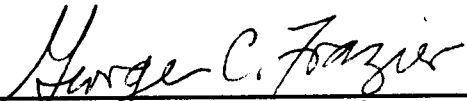
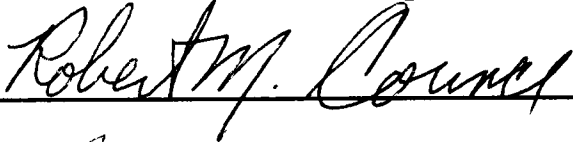


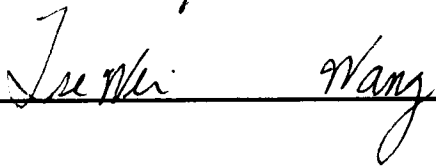
To the Graduate Council:

I am submitting herewith a thesis written by Golbarg Dehkordi Smith entitled "Evaporation Of A Volatile Solute From An Aqueous Spray Pond." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Chemical Engineering.


George C. Frazier, Major Professor

We have read this thesis
and recommend its acceptance:





Accepted for The Council:


Vice Provost
and Dean of The Graduate School

EVAPORATION OF A VOLATILE SOLUTE
FROM AN AQUEOUS SPRAY POND

A Thesis
Presented For The
Master Of Science
Degree
The University Of Tennessee, Knoxville

Golbarg Dehkordi Smith
August 1987

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ABSTRACT

Volatile contaminants in industrial waste or process water may be stripped from the water during cooling in spray ponds. However, a methodology is not known for quantitatively estimating the extent to which such contaminants are transferred to the atmosphere during the cooling process. An experimental program was therefore undertaken in a laboratory scale spray pond in order to provide sufficient data for the test of a simple model of the solute loss process from an aqueous phase, under conditions approximating those occurring in practical systems.

Twenty-five essentially isothermal experimental runs using methanol as solute were made with pool temperatures in the range of 8.0 to 46.0°C. The data yielded correlation coefficients, with a model equation based on a simple mass balance, in all cases of greater than 0.99. Eight of the runs yielded correlation coefficients of 0.999 or greater. It is concluded that the simple model is adequate for estimating volatile solute loss rates from spray ponds of this type.

An empirical correlation is also derived which provides the temperature and nozzle flow rate dependence

of the overall mass transfer coefficient-spray surface area product for the methanol-water system.

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LIST OF SYMBOLS

- a_s = Effective surface area of spray, cm^2 .
 A_i' = Relative peak area in the standard solution.
 A_i = Relative peak area of the same component when analyzing the sample.
 C_A = Methanol concentration in the pond, mole/cm^3 .
 $\bar{C}_A$ = Bulk concentration in a droplet, mole/cm^3 .
 C_{A0} = Methanol concentration at $t=0$, mol/cm^3 .
 C_A^* = Methanol concentration in the air in equilibrium with methanol at the surface of the liquid.
 C_i' = Concentration of component "i" in the standard solution.
 C_i = Uncorrected concentration value of "i" in the sample.
 d_i = Constants.
 N_A = Flux of A, $\text{mole}/\text{cm}^2 \cdot \text{hrs}$.
 F = Flow rate, gpm .
 K_G, K_L = Overall mass-transfer coefficient, $\text{mol}/(\text{hr} \cdot \text{cm}^2 \cdot \text{mol}/\text{cm}^3)$
 K_Y, K_X = Overall mass-transfer coefficient, $\text{mol}/(\text{hr} \cdot \text{cm}^2 \cdot \text{mole fraction})$
 k_Y, k_X = Mass-transfer coefficient, $\text{mol}/(\text{hr} \cdot \text{cm}^2 \cdot \text{mole fraction})$
 PH = Peak Height

t = Time, hr.

T = Temperature, $^{\circ}\text{K}$.

= Turn over time, hr.

V = Volume of the solution in the pond, cm^3

$x_{A,L}$ = Concentration of A in the main body of the liquid,
mole fraction

$x_{A,i}$ = Concentration of A at the interface, liquid side,
mole fraction

x_A^* = Concentration of A in the liquid side in
equilibrium with bulk concentration in the gas
side

$y_{A,G}$ = Concentration Of A in the main body of the liquid,
mole fraction

$y_{A,i}$ = Concentration Of A at the interface, gas side, mole
fraction

y_A^* = Concentration of A in the gas side in
equilibrium with bulk concentration in the liquid
side

1. INTRODUCTION

Industrial waste water and process water is varied in nature and may contain a diverse collection of chemicals which is used in or generated by manufacturing processes. These chemical impurities, generally present in small amounts, originate from operations such as raw material handling and the processing of these materials to final products. Many of these impurities are volatile and it is not uncommon for the process or waste water stream to require cooling before its reuse or discharge to the environment [1].

One common method of cooling process or waste water is by use of a spray pond. In this method of cooling, the water is pumped through nozzles above a basin where the resulting spray promotes evaporative cooling as the water droplets fall in the pond or basin. Volatile components in the water will also transfer to the air during this process, generating an air pollution problem whose severity will depend on the toxic nature of the volatile chemicals, the size or scale of the operation, and the rate of transfer of the volatile from the water to the air during the spraying process. Evaporation and transfer of volatiles to the air also take place from the surface of the pond.

A quantitative method for predicting the rate of

transfer of volatile impurities to the atmosphere from aqueous sprays apparently is not available at the present time (based on a search of the literature). The objective of this investigation is therefore to develop an experimental data base which can be used to guide the development and testing of a simple model of the mass transfer process for the evaporative solute loss from spray ponds. Such a model, after adequate testing, can be used in the design and operation of spray ponds where volatile components are anticipated, or to determine in advance if excessive, undesirable emissions can be expected during the operation of a proposed spray pond system. Should such be the case, other processing steps, such as impurity recovery, may be required before or in lieu of spray cooling of the aqueous stream.

A specially designed laboratory-scale, spray pond was constructed and operated in this study in order to quantitatively determine the rate of loss of solute from a water spray. Methanol was selected as solute for this study because its vapor pressure is appreciably greater than that of water in the experimentally accessible temperature range (about 8.0-46.0°C). Its vapor pressure above water is well known. It's concentration at moderately low levels (e.g., 0.1-5 mole%) in water is readily determined by gas chromatography; and it is relatively non-toxic at low concentrations in air. A

series of isothermal experimental runs was made over the temperature range of 8.0°C to 46.0°C, using a single spray nozzle which was selected to produce a relatively flat spray.

The experimental data is interpreted in terms of a simple model of the process. This model is developed in Section 2.3.3. While the model equation correlates the data of a given isothermal experimental run quite well, additional work and model development appears to be required before the effect of temperature on the solute loss rate is completely understood.

2. BACKGROUND

Typically, spray ponds have been used for cooling power plants. Also, they have been used for mass-transfer purposes such as the aeration of waste treatment plants. Previous studies of direct contact evaporation cooling and of mass-transfer between a process stream and atmosphere (such as a cooling tower or the air stripping of volatile from a secondary waste treatment plant), are not pertinent to this study, and are not covered in this review.

2.1 Direct Contact Mass Transfer

Natural and artificial basins are often used as aerobic biochemical oxidation for neutralization of organic waste water [1]. Carbonaceous compounds in the waste water are converted to carbon dioxide and water by a mixed culture of microorganisms. Carbon compounds are used as an energy source. Oxygen must be available and mechanical means are frequently employed to increase the rate of transfer and supplement the natural absorption processes. One method of promoting aeration is to spray the water through nozzles in such a manner that relatively fine droplets are dispersed in the air above the pond. Air is transferred into the droplets as they fall back in to the pond.

2.2 Mechanical Aspects

Many types of industrial processes create unwanted heat that must be dissipated. While smaller amounts can be directly ejected into the atmosphere, larger heat amounts must be dissipated via cooling water. The water, if copious amounts are available, may be discharged or else cooled and then recirculated.

2.2.1 Methods

As a practical example of liquid in gas dispersion, cooling ponds can be used for evaporation. Water can be cooled in a steady-flow process that utilizes both mass and energy transfer for the purpose of reducing water temperature by exposing such water to the atmosphere as an extended surface. Perry [2] states that where large ground areas are available, cooling ponds offer a satisfactory method of removing heat from water. Four primary processes for heat-transfer are involved in open pond-cooling. These processes are: evaporation, convection, and radiation, all of which help dissipate heat. The fourth process is solar radiation in which heat gain is the result. Other relevant factors affecting pond efficiency are air temperature, relative humidity, wind velocity, and the amount of solar radiation. Minor factors include heat transfer between the pond and the earth, changing air temperatures, rain,

and the general moisture content of air mass [2].

Spray ponds provide a means for lowering the temperature of water by evaporative cooling and, in so doing, greatly reduce the cooling area required in comparison with a cooling pond. The spray helps to greatly expand the available surface area. As the water rises and falls, evaporation cooling occurs which accounts for most of the heat-transfer. Thus, this technique can result in more efficiency and perhaps even more importantly, less size than for a cooling pond. However, the potential cost saving may well be offset by increased costs caused by the expenses of pumping, supports, piping cost, spray nozzles and other auxiliary equipment [3].

2.2.2 Equipment

The production of a spray of water, oil, or other liquid is most satisfactorily accomplished by means of properly designed nozzle to which the liquid is delivered under pressure.

Among mechanical considerations, the spray nozzle should not produce such a fine mist that it would not fall back into the pool. A fine mist does improve performance as long as loss from wind drift is not excessive. The reason small droplets are favored is because the heat or mass transfer that a dispersion can

produce is often proportional to $(1/D)^2$ where D is the droplet diameter [2]. A long, narrow pond is more efficient than a square one. This is due to the simple fact that more wind is likely to strike the droplets with such an arrangement. Therefore, a pond should be oriented perpendicular to the prevailing summer wind. Efficiency and performance can also be improved by increasing the volume of water sprayed per unit of pond area, by increasing nozzle height, and by increasing droplet height [2].

The nozzles may be of four basic types [4]:

1. High pressure liquid inlet, which causes droplet formation by impact with air, another jet, or a fixed plate. Simpson and Lynn [5], for example, used a nozzle of this type, a jet impingement nozzle, in their investigation of vacuum-spray stripping of sparingly soluble gases from aqueous solution. Lin et al. [6] used another variation of this basic concept, a fan spray nozzle, in their study of the vacuum stripping of refrigerants in water sprays.
2. Rotating nozzle (or spinning atomizer) in which low pressure is fed to the center of a rotation disk or cup and is thrown off at high speed.
3. Gas atomizing, in which a high velocity gas strikes the liquid jet with sufficient energy to break it into droplets.

4. Centrifugal spray nozzles, in which the liquid is caused to swirl by vanes or by entering the nozzle chamber more or less tangentially to the nozzle axis, so that the jet ejects in a centrifugal; fashion as a sheet of expanding diameter until it breaks into droplets. Simpson and Lynn [5] also used a nozzle of this type in their investigations.

The nozzle used in this investigation is best categorized as type 4. A description of this nozzle and the reason for its selection are provided in section 3.1.

2.3 Modeling Of Spray Pond

2.3.1 Transfer Of A Solute Through A Liquid-Gas Interface

This process is treated as a mass transfer process, occurring over four relatively distinct steps. Weber and others [7,8,2], show these four steps. First, the solute must simply pass through the liquid phase to the liquid-gas interface. Secondly, the solute passes through a "liquid-film" which is located on the liquid side of the interface and then on through a "gas-film" on the gas side of the interface for the third step of the transfer. Finally the solute must then be dispersed throughout the vapor phase. The rate limiting step during this process is deemed to be the step that take

the longest amount of time under a given set of conditions. Based on this step alone, rate calculations on the solute rate can be made.

The solute transfer flux through the interface can be expressed in terms of an overall driving force based on either liquid-side concentration difference or a gas-side mole fraction difference. These flux equations can be developed by considering either the process of solute transfer from liquid to gas phase, or from gas to liquid phase. Either approach leads to the same equation for the solute transfer flux. Treybal[8] derives these flux equations by considering the transfer of solute from gas to liquid, and it is his development that is summarized here.

Treybal shows the relationship between solute concentration in gas phase and in solution phase. Figure 2.1 represents this relationship. In this diagram:

$y_{A,G}$ =mole fraction of A in the main body of the gas.

$y_{A,i}$ =mole fraction of A at the interface, gas side.

$x_{A,i}$ =mole fraction of A at the interface, liquid side.

$x_{A,L}$ =mole fraction of A in the main body of the liquid.

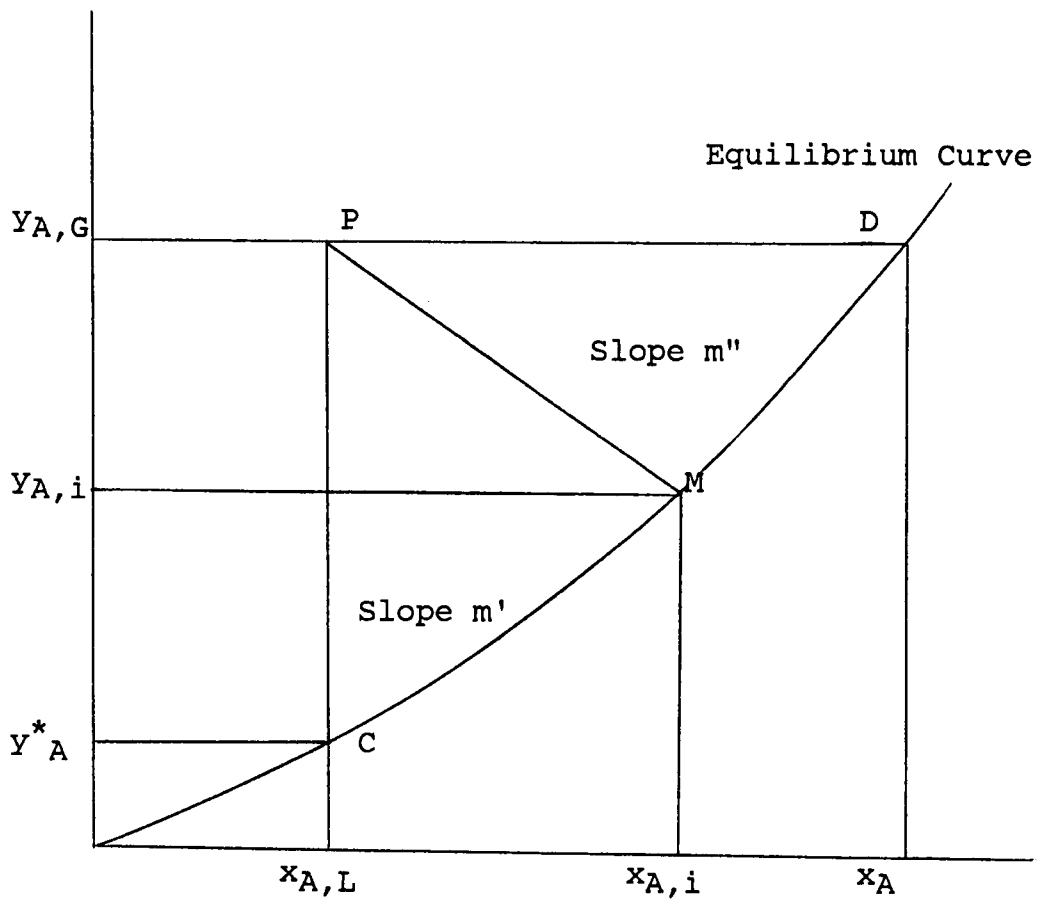


Figure 2.1 Relationship Between Solute Concentration In Gas Phase And In Solution Phase, For Transfer From The Gas To The Liquid Phase.

Point "P" represents the two bulk-phase concentrations and point "M" those at the interface. Since the equilibrium-distribution curve for the system is unique at fixed temperature and pressure, then y_A^* , in equilibrium with $x_{A,L}$, is as good a measure of $x_{A,L}$ as $x_{A,L}$, itself, and moreover it is on the same basis as $y_{A,G}$. m' and m'' are the slope of the chords CM and MD respectively.

For steady mass transfer, the rate at which "A" reaches the interface from the gas must equal that at which it diffuses to the bulk liquid. One can write the flux of "A" in terms of mass-transfer coefficients for each phase and the concentration changes appropriate to each. Thus, when k_y and k_x are locally applicable coefficients,

$$N_A = k_y(y_{A,G} - y_{A,i}) = k_x(x_{A,i} - x_{A,L}) \quad (2.1)$$

The entire two-phase mass-transfer effect can then be measured in terms of overall mass-transfer coefficient, K_y , defined according to Eq (2.2):

$$N_A = K_y(y_{A,G} - y_A^*) \quad (2.2)$$

This transfer coefficient can be expressed in terms of the individual film coefficients k_y and k_x as shown by Treybal [8].

$$1/K_y = 1/k_y + m'/k_x \quad (2.3)$$

A similar equation can be written for the liquid side:

$$N_A = K_x(x_A^* - x_{A,L}) \quad (2.4)$$

$$1/K_X = 1/k_X + 1/(m''k_Y) \quad (2.5)$$

Rates of dissolution of gases of high solubility in liquid are controlled by rate of transfer across the gas film because, for such system, m' is small (equilibrium-distribution curve very flat). Eq (2.3) shows that the overall transfer coefficient is then essentially equal to the gas phase transfer coefficient.

On the other hand, transfer of gases of low solubility in liquid is usually controlled by the rate of transfer across the liquid side of the interface since for these systems m'' is very large, and as Eq (2.5) shows, the major resistance is in the liquid phase.

Therefore, regardless of which transfer step offers the most resistance to movement of gas, the rate will always be a function of the concentration gradient.

2.3.2 Model Of Unsteady Batch Spray Pond

A search of the literature does not reveal a model of the solute loss rate process from spray ponds. Therefore, the following simplified model is put forward and it is the objective of this work to test this model. Spray ponds in practice may operate in the steady state, or quasi-steady state, with fresh feed supplied to the pond and a withdrawal rate from the pond which matches the feed rate less the evaporative loss rate.

The laboratory spray pond considered here is easier to operate in the unsteady state although the results can be applied to a similar model of the steady state. This experimental arrangement is shown in Figure 2.2. The system consists of an open pond, a recirculation pump, a spray nozzle, a rotameter, and associated plumbing. The pond is initially filled with a volume V , of methanol solution of concentration C_0 moles per unit volume. At time $t=0$, the circulation pump is started so that a steady, spray flow rate of F gallons per minute is produced. On each turnover of the liquid, some of the methanol evaporates into the surrounding air. One may write an overall material balance on the methanol for this mass transfer process as follows:

Rate of accumulation in the pond = Input rate -
Output rate

For this method of operation, the input rate is zero.

$$\text{Rate of accumulation} = d(C_A V)/dt \quad (2.6)$$

Where C_A = bulk concentration of the solute in pond.

$$C_A = C_0 \quad \text{at} \quad t = 0 \quad (2.7)$$

$$\text{Output rate} = a_s N_A \quad (2.8)$$

Where a_s = effective surface area of spray.

According to Eq (2.4)

$$N_A = K_x (x_A^* - x_{A,L})$$

In terms of concentration Eq (2.4) can be written as:

$$N_A = K_L (C_A - C_A^*) \quad (2.9)$$

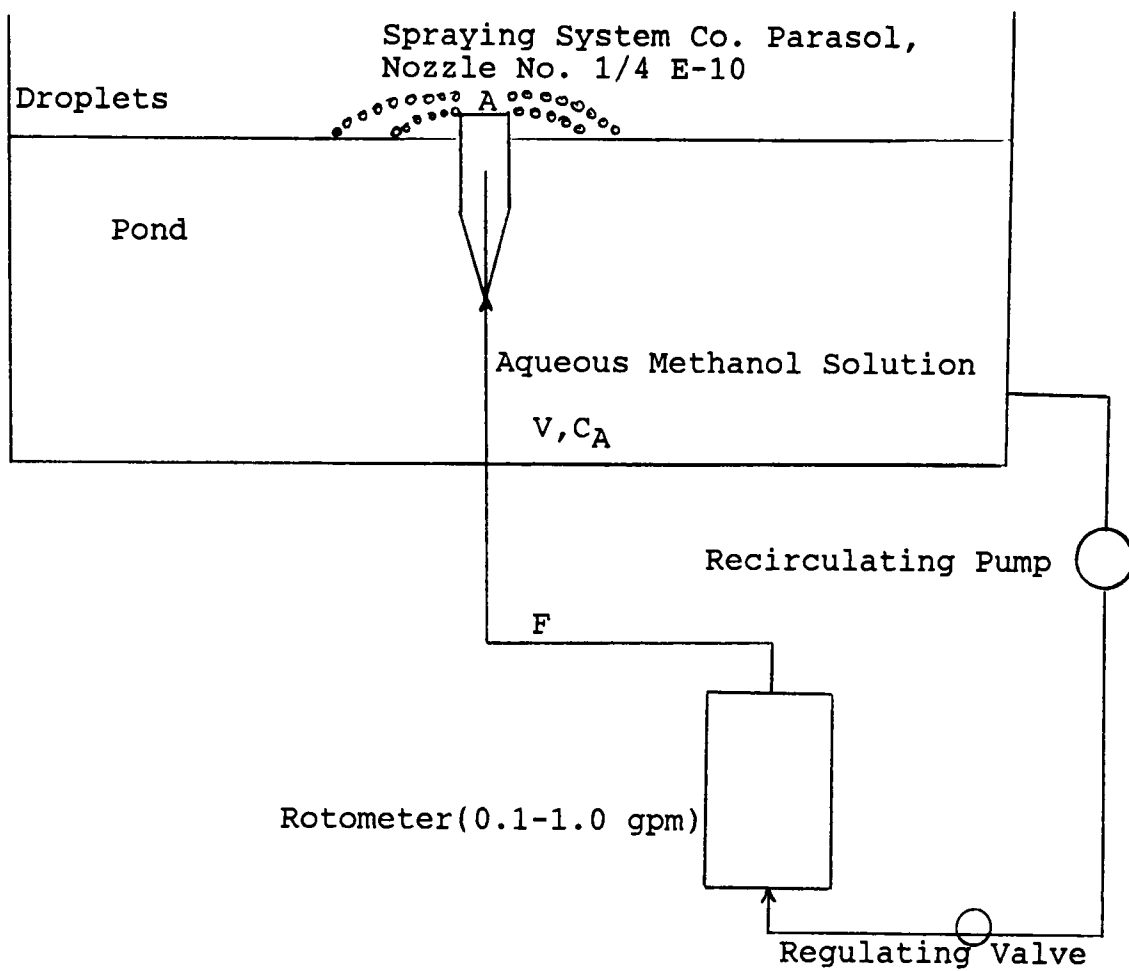


Figure 2.2 A sketch Of The Experimental Apparatus

Where:

$\bar{C}_A$ = bulk concentration in a droplet, averaged over the time of its "life" (i.e. from its formation in the spray to its return to the pond).

$$\bar{C}_A = [\int_0^{t_0} C_A(t) dt] / t_0 \quad (2.10)$$

Where t_0 = "life" time of a droplet

$\bar{C}_A = C_A$ for low solute loss rate from the pond requiring a large number of turn overs to effectively reduce the solute concentration. C_A^* = the methanol concentration in the air in equilibrium with methanol at the surface of the liquid.

Therefore Eq (2.8) becomes:

$$\text{Output rate} = K_L \cdot a_S (C_A - C_A^*) \quad (2.11)$$

Finally, substituting Eqs (2.6) and (2.11) into the unsteady material balance:

$$d(C_A \cdot V)/dt = -K_L \cdot a_S (C_A - C_A^*) \quad (2.12)$$

The solute loss rate from the free surface of the pond is neglected in this model, but may be included for those applicants where appreciable surface evaporation may occur, such as operation with appreciable wind across the pond. Assuming that the volume of water in the pond is essentially constant over the observation period, Eq (2.12) becomes:

$$d C_A / dt = - (K_L \cdot a_S / V) (C_A - C_A^*) \quad (2.13)$$

One may integrate Eq (2.13) using the following restrictions:

1. The spray flow rate and the temperature are constant in time, so the product $K_L.a_S$ is essentially constant during the course of the experiment.

2. In this study methanol in the air surrounding the spray is negligible and as a consequence, $C_A^* = 0$.

The result is, after employing the initial condition Eq (2.7),

$$C_A/C_{A0} = \text{EXP}[-(K_L.a_S/V).t] \quad (2.14)$$

This equation shows an exponential decay of the methanol in the batch pool with time. A plot of the logarithm of C_A / C_{A0} against time should yield a straight line of slope = $- K_L.a_S / V$.

One should realize that the effective interfacial area-transfer coefficient product, $K_L.a_S$ is expected to be a function of spray nozzle type, flow rate through the nozzle, and certain properties such as the surface tension of the liquid. The mass transfer coefficient is also expected to be a function of the experimental pool temperature. One should therefore be able to evaluate the $K_L.a_S$ product for a given set of conditions by measuring the pool concentration at appropriate time intervals and plotting these data as suggested by Eq (2.14).

It is not clear at the outset what the form should be for the functional dependence of $K_L.a_S$ on pool temperature and nozzle flow rate. However, it may be

possible to develop an experimental correlation useful for design purpose in terms of a truncated power series in both absolute temperature, T and flow rate, F . For example, a series terminated at the second order in both T and F and containing their cross product terms may be written as:

$$K_L \cdot a_S = d_0 + d_1 T + d_2 T^2 + d_3 F + d_4 F^2 + d_5 TF + d_6 TF^2 + d_7 T^2 F + d_8 T^2 F^2 \quad (2.15)$$

where T = Temperature, $^{\circ}\text{K}$

F = Flow rate, cm^3/hrs

d_i = Constants, to be determined by regression analysis.

Assuming quadratic forms for the temperature and flow rate dependencies leads to nine constants to be determined, which appears somewhat unwieldy. However, all terms in this expansion may not be significant. Should linear forms for the temperature and flow rate function provide an adequate fit of the data, then only four empirical constants must be determined.

3. EXPERIMENTAL METHOD

The plan is to collect data from a laboratory recirculating spray pond operating under ambient conditions. The data will be interpreted in terms of an unsteady mass balance on a simplified model of the pond spray system as developed in Section 2.3.2.

A series of experiments is performed in which the solute (methanol) concentration in water is determined as a function of time, with water recirculation rate and temperature as parameters. Methanol is selected as the solute because it is relatively volatile, and its vapor pressure over water is well-known. Analytical methods, such as GLC are available for its determination in water at low concentration (e.g. 0.1 to about 5 mole%) and it is relatively nontoxic in air when present in very low concentrations.

3.1 The Laboratory Spray Pond System

The apparatus, depicted in Figure 2.2, consists of a plastic pool approximately 1.8 m (6 ft) in diameter and about 38 cm (15 in) high (see appendix D). The water is recirculated mechanically through nozzle "A" using a centrifugal pump which is located in the center of the pool. This nozzle forms a relatively flat spray, the diameter of which depends on the flow rate. The spray

diameter is about 0.76 m (2 1/2 ft) for a flow rate of 79000 cm³/hrs (0.35 gpm) and increases to about 1.77 m (5.8 ft) for a flow rate of 140000 cm³/hrs (0.6 gpm) for the nozzle used in this work. This property of the nozzle limits the useful range of the nozzle flow because pool sizes larger than about 1.8 m (6 ft) in diameter are not conveniently useful in the laboratory. The droplets formed in the spray fall back into the pool. However, at flow rates of about 140000 cm³/hrs (0.6 gpm) and higher there is some water loss due to water droplets falling beyond the pool boundary. Selective evaporation of the methanol from water occurs because of its higher partial pressure.

A Spraying System Co. Parasol-Type nozzle is chosen to form the spray in this study because they are available in relatively small sizes and they produce relatively flat sprays. Preliminary runs with this nozzle show that water loss from a laboratory scale pool is excessive if the flow rate is not sharply restricted (0.35-0.60 gpm).

The nozzle head is in the shape of an upside down cone. Grooved lines within the cone radiate upward in a spiral manner. The water travels up the groove to the top of the cone where it is freed. The centrifugal force causes the water to come out of the nozzle in a

reasonably flat sheet pattern which then changes in to water droplets.

3.2 Instrumentation

Instrumentation required is a gas chromatograph equipped with a propak Q column to analyze the water samples, a rotameter for determination of the recirculation water flow rate, a thermometer for monitoring the temperature of the pool and of the air, and a sling-psychrometer for determining the relative humidity of the air.

The gas-liquid chromatograph is Beckman model no. Gc-M 1241 Routine S, Cat. No. 913400. See Appendix H for using the GLC. To analyze a sample taken from the pool by GLC, comparison with a standard mixture is necessary. Perkin-Elmer [7] recommends the following method if the sample consists of only a limited number of components each of which is also readily available in pure form, and if the predetermination of the proper response factors would unnecessarily extend the total analysis time. In this technique, first the sample with unknown quantitative composition is analyzed and the relative peak area values are established. A standard mixture consisting of the same components with known concentrations is then analyzed under identical conditions and again the relative peak area values are

calculated. Consequently, uncorrected concentration values for the sample are established:

$$C_i\% = A_i/A_i' \quad C_i'\%$$

(3.1)

Where: A_i' = Relative peak area in the standard solution.

$C_i'\%$ = Concentration of component "i" in the standard solution.

A_i = Relative peak area of the same component when analyzing the sample.

$C_i\%$ = So-called uncorrected concentration value of the same component in the sample.

In certain cases the peak height alone may be used instead of area for the quantitative evaluation of a chromatogram. However, in using peak heights, one should always keep in mind that peak heights are much more dependent on even slight changes in operating conditions than peak areas. A sample peak is given in Appendix G for Run number 9.

In this study component "i" is methanol. Figure 3.1 shows the calibration curve for this component for methanol concentrations in the range of 0.1-10 volume%. The data for this figure is given in Appendix F. The calibration curve is compared with a cubic equation obtained using step wise regression analysis. To get the regression curve one has to force the data through the origin by adding zeros to the data. Comparison between

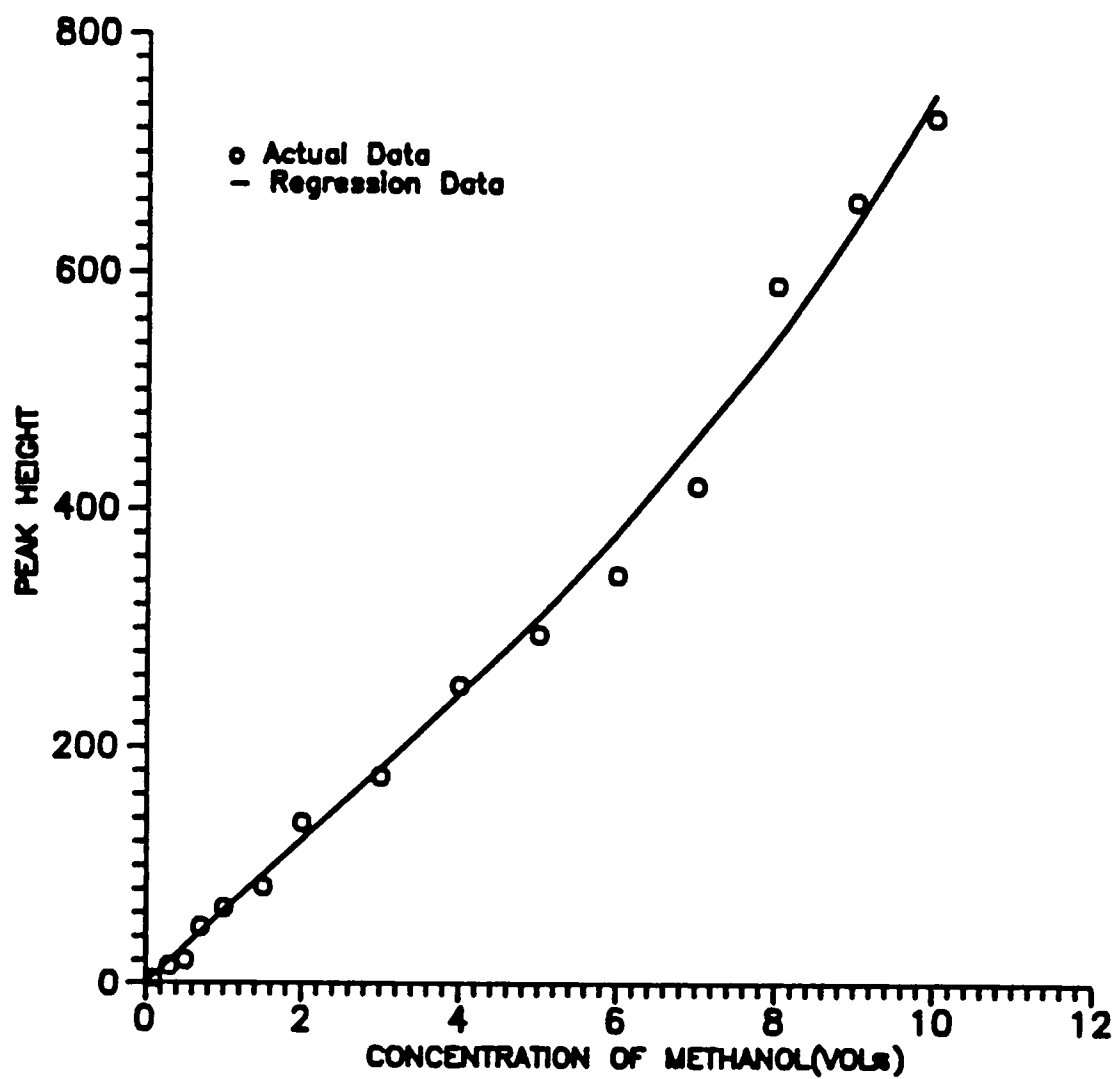


Figure 3.1 Calibration Curve For Standard Solution Of Methanol

these two curves shows as the concentration of methanol goes higher its deviation from the cubic equation curve increases slightly. This is the reason that a low concentration of methanol is chosen in this study (not more than 7 vol%). The cubic fit to the calibration data is as follows:

$$PH = 0.4069109 + 62.93C_A - 1.661C_A^2 + 0.2871C_A^3 \quad (3.2)$$

Where PH = peak height

C_A = concentration of methanol (vol%)

3.3 Experimental Procedure

Initial concentration of about 3 mole% of methanol is made by utilizing a tank on top of a platform scale. The tank is filled with 188.8 kg (416.23 lb) of distilled water (50 gal) and 17.7 kg (38.94 lb) of methanol (5.89 gal). See Appendix D for the sample calculations. The solution is mixed thoroughly with a wooden Paddle and the pool is then filled with this solution to a depth of about three inches. At this point, a sample is taken from the pool which indicates the initial concentration of methanol which should be about 3 mole%. Room temperature and initial temperature of the solution are recorded. However, the pool temperature changes from the initial temperature due to evaporative cooling. The depth of the solution in the pool at the beginning and end of the experiment are also

recorded. The flow rate through the nozzle is set to a preselected value. In this experiment, the flow rate ranges from $68000 \text{ cm}^3/\text{hrs}$ to $130000 \text{ cm}^3/\text{hrs}$ (0.30 to 0.60 gpm) which corresponds to turn over times of 2.40 to 0.98 hour (see Appendix E for sample calculations and values of τ). Samples are then taken from the pool at intervals of every half an hour or every hour except during the night for periods of time from 8 to 24 hours. Since there is a large amount of solution in the pool and it might not mix well, and since the spray nozzle produces an irregular circular pattern, it is best to take three one-ounce samples from three different points of the pool and mix them together. These samples are stored in small glass bottles with a tight cap. Each time a sample is taken, pool temperature and wet and dry bulb air temperature are obtained using a Sling-Psychrometer. Therefore, relative humidity can be determined and recorded. A number of runs are made over a limited water temperature range by circulating hot or cold tap water through an aluminum coil placed below the water level in the pool. In these cases, the water has to run for at least two hours before a steady temperature is obtained. Using the cold or hot tap water, the pool temperature ranged from 8.0°C (281.0°K) to 46.0°C (319.0°K) respectively. However, the majority of the runs are in the ambient temperature range of

about 20.0 to 25.0°C (293 - 298°K). Table 3.1 shows summary data of the twenty-five runs which includes flow rate temperature of the pool, percent water level change in the pool, and ambient temperature and %relative humidity.

The pool is set up in the Unit Operations Laboratory where the air is more or less stagnant. This is so there is not the problem of a prevailing wind blowing past the pond.

Liquid samples are analyzed after the completion of each run. One microliter of each sample is injected into the GLC three times in order to get an accurate result. The analysis of each sample is determined three times by GLC and the results are averaged. Appendix H Shows How To use the GLC in order to analyze each sample.

Table 3.1 Summary Of Raw Data For All The Runs

Run No.	Flow Rate		Water Temp. °K	Water Level Cm		Ambient Temp. °K	%Rel Humidity
	gpm	cm ³ /hr		Start	End		
1	0.30	68138	284+1.0	6.68	6.50	298	38.5
2	0.35	79494	286+1.0	7.95	6.35	301	37.5
3	0.35	79494	296+1.0	7.62	7.32	b	c
4	0.35	79494	306+1.0	7.95	6.35	300	38.0
5	0.35	79494	319+1.0	7.95	5.41	298	40.0
6	0.40	90851	285+0.5	7.95	7.32	298	36.0
7	0.40	90851	295+1.0	7.95	6.68	b	c
8	0.40	90851	306+0.5	7.95	5.72	299	37.0
9	0.40	90851	317+1.0	7.95	5.41	296	38.0
10	0.50	113563	281+1.0	7.95	7.62	295	31.0
11	0.50	113563	285+0.5	7.95	7.32	297	32.0
12	0.50	113563	292+1.0	7.62	6.35	b	c
13	0.50	113563	293+1.0	6.50	a	b	c
14	0.50	113563	293+1.0	7.95	5.41	298	39.0
15	0.50	113563	295+1.0	7.62	a	b	c
16	0.50	113563	304+1.0	7.95	6.05	296	46.0
17	0.50	113563	311+0.5	7.95	5.41	302	42.0
18	0.50	113563	317+1.0	7.95	a	297	c
19	0.60	136276	285+0.5	7.95	7.14	298	33.0
20	0.60	136276	291+1.0	7.62	5.08	b	c
21	0.60	136276	291+1.0	7.62	5.08	b	c
22	0.60	136276	304+1.0	7.95	4.45	298	38.0
23	0.60	136276	305+1.0	7.77	5.56	b	37.0
24	0.60	136276	308+1.0	7.95	2.87	297	50.0
25	0.60	136276	310+0.5	7.95	5.87	298	48.0

a Was not measured, due to excessive water loss from the pool

b Room temperature was not recorded

c Relative humidity was not measured

4. RESULTS AND INTERPRETATION

4.1 Experimental Results

Among twenty five runs eight are chosen to be discussed here (Run number 1,5,6,8,11,16,20,23) and the others are given in appendices A and B. Consider Run number one. During a period of twenty five hours, ten samples are taken (see Table 4.1). The water flow rate is set at $68000 \text{ cm}^3/\text{hrs}$ (0.30 gpm) Starting water temperature is 20.5°C at time zero; however, after one hour a constant temperature of 21.0°C is achieved. The GLC peak height of each sample is recorded using the attenuation " 1×10^4 " in the GLC. This is then converted to the attenuation " 2×10^3 " in order to use the calibration curve given in Figure 3.1. Concentration of methanol is then converted to mole% from Vol%. See Appendix C for this conversion. Other measurements for this run are air temperature 25.0°C (298°K) and relative humidity 38.5%. Figure 4.1 shows methanol concentration (mole%) versus time (hour). The experimental data of Run Number One are shown in this graph against the regression line. Data point number seven is omitted from the regression due to the over night spray nozzle flow rate drop. The correlation coefficient, R , is 0.98781 for this run.

Table 4.2 shows Run number five. The flow rate is

Table 4.1 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.1^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	20.5	62.7	313.3	5.10	2.34
2	1.0	21.0	62.0	310.0	5.08	2.33
3	2.0	21.2	56.5	282.5	4.65	2.13
4	3.0	21.5	56.5	282.5	4.65	2.13
5	4.0	21.8	54.0	270.0	4.45	2.03
6	4.5	21.8	52.0	260.0	4.30	1.96
7 ^d	21.5	21.8	49.3	246.3	4.05	1.85
8	22.0	21.8	45.4	227.0	3.75	1.71
9	22.5	21.8	44.2	221.0	3.61	1.64
10	25.0	22.0	42.0	212.5	3.50	1.61

^a Spraying System Co. Parasol No. 1/4 E-10

^b Flow rate 68138 cm³/hr (0.30 gpm)

^c Using Calibration Curve Figure No.3.1

^d Omitted From Regression (Flow Rate Dropped To 0.20 gpm)

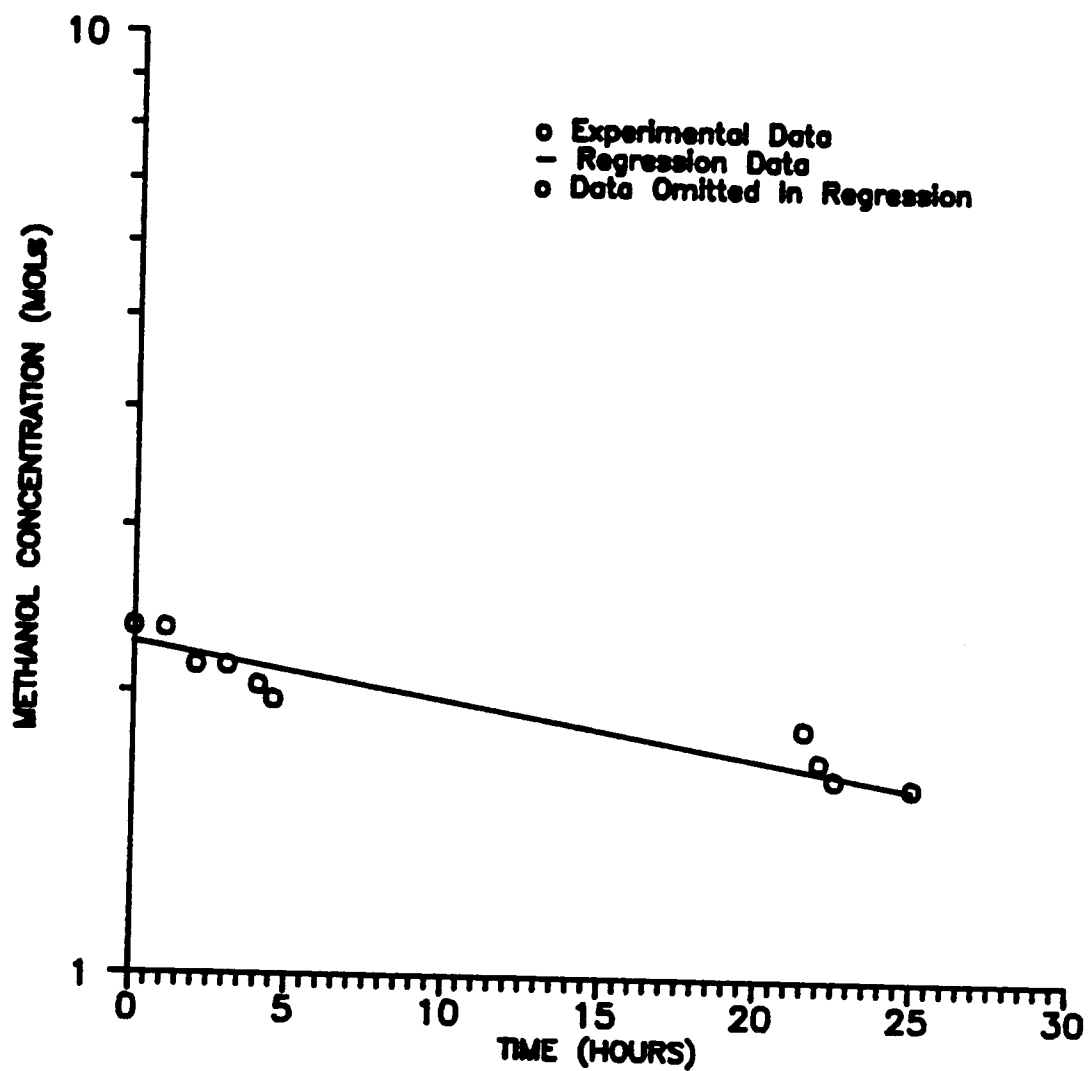


Figure 4.1 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.1

Table 4.2 Evaporation Of Methanol From A Spray Pond, Using
Nozzle A^a, Run No.5^b

Sample No.	Time hrs	Temperature °C	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.0	34.0	64.0	320.0	5.25	2.41
2	0.5	44.0	63.2	316.0	5.20	2.39
3	1.0	45.5	61.0	305.0	5.00	2.29
4	1.5	46.5	51.5	257.5	4.25	1.94
5 ^d	2.0	46.5	60.8	304.0	4.98	2.28
6 ^d	2.5	47.0	55.0	275.0	4.52	2.07
7	3.0	47.0	41.2	206.0	3.42	1.55
8	3.5	47.5	41.0	205.0	3.40	1.54
9	4.0	47.5	38.0	190.0	3.12	1.42
10	4.5	47.5	34.7	173.5	2.85	1.29
11	5.0	48.0	33.4	167.0	2.72	1.23
12	5.5	48.0	32.0	160.0	2.60	1.18
13	6.0	48.0	31.5	157.5	2.58	1.17
14	6.5	48.0	29.0	145.0	2.40	1.08
15	7.0	48.0	26.0	130.0	2.12	0.96

^a Spraying System Co. Parasol No. 1/4 E-10

^b Flow Rate 79494 cm³/hrs (0.35 gpm).

^c Using Calibration Curve Figure No.3.1.

^d Omitted From Regression (Bad Sample Injection)

set to $79000 \text{ cm}^3/\text{hrs}$ (0.35 gpm) There are fifteen samples taken over a period of seven hours. Air temperature is $24.5^\circ\text{C}(297.5^\circ\text{K})$. Water temperature is 34.0°C at time zero; however, after about two hours of running hot water through the coil a constant temperature of $46.0^\circ\text{C}(319^\circ\text{K})$ is gained. The relative humidity is 40.0%. Figure 4.2 shows the methanol concentration versus time for Run number five. Data points five and six are omitted from the regression because their peak heights are out of range. The problem is in the way samples were injected into the GLC. For this run R is 0.99388.

Table 4.3 and 4.4 show Run numbers six and eight. They have a set flow rate of $91000 \text{ cm}^3/\text{hrs}$ (0.40 gpm). Run Number six has ten samples taken over a period of 25.5 hours. Water temperature at time zero is 23.0°C . After running the cold tap water for five hours an average temperature of $12.0^\circ\text{C}(285.0^\circ\text{K})$ is gained. Room temperature is $24.5^\circ\text{C}(297.5^\circ\text{K})$ and relative humidity is 36.0%. Run number eight has seven samples taken over 24.5 hours. Water temperature is $32.5^\circ\text{C}(305.5^\circ\text{K})$ and relative humidity is 37.0% Figure 4.3 and 4.4 represent Run six and Run eight respectively. Experimental data points are plotted against regression line. Correlation coefficient, R, is 0.99395 and 0.99915 respectively.

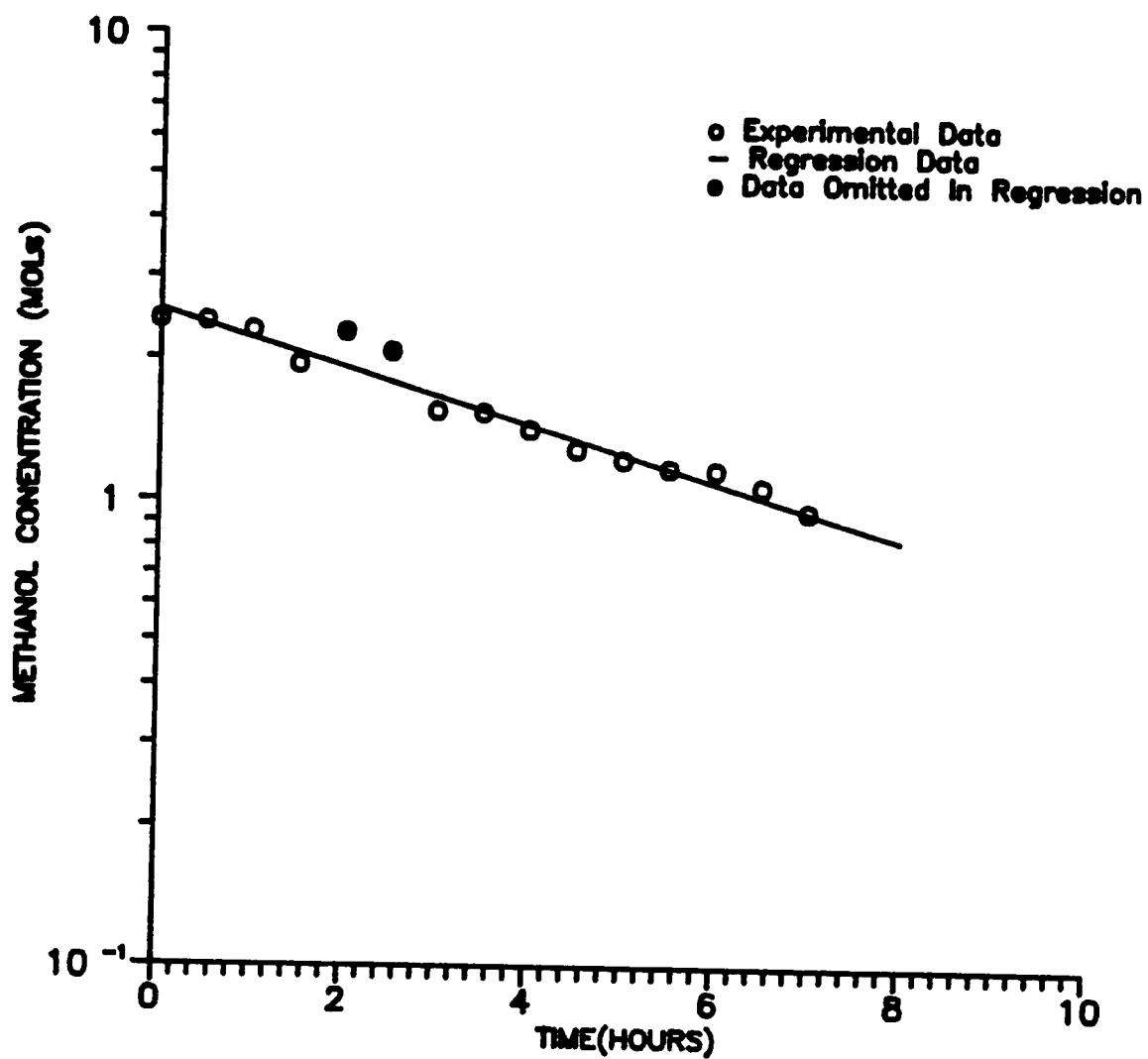


Figure 4.2 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.5

Table 4.3 Evaporation Of Methanol From A Spray Pond, Using
Nozzle A^a, Run No. 6^b

Sample No.	Time	Temperature	Peak Height Concentration ^c			
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	23.0	76.0	380.0	6.02	2.78
2	1.0	17.5	72.0	360.0	5.82	2.68
3	2.0	14.5	74.2	371.0	5.95	2.74
4	3.0	13.8	74.0	370.0	5.95	2.74
5	4.0	13.5	73.0	365.0	5.90	2.72
6	4.5	13.2	73.5	367.5	6.02	2.78
7	23.5	12.0	66.0	330.0	5.40	2.48
8	24.0	12.0	66.0	330.0	5.40	2.48
9	25.0	12.0	64.0	320.0	5.24	2.41
10	25.5	12.0	66.0	330.0	5.40	2.48

^a Spraying System Co, Parasol, No. 1/4 E-10

^b Flow Rate 90851 cm³/hr (0.40 gpm)

^c Using calibration Curve Figure No. 3.1

Table 4.4 Evaporation Of Methanol from A Spray Pond, Using Nozzle A^a, Run No. 8^b

Sample No.	Time hrs	Temperature °C	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	1.0	25.0	66.0	330.0	5.40	2.48
2	2.0	31.5	65.0	325.0	5.30	2.44
3	3.0	32.0	60.0	302.5	4.91	2.25
4	4.0	32.5	56.2	281.0	4.64	2.12
5	23.5	33.0	19.0	95.0	1.59	0.72
6	24.0	33.0	18.0	90.0	1.45	0.65
7	24.5	33.0	17.0	85.0	1.40	0.63

^a Spraying System Co, Parasol, No. 1/4 E-10

^b Flow Rate 90851 cm³/hrs (0.40 gpm)

^c Using Calibration Curve Figure No. 3.1

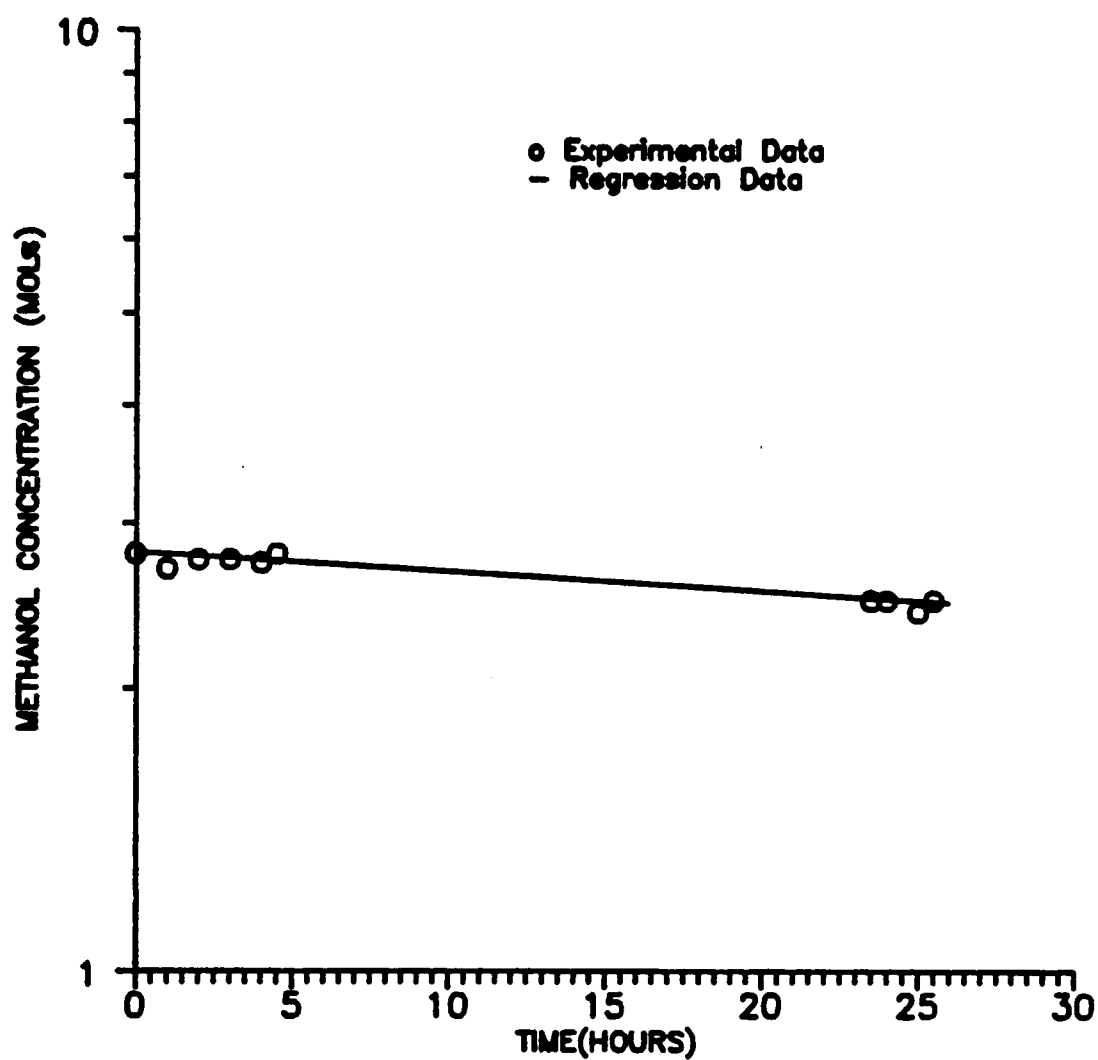


Figure 4.3 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.6

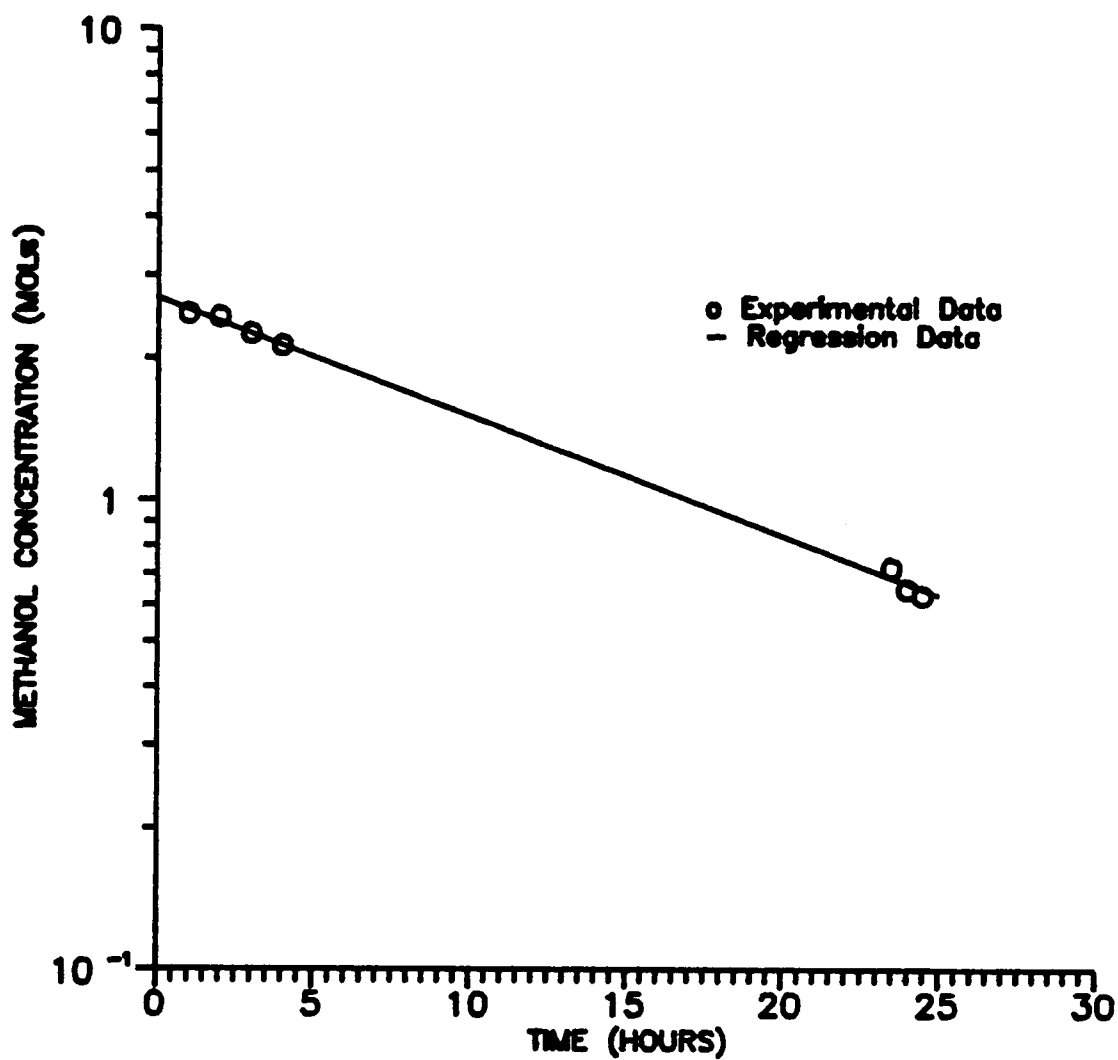


Figure 4.4 Concentration History Of Methanol In A Laboratory Spray Pond, Run NO.8

Tables 4.5 and 4.6 show Run number eleven and sixteen respectively. Both runs have a set flow rate of $110000 \text{ cm}^3/\text{hrs}$ (0.50 gpm). Run eleven has six samples over twenty five hours. Using the cold water running through the aluminum coil, an average temperature of $12^\circ\text{C}(285^\circ\text{K})$ is gained after 17.5 hours. Room temperature is $24.0^\circ\text{C}(297.0^\circ\text{K})$ and relative humidity is 32.0%. Run sixteen has eight samples taken over a period of 24.5 hours. Using hot water instead of cold water in the coil, a temperature of $31.0^\circ\text{C}(304.0^\circ\text{K})$ is obtained. Room temperature is $23.0^\circ\text{C}(296.0^\circ\text{K})$ and relative humidity is 46.0%. Figure 4.5 and 4.6 show methanol concentration versus time for Run eleven and sixteen. Correlation coefficient, R , is 0.99949 for Run eleven and 0.99917 for Run sixteen.

Table 4.7 and 4.8 represent Runs 20 and 23 respectively. The set flow rate is $140000 \text{ cm}^3/\text{hrs}$ (0.60 gpm). Run 20 has twenty five samples taken over a period of twenty five hours. The average water temperature is $18.0^\circ\text{C}(291.0^\circ\text{K})$ and relative humidity is 38.0%. Run number 23 has ten samples taken over twenty two hours. The average water temperature is $32.0^\circ\text{C}(305.0^\circ\text{K})$ using the hot water running through the coil. Relative Humidity is 37.0%. The room temperatures are not available for these two runs.

Table 4.5 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No. 11^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.5	16.5	96.0	480.0	7.30	3.39
2	1.0	14.0	95.0	475.0	7.25	3.37
3	17.5	12.0	84.0	420.0	6.60	3.06
4	23.0	12.0	80.0	400.0	6.35	2.94
5	24.0	12.0	80.6	403.0	6.34	2.93
6	25.0	12.0	80.5	402.5	6.34	2.93

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 113563 cm³/hrs(0.50 gpm)

^c Using Calibration Curve Figure No.

Table 4.6 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No. 16^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	25.0	66.0	330.0	5.40	2.48
2	1.0	28.0	62.0	310.0	5.10	2.34
3	2.0	33.0	57.0	285.0	4.70	2.15
4	5.0	25.0	51.0	255.0	4.20	1.87
5	6.0	30.0	46.5	232.5	3.85	1.75
6	7.0	31.5	44.0	220.0	3.65	0.43
7	24.0	32.0	12.0	60.0	1.00	0.45
8	24.5	32.0	11.0	55.0	0.95	0.43

^a Spraying System Co. Parasol, No.1/4 E-10

^b Flow Rate 113563 cm³/hrs (0.50 gpm)

^c Using Calibration Curve Figure No.3.1

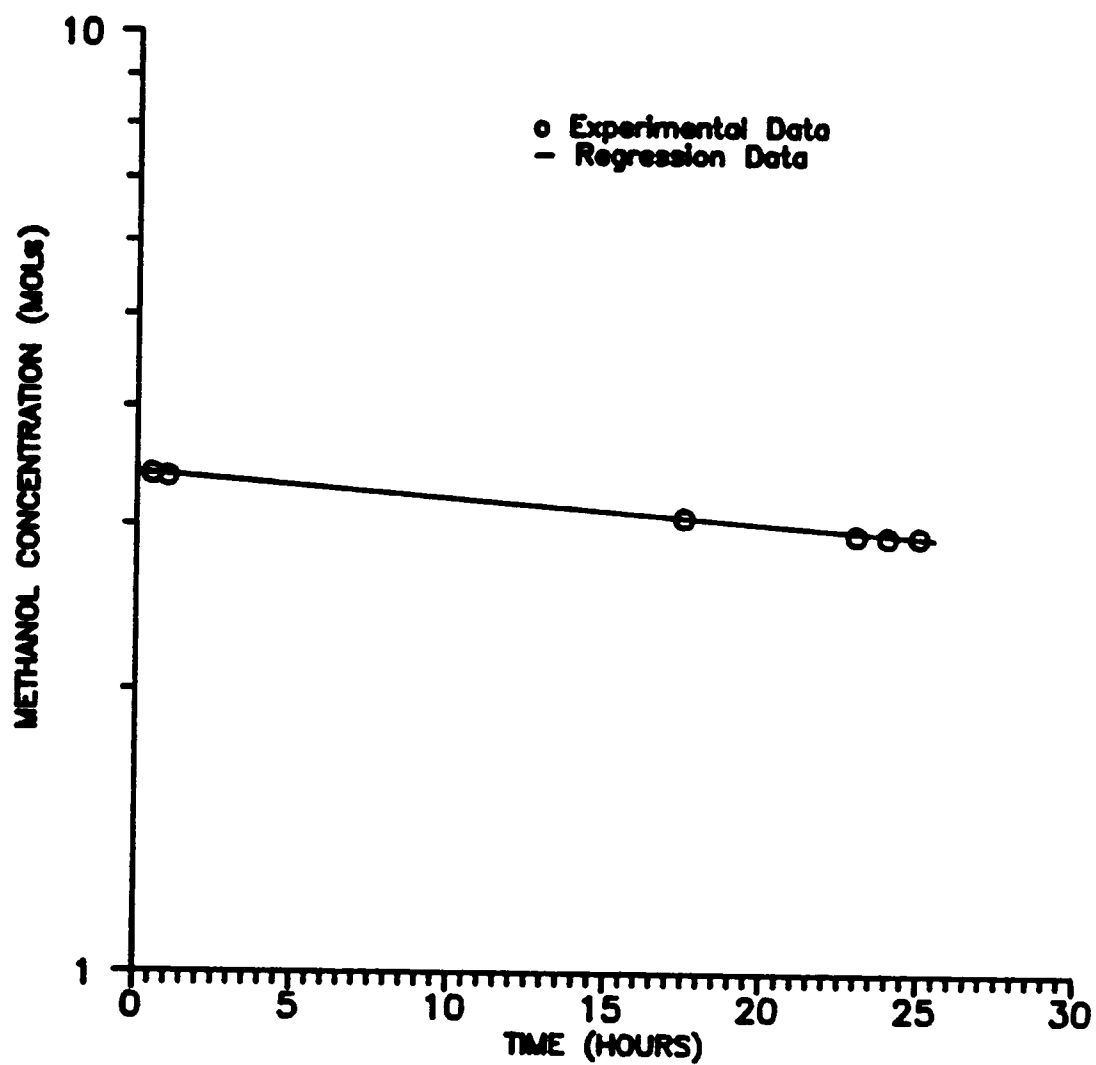


Figure 4.5 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.11

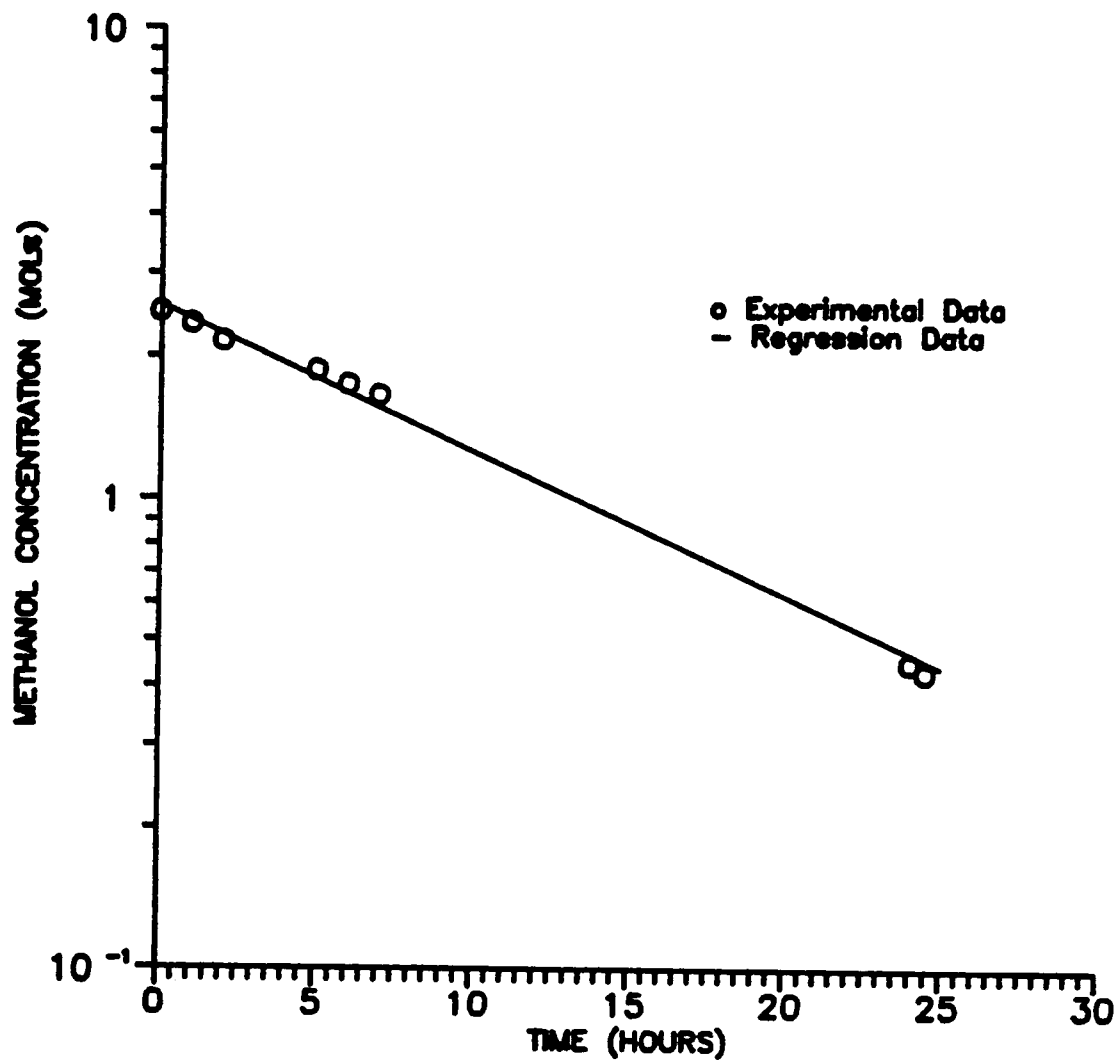


Figure 4.6 Concentration History Of Methanol In A Spray Pond, Run No.16

Table 4.7 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.20^b

Sample No.	Time hrs	Temperature °C	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.0	26.0	102.0	510.0	7.70	3.56
2	0.5	24.0	102.0	510.0	7.70	3.56
3	1.0	22.0	102.0	510.0	7.70	3.56
4	1.5	21.4	94.0	470.0	7.20	3.34
5	2.0	21.0	95.9	479.5	7.30	3.39
6	2.5	20.5	88.8	444.0	6.90	3.20
7	3.0	20.0	88.5	442.5	6.85	3.18
8	3.5	19.7	88.2	441.0	6.83	3.17
9	4.0	19.5	87.5	437.5	6.81	3.16
10	4.5	19.5	82.5	410.0	6.50	3.01
11	5.0	19.1	81.0	405.0	6.40	2.96
12	5.5	19.1	80.8	403.8	6.39	2.95
13	6.0	19.0	73.0	365.0	5.90	2.72
14	6.5	18.5	77.9	389.8	6.20	2.86
15	7.0	18.5	77.7	388.5	6.18	2.85
16	7.5	18.5	77.8	389.0	6.18	2.85
17	8.0	18.5	69.5	347.5	5.63	2.56
18	8.5	18.5	69.2	346.0	5.60	2.58
19 ^d	20.5	17.0	48.6	242.8	3.95	1.80
20 ^d	21.0	17.0	49.9	214.8	3.55	1.62
21 ^d	21.5	17.0	42.7	213.5	3.50	1.61
22	22.0	17.0	38.9	194.8	3.20	1.45
23	22.5	17.0	36.7	183.3	3.00	1.36
24	23.5	17.0	35.5	177.5	2.90	1.31
25	25.0	17.0	33.0	165.0	2.70	1.22

^a Spraying System Co. Parasol No. 1/4 E-10

^b Flow rate 136276 cm³/hrs (0.60 gpm)

^c Using Calibration Curve Figure No.3.1

^d Omitted From Regression (Flow Rate Dropped To 0.50)

Table 4.8 Evaporation Of Methanol From A Spray Pond, Using
Nozzle A^a, Run No. 23^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	28.0	80.0	400.0	6.40	2.96
2	1.0	27.0	71.5	357.5	5.80	2.67
3	1.5	28.0	65.0	325.0	5.31	2.44
4 ^d	2.0	30.0	55.5	277.0	4.60	2.11
5 ^d	6.5	28.0	35.0	175.0	2.90	1.31
6	20.5	24.5	9.5	47.5	0.80	0.36
7	21.0	30.0	9.0	45.0	0.75	0.34
8	21.5	35.0	9.0	45.0	0.75	0.34
9	22.0	34.0	8.8	44.0	0.72	0.32
10	22.5	34.0	7.1	35.5	0.60	0.27

^a Spraying System Co. Parasol, No.1/4 E-10

^b Flow Rate 136276 cm³/hrs (0.60 gpm)

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Bad Sample Injection)

Figure 4.7 and 4.8 show the concentration of methanol versus time for Runs 20 and 25 respectively. Correlation coefficient, R , is 0.99839 for Run twenty and 0.99967 for Run twenty three. For Run twenty, data points 19, 20 and 21 are omitted from the regression data because of the flow rate drop. For Run twenty three, data points 4 and 5 are omitted because their peak heights are out of range. The reason could be the way these two samples were injected into the GLC.

A comparison between all the runs shows that as the temperature and flow rate go higher, evaporation happens faster. However, the temperature raise has a stronger effect on this phenomena.

4.2 Interpretation Of Results

The experimental data, Tables 4.1-4.8 and Tables A.1-A.17, are interpreted in terms of the simple spray pond model as given by equation 2.14. Repeated here for convenience:

$$C_A/C_{A0} = \text{EXP} [-(K_L a_S/V) t] \quad (2.14)$$

as pointed out in Section 2.3.2 this equation predicts that a plot of $\ln(C_A/C_{A0})$ versus t should be a straight line whose slope is $-(K_L a_S/V)$. The data of each run is therefore plotted in Figure 4.1 through 4.8 and B.1 through B.17 in order to test the validity of this prediction. As can be seen when referring to the figures

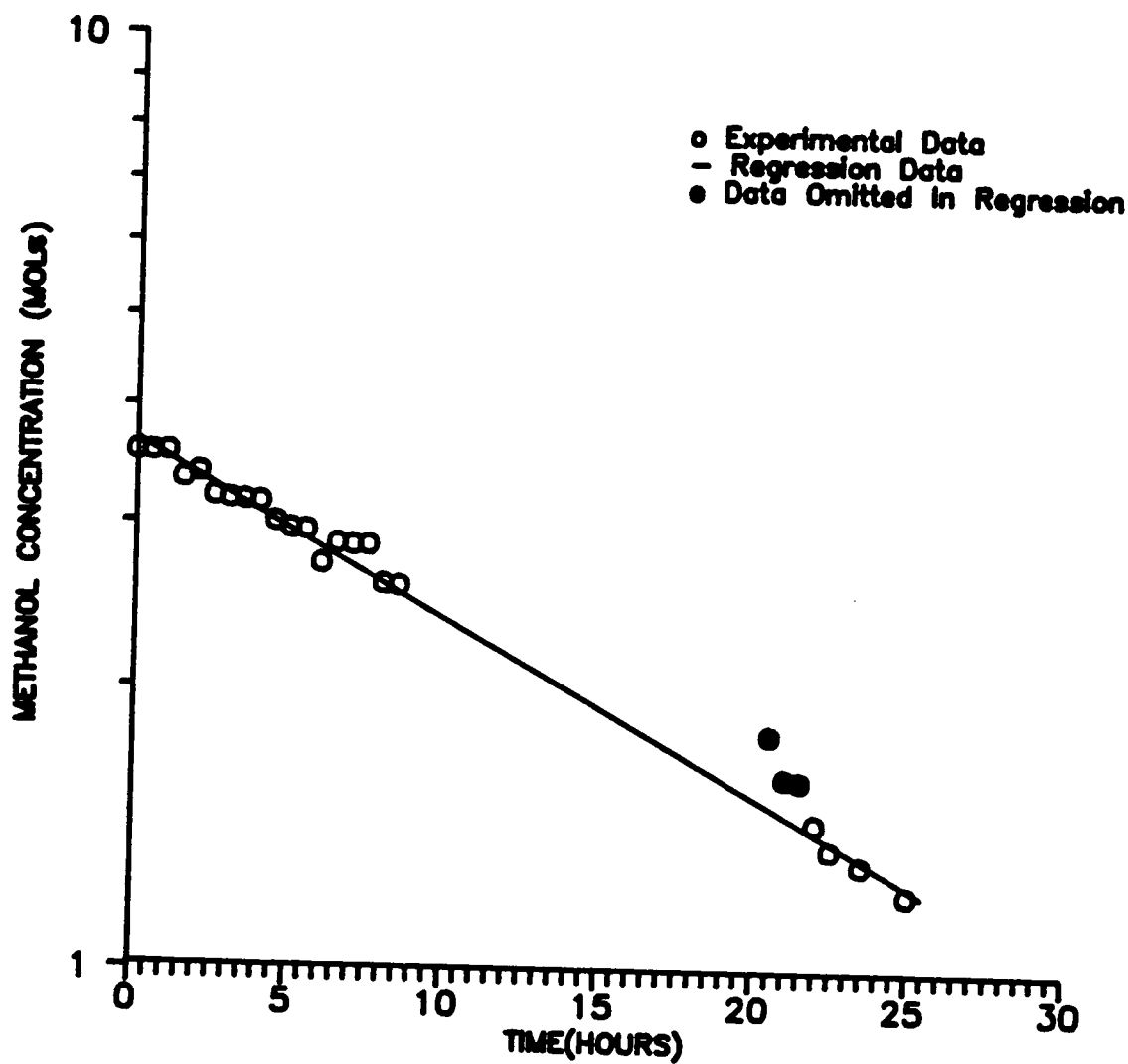


Figure 4.7 Concentration History Of Methanol In A Spray Pond, Run No.20

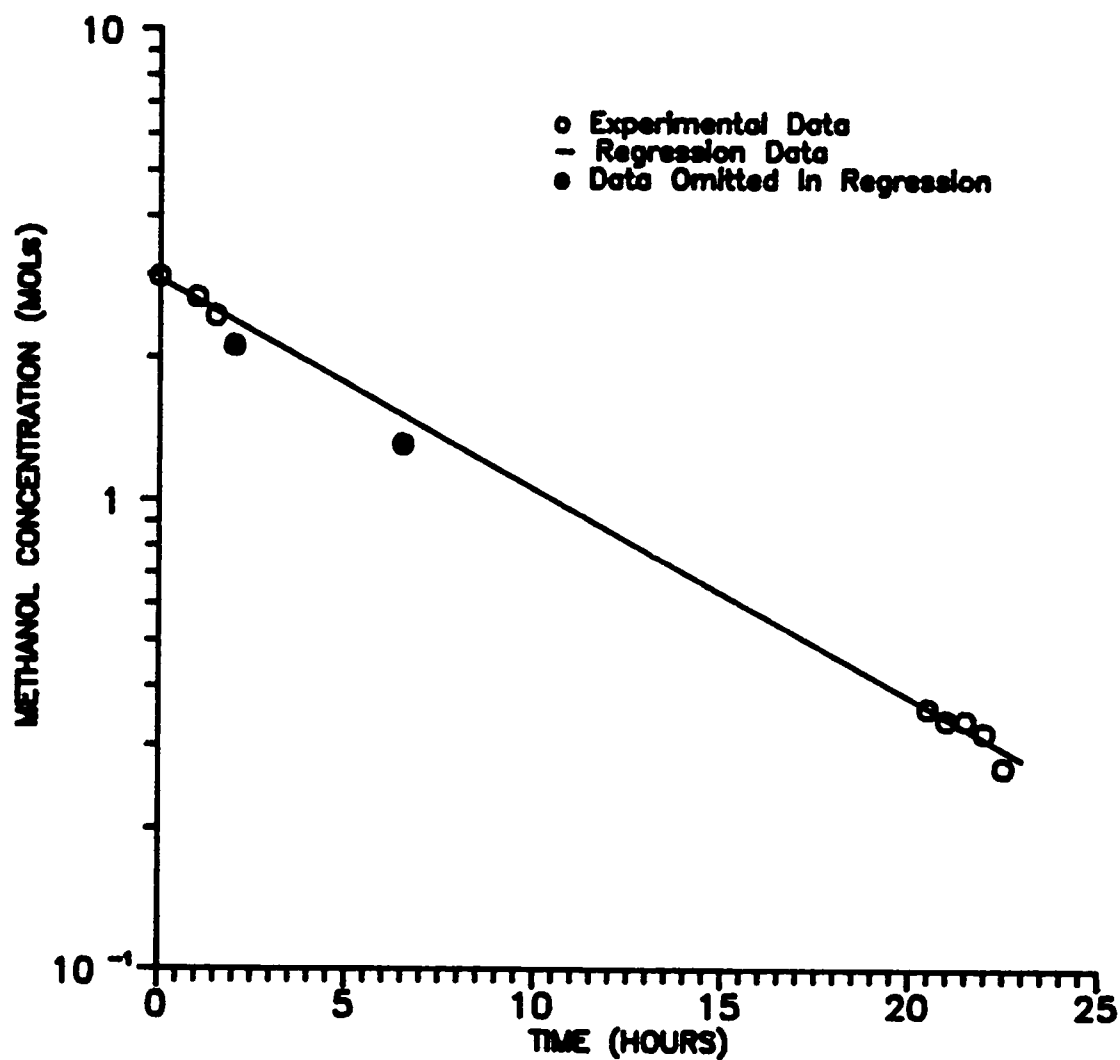


Figure 4.8 Concentration History Of Methanol In A Spray Pond, Run No.23

the data generally follows the trend predicted by the simple model for the flow rate and temperature ranges employed in the experimental program.

The logarithm of Eq(2.14) was fit to each set of experimental data and the regression line is also shown in each of the graphs, Figures 4.1 through 4.8. The correlation coefficients for the twenty five runs are summarized in Table 4.9 along with the $K_L a_S$ values, which are determined from the slopes of the regression lines. The correlation coefficients, R , in all cases are greater than 0.991, and are greater than 0.999 in eight cases (Runs number 3, 4, 8, 9, 11, 16, 22, 23). It is therefore concluded that the simple spray pond model appropriately correlates the data for most engineering purposes.

Table 4.10 shows the trend in the $K_L a_S$ values with the water recirculation rate and with the pool temperature the results may be summarized as follow:

1. As the water flow rate increases the value of $K_L a_S$ increases. This trend is consistent with expectations because the spray sheet diameter and the total number of suspended droplets formed as the sheet breaks up increases as the flow rate increases, thus increasing the total air-liquid interfacial area, a_S . Also, the droplet velocity increases with increasing flow rate. Increasing velocity is expected to increase the overall

Table 4.9 Summary Of The Model Parameters For The Experimental Runs Based On Linear Regression Analysis.

Run No.	Parameters ^a			Correlation Coefficient, R
	C _{A0} (mol%)	K _L ·a _S /V (1/hrs)	K _L ·a _S (cm ³ /hrs)	
1	0.813	0.136*10 ⁻¹	0.83*10 ⁻⁷	0.98781
2	0.959	0.334*10 ⁻²	0.18*10 ⁻⁷	0.99343
3	1.466	0.231*10 ⁻¹	0.12*10 ⁻⁶	0.99938
4	0.948	0.427*10 ⁻¹	0.24*10 ⁻⁶	0.99901
5	0.929	0.138	0.83*10 ⁻⁶	0.99388
6	1.026	0.480*10 ⁻²	0.25*10 ⁻⁷	0.99395
7	1.092	0.206*10 ⁻¹	0.11*10 ⁻⁶	0.98461
8	0.986	0.506*10 ⁻¹	0.30*10 ⁻⁶	0.99915
9	0.848	0.120	0.73*10 ⁻⁶	0.99946
10	0.958	0.109*10 ⁻¹	0.56*10 ⁻⁷	0.98982
11	1.223	0.607*10 ⁻²	0.32*10 ⁻⁷	0.99949
12	1.180	0.306*10 ⁻¹	0.18*10 ⁻⁶	0.99252
13	0.499	0.436*10 ⁻¹	b	0.99469
14	0.876	0.458*10 ⁻¹	0.28*10 ⁻⁶	0.99197
15	1.516	0.313*10 ⁻¹	b	0.99852
16	0.951	0.724*10 ⁻¹	0.42*10 ⁻⁶	0.99917
17	1.044	0.110	0.66*10 ⁻⁶	0.99852
18	0.826	0.903	b	0.99141
19	1.129	0.171*10 ⁻¹	0.91*10 ⁻⁷	0.99411
20	1.303	0.433*10 ⁻¹	0.27*10 ⁻⁶	0.99839
21	0.920	0.592*10 ⁻¹	0.39*10 ⁻⁶	0.99861
22	1.026	0.135	0.88*10 ⁻⁶	0.99905
23	1.073	0.102	0.62*10 ⁻⁶	0.99967
24	0.525	0.210	0.86*10 ⁻⁶	0.99790
25	0.882	0.132	0.76*10 ⁻⁶	0.99654

$$^a \ln(C_A) = a - b(\text{Time})$$

$$\text{Where } a = C_{A0}$$

$$b = K_L a_S / V$$

^b Not Calculated

Table 4.10 Trend In The K_{LaS} Values With Temperature And Water Recirculation Rate.

Run No.	Temperature °K	Recirculation Rate, F cm ³ /hrs	Turn Over Time ^a , τ hr	K_{LaS} cm ³ /hr
1	294	68138	2.40	0.83E-7
2	286	79494	2.23	0.18E-7
3	296	79494	2.33	0.12E-6
4	306	79494	2.23	0.24E-6
5	319	79494	2.08	0.83E-6
6	285	90851	2.08	0.25E-7
7	295	90851	1.99	0.11E-6
8	306	90851	1.87	0.30E-6
9	317	90851	1.82	0.73E-6
10	281	113563	1.70	0.56E-7
11	285	113563	1.67	0.32E-7
12	292	113563	1.53	0.18E-6
13	293	113563	b	b
14	293	113563	1.46	0.28E-6
15	295	113563	b	b
16	304	113563	1.53	0.42E-6
17	311	113563	1.46	0.66E-6
18	317	113563	b	b
19	285	136276	1.37	0.91E-7
20	291	136276	1.16	0.27E-6
21	295	136276	1.28	0.39E-6
22	304	136276	1.13	0.88E-6
23	305	136276	1.21	0.62E-6
24	308	136276	0.98	0.86E-6
25	310	136276	1.26	0.76E-6

^a Refer to Appendix E.1 for the sample calculation.

^b Not calculated, due to excessive water loss from the pool.

mass transfer coefficient, K_L , due to the thinning of the boundary layer in the air and liquid adjacent to the air-water interface.

2. The value of $K_L a_S$ increases with increasing temperature, with the exception of the results for Runs 11, 23, and 24, which appear to be anomalous. This trend is likely due to the effect of temperature on properties such as the vapor pressure of methanol at the air-water interface, diffusivity of methanol in the air and water films, and the surface tension of the methanol-water mixture. As both vapor pressure and diffusion coefficients increase with temperature, the $K_L a_S$ value will increase as well. The effect of surface tension, which decreases with increasing temperature [12], on the transfer coefficient-surface area product is not as obvious. However, if the behavior of the spray from this nozzle is similar to that of the fan-type nozzle investigated by Lin et al.[6], then the effect of decreasing surface tension (due to increasing temperature) will be to increase the transfer rate. These investigators correlated their data in terms of the Weber Number to the 0.20 power, and as the surface tension appears in the denominator of the Weber Number, the effect of decreasing surface tension is to increase the Weber Number. Qualitatively, it appears that the effect of increasing temperature on the above mentioned

properties is to produce an increase in the K_{LaS} value consistent with the experimental data.

Table 4.10 also shows the pool turn over time, τ , for each experimental run, where τ is defined as the pool volume, V , divided by the spray nozzle flow rate, F . These values ranged from 0.98 to 2.40 hours. While not shown here, it is expected that this quantity may be useful in the design and scale-up of spray pond of this type.

An attempt to develop a simple correlation to show the effect of temperature on K_{LaS} , through physically meaningful properties, was not successful. An approach was therefore taken to attempt a correlation in terms of a truncated power series in both temperature and flow rate, of the form given by Eq(2.15):

$$K_{LaS} = d_0 + d_1T + d_2T^2 + d_3F + d_4F^2 + d_5TF + d_6TF^2 + d_7T^2F + d_8T^2F^2 \quad (2.15)$$

Where T is in $^{\circ}K$ and F is in cm^3/hr . Eq(2.15) was fitted to the data of table 4.10 using stepwise multi-regression analysis in order to determine the values of the parameters d_i . The analysis revealed that the cross terms whose coefficients are d_1 , d_2 , d_3 , d_5 , and d_7 were of minor significance, and were therefore neglected. The resulting equation, with a multiple correlation coefficient, $R=0.8916$, is

$$K_L a_S = 3.003E-8 - 4.64E-15 F^2 + 3.32E-17 TF^2 - 5.95E-20 T^2 F^2 \quad (4.1)$$

the relatively high value of the correlation coefficient indicates a reasonably good fit to the data. The resulting correlation is displayed in Figure 4.9, where the abscissa values are given by the function, FUN, defined as:

$$FUN = -4.64E-15 F^2 + 3.32E-17 TF^2 - 5.95E-20 T^2 F^2 \quad (4.2)$$

combining Eqs(4.2) and (4.1) yields the form of the equation plotted in Figure 4.9:

$$K_L a_S = 3.003E-8 + FUN \quad (4.3)$$

the values of FUN used to construct Figure 4.9 are provided in Table 4.11.

It is evident on referring to Figure 4.9 that the experimental data provide a reasonably good fit to the straight line predicted by Eq(4.3). It is therefore concluded that Eq(4.1) can be used to estimate overall mass transfer-surface area products for sprays produced by a centrifugal nozzle of the type used in this investigation, as long as the pool temperatures are in the range of 281 to 319°K, and the water recirculation rates are in the range of 68000 to 140000 cm³/hr (0.30 to 0.60 gpm). Additional experimental work is required in order to test this experimental correlation against data for the larger nozzle sizes that may be of commercial interest.

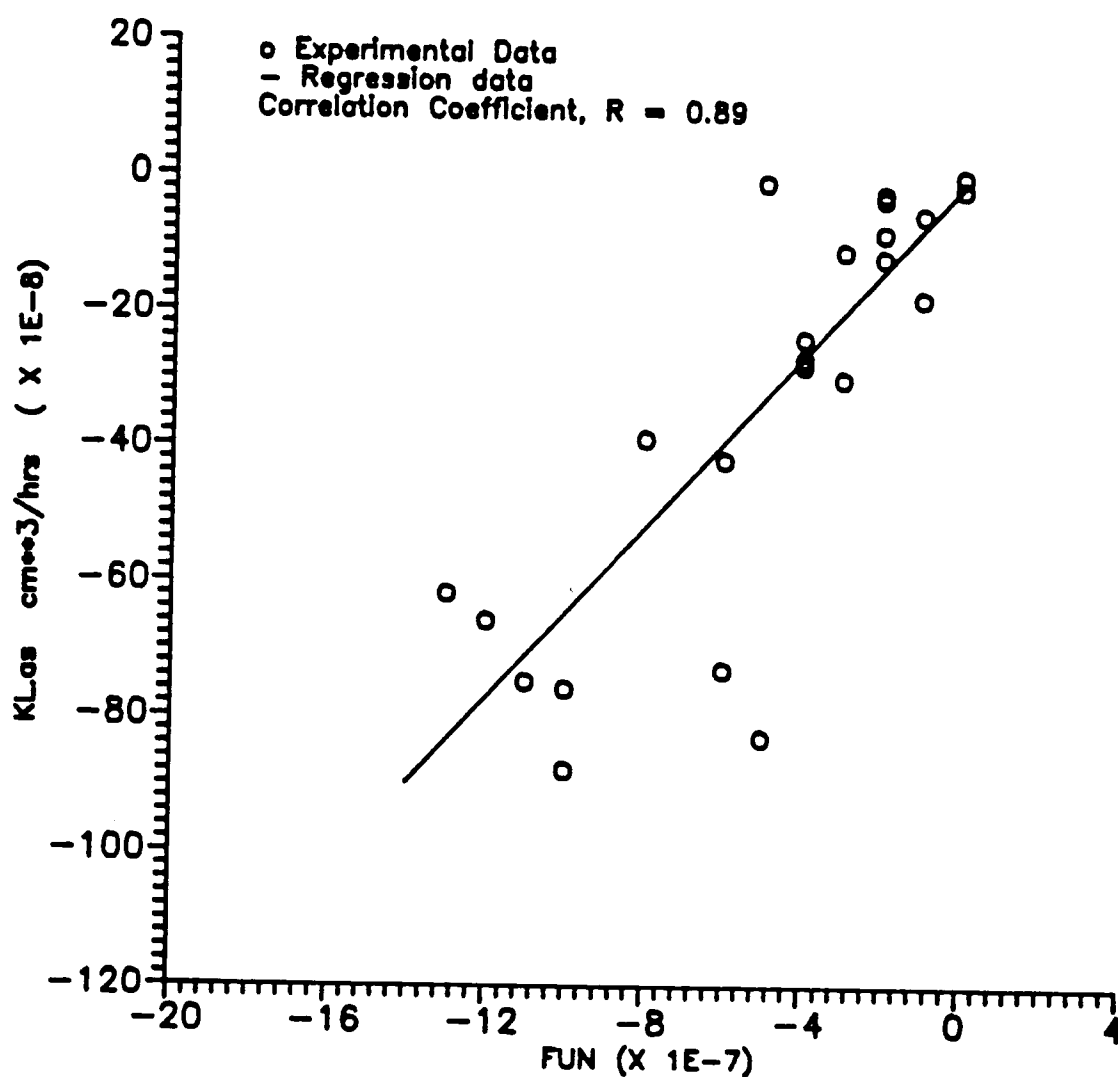


Figure 4.9 Correlation Of The K_{LaS} Values With Temperature And Flow Rate Function For The Methanol-Water System

Tab 4.11 Values Of The Function "FUN" For The Different Runs

Run No.	Temperature °K	Flow Rate cm ³ /hrs	FUN (X 1E-7)
1	294	68138	-2.0
2	286	70494	0.0
3	296	79494	-2.0
4	306	79494	-4.0
5	319	79494	-5.0
6	285	90851	-2.0
7	295	90851	-3.0
8	306	90851	-3.0
9	317	90851	-6.0
10	281	113563	-1.0
11	285	113563	-2.0
12	292	113563	-1.0
13	293	113563	a
14	293	113563	-4.0
15	295	113563	a
16	304	113563	-6.0
17	311	113563	-12.0
18	317	113563	a
19	285	136276	-5.0
20	291	136576	-4.0
21	295	136576	-8.0
22	304	136576	-10.0
23	305	136576	-13.0
24	308	136576	-11.0
25	310	136576	-10.0

^a Not calculated; due to excessive water loss from the Pool

5. SUMMARY AND CONCLUSIONS

A set of twenty-five essentially isothermal experimental runs was made in a laboratory scale spray pond in order to determine the rate of loss of a volatile solute, methanol, from the aqueous phase. Pond temperatures were varied over the range of 8 to 46°C. The water recirculation rates were held constant during each run and were varied over the range of 68000 to 140000 cm³/hrs (0.30 to 0.60 gpm), which corresponds to turnover times of 2.4 to 0.98 hours, respectively, of the aqueous phase in the 1.8m (6 ft) diameter laboratory pool. The spray nozzle employed is of the centrifugal type, which produces sprays of a relatively flat trajectory. The surrounding air was essentially stagnant during all runs and ranged in the temperature from 295 to 302 °K. The methanol content of the pool was determined by the GLC analysis of samples taken periodically over operating times ranging from 8 to 24 hours.

The data are interpreted in terms of a simple model of this unsteady, batch-type, spray process, which results in the following equation relating the alcohol concentration, C_A , in the pool to the operating time, t :

$$C_A/C_{A0} = \text{EXP}[-(K_L \cdot a_s/V) \cdot t]$$

Where V is the pool liquid volume and $K_L \cdot a_s$ is the overall mass transfer coefficient-spray surface area product. The correlation coefficients for the data of the twenty-five runs with this equation were greater than or equal to 0.991, with eight of the runs yielding correlation coefficients of greater than 0.999. It is therefore concluded that the simple model of the recirculating spray pond solute loss rate process is adequate for most engineering purposes.

The $K_L \cdot a_s$ values for the methanol-water system range from $0.83\text{E-}7$ to $0.86\text{E-}6$ cm^3/hrs , depending on the pool temperature and the flow rate through the nozzle.

An attempt to correlate the temperature dependence of the mass transfer coefficient-surface area product in terms of physically meaningful properties, such as through Henrys' Law constant H , was unsuccessful. However, a useful empirical correlation is presented which gives the temperature and nozzle flow rate dependence of the $K_L \cdot a_s$ product, with a correlation coefficient, R , of 0.89, using the data of twenty-two of the experimental runs.

6. RECOMMENDATION FOR FUTURE WORK

A simple model for solute loss rate from a spray pond was developed and tested in this work. The experimental data were used to develop a correlation for the overall mass transfer-spray surface area product in terms of the pool temperature and the water recirculation rate. Methanol was used as solute.

It would be of interest in the future to extend this work to include additional solutes, with water recirculation rates of higher values than the 0.3-0.6 gallon per minute range used here. Extending the range of the water recirculation rate can provide the data necessary so as to scale up the nozzle size for possible commercial interest. Experimental work with nozzle size larger than that used in this work most likely will require a pool size larger than the six-foot diameter pool of this study, in order to prevent excessive water loss.

Future experimentalists are cautioned against the use of plastic pools, as the plastic pool type used here was prone to leakage. Also, should methanol be used as solute in future investigations, it is recommended that its concentration be limited to no more than about 2 mole%, in order to simplify the analysis of water samples by gas chromatography.

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APPENDICES

APPENDIX A
Table Of Raw Data For Seventeen
Experimental Runs

Table A.1 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.2

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.00	33.5	71.0	355.0	5.70	2.63
2	1.00	19.5	70.0	350.0	5.65	2.60
3	2.00	17.0	69.0	345.0	5.60	2.58
4	2.25	16.5	69.0	345.0	5.60	2.58
5	23.00	13.5	65.0	325.0	5.30	2.44
6	24.00	13.2	64.0	320.0	5.25	2.41
7	25.00	13.0	63.0	315.0	5.18	2.38

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.35 gpm

^c Using Calibration Curve Figure No.3.1

Table A.2 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.3^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			2*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	26.0	66.8	668.0	9.30	4.37
2	1.0	25.5	63.5	635.0	9.00	4.22
3 ^d	1.5	25.5	51.5	515.0	7.70	3.59
4 ^e	15.0	23.0	50.0	500.0	7.50	3.49
5 ^e	15.8	23.0	50.0	500.0	7.50	3.49
6 ^e	17.5	23.0	49.5	495.0	7.49	3.48
7 ^e	18.5	23.0	47.5	475.0	7.25	3.27
8	19.5	23.0	36.5	365.0	5.90	2.72
9	20.5	23.0	36.0	360.0	5.80	2.67
10	22.5	23.5	34.2	342.0	5.55	2.55
11	23.5	23.5	33.9	339.0	5.50	2.53
12	24.5	23.5	32.9	329.0	5.40	2.48
13	25.0	23.5	32.9	329.0	5.40	2.48

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.35 gpm

^c Using Calibration Curve Figure No.3.1

^d Omitted From Regression (Bad Sample Injection)

^e Omitted From Regression (Flow Rate Dropped To 0.20
And Was Not Set Back To 0.35)

Table A.3 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run NO.4^b

Sample No.	Time hrs	Temperature °C	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.00	28.0	69.0	345.0	5.60	2.58
2	1.50	32.0	66.0	330.0	5.40	2.48
3	2.00	32.2	65.5	327.5	5.35	2.46
4	2.25	32.0	58.0	290.0	4.80	2.20
5	23.50	33.5	25.5	127.7	2.12	0.96
6	24.00	33.5	25.0	125.0	2.05	0.92
7	24.50	33.5	24.5	122.5	2.00	0.90

^a Spraying System Co. Parasol, No.1/4 E-10

^b Flow Rate 0.35 gpm

^c Using Calibration Curve Figure No.3.1

Table A.4 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No. 7

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1 ^d	0.0	30.0	102.0	510.0	7.70	3.56
2	0.5	28.0	82.9	414.5	6.51	3.01
3	1.0	26.0	80.5	402.5	6.35	2.94
4	1.5	25.5	77.5	387.5	6.20	2.86
5	2.5	24.0	74.0	370.0	5.95	2.74
6	3.5	23.0	72.8	364.0	5.90	2.72
7	4.0	23.0	75.5	377.5	6.10	2.82
8	7.0	22.5	69.8	349.0	5.64	2.60
9	7.5	22.0	74.5	372.5	5.96	2.75
10 ^e	8.0	22.0	88.9	444.8	6.90	3.20
11	8.5	22.0	67.5	337.5	5.50	2.53
12	9.0	22.0	66.4	331.8	5.40	2.48
13	9.5	21.6	63.8	319.0	5.21	2.39
14	9.8	21.6	64.5	322.5	5.25	2.41
15	10.0	21.6	65.5	327.5	5.40	2.48
16 ^f	22.5	20.5	65.7	329.0	5.38	2.47
17 ^f	24.5	20.5	65.0	325.0	5.30	2.43
18 ^f	25.0	20.5	62.6	313.3	5.10	2.34

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.40 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Unsteady Temperature)

^e Omitted From Regression (Bad Sample Injection)

^f Omitted From Regression (Flow Rate Dropped To 0.35)

Table A.5 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.9^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.0	37.0	61.5	308.0	5.07	2.33
2	0.5	42.0	60.3	301.3	4.90	2.25
3	1.0	45.0	54.6	273.0	4.50	2.06
4	1.5	45.0	52.3	262.5	4.32	1.97
5	2.0	45.0	48.5	242.5	3.95	1.80
6	2.5	41.0	45.5	227.5	3.76	1.71
7	7.0	43.0	27.6	138.0	2.28	1.03
8	7.5	43.0	23.5	117.5	1.95	0.88
9	8.0	43.0	23.2	116.0	1.92	0.87
10	8.5	43.0	22.8	114.0	1.90	0.86

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.40 gpm

^c Using Calibration Curve Figure 3.1

Table A.6 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.10^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.0	16.5	69.0	345.0	5.60	2.58
2	0.5	15.5	68.0	340.0	5.50	2.53
3	2.5	9.5	67.0	335.0	5.45	2.51
4	3.0	9.5	68.0	340.0	5.50	2.53
5	4.0	8.5	68.0	340.0	5.50	2.53
6	5.0	8.3	68.0	340.0	5.50	2.53
7	6.0	8.3	66.5	232.5	5.45	2.51
8	21.5	7.5	53.0	265.0	4.35	1.99
9	22.0	7.5	53.0	265.0	4.35	1.99
10	27.0	7.5	52.5	262.5	4.35	1.99
11 ^d	29.0	7.5	52.5	262.5	4.35	1.99
12	30.0	7.5	49.0	245.0	4.02	1.83

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.50 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Flow Rate Dropped To 0.40)

Table A.7 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.12^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	25.0	94.0	470.0	7.20	3.34
2	1.0	23.0	88.0	444.0	6.90	3.20
3	1.5	22.0	87.0	435.0	6.80	3.15
4	2.0	21.0	83.4	417.0	6.60	3.06
5	2.5	20.5	81.3	406.0	6.45	2.98
6 ^d	3.0	20.0	74.8	374.0	5.99	2.76
7 ^d	3.5	20.0	87.0	435.0	6.80	3.15
8	4.0	20.0	71.1	355.0	5.70	2.63
9	4.5	20.0	78.5	393.0	6.25	2.89
10	5.0	19.0	77.8	389.0	6.20	2.86
11	5.5	19.0	79.0	398.0	6.30	2.91
12	7.5	19.0	70.8	354.0	5.75	2.65
13	8.0	19.0	65.2	326.0	5.30	2.44
14	8.5	19.0	64.0	320.0	5.20	2.39
15	22.8	18.0	44.4	222.0	3.70	1.68
16	24.0	18.0	41.4	207.0	3.40	1.55
17	25.0	18.0	40.3	202.0	3.30	1.50

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.50 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Bad Sample Injection)

Table A.8 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.13^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.0	22.0	41.5	207.5	3.45	1.57
2	2.0	21.0	41.2	206.0	3.40	1.55
3	3.0	20.6	40.5	202.5	3.34	1.52
4	17.5	19.5	22.5	112.5	1.85	0.83
5	26.0	19.5	15.5	77.5	1.30	0.50

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.50 gpm

^c Using Calibration Curve Figure 3.1

Table A.9 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.14^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	25.5	64.0	320.0	5.25	2.41
2	0.5	23.5	64.0	320.0	5.25	2.41
3	1.0	23.0	63.4	317.0	5.20	2.29
4	1.5	22.5	60.0	300.0	4.90	2.25
5	2.0	22.3	57.8	289.0	4.79	2.19
6	3.5	21.0	55.0	275.0	4.52	2.07
7 ^d	4.5	21.0	48.0	242.5	3.98	1.82
8	6.5	20.0	47.0	235.0	3.90	1.78
9	7.0	19.5	46.0	230.0	3.80	1.73
10	7.5	19.5	45.0	225.0	3.70	1.68
11	8.0	19.5	45.5	227.5	3.74	1.70
12	8.5	19.2	45.0	225.0	3.70	1.68

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.50 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Bad Injection)

Table A.10 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.15^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			2×10^4	2×10^3	Vol%	Mol%
1 ^d	0.0	27.0	81.0	810.0	10.50	5.00
2	2.0	23.8	63.0	630.0	8.95	4.32
3	4.0	22.5	58.1	581.0	8.52	3.98
4	5.0	22.5	64.8	648.0	9.10	4.27
5	6.0	22.4	54.1	541.0	8.00	3.73
6	7.0	21.0	52.8	528.0	7.85	3.66
7	8.0	21.0	51.5	515.0	7.70	3.58

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow rate 0.50 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Unsteady Temperature)

Table A.11 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.17^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.0	33.5	73.5	365.5	5.94	2.74
2	0.5	36.0	72.5	362.5	5.85	2.58
3	1.0	37.5	68.5	342.5	5.65	2.60
4	1.5	37.5	68.0	340.0	5.55	2.55
5 ^d	2.0	37.5	65.5	327.5	5.40	2.48
6 ^d	2.5	37.5	66.5	332.5	5.45	2.51
7 ^d	3.0	37.5	59.8	299.0	4.90	2.25
8	5.0	37.5	45.0	225.0	3.70	1.68
9	5.5	37.5	41.5	207.5	3.42	1.55
10	6.0	37.5	39.0	195.5	3.20	1.45
11	6.5	37.5	36.0	182.5	3.00	1.36
12	7.0	37.5	35.0	175.0	2.88	1.31
13	7.5	37.5	33.5	167.5	2.75	1.25
14	8.0	37.5	32.5	162.5	2.65	1.20
15	8.5	38.0	29.5	147.5	2.40	1.08
16	9.5	38.0	26.5	132.5	2.20	0.99

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.50 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Bad Injection)

Table A.12 Evaporation Of Methanol From A Spray Pond,
Using Nozzle AA^a, Run No.18^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	38.0	60.0	300.0	4.90	2.25
2	0.5	42.0	57.0	285.0	4.70	2.15
3	1.0	44.0	56.8	284.0	4.69	2.15
4	1.5	45.0	50.0	250.0	4.10	1.87
5	3.0	45.0	48.2	241.0	3.98	1.82
6	3.5	45.0	43.0	215.0	3.55	1.62
7	4.0	45.0	42.0	210.0	3.45	1.57

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.50 gpm

^c Using Calibration Curve Figure 3.1

Table A.13 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.19^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	22.5	88.0	440.0	6.84	3.17
2	1.0	17.0	84.5	422.5	6.64	3.07
3	2.0	15.0	84.2	421.0	6.60	3.06
4	5.0	12.0	74.0	370.0	5.95	2.74
5	6.0	12.0	73.2	366.0	5.90	2.72
6	7.0	12.0	72.0	360.0	5.85	2.70
7 ^d	23.0	12.0	58.0	290.0	4.75	2.18
8	24.0	12.0	55.0	275.0	4.50	2.06
9	25.0	12.0	52.0	260.0	4.30	1.96

^a Spraying System Co. Parasol, No.1/4 E-10

^b Flow Rate 0.60 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Flow Rate Dropped To 0.55 gpm)

Table A.14 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.21^b

Sample No.	Time	Temperature	Peak Height Concentration ^c			
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	23.5	65.8	329.0	5.40	2.48
2	23.5	22.0	17.4	87.0	1.50	0.67
3	28.0	22.5	11.6	58.0	1.00	0.45

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.60 gpm

^c Using Calibration Curve Figure 3.1

Table A.15 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No. 22^b

Sample No.	Time hrs	Temperature °C	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1	0.0	28.0	69.0	345.0	5.60	2.58
2	0.5	29.5	67.5	337.5	5.50	2.53
3	1.0	29.5	60.0	300.0	4.90	2.25
4	2.5	34.0	50.0	250.0	4.10	1.87
5	3.5	25.0	48.0	240.0	3.95	1.80
6	4.5	29.5	45.0	225.0	3.70	1.68
7	5.5	29.5	41.0	205.0	3.40	1.54
8	23.0	32.0	4.0	20.0	0.30	0.13
9	24.0	32.0	3.5	17.5	0.25	0.11
10	25.0	32.0	3.0	15.0	0.23	0.10
11 ^d	26.0	31.0	2.5	12.5	0.15	0.07

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.60 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From Regression (Temperature Drop)

Table A.16 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.24^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
1 ^d	0.0	33.0	56.0	280.0	4.62	2.11
2 ^d	1.0	43.8	43.5	217.5	3.60	1.64
3	1.5	36.0	33.5	167.5	2.75	1.25
4	2.0	35.5	30.5	152.5	2.45	1.11
5	2.5	34.5	26.0	130.0	2.12	0.96
6	3.0	34.0	25.0	125.0	2.05	0.92
7	3.5	33.5	22.0	110.0	1.80	0.81
8	4.0	33.5	20.0	100.0	1.65	0.74
9	4.5	33.5	17.5	87.5	1.45	0.65

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.60 gpm

^c Using Calibration Curve Figure 3.1

^d Omitted From The Regression (Flunctuating Temperature)

Table A.17 Evaporation Of Methanol From A Spray Pond,
Using Nozzle A^a, Run No.25^b

Sample No.	Time	Temperature	Peak Height		Concentration ^c	
			1*10 ⁴	2*10 ³	Vol%	Mol%
	hrs	°C				
1	0.0	27.0	60.0	300.0	4.90	2.25
2	1.0	35.0	55.0	275.0	4.52	2.07
3	2.0	36.0	50.0	250.0	4.10	1.87
4	3.0	36.0	47.0	235.0	3.90	1.78
5	4.0	36.0	40.0	200.0	3.30	1.50
6	7.0	36.5	25.5	127.5	2.10	0.95
7	8.0	37.0	22.0	110.0	1.80	0.81
8	8.5	37.0	20.5	102.5	1.70	0.77

^a Spraying System Co. Parasol, No. 1/4 E-10

^b Flow Rate 0.60 gpm

^c Using Calibration Curve Figure 3.1

APPENDIX B
Plots Of Methanol Concentration In
The Spray Pond Vs. Time For Seventeen Runs

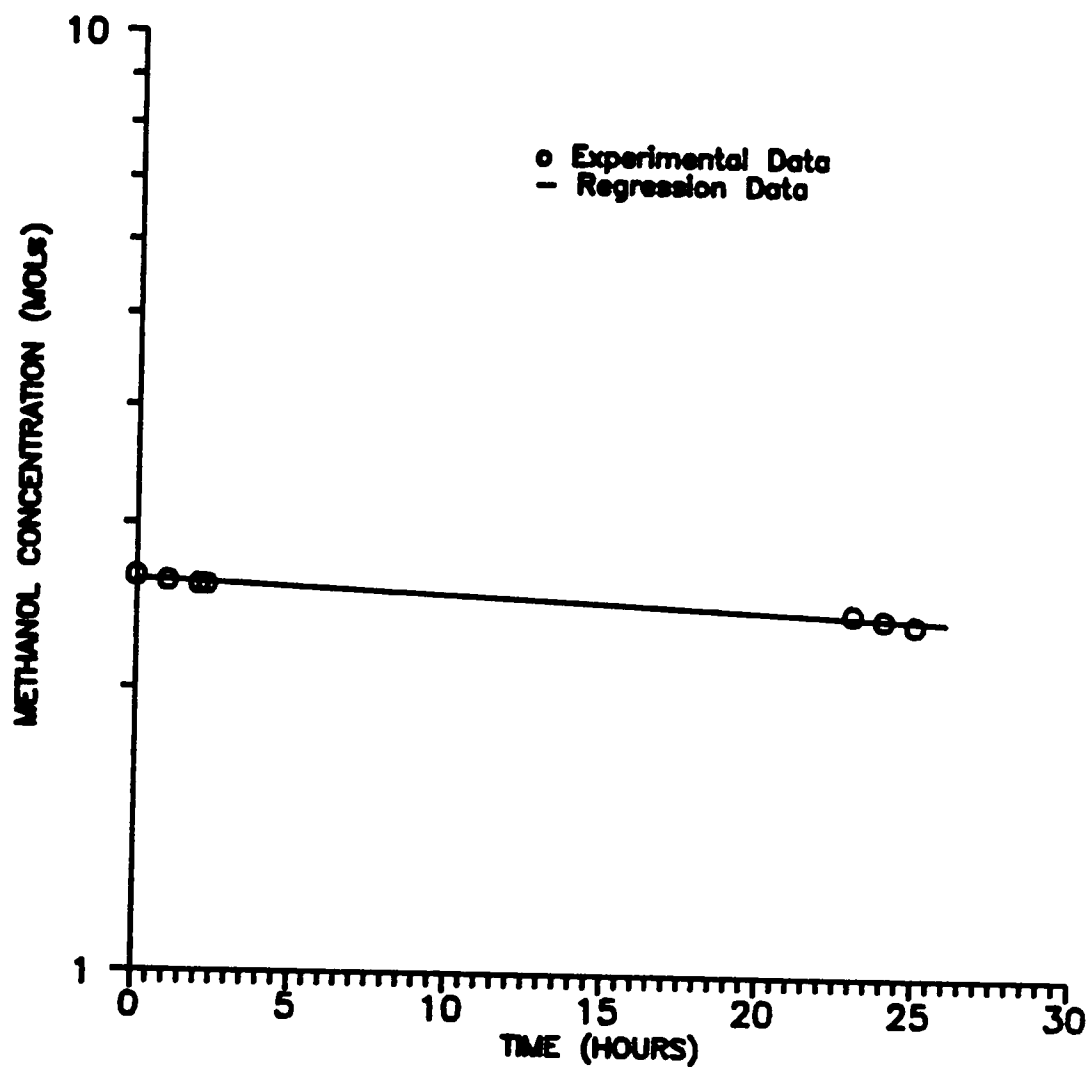


Figure B.1 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.2

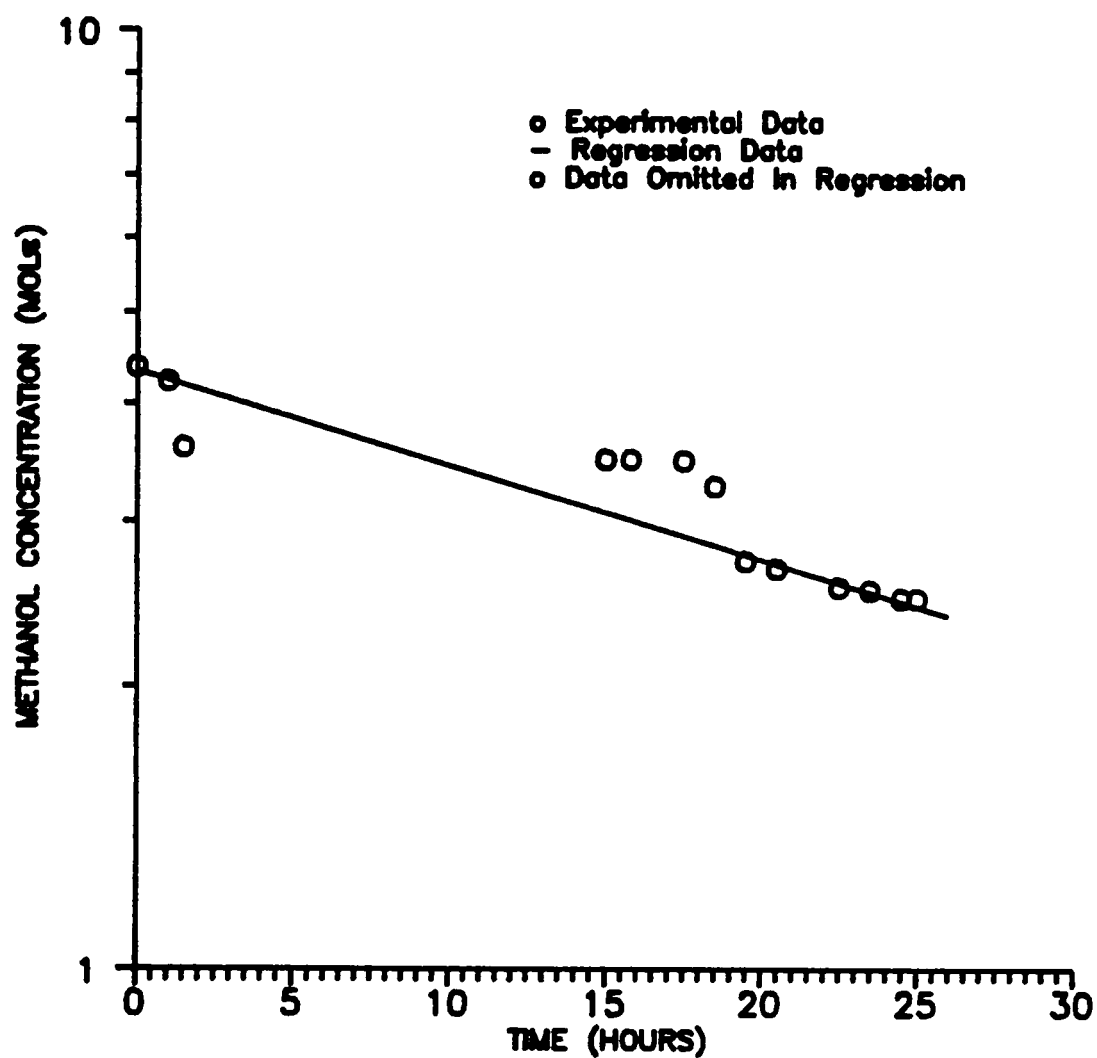


Figure B.2 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.3

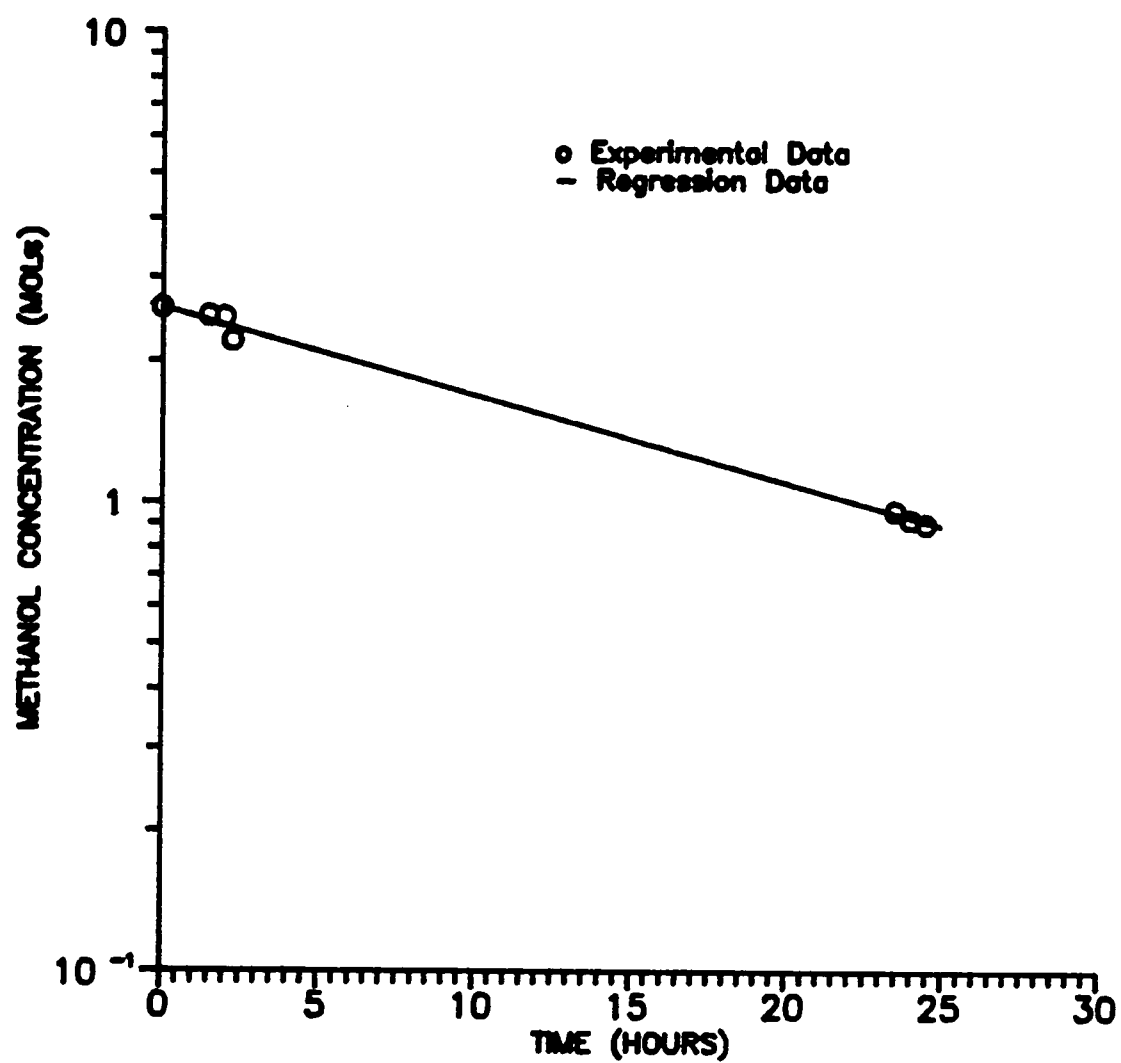


Figure B.3 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.4

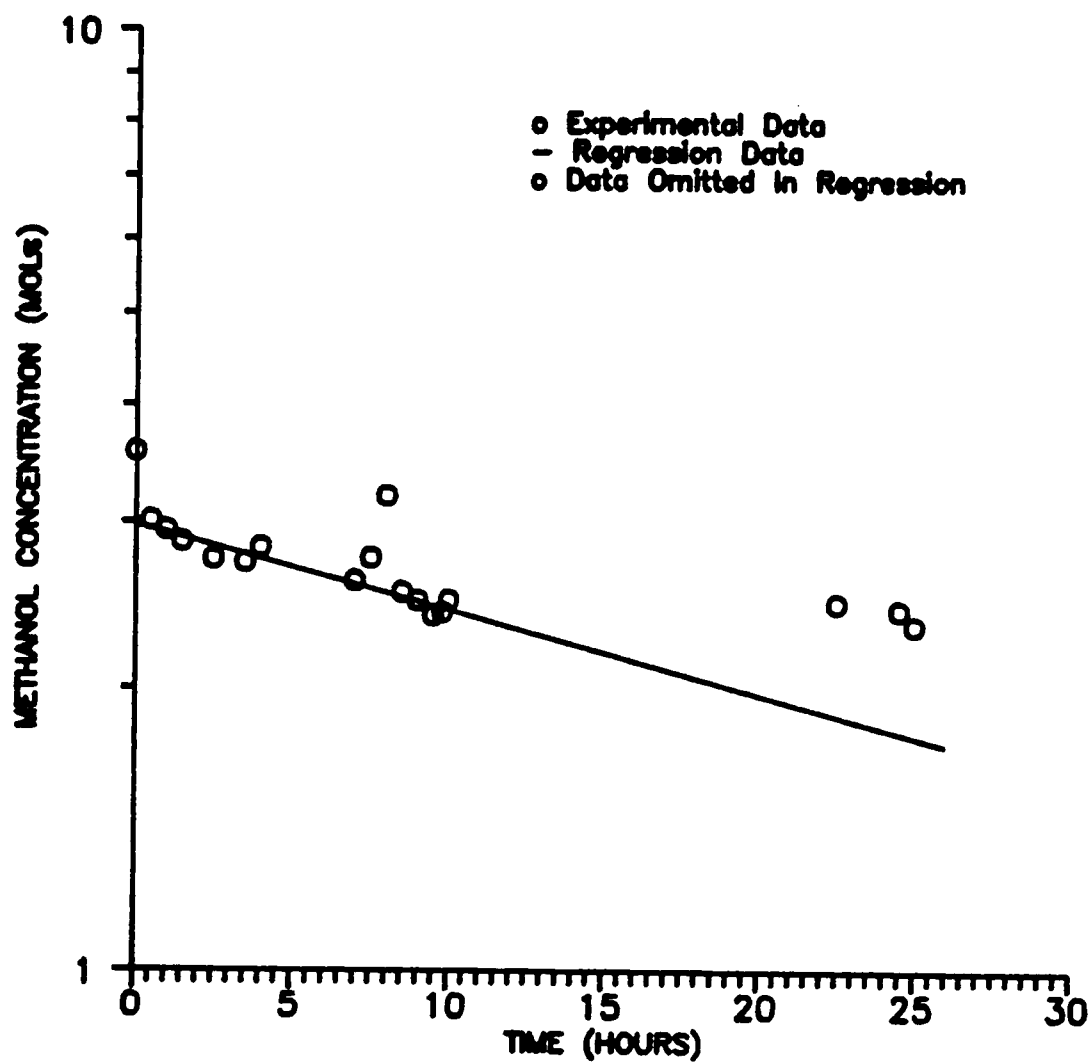


Figure B.4 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.7

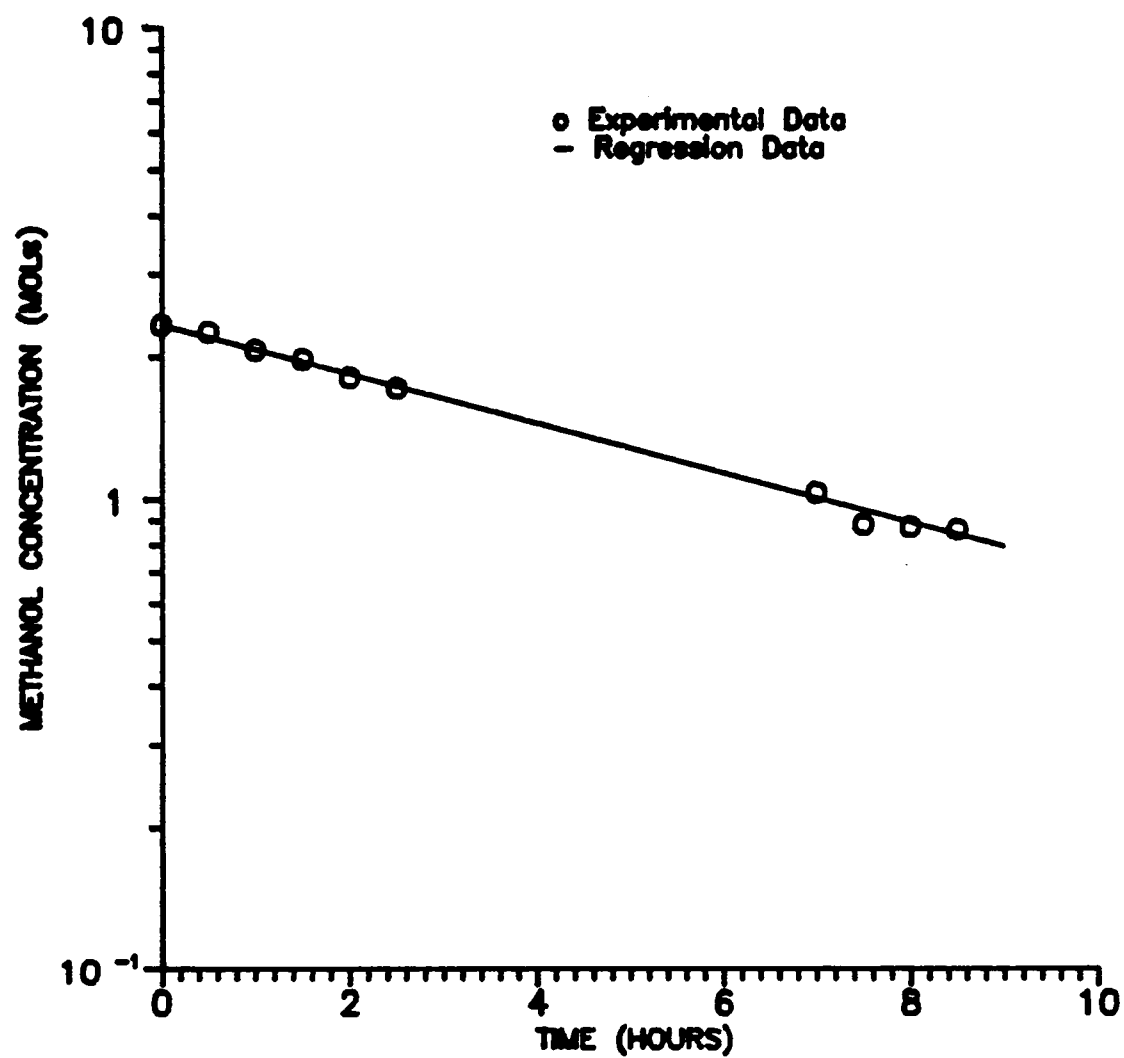


Figure B.5 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.9

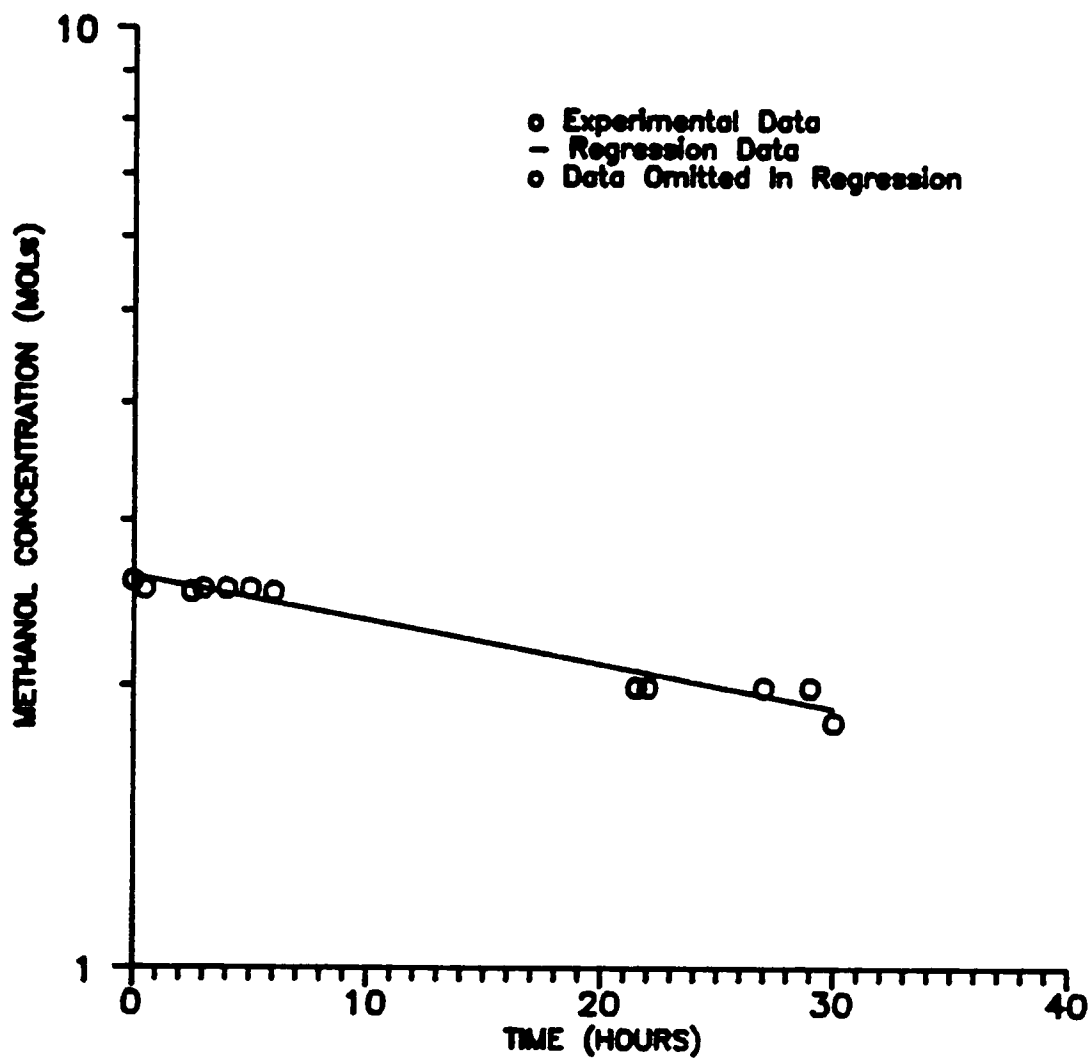


Figure B.6 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.10

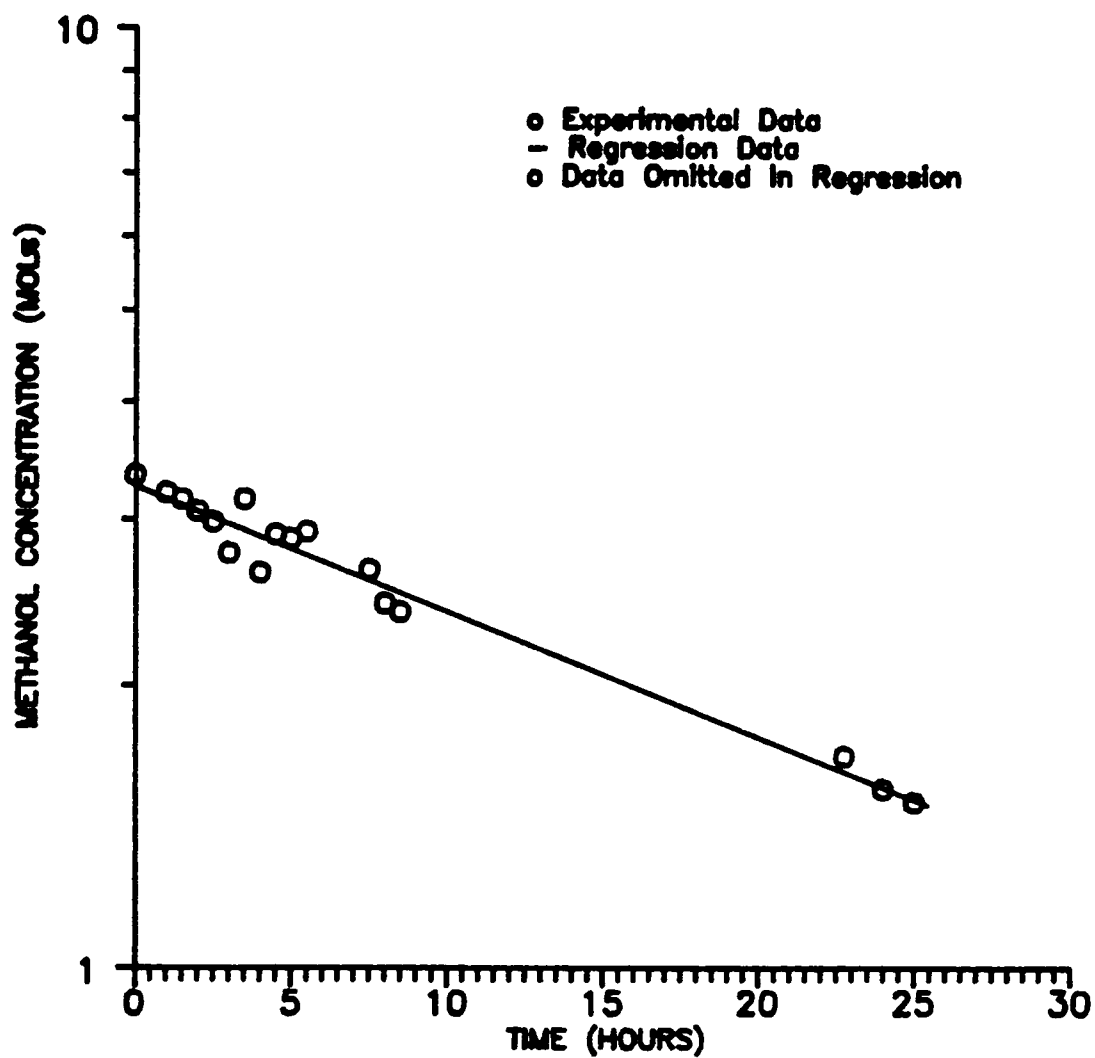


Figure B.7 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.12

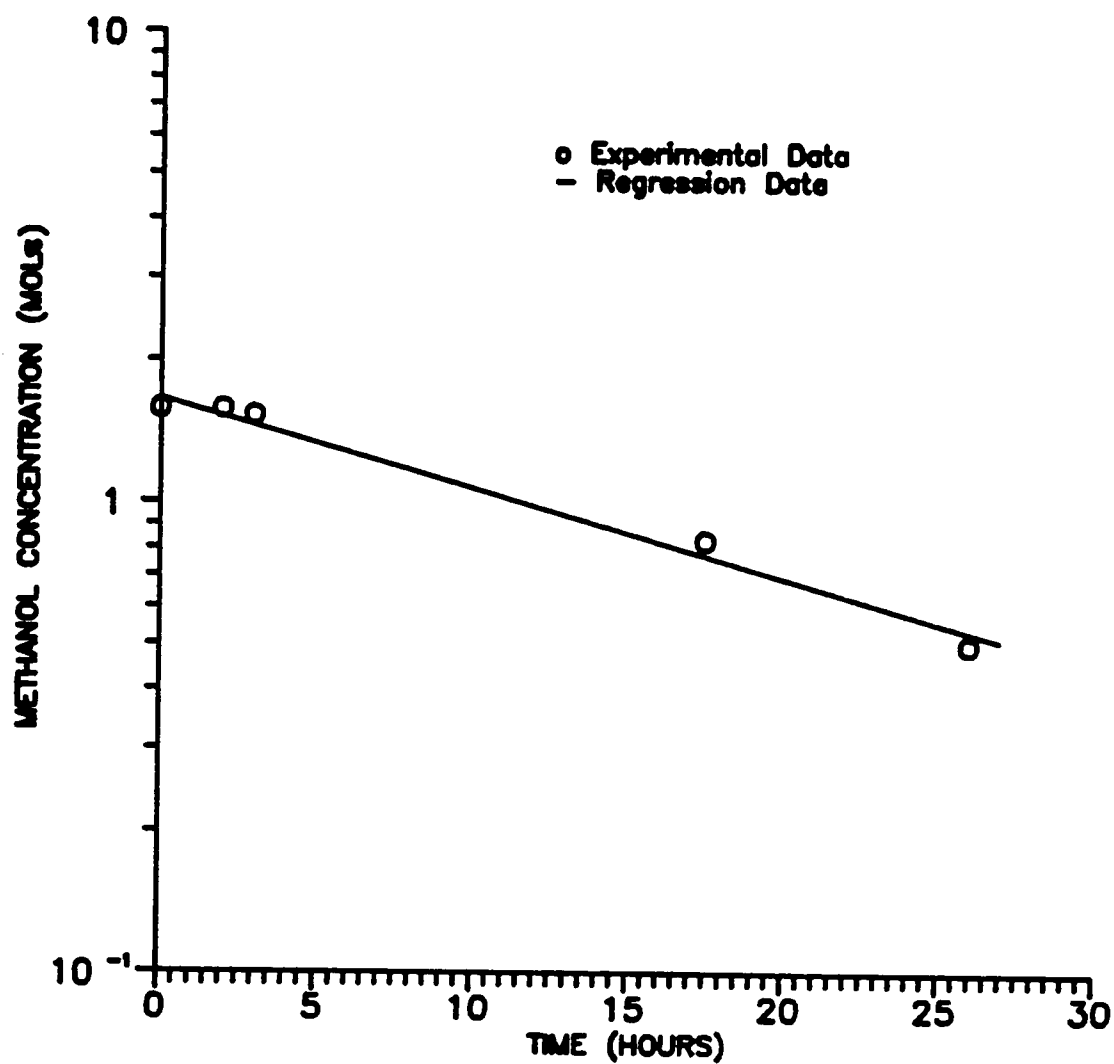


Figure B.8 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.13

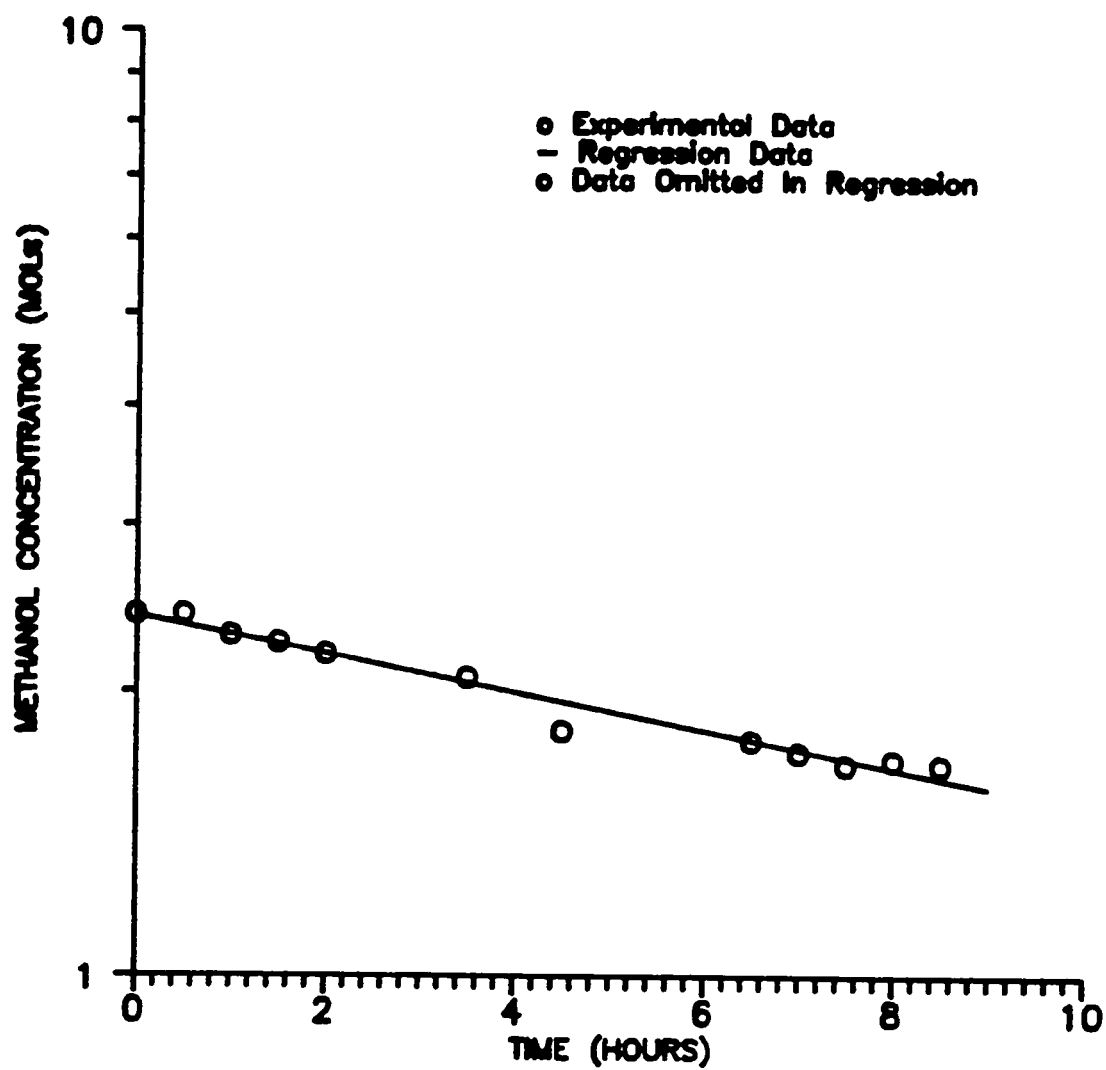


Figure B.9 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.14

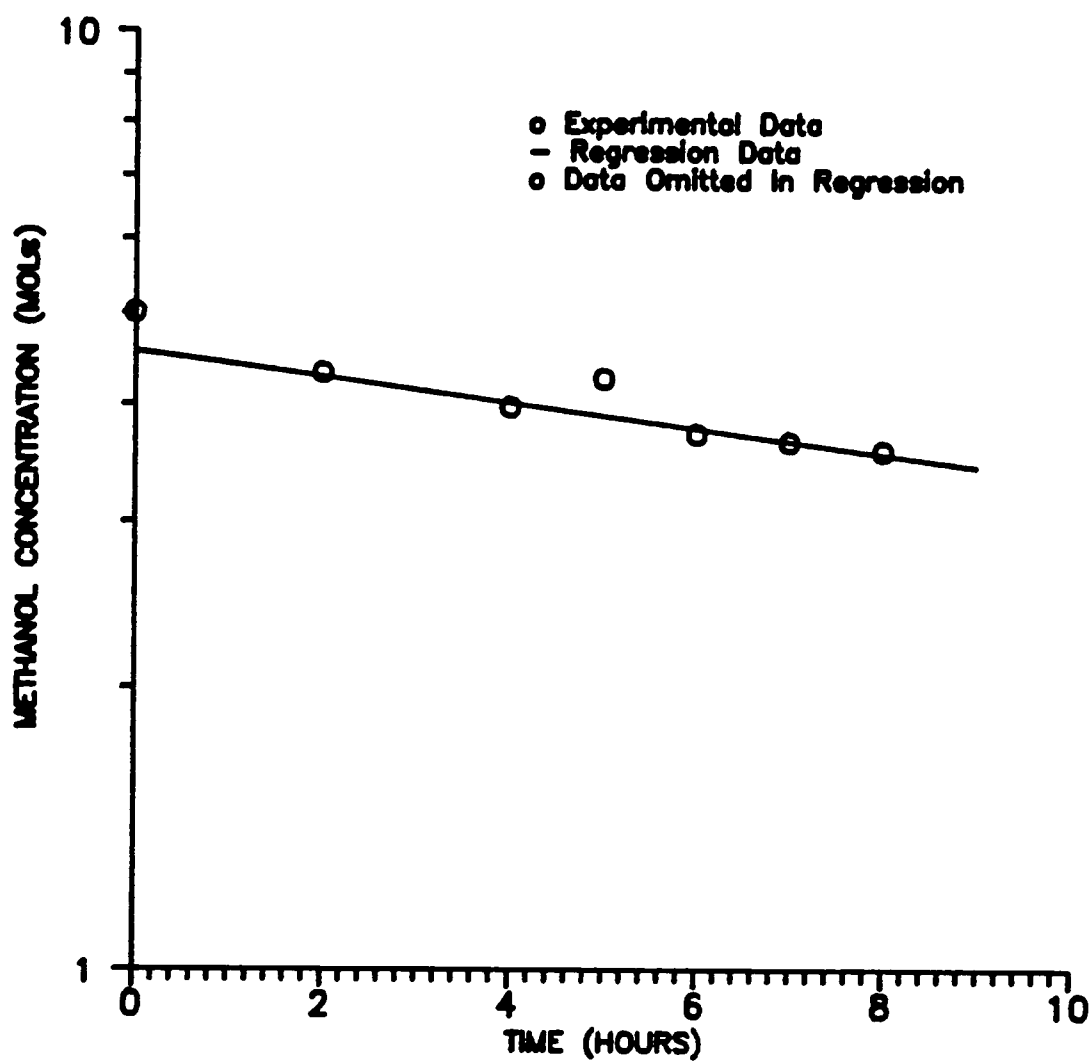


Figure B.10 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.15

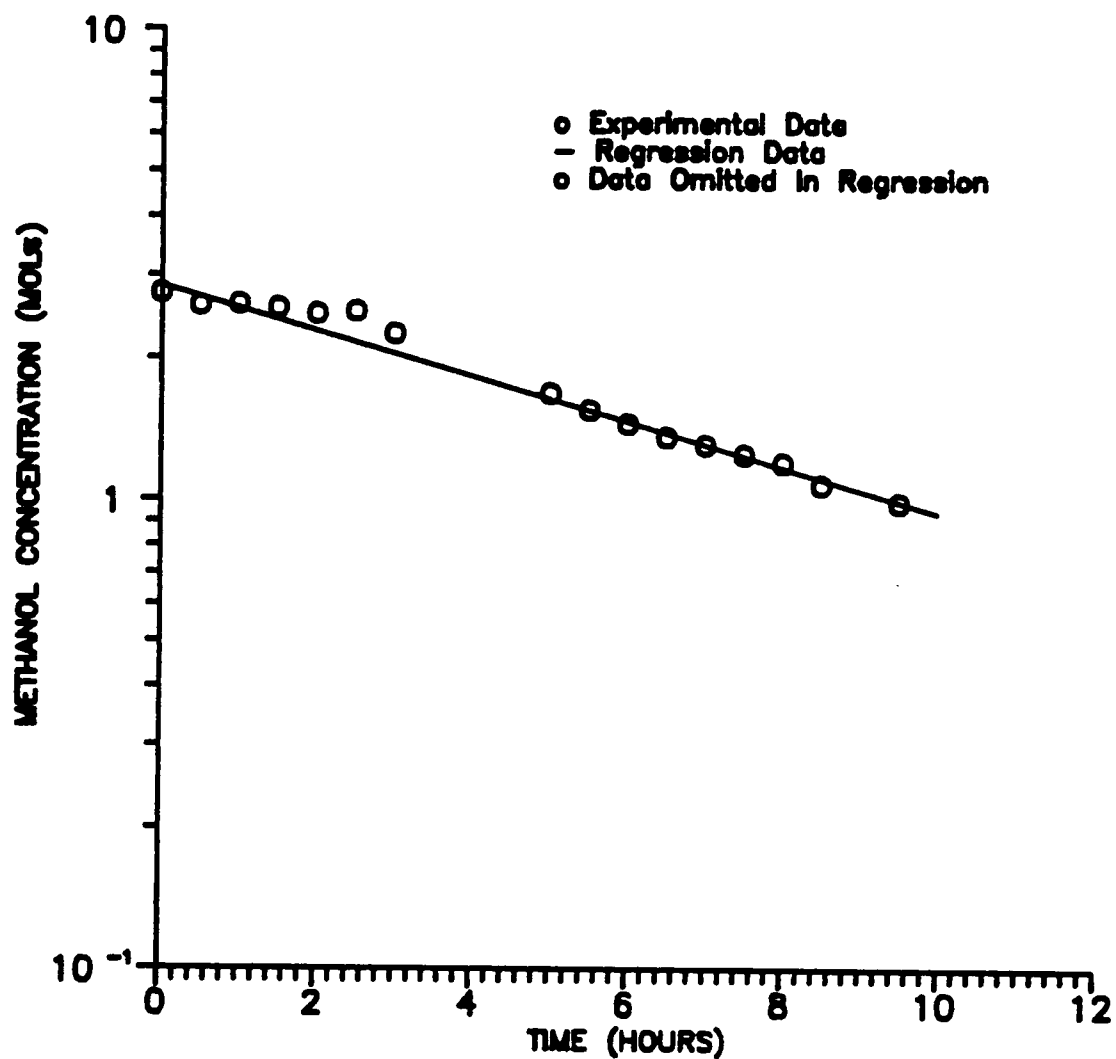


Figure B.11 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.17

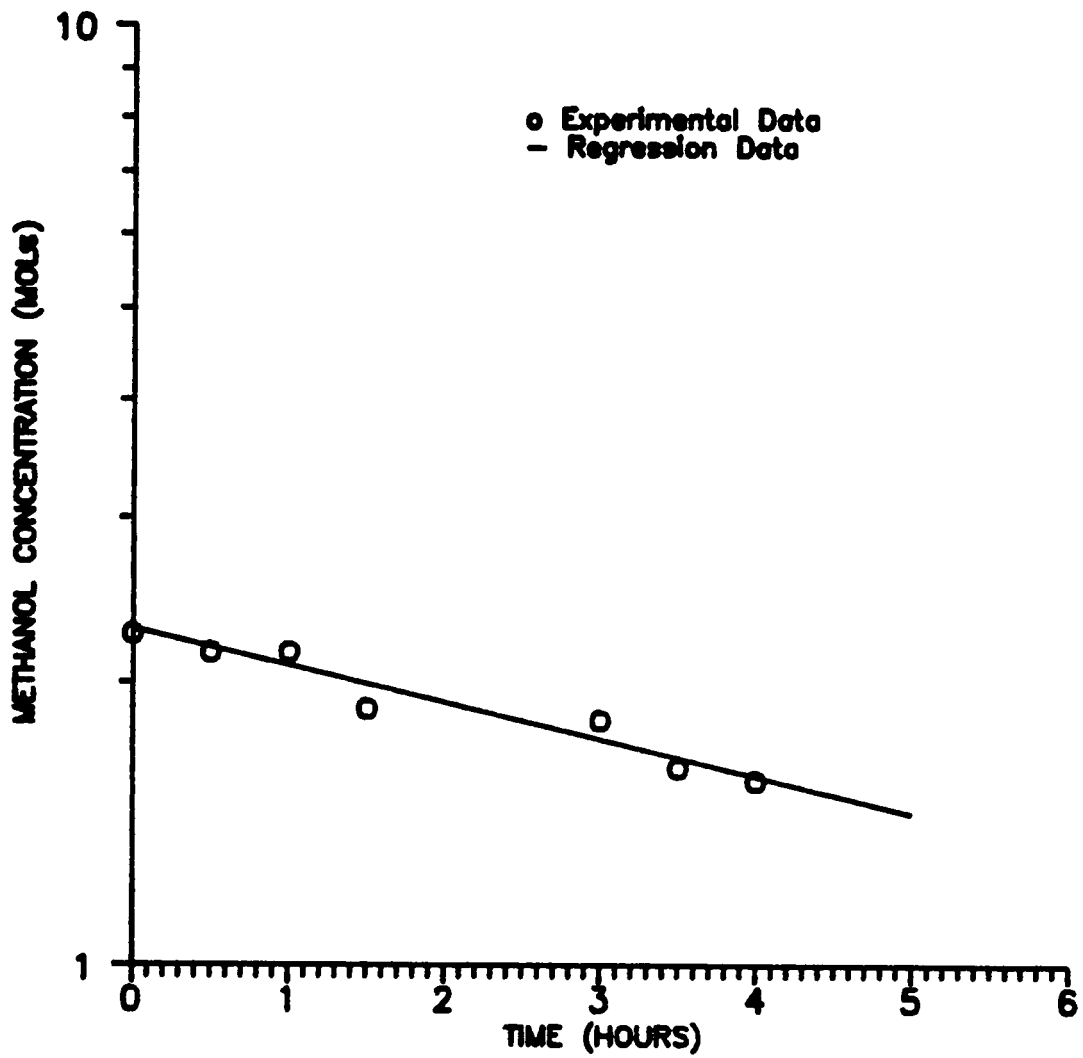


Figure B.12 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.18

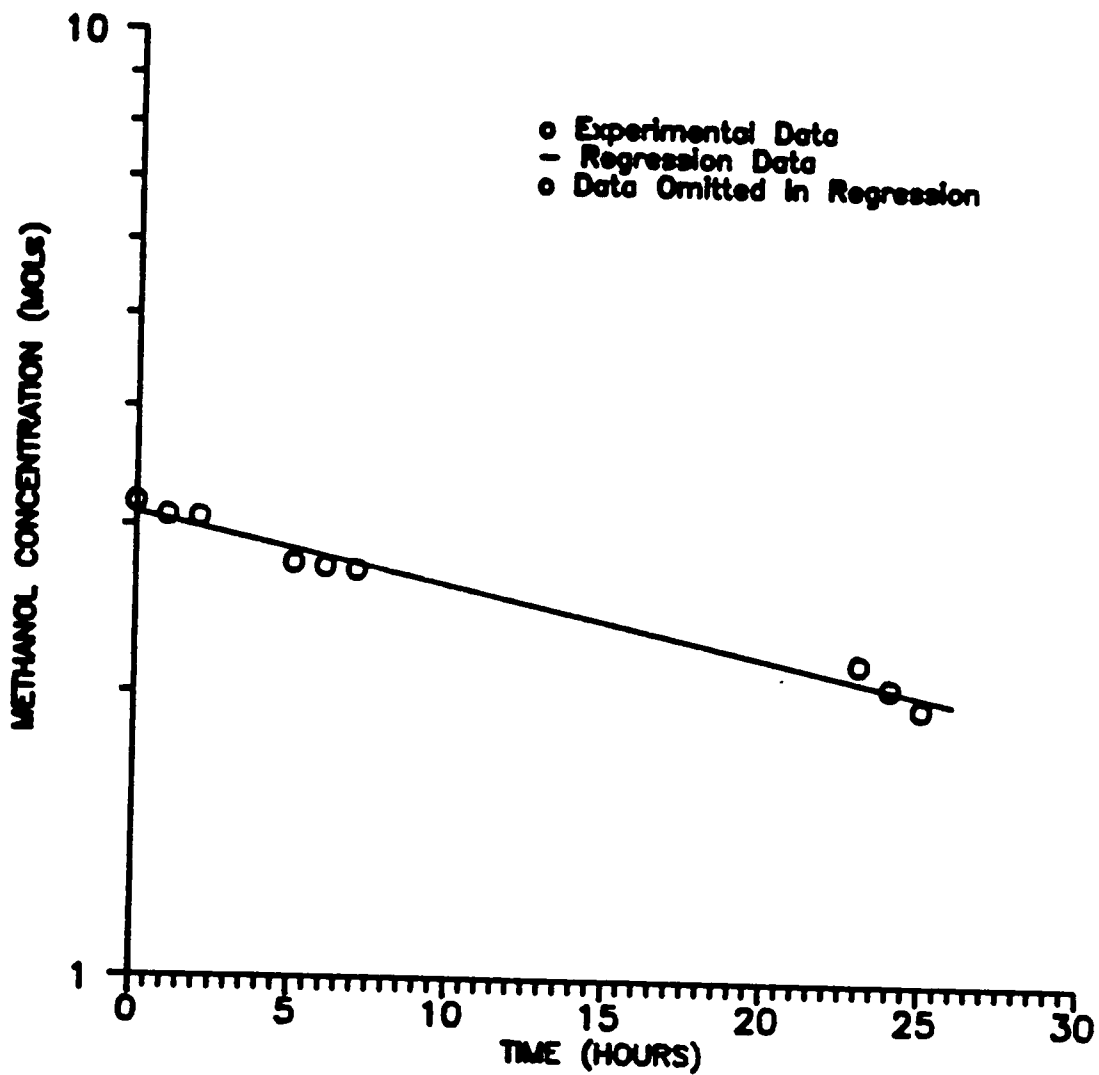


Figure B.13 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.19

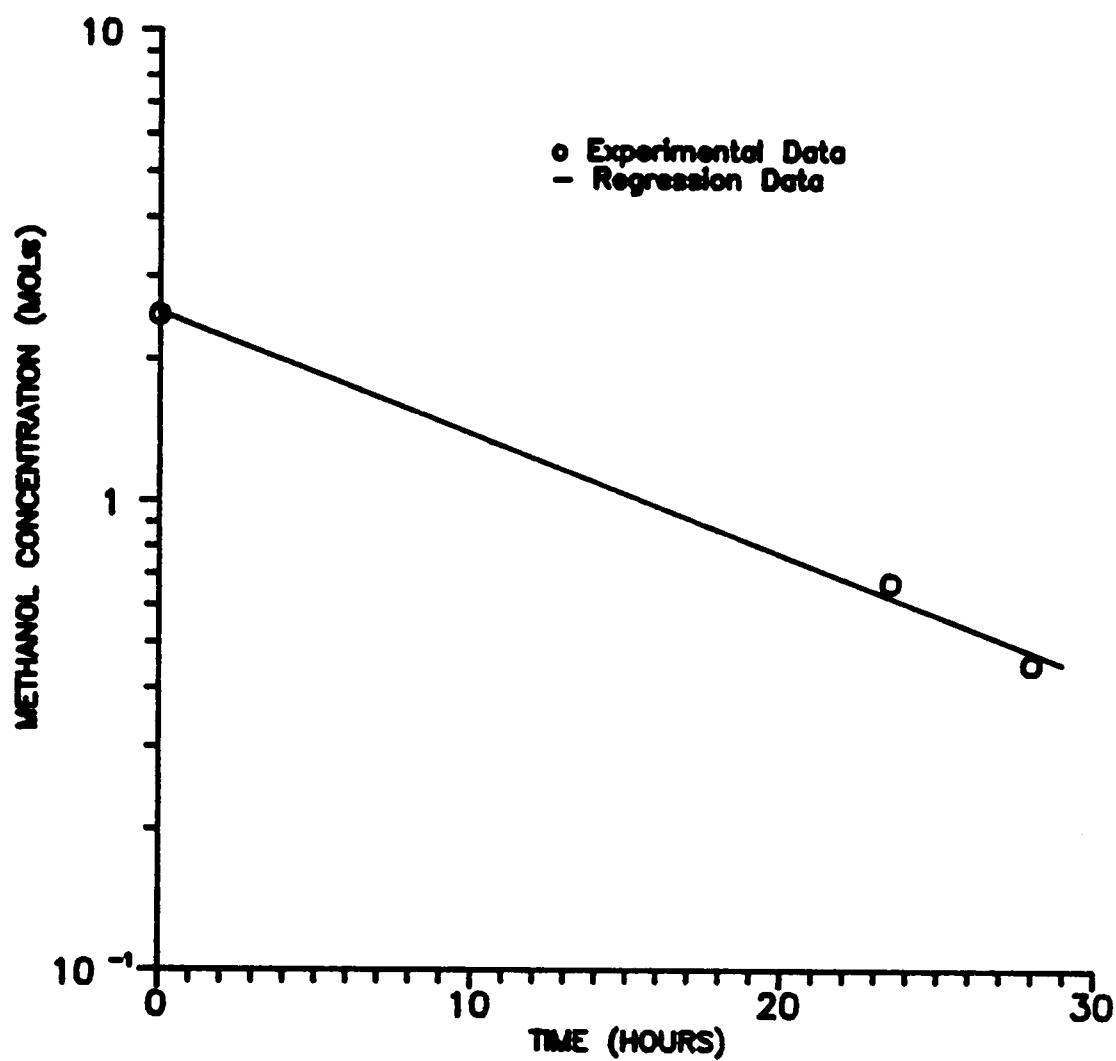


Figure B.14 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.21

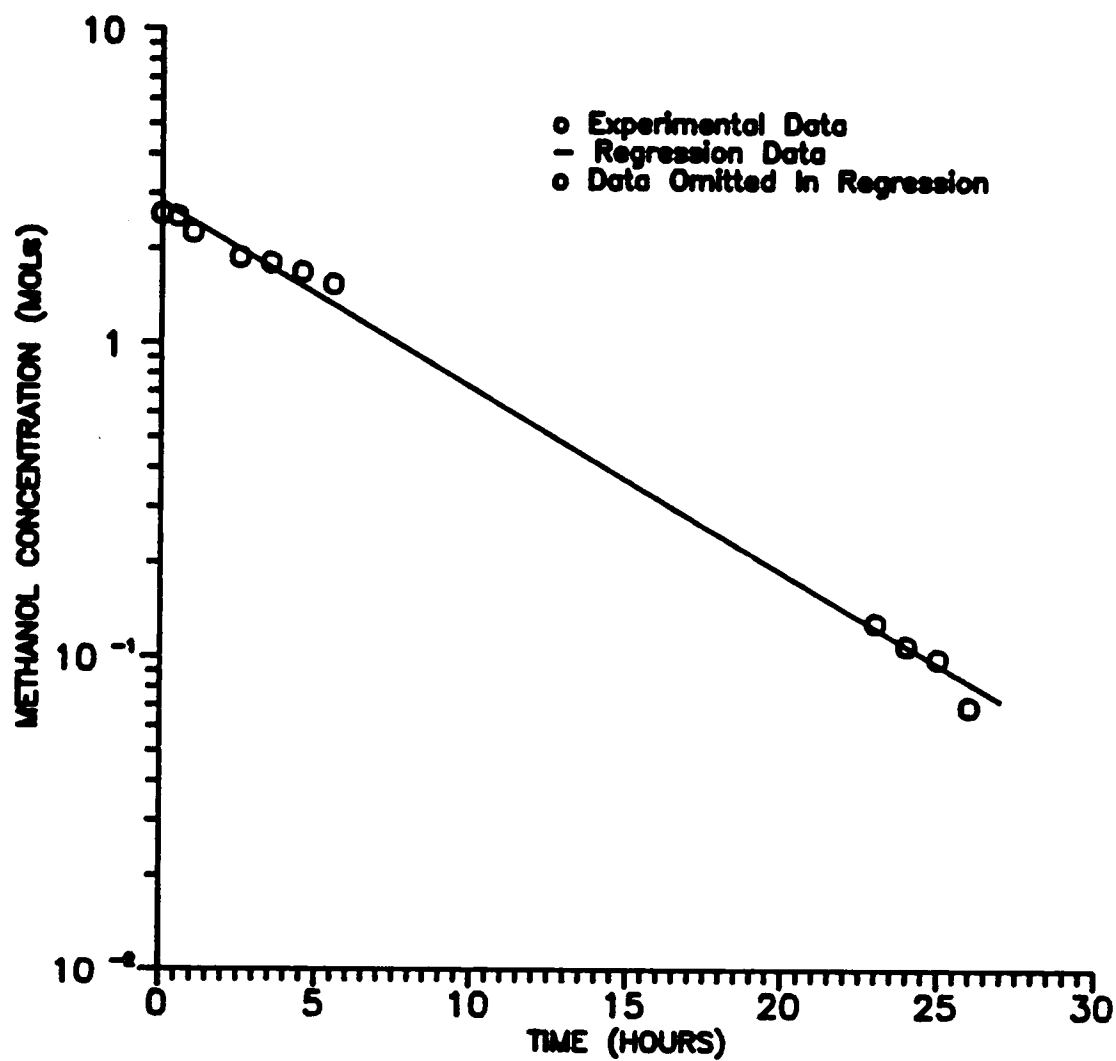


Figure B.15 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.22

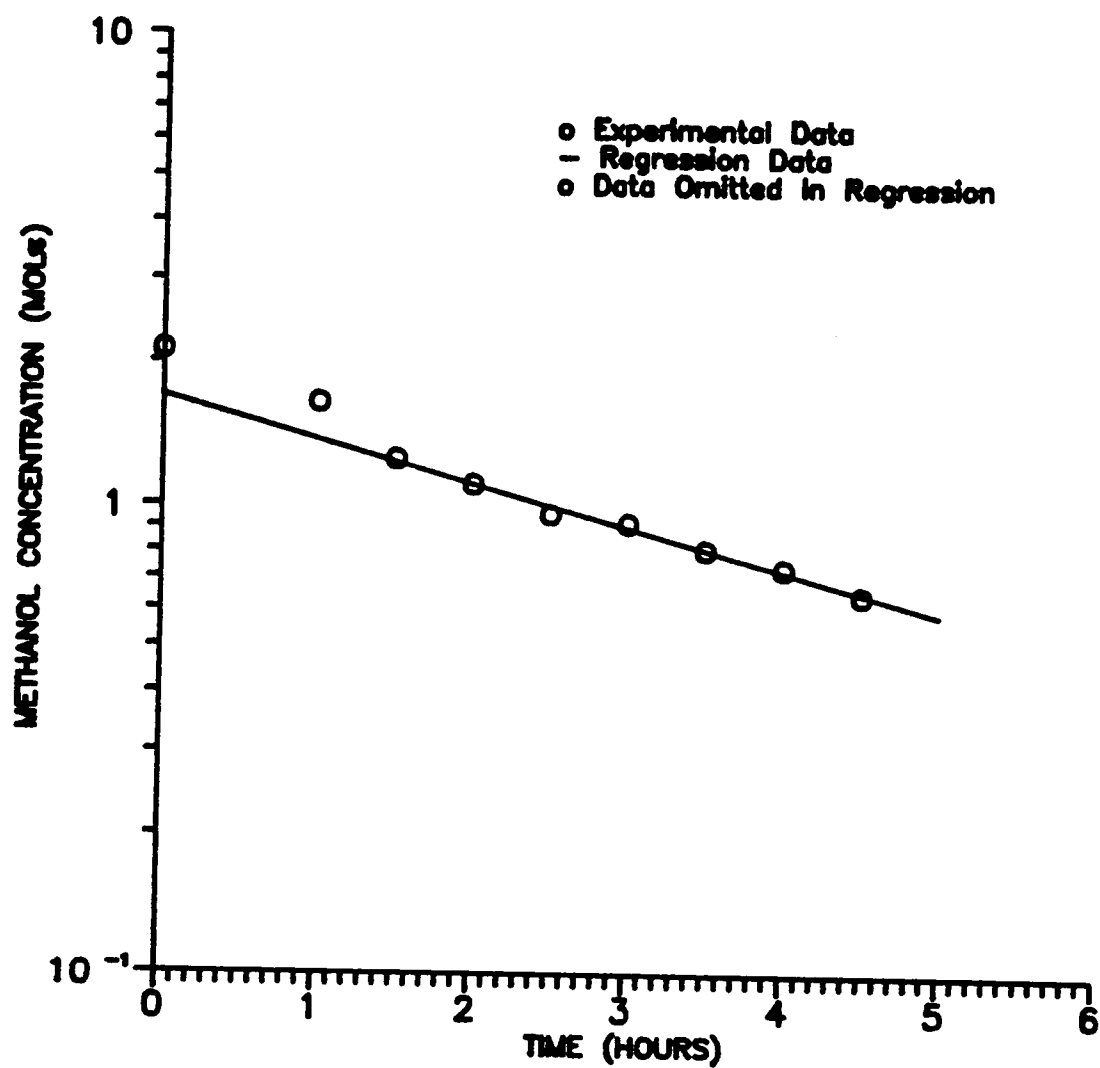


Figure B.16 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.24

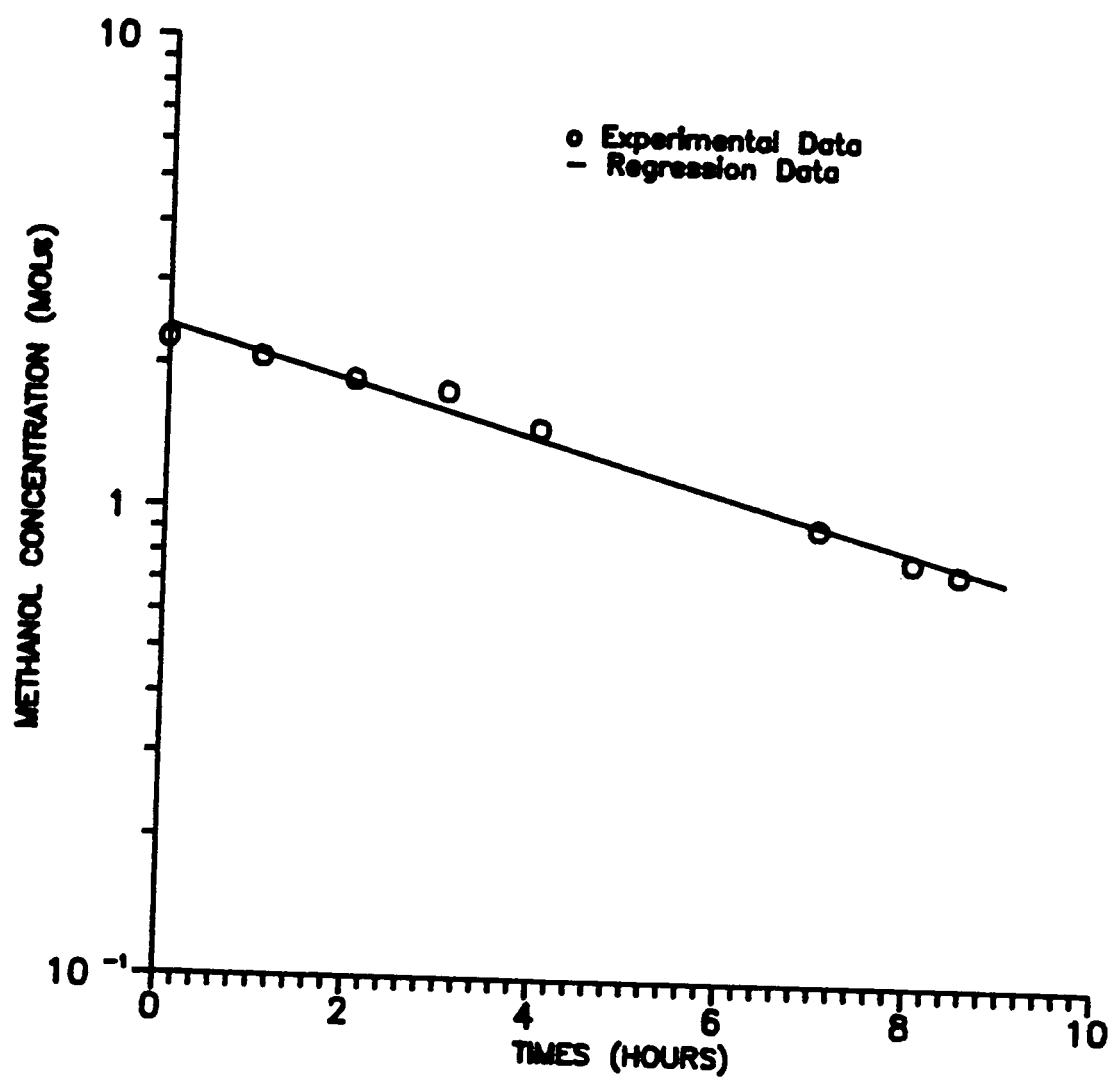


Figure B.17 Concentration History Of Methanol In A Laboratory Spray Pond, Run No.25

APPENDIX C
Conversion Of Vol% To Mol%

Conversion Of Vol% TO Mol%

$$\text{Vol\%} = (\text{Vol meoh} / (\text{Vol H}_2\text{O} + \text{Vol meoh}))$$

assume Vol% = 10.5
Vol H₂O is set to 50.0 gallon = 6.68 ft³
Therefore:
Vol meoh = 5.87 gallon = 0.7852 ft³
Mole meoh = (lb/ft³)/MW
 = (49.42*0.7852)/32.0 = 1.2
Mole H₂O = (lb/ft³)/MW
 = (62.4*6.68)/18.0 = 23.16
Mole% = (Mole meoh/(Mole H₂O + Mole meoh))*100
 = 0.0483 = 5%

APPENDIX D
Spray Pool Dimensions

Spray Pool Dimensions And Water And Methyl Alcohol Capacities.

Pool diameter = 5.83 ft
 Minimum water height = 3 in = 0.25 ft
 Volum of the pool = $\frac{1}{4}(d^2 * h)$
 = $\frac{1}{4}(5.83^2 * 0.25) = 6.67 \text{ ft}^3$
 $6.67 \text{ ft}^3 * 62.4 \text{ lb/ft}^3 = 416.23 \text{ Lbs}$
 $416.23 \text{ Lbs}/(8.33 \text{ Lbs/gals}) = 49.96 \text{ gallons}$
 So volum of the pool = 50.0 gals
 or Mol H_2O = $416.23 \text{ Lbs}/(18.0 \text{ Lbs/Lb mol})$
 = 23.12 lb mol
 So for MeOh solution:
 $0.05 = x/(x+23.12)$
 $x = 1.22 \text{ Lb mol}$
 Molecular weight MeOh = 32.0 Lbs/Lb mol
 Weight MeOh = $32 * 1.22 = 38.94 \text{ Lbs}$
 Density MeOh = 49.42 Lbs/ft³
 gals of MeOh = $38.94 \text{ Lbs}/(49.42 \text{ Lb/ft}^3)$
 = 5.89

APPENDIX E
Sample Calculations
And The Values Of τ

Sample Calculations For Turn Over Time, $\bar{t}$, For
Run No. 1

$\bar{t}$ = Volume of the liquid in the pond/Flow rate
 = gals/(gals/min)
 [=] min

Volume of liquid in the pond:

Starting Volume:

Pool diameter = 5.83 ft

Water height = 2.625 in = 0.2188 ft

Volume = $\frac{1}{4} d^2 h = \frac{1}{4} (5.83)^2 (0.2188)$
 = 5.838 ft³

gals of liquid = 5.838 ft³ * 62.4 Lbs/ft³ * 1/(8.33
 lb/gals)
 = 43.73 gals

Ending Volume:

Volume = $\frac{1}{4} (5.83)^2 (0.2135)$
 = 5.697 ft³
 = 42.67 gals

Average volume of liquid in pond = (43.73 + 42.67)/2
 = 43.20 gals

Therefore:

$\bar{t} = 43.20 / 0.30 = 144 \text{ min}$
 = 2.4 hrs

Table E.1 Values Of Turn Over Time, τ , For All The Runs

Run No.	Flow Rate gpm	Volume		τ hrs
		gals	cm ³	
1	0.30	43.20	163531	2.40
2	0.35	46.83	177272	2.23
3	0.35	48.93	185222	2.33
4	0.35	46.83	177272	2.23
5	0.35	43.72	165499	2.08
6	0.40	49.97	189158	2.08
7	0.40	47.88	181247	1.99
8	0.40	44.76	169436	1.87
9	0.40	43.72	165499	1.82
10	0.50	51.01	193095	1.70
11	0.50	49.97	189158	1.67
12	0.50	45.80	173373	1.53
13	0.50	a	-	-
14	0.50	43.72	165499	1.46
15	0.50	a	-	-
16	0.50	45.80	173373	1.53
17	0.50	43.72	165499	1.46
18	0.50	a	-	-
19	0.60	49.45	187190	1.37
20	0.60	41.64	157626	1.16
21	0.60	40.59	153651	1.28
22	0.60	40.59	153651	1.13
23	0.60	43.73	165537	1.21
24	0.60	35.34	133777	0.98
25	0.60	45.29	171443	1.26

^a Was not measured, due to excessive water loss from the pool

APPENDIX F
Data For Calibration Curve

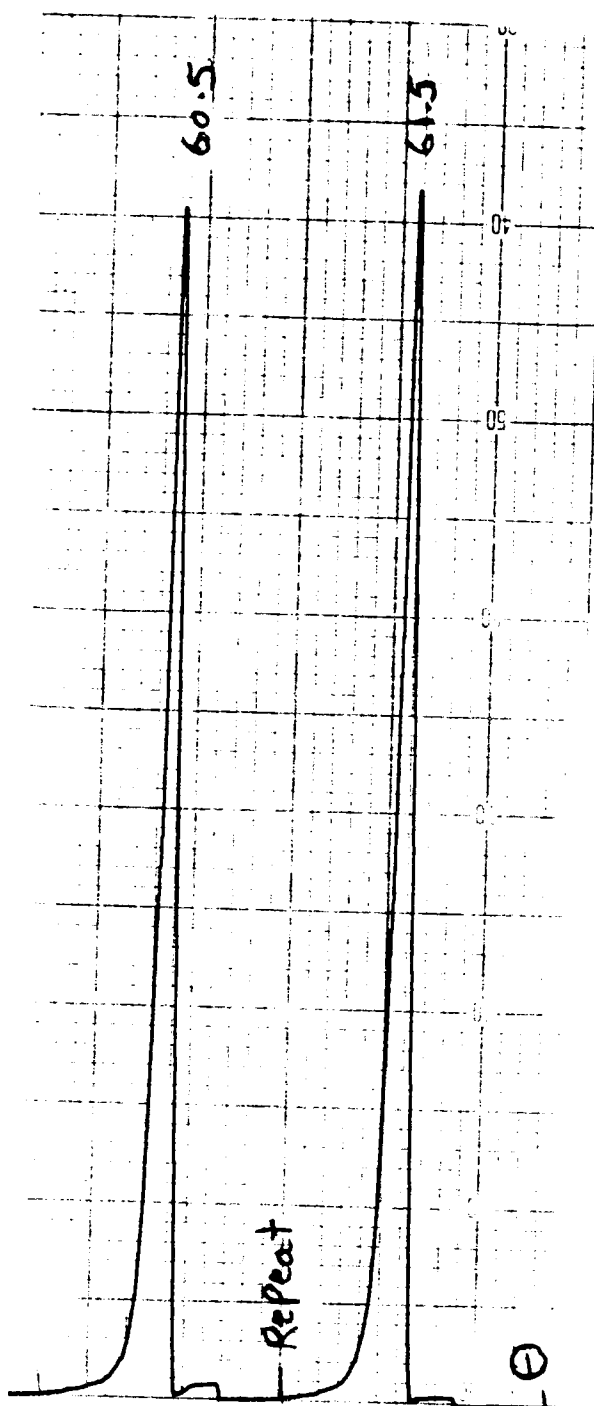
Table F.1 Data For Calibration Curve

Concentration Of Methanol, Vol%	Peak Height ^a
0.1	4.0
0.3	15.0
0.5	20.0
0.7	48.0
1.0	64.0
1.5	82.0
2.0	136.0
3.0	175.0
4.0	252.0
5.0	295.0
6.0	345.0
7.0	420.0
8.0	590.0
9.0	660.0
10.0	730.0

^a Attenuation = 2×10^3
Range = 1 mv
Speed = 0.50 in/min

APPENDIX G
Sample Peak Height

Att. 2×10^4
Range 1 mv
Speed 0.5 in/min



Methanol Peak
Water Peak

Figure G.1 Sample Peak For Run No.9

APPENDIX H
Use Of Gas-Liquid Chromatograph

Gas-Liquid Partition Chromatography

G-C-M 1241 Routine S

Cat.No.913400

To Warm Up The System:

- A) Turn the recorder function switch to the "STBY" position (the lower switch on the left side).
- B) Open the carrier gas valve all the way. The front scale on the tank must be set at 60. The carrier gas pressure must show 4.3 KP/cm^2 (on the first block).
- C) Set the carrier gas flow rate to 25.5 cc/min for both reference and sample columns. The difference between these two columns should not be greater than 1.5%. To set 1.5%, connect the gas meter tube to the outlet side of the reference or lower column and the sample or upper column separatelyseperately and adjust the flow rate by the two knobs on the left and right respectively to 25.5 cc/min.
- D) Turn on column heater (the lower switch on the right of block #3). The lower switch on the left must be set at isotherm mode. Leave the upper two switches (RECFID & TCD) at (-) sign.

Fix column temperature to 120°C and detector temperature to 150°C by using the upper and lower black knobs in the

block #3. Detector temperature must be greater than column temperature throughout the experiment.

E) Turn the switch on the block #7. Let the temperature indicate reach 160°C. This will take about one hour. Set the lower right hand knob to position 40.

F) We do not use the Thermal Conductivity Detector (TCD). Leave the switch on block #6 in the off position.

Starting Procedure:

Flame Ionization Detector (F.I.D.)

A) Installation of column (this has already been done)

B) Conditioning of newly field columns (this has already been done)

C) Adjusting gases.

The ratio of air to hydrogen should be 10:1 volumetric bases. To adjust this:

1) Cut the carrier and hydrogen gases off.

2) Open air valve all the way and let the air in.

3) Adjust air pressure to 44 psi. This will fix the air flow rate to 200 cc/min. One can see this by simply using the gasmeter.

4) Turn air off.

5) Turn yhe hydrogen valve all the way.

6) The pressure indicator on the second block must show 1.5 KP/cm² for both sample and reference columns. This will fix the flow rate of hydrogen to 20 cc/min. The scale reading on the tank (left one) must be on 30.

7) Turn on all gases.

D) The attenuator switch is set to 1×10^4 (block #4).

E) Set the "zero adjust" to position "500".

F) Turn the recorder to "CHT".

1) With the button "amplifier balance" set recorder to zero.

2) Set the chart speed to 0.5 inches/min.

3) Set the second knob in the right to 1 mv.(recorder).

4) The zero knob in the recorder does the same as the zero knob on block #4.

G) Using the match light on the F.I.D., depress button "ignition" on block #4 for about two seconds. That would help the burner to ignite.

H) Move attenuator switch to position " 5×10^3 ", after which the recorder will leave zero.

I) Reset attenuator switch to position " 1×10^4 ".

J) Inject sample by means of a suitable syringe into the left-hand injection inlet. Be sure to change the septum after several shots.

To Shut Down The System:

Turn all the switches off. Turn off the carrier gas and hydrogen and air. If one wants to leave the system on for a long time, be sure to open the fan.

VITA

Golbarg Dehkordi Smith was born in Sary, Iran on September 13, 1958. She attended elementary school in Tehran and graduated from Marjan High School in June 1977. The following Fall she entered The Melli University located in Tehran.

Golbarg came to The United States in May 1979. She attended The University of Bridgeport in Connecticut for three quarters. She then transferred to The University Of Tennessee in Knoxville so as to continue her undergraduate program. In March 1982 she received a Bachelor of Science degree with a major in Chemical Engineering. In the Spring of 1982 she began her studies toward a Master's degree in Chemical Engineering. This degree will be awarded in August 1987.

The author is married and currently resides in Florida with her family.