Conc. g/l
0	45.04	0
5	42.04	7.21
10	40.53	7.51
15	39.03	9.91
25	37.23	11.86
40	36.03	15.01
50	33.93	16.51
60	30.33	18.32
75	30.93	20.42
90	29.87	22.22
105	28.52	25.22
120	27.62	26.72
150	24.62	28.82
180	22.67	32.13

Figure 22. Acetic Acid Extraction from Benzene. Variation of C_{org} and C_{aq} With Time



$$C_{org} = 42.844 - 0.19831\ t + 5.026\ E\text{-}4\ t^2$$

$$C_{aq} = 0 + 0.27038\ t - 6.7668\ E\text{-}4\ t^2$$

Table 34

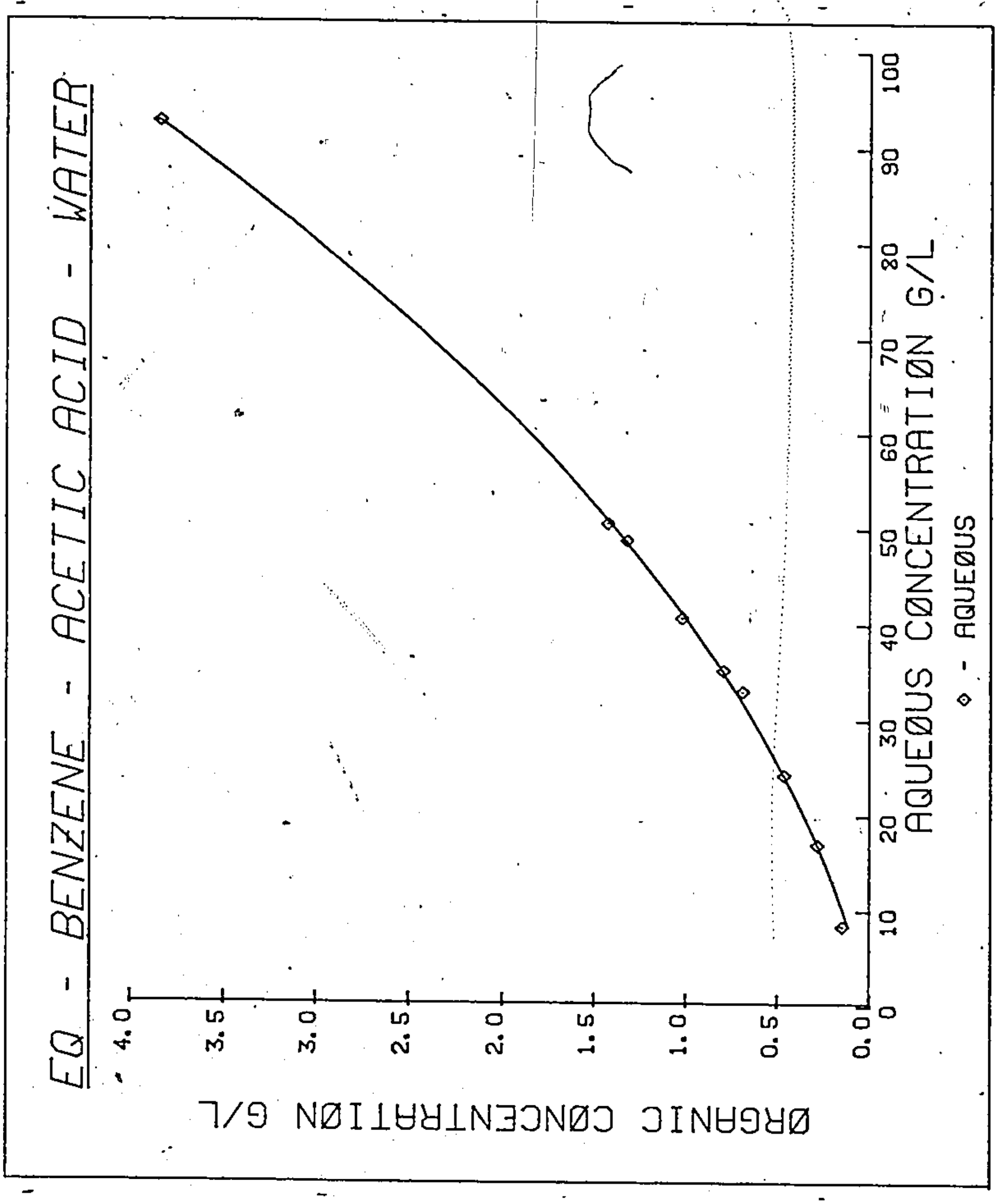
EXTRACTION

Equilibrium Isotherm

Acetic Acid in Benzene - Water System

Org/Aq Volume Ratio	Aqueous Conc. g/l	Organic Conc. g/l
0.2	8.407	0.15
0.4	16.814	0.285
0.6	24.140	0.465
0.8	32.827	0.691
1.0	40.534	1.021
1.2	48.641	1.321
2.5	92.477	3.843
1.25	50.442	1.426
0.83	35.029	0.796

Figure 23. Acetic Acid Extraction from Benzene. Variation of C_{org} and C_{aq} at Equilibrium



$C_{org} = 0.00 + 0.01149$[illegible]$C_{aq} + 3.253$ E-4 $(C_{aq})^2$

Table 35

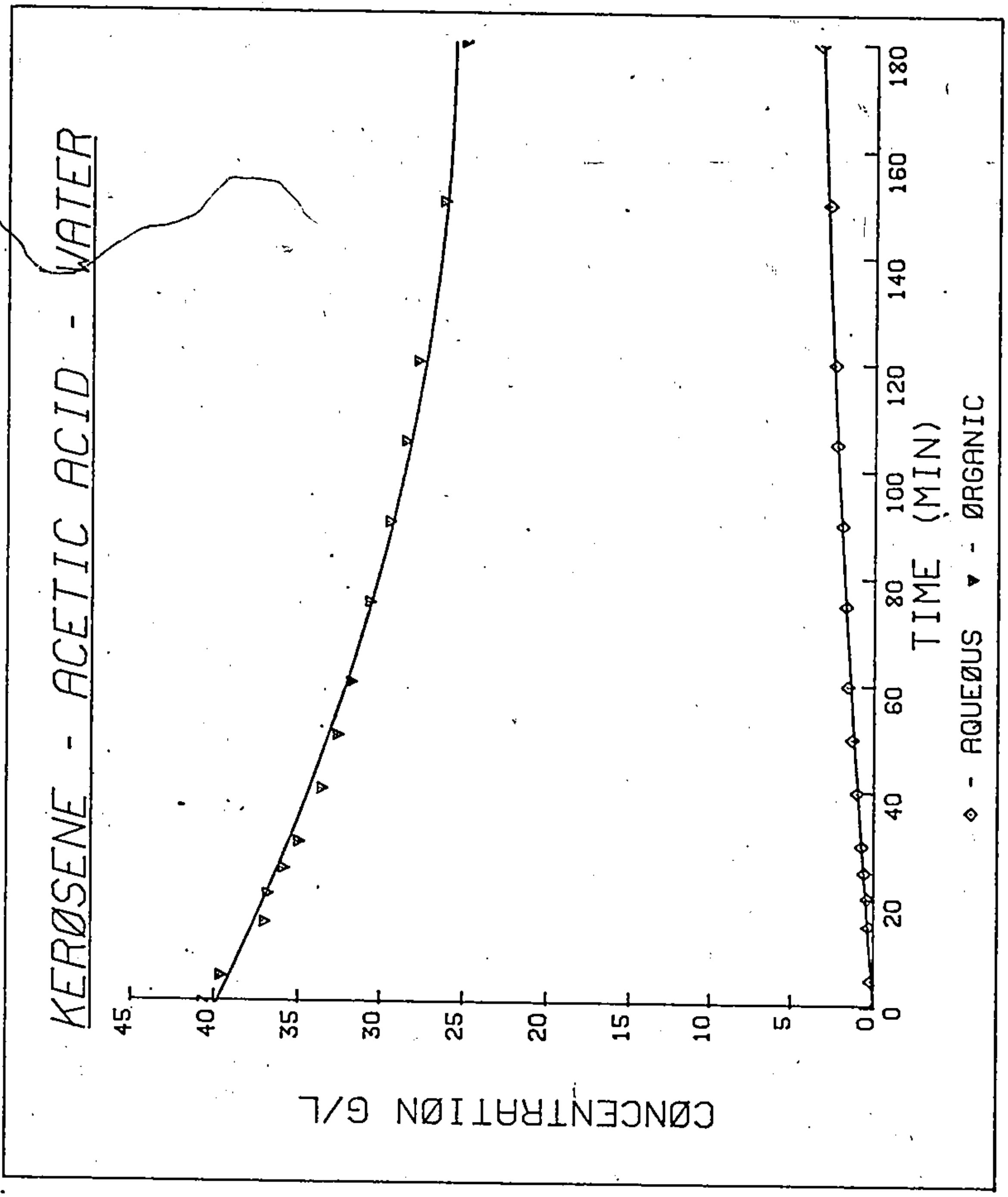
EXTRACTION

Acetic Acid - Kerosene - Water

N_{Re} Org = 1500
N_{Re} Aq = 1000

Time (min.)	Organic Conc. g/l	Aqueous Conc. g/l
0	40.75	0
5	39.7	0.18
15	37.06	0.33
20.2	36.88	0.46
25	35.95	0.59
30	35.05	0.75
40	33.63	1.01
50	32.67	1.32
60	31.89	1.59
75	30.75	1.71
90	29.55	1.94
105	28.6	2.28
120	27.9	2.4
150	26.34	2.76
180	25.11	3.36

Figure 24. Acetic Acid Extraction from Kerosene Variation of $C_{org.}$ and $C_{aq.}$ With Time



$$C_{org} = 39.858 - 0.15603\ t + 4.2877\ E\text{-}4\ t^2$$

$$C_{aq} = 0 + 0.026375\ t - 4.6616\ E\text{-}5\ t^2$$

Table 36

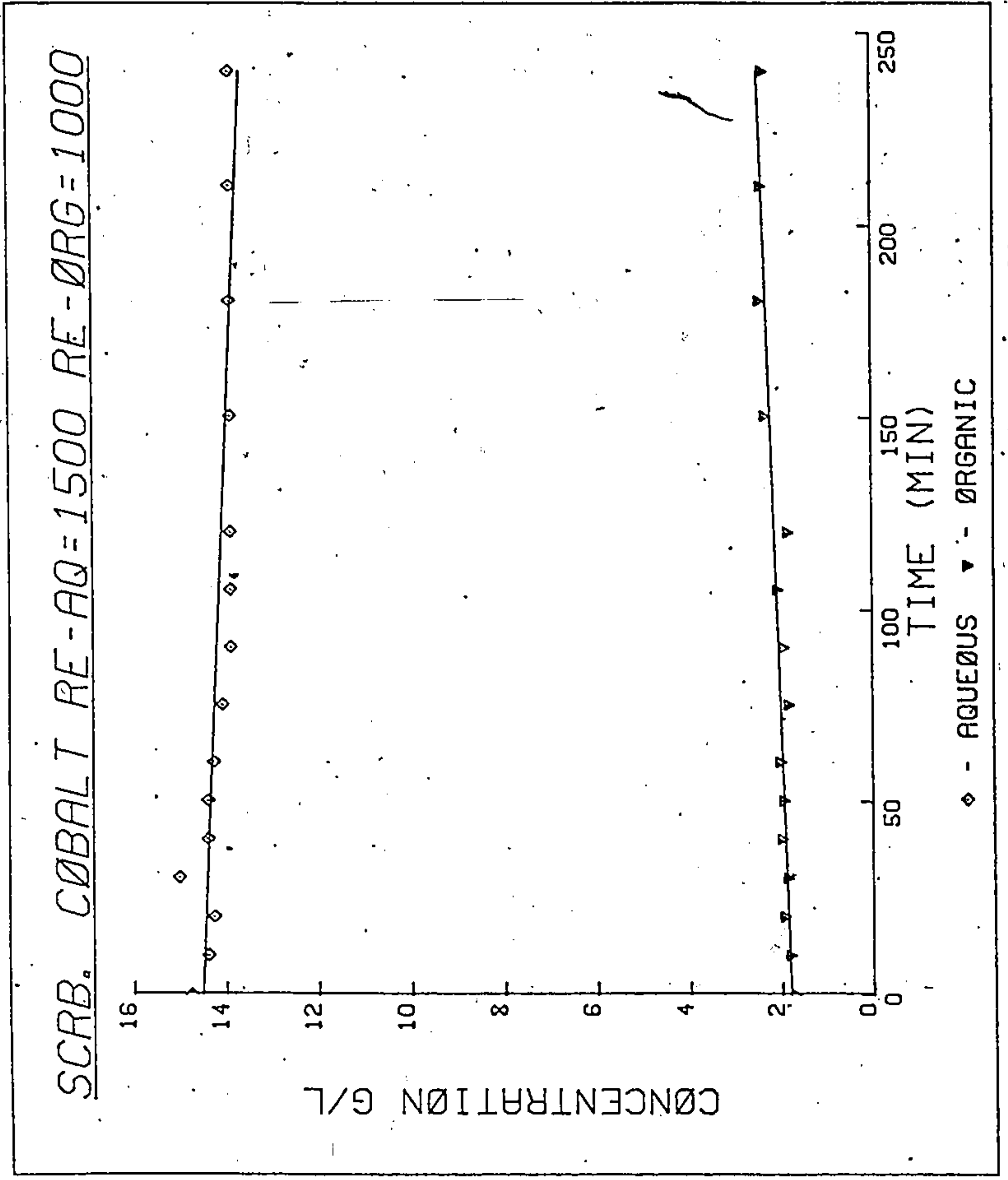
SCRUBBING

Run #1

N_{Re} Org = 1000
N_{Re} Aqu = 1500

Time (min.)	Cobalt Organic Conc. g/l	Cobalt Aqueous Conc. g/l	Nickel Organic Conc. g/l	Nickel Aqueous Conc. g/l
0	1.745	14.75	3.6	0.00
10	1.856	14.375	3.538	0.040
20	1.968	14.25	3.531	0.07
30	1.903	15.00	-	-
40	2.025	14.375	3.415	0.11
50	1.987	14.375	3.37	0.135
60	2.062	14.25	3.34	0.154
75	1.875	14.062	3.29	0.18
90	1.987	13.876	3.25	0.205
105	2.10	13.876	3.18	0.245
120	1.875	13.876	3.14	0.265
150	2.368	13.876	3.085	0.30
180	2.426	13.876	3.00	0.35
210	2.432	13.876	2.941	0.385
240	2.39	13.876	2.879	0.42
	4.75	0	0.5	-

Figure 25. Run No. 1 Cobalt - Scrubbing
Variation of C_{org} and C_{aq} With Time

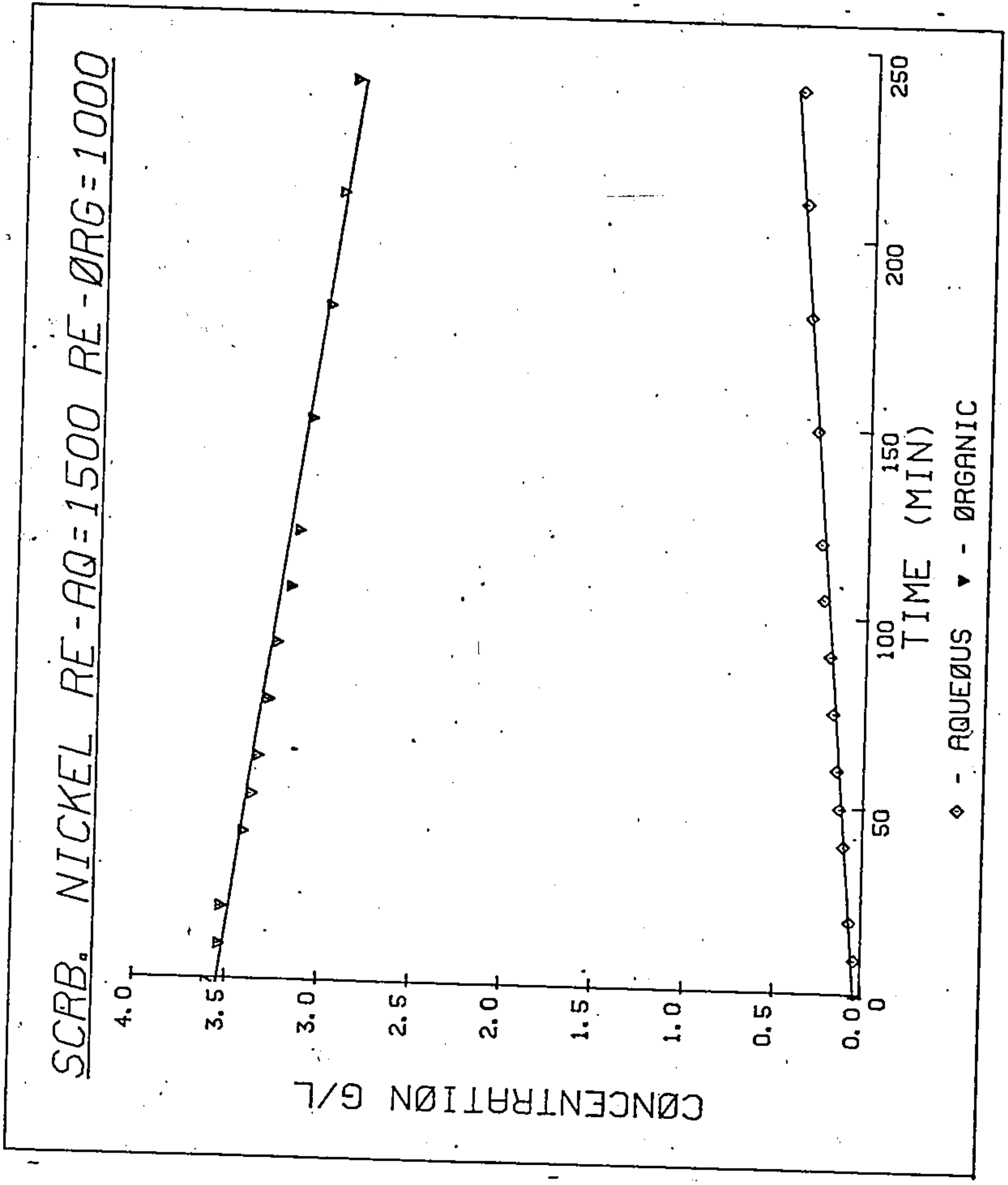


$C_{org} = 1.8187 + 0.0027309\ t$

$C_{aq} = 14.502 - 0.0035945\ t$

Figure 26. Run No. 1 Nickel - Scrubbing

Variation of C_{org} and C_{aq} With Time



$$C_{org} = 3.5932 - 0.0045065\ t + 6.561\ \mathrm{E}{-6}\ t^2$$

$$C_{aq} = 0.01339 + 0.0024976\ t - 3.4332\ \mathrm{E}{-6}\ t^2$$

Table 37

SCRUBBING

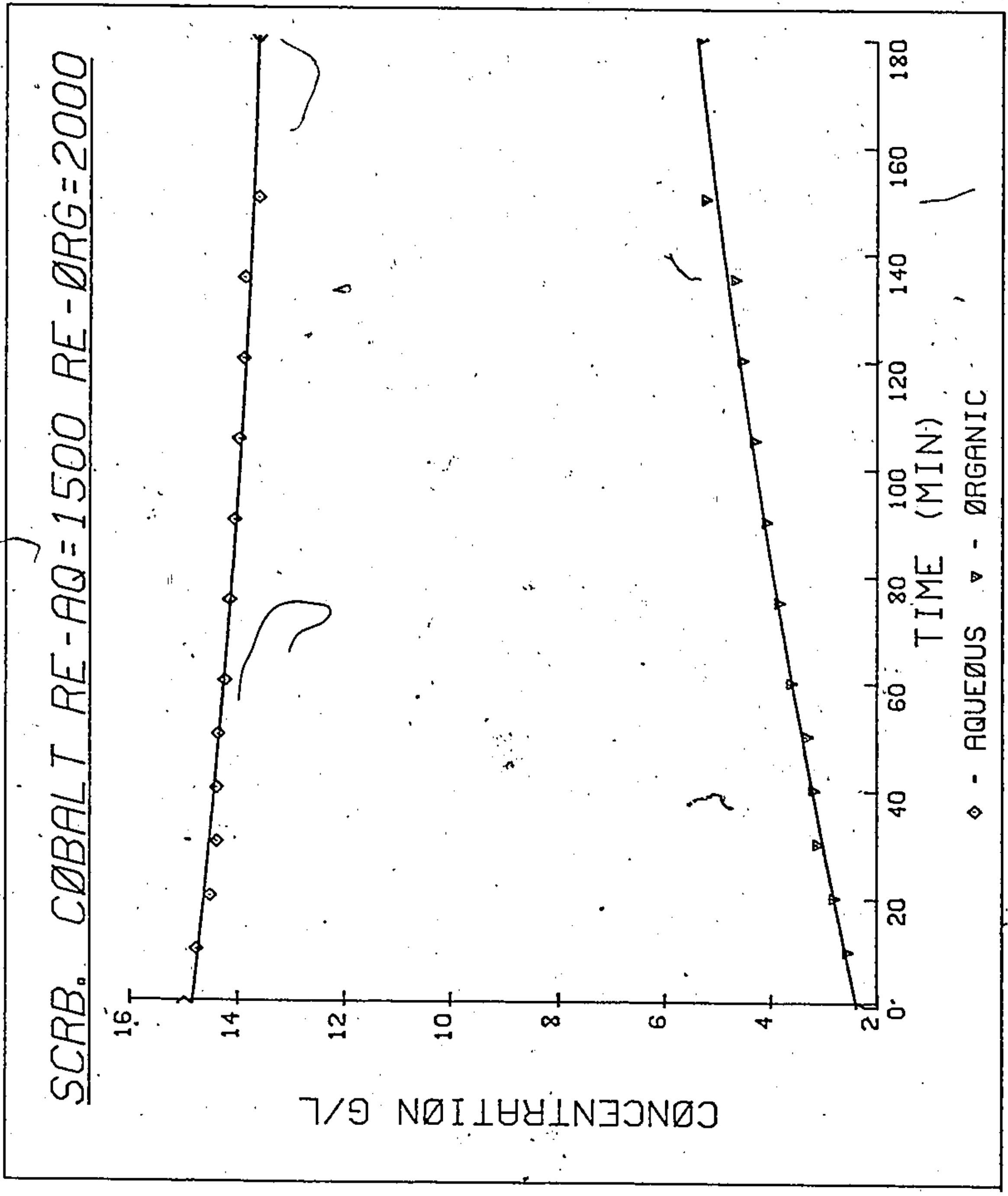
Run #2

N_{Re} Org = 1000
N_{Re} Aqu = 1500

	Cobalt		Nickel	
Time (min.)	Organic Conc. g/l	Aqueous Conc. g/l	Organic Conc. g/l	Aqueous Conc. g/l
0	2.350	15.000	4.475	0
10	2.60	14.770	4.441	0.075
20	2.850	14.517	-	-
30	3.150	14.390	4.138	0.229
40	3.225	14.390	4.087	0.322
50	3.350	14.360	3.923	0.376
60	3.650	14.24	3.846	0.469
75	3.88	14.15	3.577	0.609
90	4.118	14.062	3.400	0.690
105	4.355	13.977	3.267	0.787
120	4.588	13.890	3.067	0.878
135	4.705	13.868	2.967	0.970
150	5.26	13.611	2.830	1.167
180	5.35	13.605	2.610	1.323

Figure 27. Run No. 2 Cobalt - Scrubbing

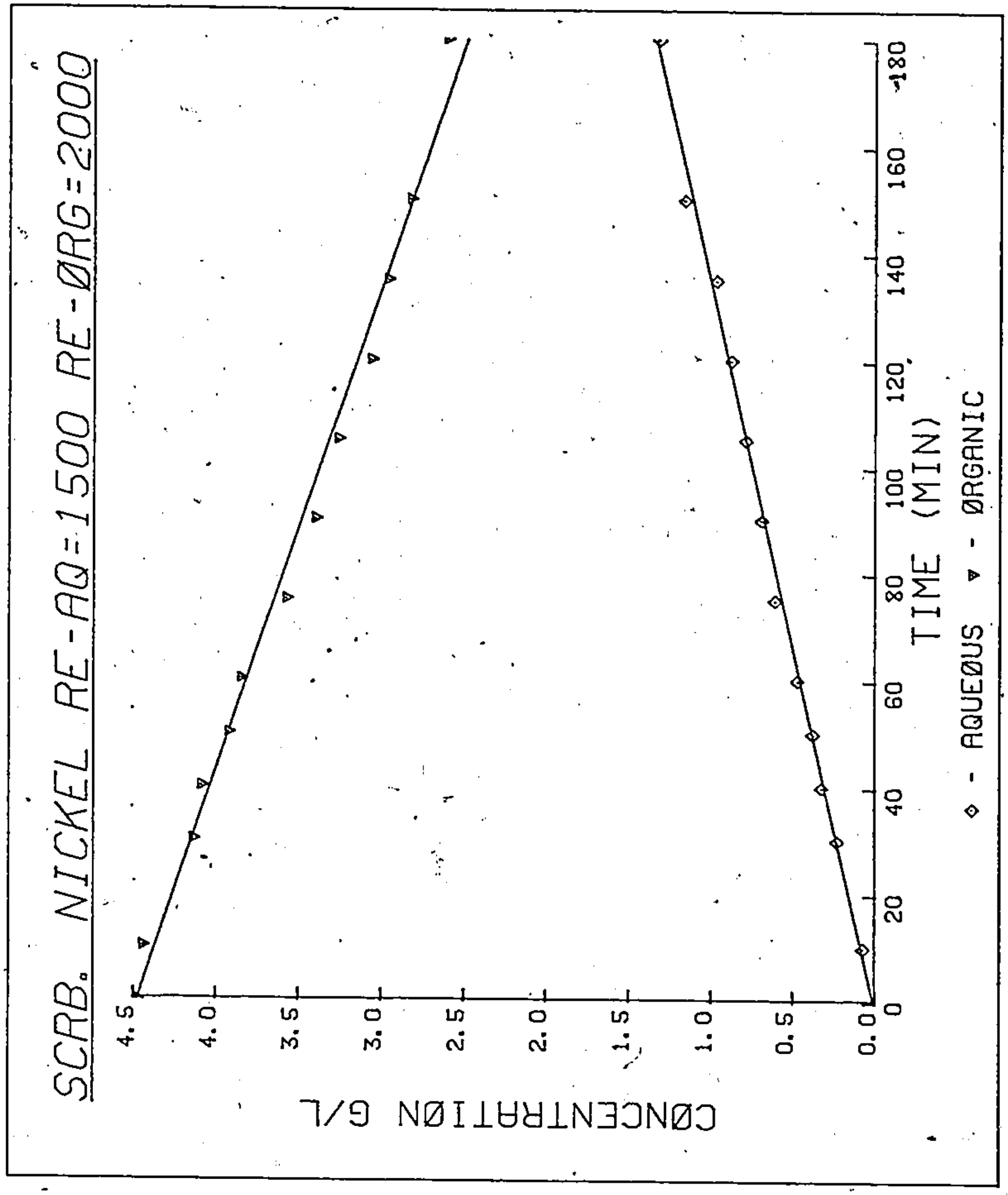
Variation of C_{org} and C_{aq} With Time



$$C_{org} = 2.3987 + 0.021949\ t - 2.9047\ \text{E-5}\ t^2$$

$$C_{aq} = 14.849 - 0.0014443\ t + 0.25786\ \text{E-5}\ t^2$$

Figure 28. Run No. 2. Nickel - Scrubbing
Variation of C_{org} and C_{aq} With Time



$$C_{org} = 4.5486 - 0.013775\ t - 1.5637\ \text{E-5}\ t^2$$

$$C_{aq} = 0.0015715 + 0.0078556\ t - 2.7654\ \text{E-5}\ t^2$$

Table 38

SCRUBBING

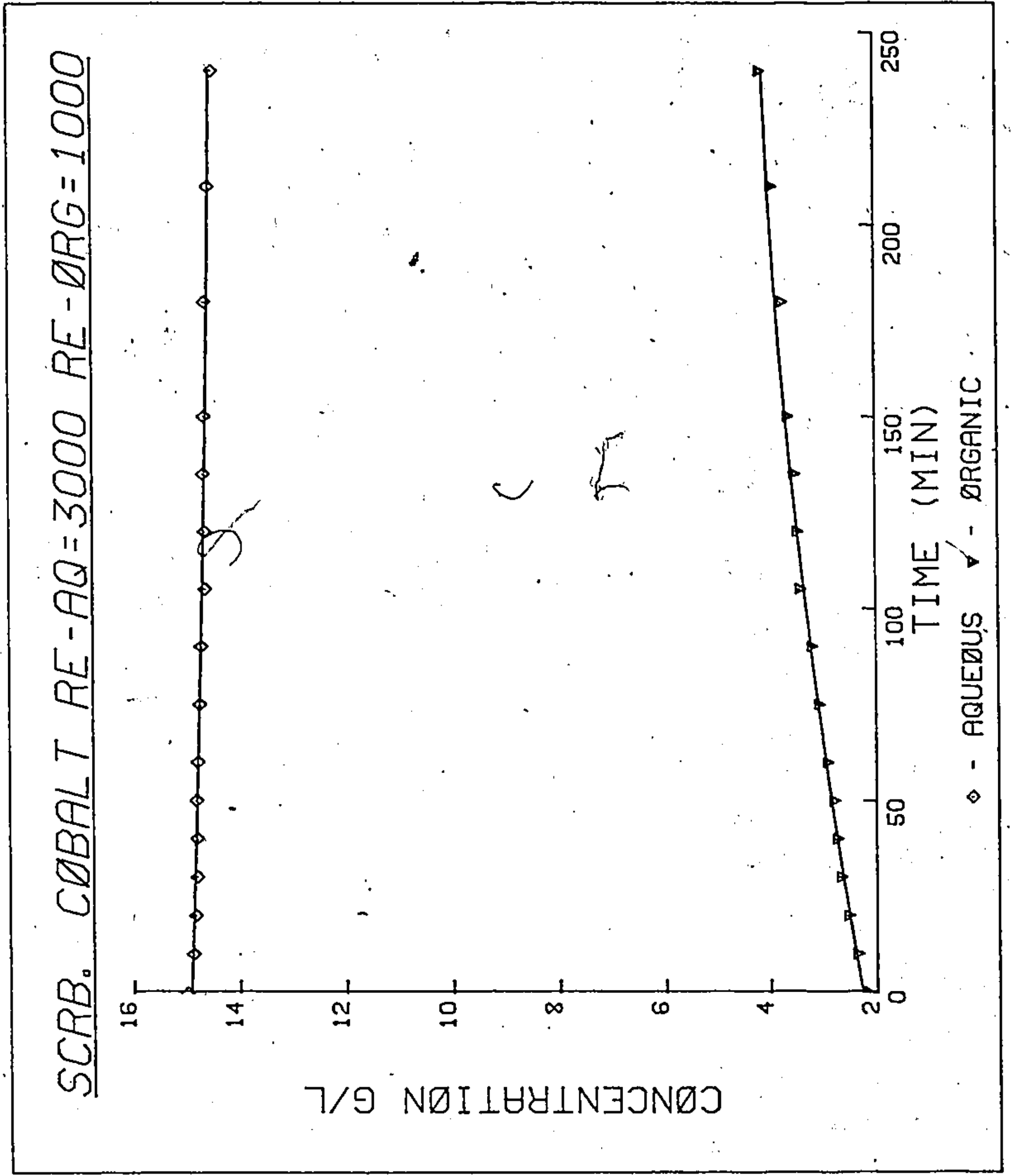
Run #3

N_{Re} Org = 1000
N_{Re} Aqu = 3000

Time (min.)	Cobalt Organic Conc. g/l	 Queous Conc. g/l	Nickel Organic Conc. g/l	 Aqueous Conc. g/l
0	2.186	15.00	4.246	0
10	2.346	14.88	4.041	0.073
20	2.559	14.83	4.00	0.154
30	2.687	14.80	3.885	0.223
40	2.759	14.80	3.770	0.301
50	2.823	14.81	3.616	0.352
60	2.941	14.78	3.577	0.412
75	3.098	14.74	3.45	0.501
90	3.233	14.71	3.313	0.577
105	3.449	14.63	3.215	0.643
120	3.500	14.64	3.075	0.715
135	3.551	14.66	2.95	0.806
150	3.664	14.64	2.925	0.848
180	3.766	14.63	2.65	0.959
210	3.963	14.56	2.425	1.084
240	4.188	14.48	2.15	1.175

Figure 29. Run No. 3 Cobalt - Scrubbing

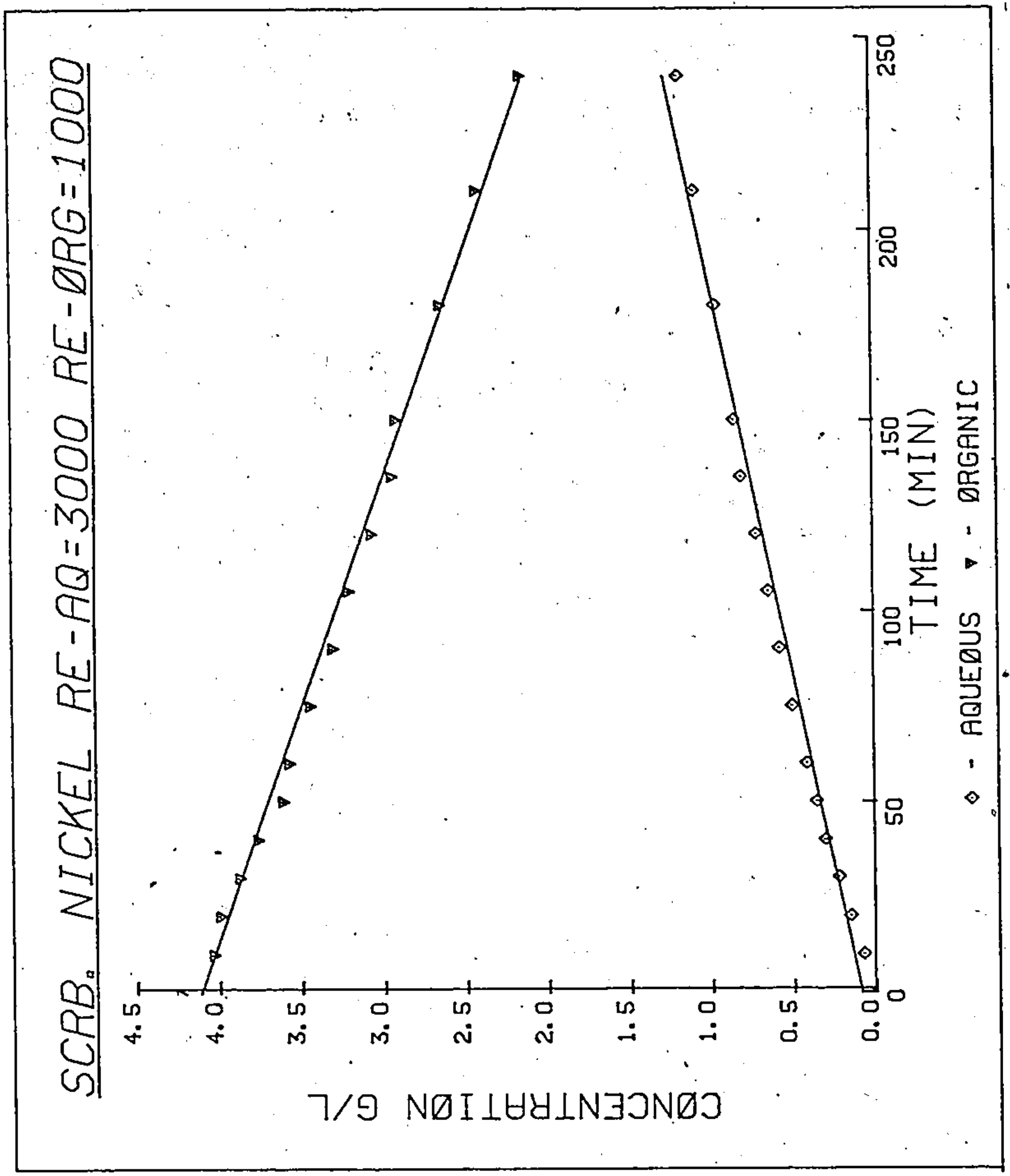
Variation of C_{org} and C'_{aq} With Time



$$C_{org} = 2.2775 + 0.012359\ t - 1.97733\ \text{E-5}\ t^2$$

$$C'_{aq} = 14.919 - 0.002701\ t + 4.4171\ \text{E-5}\ t^2$$

Figure 30. Run No. 3 Nickel - Scrubbing
Variation of C_{org} and C_{aq} With Time



$C_{org} = 4.1708 - 0.0099556\ t + 7.3405\ \text{E-6}\ t^2$

$C_{aq} = 0.015425 + 0.0070498\ t - 9.8433\ \text{E-6}\ t^2$

Table 39

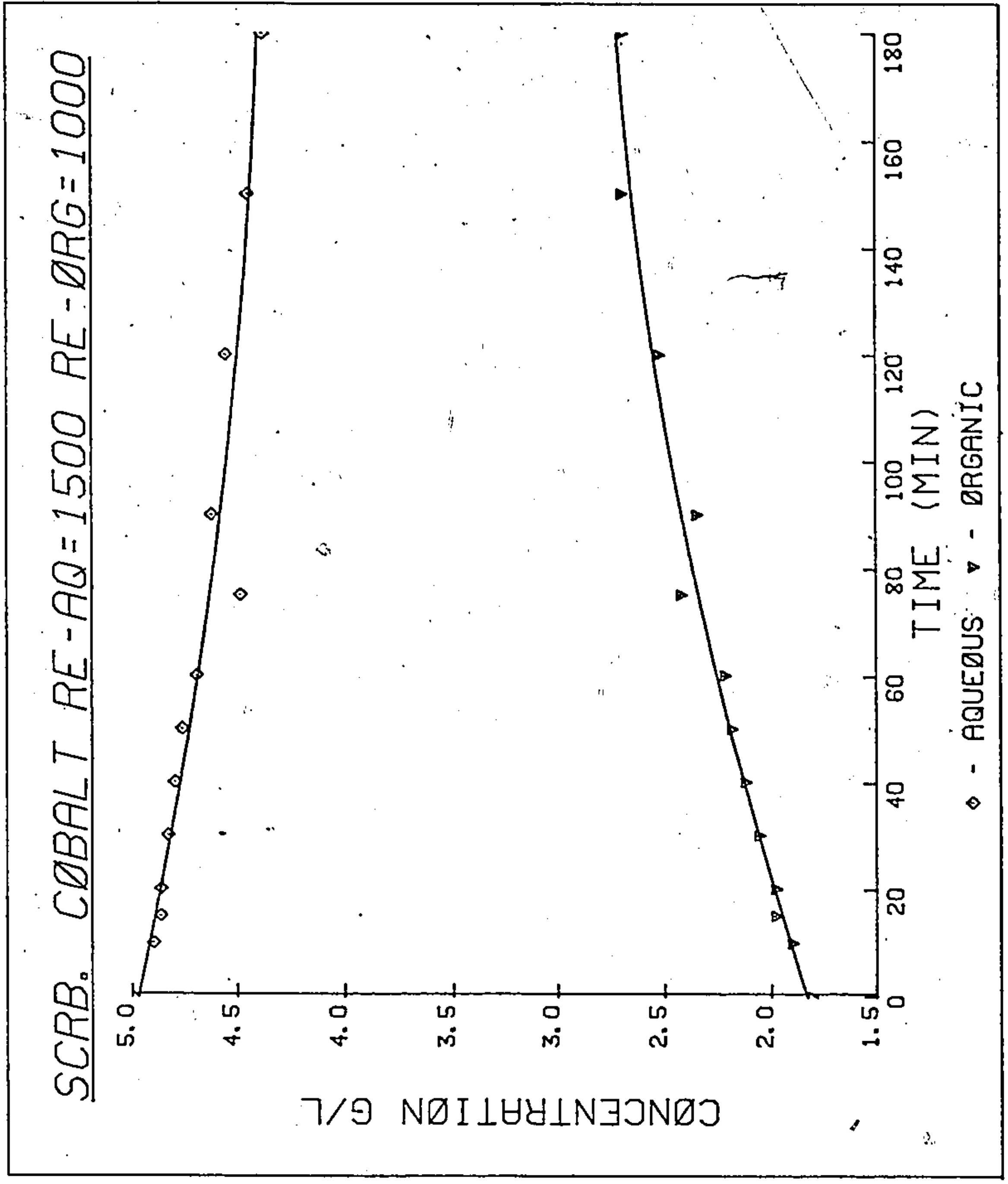
SCRUBBING

Run #4

N_{Re} Org = 1000
N_{Re} Aqu = 1500

Time (min.)	Cobalt Organic Conc. g/l	Cobalt Aqueous Conc. g/l	Nickel Organic Conc. g/l	Nickel Aqueous Conc. g/l
0	1.813	5.0	3.85	0
5	-	4.826	-	-
10	1.906	4.897	3.85	0.022
15	1.986	4.862	3.88	0.022
20	1.984	4.862	3.88	0.025
30	2.063	4.827	3.91	0.037
40	2.125	4.793	3.91	0.07
50	2.187	4.759	3.88	0.111
60	2.219	4.69	3.85	0.15
75	2.425	4.483	4.00	0.22
90	2.350	4.621	3.636	0.26
120	2.525	4.552	3.53	0.33
150	2.700	4.448	3.45	0.47
180	2.700	4.379	3.21	0.52
	4.90	3.2	-	1.41

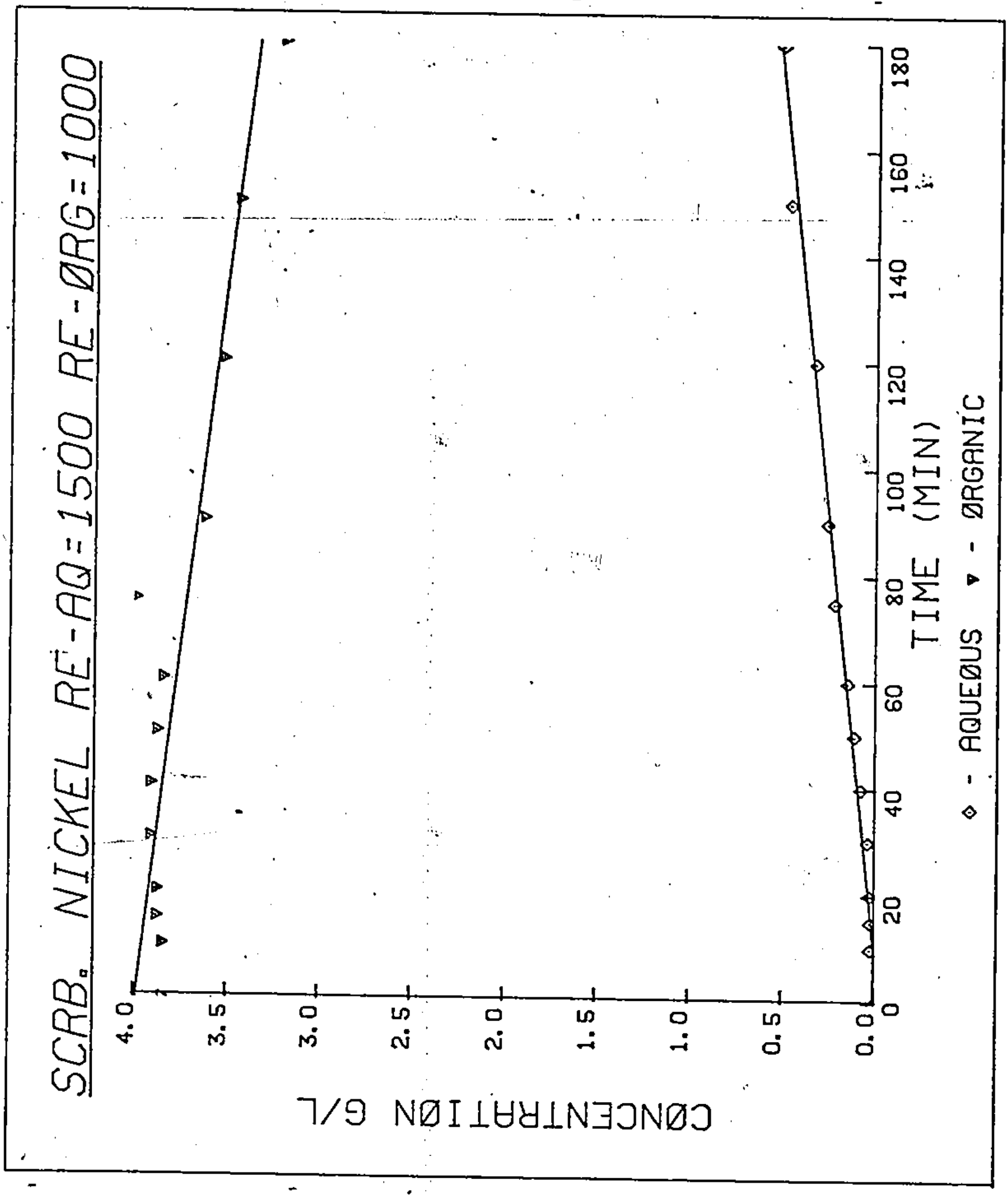
Figure 31. Run No. 4 Cobalt - Scrubbing. Variation of C_{org} and C_{aq} With Time



$$C_{org} = 1.8318 + 0.0080726\,t - 1.7473\ \mathrm{E}{-5}\ t^2$$

$$C_{aq.} = 4.9695 - 0.0055456\,t + 1.3289\ \mathrm{E}{-5}\ t^2$$

Figure 32. Run No. 4 Nickel - Scrubbing
Variation of C_{org} and C_{aq} With Time



$C_{org} = 3.8696 + 0.00151\ t - 2.9597\ \text{E-5}\ t^2$

$C_{aq} = 0.021946 + 0.008214\ t + 1.6498\ \text{E-6}\ t^2$

Table 40

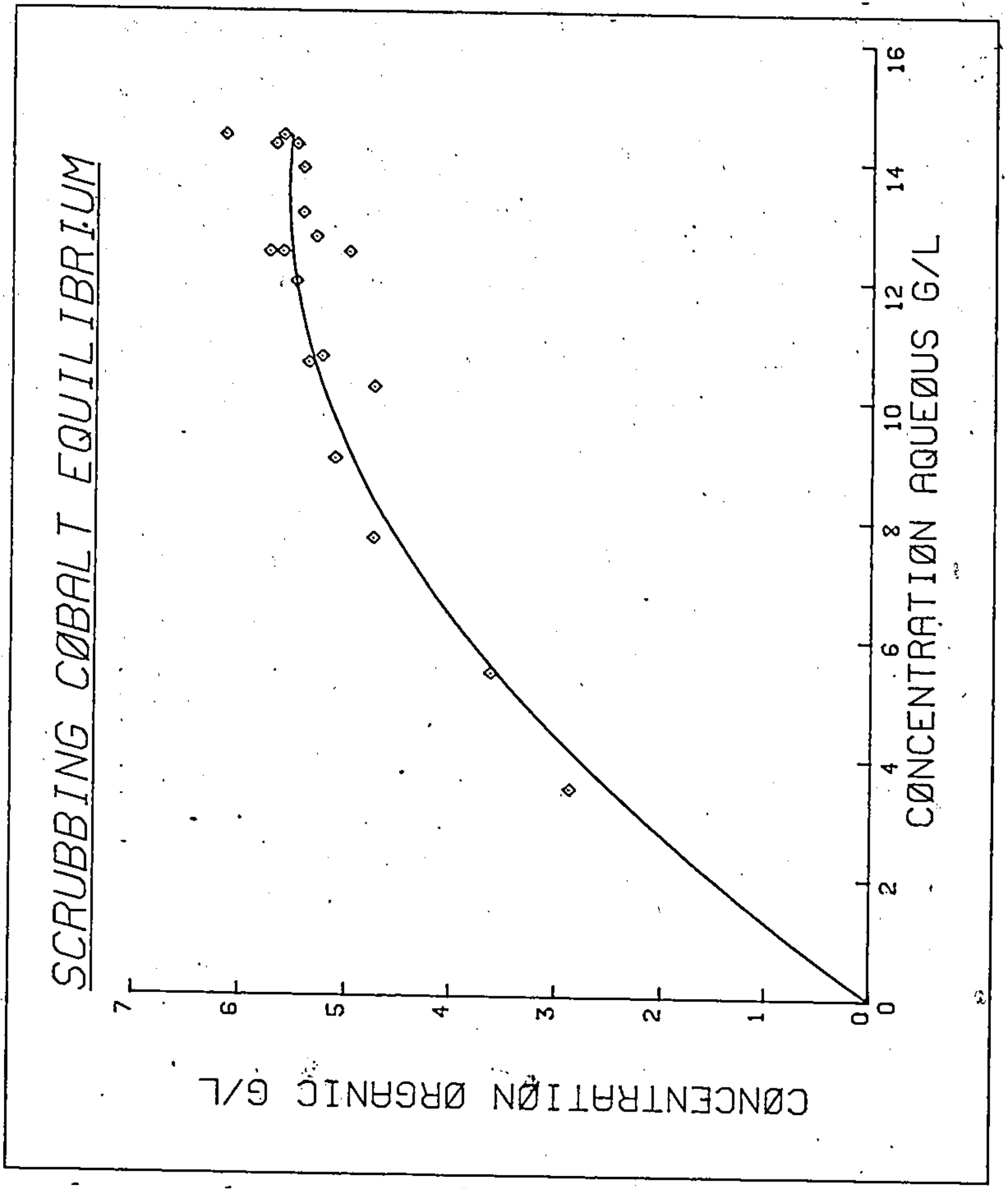
SCRUBBING

Equilibrium Isotherm

	Cobalt		Nickel	
Aq/Org Volume Ratio	Aqueous Conc. g/l	Organic Conc. g/l	Aqueous Conc. g/l	Organic Conc. g/l
0.10	3.47	2.875	7.315	3.2163
0.20			7.17	2.4735
0.25	5.40	3.625	6.6	2.141
0.50	7.66	4.75	5.4	1.196
0.75	9.00	5.125	3.95	0.818
1.00	10.20	4.75	3.3	0.631
1.10	10.70	5.25	3.125	0.494
1.50	10.60	5.375	2.394	0.341
1.75	11.95	5.5	2.025	0.387
2.00	12.45	5.75	1.806	0.319
2.25	12.45	5.00	1.644	0.233
2.50	12.45	5.625	1.5	0.181
2.75	12.70	5.312	1.363	0.184
3.25	13.10	5.437	1.15	0.1935
3.75	13.85		1.00	0.181
4.50	13.85		0.85	0.106
5.00	13.85	5.437	0.773	0.069
7.00	14.25	5.5	0.562	0.000
9.00	14.25	3.687	0.437	0.000
11.00	14.25	5.5	0.357	0.000
14.00			0.281	0.000
18.00	14.4	6.17	0.218	0.000
22.00	14.4	5.625	0.179	0.000

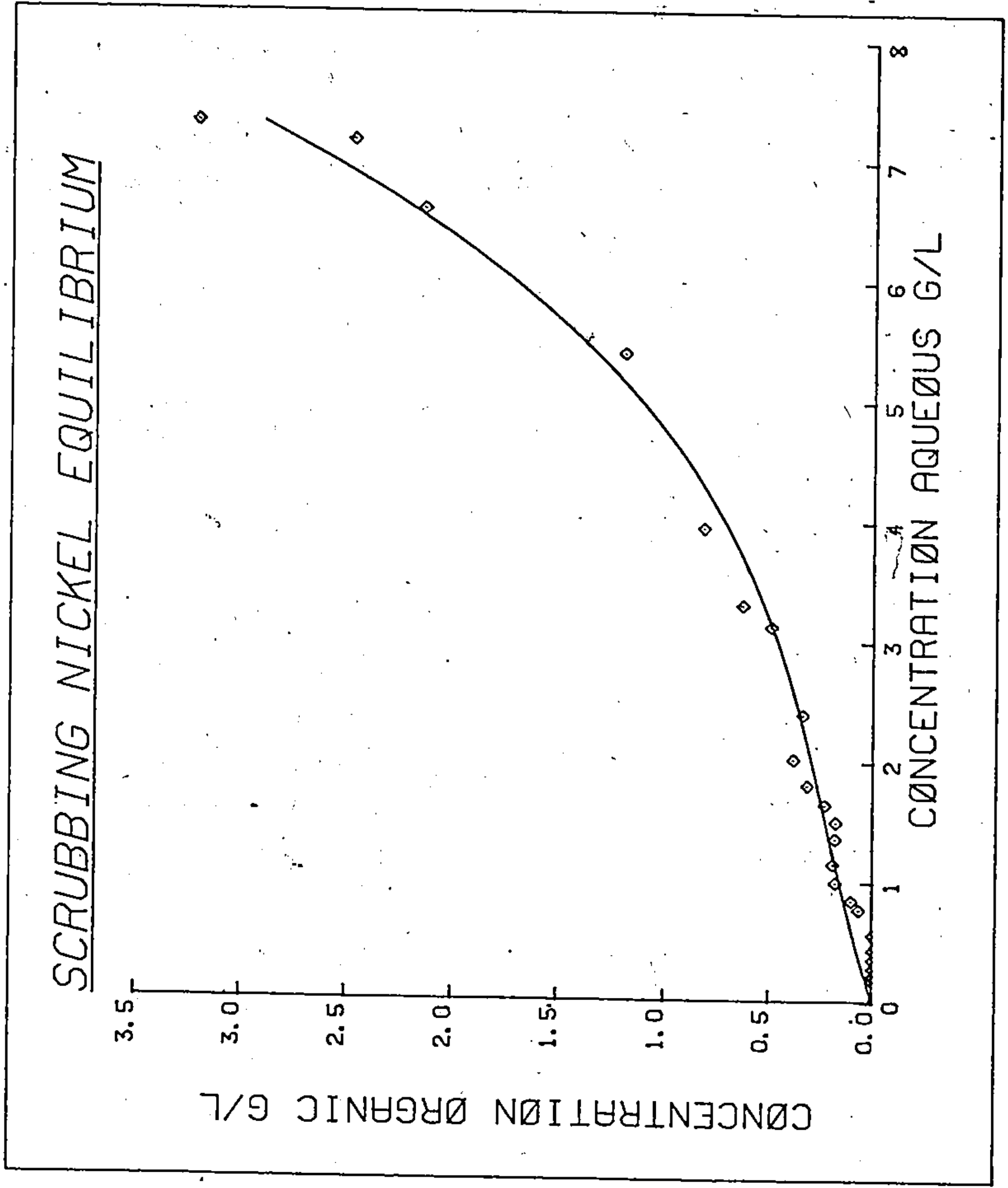
Initial Conc. Aq Cobalt = 14.75 g/l Aq Nickel = 0.000 g/l
Initial Conc. Org Cobalt = 1.745 g/l Org Nickel = 3.931 g/l

Figure 33. Cobalt - Scrubbing
Apparent Equilibrium Isotherm



$$C_{org} = 0 + 0.82572\ C_{aq} - 0.030573\ (C_{aq})^2$$

Figure 34. Nickel - Scrubbing
Apparent Equilibrium Isotherm



$$C_{org} = 0.00 + 0.019752\ C_{aq} - 0.042831\ (C_{aq})^2 - 0.009576\ (C_{aq})^3$$

Table 41

STRIPPING

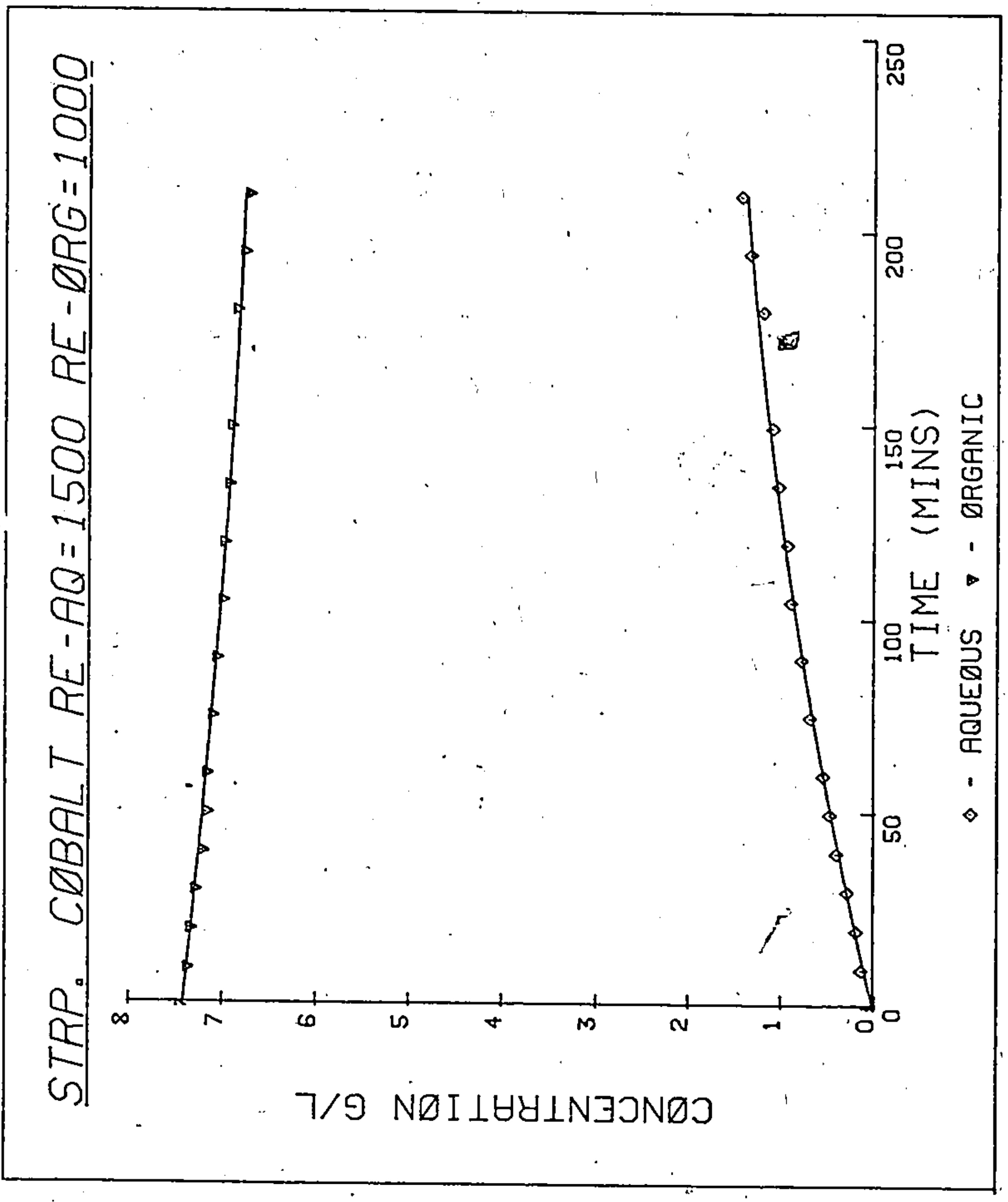
Run #1

N_{Re} Org = 1000
N_{Re} Aqu = 1500

Time (min.)	Cobalt Organic Conc. g/l	 Aqueous Conc. g/l	Nickel Organic Conc. g/l	 Aqueous Conc. g/l
0	7.45	0.000	0.3833	0.00000
10	7.373	0.125	0.3781	0.00825
20	7.336	0.182	0.3757	0.01211
30	7.284	0.276	0.3729	0.01653
40	7.205	0.392	0.3692	0.02240
50	7.161	0.463	0.3685	0.02352
60	7.159	0.535	0.3635	0.02352
75	7.100	0.677	0.3590	0.03843
90	7.055	0.769	0.3556	0.04413
105	6.994	0.884	0.3508	0.05186
120	6.982	0.922	0.3536	0.0474
135	6931	1.023	0.3458	0.05996
150	6.903	1.085	0.3480	0.05638
180	6.848	1.187	0.3465	0.05880
195	6.771	1.330	0.3450	0.06123
210	6.722	1.424	0.3438	0.06300

Figure 35. Run No. 1 Cobalt - Stripping

Variation of C_{org} and C_{aq} With Time

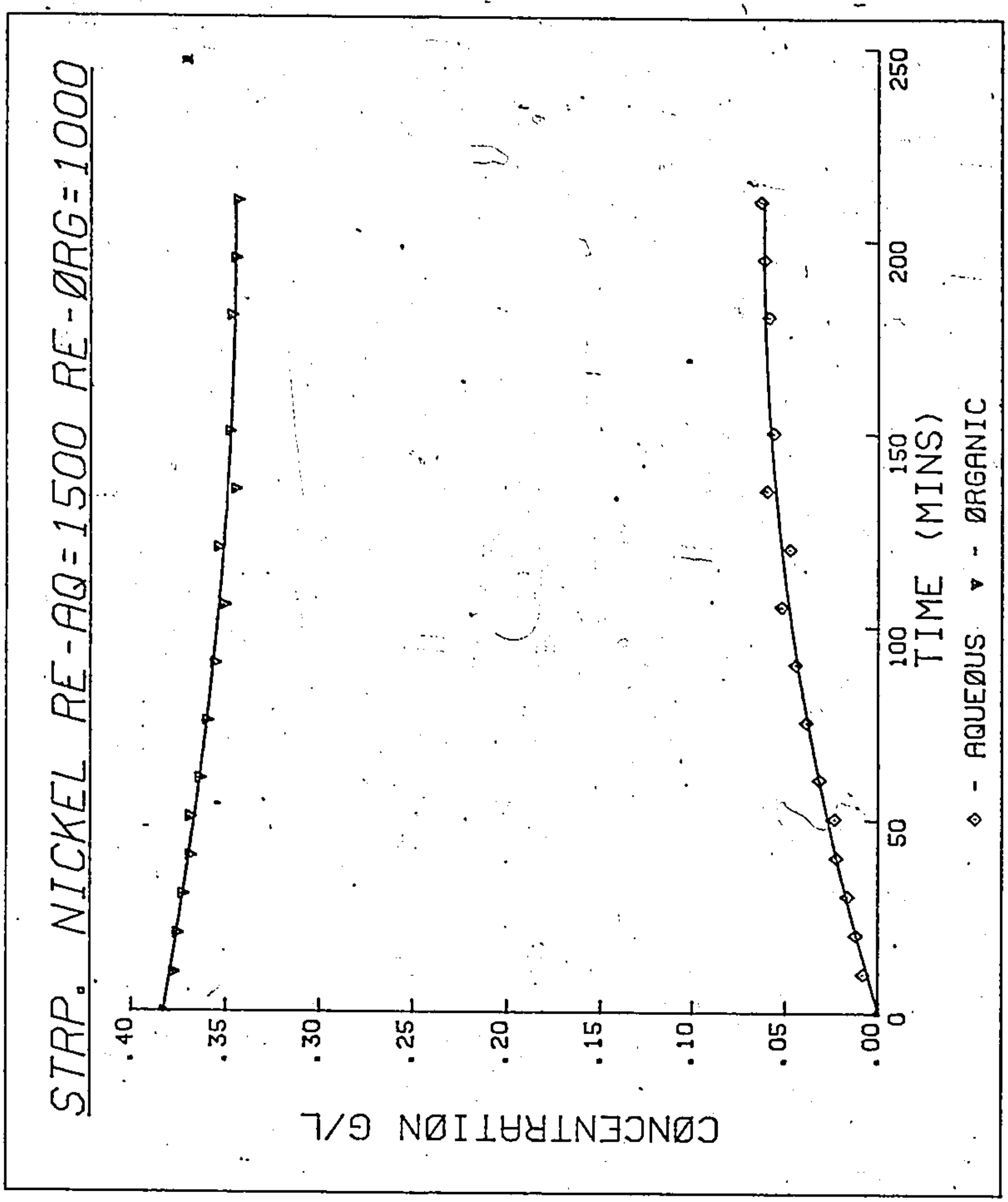


$$C_{org} = 7.41613 - 0.004669\ t + 7.2698\ E\text{-}6\ t^2$$

$$C_{aq} = 0.00 + 0.00979\ t - 1.56017\ E\text{-}5\ t^2$$

Figure 36. Run No. 1 Nickel - Stripping

Variation of C_{org} and C_{aq} With Time



$$C_{org} = 0.38308 - 0.00038209\ t + 9.4323\ \text{E-7}\ t^2$$

$$C_{aq} = 0.0 + 0.00062099\ t - 1.563\ \text{E-6}\ t^2$$

Table 42

STRIPPING

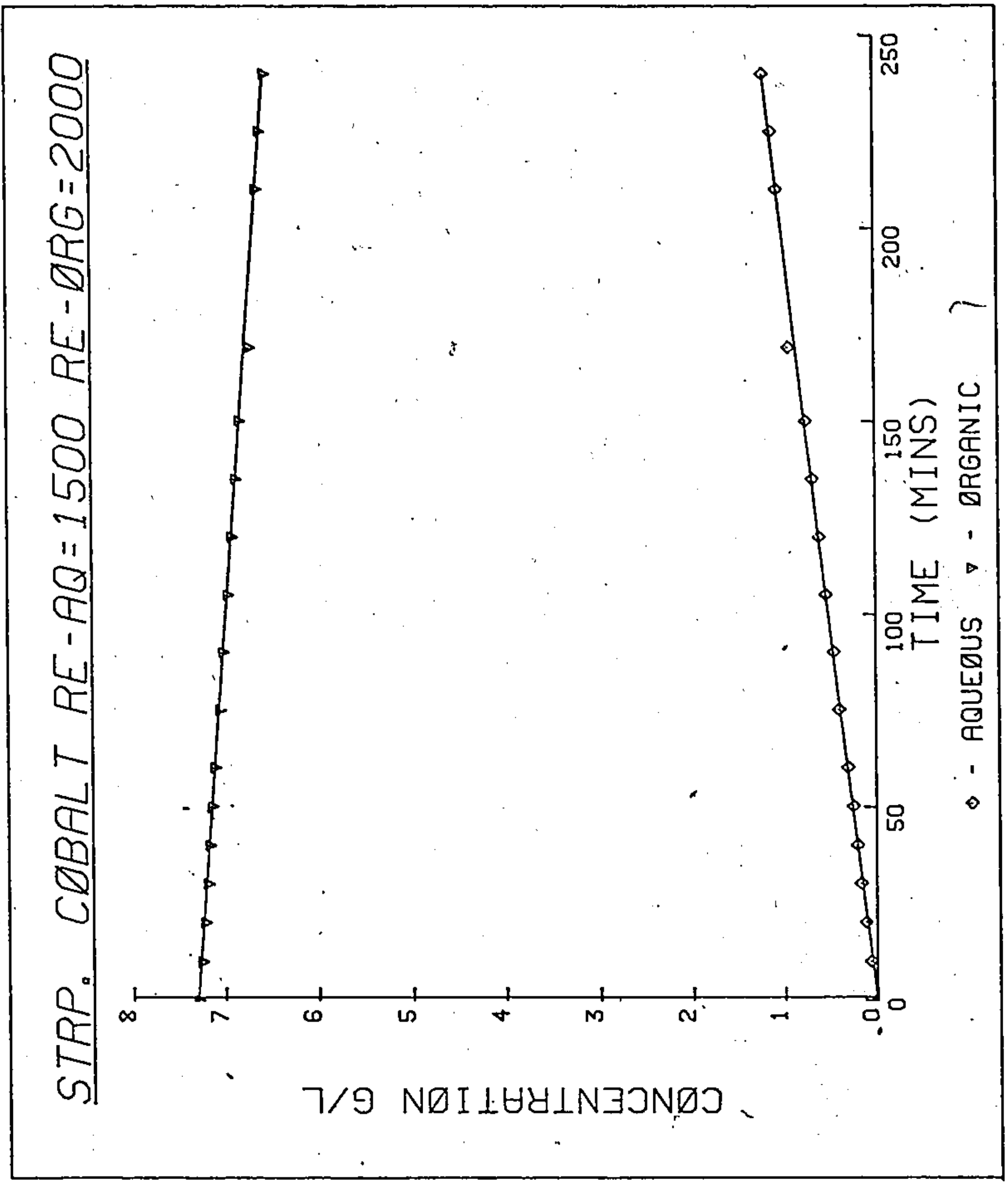
Run #2

N_{Re} Org = 2000
N_{Re} Aqu = 1500

Time (min.)	Cobalt Organic Conc. g/l	 Aqueous Conc. g/l	Nickel Organic Conc. g/l	 Aqueous Conc. g/l
0	7.303	0.000	0.4660	0.00000
10	7.262	0.065	0.4621	0.00623
20	7.229	0.119	0.4599	0.00979
30	7.198	0.168	0.4574	0.01370
40	7.174	0.206	0.4565	0.01513
50	7.146	0.250	0.4543	0.01869
60	7.113	0.304	0.4520	0.02242
75	7.054	0.398	0.4488	0.02758
90	7.020	0.452	0.4465	0.03114
105	6.968	0.534	0.4433	0.03630
120	6.923	0.608	0.4404	0.04093
135	6.878	0.680	0.4374	0.04573
150	6.834	0.750	0.4354	0.04894
169	6.720	0.933	0.4259	0.06406
210	6.644	1.054	0.4222	0.06993
225	6.608	1.112	0.4189	0.07527
240	6.553	1.199	0.4156	0.08061

Figure 37. Run No. 2 Cobalt - Stripping

Variation of C_{org} and C_{aq} With Time

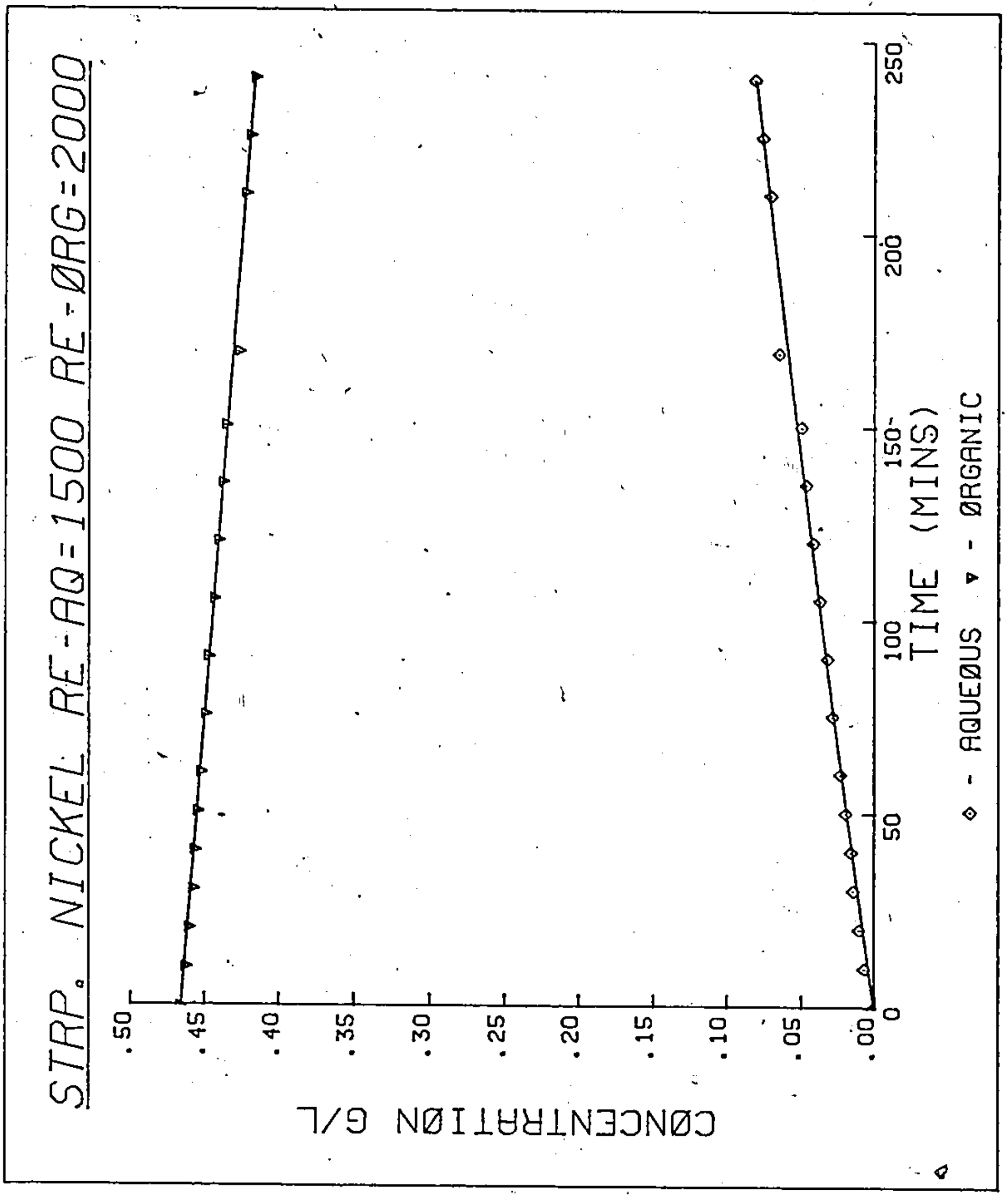


$C_{org} = 7.3005 - 0.0032636\ t + 5.9788\ \mathrm{E{-}7}\ t^2$

$C_{aq} = 0 + 0.0052859\ t - 1.172\ \mathrm{E{-}6}\ t^2$

Figure 38. Run No. 2 Nickel - Stripping

Variation of C_{org} and C_{aq} With Time



$C_{org} = 0.46469 - 0.00021412\ t + 4.285\ E\text{-}8\ t^2$

$C_{aq} = 0.0 + 0.00037228\ t - 1.618\ E\text{-}7\ t^2$

Table 43

STRIPPING

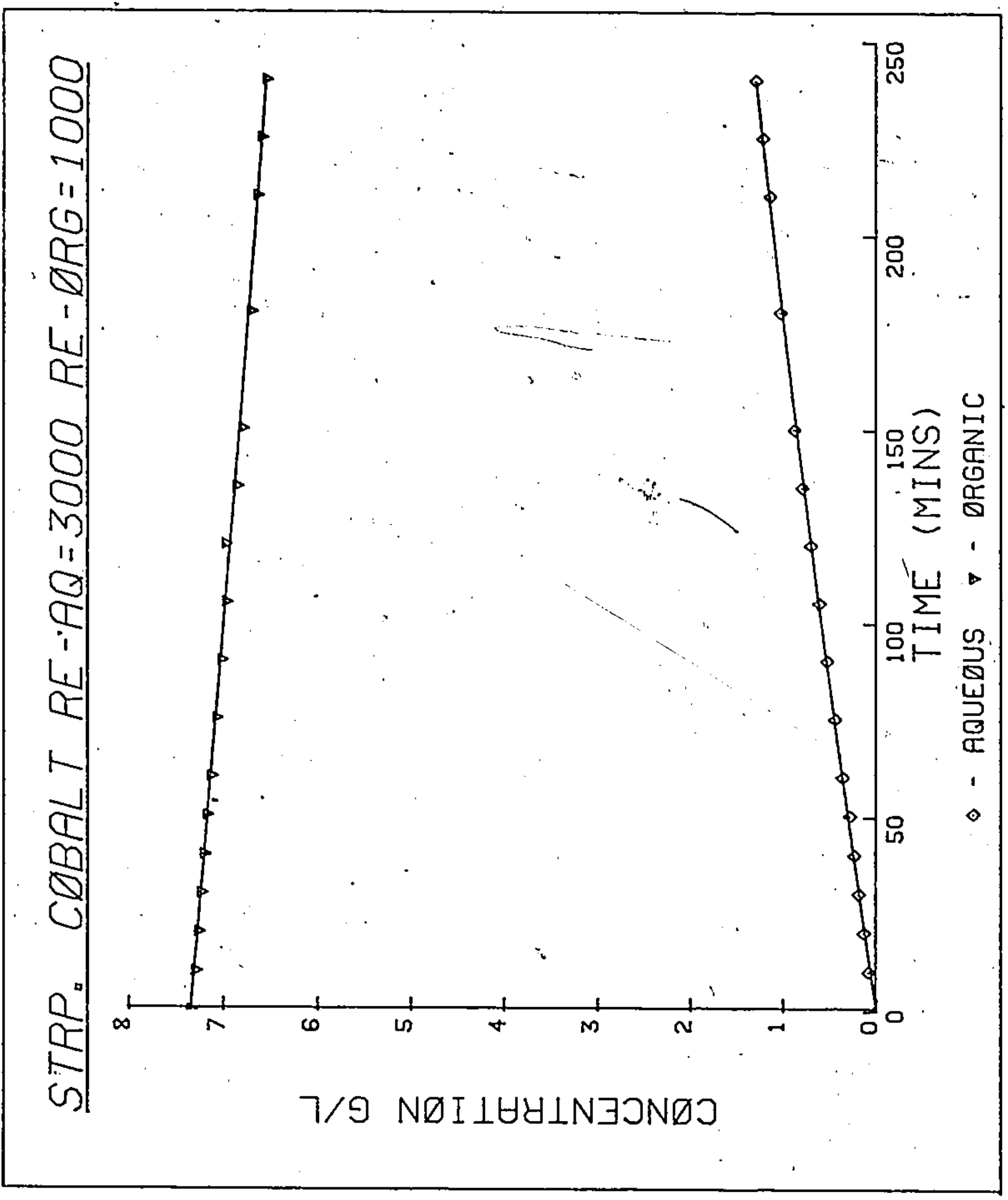
Run #3

N_{Re} Org = 1000

N_{Re} Aqu = 3000

	Cobalt		Nickel	
Time (min.)	Organic Conc. g/l	Aqueous Conc. g/l	Organic Conc. g/l	Aqueous Conc. g/l
0	7.355	0.000	0.3970	0.00000
10	7.303	0.083	0.3951	0.00303
20	7.272	0.132	0.3940	0.00587
30	7.239	0.186	0.3922	0.00979
40	7.208	0.235	0.3898	0.01477
50	7.179	0.282	0.3895	0.01637
60	7.139	0.357	0.3881	0.01957
75	7.081	0.439	0.3858	0.02438
90	7.027	0.524	0.3837	0.02865
105	6.974	0.609	0.3808	0.03434
120	6.918	0.699	0.3781	0.03968
135	6.859	0.793	0.3758	0.04431
150	6.807	0.876	0.3735	0.04894
180	6.713	1.027	0.3684	0.05801
210	6.643	1.138	0.3643	0.06530
225	6.594	1.217	0.3629	0.06851
240	6.548	1.290	0.3605	0.07331

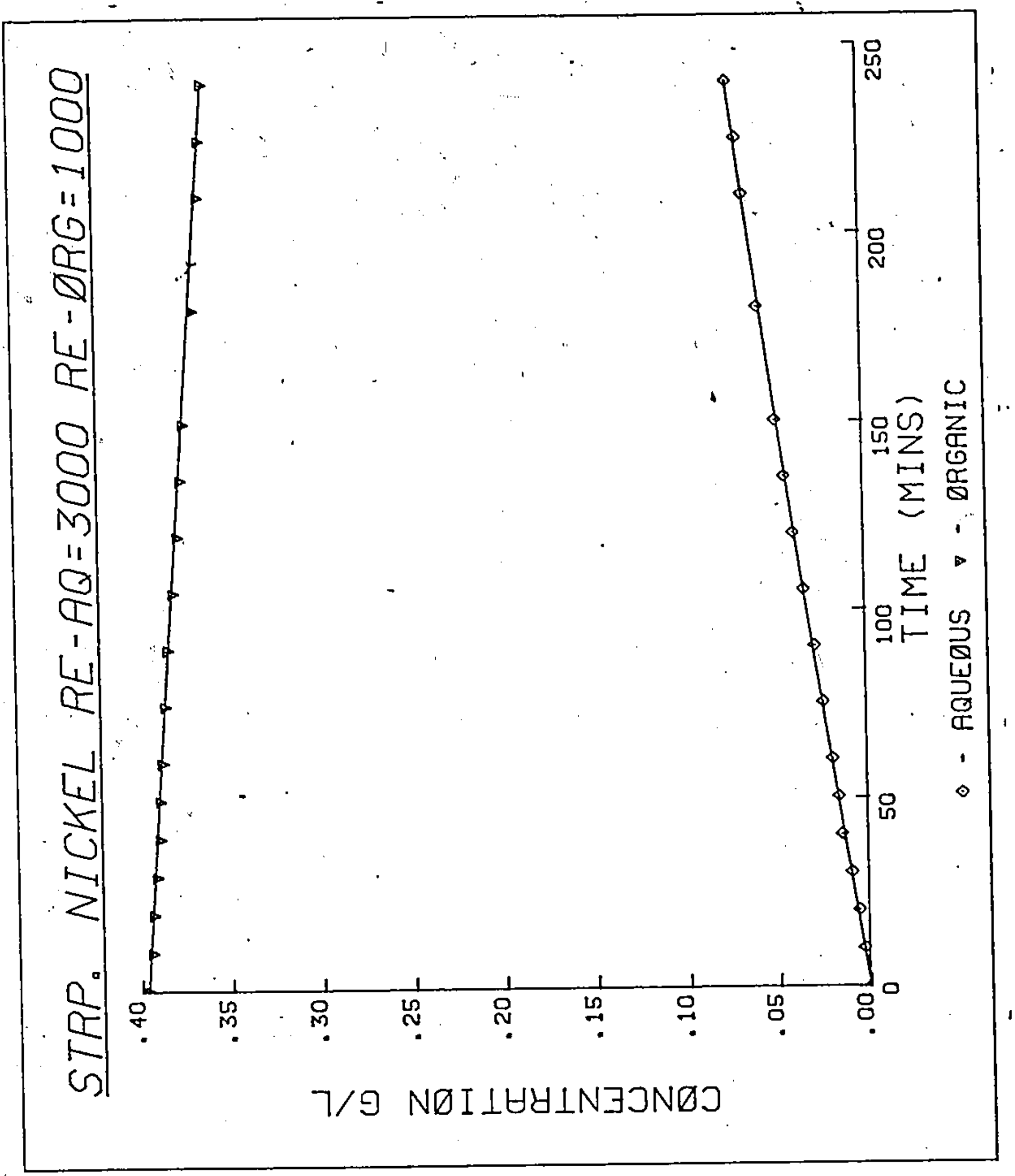
Figure 39. Run No. 3 Cobalt - Stripping
Variation of C_{org} and C_{aq} With Time



$C_{org} = 7.3499 - 0.0036759\ t + 1.3283\ E{-6}\ t^2$

$C_{aq} = 0. + 0.0062519\ t - 3.6259\ E{-6}\ t^2$

Figure 40. Run No. 3 Nickel - Stripping
Variation of C_{org} and C_{aq} With Time



$$C_{org} = 0.3969 - 0.00015594\ t + 1.2639\ E\text{-}8\ \ t^2$$

$$C_{aq} = 0 + 0.0003464\ t - 1.685\ \ E\text{-}7\ \ t^2$$

Table 44

STRIPPING

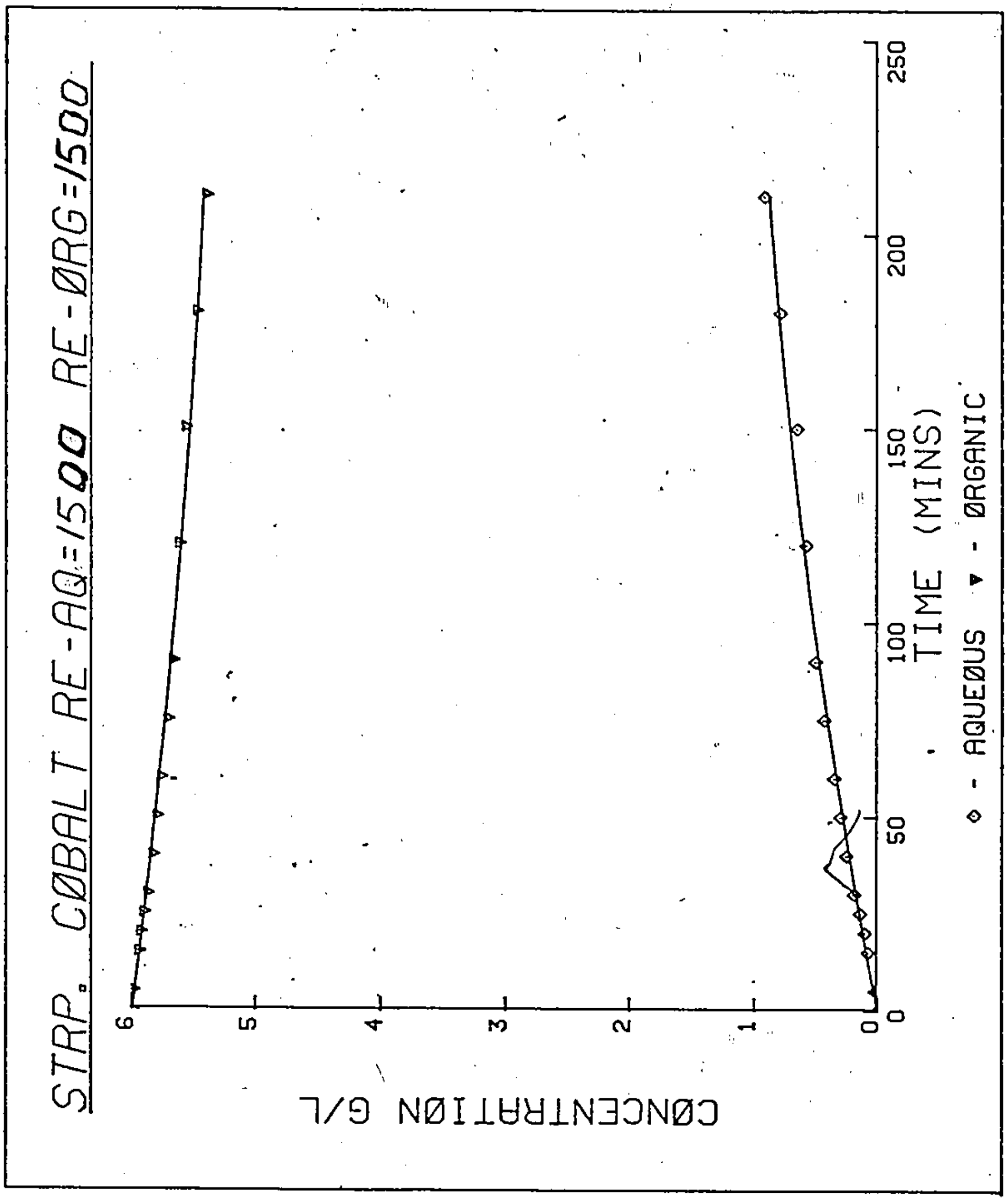
Run #4

N_{Re} Org = 1500
N_{Re} Aqu - 1500

	Cobalt	
Time (min.)	Organic Conc. g/l	Aqueous Conc. g/l
0	6.000	0.000
5	5.992	0.013
15	5.950	0.075
20	5.934	0.100
25	5.909	0.138
30	5.876	0.188
40	5.835	0.250
50	5.802	0.300
60	5.769	0.350
75	5.715	0.431
90	5.670	0.500
120	5.620	0.575
150	5.570	0.650
180	5.479	0.788
210	5.397	0.913

Figure 41. Run No. 4 Cobalt - Stripping

Variation of C_{org} and C_{aq} With Time



$C_{org} = 6.0001 - 0.004314\ t + 6.6009\ \mathrm{E}{-6}\ t^2$

$C_{aq} = 0 + 0.0061\ t - 9.1732\ \mathrm{E}{-6}\ t^2$

Table 45

STRIPPING

Equilibrium Isotherm

Aq/Org Volume Ratio	Aqueous Conc. g/l	Organic Conc. g/l	Aqueous Conc. g/l	Organic Conc. g/l
44.0	38.2655	6.146	8.668	0.292
40.0	43.887	5.918	8.74	0.270
36.0	50.964	5.6	8.29	0.258
30.0	47.42	5.435	8.115	0.218
24.0	48.424	4.998	7.692	0.168
20.0	49.473	4.542	6.69	0.154
18.0	54.570	3.984	6.567	0.124
16.0	53.327	3.683	6.104	0.107
14.0	54.637	3.113	5.705	0.081
12.0	54.401	2.482	5.154	0.059
10.0	55.40	1.476	4.635	0.025
8.0	54.053	0.215	3.876	0.004
6.0	42.07	0.004	2.907	0.004
4.0	28.047	0.004	1.938	0.004
2.0	14.0233	0.004	0.969	0.004
1.0	7.012	0.004	0.484	0.004
0.5	3.506	0.004	0.242	0.004
0.33	2.337	0.004	0.162	0.004
0.25	1.753	0.004	0.121	0.004
0.20	1.402	0.004	0.097	0.004
0.10	0.701	0.004	0.049	0.004

Initial Conc. Aq = 10% H_2S04

Initial Conc. Org Cobalt = 7.0157 g/l Org Nickel = 0.4885 g/l

Figure 42. Cobalt - Stripping
Apparent Equilibrium Isotherm

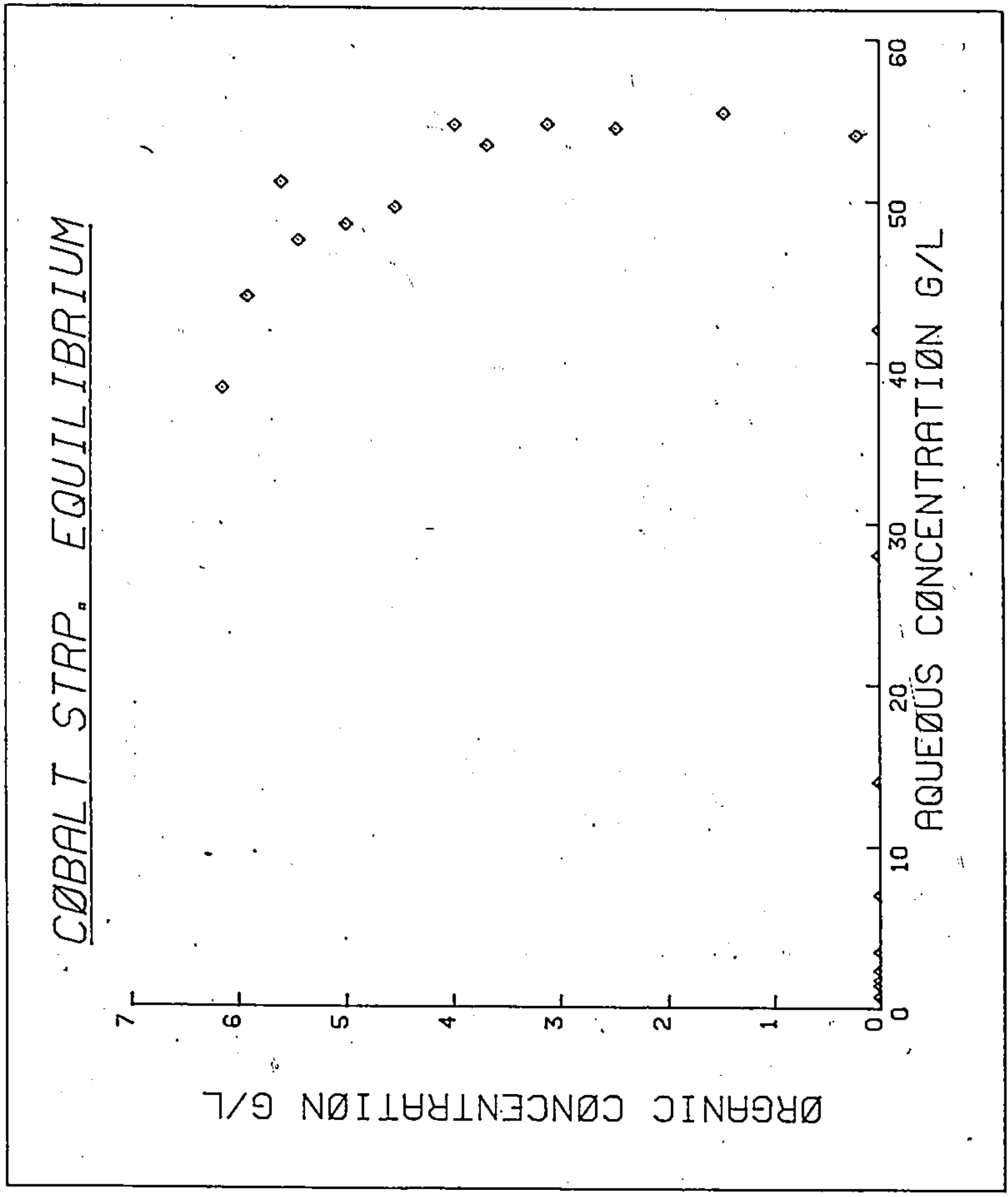
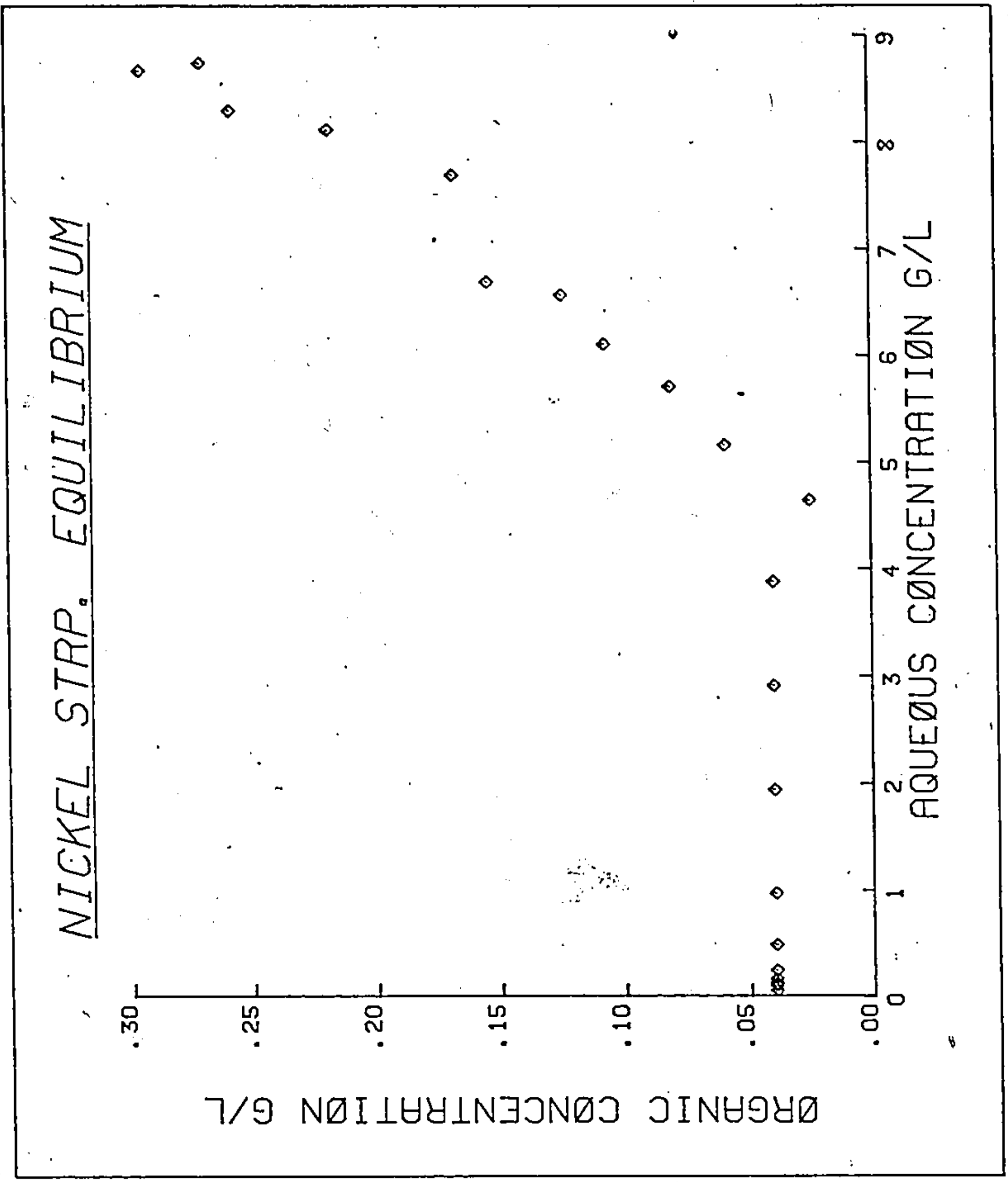


Figure 43. Nickel - Stripping
Apparent Equilibrium Isotherm



J APPENDIX III

OPERATING PROCEDURE OF
ATOMIC ABSORPTION SPECTROPHOTOMETRE
FOR ANALYSIS

PREPARATION OF UNIT

Care and Cleaning of Burner

The heart of an atomic absorption instrument is the flame. The air/acetylene burner had to be kept in spotless condition for high standard of analytical performance. The burner was cleaned after every large batch of samples and after every day of operation.

The burner head was easily disassembled for cleaning purposes. Inorganic deposits on the surface of the burner was removed by soaking (when cooled) in water. Layers of organic material and other stubborn deposits was removed with the aid of a fine emery paper. A razor blade or piece of stiff paper served to clean the burner slot.

Nebulization

The sampling system of the unit is of the nebulizer - cloud chamber - burner type. Briefly, the nebulizer, by a pneumatic action, reduces the sample solution to a spray of droplets of various diameters. The spray is directed into the cloud chamber where the larger droplets are precipitated, and the air stream carries the remaining spray into the burner and then to the flame. The fuel gas is introduced into the system at the cloud chamber stage, and the sample, air and fuel are thoroughly premixed before passing into the burner. To minimize analytical interference from sample to sample, the cloud chamber was washed continuously by aspirating distilled water between samples and thoroughly washed after each batch of analysis. The air flowrate and the acetylene rate used were respectively 5 L/min and 1 L/min for both cobalt and nickel aqueous analysis.

Types of Lamps Used

Single element hollow cathode lamps

Nickel:	Wavelength	232.0 mμ
	Maximum current	25 mA
Cobalt:	Wavelength	240.7 mμ
	Maximum current	25 mA

OPERATING PARAMETERS

Alignment and Focusing of Lamps

To achieve optimum analytical sensitivity, detection limit and stability of analytical response, it was necessary to focus the image of the hollow cathode onto the entrance slit of the monochromator and to align the lamp so that the maximum of resonance radiation falls on the photomultiplier detector. Alignment and focusing was carried out to obtain a full scale meter signal (i.e., zero absorbance) at the lowest gain setting possible. This ensured that the maximum amount of resonance radiation reaches the detector. Lamp alignment was rechecked after each batch of analysis as outlined in the machine's owners manual.

Lamp Current

Lamp current for cobalt was 15 mA and for nickel at 18 mA. These settings yielded optimum intensity of emission and analytical sensitivity for the analysis.

The Resonance Line Wavelength

The best range of quantitative A.A. analysis of any element is from 20-200 times the sensitivity (or about 50-500 times the detection limit) quoted in the technical manuals. In atomic absorption the term "sensitivity" is defined as that concentration of the element in ppm (or μg/mL) in solution which give a 1% absorption signal. Knowledge of the sensitivity figure is useful because from it the optimum concentration range of the element (i.e., giving optimum analytical precision) is computed. The most sensitive resonance line wavelength of cobalt is 240.7 n.m. and for nickel is 232.0 n.m. with an analytical sensitivity of 0.5. It follows that the optimum concentration range lies between 10 and 100 ppm.

Hence, the experimental samples containing high cobalt and nickel concentration would have had to be diluted by as much as a factor of 100. To avoid this, and to minimize the errors inherent in the dilution procedures, the less sensitive resonance lines of cobalt and nickel were used. The wave lengths of the less sensitive resonance lines are listed below.

Element	Wavelength nm	Sensitivity ppm	Concentration Range ppm	Calibration Graph Linearity
Cobalt	240.7	0.5	10-100	fair
	242.5	0.65	10-100	fair
	252.1	0.65	10-100	fair
	304.0	0.5	10-150	fair
	345.4	12	20-300	good
	352.7	14	50-1000	good
Nickel	232.	0.5	5-100	poor
	305.1	1.4	20-1000	good
	300.25	1.7	20-1000	good
	341.5	1.4	20-250	poor
	352.4	1.7	20-350	poor
	234.5	1.7	20-500	poor
	346.2	3	20-750	fair

Different wavelengths were utilized for the various experimental conditions studied, i.e., extraction, scrubbing and stripping.

Slitwidth Settings

The choice of optimum slitwidth settings was dependent on the type of lamp, the resonance line wavelength and the type of solution analysis done, i.e., aqueous solution samples or organic solution samples. Generally the slitwidth was kept as narrow as possible in order to achieve optimum analytical sensitivity. Settings varied from 0.15 mμ to 0.06 mm but no less than that depending on the smaple batch.

Burner Height and Acetylene Flowrate

Again, the analytical sensitivity was critically dependent on burner height setting and upon small changes in acetylene flow rate.

The two parameters were strongly interdependent. For aqueous analysis a setting of 1 cm burner height and a 0.7 cm burner height was used for organic analysis. The best analytical sensitivity, especially when doing the organic samples analysis, was found to be when the acetylene and air flowrates were decreased, while raising the burner towards the optical axis of the instrument.(i.e., decreasing the burner height setting as read from the mirror scale behind the burner).

Organic Samples Analysis

The kerosenes solvent that was used to dilute the samples contributed to the combustion process in the burner and it was usually necessary to reduce the acetylene flowrate to obtain the flame characteristics associated with aspiration of aqueous solutions. It was essential to set the baseline (i.e., zero absorbance signal) while the kerosene was sprayed and continuously sprayed after every sample solution. Also the syphon tube (at the rear of the instrument) was emptied of water and filled with kerosene. Failure to do this results in poor drainage of the condensed kerosene from the cloud chamber and consequent "popping" of the flame.

Calibration Graphs and Their Reproducibility

The nature of the burner flames was such that exact reproducibility of flame conditions from day to day was not possible simply by resetting the gas flow controls to their former positions. The implication was that a fresh calibration using standard solutions, was plotted every time a determination was to be carried out.