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Selective Separation of Lactic Acid and Glucose
II. Extraction by Alamine 336 in Various Diluents

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Selective Separation of Lactic Acid and Glucose

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ABSTRACT

Potentially selective recovery methods, such as extraction, are attractive for recovery of carboxylic acids from fermentation broths. In this work extraction of glucose and competitive extraction of lactic acid and glucose by Alamine 336 in various diluents have been investigated. The solvents used provide very high selectivity between lactic acid and glucose. The strong complexing ability of amine extractant for lactic acid and the high hydrophilicity of glucose are the main reasons. Coextraction of glucose is related to the amount of coextraction of water. The extent of water coextraction depends strongly the diluent used, and larger amounts of water coextracted correspond to larger uptake capacities of glucose. The performances of sorption and extraction for selective separation between lactic acid and glucose are compared.

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Introduction

Extraction processes based upon reversible chemical complexation can provide high capacities and high selectivities for separation of polar organics from water (King, 1987). In these extraction processes, a liquid-phase complexing agent (the extractant) brings the solute into the solvent phase by forming a complex with a functional group of the solute. Thus the distribution of solute into the solvent phase is substantially increased over conventional solvent extraction.

Long-chain, aliphatic amines such as Alamine 336 have strong Lewis basicity and are effective for separation of carboxylic acid from dilute aqueous solutions (Ricker et al, 1980; Kertes and King, 1986; Tamada et al, 1990; King, 1992).

An important factor affecting equilibrium characteristics for extraction of carboxylic acids is solution pH. Several researchers have examined the performances of amine extractants at values of pH typical of fermentation systems (Yabannavar and Wang, 1987, 1991; Yang et al, 1991; Tung and King, 1994). Tung and King (1994) investigated the effect of pH on extraction of lactic acid and succinic acid by Alamine 336 in different diluents, and demonstrated that Alamine 336 can provide substantial capacity even at moderately high values of pH in diluents that stabilize the acid-amine complex.

Glucose is present as the fermentation substrate in typical fermentation processes to produce carboxylic acids. A separation process for recovery of carboxylic acids from fermentation solutions should minimize simultaneous uptake of glucose. For example, the presence of small amounts of

glucose in recovered lactic acid can lead to discoloration, which is unacceptable for many of the uses of lactic acid.

Wennersten (1983) investigated extraction of citric acid from fermentation broths by Alamine 336 in different diluents, and observed the color of the extract phase and the phase separation rate. The results showed that the best selectivity and phase separation were obtained using a non-polar diluent such as n-hexane. Wang et al (1991) reported that the partition coefficient of glucose between an aqueous solution and trioctyl phosphine oxide (TOPO) in kerosene was found to be only 0.002, implying a high selectivity for carboxylic acids. To our knowledge, there are no previous in-depth studies on extraction equilibria of glucose and selectivity for carboxylic acids over glucose for extraction by Alamine 336.

The main object of the present work was to investigate the selectivity of extraction of lactic acid from dilute solutions containing lactic acid and glucose. Alamine 336 dissolved in various diluents was used as the solvent phase. Measurements of extraction equilibria for glucose alone were also carried out. Extraction selectivity experiments were performed over a range of pH values. The effects on the extraction due to diluent, pH in the aqueous phase and temperature were examined.

Materials and Methods

Materials. Alamine 336 (Henkel Corporation), an aliphatic, straight-chain tertiary amine, was used as received from the manufacturer. The alkyl groups are mainly C_8 and C_{10}, with the C_8 carbon chain predominating about 2 to 1 (Henkel Corp., 1984). Alamine 336 is a pale yellow liquid, with a specific gravity of 0.81 g/cm^3 at 25°C. A molecular weight of 406 g/mol (Tamada et al, 1990) for Alamine 336 was used in this work.

All solutions were prepared by dissolution of the solutes in distilled water, which had been further purified by a Milli-Q water filtration system (Millipore Corporation). D(+)-glucose monohydrate, USP (Fluka Chemie AG, Buchs), was used as received. Lactic acid (Aldrich, 85% in water, A.C.S. reagent grade) was diluted with water to 15% (w/w) and boiled under total reflux for 12 hours to hydrolyze lactic acid polymers. 0.3M Alamine 336 (about 15% v/v) in a diluent composed of the different ratios of 1-octanol to dodecane was used as the solvent. Dodecane (Aldrich) and 1-octanol (Aldrich) were used as received.

Equilibrium Measurements. Aqueous and organic solutions of known glucose concentration were added to 40 ml scintillation vials sealed with foil-lined caps, and equilibrated in a temperature-controlled shaker bath at an oscillation rate of 120 min^{-1} for 24 hours, which preliminary tests demonstrated to be a sufficient time for equilibration. Experiments were performed at 25, 40 and 60°C, using 10 ml each of the aqueous and organic phase solutions. The aqueous and organic phases

were separated by decantation following centrifugation for 8 minutes at 2000 rpm in a IEC HN-S2 (Damon/IEC Division) centrifuge.

Initial and final glucose concentrations in the aqueous phase were determined by High-Performance Liquid Chromatography (HPLC), Perkin-Elmer Series 10, using a Bio-Rad Fast Acid Analysis Column with a differential refractometer (Waters Model 401) detector. A mobile phase of 0.01N H_2SO_4 was used. Equilibrium glucose concentrations in the organic phase were calculated by material balances. Then the distribution ratio of glucose between the aqueous and organic phases was calculated.

Selective Extraction. Experiments for simultaneous extraction of lactic acid and glucose were performed over a range of aqueous pH values. 10 ml of aqueous solutions of 0.45M lactic acid and 0.055M glucose that were adjusted to various pH values using aqueous NaOH were contacted with an equal volume of 0.3M Alamine 336 in the appropriate diluent in 40 ml vials. After equilibration, the phases were separated by centrifugation. Aqueous phase pH measurements were performed with an Orion Model 601A pH meter equipped with an Orion Ross pH electrode. Lactic acid and glucose concentrations in aqueous solutions were determined simultaneously by HPLC. Organic-phase acid concentrations were determined by two-phase titration with aqueous NaOH, using phenolphthalein as an indicator. Material balances for lactic acid closed within 2.0%.

Organic-Phase Water Concentration Measurements. Organic-phase water concentrations were determined with a Quintel Model MS-1 automatic Karl Fischer titrator. In the treatment of

experimental data the changes in phase volumes due to water transfer to the organic phase were taken into account in the calculation of distribution ratios.

Description of Extraction Equilibrium. Proton-donating diluents such as 1-octanol may form a hydrogen bond with the available oxygen on the carboxylic group of the acid-amine complex and thus hamper binding of a second acid onto this complex (Kertes and King, 1986; Tamada et al, 1990). For the range of concentrations in which the experimental work was carried out, it was assumed that only a (1,1) complex formed for lactic acid with the amine extractant. Transfer of the acid from water into the amine-free 1-octanol diluent was also taken into account. The distribution ratio D of lactic acid between solvent and solution was therefore related to the complexation constant as follows:

$$D = \frac{B_o K_{11}}{1 + K_{11} C} + \phi P \qquad (1)$$

where

$$C = C_{a,w} / (1 + 10^{pH-pKa})$$

Equation (1) ignores simple partioning of the acid into the amine and dodecane.

A least-squares fitting method was used to determine the apparent equilibrium constant, K_{11}. The minimization parameter used was the sum of the absolute values of $(C_{a,w,pred} - C_{a,w,expt})/C_{a,w,expt}$, where the subscript "pred" denotes the value predicted by Equation (1) and the subscript "expt" denotes the experimentally determined value.

Results and Discussion

Glucose Extraction Equilibria. Figures 1, 2 and 3 give equilibrium data for the water - glucose - Alamine 336/diluent system, at 25, 40 and 60°C, with different diluent compositions.

All the solvents used provide very low uptake capacities for glucose, which is strongly hydrophilic. Nearly linear equilibrium relationships are obtained. Distribution ratios of glucose over the range of temperatures are 0.0048-0.0075 for 15% Alamine 336 with 1-octanol, 0.0040-0.0063 for 15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane, and 0.0028-0.0045 for 15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane.

As the content of active diluent (1-octanol) and temperature increase, the extraction of glucose increases.

Effect of pH upon Extraction. For the competitive extraction experiments, the capacities for extraction of lactic acid by Alamine 336 with three different diluent compositions are presented as functions of equilibrium aqueous-phase pH in Figure 4, 5 and 6. The results are reported in terms of the stoichiometric loading (mol acid/mol extractant). The extraction capacities of glucose with the same solvents are shown in Figures 7, 8 and 9. Equilibrium distribution ratios of lactic acid and glucose can readily be calculated from the data because constant feed concentrations of solutes and a constant initial phase ratio are used.

The effects of pH on extractions of several carboxylic acids by tertiary amines have been studied (Yang et al, 1991; Tung and King, 1994). Since the extraction equilibria involve the concentration of undissociated acid in the aqueous phase, the extraction capacity for a carboxylic acid decreases with increasing pH, as is apparent from Figures 4, 5 and 6.

It is known that the loading also depends on the type of diluent used (Kertes and King, 1986; Tamada et al, 1990). Diluents can be classified as "inert" or "active", depending upon the degree of interaction with the acid-amine complex. A active protic diluent, such as 1-octanol, will increase the extracting power of the amine by providing additional solvating power through hydrogen bonding that stabilizes the acid-amine complex. As is shown in Figure 4, Alamine 336 in diluents composed of high ratios of 1-octanol to dodecane provides substantial capacity at as much as two pH units above the pK_a of lactic acid (3.86). In the pH 5-6 range at 40 °C, the temperature at which a typical lactic acid fermentation might occur, the loadings are 0.640 - 0.214 for 15% Alamine 336 with 85% 1-octanol, 0.332 - 0.060 for 15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane, and 0.044 - 0.005 for 15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane.

It is clear from Figures 4, 5 and 6 that the loadings of Alamine 336 with lactic acid in all three diluents decrease with increasing operating temperature. These results are consistent with the results of other investigators (Wennersten, 1983; Tamada and King, 1990).

Using the experimental data in this work and appropriate models (Tung, 1993), the apparent equilibrium constants, K_{11}, have been obtained. The results are listed in Table 1. The partition

coefficients of lactic acid from water into 1-octanol at different temperatures were also measured in this work and are shown in Table 1.

The apparent equilibrium constants for competitive extraction are similar to those for single-component extractions at same operating conditions, as obtained by Tung and King (1994).

As shown in Figures 7, 8 and 9, all the three solvent mixtures used provide very low uptake capacities of glucose in the competitive extraction experiments. There is no significant effect of pH on the extraction of glucose in the pH range over which the experiments have been carried out. Distribution ratios of glucose over the range of temperatures examined are 0.0033 - 0.0052 for 15% Alamine 336 with 85% 1-octanol, 0.0026 - 0.0044 for 15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane, and 0.0021 - 0.0035 for 15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane. These figures are somewhat lower than in the experiments for extraction of glucose alone. This may reflect competition with lactic acid.

Water Coextraction. A typical set of results for coextraction of water with glucose present at 40 °C is shown in Figure 10. Because of very low uptake capacity of glucose for all the solvent mixtures used, the presence of glucose does not affect the extraction of water significantly. It is also apparent from Figure 10 that the higher the ratio of 1-octanol to dodecane in the diluent, the greater the amount of water extracted.

The effect of temperature on water coextraction was also studied. For the extraction of glucose by Alamine 336 in various diluents, water coextraction was found to increase slightly with increasing temperature.

Figure 11 presents the measured water coextraction in the experiments examining competitive extraction between lactic acid and glucose at 40 °C. Increasing uptake of lactic acid increases the amount of water coextracted. This result suggests that water interacts with lactic acid, or more likely the acid-amine complex, in the organic phase and thereby accompanies the extracted acid into the organic phase. The amount of water coextracted with lactic acid into the solvent phases increases with an increase in the proportion of 1-octanol in the diluent.

For the competitive extraction of lactic acid and glucose by Alamine 336 in various diluents, there also appears to be a slight effect of temperature on water coextraction. Figure 12 presents the measured coextraction of water by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol at different temperatures. Water coextraction increases with increasing temperature.

Coextraction of glucose may be related to the amount of coextraction of water, since water in the organic phase could provide local solvation power for glucose. Generally speaking, water can be coextracted for two reasons -- its solubility in the solvent and/or its interaction with the acid-base complex in the organic phase. As is shown in Figure 13, the extent of water coextraction depends strongly upon the diluent used and the operating temperature. The higher the extent of water coextraction, the higher the uptake capacity for glucose. Coextracted water becomes greater at higher

operating temperature and for diluents having large proportions of 1-octanol, and the coextracted water facilitates accommodation of glucose into the organic phase. But for a given diluent, additional water coextraction caused by the increase in uptake of lactic acid at lower pH does not significantly increase the uptake of glucose (see Figure 14).

Separation Factor for Competitive Extraction. The separation factor between lactic acid and glucose, $\alpha_{a,g}$, and between lactic acid and water, $\alpha_{a,w}$, can be expressed as

$$\alpha_{a,g} = \frac{C_{a,o}}{C_{a,w}} \frac{C_{g,w}}{C_{g,o}} \tag{2}$$

$$\alpha_{a,w} = \frac{C_{a,o}}{C_{a,w}} \frac{C_{w,w}}{C_{w,o}} \tag{3}$$

Figure 15 shows the separation factors for competitive extraction between lactic acid and glucose for extraction by Alamine 336 in various diluents at 40 °C. Figure 16 shows the separation factors between lactic acid and water for extraction by Alamine 336 in various diluents at 40 °C. Both figures are based upon data reported in earlier figures.

The uptake capacity of lactic acid has the most important influence on the separation factor between lactic acid and glucose. The separation factor therefore decreases with increasing pH and with decreasing ratio of 1-octanol to dodecane in the diluent mixture.

Selectivity for the acid over water in extraction by amine extractants is high, relative to results with conventional solvents (Tamada and King, 1990). As shown in Figure 16, the separation factor between lactic acid and water decreases with increasing pH because of decreasing extraction capacity of the extractant. Significant differences in water coextraction among the three different diluents markedly affect the separation factor between lactic acid and water. A decrease in the ratio of 1-octanol to dodecane leads to a decrease in the amount of coextracted water and thus results in an increase in the separation factor between lactic acid and water in the lower pH range. Similar results (not reported) were obtained at other operating temperatures.

Comparison of Extraction and Sorption. The performances of extraction and sorption for selective separation between lactic acid and glucose are compared in Table 2. The initial concentrations of lactic acid and glucose for these data were 4.0% (w/w) and 1.0% (w/w), respectively. The weight ratio of aqueous solution to fresh solvent or dry sorbent was equal to 10. The operating temperature was 40 °C. The solvent used was 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol. The sorbent used was Dowex MWA-1.

The data for sorption stem from Part 1 of this work. The uptake of lactic acid for extraction was calculated from the fitting parameters. The densities of organic and aqueous phases are assumed to be constant, and the effect of phase ratio on uptakes of glucose and water has been ignored.

The results show that the uptake of lactic acid for sorption by Dowex MWA-1 is much higher than that for extraction by Alamine 336. This advantage is more significant at the higher pH range. On the

other hand, the uptake capacity of water is much higher for sorption than for extraction, and this results in a substantially higher uptake of glucose onto the sorbent. Marked swelling of the sorbent in the solution reduces the selectivities for acid over water and glucose.

Acknowledgment

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Nomenclature

B_0 initial amine concentration (mol/L)

$C_{a,i}$ lactic acid concentration in initial solution (mol/L)

$C_{a,0}$ lactic acid concentration in organic phase (mol/L)

$C_{a,w}$ lactic acid concentration in aqueous phase (mol/L)

$C_{g,i}$ glucose concentration in initial solution (mol/L)

$C_{g,o}$ glucose concentration in organic phase (mol/L)

$C_{g,w}$ glucose concentration in aqueous phase (mol/L)

$C_{w,o}$ water concentration in organic phase (mol/L)

$C_{w,w}$ water concentration in aqueous phase (mol/L)

D distribution ratio of lactic acid

K_a dissociation constant of lactic acid (mol/L)

K_{11} apparent equilibrium constant for (1,1) complex (L/mol)

P partition coefficient

Greek Letters

$a_{a,g}$ separation factor between lactic acid and glucose

$\alpha_{a,w}$ separation factor between lactic acid and glucose

ϕ volume fraction of 1-octanol in solvent mixture

Literature Cited

Henkel Corp. Alamine 336. Red Line Technical Bulletin; Henkel Technical Center: Minneapolis, MN, 1984.

Kertes, A.S.; King, C.J. Extraction chemistry of Fermentation Product Carboxylic Acids. *Biotechnol. Bioeng.*, **1986**, 28, 269-282.

King, C.J. Separation Processes Based Upon Reversible Chemical Complexation. in *Handbook of Separation Process Technology*, Rousseau, R.W. ed., Wiley, New York, 1987; pp 760-774.

King, C.J. Amine-Based Systems for Carboxylic Acid Recovery. *Chemtech* **1992**, 22(5), 285-291.

Ricker, N.L.; Pittman, E.F.; King, C.J. Solvent Extraction with Amines for Recovery of Acetic Acid from Dilute Aqueous Industrial Streams. *J. Sep. Proc. Technol.*, **1980**, 1(2), 23-30.

Tamada, J.A.; Kertes, A.S.; King C.J. Extraction of carboxylic Acids with Amine Extractants. 1. Equilibria and Law of Mass Action Modeling. *Ind. Eng. Chem. Res.*, **1990**, 29, 1319-1326.

Tamada, J.A.; King C.J. Extraction of carboxylic Acids with Amine Extractants. 3. Effect of Temperature, Water Coextraction, and Process Consideration. *Ind. Eng. Chem. Res.*, **1990**, 29, 1333-1338.

Tung, L.A. Recovery of Carboxylic Acids at pH greater than pK_a. Report No. LBL-34669, Lawrence Berkeley Laboratory, Berkeley CA, August, 1993.

Tung, L.A.; King, C.J. Sorption and Extraction of Lactic and Succinic Acids at pH > pK_{a1} I. Factors Governing Equilibria. *Ind. Eng. Chem. Res.*, **1994**, 33, 3217-3223.

Wang, C.J.; Bajpai, R.K.; Iannotti, E.L. Nondispersive Extraction for Recovery Lactic Acid. *Appl. Biochem. Biotechnol.*, **1991**, 28/29, 589-603.

Wennersten, R. The Extraction of Citric Acid from Fermentation Broth Using a Solution of a Tertiary Amine. *J. Chem. Tech. Biotechnl.*, **1983**, 33B, 85-94.

Yabannavar, V.M.; Wang, D.I.C. Bioreactor System with Solvent Extraction for Organic Acid Production. *Ann. NY. Acad. Sci.*, **1987**, 506, 523-535.

Yabannavar, V.M.; Wang, D.I.C. Extractive Fermentation for Lactic Acid Production. *Biotechnol. Bioeng.*, **1991**, 37,1095-1100.

Yang, S.T.; White, S.A.; Haso, S.T. Extraction of Carboxylic Acids with Tertiary and Quaternary Amines: Effect of pH. *Ind. Eng. Chem. Res.*, **1991**, 30, 1335-1342.

Table 1. Apparent Complexation Equilibrium Constant K_{11} and

Measured Partition Coefficient P for Lactic Acid

Solvent	K_{11} (L/mol) 25 °C	40 °C	60 °C
15% Alamine 336 with 85% 1-octanol	188.9; 191.2[a]	99.4	44.5
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane	29.5	21.1	14.9
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane	1.96	1.54	1.09

Solvent	P 25 °C	40 °C	60 °C
1-octanol	0.205	0.215	0.228

[a] Fitting results from Tung's data (Tung, 1993)

Table 2. Comparison of Extraction and Sorption for Selective Separation between Lactic Acid and Glucose (40°C)

Solvent	pH	Uptake (mg/g fresh solvent)		
		Lactic Acid	Glucose	Water
15% Alamine 336 in 1-octanol	2.97	38.94	0.054	41.54
	3.88	35.09	0.052	40.92
	4.76	27.81	0.051	36.32
	5.34	19.12	0.053	29.47
	5.95	8.59	0.053	22.89
	6.44	3.43	0.052	20.20
	6.67	2.12	0.053	18.68
	7.35	0.47	0.053	18.42
Sorbent	**pH**	**Uptake (mg/g dry sorbent)**		
		Lactic Acid	Glucose	Water
Dowex MWA-1	2.75	359.0	12.0	1440.1
	3.71	350.6	11.9	1421.4
	4.64	317.8	10.4	1391.2
	5.36	268.9	10.3	1315.9
	6.19	184.7	8.6	1140.9
	6.73	116.8	6.5	958.6
	7.26	62.4	5.0	827.6
	8.01	42.3	4.0	746.3

List of Figure Captions

Figure 1. Extraction Equilibria of Glucose for 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol.

Figure 2. Extraction Equilibria of Glucose for 15% (v/v) Alamine 336 with 42.5% (v/v) 1-octanol and 42.5% (v/v) Dodecane.

Figure 3. Extraction Equilibria of Glucose for 15% (v/v) Alamine 336 with 8.5% (v/v) 1-octanol and 76.5% (v/v) Dodecane.

Figure 4. Effect of pH on Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 5. Effect of pH on Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 42.5% (v/v) 1-octanol and 42.5% (v/V) dodecane, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 6. Effect of pH on Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 8.5% (v/v) 1-octanol and 76.5% (v/v) dodecane, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 7. Effect of pH on Extraction of Glucose by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 8. Effect of pH on Extraction of Glucose by 15% (v/v) Alamine 336 with 42.5% (v/v) 1-octanol and 42.5% (v/V) dodecane, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 9. Effect of pH on Extraction of Glucose by 15% (v/v) Alamine 336 with 8.5% (v/v) 1-octanol and 76.5% (v/V) dodecane, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 10. Water Coextraction for Extraction of Glucose by 15% (v/v) Alamine 336 in Various Diluents at 40 °C

Figure 11. Water Coextraction for Extraction of Lactic Acid by 15% (v/v) Alamine 336 in Various Diluents at 40 °C, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 12. Water Coextraction for Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol at Different Temperature $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 13. Relationship of Uptake for Glucose to Uptake for Water into Three Different Solvent Mixtures at 25 and 60 °C, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 14. Relationship of Glucose and Water Uptakes for Extraction by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol at Different Temperatures, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 15. Separation Factor between Lactic Acid and Glucose for Extraction by 15% (v/v) Alamine 336 in Various Diluents at 40 °C, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

Figure 16. Separation Factor between Lactic Acid and Water for Extraction by 15% (v/v) Alamine 336 in Various Diluents at 40 °C, $C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

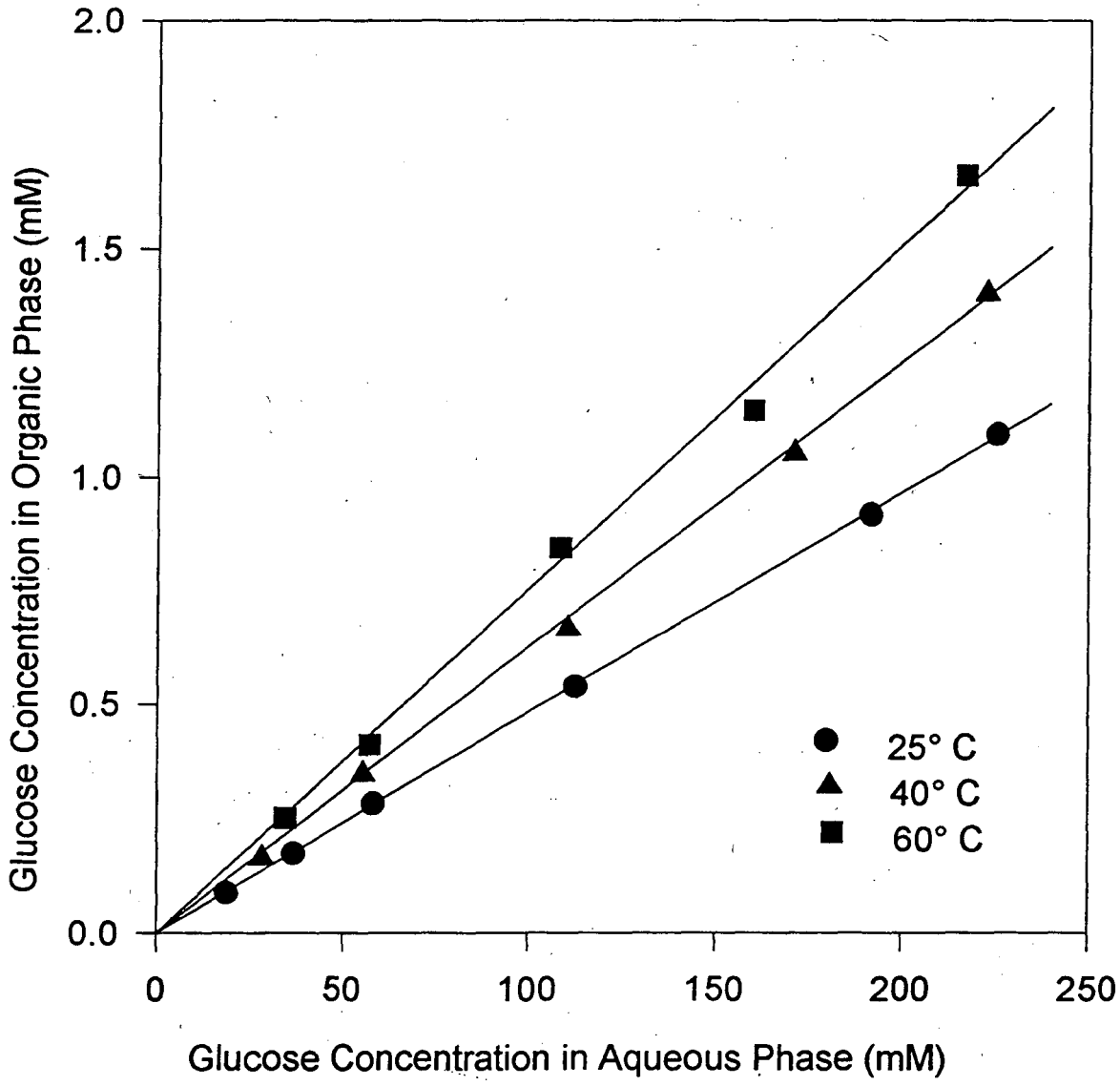


Figure 1 Extraction Equilibria of Glucose for 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol

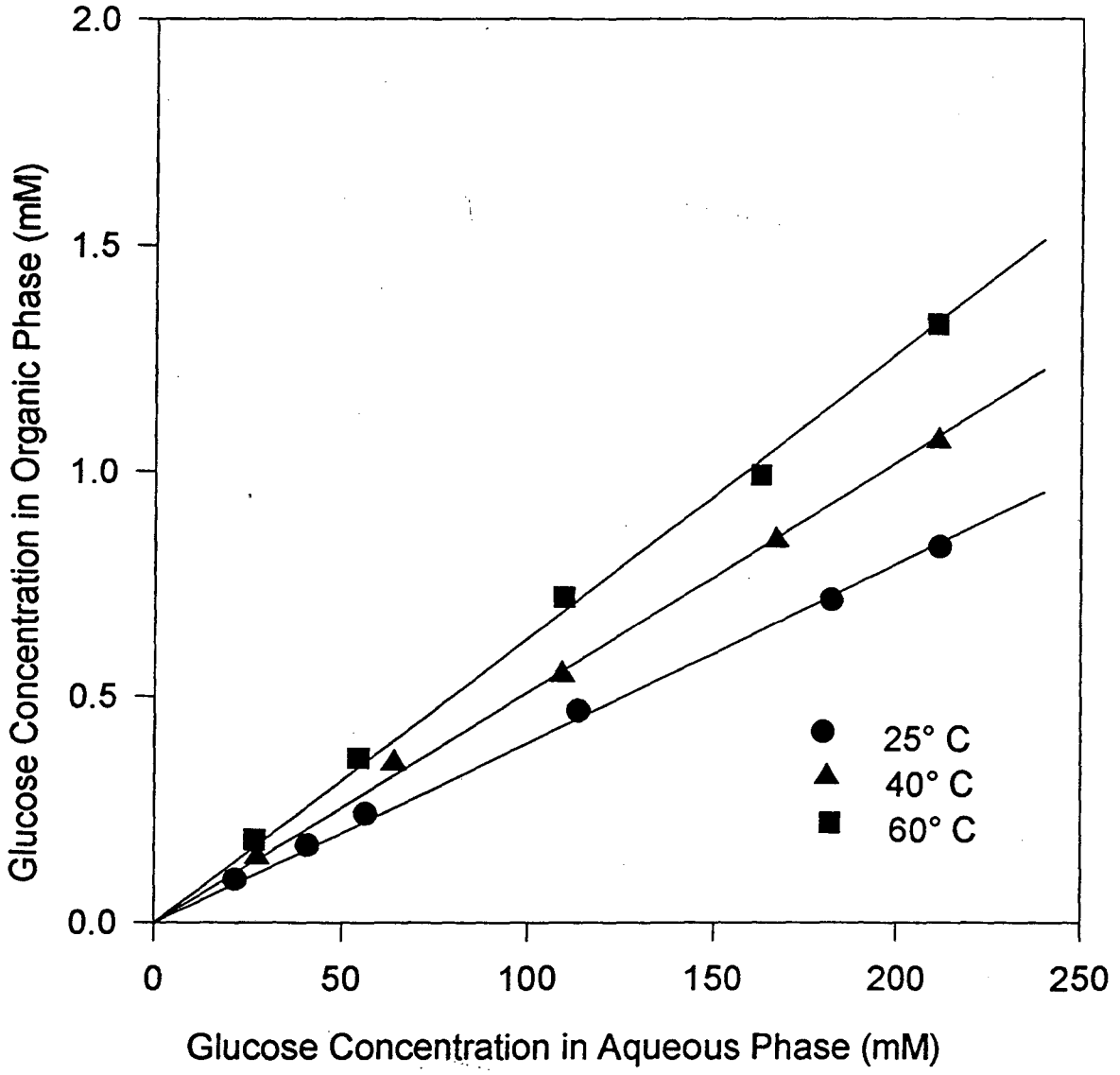


Figure 2 Extraction Equilibria of Glucose for 15% (v/v) Alamine 336 with 42.5% (v/v) 1-octanol and 42.5% (v/v) Dodecane

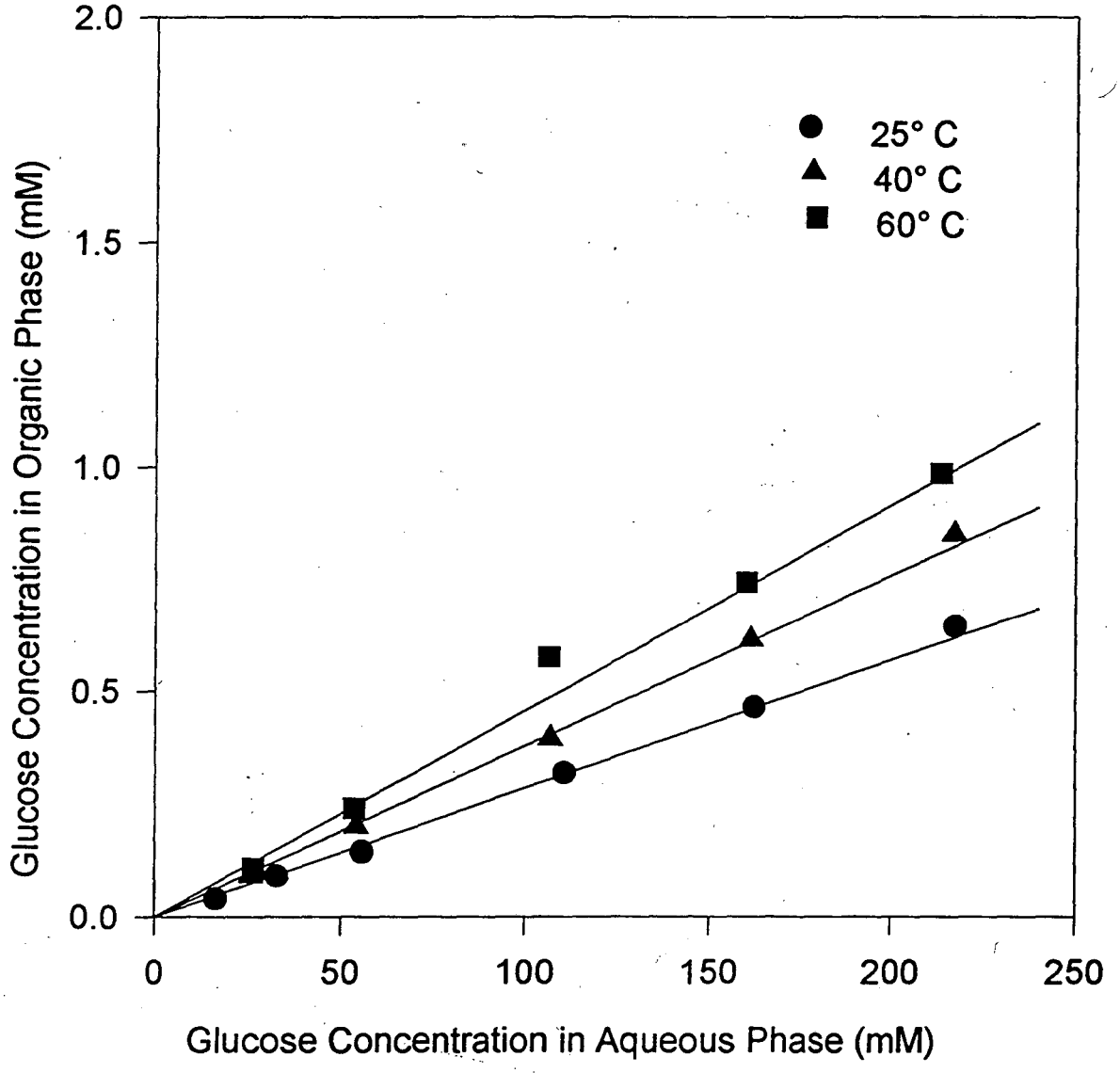


Figure 3 Extraction Equilibria of Glucose for 15% (v/v) Alamine 336 with 8.5% (v/v) 1-octanol and 76.5% (v/v) Dodecane

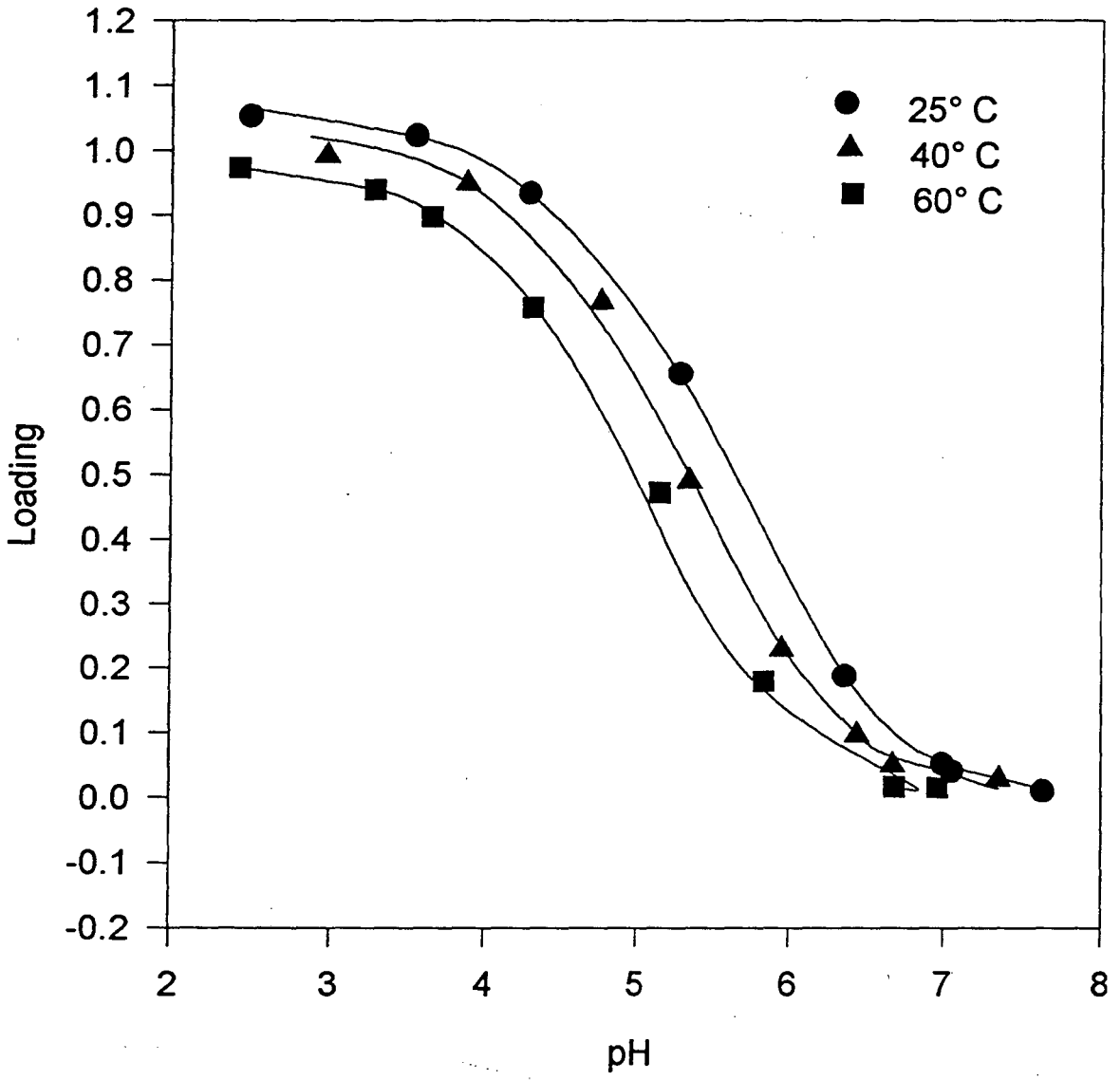


Figure 4 Effect of pH on Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol $C_{a,i}$ = 0.45 M, $C_{g,i}$ =0.055 M, Phase Ratio = 1.0

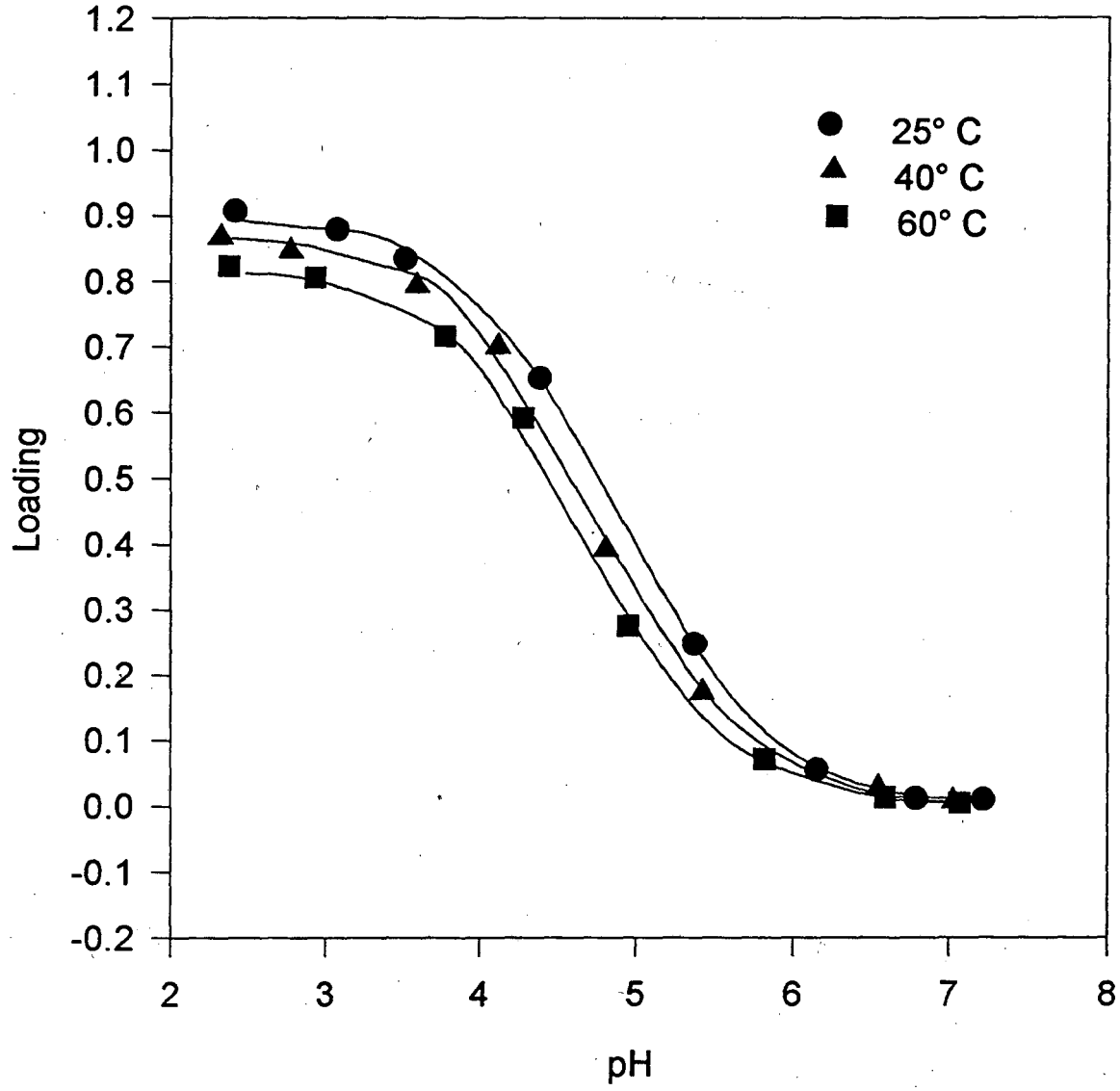


Figure 5 Effect of pH on Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 42.5% (v/v) 1-octanol and 42.5% (v/v) Dodecane. $C_{a,i}$ = 0.45 M, $C_{g,i}$ = 0.055 M, Phase Ratio = 1.0

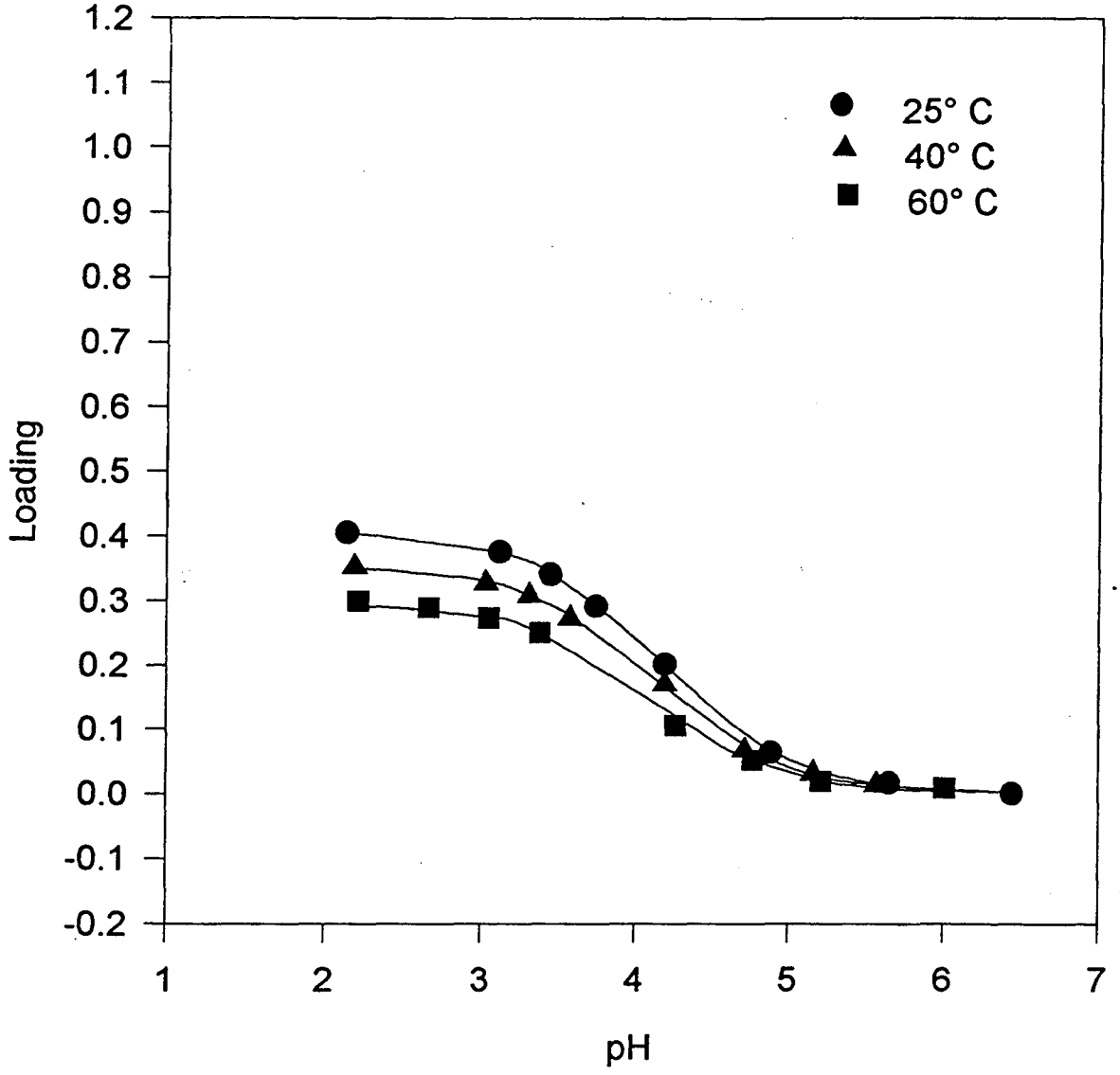


Figure 6 Effect of pH on Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 8.5% (v/v) 1-octanol and 76.5% (v/v) Dodecane. $C_{a,i}$ = 0.45 M, $C_{g,i}$ = 0.055 M, Phase Ratio = 1.0

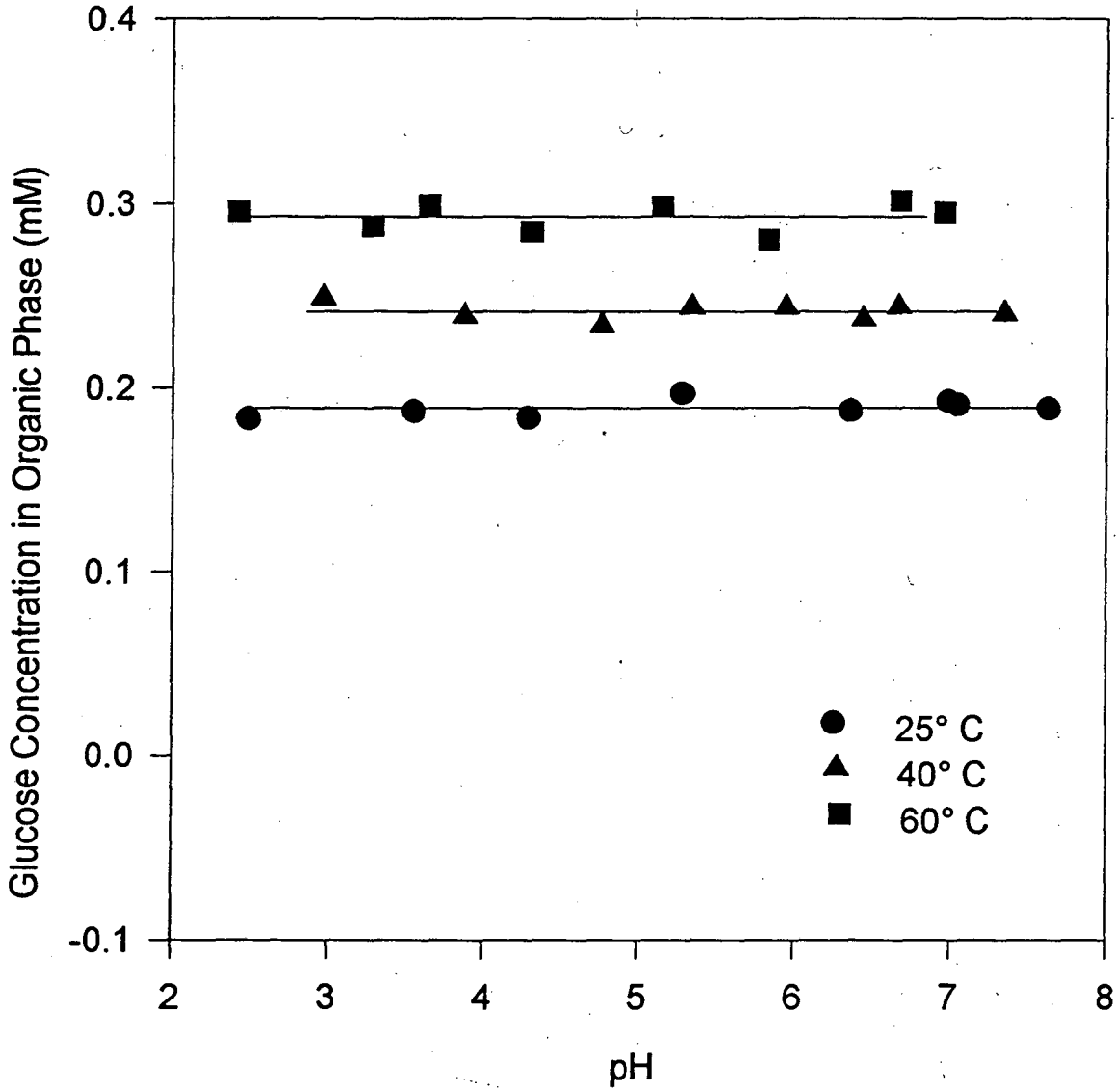


Figure 7 Effect of pH on Extraction of Glucose by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol $C_{a,i}$ = 0.45 M, $C_{g,i}$ =0.055 M, Phase Ratio = 1.0

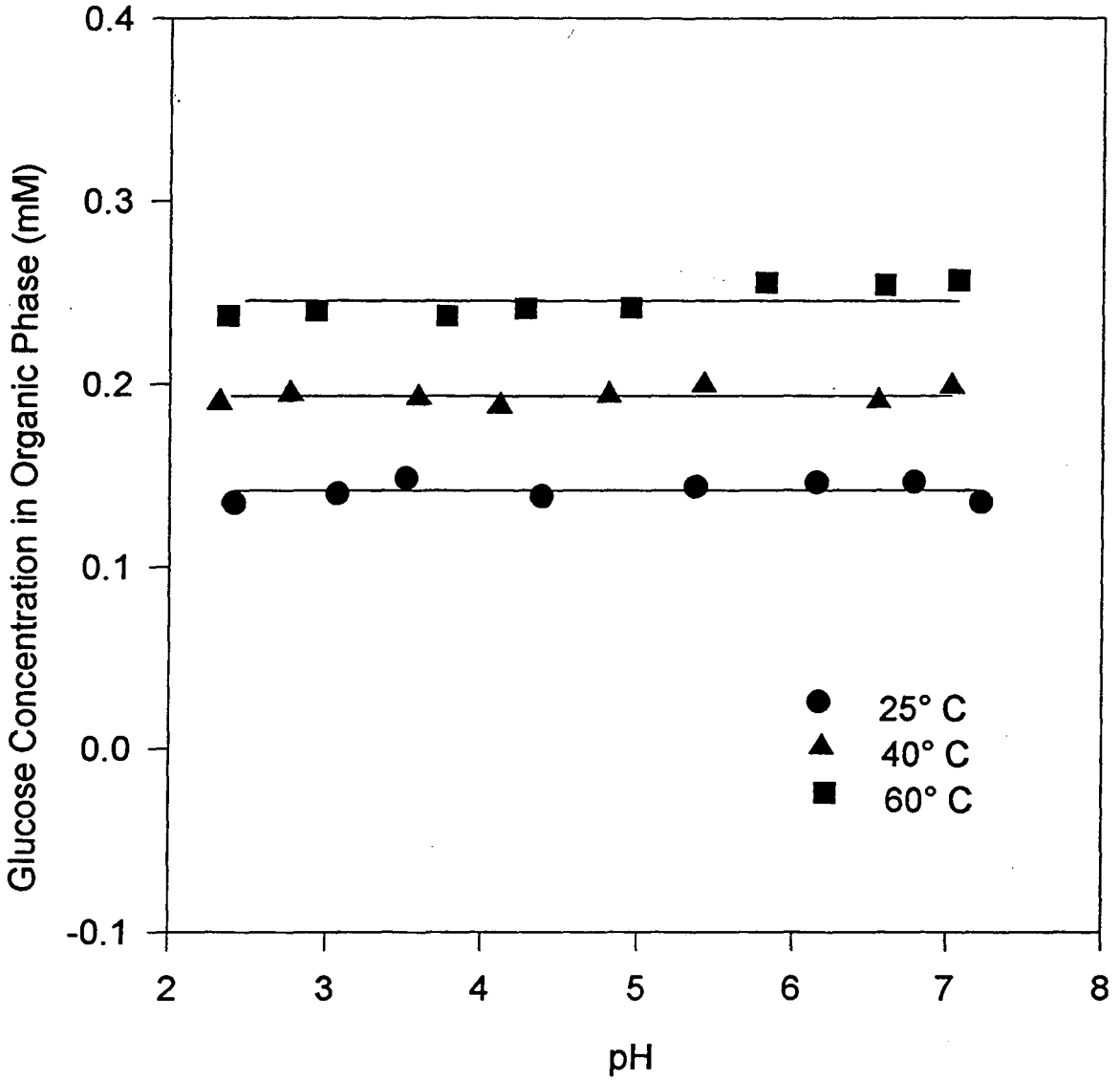


Figure 8 Effect of pH on Extraction of Glucose by 15% (v/v) Alamine 336 with 42.5% (v/v) 1-octanol and 42.5% (v/v) Dodecane. $C_{a,i}$ = 0.45 M, $C_{g,i}$ = 0.055 M, Phase Ratio = 1.0

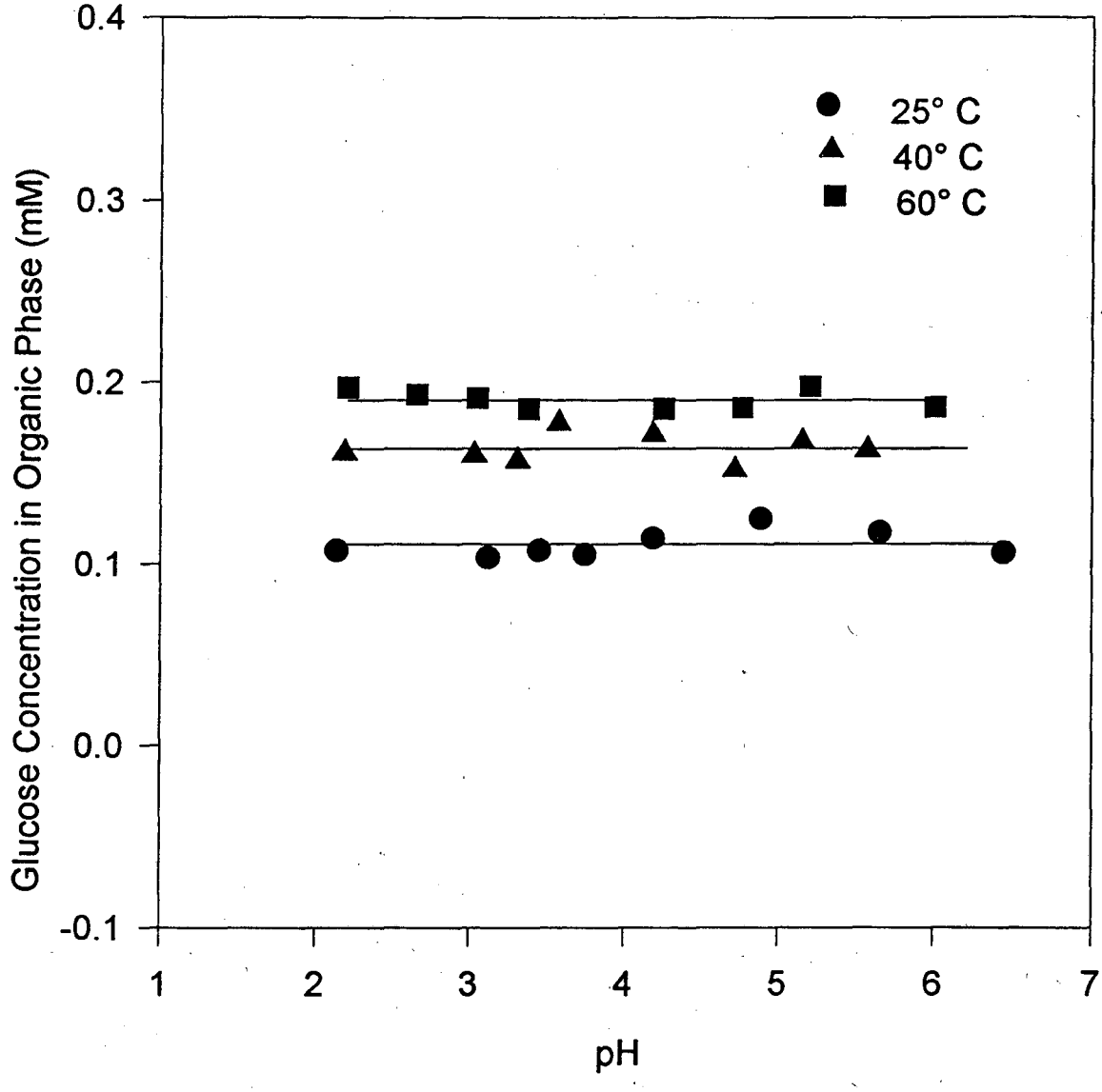


Figure 9 Effect of pH on Extraction of Glucose by 15% (v/v) Alamine 336 with 8.5% (v/v) 1-octanol and 76.5% (v/v) Dodecane. $C_{a,i}$ = 0.45 M, $C_{g,i}$ = 0.055 M, Phase Ratio = 1.0

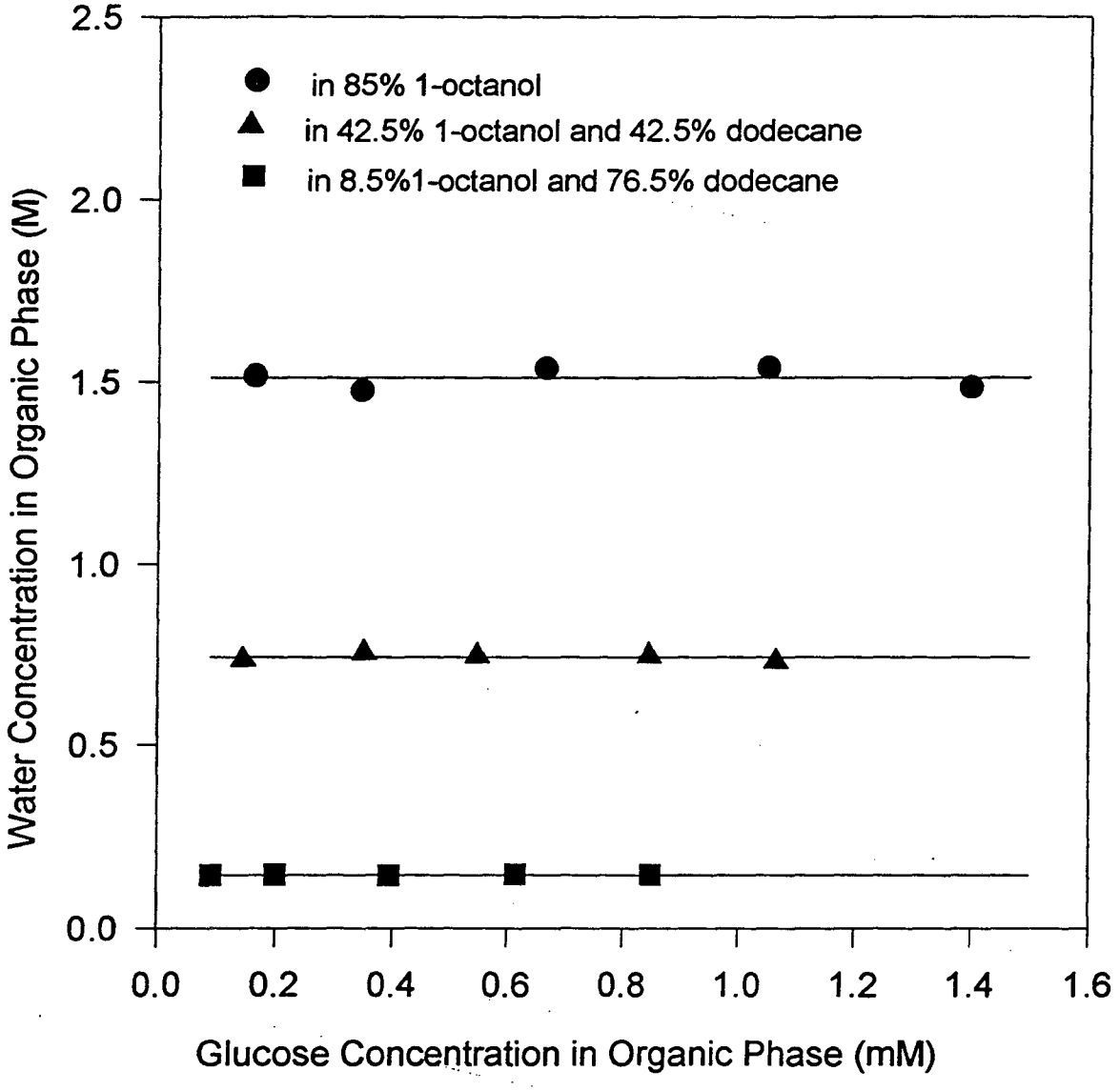


Figure 10 Water Coextraction for Extraction of Glucose by 15% (v/v) Alamine 336 in Various Diluents at 40 °C

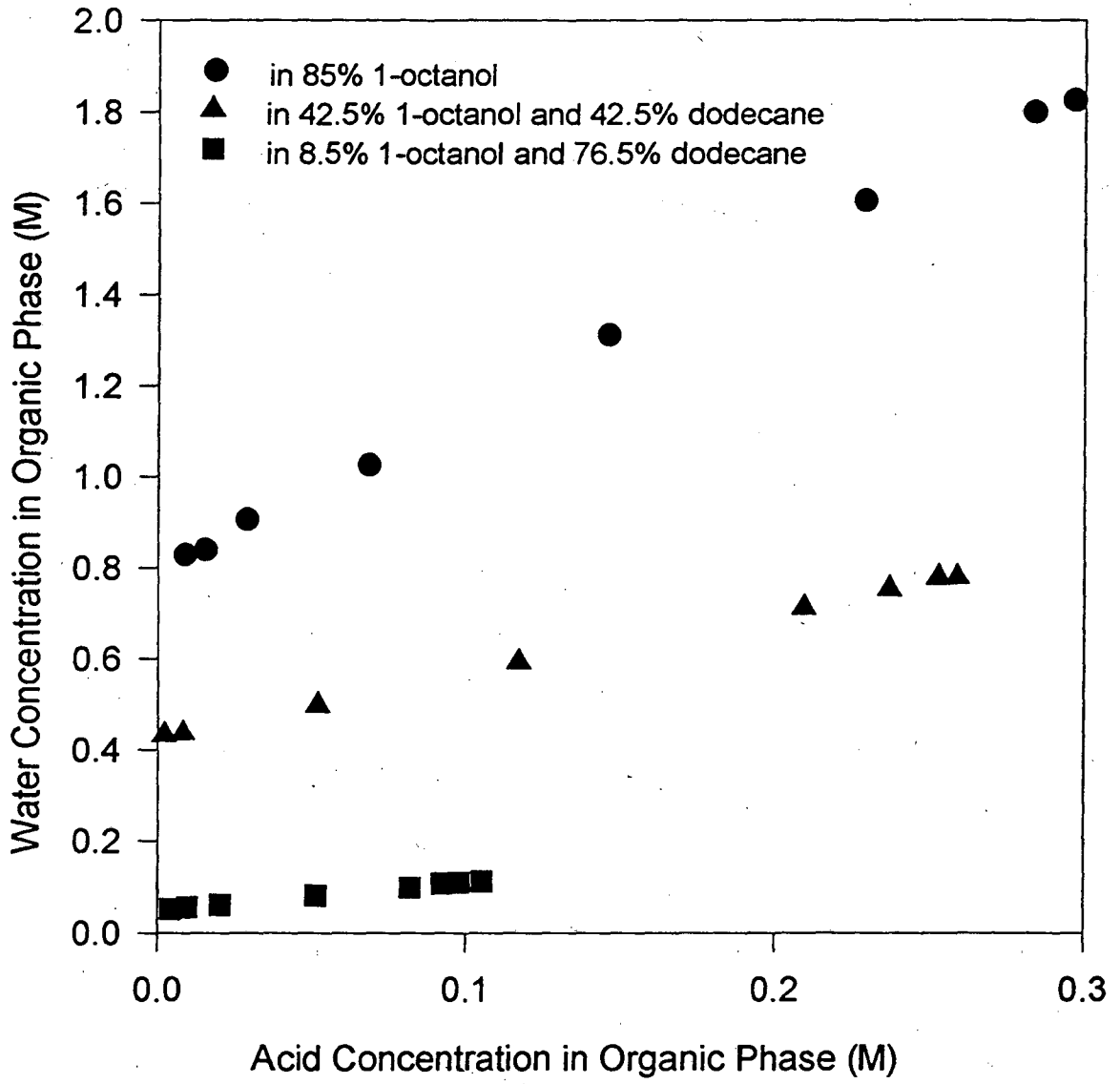


Figure 11 Water Coextracton for Extraction of Lactic Acid by 15% (v/v) Alamine 336 in various diluents at 40 °C
$C_{a,i}$ = 0.45M, $C_{g,i}$ = 0.055M, Phase Ratio = 1.0

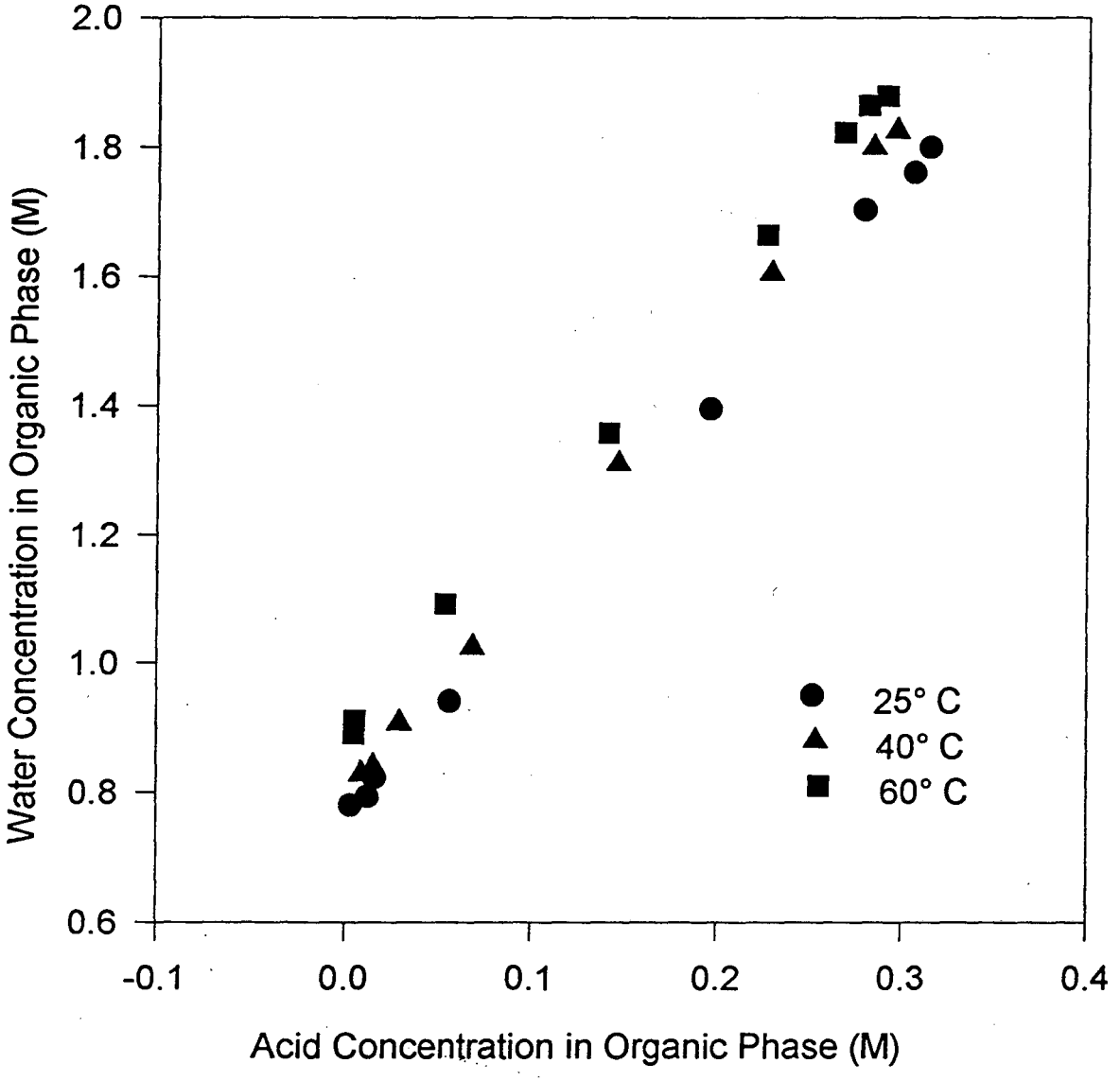


Figure 12 Water Coextracton for Extraction of Lactic Acid by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol at Different Temperature, $C_{a,i}$ = 0.45 M, $C_{s,i}$ =0.055 M, Phase Ratio = 1.0

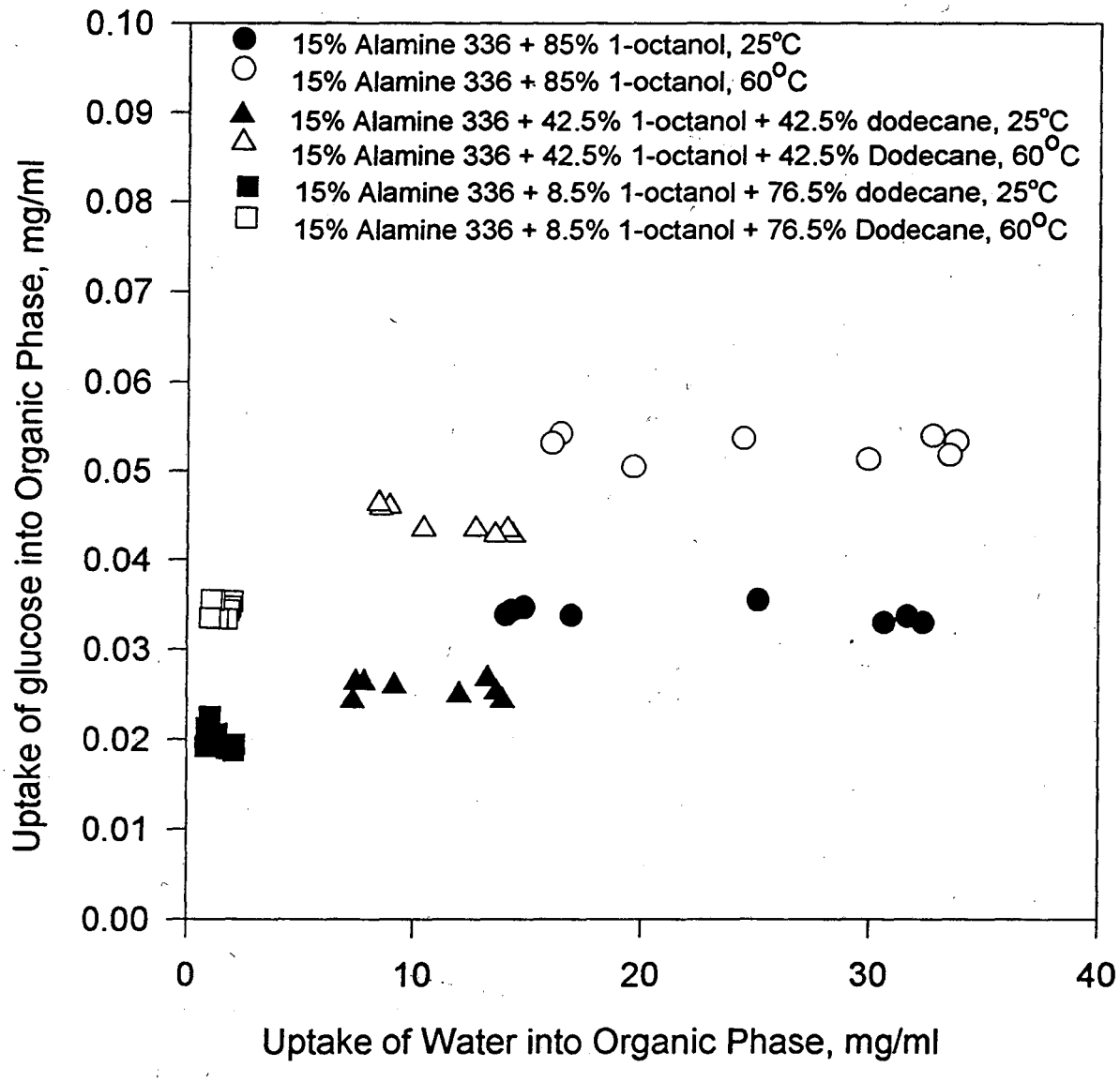


Figure 13 Relationship of Uptake for Glucose to Uptake for Water into three Different Solvent Mixtures at 25 and 60 °C, $C_{a,i}$ = 0.45M, $C_{g,i}$ =0.055M, Phase Ratio = 1.0

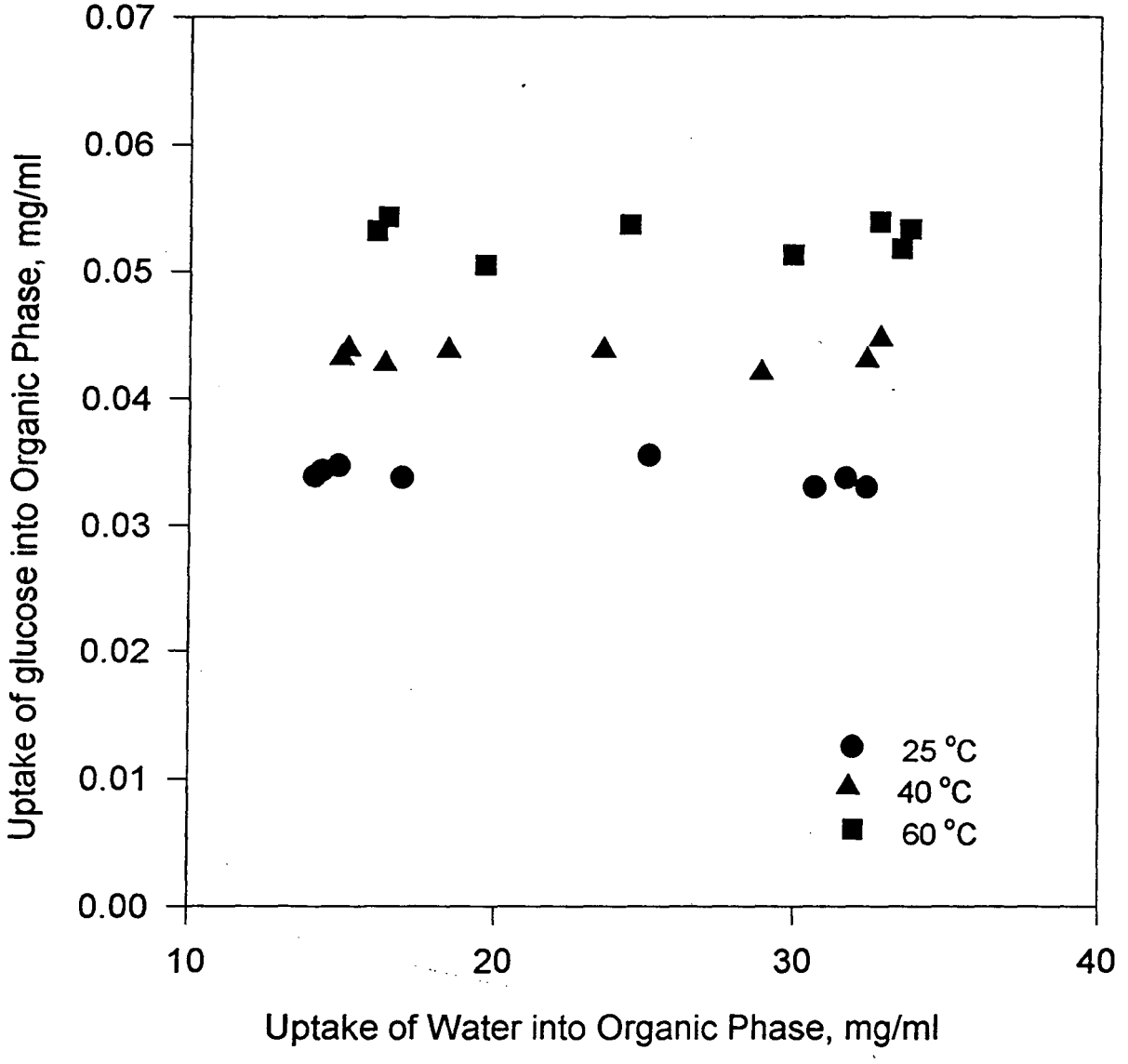


Figure 14 Relationship of Glucose and Water Uptakes for Extraction by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol at Different Temperatures, $C_{a,i}$ = 0.45M, $C_{g,i}$ =0.055M, Phase Ratio = 1.0

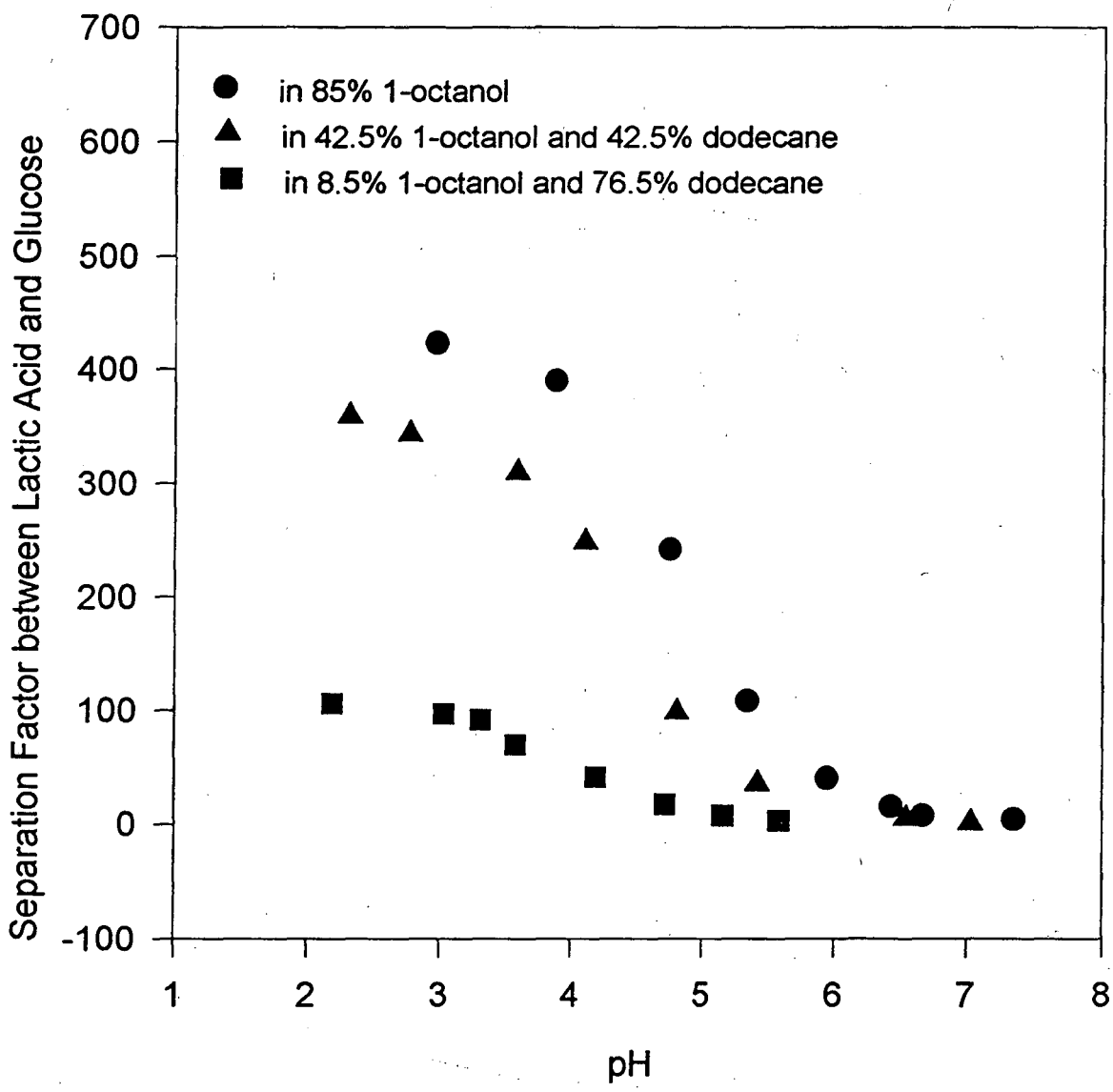


Figure 15 Separation Factor between Lactic acid and Glucose for 15% (v/v) Alamine 336 in various diluents at 40 °C
$C_{a,i}$ = 0.45 M, $C_{g,i}$ =0.055 M, Phase Ratio = 1.0

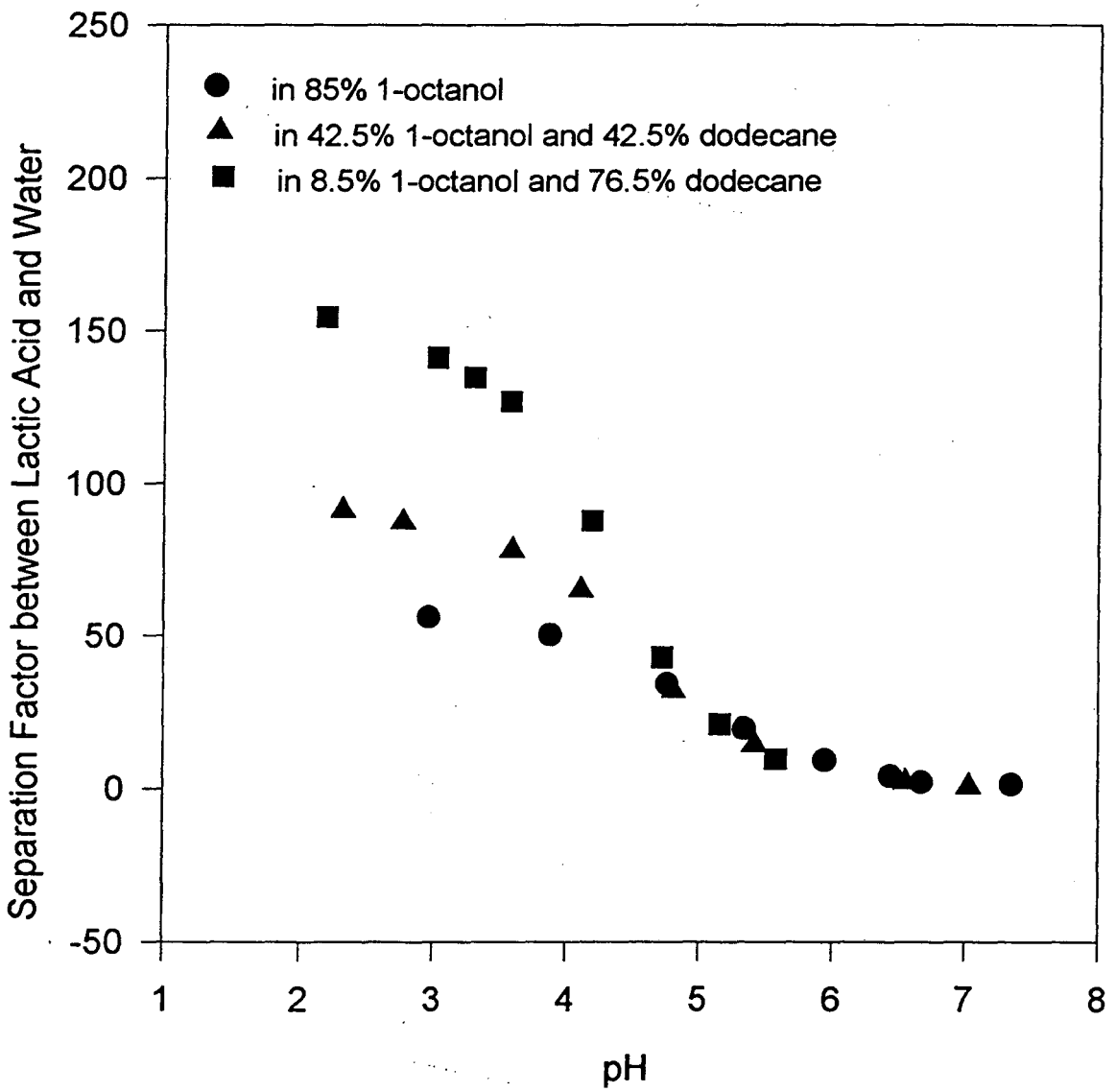


Figure 16 Separation Factor between Lactic acid and Water for 15% (v/v) Alamine 336 in various diluents at 40 °C $C_{a,i}$ = 0.45 M, $C_{g,i}$ =0.055 M, Phase Ratio = 1.0

APPENDIX B: EXPERIMENTAL DATA

The experimentally measured quantities are listed below.

W_s	mass of solution (g)
$W_{w,o}$	mass of water extracted into organic phase (g)
pH_i	pH value in initial aqueous solution
pH_f	pH value in final aqueous solution
$C_{g,i}$	glucose concentration in initial solution (mM)
$C_{g,w}$	glucose concentration in aqueous phase after equilibration (mM)
$C_{g,o}$	glucose concentration in organic phase after equilibration (mM)
$C_{a,i}$	lactic acid concentration in initial solution (mM)
$C_{a,w}$	lactic acid concentration in aqueous phase after equilibration (mM)
$C_{a,o}$	lactic acid concentration in organic phase after equilibration (mM)
Q_w	uptake of water into organic phase (mg/g)
V_o	volume of organic phase (ml)
Z	loading of extractant

B.1 Extaction Equilibria

The results of the extraction experiments of glucose are shown in Table B-1.

Table B-1. Data for Extraction Equilibria of Glucose

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 in 85% 1-octanol (25 °C)					
10.0072	10.00	18.56	24.423	18.85	0.0893
10.0393	10.00	35.99	23.772	36.53	0.1738
10.0948	10.00	57.39	24.378	58.27	0.2828
10.1905	10.00	110.77	24.708	112.49	0.5387
10.3463	10.00	189.04	23.798	191.79	0.9177
10.4263	10.00	222.25	24.383	225.55	1.0933

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 in 85% 1-octanol (40 °C)					
10.0317	10.00	27.77	27.305	28.24	0.1642
10.0885	10.00	54.62	26.560	55.48	0.3472
10.1958	10.00	108.64	27.685	110.46	0.6656
10.3280	10.00	168.47	27.719	171.24	1.0525
10.4361	10.00	219.33	26.727	222.69	1.4001

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 in 85% 1-octanol (60 °C)					
10.0530	10.00	33.83	28.354	34.38	0.2508
10.0845	10.00	56.29	28.594	57.22	0.4110
10.1963	10.00	106.70	28.846	108.40	0.8446
10.2965	10.00	157.61	28.792	160.19	1.1460
10.4214	10.00	213.54	28.414	216.82	1.6610

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (25 °C)					
10.0123	10.00	21.35	12.139	21.46	0.0960
10.0561	10.00	40.44	12.506	40.67	0.1712
10.0918	10.00	55.85	12.459	56.16	0.2408
10.1993	10.00	112.85	12.372	113.48	0.4684
10.3437	10.00	181.07	12.362	182.10	0.7143
10.4157	10.00	210.80	12.344	211.99	0.8313

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (40 °C)					
10.0426	10.00	27.13	13.257	27.27	0.1455
10.1047	10.00	63.37	13.584	63.70	0.3513
10.2024	10.00	108.47	13.445	109.07	0.5483
10.3213	10.00	166.08	13.438	166.98	0.8466
10.4141	10.00	210.34	13.159	211.43	1.0665

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (60 °C)					
10.0200	10.00	26.49	14.424	26.61	0.1835
10.0728	10.00	53.95	14.478	54.22	0.3626
10.2008	10.00	108.93	14.212	109.43	0.7206
10.3069	10.00	161.81	14.901	162.71	0.9909
10.4080	10.00	210.22	13.963	211.19	1.3239

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (25 °C)					
10.0143	10.00	16.78	2.419	16.77	0.0410
10.0461	10.00	32.90	2.445	32.87	0.0916
10.0873	10.00	55.78	2.439	55.74	0.1443
10.1993	10.00	110.48	2.445	110.37	0.3186
10.3088	10.00	162.47	2.416	162.31	0.4649
10.4243	10.00	217.79	2.500	217.57	0.6453

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (40 °C)					
10.0327	10.00	26.05	2.601	26.01	0.0919
10.0955	10.00	54.33	2.633	54.24	0.2001
10.1958	10.00	106.81	2.592	106.63	0.3949
10.3147	10.00	161.60	2.646	161.32	0.6153
10.4371	10.00	217.62	2.605	217.22	0.8502

W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (60 °C)					
10.0180	10.00	26.80	2.844	26.75	0.1083
10.0721	10.00	53.71	2.879	53.59	0.2389
10.1819	10.00	106.55	2.834	106.21	0.5763
10.2865	10.00	160.46	2.793	160.07	0.7431
10.4031	10.00	214.06	2.848	213.56	0.9853

B.2 Extraction-pH Experiments

The results of the extraction-pH experiments are given in Table B-2-1 and B-2-2.

Table B-2-1. Data from Extraction-pH Experiments (lactic acid and glucose to be extracted)

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 85% 1-octanol (25 °C)										
10.0166	1.99	2.49	55.91	462.0	0.324	57.59	0.18	152.6	314.9	1.053
10.0385	2.49	3.55	55.28	456.8	0.317	56.89	0.19	156.9	306.0	1.023
10.0234	3.08	4.29	55.11	454.4	0.307	56.66	0.18	181.0	279.6	0.935
10.0085	3.69	5.28	55.64	459.8	0.251	56.87	0.20	270.7	196.1	0.656
10.0345	4.37	6.36	54.20	447.7	0.169	54.94	0.19	398.5	56.3	0.188
10.0030	4.88	6.99	54.23	448.1	0.148	54.85	0.19	438.9	15.7	0.053
10.0153	5.19	7.05	55.49	458.5	0.143	56.10	0.19	452.7	12.3	0.041
10.0001	5.66	7.63	55.49	458.5	0.141	56.09	0.19	461.8	3.2	0.011

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 85% 1-octanol (40 °C)										
10.0190	2.44	2.97	55.32	451.5	0.329	56.94	0.25	160.6	296.8	0.933
10.0042	2.68	3.88	55.46	452.2	0.324	57.07	0.24	173.9	284.0	0.950
10.0116	3.38	4.76	55.53	452.8	0.289	56.94	0.23	230.6	229.1	0.766
10.0071	3.74	5.34	55.45	452.2	0.236	56.54	0.24	313.2	146.5	0.490
10.0079	4.25	5.95	55.80	455.0	0.185	56.60	0.24	393.9	68.4	0.229
10.0135	4.71	6.44	55.58	453.2	0.163	56.26	0.24	431.5	28.8	0.096
10.0043	5.26	6.67	55.88	455.7	0.151	56.49	0.24	447.3	15.2	0.051
10.0124	5.61	7.35	55.13	449.6	0.149	55.72	0.24	447.7	8.6	0.029

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 85% 1-octanol (60 °C)										
10.0039	1.99	2.42	55.05	444.6	0.338	56.67	0.30	159.0	291.1	0.974
10.0148	2.55	3.28	54.72	441.9	0.336	56.32	0.29	166.8	281.1	0.940
10.2943	2.97	3.65	53.78	434.3	0.328	55.25	0.30	179.2	268.5	0.898
10.0065	3.44	4.31	55.56	448.7	0.299	56.98	0.29	229.1	226.6	0.758
10.0314	3.97	5.15	55.86	451.1	0.244	56.95	0.30	318.2	141.1	0.472
10.0081	4.41	5.83	55.71	449.9	0.197	56.54	0.28	404.3	53.6	0.179
10.0235	5.32	6.68	55.61	451.0	0.164	56.23	0.30	453.3	5.1	0.017
10.0083	5.48	6.96	55.84	449.1	0.161	56.45	0.30	451.7	4.6	0.015

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (25 °C)										
10.0129	1.99	2.41	55.05	451.5	0.139	55.69	0.13	183.3	271.1	0.907
10.0035	2.54	3.07	54.99	451.0	0.137	55.61	0.14	191.0	262.7	0.879
10.0047	2.93	3.51	55.10	451.9	0.133	55.69	0.15	205.4	249.3	0.834
10.0111	3.48	4.38	55.04	451.4	0.120	55.57	0.14	259.7	195.0	0.652
10.0086	4.25	5.37	54.55	447.4	0.092	54.91	0.14	376.9	74.0	0.248
10.0063	4.87	6.15	54.29	445.3	0.078	54.57	0.15	432.2	16.5	0.055
10.0077	5.38	6.79	54.31	445.4	0.075	54.57	0.15	445.2	3.5	0.012
10.0018	5.93	7.22	55.02	451.2	0.073	55.29	0.14	451.6	2.9	0.010

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (40 °C)										
10.0100	1.99	2.32	55.66	458.5	0.141	56.26	0.19	202.3	259.2	0.867
10.0080	2.35	2.77	55.44	456.7	0.140	56.03	0.19	206.6	253.1	0.847
10.0040	3.03	3.59	55.58	457.8	0.136	56.15	0.19	223.7	237.2	0.793
10.0089	3.29	4.11	55.46	456.9	0.128	55.99	0.19	251.0	209.3	0.700
10.0065	3.92	4.81	55.28	455.4	0.107	55.68	0.19	341.9	117.2	0.392
10.0206	4.48	5.42	54.20	446.4	0.090	54.49	0.20	398.6	51.6	0.173
10.0162	5.38	6.55	54.52	451.0	0.079	54.76	0.19	446.4	8.1	0.027
10.0067	5.93	7.03	54.74	449.1	0.078	54.97	0.20	450.5	2.1	0.007

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (60 °C)										
10.0048	2.01	2.37	55.11	453.5	0.143	55.67	0.24	210.6	246.0	0.823
10.0009	2.43	2.93	55.42	456.0	0.141	55.97	0.24	218.2	240.9	0.806
10.0077	3.15	3.77	55.99	460.7	0.136	56.52	0.24	250.2	214.1	0.716
10.0191	3.42	4.27	55.49	456.6	0.127	55.96	0.24	283.5	177.0	0.592
10.0060	4.08	4.95	55.41	455.9	0.104	55.75	0.24	377.6	82.3	0.275
10.0297	4.80	5.82	55.33	455.3	0.089	55.57	0.26	437.9	21.4	0.072
10.0081	5.56	6.59	54.05	444.8	0.086	54.26	0.25	444.5	4.1	0.014
10.0008	5.99	7.07	55.06	453.1	0.085	55.27	0.26	455.5	1.5	0.005

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (25 °C)										
10.0025	1.99	2.14	55.45	456.2	0.021	55.46	0.11	335.5	121.4	0.406
10.0015	2.45	3.12	55.46	456.2	0.021	55.47	0.10	344.5	112.4	0.376
10.0069	2.93	3.45	55.43	456.0	0.019	55.43	0.11	355.0	101.9	0.341
10.0015	3.32	3.75	54.77	450.5	0.017	54.76	0.11	363.8	87.3	0.292
10.0177	3.71	4.19	55.33	455.1	0.013	55.29	0.11	395.4	60.3	0.202
10.0074	4.45	4.89	54.71	450.1	0.010	54.64	0.12	431.4	19.2	0.064
10.0002	5.15	5.66	55.45	456.1	0.009	55.38	0.12	451.4	5.1	0.017
10.0095	5.68	6.45	55.85	459.4	0.008	55.79	0.11	459.6	0.0	0.001

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (40 °C)										
10.0923	2.01	2.19	54.99	441.9	0.020	54.94	0.16	338.2	105.3	0.352
10.0366	2.56	3.03	55.57	446.6	0.020	55.52	0.16	349.7	97.9	0.327
10.0768	2.91	3.31	55.08	442.6	0.019	55.03	0.16	351.8	92.2	0.308
10.0113	3.26	3.58	55.39	445.1	0.018	55.31	0.18	364.2	81.6	0.273
10.0059	3.84	4.19	55.79	448.3	0.015	55.70	0.17	398.0	50.9	0.170
10.0844	4.39	4.72	55.71	447.7	0.011	55.62	0.15	428.2	20.2	0.068
10.0222	4.68	5.16	56.55	454.4	0.010	56.44	0.17	445.4	9.5	0.032
10.0031	5.16	5.58	56.75	456.0	0.009	56.64	0.16	452.3	4.1	0.014

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$W_{w,o}$	$C_{g,w}$	$C_{g,o}$	$C_{a,w}$	$C_{a,o}$	Z
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (60°C)										
10.0027	2.02	2.21	54.33	447.4	0.020	54.24	0.20	358.6	89.6	0.300
10.0228	2.48	2.66	54.27	446.9	0.019	54.18	0.19	361.2	86.6	0.290
10.0230	2.89	3.05	54.99	452.9	0.018	54.90	0.19	372.0	81.7	0.273
10.0025	3.02	3.38	55.15	454.2	0.017	55.06	0.19	379.9	74.9	0.251
10.0075	3.92	4.26	55.39	456.2	0.014	55.28	0.19	425.3	31.5	0.105
10.0032	4.40	4.77	55.29	455.3	0.012	55.17	0.19	440.2	15.6	0.052
10.0066	4.75	5.21	54.71	450.6	0.011	54.57	0.20	445.3	5.8	0.019
10.0076	5.58	6.01	56.08	461.8	0.010	55.95	0.19	459.6	2.7	0.009

Table B-2-2. The Results of Acid Concentrations in Organic Phase Using different Methods (lactic acid and glucose to be extracted)

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 85% 1-octanol (25 °C)						
10.0166	1.99	2.49	55.91	462.0	314.9	314.4
10.0385	2.49	3.55	55.28	456.8	306.0	305.8
10.0234	3.08	4.29	55.11	454.4	279.6	280.0
10.0085	3.69	5.28	55.64	459.8	196.1	196.1
10.0345	4.37	6.36	54.20	447.7	56.3	56.0
10.0030	4.88	6.99	54.23	448.1	15.7	16.0
10.0153	5.19	7.05	55.49	458.5	12.3	12.4
10.0001	5.66	7.63	55.49	458.5	3.2	3.9

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 85% 1-octanol (40 °C)						
10.0190	2.44	2.97	55.32	451.5	296.8	295.1
10.0042	2.68	3.88	55.46	452.2	284.0	184.9
10.0116	3.38	4.76	55.53	452.8	229.1	229.4
10.0071	3.74	5.34	55.45	452.2	146.5	146.7
10.0079	4.25	5.95	55.80	455.0	68.4	68.6
10.0135	4.71	6.44	55.58	453.2	28.8	29.1
10.0043	5.26	6.67	55.88	455.7	15.2	14.8
10.0124	5.61	7.35	55.13	449.6	8.6	8.3

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 85% 1-octanol (60 °C)						
10.0039	1.99	2.42	55.05	444.6	291.1	291.1
10.0148	2.55	3.28	54.72	441.9	281.1	281.0
10.2943	2.97	3.65	53.78	434.3	268.5	268.6
10.0065	3.44	4.31	55.56	448.7	226.6	226.7
10.0314	3.97	5.15	55.86	451.1	141.1	141.9
10.0081	4.41	5.83	55.71	449.9	53.6	53.7
10.0235	5.32	6.68	55.61	451.0	5.1	5.5
10.0083	5.48	6.96	55.84	449.1	4.6	5.2

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (25 °C)						
10.0129	1.99	2.41	55.05	451.5	271.1	271.5
10.0035	2.54	3.07	54.99	451.0	262.7	263.0
10.0047	2.93	3.51	55.10	451.9	249.3	249.0
10.0111	3.48	4.38	55.04	451.4	195.0	195.8
10.0086	4.25	5.37	54.55	447.4	74.0	74.0
10.0063	4.87	6.15	54.29	445.3	16.5	16.3
10.0077	5.38	6.79	54.31	445.4	3.5	3.6
10.0018	5.93	7.22	55.02	451.2	2.9	2.9

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (40 °C)						
10.0100	1.99	2.32	55.66	458.5	259.2	258.5
10.0080	2.35	2.77	55.44	456.7	253.1	253.4
10.0040	3.03	3.59	55.58	457.8	237.2	237.0
10.0089	3.29	4.11	55.46	456.9	209.3	208.4
10.0065	3.92	4.81	55.28	455.4	117.2	117.7
10.0206	4.48	5.42	54.20	446.4	51.6	51.9
10.0162	5.38	6.55	54.52	451.0	8.1	8.4
10.0067	5.93	7.03	54.74	449.1	2.1	2.1

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 42.5% 1-octanol and 42.5% dodecane (60 °C)						
10.0048	2.01	2.37	55.11	453.5	246.0	246.0
10.0009	2.43	2.93	55.42	456.0	240.9	241.1
10.0077	3.15	3.77	55.99	460.7	214.1	214.4
10.0191	3.42	4.27	55.49	456.6	177.0	176.3
10.0060	4.08	4.95	55.41	455.9	82.3	83.0
10.0297	4.80	5.82	55.33	455.3	21.4	21.1
10.0081	5.56	6.59	54.05	444.8	4.1	4.8
10.0008	5.99	7.07	55.06	453.1	1.5	2.2

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (25 °C)						
10.0025	1.99	2.14	55.45	456.2	121.4	121.4
10.0015	2.45	3.12	55.46	456.2	112.4	112.2
10.0069	2.93	3.45	55.43	456.0	101.9	102.2
10.0015	3.32	3.75	54.77	450.5	87.3	86.3
10.0177	3.71	4.19	55.33	455.1	60.3	59.5
10.0074	4.45	4.89	54.71	450.1	19.2	17.9
10.0002	5.15	5.66	55.45	456.1	5.1	4.5
10.0095	5.68	6.45	55.85	459.4	0.0	0.6

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (40 °C)						
10.0923	2.01	2.19	54.99	441.9	105.3	105.2
10.0366	2.56	3.03	55.57	446.6	97.9	98.5
10.0768	2.91	3.31	55.08	442.6	92.2	93.2
10.0113	3.26	3.58	55.39	445.1	81.6	82.6
10.0059	3.84	4.19	55.79	448.3	50.9	51.4
10.0844	4.39	4.72	55.71	447.7	20.2	20.0
10.0222	4.68	5.16	56.55	454.4	9.5	9.2
10.0031	5.16	5.58	56.75	456.0	4.1	3.4

W_s	pH_i	pH_f	$C_{g,i}$	$C_{a,i}$	$C_{g,o}$ (balance)	$C_{g,o}$ (titration)
15% Alamine 336 with 8.5% 1-octanol and 76.5% dodecane (60°C)						
10.0027	2.02	2.21	54.33	447.4	89.6	90.0
10.0228	2.48	2.66	54.27	446.9	86.6	86.1
10.0230	2.89	3.05	54.99	452.9	81.7	81.8
10.0025	3.02	3.38	55.15	454.2	74.9	74.2
10.0075	3.92	4.26	55.39	456.2	31.5	31.9
10.0032	4.40	4.77	55.29	455.3	15.6	15.9
10.0066	4.75	5.21	54.71	450.6	5.8	5.7
10.0076	5.58	6.01	56.08	461.8	2.7	2.1

B.3 Measurement of Partition Coefficient P

The results of the extraction experiments of lactic acid by 100% 1-octanol are shown in Table B-3. The initial concentration of glucose is 55 mM.

Table B-3. Data for Extraction of Lactic Acid by 100% 1-octanol

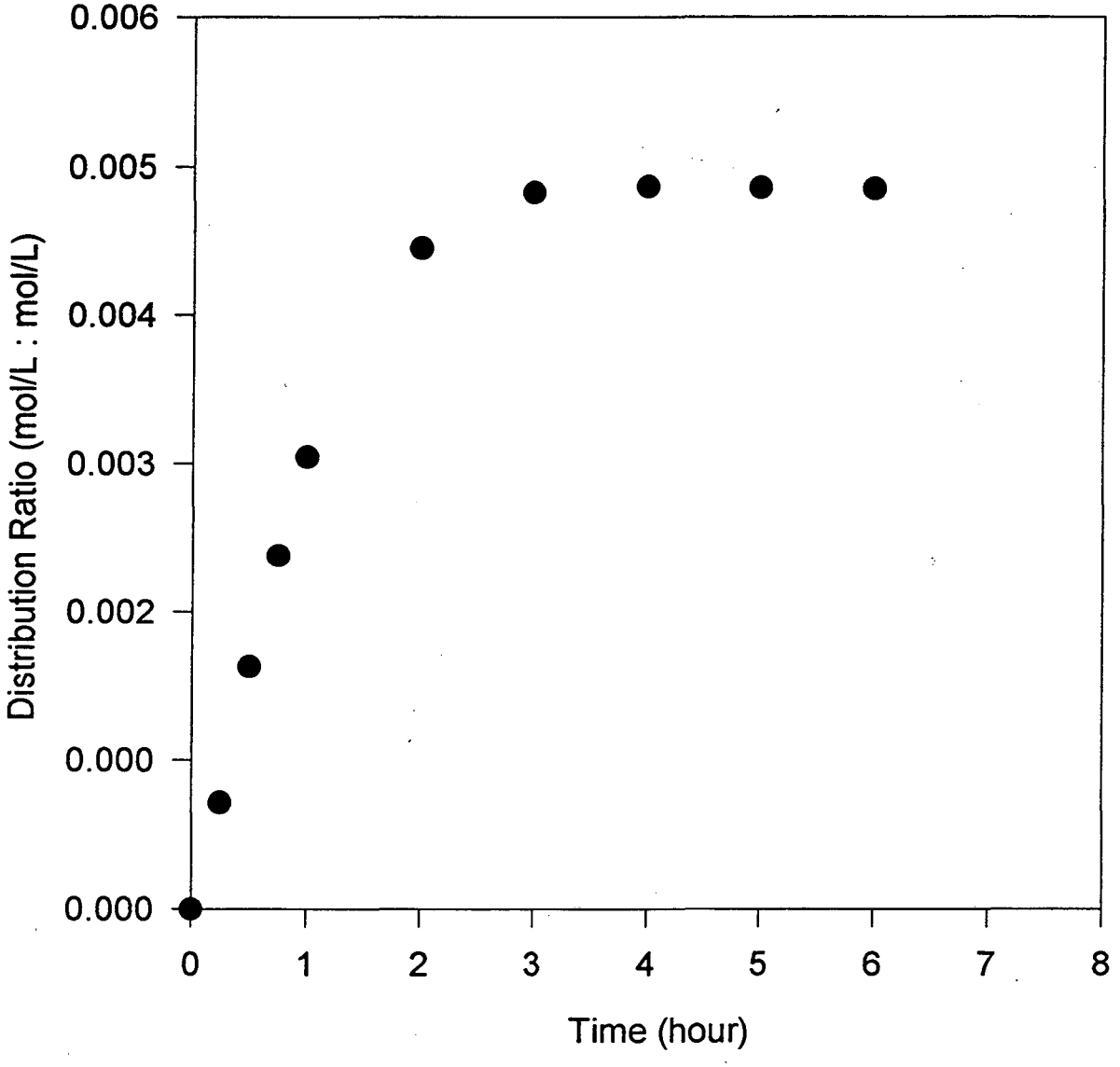
temperature (°C)	$C_{g,i}$	$C_{a,i}$	$C_{a,w}$	$C_{a,o}$	P
25	55.0	486.8	404.9	83.0	0.205
	55.0	363.8	303.0	62.1	0.205
	55.0	243.3	201.8	41.3	0.205
	55.0	122.0	101.3	20.7	0.204
40	55.0	486.8	400.5	86.5	0.216
	55.0	363.8	299.1	64.3	0.215
	55.0	243.4	199.9	43.0	0.215
	55.0	122.0	100.1	21.5	0.215
60	55.0	486.8	396.5	90.4	0.228
	55.0	363.8	296.5	67.6	0.228
	55.0	243.4	198.4	44.9	0.226
	55.0	122.0	100.2	22.8	0.228

B.4 Extraction Kinetics

The results of the extraction kinetics experiment of glucose are shown in Table B-4.

Table B-4. Data of Extraction Kinetics of Glucose

t(hr)	W_s	V_o	$C_{g,i}$	Q_w	$C_{g,w}$	$C_{g,o}$
15% Alamine 336 in 85% 1-octanol (25 °C)						
0.25	10.0213	10.00	56.10	3.04	56.20	0.0893
0.50	10.0129	10.00	56.10	4.37	56.21	0.1738
0.75	10.0081	10.00	56.10	6.36	56.26	0.2828
1.00	10.0065	10.00	56.10	11.90	56.48	0.5387
2.00	10.0154	10.00	56.10	20.02	56.78	0.9177
3.00	10.0058	10.00	56.10	23.23	56.91	1.0933
4.00	10.0082	10.00	56.10	23.69	56.93	0.2772
5.00	10.0136	10.00	56.10	23.90	56.94	0.2767
6.00	10.0000	10.00	56.10	24.50	56.97	0.2765



Kinetics for Extraction of Glucose by 15% (v/v) Alamine 336 with 85% (v/v) 1-octanol at 25 °C

$C_{g,i}$ =1.0 %, Phase Ratio = 1.0

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