

PERFORMANCE CHARACTERISTICS OF A
DESICCANT DEHUMIDIFICATION
SYSTEM USING CALCIUM
CHLORIDE SOLUTION

By

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1980

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the degree of
MASTER OF SCIENCE
July, 1982

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1982
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ACKNOWLEDGMENTS

This study was concerned with development and testing of a dehumidification system using calcium chloride for maintaining environments in housed animal structures. The major objectives were to develop dehumidification equipment suitable for this application and test the effectiveness of calcium chloride under conditions found in these environments.

The author wishes to express deep thanks and appreciation to his major advisor, Dr. Gerald H. Brusewitz for his advice, criticism and encouragement throughout the course of this study. Appreciation is also given to Dr. Peter Bloome and Dr. Ray Huhnke, members of the advisory committee, for their helpful contributions and suggestions.

Gratitude is extended to Dr. C. T. Haan, Department Head of Agricultural Engineering, for providing the financial support and facilities required to complete this study.

To Mr. Norvil Cole and all the technicians at the Agricultural Engineering Laboratory, a sincere thanks is given for their patience and invaluable experience offered for constructing equipment for experimentation.

Thanks is given to Mr. Jack Fryrear for photography and the reproduction of final drawings and to Mrs. Laura Johnson for the patience required in the typing of this thesis.

Finally, I would like to thank the rest of the staff at the Agricultural Engineering Department for providing such a cooperative and interesting environment in which to work.

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LIST OF SYMBOLS

A	- Difference between initial and equilibrium concentration values, % (dw/ww)
C	- Instantaneous concentration, % (dw/ww)
C_e	- Equilibrium concentration, % (dw/ww)
C_e^*	- Pseudo equilibrium concentration, % (dw/ww)
C_o	- Initial concentration, % (dw/ww)
CR	- Concentration ratio, dimensionless
k	- Sorption constant
M	- Instantaneous moisture content, % db
M_e	- Equilibrium moisture content, % db
M_o	- Initial moisture content, % db
MR	- Moisture ratio, dimensionless
R.H.	- Relative humidity, %
td	- Desiccant temperature, °C
tdbair	- Dry bulb air temperature, °C
twbair	- Wet bulb air temperature, °C
θ	- Elapsed time, hours
$\Delta V.P.$	- Initial vapor pressure difference, mm-Hg

CHAPTER I

INTRODUCTION

The Problem

In confined livestock environments, ventilation air is required at all times for one or more of the following purposes: (1) to provide oxygen to the animals, (2) to remove moisture and odors, (3) to prevent heat build up, and (4) to control airborne disease organisms. It has been estimated that a 50 kg. pig at a room temperature of 32.2°C produces approximately 0.10 kg. of water vapor per hour on fully slotted floors. The suggested winter ventilation rate required to remove this water vapor can be as high as 0.2 m³/min. Primary requirements for ventilation design of controlled environments is summer cooling and winter dehumidification.

The conventional method of ventilating for winter dehumidification results in a high energy demand. Cold ventilation air entering a building is warmed by water vapor adsorption and sensible heating before being expelled, resulting in considerable energy loss to the building. The quantity of air required for dehumidification in this manner is far in excess of the oxygen requirements of

the animals. If other means were used to control humidity so that ventilation could be limited to oxygen requirements, possibly 50% or more of the ventilation heat load could be saved.¹ The use of desiccants for moisture removal has potential application with respect to this problem.

A large portion of work with desiccants has been involved in the drying of industrial gases and control of human environments, and they have received some attention in agriculture and related industries. Odigboh (1976) used calcium chloride to study preservation of food grains under humid tropical conditions. Fletcher (1980) constructed and tested a grain drying system using liquid calcium chloride with solar regeneration of the desiccant. Farmer, Brusewitz and Farouk (1979) studied direct solar paunch drying, supplemented by solar regenerated desiccant. With present solar technology the prospect of using desiccants for dehumidification is further enhanced by using this alternate energy source for regeneration.

Scope of Study

To investigate the use of calcium chloride desiccant for dehumidification of housed animal environments, it was

¹Value of 50% or more taken from graphical information contained in Environmental Control For Confinement Livestock Housing, (1980) Don Jones and William Friday, Purdue University.

necessary to develop model testing equipment which was considered suitable for this application and then test the effectiveness of this equipment under simulated conditions of the intended use. Liquid desiccants were chosen over solid desiccants primarily because of cost and ease of handling.

Calcium chloride was chosen as the desiccant to be tested after a preliminary investigation into the characteristics of some common liquid desiccants. Important properties considered were corrosiveness, chemical stability, vapor pressure characteristics, cost and availability. A simple and low cost dehumidifying system was designed and constructed. It consisted essentially of a rotating cylindrical frame covered with mesh which serves as a desiccant-air contactor. The drum is partially submerged in solution and air is passed through the exposed mesh wetted with desiccant.

The specific objectives of this research were to:

(1) design and construct a dehumidification system which was considered suitable for use in housed animal environments, and (2) test the dehumidification effectiveness of calcium chloride at temperatures found in these environments. The calcium chloride desiccant system was tested under different inlet air temperatures and at different desiccant temperatures. Inlet air conditions were held at

80% relative humidity, which is considered the maximum allowable relative humidity for air conditions inside animal environments. The rate of concentration change as a function of time was recorded in the tests.

CHAPTER II

LITERATURE REVIEW

Hougen and Dodge (1947) have referred to calcium chloride as one of the oldest and most well known desiccants amongst chemists and the gas industry. Because of its low cost and availability, it was one of the first agents to be considered for industrial drying of air and gases. Calcium chloride is commercially available in a form of 94-97% CaCl with a small percentage of NaCl and minor quantities of other impurities. Allied Chemical Corporation, a major manufacturer of calcium chloride, uses an ammonia-soda process for commercial production. Fundamentally, the process involves the reaction of sodium chloride with calcium carbonate in several successive stages with the assistance of large quantities of ammonia (Allied Chemical, 1956).

Calcium chloride solutions are no more corrosive to steel than plain water as demonstrated by several researchers. They do have the tendency to dry more slowly than water. Thus a CaCl wetted surface is likely to remain wet longer than a surface wetted with water therefore causing more corrosion. Calcium chloride solutions are slightly alkaline and will attack aluminum, zinc and tin if the pH

of the solution is not maintained near the neutral point (Allied Chemical, 1956). The presence of hydrogen sulfide forms objectionable precipitates with calcium chloride. Entrained oil, absorption oil, etc. will emulsify with calcium chloride, decreasing the efficiency of contacting equipment. For extremely concentrated solutions, care must be taken not to allow the temperature of the solution to fall below its crystallization temperature or the solution will solidify causing problems in piping networks and pumps (Hougen and Dodge, 1947).

Hygroscopic Properties

Some hygroscopic properties of calcium chloride and its solutions have been studied and documented by the Solvay Process Company, now Allied Chemicals. Calcium chloride is considered deliquescent because, in the presence of appreciable amounts of water vapor, it will dissolve or dilute completely in its own absorbed moisture. It will continue to absorb water vapor from surrounding air or gas until the vapor pressure of solution and surrounding medium are equal. During the process of water absorption, considerable amounts of latent and sensible heat energy are transferred to the desiccant due to heat of hydration and heat of solution of the process.

Vapor pressures of calcium chloride solutions can be described graphically as a function of the concentration and temperature of the desiccant solution. For a given

concentration of calcium chloride solution, vapor pressure increases logarithmically with increasing temperature. Vapor pressure data of the desiccant solution are useful for determining the vapor pressure differential between the solution and gas. The vapor pressure differential, in turn, is useful for describing the potential for water absorption rate. Hougen and Dodge (1947) stated dehumidification of air with calcium chloride under normal temperature ranges is limited to a minimum of 20-25% relative humidity.

Dehumidification/Regeneration Systems

Several types of liquid desiccant dehumidification and regeneration systems using calcium chloride and other desiccants have been studied. C. R. Downs and the Colorider Corporation (Hougen and Dodge, 1947) developed a dehumidifier using calcium chloride in the form of 38 to 50 mm cubes made under a patented process. The cubes, containing approximately 72% CaCl by weight, were hard and crystalline so as to confine water absorption to the surface of the cube. In the Colorider system, air is passed through a parallel flow spray chamber of CaCl solution followed by compartments filled with the cubed CaCl. The CaCl solution for the spray chamber is supplied by the deliquescence of the cubed CaCl. Cooling coils are used to remove the heat of condensation and solution from the CaCl liquid. A parallel flow spray chamber is used to

allow a large air-to-liquid ratio and to avoid flooding. With this system it is possible to dry air at 36.5°C and 85% relative humidity to 27% relative humidity. Because there is no means of regeneration, it is low in cost, and readily available the spent CaCl solution is discarded.

Heath (1932) investigated domestic dehumidification with CaCl solution and compared the cost of this method with that of conventional methods. The equipment used for testing consisted of 20 steel plate circular discs mounted centrally and perpendicularly on a shaft. The discs were spaced 38 mm apart and were 0.91 meters in diameter. The shaft was mounted in a steel box which was partially filled with the desiccant solution. A segment of the circular discs dips into the solution. Humid air was passed through the box parallel and through the circular discs. Calcium chloride flakes were fed intermittently to the solution to maintain the concentration near 78.5% and an overflow pipe was used to keep the solution level constant as it absorbs moisture. Overflow of the desiccant solution was discarded. This system and conventional systems were compared economically on the basis of removing a total load of 1,000 Btu of heat from the air. Two total load conditions were considered: (1) the total load comprised of 25% latent heat and 75% sensible heat and (2) the total load comprised of 50% latent heat and 50% sensible heat. The comparisons revealed that the CaCl system

could remove a 75% sensible - 25% latent load at lower cost than conventional systems. The temperatures and humidities of the air used to obtain data in these tests were not presented in the literature.

Solar energy has been offered as a suitable means of regenerating calcium chloride solutions for reuse as a desiccant in dehumidification. Mullick and Gupta (1973) and Ko and Merrifield (1977) regenerated solutions by heating them to 40-70°C and contacting the solution with ambient air.

Holland (1963), experimenting with a solar still, found the daily efficiency for regenerating lithium chloride brine to be 5-20% depending on the insolation and concentration of the brine. The still used was of the type developed by Wilson (1958) with glass covers sloping 10 degrees, an asbestos cement tray and an approximate solution depth of 75 mm. The efficiency of this type of still acting as a desalinator has been found to be 40 to 60 percent. The apparent reduction in efficiency of regenerating LiCl to that of desalination of water is the considerable vapor depression of a concentrated lithium chloride solution compared with the negligible depression due to salt in water.

Using equipment resembling that of an inclined flat plate collector, Mullick and Gupta (1973) studied the solar desorption rate of water from CaCl solutions as compared to solar stills. The collector was open at the

bottom and top to allow ambient air to thermosiphon over the absorber plate. The absorber plate was constructed from corrugated iron and the desiccant solution was trickled down the corrugations giving up moisture as it was heated. The efficiency for this system was defined as the energy used in mass transfer divided by the intercepted solar energy of the collector. It was found that the collector-desorber had an efficiency in the region of 40% and were higher than a solar still at all levels of irradiation. In addition the collector desorber could function at lower levels of irradiation than a solar still.

A packed bed dehumidifier-regenerator was studied by Factor and Grossman (1980) to determine the effect of varying desiccant to air flow rates (L/G, liquid-gas) on the absorption and desorption of water vapor. Lithium bromide was used as the desiccant with concentration varied from 56 to 60 percent and temperature from 25 to 80°C. Air temperature was varied from 26 to 52°C and absolute humidity from 11.44 to 14.86 g H₂O/kg air. It was concluded that a L/G ratio of 0.5 to 0.8 was optimal from considerations of mass transfer and pressure drop through the packed bed for both dehumidification and regeneration. Under certain conditions, the desiccant reached equilibrium conditions with the incoming air before passing through the bed. By studying the temperature variation of the desiccant as it flowed through the bed, it was determined

that bed performance was enhanced by pre-cooling or pre-heating the inlet air in dehumidification and regeneration, respectively. One major disadvantage of this system acknowledged by the authors is the large pressure drop incurrent in the bed.

Fletcher (1980) constructed a calcium chloride desiccant crop dryer with solar regeneration. The major improvement of this system over others is the integration of the solar collection/regeneration system with the absorber/drying system. The system was similar to that of Heath's (1932) with the exception of a transparent cover over the rotary air desiccant contactor which allowed solar regeneration of the desiccant. This was achieved by exposing the wetted surface of the cylindrical desiccant air contactor to incoming solar radiation. The system was designed to operate on an annual cycle of drying grain in the fall and regenerating the desiccant throughout the rest of the year. Disadvantages of the system were the large amount of desiccant needed to operate on an annual cycle and the slow rate of regeneration.

Ko and McCormick (1977) proposed more complex systems using packed beds and solar energy for simultaneous absorption and regeneration. Solar energy can be used in the system to regenerate dilute desiccant solution, the heat of hydration and solution energy are utilized via heat exchangers to reduce energy input. Theoretical estimates

on fossil fuel energy savings were approximately 40 to 50%. If solar energy is used 70 to 90% fossil fuel savings were estimated.

CHAPTER III

MATERIALS, EQUIPMENT, AND METHODS

Calcium Chloride

Commercially available anhydrous calcium chloride in granular form was obtained in 36 kg. bags for experiments. Chemical analysis by the manufacturer states the granular material was 94-97% calcium chloride by weight. Allied Chemical (1956) states that the granular material in this form is composed largely of anhydrous (CaCl_2) and some monohydrate ($\text{CaCl}_2 \cdot \text{H}_2\text{O}$) calcium chloride, the remainder contains a small percentage of sodium chloride and minute quantities of other substances. Some relevant properties of calcium chloride are contained in Appendix A. Also in Appendix A are graphical presentations of characteristics of calcium chloride solutions with regard to vapor pressure, solubility, pH and specific heat.

Dehumidification System

To study the use of calcium chloride as a desiccant for dehumidification it was necessary to design and build a dehumidification system. Reviewed literature indicated

that there were many types of dehumidification system concepts proposed by researchers. As a consequence, requirements of a system for its intended use in housed animal environments were set. These were outlined as follows:

1. To achieve simplicity and compactness the system should be able to perform both dehumidification and regeneration as a reverse process using a minimal amount of additional or duplicate equipment.

2. The system should have a small amount of liquid desiccant circulation to minimize the energy input and reduce the possibility of desiccant solidification in pipes and pumps.

3. To reduce the energy input for regeneration, the system should be adaptable to simple solar energy collection systems.

4. The mechanical design should be simple and relatively maintenance free.

Using the above requirements as criterion for a design concept, a system was developed. The system consists of a cylindrical frame covered with a mesh material which rotates about a horizontal axis. The cylindrical frame is partially submerged in desiccant solution while air is passed through the unsubmerged mesh. Air passes through the mesh from the inside of the cylindrical drum to the outside. For dehumidification, concentrated desiccant is picked up by the mesh and moisture is absorbed as air passes through. The regeneration air will reconcentrate the

solution by absorbing water from it. The mode of regeneration or dehumidification can be determined by controlling the temperatures of the solution and air, which in turn controls their vapor pressures.

Figure 1 illustrates the dehumidification/regeneration equipment constructed for testing. The rotating drum consists of a circular air duct tube which also forms the axle for rotation. Mounted at the ends of the tube ducting are two circular plates to which 5 mm diameter aluminum rods are bolted to carry the mesh. Twelve rods carry one layer of mesh. Provision has been made for more rods to be added and thus more layers of mesh may be used. The spacing between the layers of mesh is 15 mm. For all tests undertaken two layers of woven polypropylene mesh were used with an opening size of 0.985 mm and 7.2 openings per centimeter. Polypropylene mesh was used as it was inexpensive and readily available. Steel mesh used in preliminary testing was found to corrode rapidly. The mesh opening size was selected to give a large wetted surface area but not too large of air pressure drop across it. Thought was given to the possible undesirable transport of solution from the mesh by excessive air velocity through the mesh. The system flow rate was designed around a capacity of approximately $10 \text{ m}^3/\text{min}$. With this air capacity the velocity of the air flowing through the screen is limited to 8.85 m/min.

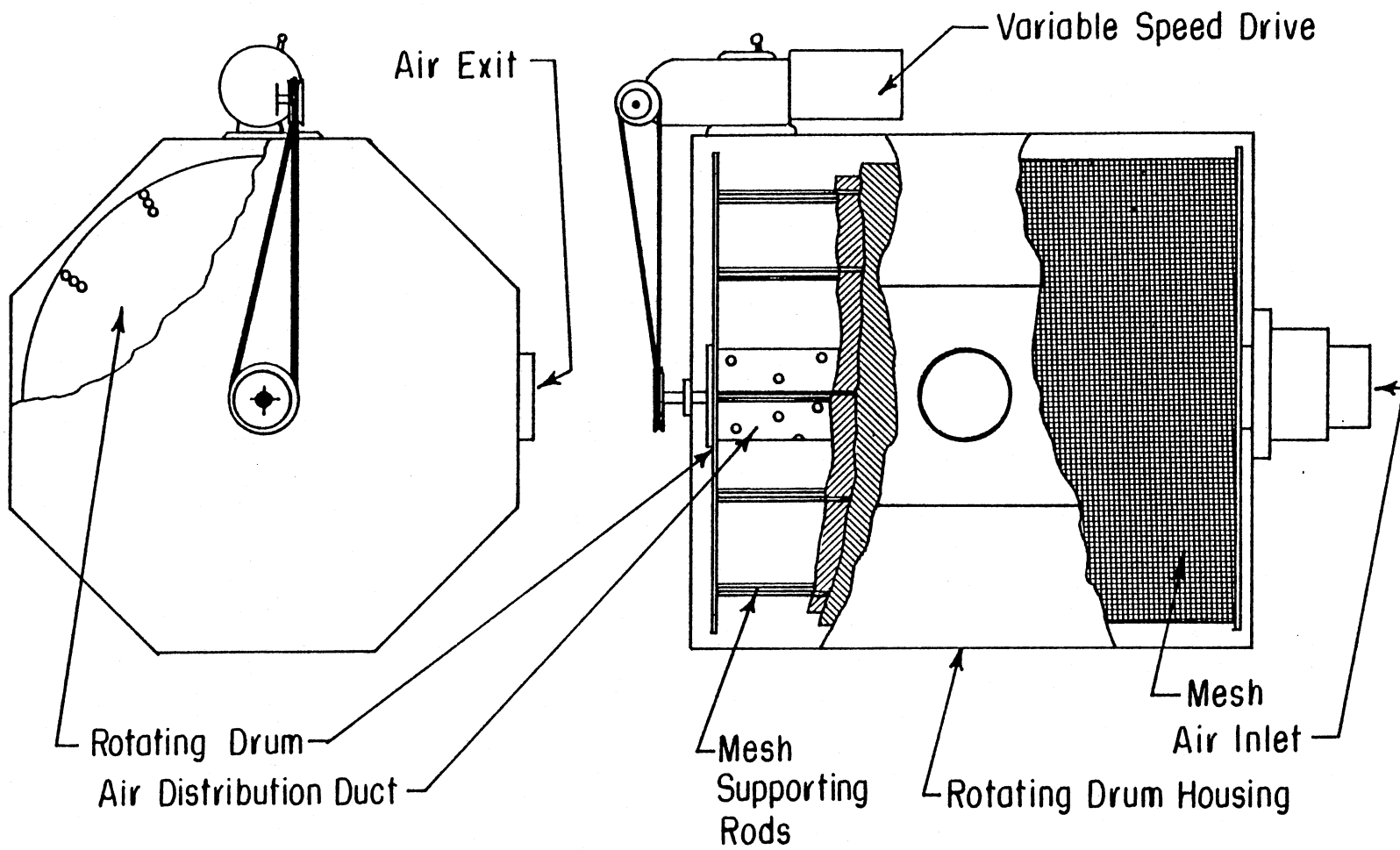


Figure 1. Schematic Diagram of Air Dehumidification Equipment

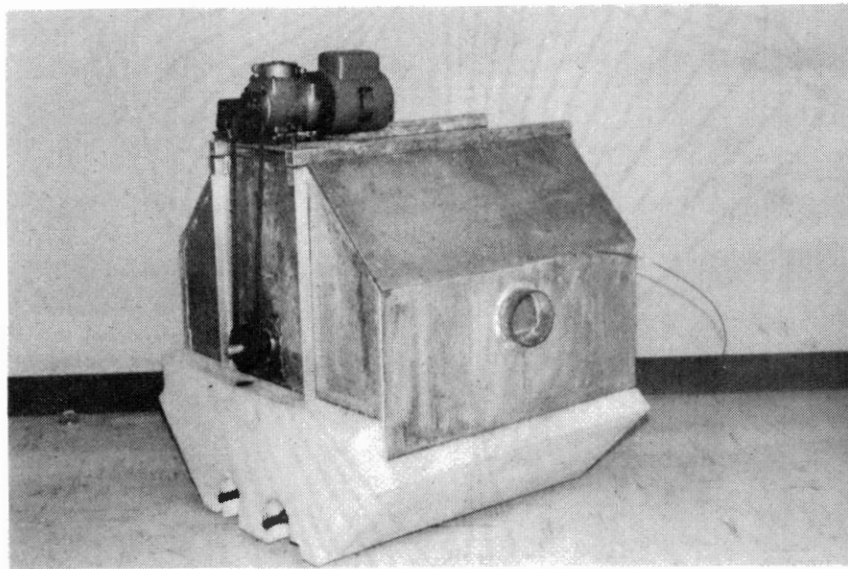


Figure 2. Air Dehumidification
Equipment

The tubular distribution duct is made from 100 mm diameter aluminum pipe with 64, 12 mm holes drilled equally spaced along and around the duct. At the air entrance to the duct a wooden bearing supports the duct and acts as an air seal. At the other end of the duct a 16 mm aluminum shaft is used for support of the drum. This shaft is used for rotating the drum.

A short length of the distribution duct protrudes from the drum housing. Fitted over this is a 150 mm diameter tube attached to the housing which serves as a mounting for plastic ducting connected to the controlled environment chamber. The entire rotating drum acts as a low head pump to keep the solution mixed to achieve equal concentration and temperature.

A variable speed drive with a 0.09 kW motor was coupled to the drum by a V-belt. A speed of approximately 3 rpm was established as the maximum speed allowable to prevent separation of the desiccant from the mesh. This was determined by visually observing the drum as it rotated through the desiccant and varying its speed. It was desirable that the exchange rate of desiccant to air flow be as high as possible, therefore the drum was rotated at 3 rpm for all tests. A heat exchanger constructed from 2 meters of 16 mm copper tubing was placed in the bottom of the drum housing. This water heat exchanger is used for desiccant temperature control.

The drum housing was constructed from aluminum sheet metal and all joints were welded and sealed with silicone rubber. Access to the inside of the housing for drum installation and desiccant changing is by a removable door which covers the top three portions of the octagonal housing.

The housing has a capacity of 110 liters. The design level of the desiccant is to the bottom edge of the vertical sides. This level of desiccant submerges approximately 1/3 of the circumference of the mesh. It was considered that submerging this portion of the mesh would allow ample time for reconcentration of desiccant on the mesh during its period of revolution. The octagonal shape was used to reduce the total amount of desiccant used for experimentation and thus reduce handling problems. The length of the housing is 660 mm. The drum is 600 mm in length and has a radius of 280 mm.

Equipment and Instrumentation

Controlled Environment

An AMINCO-AIRE unit was used to supply constant temperature/humidity air during dehumidification tests. This air conditioning unit delivers 29 m³/min of air with a range of dry bulb temperatures from 4.5°C to 71°C and relative humidities from 8% to 98%. The unit is capable

of maintaining temperatures within $\pm 0.5^{\circ}\text{C}$ and relative humidity within $\pm 2.5\%$ depending on the amount of air used.

An environment chamber was connected to the AMINCO unit. The chamber was a large box from which the desired amount of air could be tapped for experiments. It was constructed from 14 mm plywood with 75 mm polystyrene insulation covering the inside. The chamber's outside dimensions were 1.12 m by 0.95 m by 1.74 m long. For access to recording instruments inside the chamber, a sealed door was located on one side.

A small fan located on the outside of the box, delivered air to the dehumidification system. The air flow was controlled by restricting the fan entrance inside the chamber. For all tests, the fan air flow was $4.41 \text{ m}^3/\text{min}$. Air not taken out of the environment chamber was recirculated through the AMINCO. Air temperatures inside the chamber were maintained within $\pm 0.1^{\circ}\text{C}$ of the desired temperature during the tests. Air temperature inside the chamber was monitored for checking of proper operation of the AMINCO and that the conditions did not deviate far from the setpoint.

Desiccant Temperature Control

Desiccant temperatures were controlled as a means of controlling vapor pressure. Cold water was circulated through the heat exchanger located in the dehumidifier.

To condition the heat exchanger water, approximately 100 liters of water in a barrel were placed inside a Hotpack environment chamber. A pump providing 17 liters/min flow was connected via insulated pipes between the water storage and the heat exchanger. A Y.S.I. temperature controller was connected to the pump motor. The thermocouple from the controller mounted in the desiccant inside the drum housing sensed the desiccant temperature. The controller would turn the pump motor on or off depending on the signal it received from the thermocouple. This controller held desiccant temperature to within $\pm 0.1^{\circ}\text{C}$ of the setting.

During some tests it was necessary to add ice to the cooling water as the barrel acting as heat exchanger in the Hotpack chamber was not very effective. For this reason, the cooling water temperature was monitored by a thermocouple connected to the data logger recording air temperatures.

Temperature Recording

Temperatures were monitored and recorded using a Doric Digitrend 220 data logger. Entrance and exit temperatures of the air through the dehumidification system were measured using a wet and dry bulb thermocouple, a Weather Measure hygrothermograph and a Honeywell dew-point probe. These measuring devices were placed both in the

environment chamber connected to the AMINCO for entrance conditions, and in a recording box through which the dehumidified exit air passed. The hygrothermograph and the dew-point probe were used to confirm thermocouple readings. Wet and dry bulb thermocouples were constructed from 30 gauge copper-constantan wire. One end of a fabric sock was placed in a 150 ml reservoir of water. Thermocouples were tested against a sling psychrometer. The wet-bulb thermocouple worked reliably in wind velocities over 0.5 m/s. Figure 3 shows the instrumentation for recording the exhaust air conditions from the dehumidifier.

Methods

Concentration Measurement and Recording

To determine solution concentrations of the desiccant during dehumidification experiments, tests were conducted to determine the relationship of specific gravity versus concentration. Allied Chemical (1956) gives tabled values of specific gravity versus temperature for a large range of concentrations. It was considered necessary to establish the validity of these values as minor impurities in the granular calcium chloride used could result in some measurement error. In order to mix precise solution concentrations, it was necessary to establish the mean moisture content of the granular calcium chloride. Three

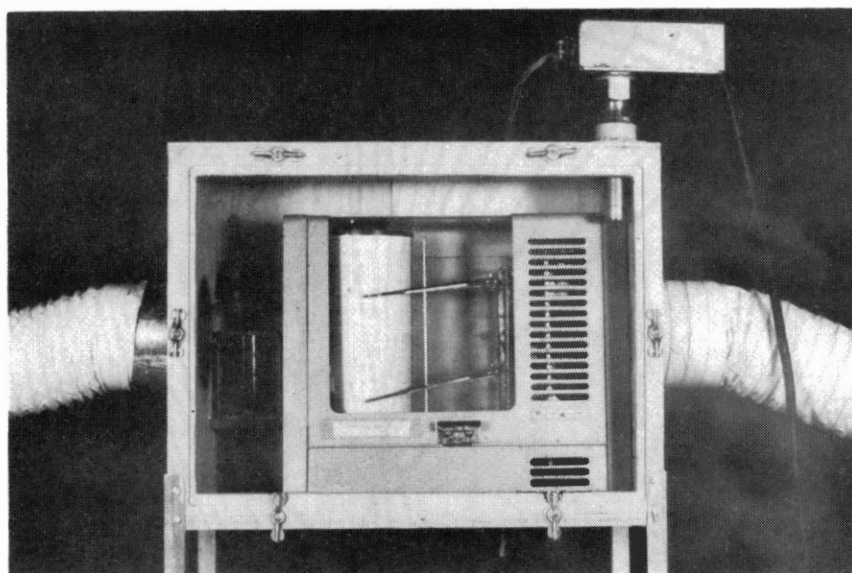


Figure 3. Recording Instrumentation
for Measuring Exhaust Air
Conditions

samples from three different bags were collected and oven dried at 120°C for 24 hours. The weight change divided by the original weight of calcium chloride was the original moisture content. An average value of moisture content from the nine samples was used when mixing solutions of known concentration. Moisture content results are tabulated in Table 1.

A standard procedure was set for experimentation in measuring specific gravity. This standard was to weigh a graduated flask containing 500 ml of the solution at 25°C. Results of specific gravity versus solution concentration are plotted in Figure 4. Also shown are values taken from literature.

A method of determining the change in solution concentration with time was necessary for dehumidification tests. This was achieved by recording the initial concentration and the total weight of desiccant used in each experiment. The weight change of desiccant solution was then recorded over the time each test was run. At the end of each test the concentration was again measured and recorded. The concentration at any time during each test could then be calculated by using the changes in weight. The concentration measurement at the end of the test provided a check on calculations and recording. Weight changes were measured by placing the dehumidification equipment on a platform scale. The scale had a maximum range of 500 kg with 0.5 kg increments.

TABLE I
AVERAGE MOISTURE CONTENT OF
GRANULAR CALCIUM CHLORIDE

Sample Bag	Sample	Moisture Content
1	1	7.9%
	2	7.5%
	3	9.0%
2	1	7.4%
	2	7.0%
	3	7.6%
3	1	7.8%
	2	7.4%
	3	7.9%

Average Moisture Content = 7.7%

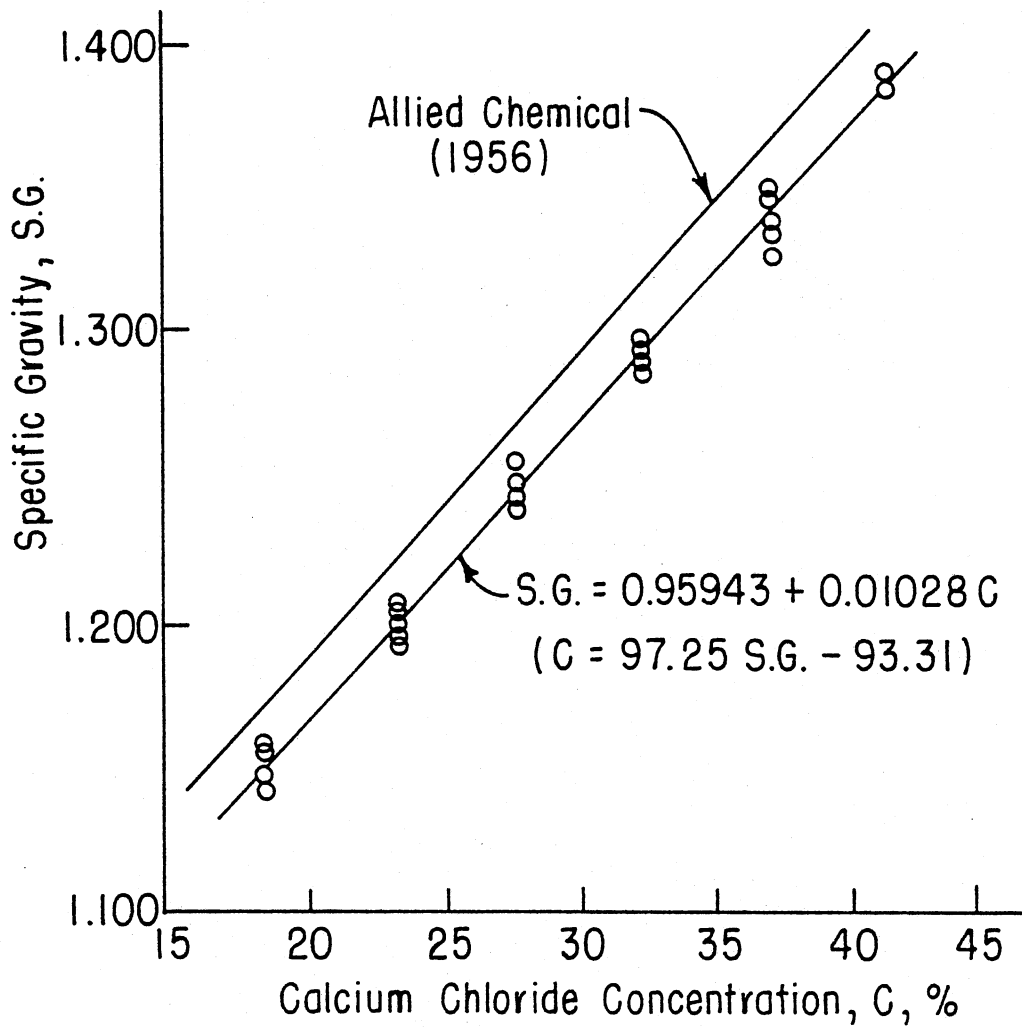


Figure 4. Specific Gravity as a Function of Calcium Chloride Concentration
Specific Gravity Measured at 25.0°C.

Plan of Experiments

Dehumidification experiments were planned using two entrance air temperatures. For each air temperature, three desiccant temperatures were used. Dry bulb air temperatures were selected from literature which gave optimum temperatures for growth of different animals at various stages of growth.² The temperatures used are representative of the temperatures found in animal environments containing newborn and young animals. The wet bulb air entrance temperature was selected to give a relative humidity of approximately 80%. A relative humidity of 80% has been described as the upper limit for control of airborne bacteria, respiratory problems and building deterioration. Desiccant temperatures were selected at temperatures which the desiccant could be stored without solidification problems. In all tests, the calcium chloride solution started as a saturated solution. Refer to Figure 17, Appendix A, for vapor pressures of the saturated solution at various temperatures.

To enhance the flow of air through the mesh of the rotating drum, 75 ml of liquid detergent was added as a wetting agent to appropriately 100 liters of freshly

²D. Jones and W. Friday, (1980) Environmental Control for Confinement Livestock Housing, Purdue University, suggest optimum temperatures of 21.1-26.7°C for 3 week old pigs or nursery pigs.

prepared CaCl solution. Fresh solutions were used at the start of each test involving a different desiccant temperature. To replicate each test, the solution was reconcentrated by adding more calcium chloride. When a solution was reconcentrated, 25 ml of wetting agent was added. Two replications of each test were conducted in all but one case. Each test was followed by its replicate tests before test conditions were altered for succeeding tests.

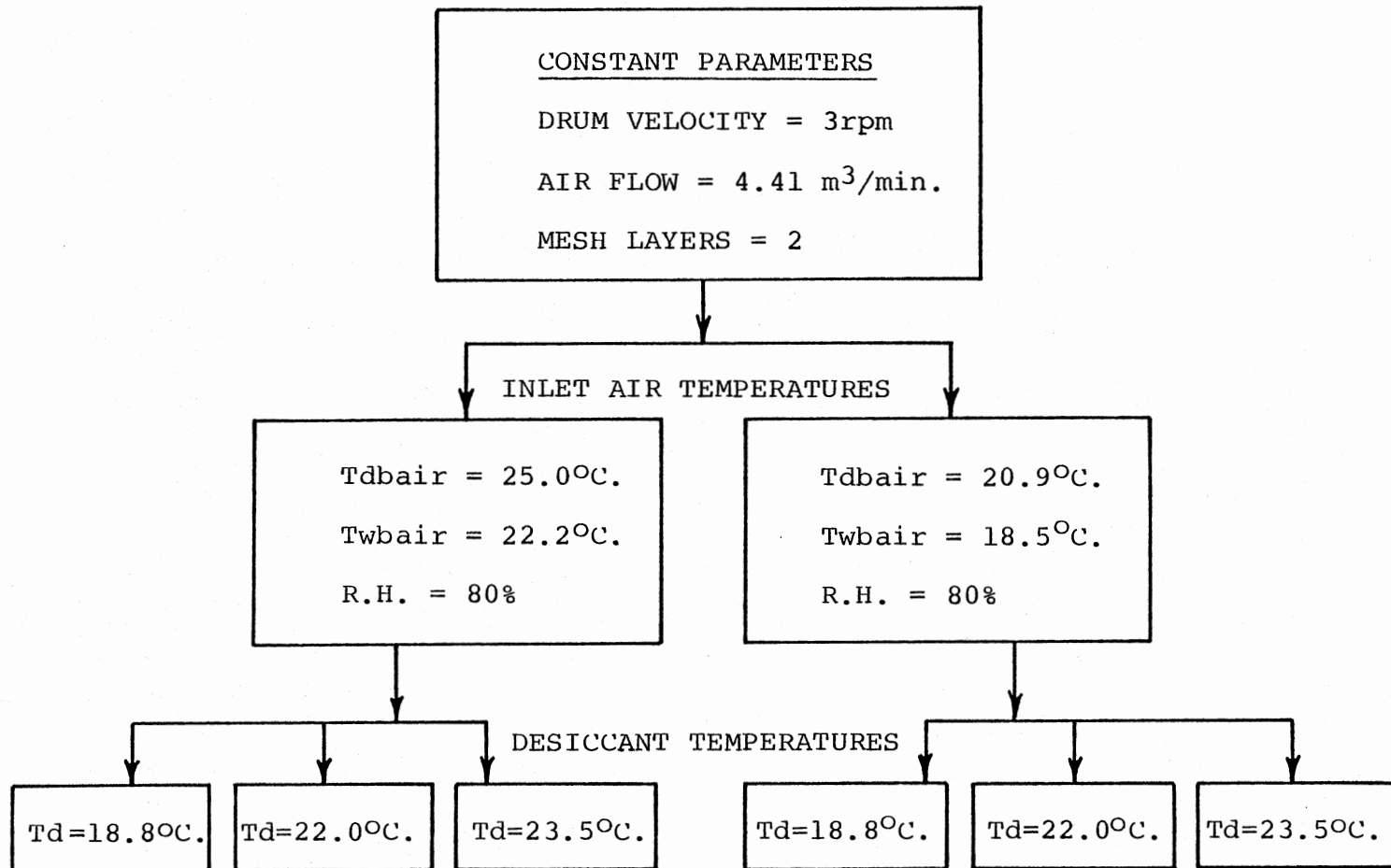


Figure 5. Experimental Plan.

CHAPTER IV

RESULTS AND DISCUSSION

Dehumidification System

The dehumidifier operated through all testing with few mechanical problems. The experimental equipment provided test conditions within close tolerances to that of the set conditions. Approximately 1500 hours of data was collected in all testing and the good behaviour of the data collected in initial tests and replicates indicate the data is highly reliable.

It was considered that the absorption rate of the system could be considerably influenced by the contact time the desiccant had with the air during the unsubmerged part of the rotation of the mesh. As the desiccant was being transported by the mesh it was being sensibly heated by the air as well as by water vapor absorption, all which contribute to decreasing vapor pressure difference and absorption rate. Thus the solution may reach equilibrium with the air before the completion of its unsubmerged revolution, resulting from the sensible heat it received. Factors which influence the degree of sensible heat it received are air temperature and time of contact which is

directly related to drum speed and drum diameter. To reduce contact time by increasing drum speed would result in a higher potential for water vapor absorption over the entirety of the unsubmerged mesh. Restrictions previously imposed on drum speed may restrict this method for reducing the sensible heating effect and alternate methods may have to be sought.

No essential changes in design of the dehumidifier were considered necessary, although the following suggestions may help simplify design and alleviate possible problems.

1. Steel is considered as an adequate construction material for the dehumidifier except for the desiccant-air contactor.

2. The air distribution duct may be constructed with fewer and larger holes and still maintain an even air flow through the mesh.

3. The wooden bearing which supports the air distribution duct could be made from a material more resistant to wear, although no problems were encountered over the period the system operated.

4. A separating device to trap air transported desiccant should be fitted to the air exit as a small amount of desiccant was found inside the exit air ducting after tests.

In practical terms for dehumidification of animal housing, the system was able to absorb approximately 15 kg

of water vapor in 50 hours at the greatest absorption rate found under testing. This represents an average absorption rate of 0.30 kg/hr which is equivalent to the total moisture production rate of three 50 kg pigs on fully slotted floors in an environment at 25°C.

Mathematical Model

The rate of moisture exchange at any instant was a function of the calcium chloride concentration and temperature and the temperature and relative humidity of the air. For each experiment the relative humidity and temperature of the air was held constant, providing a constant vapor pressure throughout the experiment. However, the concentration and vapor pressure of the calcium chloride solution was continuously changing during each experiment. The resulting change in moisture exchange rate could not be used directly in determining the effect of desiccant temperature on moisture absorption. A method was needed to analyze the moisture exchange rate data.

A simple and effective mathematical model mentioned by Henderson and Perry (1976) and often used in the study of porous solid materials was considered as a means of describing the absorption process. The equation is based on the empirical observation that the moisture content of a hygroscopic material asymptotically approaches an equilibrium value in a steady-state environment. This observation similarly applies to desiccant solutions. It is

assumed that the rate of moisture transfer is directly proportional to the difference between the final and an instantaneous moisture content.

Mathematically,

$$dM/d\theta = k(M-M_e) \quad (1)$$

Separating the variables and integrating within proper limits yields the following equation.

$$MR = \exp(-k\theta) \quad (2)$$

where:

$$MR = \text{Moisture ratio} = (M-M_e)/(M_o-M_e)$$

M = Instantaneous moisture content, %

M_e = Equilibrium moisture content, %

M_o = Initial Moisture Content, %

k = Sorption Constant

θ = Elapsed time, hours

If concentration of calcium chloride is used in the above equation instead of moisture content a similar equation is formed.

$$CR = \exp(-k\theta) \quad (3)$$

where:

CR = Concentration ratio =

$$(C-C_e)/(C_o-C_e)$$

C = Instantaneous concentration, %

C_e = Equilibrium concentration, %

C_o = Initial concentration, %

k = Sorption Constant

θ = Elapsed time, hours

The mathematical model above uses the non-dimensional concentration ratio CR to reduce instantaneous concentration data and eliminate initial and equilibrium concentrations, C_o and C_e . The dependent variable MR can be directly expressed as a function of time using the sorption constant k . The sorption constant, k describes the rate of approach towards equilibrium under the prevailing conditions.

A problem with this approach was that at the desiccant and air temperatures used, equilibrium concentration values C_e do not exist. At a solution concentration of 0% under the experimental conditions there still exists a vapor pressure difference. To utilize this model a pseudo equilibrium value, C_e^* was estimated. Using the data in the original form of concentration C as a function of time, non-linear regression was used to fit the data to the equation below:

$$C = C_o + A(e^{-k\theta} - 1) \quad (4)$$

where:

A = Difference between initial and pseudo equilibrium concentrations = $C_o - C_e^*$

This equation is a simple rearrangement of equation (3) using C_e^* as the variable C_e . Results of the analysis gave values of the coefficient A which could then be used to find values of C_e^* . The sorption constant values were also given. The analysis did not give any indication of how well the data fitted the model. Values of A and k and calculated values of C_e^* are given in Table II for each test.

To establish how well the data fitted the model of equation (3) data of concentration ratio CR as a function of time were fitted to a linear model upon transformation to the natural log of CR which yielded the following equation.

$$\ln(\text{CR}) = -k\theta \quad (6)$$

where:

$$\text{CR} = (C - C_e^*) / (C_0 - C_e^*)$$

Data in Appendix B was fitted to this equation using linear regression. Values of k are shown in Table III with the R-square values obtained from the statistical analysis. The k values calculated from both non-linear and linear regression show little difference as expected. The values of R-square show the appropriateness of the model used.

Figures 6 to 11 show the regression lines obtained for concentration and concentration ratio as a function of time for all the data obtained. The sorption constant

TABLE II
 VALUES OF C_e^* , A AND k FOUND
 FROM NON LINEAR
 REGRESSION*

<u>tdbair = 25.0°C, R. H. = 80%</u>				
	C_o	A	C_e^*	k
td = 18.8°C	45.0	18.7	26.3	-0.0244
		18.0	27.0	-0.0258
		17.6	18.0	-0.0243
td = 22.0°C	45.0	15.8	29.2	-0.0234
		15.4	29.6	-0.0232
td = 23.5°C	45.0	14.0	31.0	-0.0203
		14.3	30.7	-0.0196
		14.9	30.1	-0.0201

<u>tdbair = 20.9°C, R. H. = 80%</u>				
	C_o	A	C_e^*	k
td = 18.8°C	45.1	16.2	28.9	-0.0141
		16.0	29.1	-0.0141
		15.5	29.6	-0.0135
td = 22.0°C	45.1	16.5	28.6	-0.0109
		15.8	29.3	-0.0119
		16.3	28.8	-0.0113
td = 23.5°C	45.1	16.4	28.7	-0.0086
		16.0	29.1	-0.0089
		16.2	28.9	-0.0086

*Data fitted to equation $C = C_o + A(e^{-k\theta} - 1)$.

TABLE III
 VALUES OF k , AVERAGE k ,
 AND R-SQUARE FROM
 LINEAR REGRESSION*

<u>tdbair = 25.0°C, RH = 80%</u>			
	k	R-square	k average
td = 18.8°C	-0.0245	0.999	-0.0248
	-0.0258	0.999	
	-0.0241	0.999	
td = 22.0°C	-0.0235	0.998	-0.0234
	-0.0231	0.998	
td = 23.5°C	-0.0201	0.998	-0.0199
	-0.0195	0.997	
	-0.0200	0.998	
<u>tdbair = 20.9°C, RH = 80%</u>			
td = 18.8°C	-0.0139	0.999	-0.0137
	-0.0139	0.999	
	-0.0134	0.999	
td = 22.0°C	-0.0108	0.999	-0.0113
	-0.0117	0.998	
	-0.0114	0.996	
td = 23.5°C	-0.0087	0.997	-0.0089
	-0.0090	0.998	
	-0.0088	0.998	

*Data fitted to $\ln(CR) = -k\theta$.
 Air flow = 4.41 m³/min
 Drum Velocity = 3 rpm
 Number of mesh layers = 2

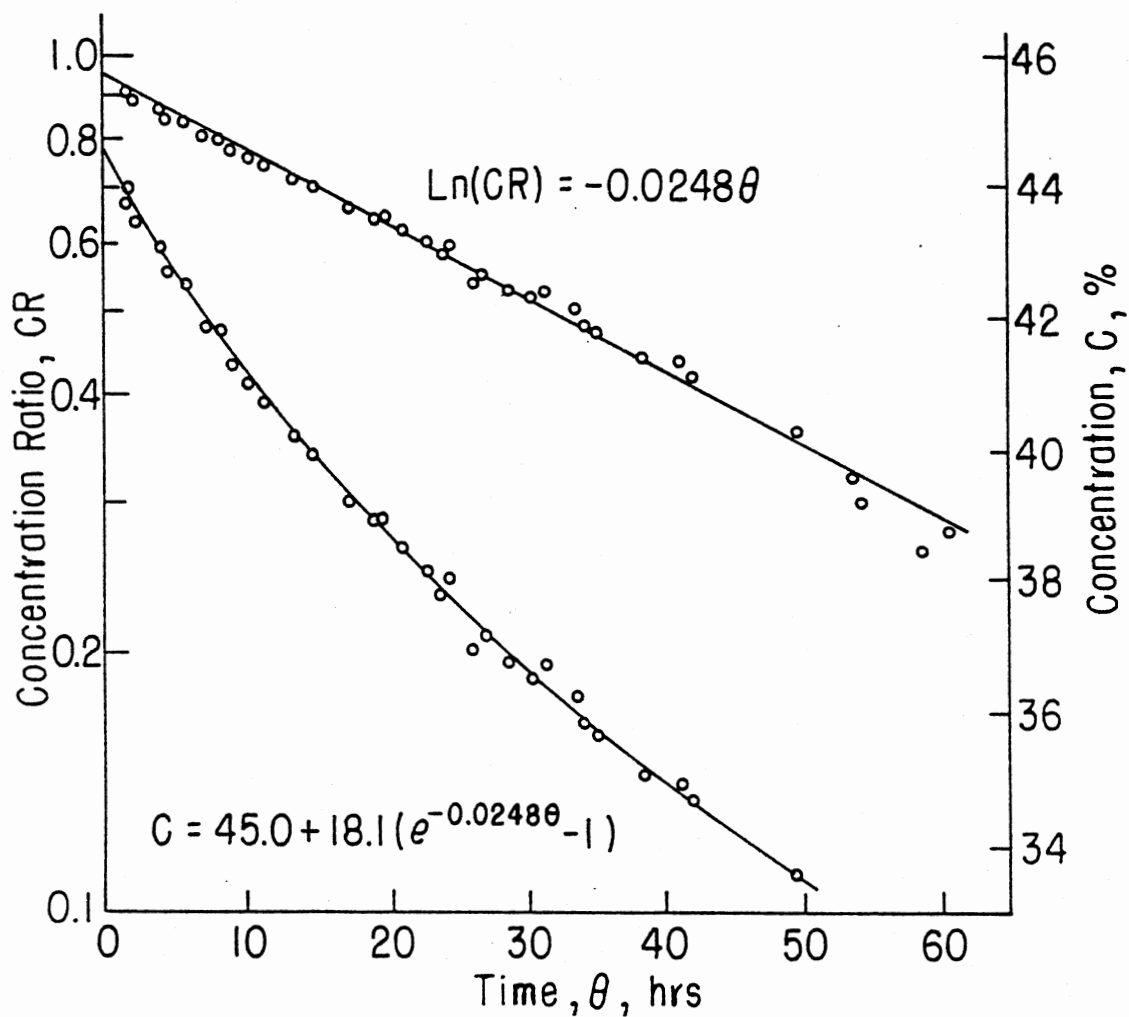


Figure 6. Regression Lines and Data for Concentration and Concentration Ratio as a Function of Time $T_{\text{dbair}} = 25.0^{\circ}\text{C}$., $T_{\text{wbair}} = 22.2^{\circ}\text{C}$., $T_{\text{d}} = 18.8^{\circ}\text{C}$.

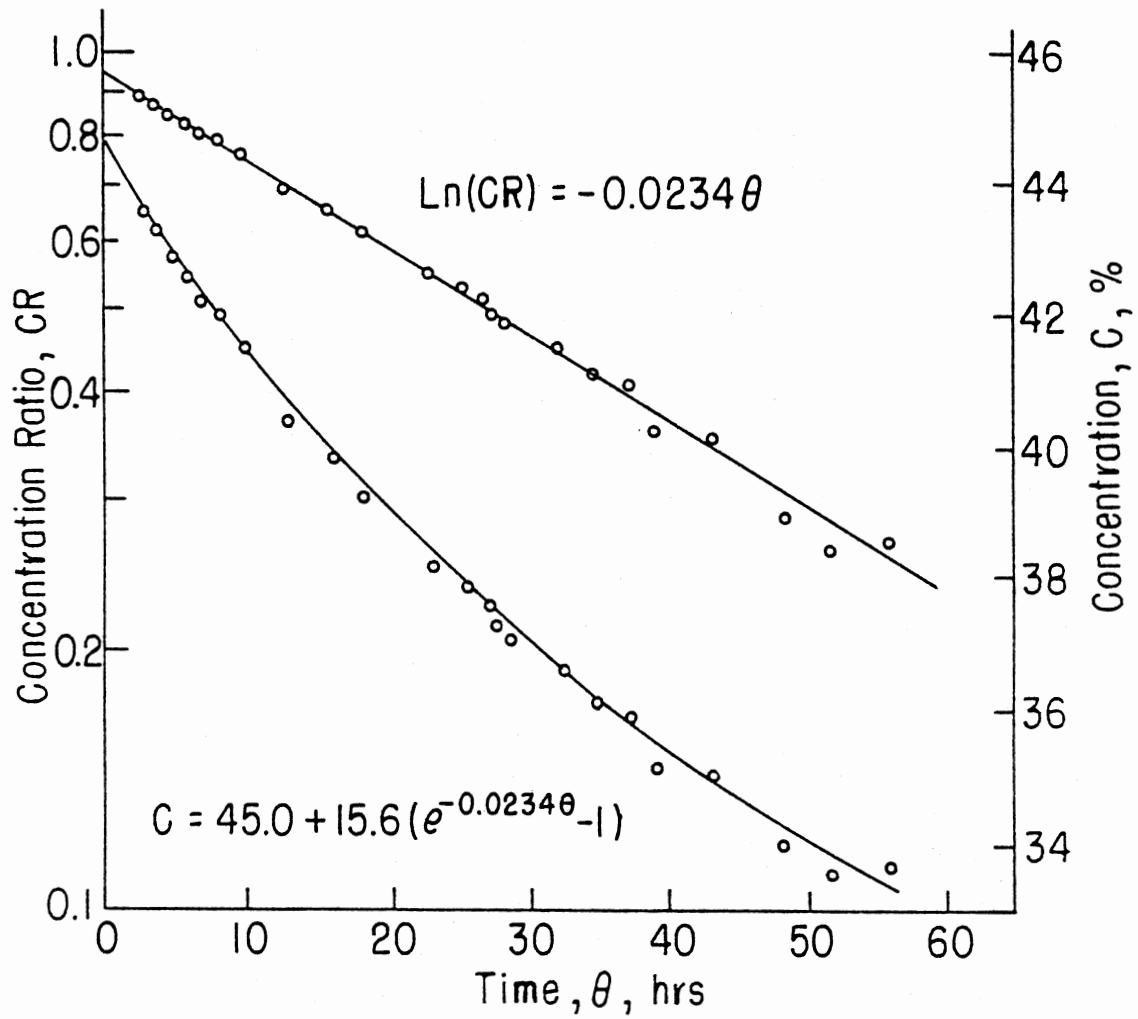


Figure 7. Regression Lines and Data for Concentration and Concentration Ratio as a Function of Time $T_{dbair} = 25.0^{\circ}\text{C}$., $T_{wbair} = 22.2^{\circ}\text{C}$., $T_d = 22.0^{\circ}\text{C}$.

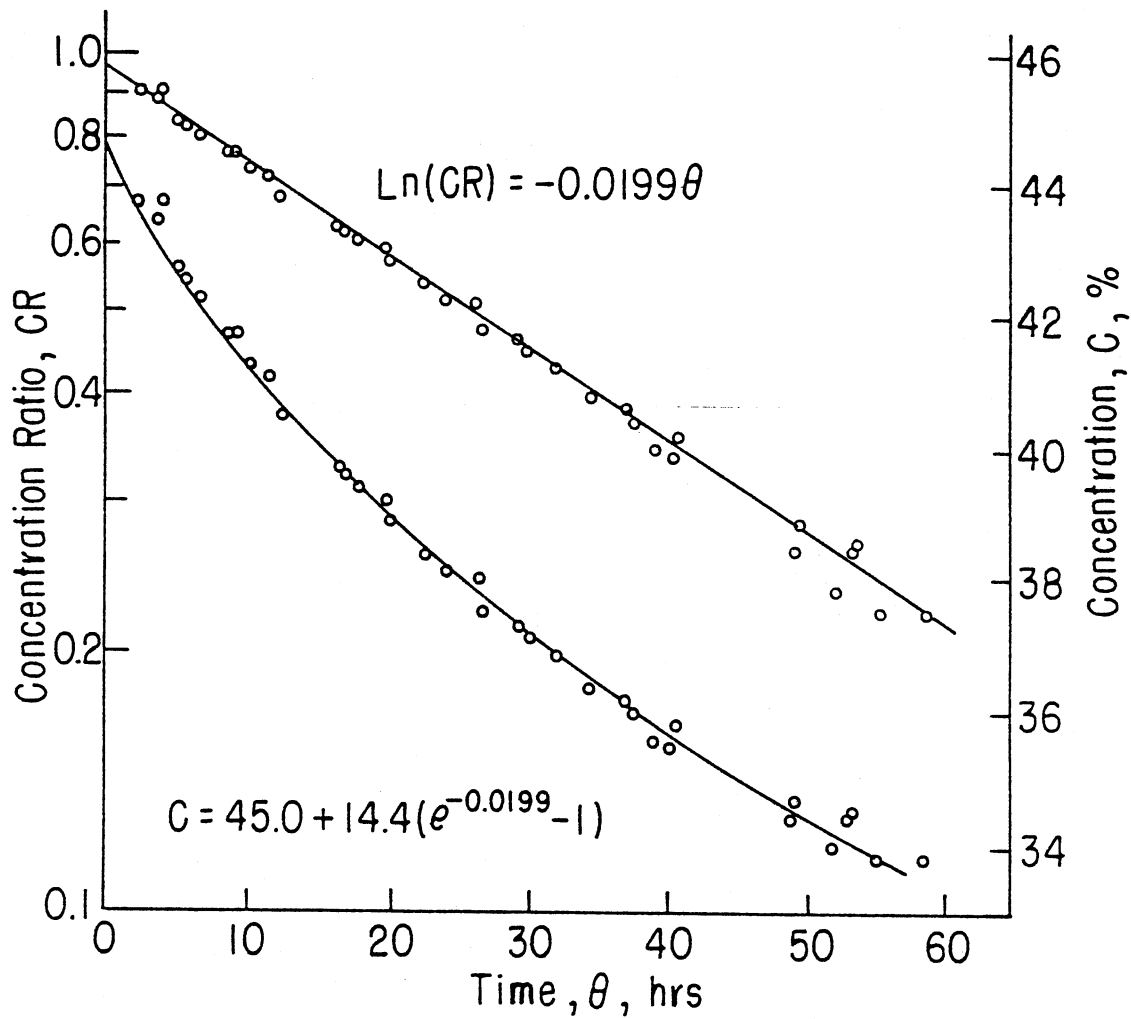


Figure 8. Regression Lines and Data for Concentration and Concentration Ratio as a Function of Time $T_{\text{dbair}} = 25.0^{\circ}\text{C}$., $T_{\text{wbair}} = 22.2^{\circ}\text{C}$., $T_{\text{d}} = 23.5^{\circ}\text{C}$.

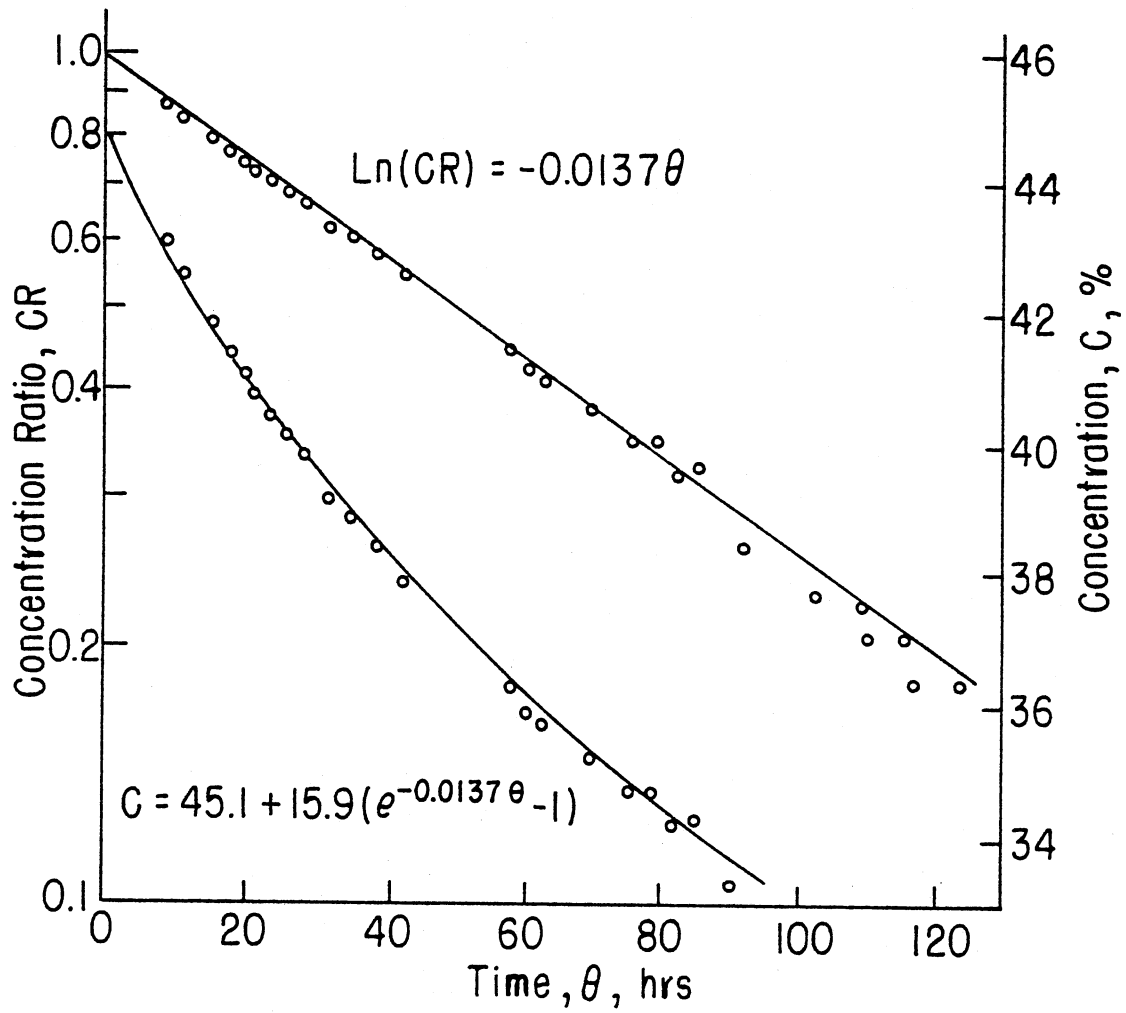


Figure 9. Regression Lines and Data for Concentration and Concentration Ratio as a Function of Time $T_{dbair} = 20.9^{\circ}\text{C}$., $T_{wbair} = 18.5^{\circ}\text{C}$., $T_d = 18.8^{\circ}\text{C}$.

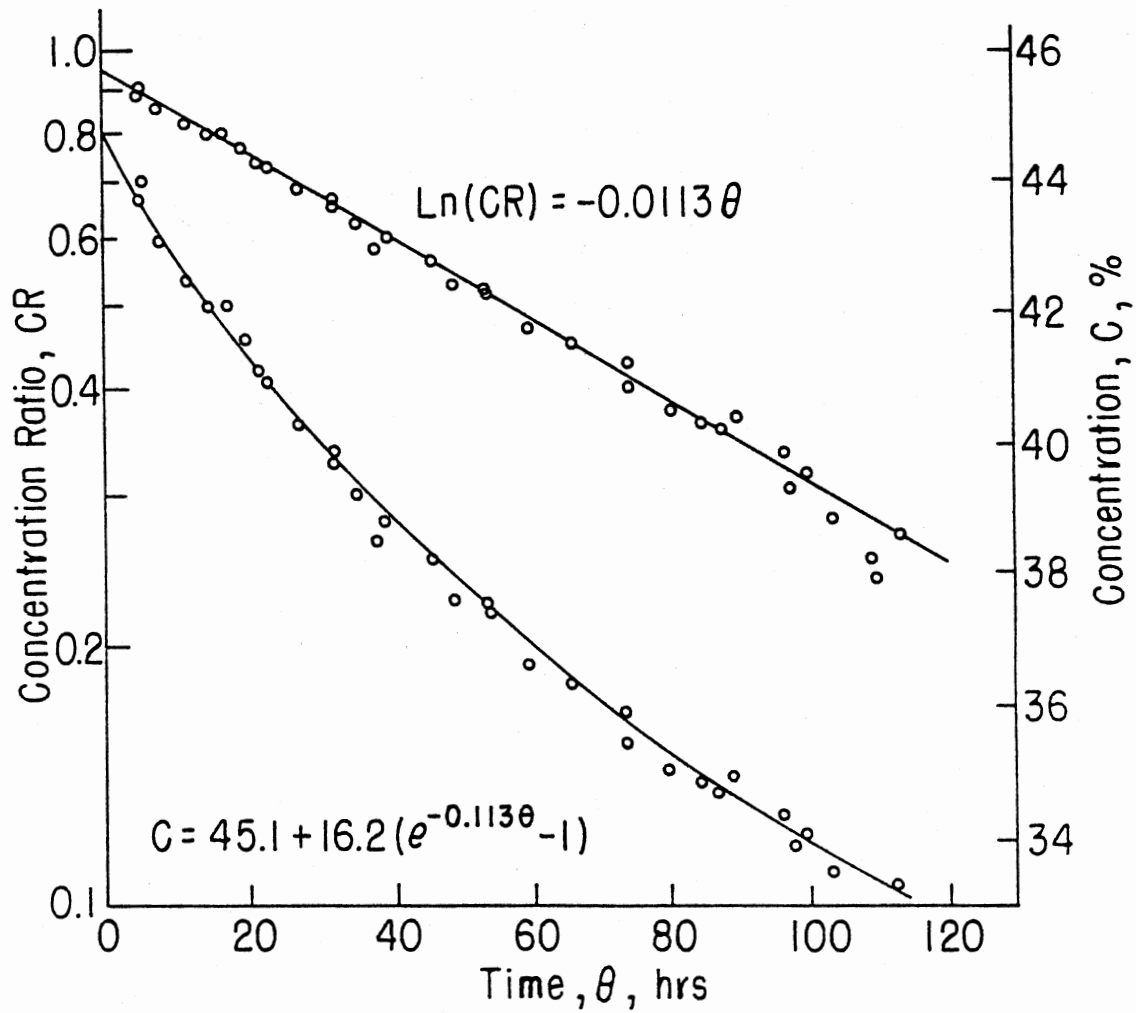


Figure 10. Regression Lines and Data for Concentration and Concentration Ratio as a Function of Time $T_{dbair} = 20.9^{\circ}\text{C}$., $T_{wbair} = 18.5^{\circ}\text{C}$., $T_d = 22.0^{\circ}\text{C}$.

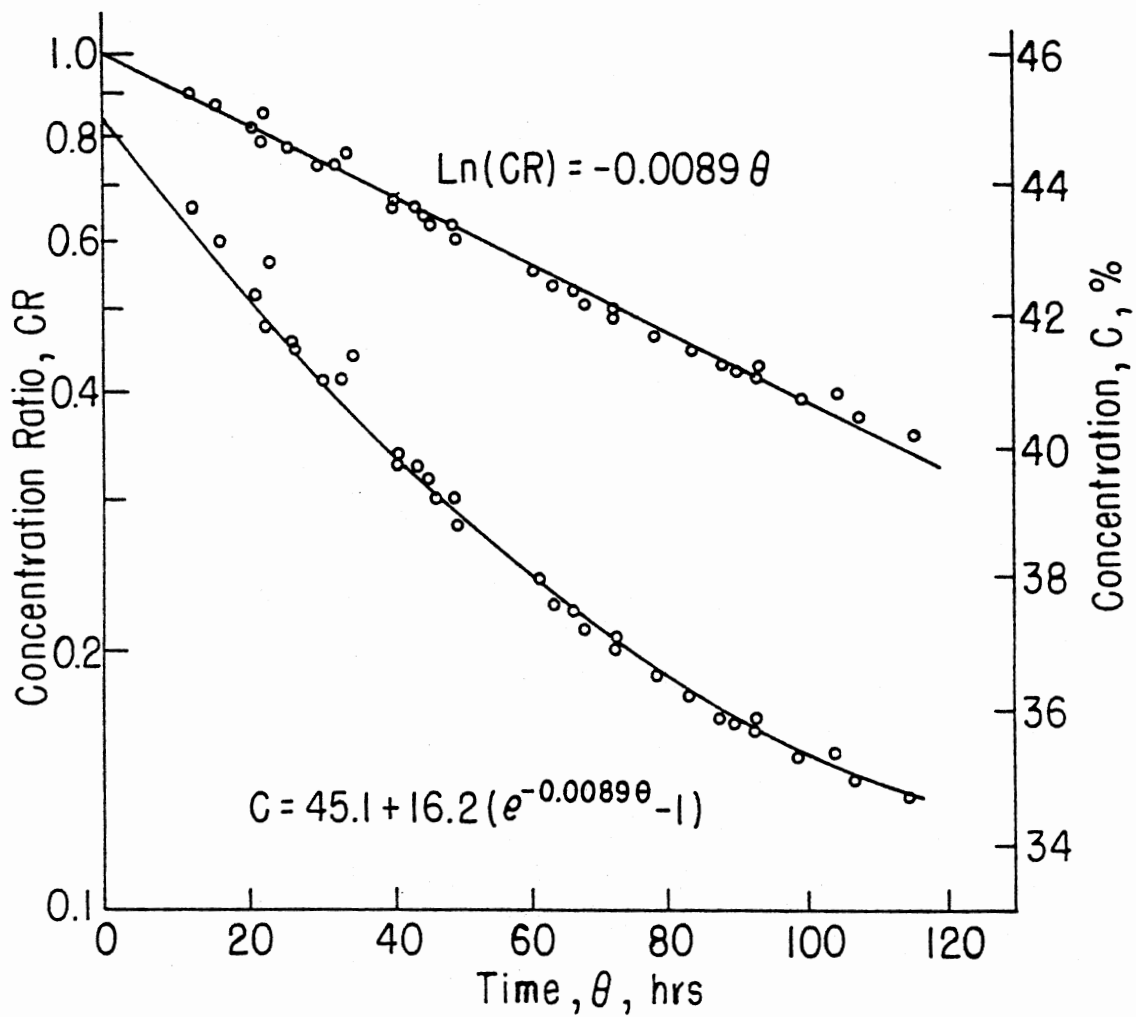


Figure 11. Regression Lines and Data for Concentration and Concentration Ratio as a Function of Time $T_{\text{dbair}} = 20.9^{\circ}\text{C}$., $T_{\text{wbair}} = 18.5^{\circ}\text{C}$., $T_d = 23.5^{\circ}\text{C}$.

values shown in these figures were obtained by averaging the k values from the linear regression analysis for each test and replicates.

The Effect of Desiccant Temperature on k Values

Figures 12 and 13 show the average sorption constant k values obtained at different desiccant temperatures for the higher air temperature of 25.0 and 20.9°C, respectively. In both cases, k values increase with increases in temperature difference between the desiccant and air temperature. Greater k values represent a faster approach to equilibrium concentration values meaning a greater absorption rate is occurring for greater temperature differences. This is explained by the fact that the larger the temperature difference the larger is the vapor pressure difference between the solution and air.

Sorption constant values can be directly related to the time required by the desiccant to reach equilibrium concentration with the environment. For an air temperature of 25.0°C and 80% relative humidity and desiccant temperature of 18.8°C, the absolute value of k is 6.0% greater than the value at 22.0°C and 20.1% greater than at 23.5°C. In terms of time, the desiccant at 18.8°C will reach its equilibrium value in 94% and 79.9% of time

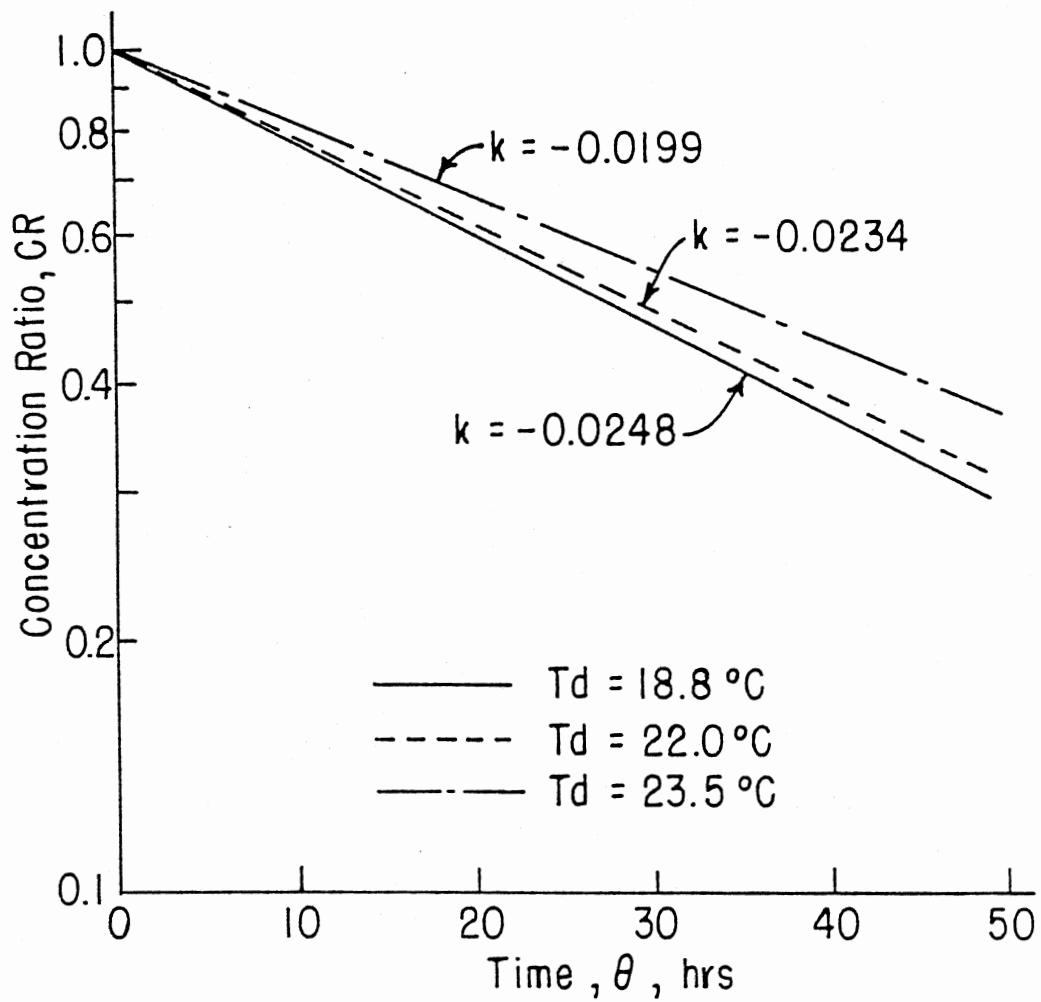


Figure 12. Regression Lines for Concentration Ratio as a Function of Time at Different Desiccant Temperatures $T_{dbair} = 25.0^\circ\text{C}$, $T_{wbair} = 22.2^\circ\text{C}$.

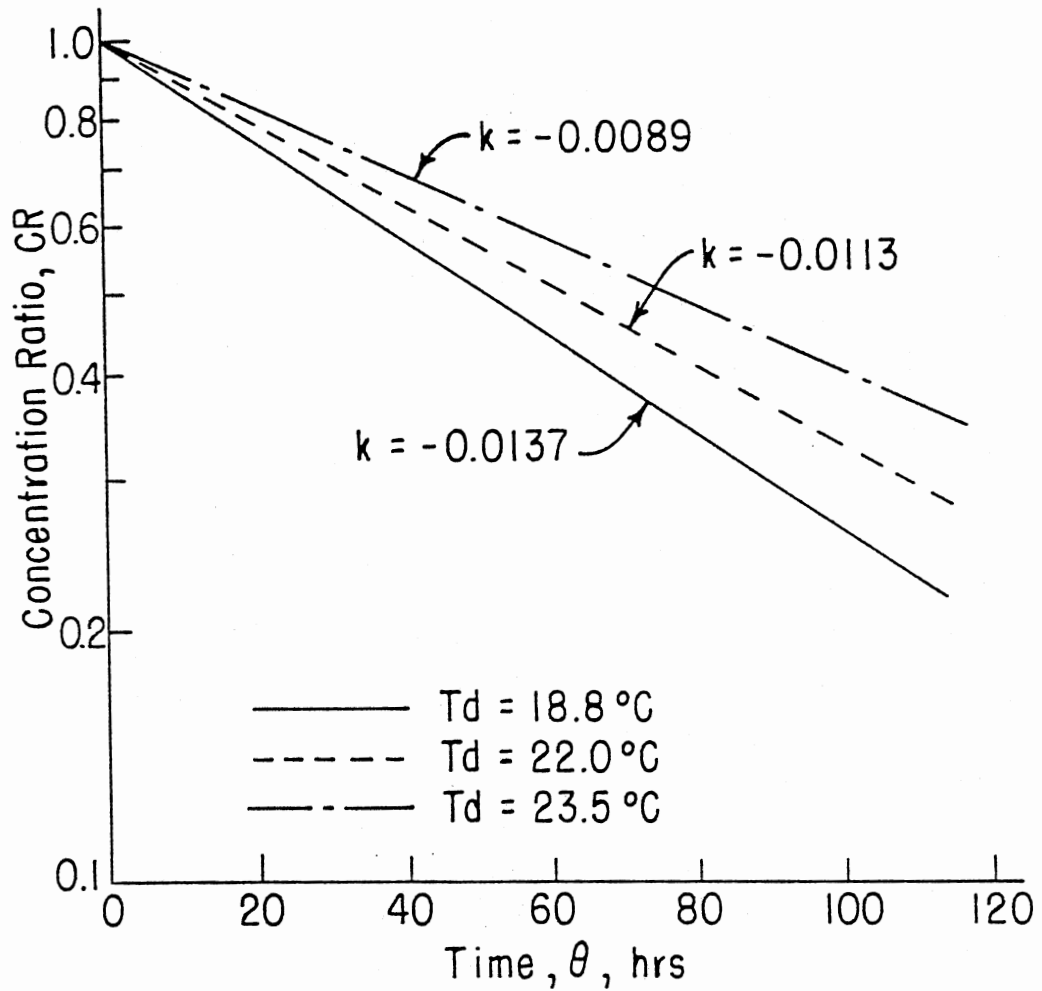


Figure 13. Regression Lines for Concentration Ratio as a Function of Time at Different Desiccant Temperatures $T_{dbair} = 20.9^\circ\text{C}$, $T_{wbair} = 18.5^\circ\text{C}$.

required for the desiccant at 22.0 and 23.5°C respectively. At the air temperature of 20.9°C and 80% relative humidity the k value at the desiccant temperature of 18.8°C is 16.5% and 33.8% greater than the k values at 22.0 and 23.5°C respectively.

The Effect of Initial Vapor Pressure Difference of k Values

To predict the moisture absorption behavior of the system for different air and desiccant temperatures, k was found as a function of the vapor pressure difference between air and desiccant at the beginning of each test. The initial vapor pressure difference was found from Figure 17. In all tests the desiccant solution was initially saturated, therefore vapor pressure difference was determined as the vapor pressure of inlet air minus the vapor pressure of the saturated desiccant solution.

Figure 14 illustrates k as a function of initial vapor pressure difference as found from regression analysis. It was expected that a non-linear relationship existed. The vapor pressure of a saturated solution increases non-linearly with temperature. Therefore the vapor pressure difference between air and desiccant will decrease non-linearly for an increasing desiccant temperature and constant air conditions. The equation developed was forced through a zero intercept because a zero vapor

pressure difference produced by desiccant and air at the same vapor pressure has a sorption constant of zero. The quadratic model forced through zero had an R-square of 0.993 compared to an R-square of 0.964 for a linear model tested over the range of 8.1 to 13.6 Δ V.P. This quadratic model can only be expected to be reliable over an initial vapor pressure range of 8.1 to 13.5 Δ V.P. with an air inlet relative humidity of 80% and an initial desiccant concentration of 45%.

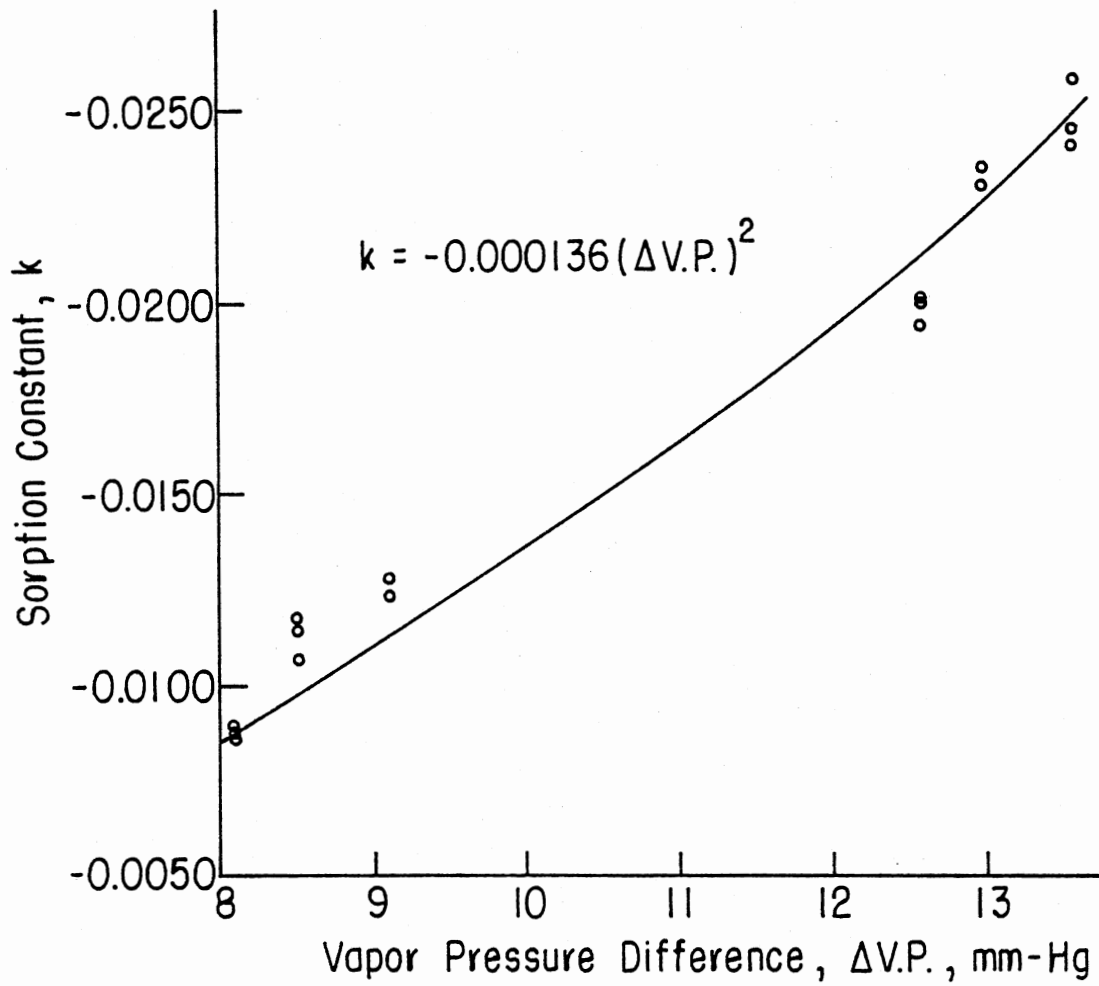


Figure 14. Regression Line of k as a Function of Initial Vapor Pressure Difference

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

A study of dehumidification systems used by past researchers was undertaken to identify a system compatible for dehumidification in housed animal environments. Requirements of the system were that it: (1) was to be able to perform both dehumidification and regeneration of calcium chloride desiccant, (2) have a minimal amount of desiccant circulation, (3) be adaptable to utilize solar energy for desiccant regeneration, and (4) be of simple mechanical design. A system was designed and constructed which consisted of a cylindrical frame covered with polypropylene mesh which rotated partly submerged through calcium chloride solution. Air is passed through the mesh which is unsubmerged and moisture is exchanged between this air and the desiccant wetting the mesh.

The effect of desiccant temperature, using calcium chloride solution, was observed for dehumidification experiments. Three different desiccant temperatures, 18.8, 22.0 and 23.5°C, were used at air temperatures of 25.0 and 20.9°C at 80% relative humidity. The water absorbed

by a fixed amount of desiccant was observed over time. The data were transformed to concentration versus time. Regression analysis was applied to the data and fitted to the exponential model, $C = C_0 + A(\exp^{-k\theta} - 1)$ from which a pseudo equilibrium concentration was derived. The concentration was then transformed to a dimensionless concentration ratio and fitted by regression analysis to the equation $CR = \exp^{-k\theta}$.

Conclusions

The desiccant dehumidification system performed satisfactorily during testing. It was evident that a small amount of air transported desiccant was being carried out the exit of the dehumidifier. It may be desirable to attach a separating device to this exit.

The following conclusions were made from the analysis of the performance data:

1. The mathematical model fitted to concentration and concentration ratio as a function of time was justified by the high values of R-square obtained by regression analysis. In all cases the correlation coefficient was 0.98 or higher.

2. Desiccant temperatures had a significant effect on k values obtained representing a marked difference in the time each solution would reach equilibrium. A decrease in desiccant temperature resulted in higher sorption constant values in all cases.

3. Air temperature had a greater effect on the sorption constant than did the desiccant temperature.

4. The sorption constant can be adequately described as a function of initial vapor pressure differences between that of the desiccant and air using a quadratic model. The model is limited to within the range of initial pressure differences used in experimentation and to an initial desiccant concentration of 45%.

5. The dehumidification system under study was considered to be technically feasible for housed animal dehumidification.

Suggestion for Future Work

Three levels of desiccant temperatures were used under two air conditions which resulted in a limited number of k values obtained under different conditions. A more reliable model could be predicted of k as a function of initial vapor pressure difference if more data were obtained at vapor pressure differences between 8.1 and 13.5 mm Hg.

Varying air flow rates, drum velocity and number of mesh layers could reveal their effect upon the absorption process. Apart from the polypropylene mesh used for this study alternate materials may prove more effective. It is suggested that the initial step for further work be in the direction of finding the most effective desiccant air contacting medium.

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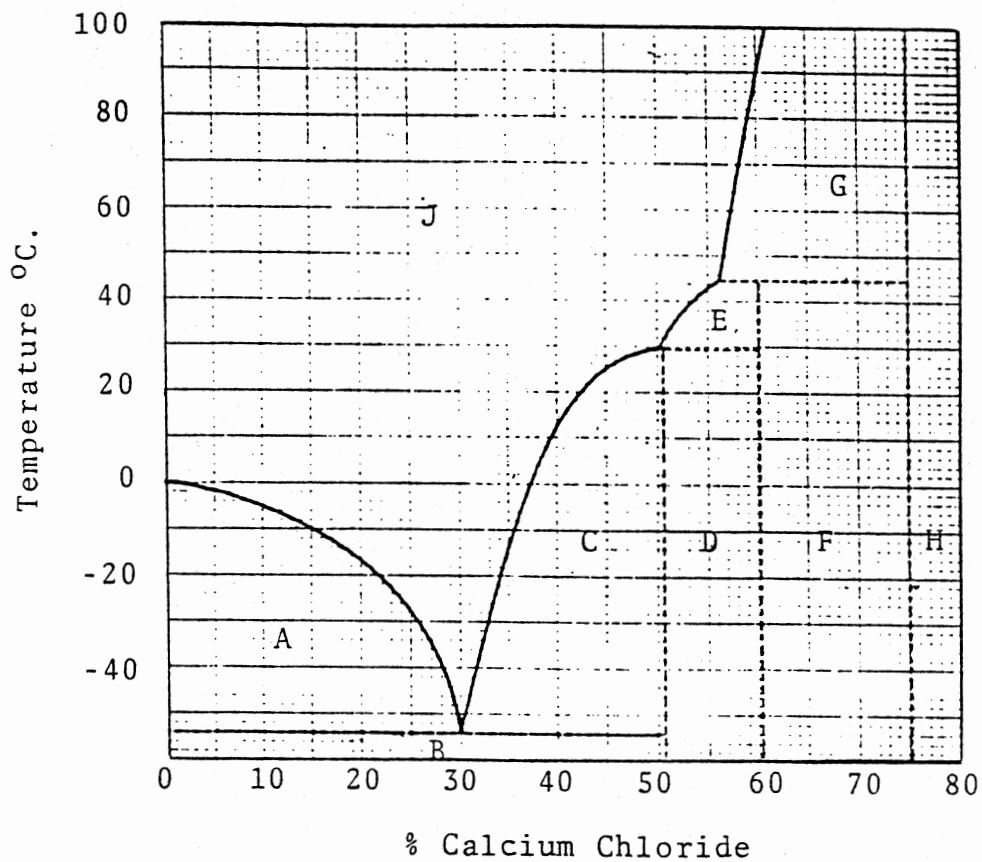
APPENDIXES

APPENDIX A

PROPERTIES OF CALCIUM
CHLORIDE SOLUTIONS

TABLE IV
PROPERTIES OF ANHYDROUS CALCIUM CHLORIDE

Molecular Weight (CaCl ₂)	110.99
Melting Point	772°C.
Latent Heat of Fusion at 772°C.	54.2 cal/g
Heat of Solution at 18.0°C. in 400 moles of Water	17.99 kg-cal/gfw*
Heat of Formation at 18.0°C.	190.6 kg-cal/gfw*
Coefficient of Expansion	0.00062
Boiling Point	above 1600°C.
Surface Tension of 35% CaCl ₂ Solution at 35°C.	93.7 dynes/cm.
Viscosity of 35% CaCl ₂ Solution at 25°C.	4.8 centipoises



AREA	SATURATION CURVE FOR	% CaCl ₂		TEMPERATURE °C			LIQUID PHASE CONTAINS % CaCl ₂		SOLID PHASES	SOLID PHASE TRANSITION AT		
		FROM	TO	AT AND BELOW	FROM	TO	FROM	TO		% CaCl ₂	°C.	
A	ICE	0	29.8		0	-55	0	29.8	ICE			
B		0	50.7	-55					NONE	ICE CaCl ₂ ·6H ₂ O	29.8 -55	
C	CaCl ₂ ·6H ₂ O	29.8	50.7		-55	+29.8	29.8	50.3	CaCl ₂ ·6H ₂ O			
D		50.7	60.6	+29.8					NONE	CaCl ₂ ·6H ₂ O CaCl ₂ ·4H ₂ O	50.3 +29.8	
E	CaCl ₂ ·4H ₂ O	50.3	60.6		+29.8	48.3	50.3	56.6	CaCl ₂ ·4H ₂ O			
F		60.6	75.5	45.3					NONE	CaCl ₂ ·4H ₂ O CaCl ₂ ·2H ₂ O	56.6 45.3	
G	CaCl ₂ ·2H ₂ O	56.6	75.5		45.3	175.5	56.6	74.9	CaCl ₂ ·2H ₂ O			
H		75.5	86	175.5					NONE	CaCl ₂ ·2H ₂ O CaCl ₂ ·H ₂ O	74.9 175.5	
J	AREA ABOVE SATURATION CURVE UNSATURATED SOLUTIONS									None		

Figure 15. Solubility of Pure Calcium Chloride in Water - Freezing Point Diagram

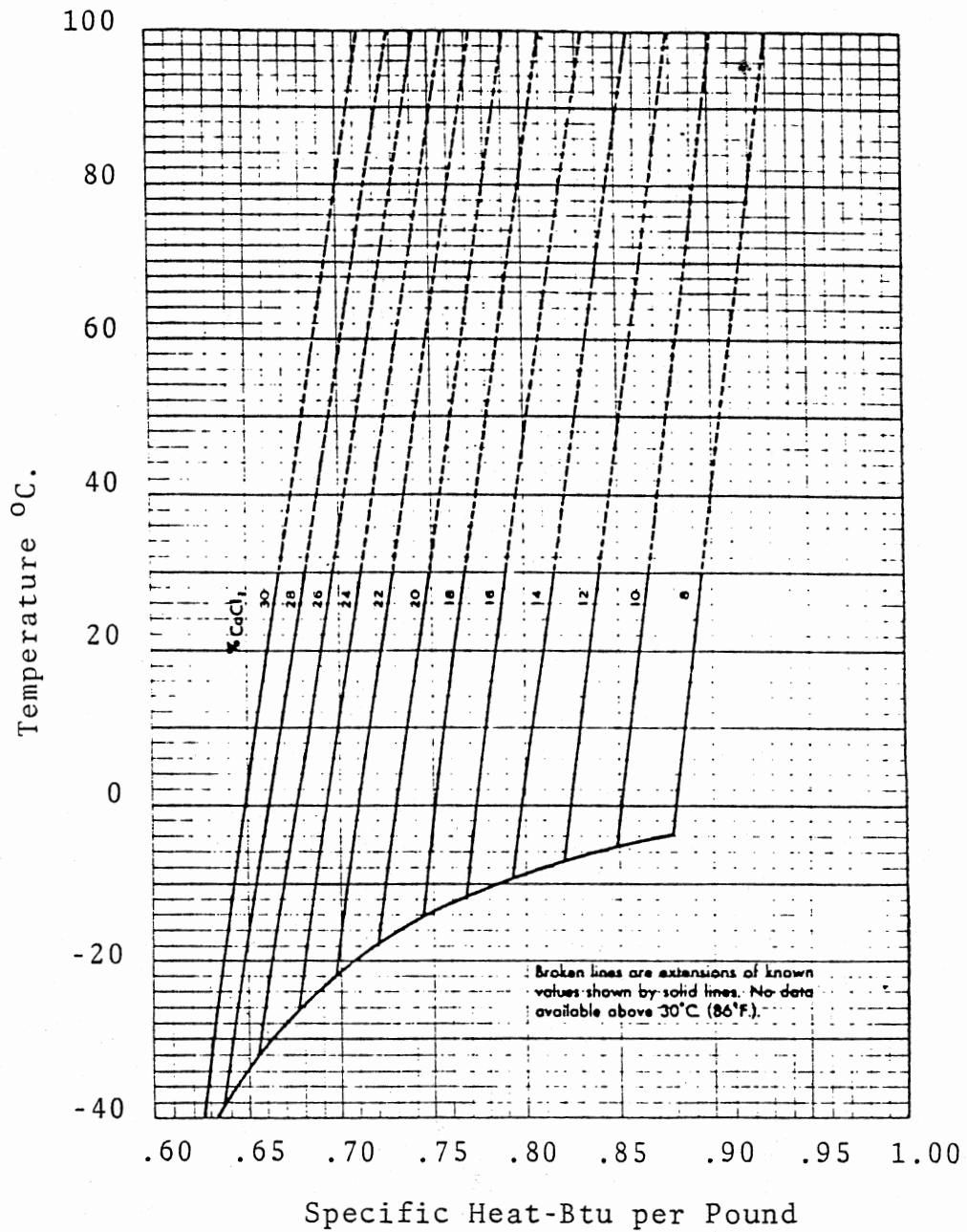


Figure 16. Specific Heats of Pure Calcium Chloride Solutions

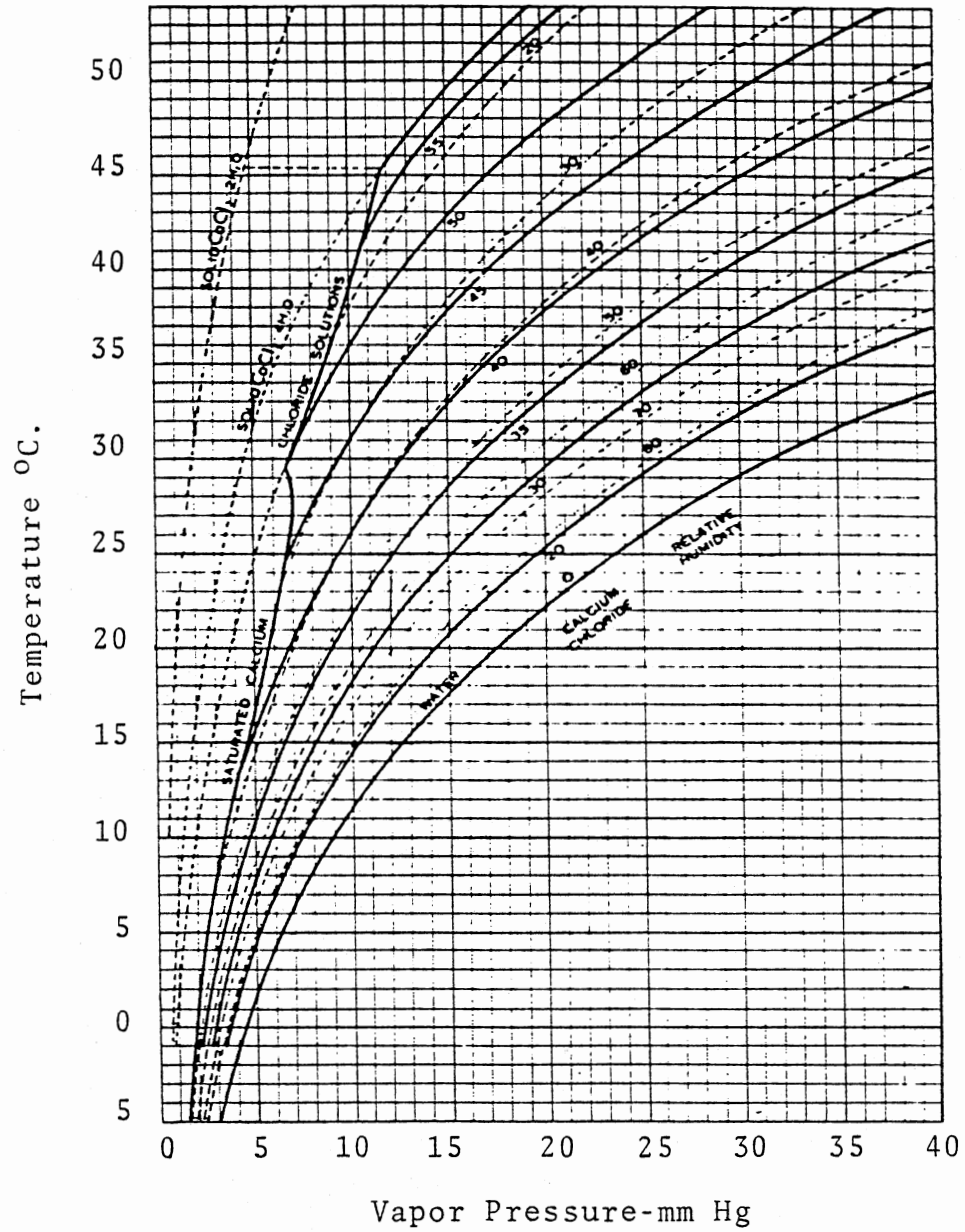


Figure 17. Vapor Pressures of Calcium Chloride Solutions

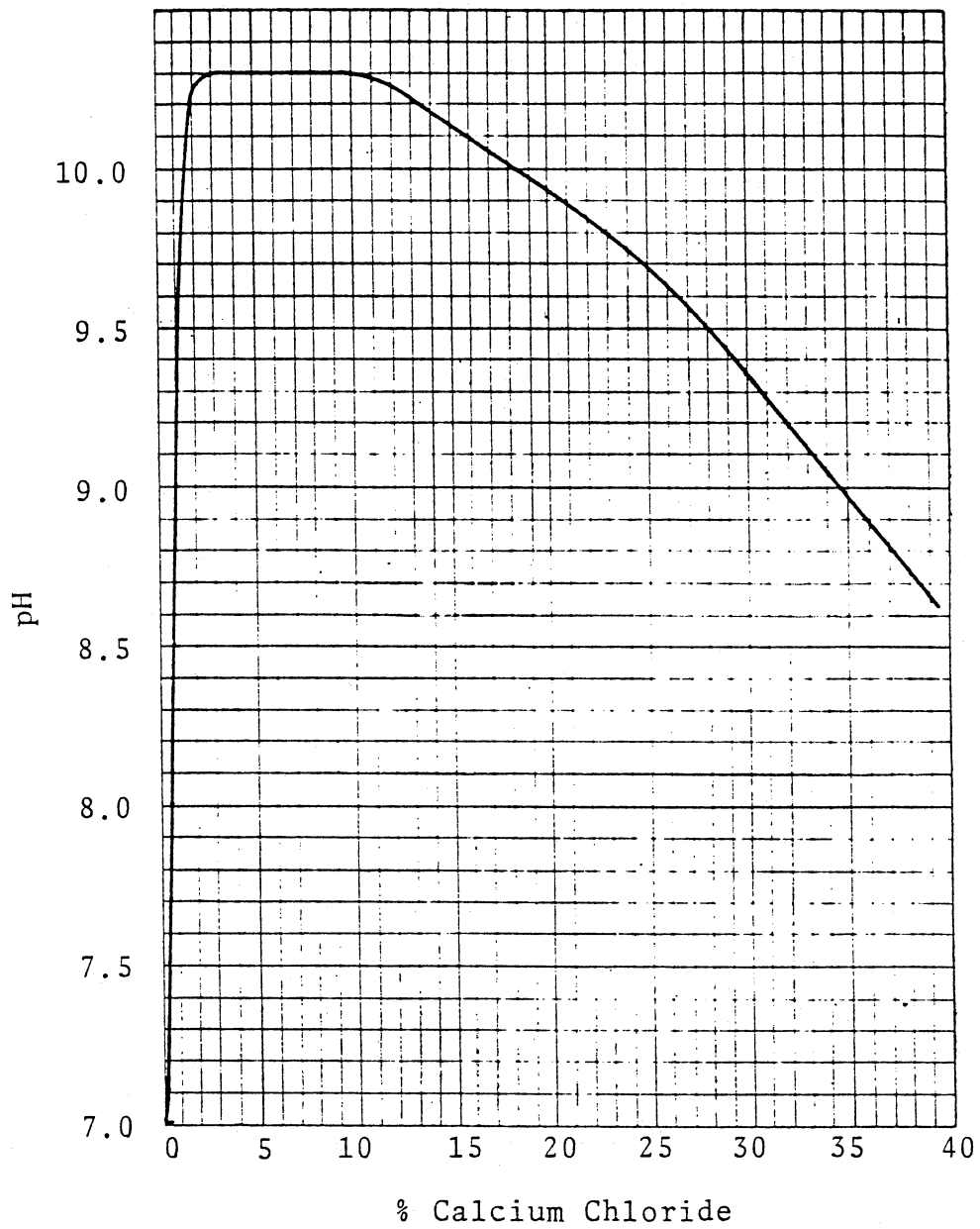


Figure 18. pH of Freshly Prepared Solutions of Commercial Calcium Chloride

APPENDIX B
ABSORPTION DATA FROM
EXPERIMENTS

TABLE V
 DEHUMIDIFICATION DATA FOR
 $T_{dbair}=25.0^{\circ}\text{C}$, $\text{RH}=80\%$

$T_d=18.8^{\circ}\text{C}$.

TEST	OBS.	TIME (θ)	CONC. (C)	CONC. RATIO (CR)
TEST 1	1	0.00	45.0	1.0000
	2	2.60	43.7	0.9283
	3	6.10	42.7	0.8731
	4	9.40	41.5	0.8069
	5	13.90	40.4	0.7463
	6	19.90	39.1	0.6745
	7	21.90	38.7	0.6524
	8	25.40	38.2	0.6248
	9	29.70	36.9	0.5531
	10	36.30	35.8	0.4925
	11	50.70	33.7	0.3766
TEST 2	1	0.00	45.0	1.0000
	2	2.10	44.2	0.9559
	3	4.90	42.9	0.8842
	4	7.55	42.1	0.8400
	5	10.65	41.2	0.7904
	6	15.40	40.1	0.7297
	7	17.85	39.4	0.6911
	8	23.65	38.3	0.6304
	9	27.90	37.3	0.5752
	10	31.30	36.7	0.5421
	11	35.40	36.0	0.5035
	12	42.40	35.1	0.4539
	13	55.45	32.5	0.3105
	14	61.70	32.1	0.2884
TEST 3	1	0.00	45.0	1.0000
	2	2.00	44.0	0.9448
	3	4.50	43.3	0.9062
	4	8.60	42.0	0.8345
	5	11.90	40.9	0.7738
	6	20.50	39.1	0.6745
	7	24.70	37.9	0.6083
	8	26.90	37.1	0.5642
	9	32.50	36.9	0.5532
	10	34.80	36.4	0.5256
	11	39.60	35.2	0.4594
	12	43.20	34.8	0.4373
	13	54.70	32.9	0.3325
	14	59.70	31.8	0.2719

TABLE VI
 DEHUMIDIFICATION DATA FOR
 $T_{dbair}=25.0^{\circ}\text{C}$, $\text{RH}=80\%$

$T_d=22.0^{\circ}\text{C}$.

TEST 1	OBS.	TIME (θ)	CONC. (C)	CONC. RATIO (CR)
	1	0.00	45.0	1.0000
	2	3.20	43.8	0.9230
	3	5.15	43.1	0.8781
	4	7.25	42.4	0.8332
	5	10.25	41.7	0.7883
	6	18.90	39.4	0.6408
	7	26.40	38.0	0.5510
	8	28.55	37.4	0.5125
	9	33.50	36.7	0.4676
	10	36.00	36.2	0.4355
	11	49.75	34.0	0.2944
	12	53.10	33.6	0.2688
	13	57.50	33.7	0.2751
TEST 2	1	0.00	45.0	1.0000
	2	4.10	43.5	0.9038
	3	6.30	42.8	0.8589
	4	8.60	42.2	0.8204
	5	13.30	40.6	0.7178
	6	16.50	40.0	0.6793
	7	24.00	38.3	0.5703
	8	28.00	37.7	0.5318
	9	29.60	37.2	0.4997
	10	38.60	36.0	0.4227
	11	40.40	35.2	0.3714
	12	44.70	35.1	0.3650

TABLE VII
 DEHUMIDIFICATION DATA FOR
 Tdbair=25.0°C, RH=80%

Td=23.5°C.

TEST	OBS	TIME (θ)	CONC. (C)	CONC. RATIO (CR)
TEST 1	1	0.00	45.0	1.0000
	2	2.90	44.0	0.9304
	3	6.30	42.8	0.8470
	4	9.80	42.0	0.7914
	5	10.90	39.6	0.7566
	6	18.60	39.6	0.6245
	7	20.75	39.4	0.6106
	8	23.50	38.6	0.5549
	9	31.10	37.3	0.4653
	10	33.20	37.0	0.4437
	11	35.60	36.5	0.4089
	12	41.60	35.6	0.3463
	13	50.75	34.8	0.2907
	14	55.10	34.6	0.2768
	15	60.30	33.9	0.2280
TEST 2	1	0.00	45.0	1.0000
	2	4.60	44.0	0.9305
	3	7.30	42.5	0.8261
	4	13.00	40.7	0.7009
	5	17.60	39.8	0.6384
	6	25.10	38.3	0.5341
	7	27.80	37.7	0.4924
	8	30.40	37.5	0.4784
	9	38.80	36.1	0.3811
	10	40.30	35.7	0.3532
	11	50.40	34.5	0.2698
	12	53.40	34.1	0.2420
TEST 3	1	0.00	45.0	1.0000
	2	4.20	43.7	0.9096
	3	5.70	43.0	0.8609
	4	9.50	42.0	0.7914
	5	12.20	41.3	0.7427
	6	17.30	39.9	0.6453
	7	21.00	39.1	0.5897
	8	27.40	38.2	0.5271
	9	38.20	36.3	0.3950
	10	42.00	35.9	0.3672
	11	54.70	34.5	0.2698

TABLE VIII
 DEHUMIDIFICATION DATA FOR
 Tdbair=20.9°C, RH=80%

Td=18.8°C.

TEST	OBS.	TIME (θ)	CONC. (C)	CONC. RATIO (CR)
TEST 1	1	0.00	45.1	1.0000
	2	9.20	43.1	0.8744
	3	11.50	42.6	0.8430
	4	15.80	41.9	0.7990
	5	29.30	39.9	0.6734
	6	39.70	38.5	0.5855
	7	62.20	36.0	0.4285
	8	71.60	35.3	0.3846
	9	92.30	33.4	0.2653
TEST 2	1	0.00	45.1	1.0000
	2	18.40	41.4	0.7676
	3	21.60	40.8	0.7300
	4	26.70	38.9	0.6106
	5	36.00	38.9	0.6106
	6	43.80	38.0	0.5541
	7	60.00	36.4	0.4536
	8	77.50	34.8	0.3532
	9	84.10	34.3	0.3218
	10	103.75	32.9	0.2339
	11	111.30	32.5	0.2087
	12	117.60	32.1	0.1836
TEST 3	1	0.00	45.1	1.0000
	2	20.40	41.1	0.7488
	3	24.20	40.5	0.7111
	4	32.80	39.2	0.6295
	5	64.40	35.8	0.4160
	6	81.10	34.8	0.3532
	7	87.20	34.4	0.3281
	8	110.60	32.8	0.2276
	9	116.60	32.5	0.2087
	10	124.70	32.1	0.1836

TABLE IX
 DEHUMIDIFICATION DATA FOR
 Tdbair=20.9°C, RH=80%

Td=22.0°C.

TEST	OBS.	TIME (θ)	CONC. (C)	CONC. RATIO (CR)
TEST 1	1	0.00	45.1	1.0000
	2	6.00	43.9	0.9259
	3	15.50	42.3	0.8271
	4	22.60	41.3	0.7653
	5	33.75	40.1	0.6913
	6	41.40	39.0	0.6233
	7	55.60	37.7	0.5431
	8	68.20	36.5	0.4690
	9	76.40	36.1	0.4443
	10	92.10	35.1	0.3825
	11	102.40	34.2	0.3269
	12	116.00	33.4	0.2775
TEST 2	1	0.00	45.1	1.0000
	2	6.20	44.2	0.9444
	3	8.50	43.3	0.8888
	4	12.50	42.7	0.8518
	5	28.50	40.5	0.7160
	6	33.60	39.9	0.6789
	7	37.20	39.4	0.6480
	8	51.10	37.8	0.5492
	9	55.75	37.6	0.5369
	10	61.70	36.8	0.4875
	11	76.40	35.6	0.4134
	12	82.50	35.2	0.3887
	13	86.90	35.0	0.3763
	14	100.00	34.0	0.3146
	15	106.20	33.6	0.2898
	16	112.30	32.9	0.2466
TEST 3	1	0.00	45.1	1.0000
	2	18.20	42.3	0.8271
	3	20.75	41.8	0.7962
	4	24.40	41.1	0.6048
	5	39.60	38.7	0.5863
	6	47.80	38.4	0.5862
	7	90.00	34.9	0.3702
	8	99.10	34.5	0.3455
	9	111.80	33.1	0.2590

TABLE X
 DEHUMIDIFICATION DATA FOR
 Tdbair=20.9°C, RH=80%

Td=23.5°C.

TEST	OBS.	TIME (θ)	CONC. (C)	CONC. RATIO (CR)
TEST 1	1	0.00	45.1	1.0000
	2	12.20	43.7	0.9135
	3	15.90	43.2	0.8826
	4	21.00	42.4	0.8331
	5	34.70	41.5	0.7775
	6	41.60	40.0	0.6848
	7	46.10	39.6	0.6600
	8	61.75	38.1	0.5673
	9	67.50	37.6	0.5364
	10	73.80	37.2	0.5117
	11	94.80	36.0	0.4375
	12	106.70	35.5	0.4066
TEST 2	1	0.00	45.1	1.0000
	2	22.70	42.9	0.8640
	3	26.10	41.7	0.7898
	4	33.00	41.1	0.7528
	5	44.50	39.8	0.6724
	6	49.90	39.3	0.6415
	7	79.60	36.6	0.4746
	8	85.20	36.3	0.4561
	9	91.50	35.9	0.4313
	10	109.75	35.1	0.3819
TEST 3	1	0.00	45.1	1.0000
	2	22.25	41.9	0.8022
	3	26.20	41.6	0.7837
	4	30.40	41.1	0.7527
	5	41.40	39.8	0.6724
	6	46.80	39.3	0.6415
	7	50.60	38.9	0.6168
	8	64.50	37.7	0.5426
	9	69.30	37.3	0.5178
	10	73.70	37.0	0.4993
	11	89.60	36.0	0.4375
	12	94.50	35.8	0.4252
	13	101.10	35.4	0.4004
	14	117.60	34.8	0.3634

2
VITA

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