THE DETERMINATION OF THE RATE OF DRYING OF ABATTOIR COW PAUNCH CONTENT (CPC) AS A FUNCTION OF RELATIVE HUMIDITY, DEPTH AND AGE

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PREFACE

There are many who say the Master of Science degree is a learning degree. I unequivocally subscribe to this ascertion.

Within the constraints of this learning behaviour, the experience I acquired and the highly tolerable appreciation for the complexities involved in research, is heavily weighted.

I deeply appreciate the basic understanding and purpose for a sound experimental design, for without which the entire experiment would be useless.

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NOMENCLATURE

A = Cross-sectional area of duct, m^2.

A_g = Age, hr.

A_i = Intercept at zero time.

C_f = Dimensionless skin friction coefficient.

C_j = Effect due to the j column, j = 1, 2, 3.

C_{wj} = Effect due to cow, j = 1, 2, 3.

D = Depth, cm.

D_k = Effect due to depth, k = 1, 2, 3.

e = Natural logarithm.

e_1 = Error term describing moisture depletion with a non-existent constant rate period.

h_d = Mass transfer coefficient, Nm°k/sec.

h_w = Velocity pressure of drying air, mm of water.

H_i = Effect due to drying time, i = 1, 2, 3, 4, 5, 6, 7.

K = Diffusion constant, m^2/sec.

K_c = Bulk drying constant, sec^{-1}.

K_g = Drying constant in general prediction equation, hr^{-1}.

K_{ijkl} = Deduced response variable rate of drying of CPC, hr^{-1}.

K_1 = Change in rate of drying for 20% relative humidity, age of 776 hours and depths 2.5 and 6.4 cm.

K_2 = Change in rate of drying for 20% relative humidity, age of 679 hours and depths 2.5 and 6.4 cm.

K_3 = Change in rate of drying for 50 and 80% relative humidity, 6.4 cm depth and age 194 hours.

K_4 = Change in rate of drying for 20 and 80% relative humidity, 2.5 cm depth and age 679 hours.

K_5 = Change in rate of drying for 50 and 80% relative humidity, 2.5 cm depth and age 485 hours.

K_6 = Change in rate of drying for 50% relative humidity, 2.5 cm depth and ages 97 and 388 hours.

K_7 = Change in rate of drying for 50% relative humidity, 6.4 cm depth and ages 194 and 485 hours.

K_8 = Change in rate of drying for 80% relative humidity, 2.5 cm depth and age 97 and 485 hours.

K_9 = Change in rate of drying for 80% relative humidity, 6.4 cm depth and ages 194 and 388 hours.

K_{10} = Change in rate of drying for 80% relative humidity, 10.2 cm depth and ages 291 and 697 hours.

L_{AG} = Number of levels of age.

L_{CW} = Number of levels of cows.

L_{DPT} = Number of levels of depths.

L_{rh} = Number of levels of relative humidities.

L_S = Number of sampling units per cow.

L_{TM} = Number of levels of drying time.

m = Rate of mass transfer, kg/sec.

M = Moisture content, % dry basis.

M_a = Molecular weight of air, kg/mole.

M_e = Equilibrium moisture content, % dry basis.

M_i = Initial moisture content, % dry basis.

M_v = Molecular weight, kg/mole.

MR = Moisture ratio.

n = Number of stations at which velocity pressure measurements are taken.

N = Total number of measurements on response variable weight.

P_a = Partial pressure of the air, N/M^2.

P_k = Cow effect in preliminary experiment, k = 1, 2, 3.

P_s = Partial pressure of saturated air, N/M^2.

Q = Volume flow rate of drying air, m^3/sec.

R = Half slab thickness, m.

$\overline{R}$ = Universal gas constant, N - m/kg° K.

R_a = Gas constant (dry air), N - m/kg° K.

R_i = Effect due to the ithrow, i = 1, 2, 3.

R_v = Gas constant (vapour), N - m/kg° K.

R_e = Reynold's number.

R_h = Relative humidity, %.

Rh_i = Effect due to the relative humidity in general drying constant prediction equation, i = 1, 2, 3.

S_c = Schmidt number.

t = Drying time, sec.

T_a = Temperature of drying air, °K.

T_{db} = Temperature (dry bulb), °K.

T_{wb} = Temperature (wet bulb), °K.

V = Velocity of drying air, m/sec.

Wt_d = Sample dry weight, kg.

Wt_f = Sample final weight, kg.

Wt_i = Sample initial weight, kg.

X_i = Variables in general drying constant prediction equation, i = 1, 2, ..., 48.

$E(Y)$ = Expected estimate of the log of moisture ratio.

Y_{ijkl} = Response variable weight, kg.

Z = Total number of responses in each replicate.

β_0 = Estimate of intercept when drying time is zero.

γ_0 = Estimate of intercept in general drying constant prediction equation.

β_1 = Estimate of rate of drying for three samples of CPC from the same cow and same experimental run.

γ_1 = Estimate of relative humidity coefficient in general drying constant prediction equation.

γ_2 = Estimate of depth coefficient in general drying constant prediction equation.

γ_3 = Estimate of age coefficient in general drying constant prediction equation.

γ_4 = Estimate of second degree relative humidity coefficient in general drying constant prediction equation.

γ_5 = Estimate of second degree age coefficient in general drying constant prediction equation.

γ_6 = Estimate of interaction of relative humidity and depth coefficient in general drying constant prediction equation.

γ_7 = Estimate of interaction of relative humidity and age coefficient in general drying constant prediction equation.

ε_{ijk} = Error term due to sub-sampling in latin square design.

ε_2 = Error term in general drying constant prediction equation.

δ_{ijkl} = Experimental error in latin square design.

κ = Overall mean in split-plot design.

λ_{ijkl} = Error term in split-plot design.

μ = Overall mean in latin square design.

ρ_a = Density of drying air, kg/m^3.

$\frac{\partial m}{\partial t}$ = Change in moisture concentration per unit change in time, kg/m^3 sec.

CHAPTER I

INTRODUCTION

Developed as well as undeveloped countries are constantly increasing the productivity of livestock to provide an ample supply, for the demand of meat-protein for human consumption. Top management of the livestock as well as the meat-packing industry in the United States of America have always been plagued with the problem of disposal of livestock wastes. The meat-packing industry is specifically concerned with the problems of disposal of their abattoir's Cow Paunch Contents (CPC).

In order to identify where the specific problems are in the present CPC technology, an attempt is made to outline the definition of CPC and its basic known properties, discuss some legal, biological, ecological and technological problems associated with each disposal method, examine the unit operations associated with CPC and discuss the proposed solution to these problems.

Basic Properties

CPC is not fecal material since it has not passed through the entire alimentary canal. It is partially digested material and as such contains more nutrients than fecal material. One of the major contributions to the quality of CPC from a nutritional point of view is the ration fed to the animals.

Witherow (33) reported the average wet weight and dry weight of CPC as 25.4 kg/animal and 3.9 kg/animal, respectively. The average BOD_5 is 5.02×10^4 mg/l and average COD is 1.34×10^4 mg/l. The basic constituents of CPC was found to be moisture, protein, fat, crude fiber, calcium, ash P_2O_5 and carbohydrate.

Disposal Methods

The three basic methods of disposing of CPC are; no dump, wet dump and dry dump.

No Dump

For this method, the entire sack of CPC is sent to rendering. In the rendering process fats, oils and fertilizer supplements are extracted from CPC. An economic constraint applied to this process is low protein content of the meal which reduces the quality of the meal hence its value. Discoloration in grease reduces the value of the grease. The cost to reduce odor is high and is considered an economic factor. Another disadvantage is that because the sack is used in this process, the use of the commercial commodity, tripe, is lost. The relative cost to transport and dispose of CPC, is less than the other two methods.

Wet Dump

For this method the sack containing CPC is gashed and its contents are washed into the sewer with water. The methods used in handling municipal sewage wastes cannot readily be applied to CPC primarily because of the complexities involved in the anaerobic as well as aerobic decay of the material. In effect the solid portions of CPC settle out and form a highly viscous mass. This mass clogs pits, pumps and other moving parts.

This means of biological disposal of CPC can only take care of the solution component of the CPC complex. In order to make this system functionally operative with minimum maintenance some means of separating the solids from the liquids is implemented. Vibrating as well as rotating screens fit this category of added component parts. The capital investment for such equipment is relatively high in addition to the operating costs. No commercially recovered products are obtained from this process, the cost of the huge volume of water that goes into operation is high, and the cost for treating the carriage water that is disposed of in streams is enormous. This type of disposal method is not economical.

Dry Dump

The sack containing the CPC is sliced and dumped into a hopper where it is transported to a specified region by either screw conveyor or pumped as a highly viscous slurry. CPC handled by this method may also be conveyed to a destination by specially built trucks. The land disposal processes associated with this method are surface spreading and below surface spreading.

The surface spreading is done by a specially designed truck that disposes of CPC at a rate of approximately 7.35×10^3 kg/hectares. This process serves well in the winter season, but for spring, summer and fall, the increase in the population of flies as well as the obnoxious gases present, becomes undesirable in the environment. These gases form a complex mixture of ammonia, hydrogensulphide, carbondioxide and methane. No literature has been found relevant to surface runoff from such disposal practices.

The two means of below surface spreading are; plow into ground method and injector method.

For the plow into ground method the CPC slurry is sprayed on the land surface and immediately incorporated into the ground by a mould board plow. This system has two advantages in that it reduces the production of flies as well as obnoxious odors.

Smith and Gold (24) reported that injections at 0.076 m to 0.25 m deep with an application rate of 1.13×10^5 kg/hectares. This system has the same ecological advantages as plow into ground method. One of the primary disadvantages of this system is that it does not function well in frozen high moisture soils.

Mixing with Additives

This process depends upon the ultimate use of the paunch. If land filling is the objective then brush and wood shavings are incorporated into the mixture to provide a degree of stability, thus preventing the high moisture paunch from surfacing. The major problem associated with this process is ground water pollution in which nitride-nitrogen and soluble sulphates leached into nearby streams thus causing fish kills.

Nutritionists have proposed (33) that CPC could be used in part for feeding animals. Summerfelt and Yin (26) reported comparable growth in their catfish studies. The only setback with respect to feeding dried CPC to fish is that if it is not consumed, severe water pollution could occur.

Stock Piling

This is a process in which the CPC is stacked up in huge heaps so that the moisture could be lowered by mass transfer to either the air or to the ground. Associated with this process of disposal is excessive fly production and foul odors. Groundwater pollution may be evident, also.

Rotary Dryers

This type of thermal drying system is very costly in terms of capital cost per dryer as well as odor control costs. Witherow (33) reported that the costs per dryer and housing is $85 per animal slaughtered per day.

Incineration and Pyrolysis

The difference between incineration and pyrolysis is that the latter involves heating without oxygen. The cost associated in operating an incinerator as means of disposing of CPC is approximately $400/animal killed/day. Processing by pyrolysis yields aldehydes, ketones, acids, amines and phenols. No literature was found dealing with the specific economics of pyrolysis.

Composting and Lagooning

Composting is a process in which CPC degrades biologically in an anaerobic environment. This process is free of odor and flies.

In lagooning the environment is aerobic. There are severe economic as well as legal impacts of lagooning (18). It is evident that each method of disposal or processing currently in operation discussed has its implications and/or constraints. Although no literature has been found dealing primarily with the legal implication with CPC, the problems of manure disposal are similar to CPC.

The Water Quality Act of 1965 and Air Pollution Act of 1967 required states to develop means of preventing water and air pollution. The effect was that states, counties, and governmental agencies implemented numerous regulations and laws. The most common restriction is based on the nuisance law. This law gives individuals whose property is injured by a harmful substance that has been discharged in water or air, a legitimate cause to action the parties or firm responsible for the act. Odor is considered a nuisance.

The economic constraints applied to foul odor as a nuisance in an environment, is that it reduces the value of property (dwelling within that environment). A health effect is that it causes mental distress when inhaled consistently by humans.

The problems associated with some of the various processes involved in the technology related to CPC have been discussed, so it is, therefore, evident that some low cost means of processing CPC is needed. This suggests that there is a great need for the development of a unit operation with minimum maintenance problems, relative low investment costs, low operating costs and essentially no pollutants (air, land or water), nor involving large inputs of costly energy.

The implementation of a low cost solar air dryer can serve the purpose. Its primary function is to separate the solid fraction from the liquid by evaporation; thus realizing huge energy savings. The solid fraction can eventually be commercialized into the recovery for silage, protein concentrate for animal feed supplement; a soil conditioner-ash; or as a source of fuel.

Objective

It is apparent that in order to effect a sound design for the drying system, the characteristics of CPC must be known. A rigorous survey of the literature suggests that a complete list of engineering properties of CPC has never been investigated.

In this context, controlled experiments are needed to ascertain engineering properties of this inhomogeneous material. Thermal conductivity, bulk density, specific heat, thermal diffusivity, particle size distribution, coefficient of friction and the drying characteristics constitute a sample of the engineering parameters. At this stage the most important parameter which is needed for prototype solar air dryer design is the drying characteristics of CPC.

The specific objective of this study is to determine the drying rate of slaughtered cow paunch contents (CPC) under constant drying conditions, as a function of air relative humidity, material depth, and time after slaughter or age.

Limitations of Study

The term drying characteristic attempts to describe the physical relationships associated with the material. The relationships here are those inputs that go into the operation of drying. Such a study is very extensive. To obtain the drying characteristics of CPC, separate and/or combine studies would have to be executed in the following areas:

1. Investigation into the mechanism of drying CPC. Here it is important that the forces giving rise to the movement of moisture within the material at specified drying conditions be sought. Examples of such forces are gravity, friction, convection, diffusion and both modes of suction potentials, i.e. capillary or osmotic. Also included, is the rate of drying studies which will include effect of temperature, relative humidity, vapour pressure differential, airflow rate, depth or thickness and age of material on the parameter (rate of drying). Moisture distribution studies are also included on the parameter. The moisture distribution as well as temperature distribution studies reveal the different periods of the drying process as well as the domineering mechanism or a combination of mechanisms controlling the drying at a particular period, within the confines of the drying condition.
2. Investigation into the nature of the water bonding properties of the basic structure of CPC to provide information to aid in the understanding of the phenomenon under study. Example of such methods are the determination of unfrozen water, nuclear magnetic resonance and sorption behaviour. By sorption behaviour it is intended that the study will ascertain the relationship between the isotherms of the partial pressure of water and the water activity of CPC.
3. Investigation into the water - solid CPC relationship. The particle size distribution will be investigated as well as

information on absorbed water or hygroscopic water existence.

4. Investigation into the shrinkage behaviour of CPC under different drying conditions.
5. Investigation into the plastic behaviour of CPC. This study should provide information into the deformation behaviour as well as the stability of water around the particles within the CPC complex.
6. Investigation into the crusting characteristic of CPC. This will provide information about the levels of environmental variables associated with the degree of crusting.

It is beyond the scope of this study to investigate all these areas. The variables considered in this study are relative humidity and temperature of the drying agent, which is air in this case; depth or thickness of the CPC; airflow rate; and age. The basic definition of age of CPC is the time that elapsed after slaughter and CPC is exposed to the ambient air. From this definition of age, it is not possible to discriminate drying time from age.

CHAPTER II

LITERATURE REVIEW

Anthony (1) used the manure of yearling beef steers to appraise the feeding of rations containing manure to fattening the animals, as well as to investigate if cooking the manure improved its feeding value. The tests revealed that cattle could be fed with rations containing appreciable amounts of wet manure. Adding manure to the ration lowered the non-manure feed per unit of gain. These pre-feeding processes did not improve the palatibility or feeding value of the ration. He concluded that the carcass data (rib eye area, fat thickness, and marbling score) were similar for other cattle and that the manure did not impair digestability.

D. J. Baumann (4) demonstrated that it is economically feasible to separate blood from rumen. Also included in his economic studies is the cost of drying blood and rumen separately or together. The dehydration costs for one ton rumen is \$40.93 while that of blood is \$38.46. These cost figures are for utilization of natural gas as fuel in 1971. The cost to remove BOD_5 by dehydration is 18.8 cents per kilogram.

In order to provide a means or indicator to tell the extent a particular treatment has on controlling pollution by disposal he suggests BOD_5 and COD tests should be performed. The tests conducted indicated BOD_5 of 5.92×10^4 ppm and COD of 1.773×10^5 ppm. A 24.49 kg wet paunch yielded 3.86 kg of dried paunch at 7% moisture. Dried paunch investigated indicated 12.7% protein by Kjeldahl method. The economic method utilized for drying the paunch content was gas-fired dryers. This method of drying provides a high potential to prevent excessive water pollution. It also provides one means of separating the blood constituents from the paunch constituents. He also demonstrated that no air pollution occurred when paunch constituents is dehydrated.

Boruff (5) reported that organic wastes disposal problems can greatly be reduced if the material is handled in a concentrated form. A special type of drum digester has been found to digest and stabilize cattle, hog paunch manures, and packinghouse screenings at feeding rates of 4.5, 6.0 and 5.6 grams day^{-1} dry weight, respectively. Combustible gases of 1.0 to 4.0 tank volumes are obtained each day from the stabilization process. This amount depends upon the rate at which the material is fed as well as the nature of the material utilized.

Waste disposal of CPC or manure has been involved in legal implications (7, 18). Although the cases were not directly associated with cow paunch contents disposal per-se, they suggest that the legal as well as economic impacts felt by the defendants are most critical.

A civil action was reported (18) in the case of Bower versus Hog Builders, Inc. (HBI), 1970. In this case the plaintiffs were Mr. and Mrs. Frank Bower and Mr. and Mrs. Glen Bower and the defendent was HBI. HBI had purchased 56.99 hectares across the road and north of the Bower families and erected one of their anaerobic lagoons about 2.44×10^2 m from Glen Bower's home. The Bower families accused the HBI of private nuisance. The court, after hearing all the evidence awarded the Bower families $136,200 for damages.

The county of Winnebago, Illinois, along with eight property owners, levied a law suit against David Fluegel (7). Fluegel was the owner of 9.84 hectares plot with 1400 head of cattle in a confined feedlot operation. The properties of the plaintiffs were located within a mile from the defendent's property. The plaintiff accused Fluegel of (a) unlawfully erecting a feedlot operation contrary to the zoning ordinance of that county, (b) implementing the feedlot operation which was a public nuisance due to odors, flies, insects, and leached nitrates in the groundwater. The court found Fluegel guilty of violating the Industrial Zoning Ordinance and contended that the feedlot was not a domestic animal-breeding operation, nor was it a stock farm; but it was a commercial cattle feedlot which is classified as a stockyard. The court also found that the feedlot was a public nuisance due to contaminated groundwater, offensive odors and substantial contribution to fly population. In addition, the court ordered the defendent to terminate his operation effective as of March 1, 1970.

Coddling (8) reported that abattoir offals, intestines, farthings, paunches and various organs when treated together produced a fertilizer. This fertilizer when dried down to 10% moisture had between 5% and 6% nitrogen and about 3% phosphoric acid. The bulk of vapours that evolved from cow waste are soluable in water. So vapours emitted in dryers are channeled into a condenser containing fine water droplets. The effect is a solution which is disposed of as runoff to the sewage system. The uncondensed vapours are rendered odorless by passing this gas through a chloronome. The ultimate odorless mixture of chlorine and vapour is transported to the atmosphere. In order to prevent the corrosion of metals in this environment, a coat of bitumen should be applied.

Eldridge (10) disclosed that the most objectionable ingredients in wastes from a stream pollution reference are grease, hair, manure and fleshings. Some abattoirs do not make any attempt to save the blood immediately after the animal (cow) is slaughtered.

Farmer and Yin (11) attempted to distinguish between cow fecal material and cow paunch contents. The former is the non-digested material that has passed through the entire alimentary canal, while the latter is material that is partially digested and is found in the first stomach of the cow. Wet-dumping, sewer-dumping, dry dumping, ensilaging, air flotation and gravity settling process and incineration process were included in the disposal practices. Although mention was made of crusting when utilizing solar and other drying methods, no mention was made with respect to the drying air temperature used or the depth of material investigated. S. C. Yin and J. L. Witherow (34) proposed commercial catfish feeding as a potential use of dehydrated cow paunch.

Another potential use is the utilization of heat given up to the environment by the refrigeration system which is used to store animal carcasses. Such heat could be harnessed and implemented into a system involving convective drying for the cow paunch contents. The dried cow paunch contents could be reused as fuel to the refrigeration system.

Nells and Krige (16) contended that most of the abattoirs in South Africa disposed of their wastes into the sewage system or by dumping on land. The waste dumped into the sewage is treated by anaerobic digestion after sedimentation. A scum is formed during the digestion process as well as the organic properties effect a resistance to anaerobic fermentation. The solution to these problems, the authors asserted, is realized by composting. It served as a means of treating the product at the abattoir and supplying a soil conditioner.

The two main stages of composting are stabilization or fermentation and maturization. In order to find out the completion of stabilization and maturization stages, decomposition and chemical analysis must be performed. The stabilization studies involved paunch aeration rate, C:N ratio, pH range, moisture content, temperature, phosphorus, potassium, and stabilization time. In the cow paunch contents study a concentration of 80% was used. This mixture contained 75% moisture content and 25% free air space. These conditions were not conducive to aerobic activities.

In the aeration studies, whenever the oxygen content of the mixture dropped below 5%, anaerobic conditions were attained and a pungent-odor was produced. If the oxygen content is 10%, the compost experienced rapid cooling. But an oxygen content of 7% was highly satisfactory. The aeration rate was 1031 L kg^{-1} day^{-1} which was less than Schultz's (22) 2811 L kg^{-1} day^{-1} for garbage. The studies confined to the C:N ratio indicated that the material becomes stabilized when the C:N ratio is between 16:1 to 30:1. Too high a ratio would indicate that the conditions are not fit for bacteriological activity. Too low a ratio causes ammonia to be released.

The pH studies indicated that a pH value greater than 8.5 seemed to inhibit biological activity. When acetic acid and molasses are added to the paunch contents that has the blood removed, the composting mixture never mixed at a pH over 8.5. The stabilization time was two days. The pH value exceeded 8.5 on the third day without effect on the biological degradation of the material.

The limit and extent of the effect of moisture content in composting was not investigated, but the author suggested that moisture content in excess of 70% has adverse effects on composting.

Low temperatures were obtained for some runs due to excessively high pH level, aeration, and moisture content. No correlation was obtained between temperature and C:N ratio. Temperature was used as a comparison index between runs of same conditions, and was not a measure of biological degradation. Temperatures greater than 60° C kill the flora.

The phosphorus and potassium level are regarded as sufficient to satisfy the flora needs. Stabilization time or time to complete prefermentation should be four days.

The maturization studies revealed that the nitrogen content is constant within experimental error. There was a correlation between volatile matter and length of maturization time. The C:N ratio correlates well with final product although some evidence indicated that it decreased during maturization. No correlation between time and degree of maturization was observed when C:N ratio is used. Complete maturization was achieved in 133 days.

Steffen (28) disclosed that paunch content is dumped directly into flowing streams by many abattoir vendors. The BOD of the flowing stream depends primarily upon the volume of water flowing as well as the rate of paunches deposit. Samples obtained from federally inspected plants show the BOD of this liquid waste is 4.0×10^2 ppm. Such strengths may vary from abattoir to abattoir. He advocated that the most reliable measure of strength of paunch contents is to analyze the raw undiluted sample. B complex synthesis takes place in the paunch. He also reported that Hammond (12) studies indicated that dried cow paunch content, dried rumen and fish meal, contain a nutrient that encouraged high hatchability, fast growth, reduces death rate and good efficiency of utilization when fed to growing chickens.

Witherow (31) reported that it costs $12.00 to dispose of one ton of paunch content by dumping. The following were measured; moisture content, protein, ash, fat, calcium P_2O_5, crude fiber and carbohydrates. Filtration studies included the determination of filtration rate, volume and pressure drop. Dewatering equipment which can be used to reduce moisture content of material was described in some detail. Screw presses, improved screws, disc presses, rollers, roller type hydraulic presses and multiple roller presses were included in the set of dewatering equipments. Sedimentation and incineration were also described as processes associated with paunch content handling. He concluded that the dewatering operation is divided into fine fraction and coarse fraction.

A. G. Unger (29) performed a study of the leading energy-consuming food industries in 1974. The statistics revealed that the food processing and related industries ranked sixth as a energy user in the major industrial groups in the United States of America. It accounts for 7% of the total industrial energy use utilizing 9% of the total industrial employment.

Of all the food related industries, the meat packing industry is the leading energy consumer using 11.9% of the total energy consumed by these industries. These percentages are for animals associated with the meat packing industry which are primarily cattle, hogs, sheep, lambs, and calves. In beef slaughter, 1.74×10^6 watts is required per kilogram for slaughtering and processing whereas 4.22×10^5 watts is required per kilogram for slaughtering, rendering, and primal cutting.

Witherow, Yin and Farmer (32) concluded that improvements in the inplant meat packing operations can reduce discharged pollutants by 50%. If a treatment process is to be designed for no discharge pollutants, then there should be a means of separating the stream for by-product recovery from that responsible for reusable quality. The waste water from the meat packing plant is identified as the number one pollutant in the food chain industry, in the United States of America.

He also suggested that the meat packing waste management research program should develop a technology in a number of areas. In plant control, solid recovery and disposal, odor control and treatment for discharge and utilization in closed loop and dissemination constitute the important areas.

Yin and Witherow (34) conducted air drying, BOD_5, salmonella and catfish studies on cow paunch contents. The air drying studies revealed that during unsteady state drying conditions, a crust developed. The rate of drying was accelerated when the material was churned up manually, daily. Their demonstration of a scale up model of 5.49 m x 2.74 m x 1.02 m tray filled with paunch contents, fell far from satisfying the objective of drying under prevailing conditions.

The BOD_5 results indicated that paunch material was still exerting a tremendous oxygen uptake.

The salmonella studies for determining the frequency of occurrence of salmonellae were negative. The culture procedure effected results of no unclear salmonella isolated. The paunch proved to be palatable to catfish.

Wells, Esmay, Bakker-Arkema (30) reported that drying curves of chicken excreta can be approximated by straight lines using least square's method. The theory used in an attempt to describe the moisture migration from the surface of the material considered, was described for mass transfer rate in terms of vapor pressure differentials. The basic equation presented is:

$$m = \frac{h_d\ (Ps - Pa)}{Ra\ Ta} \qquad [1]$$

The mass transfer coefficient was obtained by using Colburn analogy as

$$h_d = \frac{C_f\ V\ P_a}{2(Sc)^{2/3}} \qquad [2]$$

The skin friction coefficient for laminar flow over a flat plate was evaluated for Reynolds number of 2X 10^5. The relevant equation for skin friction coefficient

$$C_f = \frac{1.328}{R_e^{1/2}} \qquad [3]$$

The response variable weight was transferred to moisture ratio by using

$$MR = \frac{M - Me}{M_i - M_e} \qquad [4]$$

The prediction regression equation obtained is

$$MR = A_i - K_c\ t \qquad [5]$$

Laminar flow was assumed to prevail throughout the experiment even though mention was made of some degree of turbulence in the vicinity of the front edge of the drying sample.

The overall drying process consists of a constant and a falling rate period. The transition from constant rate to falling rate is gradual. During the constant rate period approximately 50% of the moisture is removed. The drying air temperature and humidity showed great effects on the constant rate period. It was also reported that the constant rate period is a function of boundary layer thickness and the concentration gradients within the boundary layer.

Sherwood, T. K. (20) solved Ficks Equation for diffusion in the falling rate period for drying a solid medium. Fick's Law of Diffusion is:

$$\frac{\partial M}{\partial t} = K\frac{\partial^2 M}{\partial X^2} \qquad [6]$$

The solution to this partial differential equation is:

$$\frac{M - M_e}{M_i - M_e} = \frac{8}{\pi}\left[e^{-\left(\frac{\pi}{2}\right)^2 \frac{kt}{R^2}} + \frac{1}{25}e^{-25\left(\frac{\pi}{2}\right)^2 \frac{kt}{R^2}} + \ldots\right] \qquad [7]$$

Kirkwood, K. C., and T. J. Mitchell (14) used a fractional three-level factorial experiment to examine the effects of tray loading, drying air temperature, relative humidity and velocity on the drying times of porous ceramic granules, coke and Brewer's spent grain. It was concluded that the investigation illustrated the effectiveness of the fractional three-level factorial experiments in determining the effect of the above mentioned variables on the drying times of the materials investigated. The falling rate drying constant, for all the materials investigated, depended only upon the air temperature and tray loading.

CHAPTER III

THEORETICAL BACKGROUND

It is intended that this chapter will discuss the general concepts associated with drying. The constant rate period and falling rate period constitute the discussion on drying. For the falling rate period, the zone of unsaturated surface drying and the zone of internal moisture distribution are discussed.

Drying

Drying is a fundamental unit operation in which there is removal of moisture from a solid medium through a gaseous or liquid interface into a gas. Such a process is divided into the constant rate period and the falling rate period.

Constant Rate Period

This is a period of drying that takes place before the critical moisture content of the solid medium being dried is attained. The critical moisture content thus truncates this period of drying. T. K. Sherwood (20) reported that appreciable moisture gradients exist between the surface of the material and its interior during this period. Such moisture gradients may depend upon the dimensions, the rate of drying, and the nature of the material. T. K. Sherwood (21) suggested the large capillary openings are emptied in this period and are filled by air from the drying environment.

Associated with this period is the complete saturation of liquid on all surfaces of the solid medium. There is a film forming an interface between the exposed liquid and the environmental drying air. Vapor diffuses from the saturated surface through this interface, into the environmental drying air. The interfacial vapor diffusion which may be referred to as evaporation or the process in which vaporization takes place below boiling, is affected by a number of interesting entities. The major contributor to the rate of evaporation is the vapor pressure differential between the drying air and that of the saturated surface. W. H. Carrier (6) reported that air velocity, wet bulb temperature depression, chemical and physical properties of the material affect the rate of evaporation. Relatively high air velocity reduces the interfacial thickness at the evaporative surface, thus increasing the rate of evaporation at the surface. The flow of internal moisture to the surface at which evaporation is taking place is also an important factor. This is evidently related to the availability of the quantity of free and/or hygroscopic liquid present in the medium. The rate of such an internal moisture flow must be fast enough to maintain a relatively high degree of saturation at the evaporative surface.

The rate of drying is constant for this period because the rate of heat transfer to the completely saturated evaporative surface is the same as rate of mass transfer or interfacial vapor diffusion from that surface. Evidently the temperature of the evaporative surface is also constant. The heat transferred from the immediate environment to the completely saturated surface is directly responsible for the interfacial vapor diffusion at the evaporative surface. Such heat is known as the heat of vaporization.

Perry and Chilton (17) suggested that the heat of vaporization could be transferred to the evaporative surface by any of the three basic modes of heat transfer. If the heat of vaporization is due to convection only, then the temperature of the saturated surface remains constant and approaches the drying air wet bulb temperature. If conduction is the domineering mode of heat transfer through the surfaces of the supporting medium, then convection may be neglected; the solid in contact with the surface of the medium approaches the t_{db} of the drying air instead of t_{wb}; and the rate of drying is higher than the rate of drying for convective air-drying at the same temperature.

If radiation from solid surfaces or the hot air in the immediate vicinity of the evaporated surface is the major mode of heat transfer for vaporization, then the evaporative surface temperature is between t_{wb} and t_{db} of the drying air; and the rate of drying is increased, due to a higher rate of the heat transfer to the evaporative surface.

For a combination of convection, radiation and conduction modes of heat transfer contributing to the heat of vaporization, then the evaporative surface temperature is between t_{wb} and t_{db} of the drying air; and the rate of heat transfer is much higher, thus increasing the rate of drying.

Falling Rate Period

This is the period which follows the constant rate period and desorption beginning at the point of critical moisture content. This suggests that this period is non-existent if the final moisture content is above the critical moisture content. Once the initial moisture content is below the critical moisture content, then the entire drying process is in the falling rate period. The two zones of drying are associated with this period. They are the zone of unsaturated surface drying and zone of internal moisture movement.

Zone of Unsaturated Surface Drying

This zone may also be referred to as zone of decreasing wetted surface and comes into existence at the commencement of the falling rate period. A completely saturated evaporative surface no longer exists and moisture gradients are set up within the drying medium. But, despite this fact, there is still replenishment of moisture to the evaporative surface from within the solid medium.

T. K. Sherwood (20) suggested that the rate of evaporation of liquid at the exposed surface equals the rate at which this liquid is transported through the solid medium to the evaporative surface. It could then be easily perceived that the internal resistance to moisture movement is much less than the resistance to vapor flow through the interfacial thickness at the evaporative surface.

The rate of drying for this zone is usually decreasing and could still be influenced by external variables such as the drying air temperature, velocity, relative humidity and depth of the solid medium. The decrease in the rate of drying is due to the decrease in the wetted evaporative surface.

A modification of equation [5] is

$$MR = A_i e^{-K_c t} \qquad [8]$$

This equation is used to describe moisture depletion in the falling rate period, with essentially a non-existent constant rate period. For this study equation [8] is used to describe moisture depletion in the zone of unsaturated surface drying. Equation [8] really describes a plot moisture ratio (MR) versus drying time (t) with A_i as the zero intercept at drying time equals zero and K_c the rate of drying.

In order to use equation [8] along with relevant statistical procedures, it is necessary to rewrite it as

$$\ln MR = \ln A_i - K_c t + e_1 \qquad [9]$$

Equation [9] is written as

$$E(Y) = \beta_0 - \beta_1 t + e_1 \qquad [10]$$

so that its parameters could be statistically estimated. The estimate of the rate of drying of CPC as a function of a relative humidity, a depth and an age is β_1 as shown in equation [10]. The general linear model to estimate the rate of drying of CPC, in the zone of unsaturated surface drying of the falling rate period is obtained by the method of least square analysis. The general linear model from which the prediction equation is chosen is written as

$$K_g = \gamma_0 + \sum_{i=1}^{48} \gamma_i X_i + \varepsilon_2 \qquad [11]$$

Zone of Internal Moisture Movement

This zone comes into focus when the plane of evaporation began moving into the solid medium. This is the point at which the evaporative surface is no longer saturated and the resistance to moisture movement within the solid medium is much greater than the resistance to flow of vapor through the interfacial thickness. Once drying is sought to a relatively low moisture content, then this zone dominates. T. K. Sherwood (20) reported that actual vaporization may occur at the interior of the solid medium rather than at the surface once this zone is controlling. Although some shrinkage may occur in the period preceeding this zone, most of the shrinkage in the solid medium is experienced in this zone.

Within this zone, the rate of drying is constantly decreasing. It is not a function of external variables such as drying air-temperature, air velocity, relative humidity, and depth of the solid medium.

CHAPTER IV

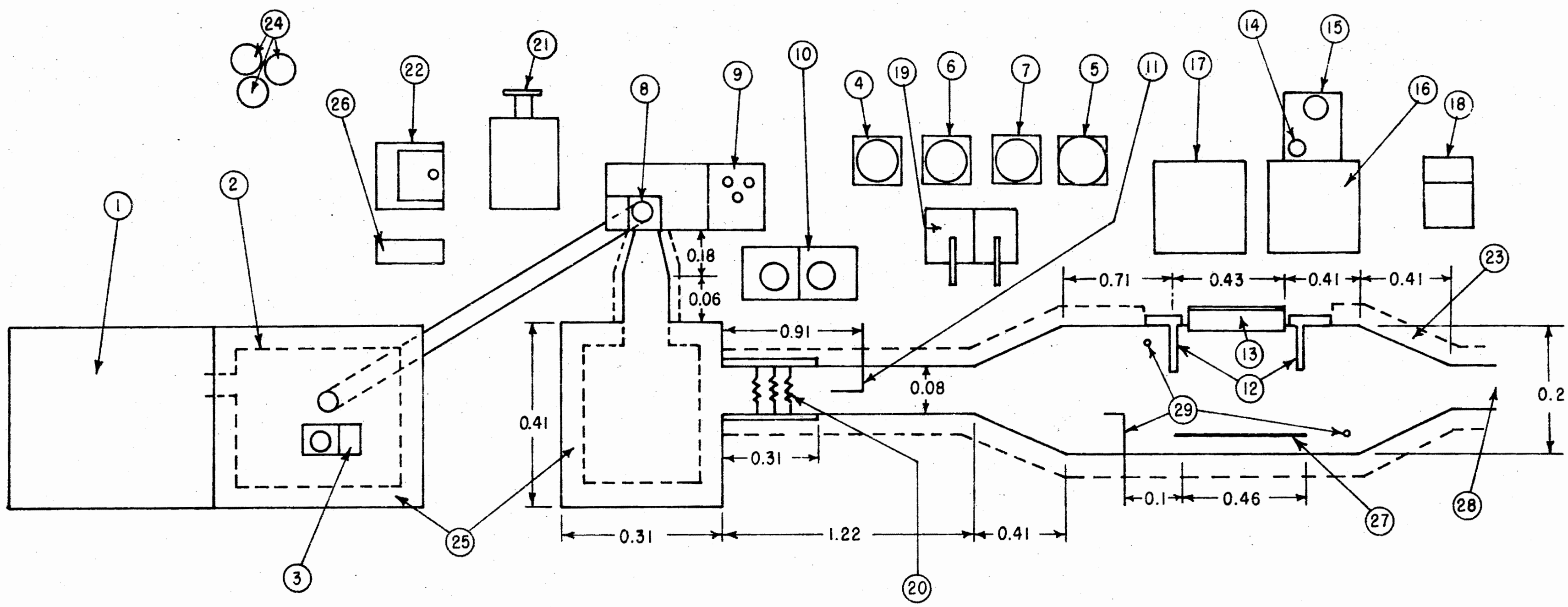
EXPERIMENTAL EQUIPMENT, INSTRUMENTATION, AND PROCEDURE

This section includes the overall layout of the relevant equipment, a more detailed description and function of each component.

Experimental Equipment Layout

The general layout of the equipment for obtaining the drying rate of cow paunch content is shown schematically in Figure 1 and pictorially in Figure 2. This figure depicts the Aminco-Aire unit is connected to plenum No. 1 by two 0.1 m diameter projections. Plenum No. 1 is connected to the shaded-pole blower which is in turn joined to plenum No. 2; by a 0.1 m diameter high temperature flexible duct. The entire duct which is external to plenum Nos. 1 and 2 is insulated with 0.1 m fiberglass insulation.

One side of the heating chamber is connected to the side of plenum No. 2 and the other end clamped to a 0.1 m diameter aluminum pipe. Located in the aluminum duct is a No. 24 gauge thermocouple junction, the leads of which are connected to the Doric Digitrend 200 temperature recorder. The Dwyer pitot static tube is also located in this duct. The length of this duct is 1.22 m, and the other end of it is clamped and sealed to a smooth transitioned 0.20 m x 0.20 m square duct which is 1.83 m long.



1. Aminco Aire Unit
2. Wooden Plenum No. 2
3. HM Psychrometer No. 2
4. Variable Transformer
5. Variable Transformer
6. Variable Transformer
7. Variable Transformer
8. Shaded Pole Blower
9. Switching Box
10. AC Ammeter + Voltmeter
11. Pitot Tube
12. Dew Probes
13. Chamber Door
14. Fan (Bodine)
15. Barometer
16. Resistance Thermometer Recorder
17. Temperature Recorder
18. Ice Flask
19. Micromonometer
20. Electric Heat Resistance Heaters
21. Balance
22. Oven
23. Fiber Glass Insulation (4") (0.10 m)
24. Stainless Steel Cans
25. Styrofoam Insulation
26. Drying Pans
27. Drying Platform
28. Exit Duct
29. Thermocouples

Figure 1. Diagramatic Experimental Equipment Layout

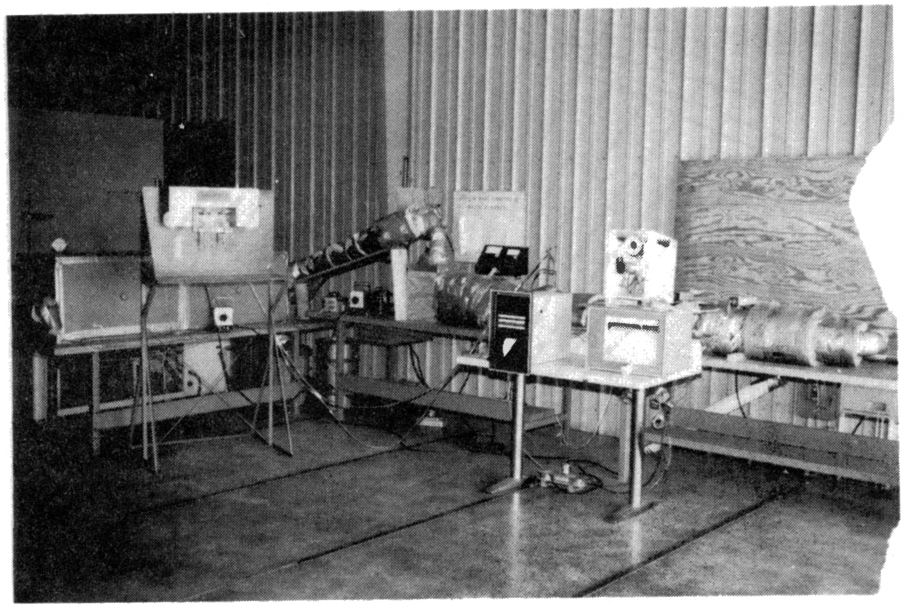


Figure 2. Pictorial Layout of Experimental Equipment

The square duct is made of USS No. 18 gauge sheet metal. Two Honeywell SSP12913 dew probe sensors are located on this duct. The segment between the locations of these two dew probes sensors is known as the drying compartment. A flexible galvanized 0.1 m diameter circular exit duct adjoins the other end of this square duct. The circular aluminum duct as well as the square duct is insulated with fiberglass insulation. A door to facilitate the insertion and removal of samples to be processed in the drying compartment is located on the top surface of the square duct. This door is made of rigid styrofoam. Within the walls of the drying compartment there are six No. 24 gauge thermocouple junctions. These thermocouple junctions are located in a pool of epoxy cement to minimize error in thermocouple readings due to the effect of small circuits set up in the walls of the drying compartment. A representation of the latter arrangement is seen in Figures 3 and 4.

All electrical implements except the Aminco-Aire unit are connected to two junctions which have a 115 volt source. The Aminco-Aire unit has a 230 volt source.

Equipment Description

This description is confined to plenum Nos. 1 and 2, Aminco-Aire unit, homemade psychrometer Nos. 1 and 2, Electronix 16 multipoint strip chart recorder, barometer, balance, oven, switching circuit, drying pans and Doric Digitrend 200 temperature recorder.

Plenum No. 1

This piece of equipment made of plywood has an internal capacity of 0.27 m^3 and is lined on the inside with 0.1 m thick styrofoam

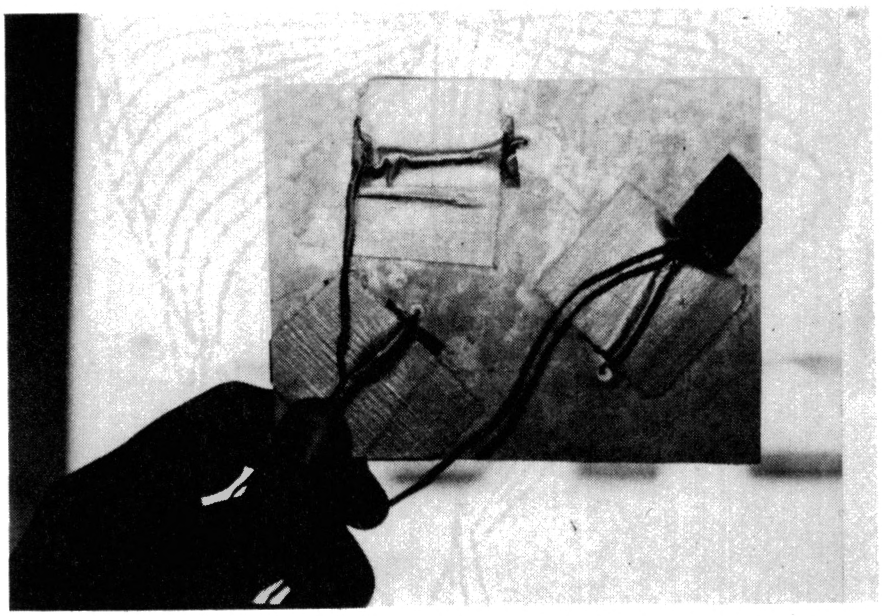


Figure 3. Backside Location of Thermocouple Junctions in the Walls of the Drying Compartment

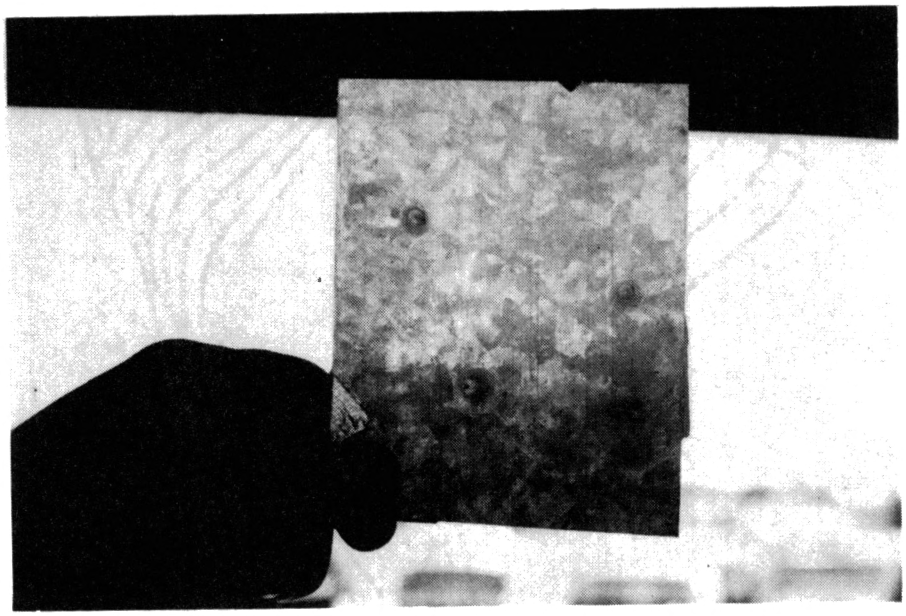


Figure 4. Front Side Location of Thermocouple Junctions in the Walls of the Drying Compartment

insulation, thus minimizing the heat loss or gain from the surrounding environment. Production of excessive turbulence and uniformity in condition of the conditioned air, before it is drawn through the drying chamber, constitute the primary purpose of plenum No. 1.

Two ducts are also located inside this plenum No. 1 chamber as shown in Figure 5. One duct is made of a flexible high temperature hose material and is 0.1 m in diameter. A constant supply of conditioned air to the Shaded-Pole Blower Model 26781, which is located on plenum No. 2, is considered the primary purpose of this duct. The other duct is 3.75×10^{-2} m in diameter and is made of No. 22 gauge USS sheet metal. This duct is projected about 1.0 m inside the 0.1 m diameter high temperature flexible duct. The purpose of 3.75×10^{-2} m duct is to provide a constant supply of the same conditioned air that goes through the 0.1 m diameter flexible high temperature duct to a Shaded-Pole Blower Model 4C 443. This blower is located at the side of the plenum No. 1 as seen in Figures 5 and 6. A flexible high temperature hose is located in opening No. 3 as shown in Figure 5. The primary function of this high temperature hose is to provide a constant source of room air for the air conditioning process. This is necessary since the entire air circulation system is considered an open system.

Plenum No. 2

The purpose of this plenum is to generate more turbulence in the conditioned air as it proceeds towards the heating chamber. The internal capacity of this plenum is 1.69×10^{-3} m and is lined on the inside with 0.05 m styrofoam insulation. A copper-constantan No. 24 gauge thermocouple junction located inside this plenum to obtain the

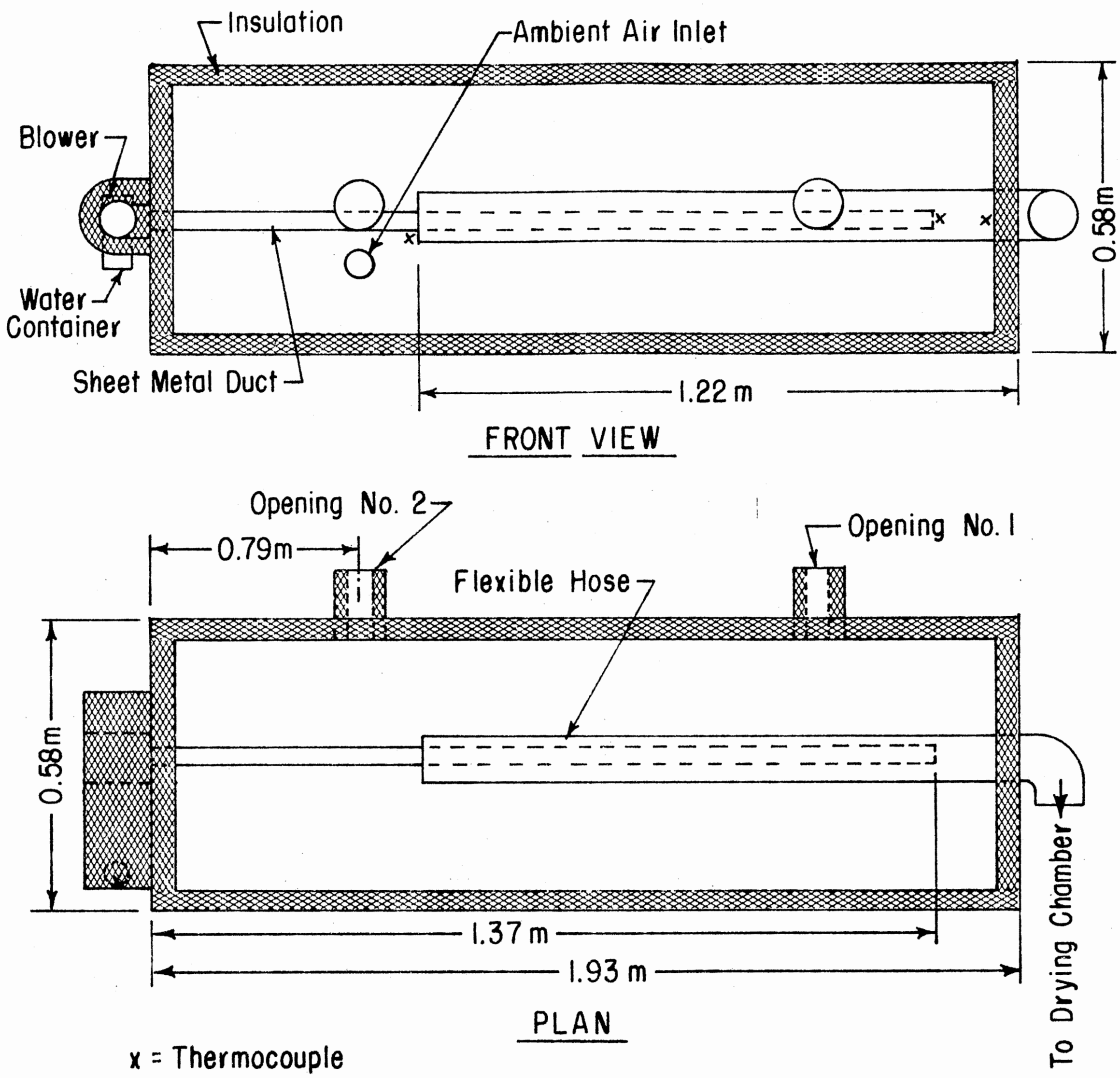


Figure 5. Plenum No. 1

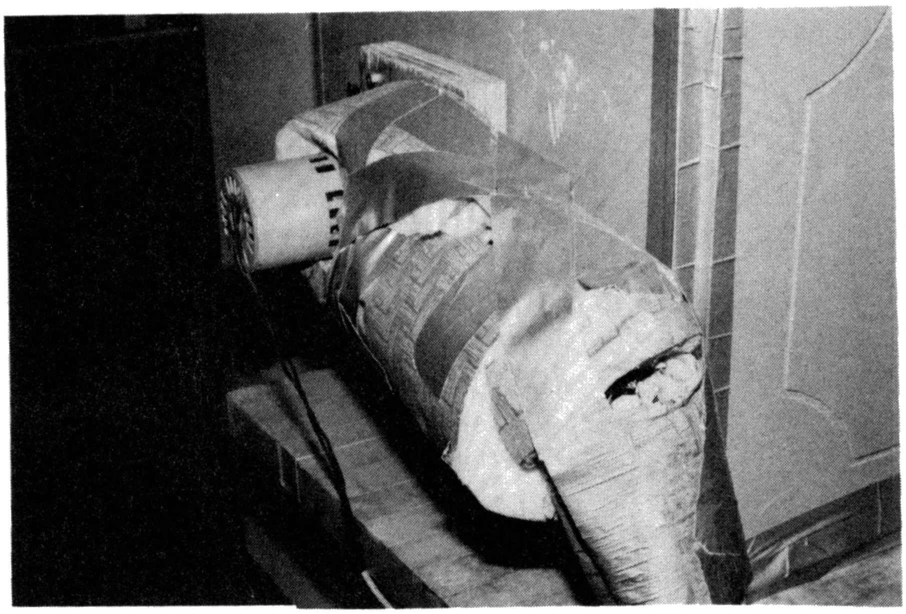


Figure 6. Shaded-Pole Blower with Insulated HMP No. 2 Attached to Plenum No. 1

temperature of the conditioned air at that state point. An aperture is located at a longitudinal side of this chamber, to facilitate the air-flow to the heating chamber. The supply of current to the three heaters that are connected in parallel, and are located in the heating chamber, is controlled by the electrical circuit arrangement as shown in Figure 7.

Aminco-Aire Unit

This unit is basically a precision temperature humidity conditioner. The model is 4-5460A. The primary purpose of which is to provide air at different psychometric states with appreciable accuracy in humidity and temperature control. It utilizes the principle through which the controlled water temperature and dry bulb temperature provides the means of obtaining the relative humidity of the air. Figure 8 shows the spraying chamber of this unit.

Homemade Psychrometer No. 1 (HMP No. 1)

A 1.5 x 10^{-2} kilowatts, type (NSI-12) Bodine Electric Company Blower is situated upon a perforated truncated cone made of No. 22 gauge USS sheet metal, as seen in the upper right of Figure 9. A 0.04 m diameter and 0.1 m high cylinder which is also made of No. 22 gauge USS sheet metal is attached to the exit side of this blower. One end of this cylinder is fully opened to the air stream. A 6.25 x 10^{-3} m projection to which a piece of rubber tubing is attached is located at the bottom of the cylinder. The water level indicator is a piece of rubber tubing 1.07 x 10^{-1} m long and 6.25 x 10^{-3} m diameter clear glass tubing. This piece of clear glass tubing is situated in a vertical position.

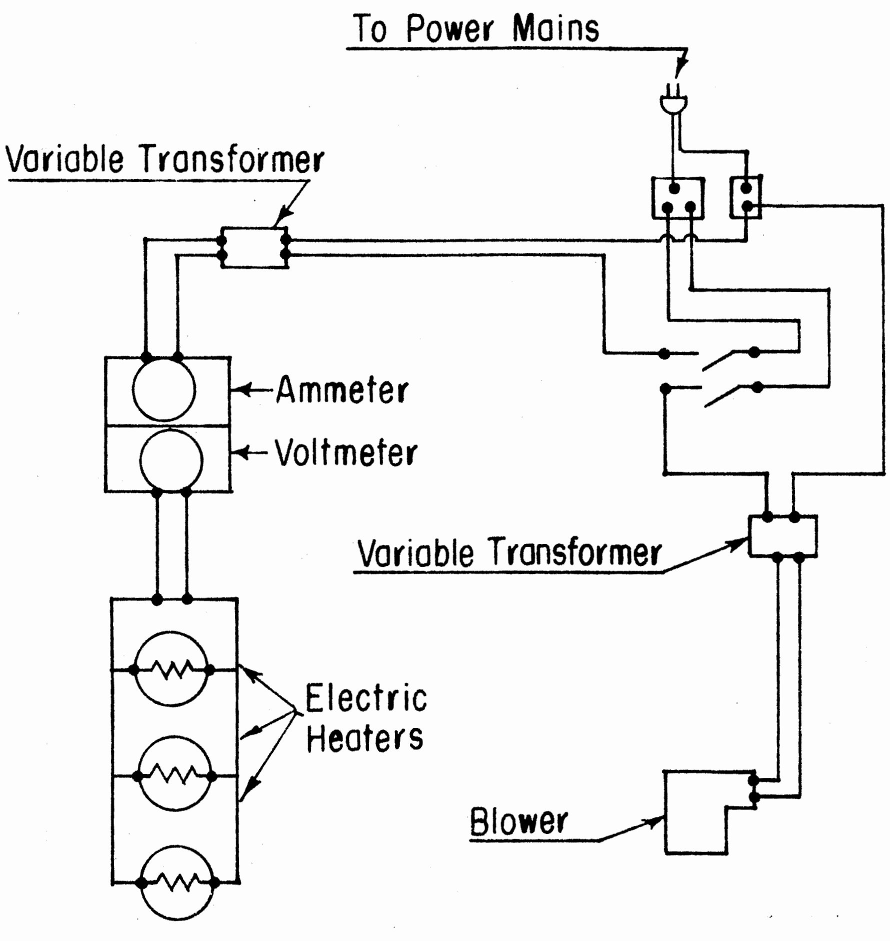


Figure 7. Schematic Diagram for Electrical Circuit Arrangement for Heaters and Blower on Plenum No. 2

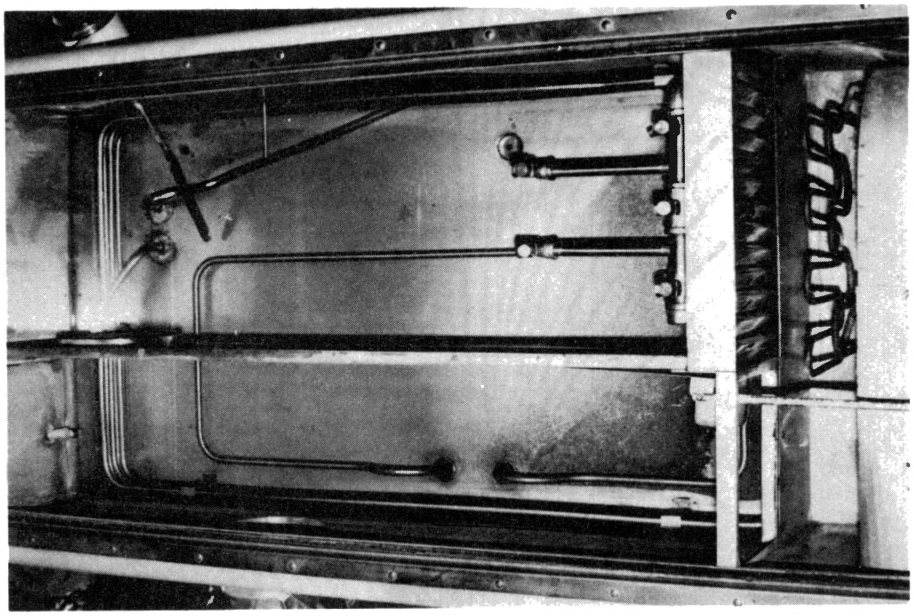


Figure 8. Spraying Chamber of Aminco Aire Unit

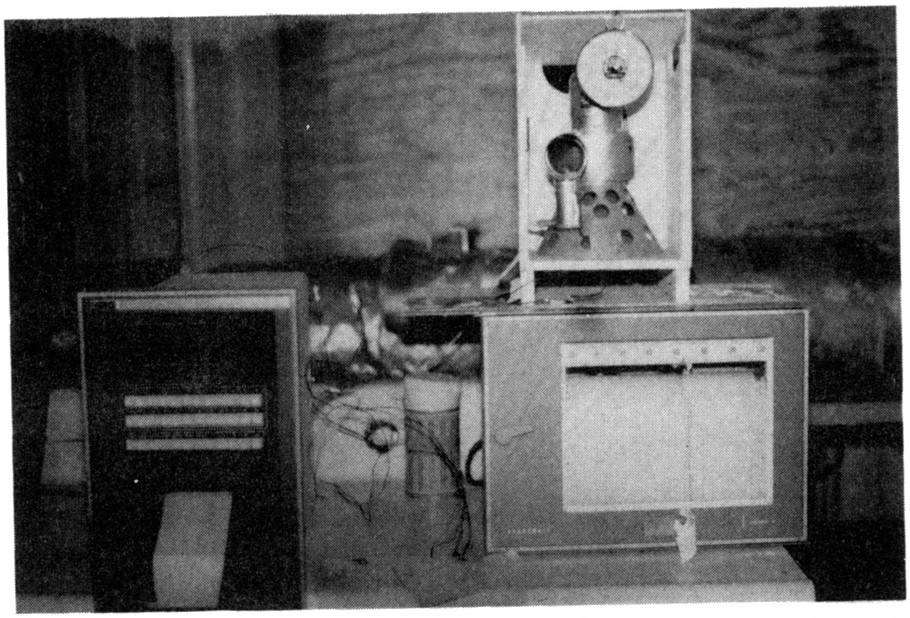


Figure 9. Homemade Psychrometer No. 1, Doric Temperature Recorder, Aneroid Barometer and Resistance Thermometer Recorder

The purpose of this equipment is to obtain a continuous wet bulb temperature of the air in the room in which the experimental equipment is situated. The cylinder is filled with distilled water which surrounds a piece of clean wetted wick. This wick in turn surrounds a copper constantan No. 24 gauge thermocouple junction which is attached to a Digitrend 200 Temperature Recorder. A similar thermocouple junction to measure dry bulb temperature is situated about 1.27 x 10^{-2} m in front of the wetted wick and is attached to the same recorder.

The general principle in obtaining a continuous wet bulb temperature measurement is to blow continuously, a constant volume of air at about 5.08 m/sec over the wetted wick. This process ultimately would effect an adiabatic (evaporative) action which results in a wet bulb temperature measurement at the thermocouple junction. The dry bulb temperature measurement is obtained from the other thermocouple junction. The required air velocity was obtained by setting the probe of an annemometer in front of the exit duct of the Shaded-Pole Blower Model 4C 443 and simultaneously adjusting the VT4FC Ohmitron Transformer until the

Homemade Psychrometer No. 2 - (HMP No. 2)

The only major differences between (HMP No. 2) and (HMP No. 1) are in their purpose and slight modification in construction. The purpose of this psychrometer is to obtain the condition of the air that goes to the heating chamber which is adjoining plenum No. 1. The principle in obtaining these measurements is the same as in (HMP No. 1). With respect to its construction, there is no water level indicator and a duct which is 3.81 x 10^{-2} m in diameter and made of No. 22 gauge USS sheet metal, is attached to the suction end of a Shaded-Pole Blower Model 4C 443 as shown in Figure 6.

The entire duct is heavily insulated by 0.1 m thick fiberglass insulation as seen in Figure 6.

Pitot Tube and Micromanometer

A Dwyer No. 100 pitot static tube and Dwyer No. 1420 hook gauge micromanometer as seen in Figure 10 were used to obtain velocity pressure.

The pitot tube is made of No. 304 stainless steel throughout and has a hemispherical tip that is difficult to damage by the impact of missile particles in the environment in which it is being used. It is connected to the micromanometer by 0.01 m internal diameter plastic tubings.

The Dwyer No. 1420 hook gauge micromanometer is fitted with two micrometers, from which the change in velocity pressure is obtained.

Dew Probes

Obtaining the dewpoint temperature of the drying compartment constitutes the primary purpose for the use of the two Honeywell SSP12918 dew probes.

A resistance thermometer is located within the dew probe bobbins. Surrounding the bobbin is an insulated sleeve. The insulated tube is covered by a cloth sleeve which is impregnated with lithium chloride. Lithium chloride becomes hygroscopic when the relative humidity of the environment in which it finds itself is higher than 11%. The resistance of the lithium chloride is decreased as current passes through the

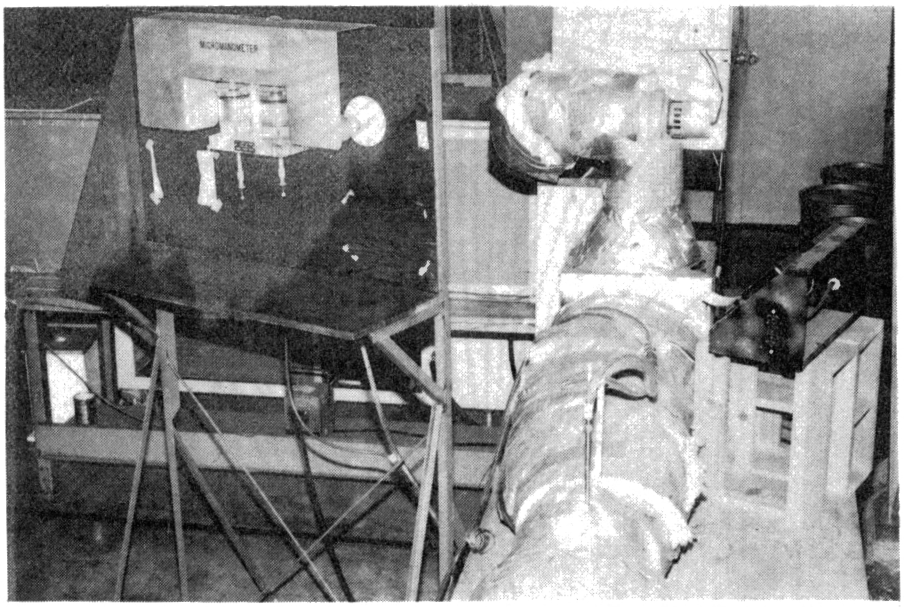


Figure 10. Micromanometer, Insulated Shaded-pole Blower and Stem of Pitot Static Tube

bobbin. The temperature of the bobbin is increased but the relative humidity of the surface air is reduced to 11%. The bobbin temperature is converted into resistance by the resistance thermometer. The values of such resistance are interpreted as dewpoint temperature by the Electronix 16 multipoint strip chart recorder, which is a resistance thermometer recorder. The location of the two dew probes is shown in Figure 11.

Electronix 16 Multipoint Strip Chart Recorder

This instrument which is shown in Figure 9 is sometimes called the resistance thermometer recorder. It can sequentially measure 24 dewpoints. Each signal it receives from the SSP129B dew probe is rebalanced by a feedback signal from the measuring circuit and is then printed on strip chart paper.

Barometer

It is an air guide No. 211-B anaeroid type and its main function is to provide the barometric pressure of the environment in which the experiment is being conducted. Such information is utilized when calculating the required flow rate of conditioned air through the drying compartment. The precision of this measuring instrument as shown in Figure 9 is 0.05 m.

Balance

A Sartorius balance is utilized to obtain the weight of sample at prescribed periods. It has a precision of 0.01 gram.

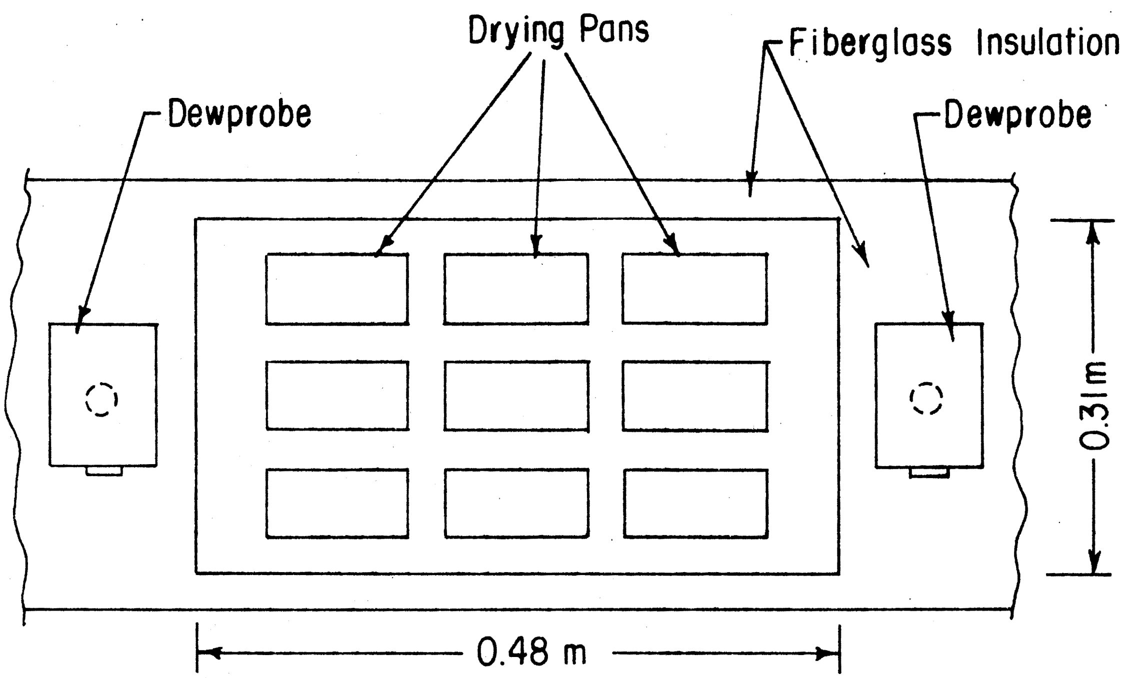


Figure 11. Location of Nine Sampling Drying Pans and Dew Probes in Drying Compartment

Oven

The TS-31050-4 (type A) mechanical convection oven is used to reduce the moisture content of partially processed samples of cow paunch material to a final dry matter. The temperature of the oven is set at 100° C.

Storage Containers

Stainless steel containers of approximately 42 litres were used in storing the cow paunch constituent after it is obtained from the abattoir. The covered containers are placed in the same room in which the experiment is conducted.

Electric Circuit Arrangement for Heaters and Blower on Plenum No. 2

Electric Circuit Arrangement as seen in Figure 7 controls the on and off behaviour of the Shaded-Pole Blower Model 4C 443, as well as that for the three electric heat resistance cone heaters No. 415A. A VT4FC ohmitron transformer, Simpson No. 35043 AC ammeter and voltmeter as well as a Powerstat type F-136 variable auto transformer are included in this circuit.

The purpose of the VT4FC ohmitron transformer is to control the flow of current to the Shaded-Pole Blower Model 2C781, thus regulating the flow of the conditioned air throughout the drying chamber.

Indicating the voltage and current to the three electric heat resistance cone heaters No. 415A constitute the function of the Simpson No. 35043 AC ammeter and voltmeter. The control of the voltage and current that passes through the Simpson No. 35043 AC ammeter and voltmeter is provided by the powerstat type F-136 variable auto transformer. The heating effect of these three heaters causes the temperature of the air to increase hence providing a means of obtaining the desired relative humidity of the conditioned air.

Sampling Drying Pans

The function of these sampling drying pans which are of three depths is to provide a means of enclosing the cow paunch constituents as drying progresses. The depths of these rectangular shaped pans are 0.03, 0.06, and 0.10 m, respectively, as shown in Figure 12. These pans are made of No. 24 gauge USS sheet metal and are 4.38×10^{-2} m wide and 0.01 m long. Metal handles are soldered to the tops of these pans to provide an easy means of inserting and removing the pans from the drying compartment. The pans are painted black to prevent any corrosive effect the cow paunch material may have on sheet metal walls and bottoms.

Doric Digitrend 200 Temperature Recorder

This is a digital multipoint recorder capable of sensing, displaying, and printing temperature of 1-24 points. A display is shown in Figure 9.

Experimental Method of Operation

The segments for discussion in this section consist of conditioning the air, obtaining flow rate measurements and sampling and weighing techniques.

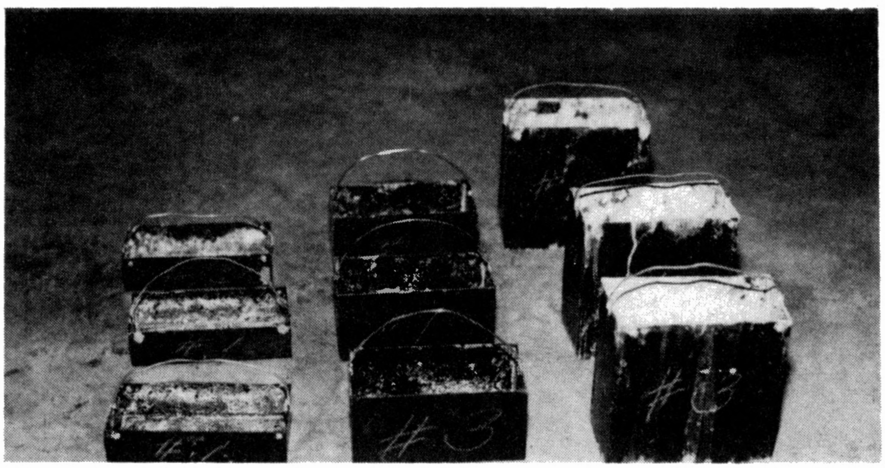


Figure 12. Sampling Drying Pans

Conditioning the Air

The conditioned air from the Aminco-Aire unit is blown into plenum No. 1 where turbulence is encouraged. In order to obtain the required drying air temperature of 35° C and respective 80%, 50% and 20% relative humidities, a series of controlled adjustments are performed on the Aminco-Aire unit. The instructions for such operations are obtained from section No. 1V of the manufacturer's catalogue for the unit.

The experimental design necessitates air at 20% relative humidity and 35° C drying air temperature be utilized as a drying state point. Because of slight instability in the conditioning of the air at 20% relative humidity, the Aminco-Aire unit is adjusted to generate an air condition of 50% relative humidity at 12.8° C water temperature. This air is blown into the heating chamber by the Shaded Pole Blower Model 2C781 where it is further conditioned by adding sensible heat to it. The temperature of the air leaving the heating chamber is monitored by five No. 24 gauge thermocouple junctions which are located along the length of the drying compartment. The average temperature of these five thermocouple readings is used as the drying air temperature. The powerstat type F0136 variable auto transformer is set at 40 on its graduated scale and this provides a flow of 42 volts and 2.8 amps to the three heaters as indicated by the Simpson No. 35043 AC ammeter and voltmeter. In order to ascertain if the required relative humidity is attained, two SSP12913 dew probes are located in the drying compartment to obtain the dewpoint temperature of the conditioned air. The average of these two temperatures is used in conjunction with the General

Electric Psychrometric Chart to determine the relative humidity of the drying air. Any departure from this required relative humidity is neutralized by adjusting the current input into the heaters, hence the heat contribution to the partially conditioned air. After obtaining the necessary air condition, the air is continuously drawn through the entire drying system for a period of six hours before any cow paunch is placed in the drying compartment to be processed.

Sampling and Weighing Operation

Once the temperature as indicated by the thermocouples that are seated in the walls of the drying chamber as well as those responsible for the drying air temperature are constant, it is assumed that constant conditions are attained both by the drying air and the drying compartment.

Nine drying pans of relevant depth are weighed on the Sartorious balance, and their weights recorded. The cow paunch contents which are obtained from Ralph's Meat Processing Plant at Perkins, Oklahoma, were stored in stainless steel cans. It was stirred vigorously by a wooden blade to ensure that the moisture distribution is uniform for sampling. Triplicate subsamples of CPC per cow were placed in the already weighed drying pans of the same depth by a stainless steel spoon. The drying pans containing CPC per cow were weighed on the Sartorious balance and weights recorded. During the entire weighing operation the drying pans were held by a pair of tweezers.

The triplicate subsamples of CPC are placed in a latin square matrix on the drying platform of the drying compartment. The width of all the drying pans are pointing in direction of the airflow. Upon completion of inserting the samples in the drying compartment operation, the opening of the drying compartment is closed. A representation of the locations of the drying pans is seen in Figure 11.

Within the confines of the experimental design the triplicate subsamples per cow are quickly removed from the drying compartment and their relevant weights obtained on the Sartorious balance and recorded. It takes 4-5 minutes to perform this operation. Such operations are performed at the 1st hr., 3rd hr., 7th hr., 15th hr., 31st hr., and 63rd hr., after it is first placed in the drying compartment. Weighing is also performed at 70th, 80th, and 88th hour. The temperatures of the drying air as well as that of the drying compartment, and room psychometric condition are noted immediately after each time the weighing operation is performed. After obtaining the readings for the nine sampling drying pans at the end of the 88th hour, these nine sampling drying pans are then placed in the oven to reduce the moisture content of these samples that are already partially processed to a final state. After two days, the final weight of the samples are obtained on the Sartorious balance and recorded.

Because of the nature in which the treatment application is implemented, within the confines of conducting the experiment of the design of the experiment, block replication is performed, then a new conditioned air state point is obtained.

CHAPTER V

STATISTICAL EXPERIMENTAL DESIGN

Preliminary Experimental Design

The purpose of the preliminary experimental design was to determine the effect of position of the drying pans in the drying duct.

The basic design of the preliminary experiment is a 3 x 3 latin square in which the transverse effect due to airflow is designated as column effect. The longitudinal effect due to airflow is designated as row effect. The three treatments are applied to samples of CPC taken from three sacks of CPC. Each sack of CPC is taken from each of three different cows.

Seven runs are investigated over ranges of relative humidities 20%, 50% and 80%, respectively. Each drying pan is filled to the same depth of CPC for each of the seven runs. The response variable is weight of CPC in grams, and such responses are observed by removing the drying pans from the drying compartment at the end of 0, 1, 3, 7, 15, 31, 63, and 88 hours, respectively.

The relevant statistical model is written as

$$Y_{ijkl} = \mu + R_i + C_j + P_k + H_l + (RH)_{il} + (CH)_{jl} + (PH)_{kl} + \varepsilon_{ijk} + \delta_{ijkl} \qquad [12]$$

Overall Experimental Design

The following statistical approach dealt with the design, execution, and analysis of the experiment which was adopted.

There are a number of different phases of this overall experimental design that must be satisfied before arriving at the final design. The conception phase is centered around formulating the experiment. The synthesis phase includes the design of the structural model, functional model, the analytical model and the experimental model. With respect to the evaluation phase only conducting the experiment is applicable here but there will be discussion on how the analysis would be proceeded.

Conception Phase

The conception phase essentially deals with the setting of definite boundary conditions that must be fixed within the experiment. The boundary condition is chosen from a need scale. This need scale or what may be termed need environment is defined as those elements or parameters which are engineering in nature within the context of the problem.

It has been discussed in some detail in the Introduction, that there is an unquestionable need for a zero pollutant process to dispel of abattoir CPC. Of all the engineering parameters, the immediate investigation into the rate at which this material dries is most relevant. The rate at which CPC dries is considered the boundary condition of the study. Such a drying rate is sometimes referred to in the literature as the drying characteristic. It must be pointed out that this conception phase differs from the statement of the problem area in that the statement of the problem is very much associated with a detailed discussion of what is the experimental problem. Now that the boundary condition has been chosen, it becomes part of the experimental design.

The next part of the conception phase is to tie down the rate of drying of abattoir CPC within the confines of the intended experimental design. Such a restriction identifies the necessary ingredients or abattoir CPC. S. M. Henderson (13) equation [5] for obtaining the moisture ratio of inhomogenous materials is utilized as a means of identifying some of the relevant variables. No new theory is investigated in this study. S. M. Henderson (13) equation for drying in the falling rate period does not include explicity some other relevant factors which are depth, relative humidity of the drying environment, and age. Two other fixed factors that must be considered in this study are airflow rate at 1.2 m^3/sec and the drying air temperature at 35° C.

Synthesis Phase

The design of the structural model, functional model, analytical model and experimental model constitute the ingredients of this phase.

Structural Model

Associated with the design of the structural model is the hypothesis statement and the determination of the number of factor levels.

The hypothesis statement tells at all times what is being investigated. Within the context of this experiment, the relevant hypothesis is: the abattoir CPC drying characteristic, or sometimes referred to in the literature as the rate of drying, is dependent upon the depth of CPC, age of CPC and the relative humidity of the environment in which the samples of CPC are located.

The literature reviewed, dealing with various aspects of cow paunch contents, did not indicate any previously published material. It is desirable to investigate the simple or linear effect of treatments, main effects of treatments, interaction effects of treatments and if possible non-linear (quadratic) effects of treatments. Three levels each of depth and relative humidity as well as 9 units of location of age were used in this experiment. The selection of these levels will indicate qualitatively a low, medium and high depth, relative humidity and age.

Functional Model

The functional model is associated with the concept of the number of responses in a replicate. When all the cells contain response measurements, the functional model is said to be a complete model. Any violation of the latter idea places the functional model in an incomplete model category. The functional model applied here is incomplete in nature. The total number of responses in each replicate is

$$Z = L_{rh} \times L_{DPT} \times L_{AG} \times L_{TM} \times L_{CW} \times L_{S}$$
$$= 3 \times 3 \times 1/3 \times 9 \times 7 \times 3 \times 3 = 1701 \text{ responses} \qquad [13]$$

Analytical Model

The analytical model is dealt with from a unit cell point of view. It is necessary to look at a unit cell and ascertain what takes place within its confines. In each unit cell there are nine samples of CPC from 3 cows. Since it is intended that the analysis of this study be done on the slopes of the Log of MR as a function of drying time curves, an average slope is obtained for each cow within each cell. So in effect, each cell will contain three values of the rate of drying of CPC for that particular condition. The rate of drying of samples of CPC becomes the new response variable for analysis. It seemed convenient that since all the data cannot be obtained in one day, a split-plot model is adopted. The statistical model may be written as

$$K_{ijkl} = \kappa + Rh_i + Cw_j + (RhCw)_{ij} + D_k + (RhD)_{ik} + Cw_jD_k(Rh_i) + \lambda_{ijkl} \qquad [14]$$

From this statistical model it seems that as the depth of CPC change, the age of CPC changes simultaneously. So unfortunately depth is completely confounded with age of CPC.

Experimental Model

The analytical model suggests that the final experiment design be set up as a 3 x 3 factorial experiment in a split-plot design for each age of CPC. Another way to write this design is a 3 x 3 factorial to be conducted in a split-plot design over time with age as location. The relative humidity is considered the main plot and is randomized. The sub-plot is depth of CPC since its levels change within the main plot rather than between the main plots. Cows are considered the experimental unit. Because there is a change in the levels of depth of CPC for each setting of relative humidity, this arrangement makes the experiment a basic split-plot design.

The levels of age are 97, 194, 291, 388, 485, 582, 679, 776, and 873 hours, respectively. The levels of relative humidity are 20, 50 or 80%, respectively. The levels of depths are 2.5, 6.4, and 10.2 cm, respectively. The variation among cows is used as the experimental error for making the statistical tests. This is because there is no way in which a pure error could be obtained due to the confounding nature of variable age.

Paunch contents from nine cows are chosen to run this entire experiment and since it has already been indicated that there are three (3) cows in each replicate, it is evident that the entire experiment will have 3 replications. The total number of responses that is utilized for this study is

$$N = 3\ Z = 567 \times 3 = 1701 \text{ responses} \qquad [15]$$

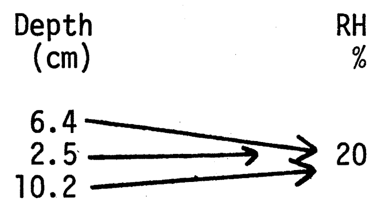
Now that the final experiment design has been completed it is necessary to include a treatment matrix layout. This treatment matrix layout must not be confused with the experimental design. It is only a representation of how the treatments (depths, relative humidity and age of CPC) are applied in their relevant combinations and levels. Treatment matrix layout is found in Appendix A.

Evaluation Phase

The evaluation phase entails a description of how the experiment is to be conducted as well as a structure of how the analysis is to be conducted. Also inclusive in this category is the collection of the data.

Conducting the Experiment

The order of run is important in this phase. In conducting the functional operations of the runs in each replicate, it is desirable to run the depth of CPC in block replication, with the main plot which is relative humidity. By block replication, it is meant that, for example,



This suggests that a run of depth 6.4 cm at 20% relative humidity be conducted, then depth 2.5 cm at the same 20% relative humidity, then 10.2 cm at the same relative.

A change in the setting of the relative humidity is made, depth is randomized once more, then block replicate once more. This procedure is adopted until the replicate is completed.

Approach to Analysis

The analysis of this entire study is divided into an analysis on the preliminary experiment; comments on the prediction equation and overall rates of drying curves and an analysis each on the effect of relative humidity, depth and age of CPC on the change on the rate of drying of CPC, respectively.

The analysis on the preliminary experiment is done on moisture ratio. Weight in grams is the basic response variable in both experiments. The weight is converted to moisture-content dry-basis by using

$$M = \left(\frac{Wt_i - Wt_f}{Wt_d}\right) 100 \qquad [16]$$

Time is known as drying time and is for fixed periods of 0, 1, 3, 7, 15, and 31 hours, respectively. There are three sub-sampling units for each cow for each experimental run. The average moisture-ratio at a drying time location within an experimental run for a cow is found by averaging the moisture-ratios of the three sub-sampling units at that drying time. The log of the respective average moisture ratios as a function of drying time is plotted for each cow within each experimental run for twenty-seven such runs. Computer programme No. 3 is used to aid in the computation of moisture ratio, average moisture ratio and log of moisture ratio in this segment of the analysis. The rate of drying of CPC for each cow within each experimental run is calculated by taking the slope of the plot of log of moisture ratio versus drying time. The least square regression technique is used to fit these slopes. Computer programme No. 3 is used to aid in computing the average rates of drying of CPC for each cow within each experimental run.

Since there are three cows per experimental run, it follows that for the total of twenty-seven such runs, there are eighty-one units of slope measurements as separate rates of drying of CPC, available for further analysis. The values of the eight-one slopes are used as new response variables in the AOV. An LSD (0.05) as well as the prediction equation expressing the rate of drying of CPC as a function of relative humidity, depth and age of CPC are also obtained from the values of the eighty-one slopes. The prediction equation is obtained by using least square regression analysis and the aid of Computer programme No.

4. Confidence intervals at 5.0% level on the different rates of drying of CPC are also established by use of Computer programme No. 4.

With respect to the separate analysis on the effect of relative humidity, depth and age of CPC on the change in the rate of drying of CPC, it is necessary to calculate the rates of drying of CPC in each experimental run over the three cows. A least square regression line is fitted to the data points on the log of moisture ratio versus drying time for the three cows within each experimental run. These slopes of the least square regression lines on the plots of log of moisture ratio versus drying time are interpreted as twenty-seven separate rates of drying of CPC for the total of twenty-seven runs. Within the structure of Computer Programme No. 4, it is the variation among cows within a given relative humidity, depth and age, is used as the error term to establish the confidence intervals at 5.0% level on each predicted rate of drying of CPC value. This same variation among cows is also used as the error term for the selected contrasts in which the desired effects are not confounded. These contrasts will also be presented in the discussion of the analysis of the results.

To effect qualitative conclusions for this study the following terms are adopted.

Low Depth	-	2.5 cm	-	thin or shallow depth
Medium Depth	-	6.4 cm	-	medium depth
High Depth	-	10.2 cm	-	thick depth
Low Relative Humidity	-	20%	-	fast drying potential
Medium Relative Humidity	-	50%	-	medium drying potential
High Relative Humidity	-	80%	-	slow drying potential

Low Age	-	0 - 291 hours	-	fresh
Medium Age	-	292 hours - 582 hours	-	medium age
High Age	-	583 hours - 873 hours	-	old age.

CHAPTER VI

ANALYSIS AND PRESENTATION OF DATA

Analysis of the Preliminary Experiment

Seven separate runs were investigated over ranges of relative humidities 20%, 50% and 80%, respectively. Computer programme No. 1 was used to aid in the computation involved in the analysis of the latin square design in time, for each of the seven runs. A summary of the analysis is seen in Table I. The analysis was performed on moisture ratio (MR).

The results on Table I indicated that only drying time was statistically significant in the preliminary experiment. So, in effect, the position of the sampling drying pans in the drying compartment did not affect the moisture ratio.

It was possible to plot log of moisture ratio versus drying time for each of the three cows investigated. From these plots the average rate of drying of CPC was extrapolated and plotted against age for each location. These plots could be seen in Appendix E.

The type of CPC used for the preliminary experiment was visibly greater than 95% grains in a viscous yellowish slurry as was obtained from each of the three cows. From the plots in Appendix E (Figure 47) it appeared that the rates of drying of CPC was essentially constant for cow No. 1 for different ages of CPC. With respect to cow No. 2,

TABLE I

ANALYSIS OF VARIANCE FOR TEST OF SIGNIFICANT DIFFERENCE BETWEEN ROWS AND COLUMNS

Run No. 1: RH = 80%

Source	DF	Sum of Squares	Mean Square	F
Row	2	0.00495	0.00245	0.0198
Col	2	0.00070	0.00035	0.0028
Cow	2	0.021882	0.01094	0.0884
Time	6	7.57586	1.26264	10.203 *
Cow * Time	12	0.0234	0.00195	0.0157
Row * Time	12	0.01158	0.00096	0.00775
Col * Time	12	0.00054	0.00004	0.00032
Row * Col - Cow	2	0.00372	0.00186	0.015
Row * Col * Time - Cow * Time	12	0.02968	0.00247	0.0199
Corrected Total	62	7.6723	0.12374	

Run No. 2: RH = 80%

Row	2	0.000612	0.000306	0.0025557
Col	2	0.000056	0.000027	0.0002255
Cow	2	0.000058	0.000029	0.0002422
Time	6	7.414683	1.235781	10.3212 *
Cow * Time	12	0.0013845	0.0001155	0.009646
Row * Time	12	0.0005804	0.000048	0.00040089
Col * Time	12	0.0003986	0.000033	0.00027562
Row * Col - Cow	2	0.0030478	0.00.524	0.0127284
Row * Col * Time - Cow * Time	12	0.0025778	0.0002148	0.001794
Corrected Total	62	7.423398	0.1197322	

Run No. 3: RH = 20%

Row	22	0.0037706	0.0018853	0.0147228
Col	2	0.00244348	0.0012217	0.0095406
Cow	2	0.00188283	0.0009414	0.0073516
Time	6	7.8319976	1.3053329	10.193715 *
Cow * Time	12	0.0258759	0.00215633	0.01683939
Row * Time	12	0.0281623	0.00234685	0.0183272
Col * Time	12	0.0258064	0.00215053	0.016794

TABLE I (Continued)

Source	DF	Sum of Squares	Mean Square	F
		Run No. 3: RH = 20%		
Row * Col * Time	2	0.00092286	0.00046143	0.0036034
Row * Col * Time - Cow * Time	12	0.0184069	0.00153391	0.01197874
Corrected Total	62	7.9892689	0.12805272	
		Run No. 4: RH = 50%		
Row	2	0.0011485	0.0005743	0.0049166
Col	2	0.00156767	0.00078383	0.0067105
Cow	2	0.0165237	0.00826185	0.0707305
Time	6	7.20601455	1.20100242	10.28191059 *
Cow * Time	12	0.0087649	0.00073041	0.0062531
Row * Time	12	0.00095497	0.00007958	0.00068129
Col * Time	12	0.00130687	0.00010891	0.00093223
Row * Col - Cow	2	0.00264003	0.00132002	0.01130066
Row * Col * Time - Cow * Time	12	0.00313278	0.00026106	0.00223496
Corrected Total	62	7.2420539	0.11680732	
		Run No. 5: RH = 20%		
Row	2	0.01684278	0.00842139	0.0717515
Col	2	0.012558256	0.00629128	0.0536026
Cow	2	0.00539044	0.00269522	0.00229636
Time	6	7.12268059	1.18711343	10.1143789 *
Cow * Time	12	0.01922943	0.00160245	0.01365311
Row * Time	12	0.03638429	0.00303202	0.0258333
Col * Time	12	0.02114304	0.00176192	0.0150118
Row * Col * Cow	2	0.01634445	0.00817223	0.06962858
Row * Col * Time - Cow * Time	12	0.02629334	0.00218944	0.01865434
Corrected Total	62	7.27687093	0.11736889	
		Run No. 6: RH = 50%		
Row	2	0.02000682	0.01000341	0.0776877

TABLE I (Continued)

Run No. 6: RH = 50%

Source	DF	Sum of Squares	Mean Square	F
Col	2	0.01676175	0.00838087	0.0650869
Cow	2	0.02061951	0.01030975	0.08006677
Time	6	7.57215417	1.26202570	9.8010444 *
Cow * Time	12	0.11991408	0.00999284	0.0776056
Row * Time	12	0.09186196	0.00765516	0.05945089
Col * Time	12	0.09744054	0.00812005	0.06306129
Row * Col - Cow	2	0.01838992	0.00949496	0.07373901
Row * Col * Time - Cow * Time	12	0.02624451	0.002188705	0.01699775
Corrected Total	62	7.98339329	0.12876441	

Run No. 7: RH = 50%

Source	DF	Sum of Squares	Mean Square	F
Row	2	0.00067498	0.00033749	0.0027869
Col	2	0.00659195	0.00329597	0.0272173
Cow	2	0.01034624	0.00517312	0.04271833
Time	6	7.46158694	1.24359782	10.269319 *
Cow * Time	12	0.01173999	0.00097833	0.0080788
Row * Time	12	0.00746623	0.00062219	0.00513789
Col * Time	12	0.00581724	0.00048477	0.0040031
Row * Col - Cow	2	0.00110778	0.00055389	0.00457388
Row * Col * Time - Cow * Time	12	0.00276770	0.00023064	0.001904567
Corrected Total	62	7.50809905	0.12109837	

*Indicates significance at $\alpha = 0.01$ level.

the plot indicated that there was a constant increase with rate of drying of the CPC up to 187 hours; then a progressive increase in the rate of drying of the CPC up to the 441st hour. Beyond this age, the rate of drying of CPC was constant. For cow No. 3, the pattern in the rate of drying of CPC was almost similar as that for cow No. 2.

The General Prediction Equation and Overall Rates of Drying Curves

Equation [11] essentially describes all the relevant combinations of age, relative humidity and depth associated with the overall rate of drying of CPC (K_g). The combination of variables that were found to be statistically and practically significant are represented by this general polynomial equation

$$K_g = \gamma_o + \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \gamma_4 X_4 + \gamma_5 X_5 + \gamma_6 X_6 + \gamma_7 X_7 + \varepsilon_2 \qquad [17]$$

Equation [17] is rewritten as

$$K_g = \gamma_o + \gamma_1 \, Rh + \gamma_2 \, D + \gamma_3 \, Ag + \gamma_4 \, (Rh)^2 + \gamma_5 (Ag)^2 + \gamma_6 \, (Rh) \, (D) + \gamma_7 \, (Rh) \, (Ag) + \varepsilon_2 \qquad [18]$$

The difference between equation [17] and [18] is replacing the X's in [17] by the actual variables as in [18].

Equation [18] was derived by performing a regression analysis on all eighty-one slope (β_1) values, which represent the rates of drying of CPC in the entire study for all ages, depth and relative humidities considered.

Equation [18] is rewritten with the relevant estimates of the coefficients of the variables and their combinations. The best of the general polynomial equations deduced in this entire study is:

$$K_g = -5.0233 \times 10^{-2} + 6.8151 \times 10^{-4}\ Rh + 1.124 \times 10^{-5}\ D + 8.017 \times 10^{-5}\ Ag - 2.86 \times 10^{-6}\ (Rh)^2 - 6.0 \times 10^{-8}\ (Ag)^2 - 1.8 \times 10^{-7}\ (Rh)\ (D) - 4.2 \times 10^{-7}\ (Rh)\ (Ag) \quad [19]$$

Other similarly deduced regression models are shown in Appendix F (Figure 48).

It must be clearly understood that the statistical model equation [14] does not include age explicitly as a variable. Equation [14] represents the split-plot model for a 3 x 3 factorial design for each age of CPC. So, because of the fact that age and depth changed simultaneously, and drying time is completely confounded in age, it was necessary to generate equation [19] by regression analysis.

Figures 13, 14, and 15 are three representative samples of a total of twenty-seven experimental runs. Each of these figures essentially show the least square regression line fitted to the deduced data points on a plot of the log of moisture-ratio versus drying time for the three cows within an experimental run. Figures 16, 17, and 18 provide a means of visually perceiving the rates of drying of CPC for all twenty-seven runs divided into the three relevant replicates. It could easily be deduced from Figures 16, 17, and 18 that for within each replicate, each of the nine runs' rates of drying of CPC curves are at variance with each other. Hence, the rates of drying of CPC in this study are not the same. It is not possible to deduce from Figures 16, 17, and 18 the types of changes in the rates of drying of CPC for the constraints utilized in this study. Another interesting feature of Figures 16, 17, and 18 is that the same pattern with respect to the shape of the slope

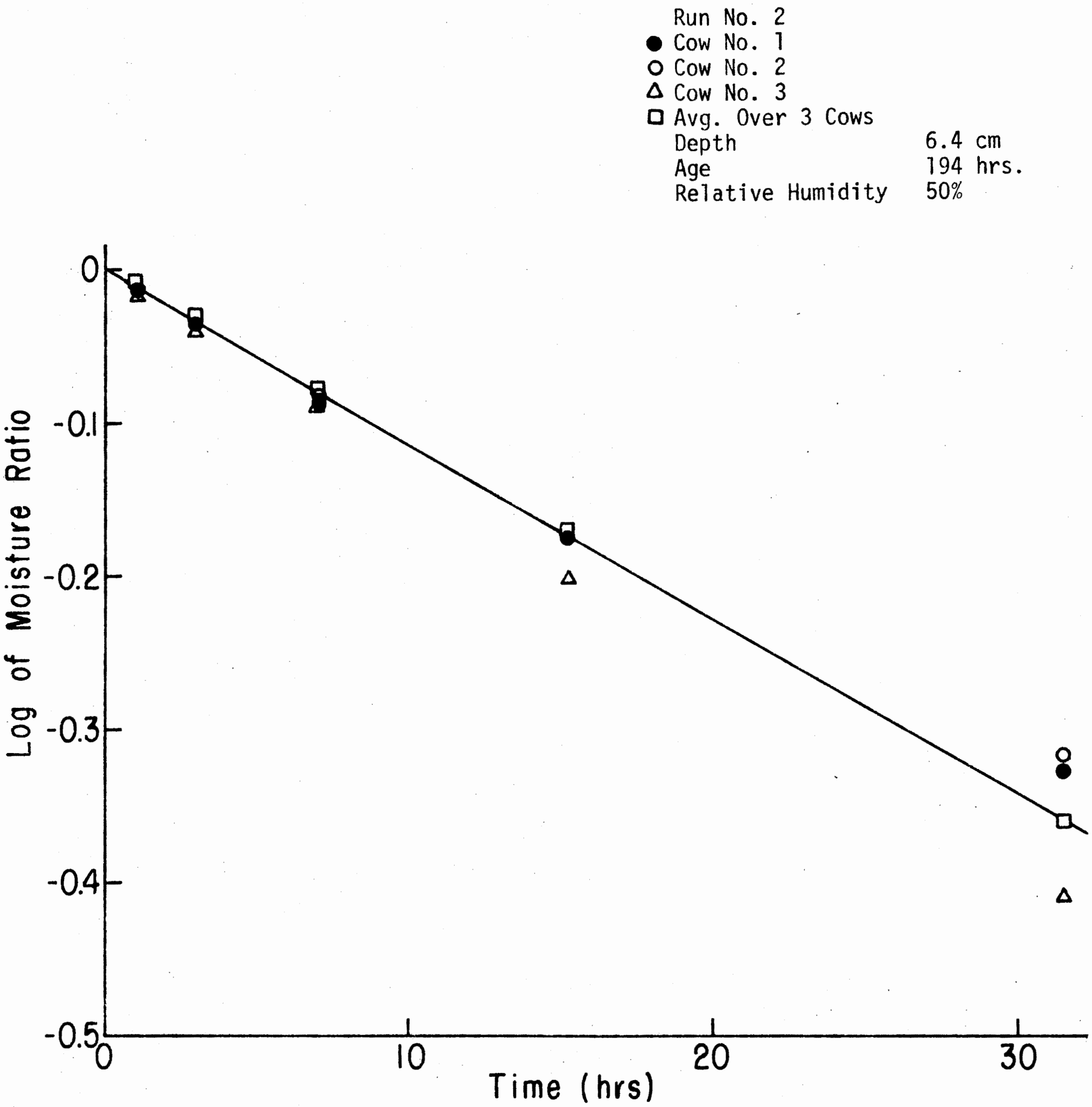


Figure 13. Regression Line of LG-MR as a Function of Drying Time for Run No. 2, Replicate No. 1

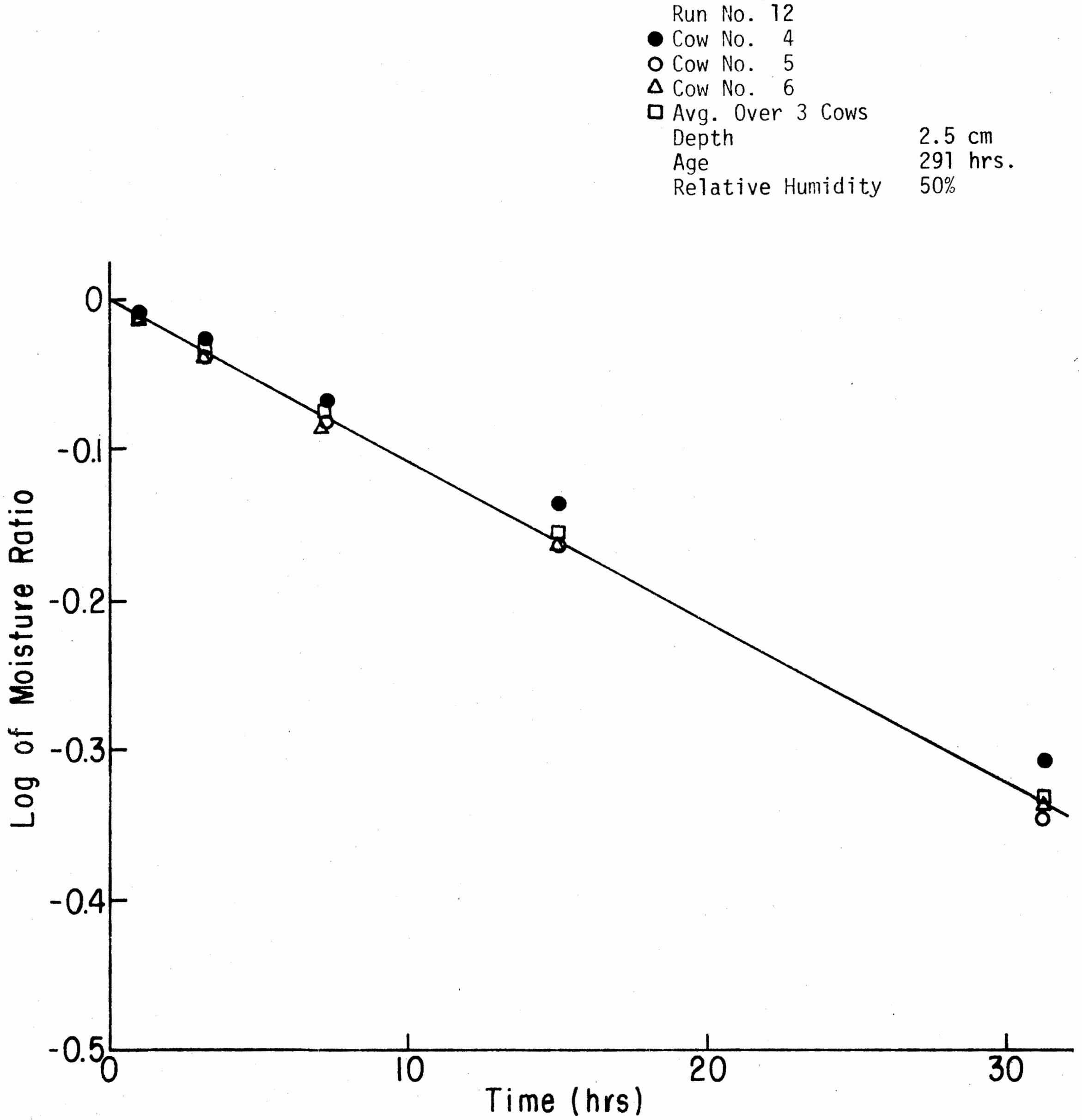


Figure 14. Regression Line of LG-MR as a Function of Drying Time for Run No. 12, Replicate No. 2

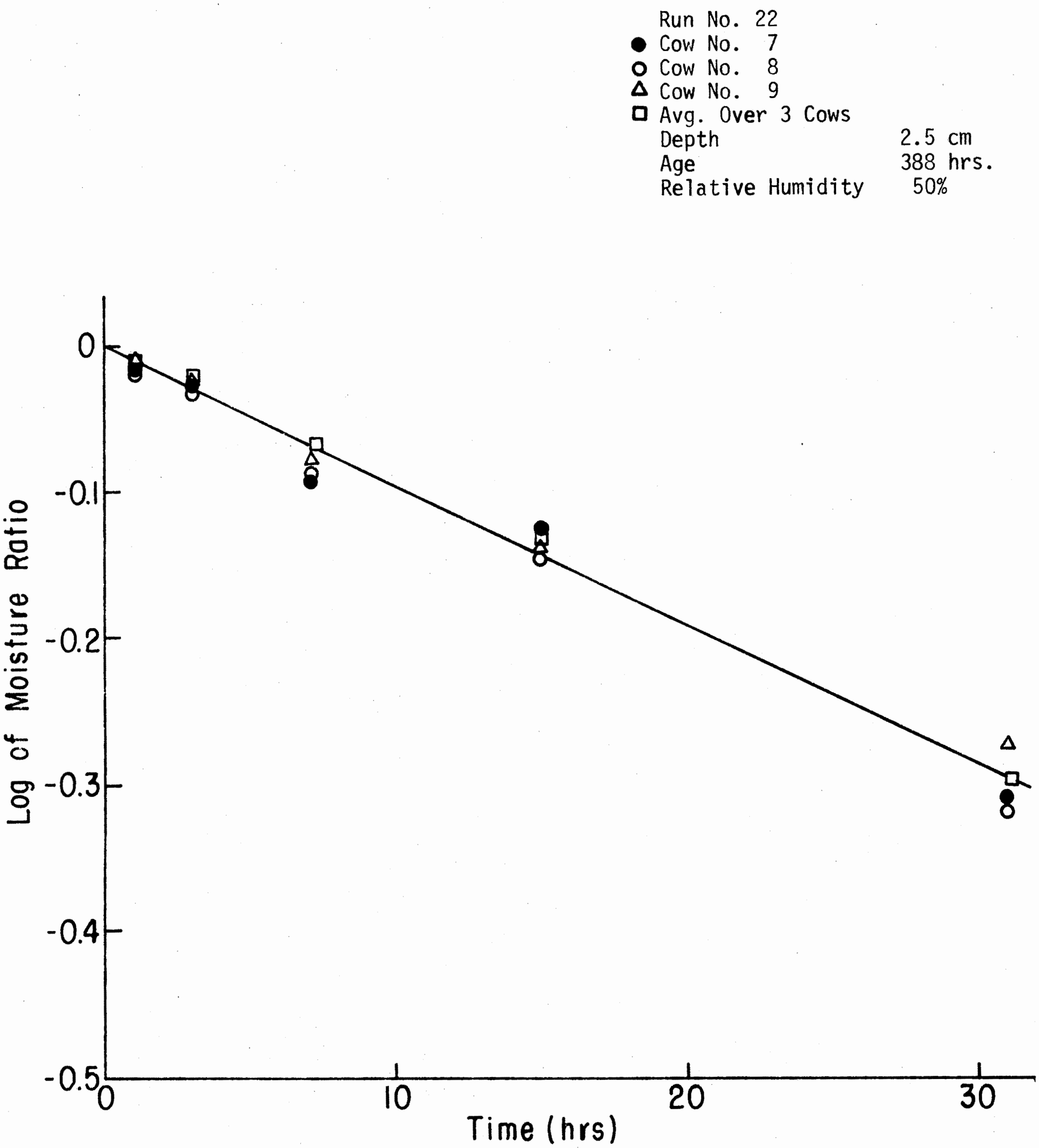


Figure 15. Regression Line of LG-MR as a Function of Drying Time for Run No. 22, Replicate No. 3

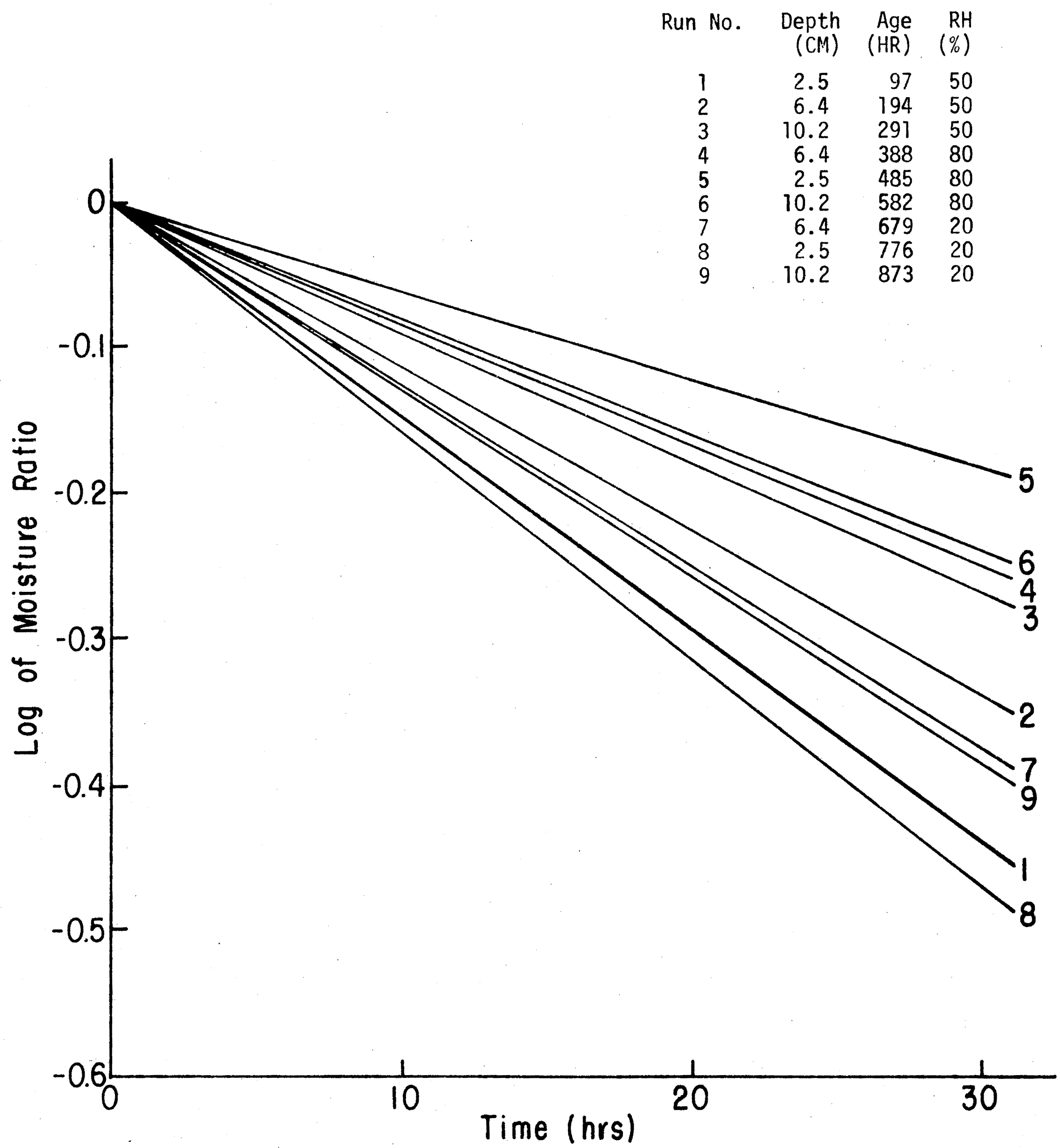


Figure 16. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Replicate No. 1

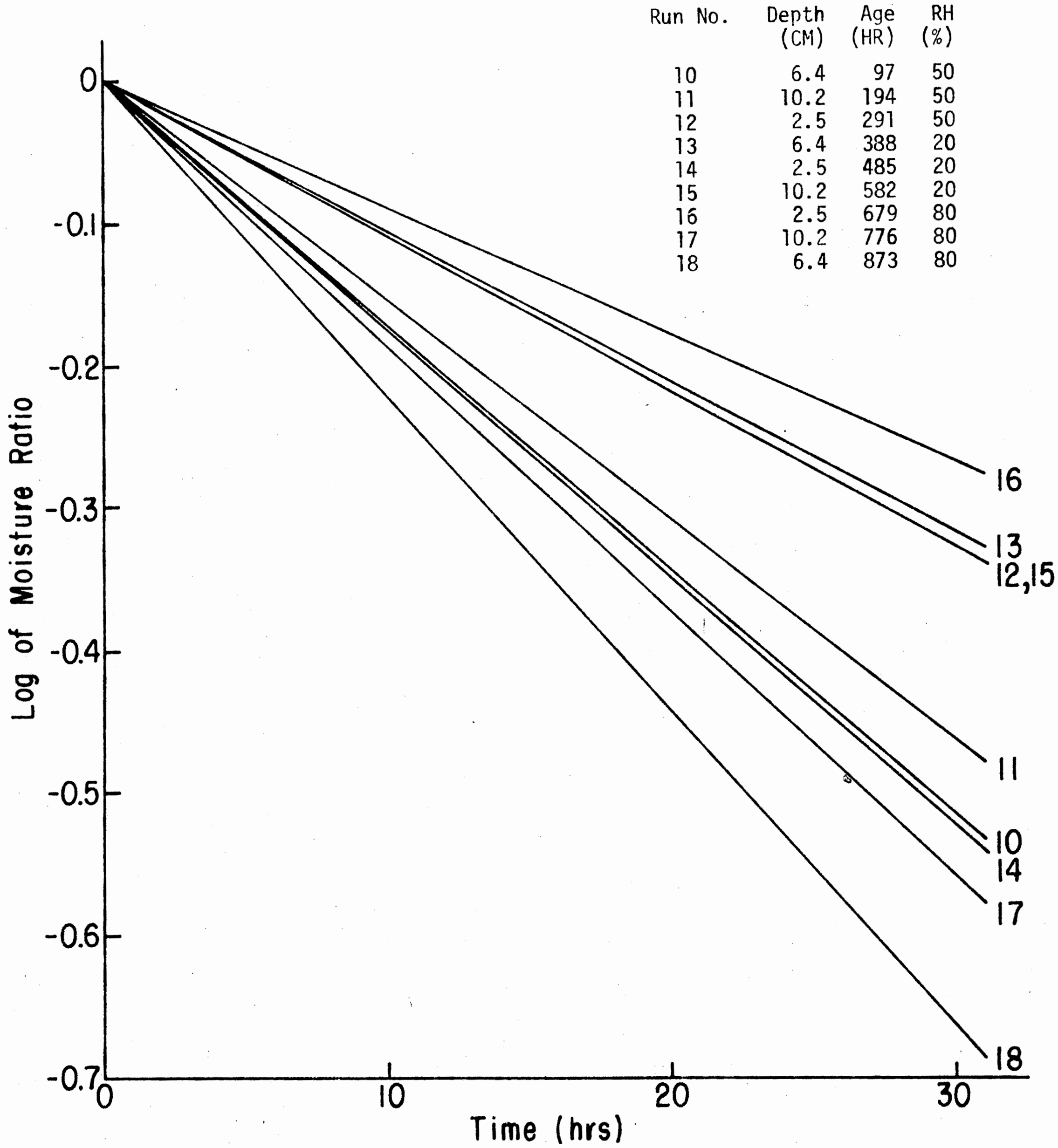


Figure 17. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Replicate No. 2

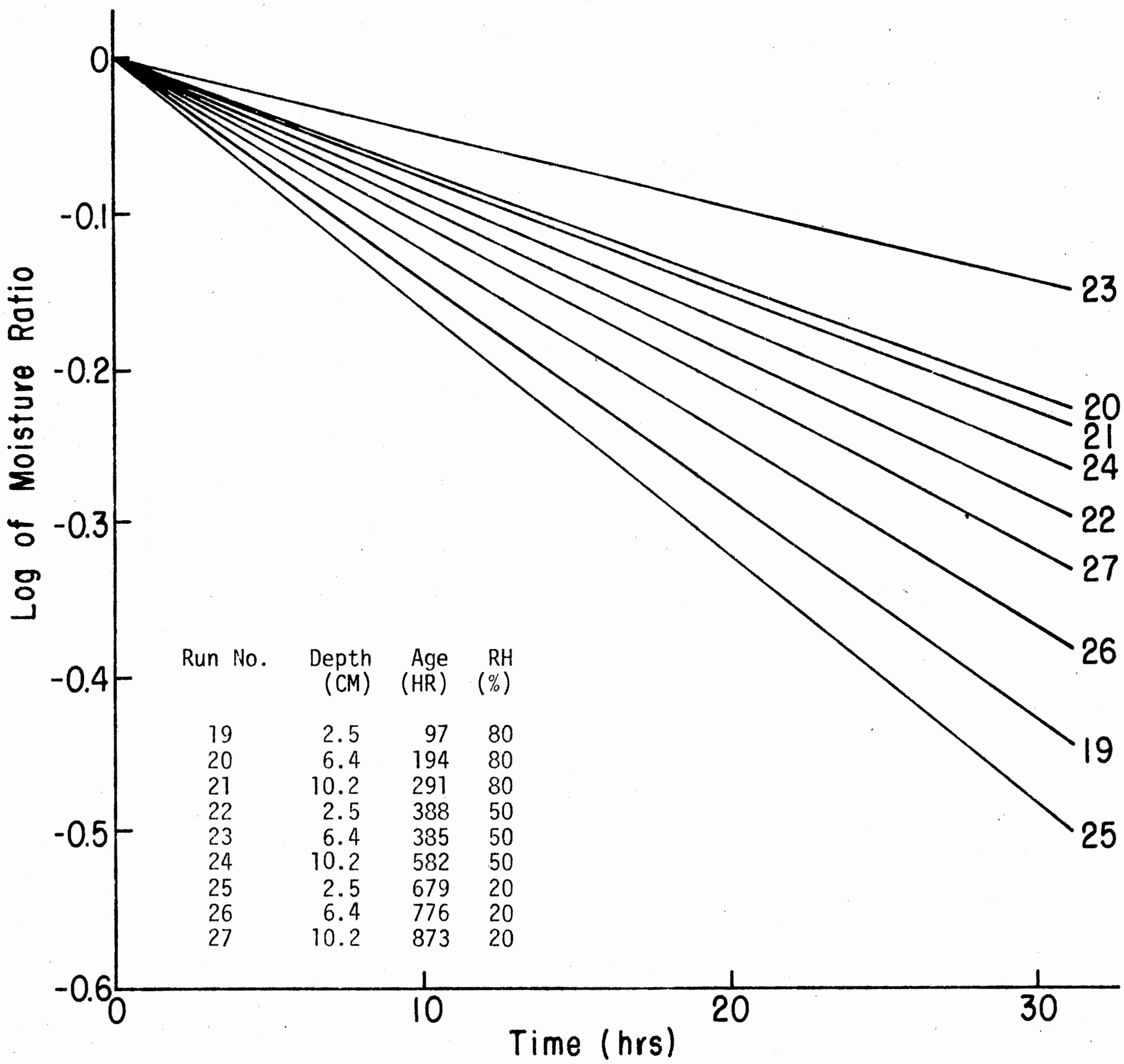


Figure 18. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Replicate No. 3

of the graphs of the log of moisture ratio versus drying time. All the slopes of the graphs of Figures 16, 17, and 18 tend to suggest that the log of moisture ratio decreases linearly in drying time.

By virtue of the definition of moisture ratio, all the graphs of log of moisture ratio versus drying time (hours) were forced through zero.

Effect of Depth

Because of the confounding nature of the variable age, it was only possible to look at the effect of depth on the rate of drying of CPC at certain age locations within relative humidity 20% and 50%. With respect to the 20% relative humidity, age locations are 679 and 776 hours, respectively, for depths 2.5 cm and 6.4 cm. Whereas for the 50% relative humidity, age locations are 97, 194 and 291 hours, respectively. The change in the rate of drying within the 97th hour was compared for depth of 2.5 cm and 6.4 cm; that for the 194th hour was compared for depth of 2.5 cm and 10.2 cm. The same type of comparison was made for the 291st hour for 2.5 cm and 10.2 cm, respectively.

The primary purpose of computer programme No. 5 is to perform an ANOVA on the rates of drying of CPC values with replication, age of material and number of cows as classes. In effect, values for overall means for each of the 27 runs for the 3 replications were generated. Each of these overall mean values is really an appropriate average value of the rate of drying of CPC. Other values utilized from this programme are on experimental error and LSD at the 5% level. The experimental error is used to test for significance in linear and quadratic effects when performing contrasts between the change of the rate of drying of

CPC for specific runs.

The LSD at the 5% level is utilized as means of a test for the difference between two mean rates of drying of CPC values. This difference in the relevant two rates of drying of CPC values is really a measure of the change in the rate of drying of CPC. This difference is expressed as a percentage based upon the smaller of the two rates of drying of CPC.

It is extremely important to note that this method or the approach to make contrasts on the rate of drying of CPC values is only valid if the interval or spacing between each relevant observation is of the same magnitude.

It is obvious that the approach utilizing the method of analysis as was briefly outlined in computer programme No. 5 is a hand technique. The fact that computer programme No. 5 gives the magnitude as well as the type of change existing between two relevant rates of drying of CPC values, it does not generate an equation for such a change.

So in this context, computer programme No. 6 was designed specifically to generate the equation for such a change as well as to perform the contrast between the change in the two relevant rates of drying of CPC, irrespective of the spacing between the observations.

It is also essential to point out that another design feature of this program is to specifically compare the change in the rate of drying of CPC over depth with the pertinent age and relative humidity held constant. This programme also checks the significant difference between two rates of drying of CPC values as obtained from the LSD test from computer programme No. 5.

This computer programme was not designed to look at quadratic features of contrasting since there are only two observations in each comparison test.

Effect of Depth at 20% Relative Humidity

Figure 19 essentially displayed the pictorial representation of plotted results of experimental runs Nos. 07, 08, 25 and 26, respectively.

Upon comparing runs Nos. 8 and 26 for 2.5 cm and 6.4 cm depths, the graphs for the rate of drying indicates that the samples of CPC for the 2.5 cm depth dries faster than those for the 6.4 cm depth. Such a change in the rate of drying between these two depths is 29.9% and is significant at LSD (0.05). When confronted with the question as to the type of change in the rate of drying of CPC at this period, it was found that it is linear in nature. Since such a change is linear, the specific equation describing this change in the rate of drying of CPC during this period of drying is

$$K_1 = -1.8145 \times 10^{-2} + 9.49 \times 10^{-6} D \qquad [20]$$

This equation does not account for 10.4% of the total sums of squares associated with the variation in the change in rate of drying of CPC associated for this period.

Figure 20 displays a way to perceive the linear change in the rate of drying of CPC as a function of depth of CPC. It also shows that all values for the change in the rate of drying of CPC during this period as indicated by the relevant specific equation falls well within the end limits of the general equation. The fact that this specific

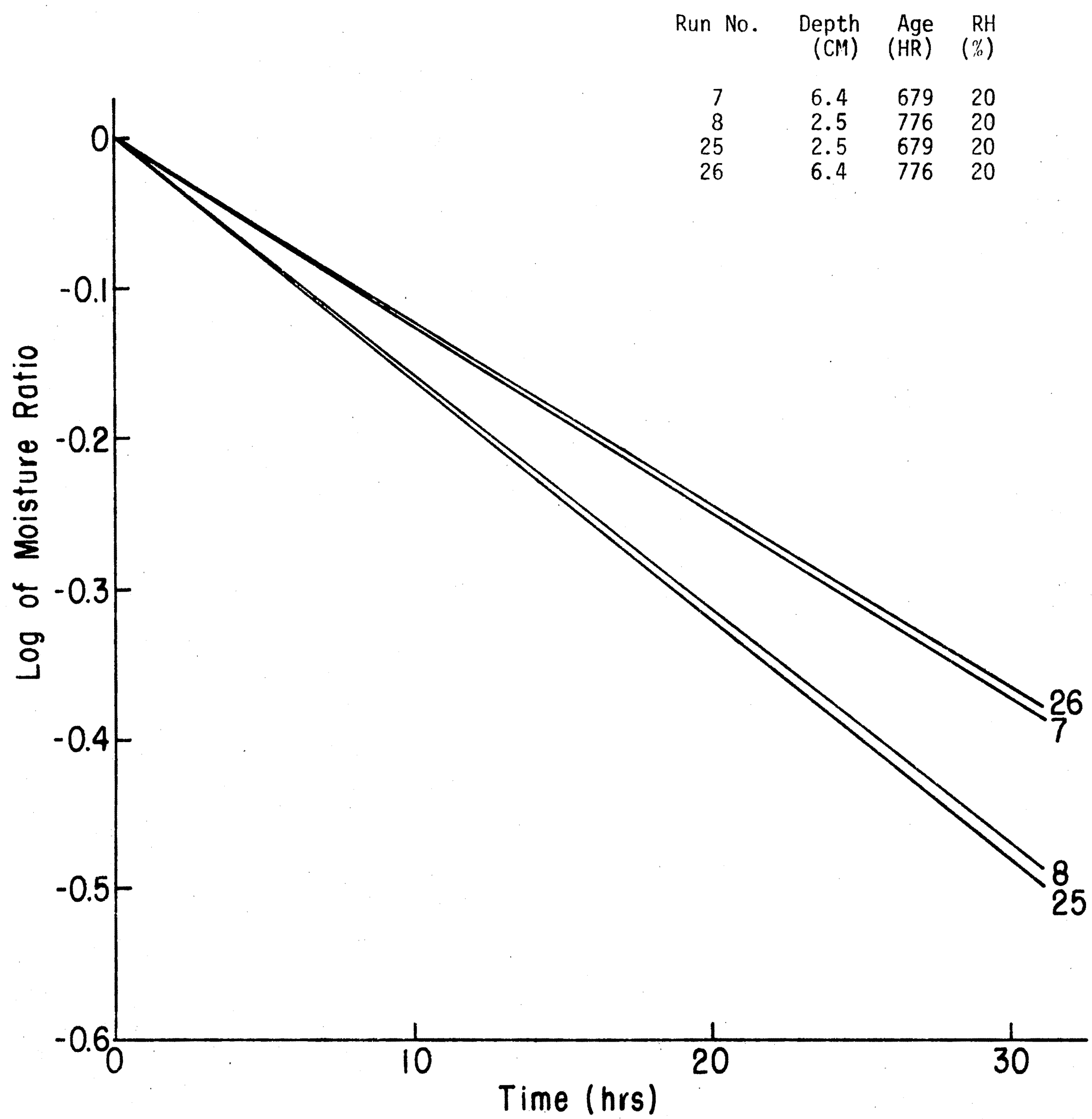


Figure 19. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 20%

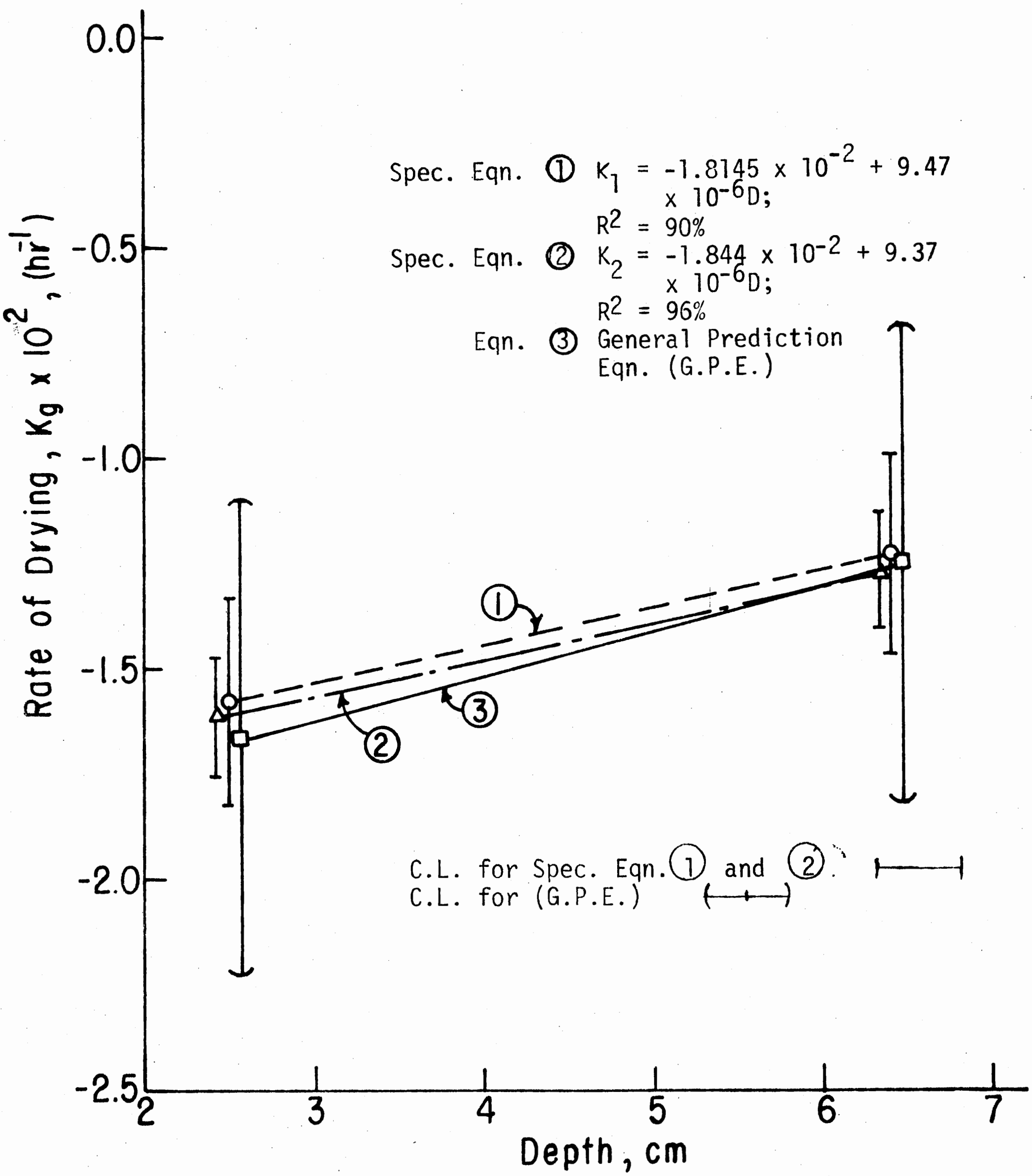


Figure 20. Rate of Drying of CPC as a Function of Depth for Relative Humidity of 20% and Ages of 697 and 776 Hrs.

equation falling well within the limits (C.L.) of the general equation suggests that the relevant specific equation is sound enough to estimate the change in rate of drying of CPC for this period and other stipulated conditions. Such conditions are tabulated in Table II.

The difference in the rate of drying between runs Nos. 07 and 25 for depths 6.4 cm and 2.5 cm, respectively, and fixed age of 679 hours is 28.6%. This difference is significant at LSD (0.05). The difference essentially tends to indicate that the samples of depth of 2.5 cm dried faster than that for 6.4 cm. The type of change in the rate of drying of CPC here is linear using the procedure outlined by computer programme No. 6 for linear contrasting. Figure 20 also shows plot of rates of drying of CPC versus depth for both the general equation and the specific equation for the relevant age location of 679 hours. The specific equation is

$$K_2 = -1.844 \times 10^{-2} \times 9.37 \times 10^{-6} D \qquad [21]$$

3.8% of unexplained sums of squares associated with the variation in the change in the rate of drying of CPC is coupled to this equation.

This equation is considered sound since it falls in close proximity to the general equation, for the constraints associated with age location of 679 hours. Such constraints are seen in Table II. So in effect, Figure 17 also indicates that for the given constraints for the depths considered, the shallow depth samples of CPC dried at a faster rate than those for the medium depth for the fast drying potential air.

Effect of Depth at 50% Relative Humidity

Figure 21 essentially shows the variations associated in the rates of drying for CPC for 50% relative humidity at ages 97, 194, and 291

TABLE II

SUMMARY OF ANALYSIS OF DATA

Run No.	Depth (CM)	RH (%)	Age of CPC (HRS)	Negative Rate of Drying of CPC ($HR^{-1} \times 10^{-2}$)	Change in Rate of Drying of CPC ($HR^{-1} \times 10^{-3}$)	|%| Change in Rate of Drying of CPC	Value of LSD (0.05) $\times 10^{-3}$	Comment on Change in Rate of Drying of CPC	Type of Change in Rate of Drying of CPC	Equation of Change in the Rate of Drying of CPC
09	10.2	20	873	1.28009	2.1	19.9	3.046	No		
15	10.2	20	582	1.06773						
09	10.2	20	873	1.28009	2.21	20.91	3.046	No		
27	10.2	20	873	1.05876						
15	10.2	20	582	1.06773	0.089	0.85	3.046	No		
27	10.2	20	873	1.05876						
07	6.4	20	679	1.24898	2.0	19.1	3.046	No		
13	6.4	20	388	1.04886						
07	6.4	20	679	1.24898	0.37	3.1	3.046	No		
26	6.4	20	776	1.21159						
13	6.4	20	388	1.04886	1.63	15.52	3.046	No		
26	6.4	20	776	1.21159						

TABLE II (Continued)

Run No.	Depth (CM)	RH (%)	Age of CPC (HRS)	Negative Rate of Drying of CPC (HR^{-1} X 10^{-2})	Change in Rate of Drying of CPC (HR^{-1} X 10^{-3})	|%| Change in Rate of Drying of CPC	Value of LSD (0.05) X 10^{-3}	Comment on Change in Rate of Drying of CPC	Type of Change in Rate of Drying of CPC	Equation of Change in the Rate of Drying of CPC
08	2.5	20	776	1.57335	1.70	10.97	3.046	No		
14	2.5	20	485	1.74579						
08	2.5	20	776	1.57335	0.33	2.07	3.046	No		
25	2.5	20	679	1.60598						
14	2.5	20	485	1.74579	1.40	8.7	3.046	No		
25	2.5	20	679	1.60598						
01	2.5	50	97	1.45764	3.74	34.5	3.046	Yes		
12	2.5	50	291	1.08387						
01	2.5	50	97	1.45764	4.97	51.9	3.046	Yes	Linear	$K_6=-1.617x10^{-2}+1.741 x10^{-5}(Ag)$
22	2.5	50	388	0.95994						
12	2.5	50	291	1.08387	1.23	12.9	3.046	No		
22	2.5	50	388	0.95994						
02	6.4	50	194	1.13956	5.73	50.2	3.046	Yes		
10	6.4	50	97	1.17127						

TABLE II (Continued)

Run No.	Depth (CM)	RH (%)	Age of CPC (HRS)	Negative Rate of Drying of CPC (HR^{-1} X 10^{-2})	Change in Rate of Drying of CPC (HR^{-1} X 10^{-3})	|%| Change in Rate of Drying of CPC	Value of LSD (0.05) X 10^{-3}	Comment on Change in Rate of Drying of CPC	Type of Change in Rate of Drying of CPC	Equation of Change in the Rate of Drying of CPC
02	6.4	50	194	1.13954	6.68	141.7	3.046	Yes	Linear	$K_7 = -1.8814 \times 10^{-2} + 2.99 \times 10^{-5} (Ag)$
23	6.4	50	485	0.47155						
10	6.4	50	97	1.17127	12.4	263.0	3.046	Yes		
23	6.4	50	485	0.47155						
24	10.2	50	582	.86457	0.343	0.89	3.046	No		
03	10.2	50	291	0.89883						
24	10.2	50	582	0.80457	6.75	78.13	3.046	Yes	Constant	
11	10.2	50	194	1.5401						
03	10.2	50	291	0.89883	6.4	73.4	3.046	Yes		
11	10.2	50	194	1.5401						
05	2.5	80	485	0.61403	3.0	30.96	3.046	Yes		
16	2.5	80	679	0.88942						

TABLE II (Continued)

Run No.	Depth (CM)	RH (%)	Age of CPC (HRS)	Negative Rate of Drying of CPC (HR^{-1} X 10^{-2})	Change in Rate of Drying of CPC (HR^{-1} X 10^{-3})	$\lvert\%\rvert$ Change in Rate of Drying of CPC	Value of LSD (0.05) X 10^{-3}	Comment on Change in Rate of Drying of CPC	Type of Change in Rate of Drying of CPC	Equation of Change in the Rate of Drying of CPC
05	2.5	80	485	0.61403	8.1	131.7	3.046	Yes	Quadratic	$K_8=-1.9077x10^{-2}+5.87x10^{-5}(Ag)-6.0x10^{-8}(Ag)^2$
19	2.5	80	97	1.42244						
16	2.5	80	679	0.88942	5.33	59.9	3.046	Yes		
19	2.5	80	97	1.42244						
04	6.4	80	388	0.83705	13.38	164.38	3.046	Yes		
18	6.4	80	873	2.21306						
04	6.4	80	388	0.83705	1.1	15.5	3.046	No	Quadratic	$K_9=-8.6305x10^{-3}-3.0x10^{-8}(Ag)^2$
20	6.4	80	194	0.72485						
18	6.4	80	873	2.21306	14.88	205.3	3.046	Yes		
20	6.4	80	194	0.72485						
06	10.2	80	582	0.79638	10.6	133.7	3.046	Yes		
17	10.2	80	776	1.86114						
06	10.2	80	683	0.79648	0.34	4.56	3.046	No	Quadratic	$K_{10}=-2.604x10^{-2}+9.553x10^{-5}(Ag)-1.1x10^{-7}(Ag)^2$
21	10.2	80	291	0.76247						

TABLE II (Continued)

Run No.	Depth (CM)	RH (%)	Age of CPC (HRS)	Negative Rate of Drying of CPC (HR^{-1} X 10^{-2})	Change in Rate of Drying of CPC (HR^{-1} X 10^{-3})	1%1 Change in Rate of Drying of CPC	Value of LSD (0.05) X 10^{-3}	Comment on Change in Rate of Drying of CPC	Type of Change in Rate of Drying of CPC	Equation of Change in the Rate of Drying of CPC
17	10.2	80	776	1.86114	11.0	144.1	3.046	Yes		
21	10.2	80	291	0.76247						
08	2.5	20	776	1.57335	3.6	29.85	3.046	Yes	Linear	$K_1 = -1.815x10^{-2} + 9.49x10^{-6}$ (D)
26	6.4	20	776	1.211595						
25	2.5	20	679	1.60598	3.6	28.58	3.046	Yes	Linear	$K_2 = -1.84x10^{-2} + 9.37x10^{-6}$ (D)
07	6.4	20	679	1.24898						
01	2.5	50	97	1.45764	2.55	17.5	3.046	No		
10	6.4	50	97	1.71269						
12	2.5	50	291	1.8388	1.85	20.59	3.046	No		
03	10.2	50	291	0.89883						
02	6.4	50	194	1.13954	4.01	35.15	3.046	Yes		
11	10.2	50	194	1.5401						
01	2.5	50	97	1.45764	0.35	2.47	3.046	No		
19	2.5	80	97	1.42244						

TABLE II (Continued)

Run No.	Depth (CM)	RH (%)	Age of CPC (HRS)	Negative Rate of Drying of CPC (HR^{-1} X 10^{-2})	Change in Rate of Drying of CPC (HR^{-1} X 10^{-3})	|%| Change in Rate of Drying of CPC	Value of LSD (0.05) X 10^{-3}	Comment on Change in Rate of Drying of CPC	Type of Change in Rate of Drying of CPC	Equation of Change in the Rate of Drying of CPC
25	2.5	20	679	1.60598	7.16	80.56	3.046	Yes	Linear	$K_4=-1.8307x10^{-2}+1.382 x10^{-4}(RH)$
16	2.5	80	679	0.88942						
14	2.5	20	485	1.74579	11.32	184.32	3.046	Yes	Linear	$K_5=-2.123x10^{-2}+1.886 x10^{-4}(RH)$
05	2.5	80	485	0.614031						
13	6.4	20	388	1.04886	2.12	25.3	3.046	No		
04	6.4	80	388	0.83705						
02	6.4	50	194	1.13954	4.15	57.2	3.046	Yes	Linear	$K_3=-1.8307x10^{-2}+1.3823 x10^{-4}(RH)$
20	6.4	80	194	0.72485						
03	10.2	50	291	0.89883	1.35	17.81	3.046	No		
21	10.2	80	291	0.76247						
15	10.2	20	582	1.06773	2.71	34.0	3.046	No		
06	10.2	80	582	0.796384						
15	10.2	20	582	1.06773	5.38	50.41	3.046	Yes		
25	10.2	80	582	1.60598						

TABLE II (Continued)

Run No.	Depth (CM)	RH (%)	Age of CPC (HRS)	Negative Rate of Drying of CPC (HR^{-1} X 10^{-2})	Change in Rate of Drying of CPC (HR^{-1} X 10^{-3})	|%| Change in Rate of Drying of CPC	Value of LSD (0.05) X 10^{-3}	Comment on Change in Rate of Drying of CPC	Type of Change in Rate of Drying of CPC	Equation of Change in the Rate of Drying of CPC
06	10.2	50	582	0.86475	0.68	8.56	3.040	No		
24	10.2	80	582	0.79638						

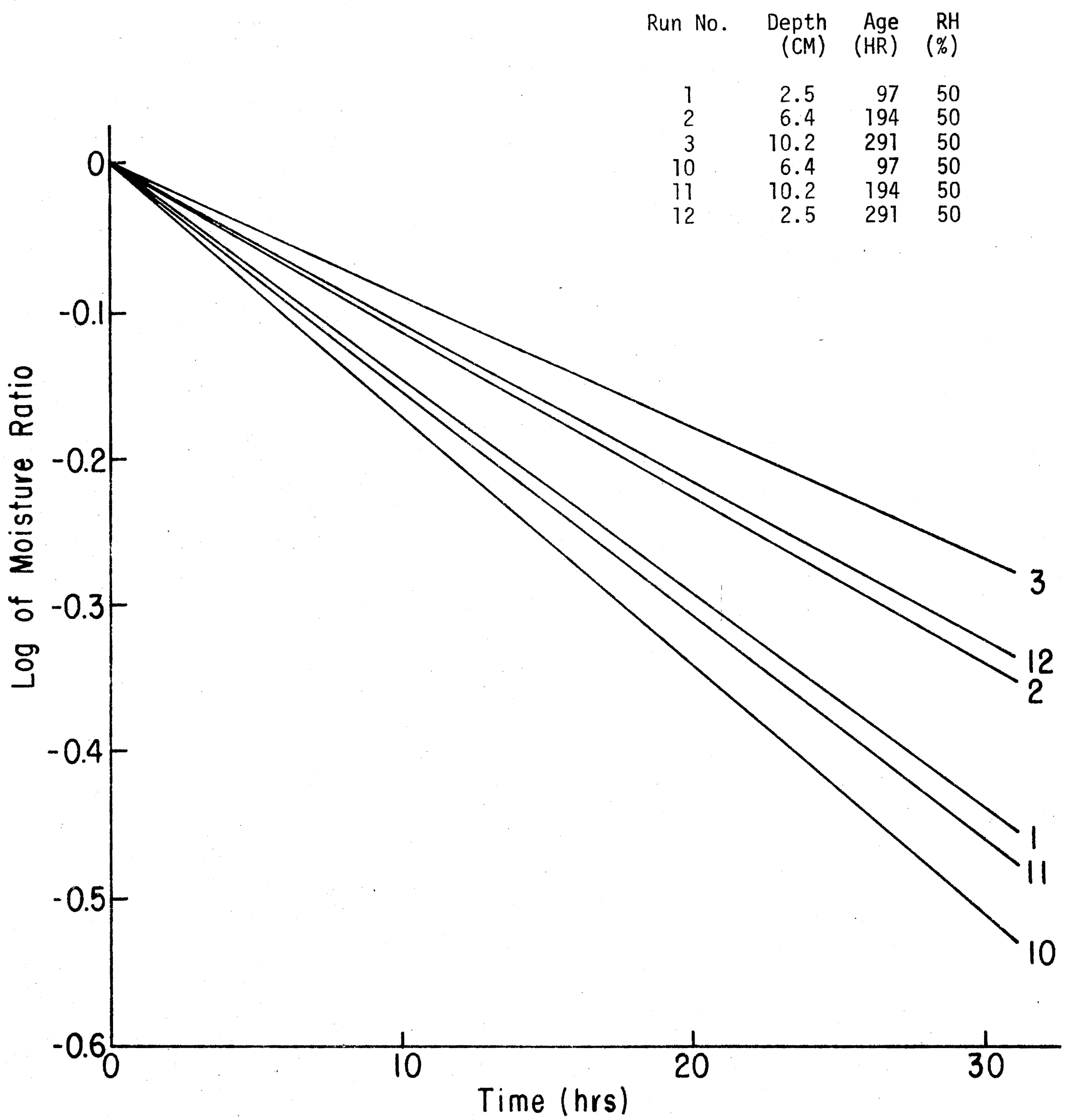


Figure 21. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 50%

hours for runs 01, 02, 03, 10, 11, and 12.

Runs No. 1 and No. 10 are for age location of 97 hours and depths 2.5 and 6.4, respectively. The difference between the rates of drying of CPC for samples associated with the 2.5 cm depth and those for the 6.4 cm depth is not significant at LSD 0.05. Although the magnitude of difference is 17.5%, when the two relevant drying rates were compared, it would appear from both Figures 21 and 22 that the 2.5 cm dried faster than the 6.4 cm. Within the constraints of the factors associated with this investigation such a difference is very small and the statistical test prevails.

Upon comparing depths 2.5 cm and 10.2 cm of runs Nos. 03 and 12 for age location 291 hours, there was no statistically significant differences existing between the rates of drying of CPC for samples associated with the 2.5 cm depth and those for the 10.2 cm. From both Figures 21 and 22 there seem to exist a small difference between the rates of drying of CPC for 6.4 cm and the 2.5 cm. The samples associated with 2.5 cm depth dried faster than the 10.2 cm. The magnitude of this variation is 20.6% and was obtained from comparing the overall mean drying rate values for samples from both of these relevant depths.

In effect, this change in the rate of drying of CPC between depths 2.5 cm and 10.2 cm is small and both rates of drying of CPC can be treated as the same.

With respect to the comparison at age location 194 hours for runs No. 02 and No. 11 for samples associated with the 6.4 cm and 10.2 cm depths, both Figures 21 and 22 indicate that an extremely small difference in drying rate exists between samples of CPC taken at these depths. This difference is insignificant at an LSD (0.05), although

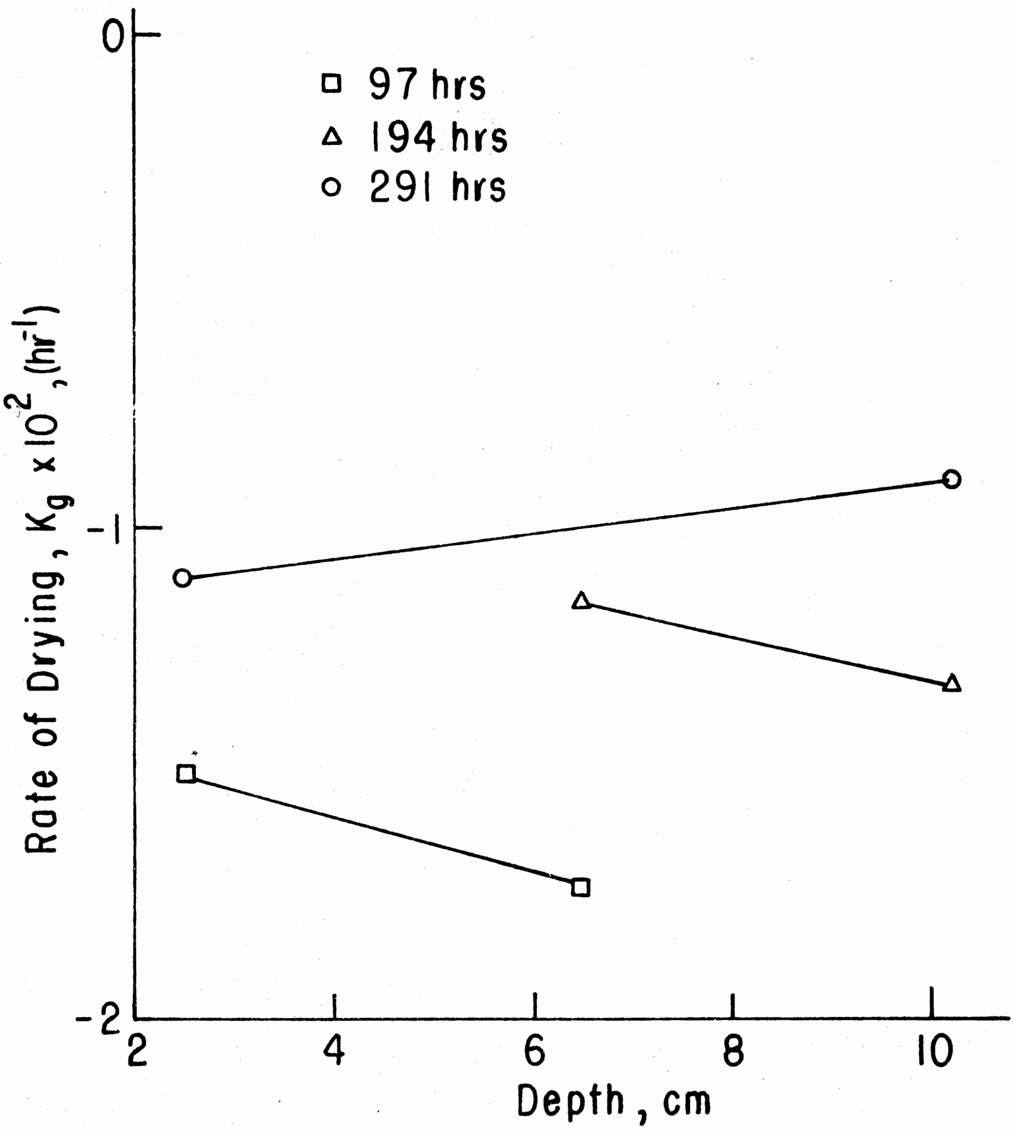


Figure 22. Rate of Drying of CPC as a Function of Depth for Relative Humidity of 50% and Ages of 97, 194 and 291 Hrs.

the magnitude of the variations 14.08%. The constraints associated with runs Nos. 02 and 11 is shown on Table II.

Effect of Relative Humidity

It was possible to look at the effect of relative humidity on the change in rate of drying of CPC at ages 291 hours and 582 hours for depth 10.2 cm. The effects of 20, 50 and 80% relative humidity were investigated for age location of 582 hours and depth of 10.2 cm; whereas for the age location of 291 hours only the effects of 50% and 80% relative humidity could be analyzed.

With respect to the 2.54 cm depth, it was also possible to hold age locations, 97, 485, 679 hours, respectively, fixed and analyze the effect of relative humidity on the change in rate of drying of CPC. For age location of 97 hours, relative humidities of 50% and 80% were compared. With age location at 485 hours, relative humidities were compared for age location of 679 hours. No other analysis was made with respect to the effect of relative humidity on the change in the rate of drying of CPC as a result of the variable age confounded over depth and relative humidity in many experimental cells.

The use of computer programs Nos. 5 and 7 aided considerably in calculating the overall mean rate of drying of CPC for each run. Computer programme No. 7 was designed specifically to perform the necessary calculations on linear and quadratic contrasting on the change in rate of drying of CPC, as the pertinent age and depth held constant, over the relative humidities. A check on the values obtained by the hand calculated values associated with comptuer programme No. 5 can be considered another function of this computer programme.

Similar to computer programmes Nos. 6 and 8, it will generate a least square regression equation to describe the linear or quadratic change in the change in the rate of drying of CPC.

Effect of Relative Humidity for a Depth of 10.2 cm

Figure 23 shows the rate of drying curves for runs Nos. 03, 06, 15, 21, and 24.

For a constant age location of 291 hours, there is no change in the rate of drying of CPC in the samples investigated for relative humidities 50% and 80%, respectively. Appropriate rún Nos. were 03 and 21, respectively. Upon comparing the overall mean values for the rates of drying of CPC for relative humidities of 50% and 80%, the samples associated with the 50% relative humidity seem to dry faster than those associated for the 80% relative humidity by a magnitude of 17.8%. Such a difference is not statistically significant at LSD (0.05).

With respect to the change in the rate of drying of CPC for 20% and 80% relative humidities for a fixed age location of 582 hours, there is a 34.0% variation in the rate of drying for samples associated therein when the average rates of drying of CPC are compared. The samples associated with the 20% relative humidity for run No. 06 seemed to dry at a faster rate than those for the 80% relative humidity level for run No. 15, as indicated by Figures 23 and 24. This variation even though relatively large is surprisingly not statistically significant at LSD (0.05).

Figures 23 and 24 suggest that there is some degree of variation in the rates of drying for samples of CPC dried at 20% and 50% relative

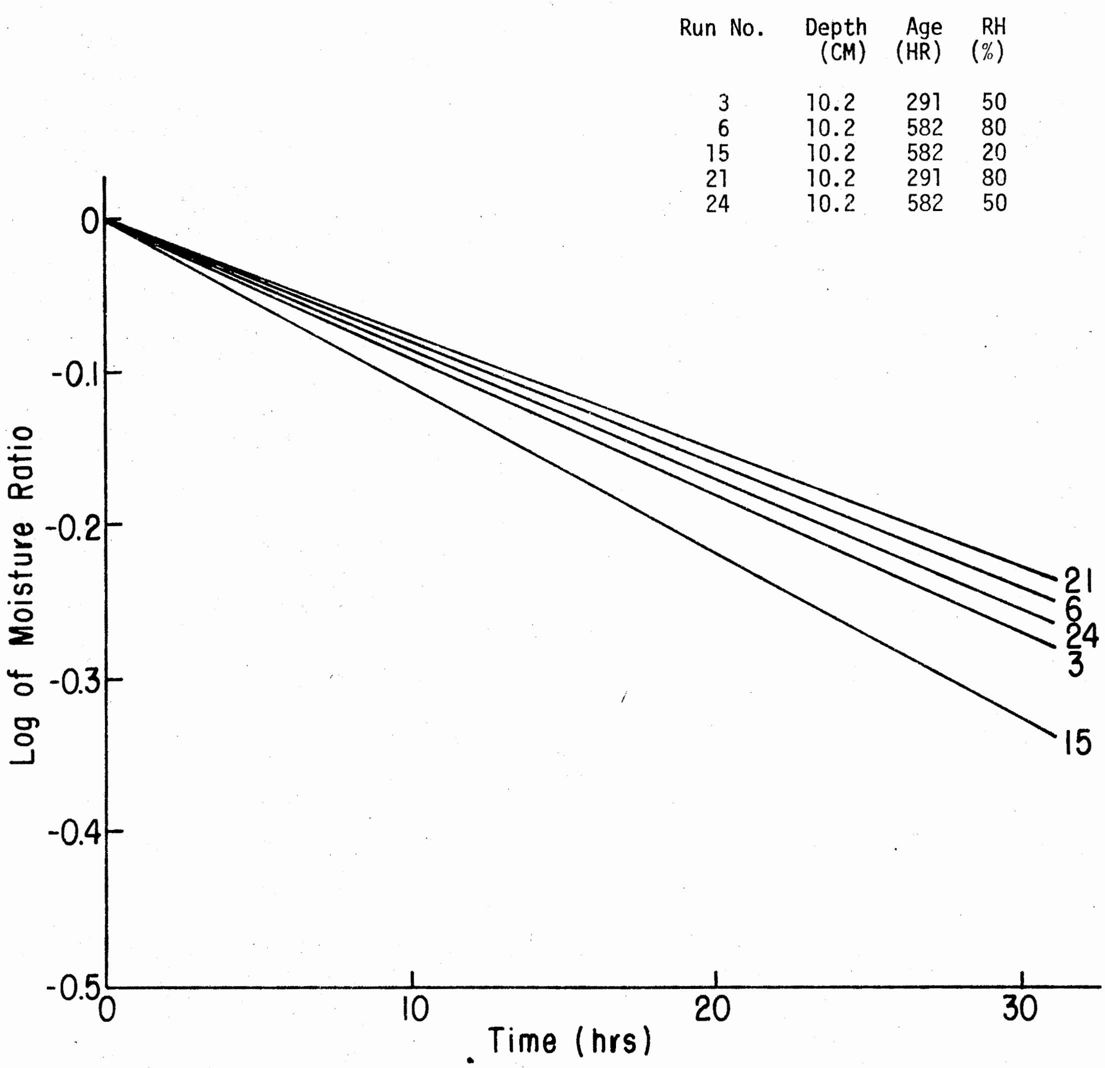


Figure 23. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Depth of 10.2 cm

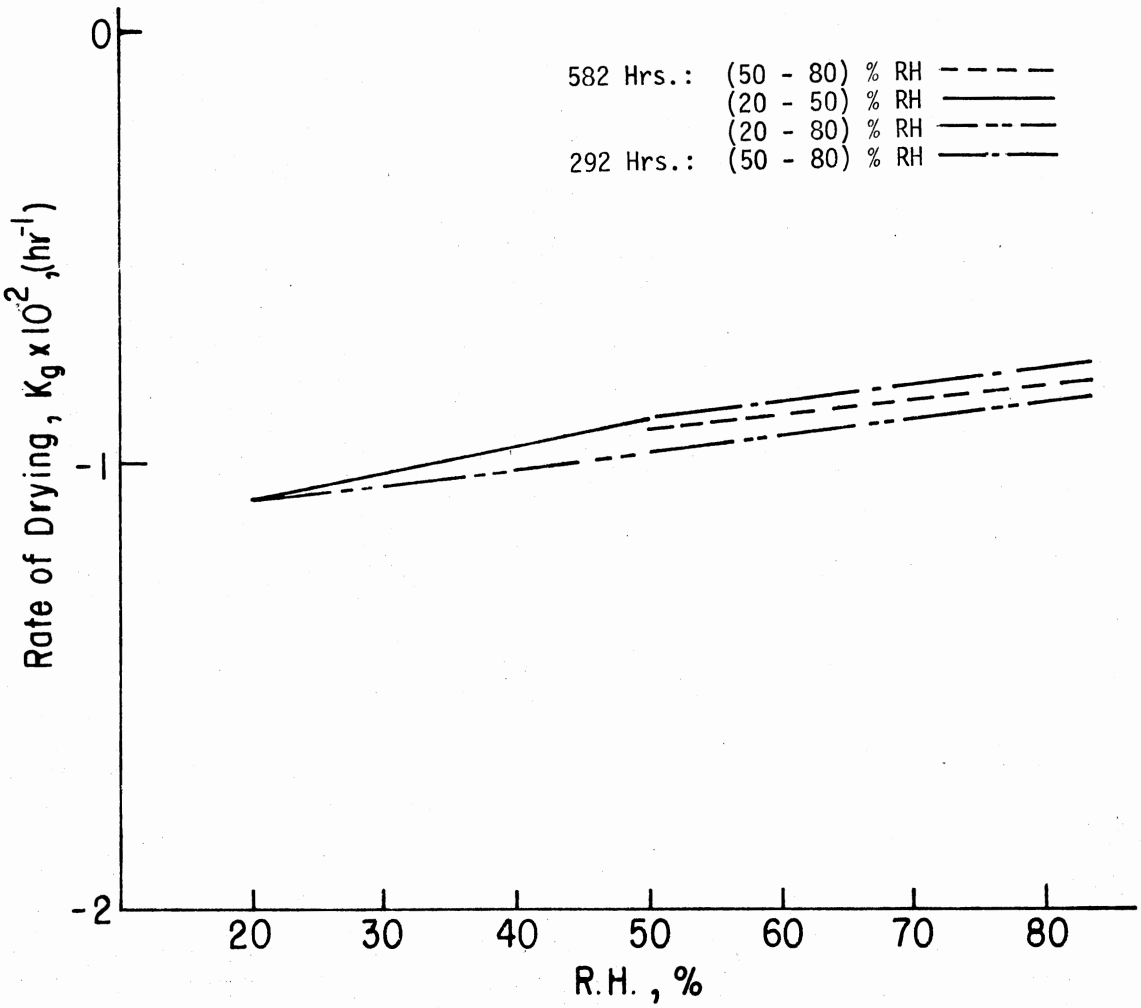


Figure 24. Rate of Drying of CPC as a Function of Relative Humidity for Depth of 10.2 cm and Ages of 291 and 582 Hrs.

humidities, respectively. The respective run Nos. 15 and 24 are for age location 582 hours. The rate of drying of samples of CPC for the 20% relative humidities level, as indicated by run No. 15 on Figures 24 and 25, does seem to be higher than that for the 50% relative humidity level as indicated by run No. 24. Such a variation between these two rates of drying of CPC is, however, not statistically significant at LSD (0.05).

Another comparison for the change in the rate of drying at the 582 hours age location is made at the 50% and 80% relative humidity levels for runs Nos. 24 and 06. The rate of drying for samples of CPC at relative humidity 80% is essentially the same as that for the 20% relative humidity. This claim is substantiated by the fact that no statistically significant difference exists between these two drying rates at LSD (0.05). There is, however, an 8.6% variation in the rates of drying between samples of CPC at these two levels of relative humidities. All other constraints associated with this analysis on the 10.2 cm level of depth, for the effect of relative humidity on the rate of drying for CPC, are shown on Table II.

Effect of Relative Humidity for a Depth of 6.4 cm

The 20% level of relative humidity is identified by run No. 13 while that for the 80% level of relative humidity by run No. 04. The change in the rate of drying for samples of CPC between the 20% and 80% levels of relative humidities is 25.3%, with the 20% level of relative humidity seeming to dry at a faster rate than the 80% level of relative humidity. Both Figures 25 and 26 seem to indicate a large change in

Run No.	Depth (CM)	Age (HR)	RH (%)
2	6.4	194	50
4	6.4	388	80
13	6.4	388	20
20	6.4	194	80

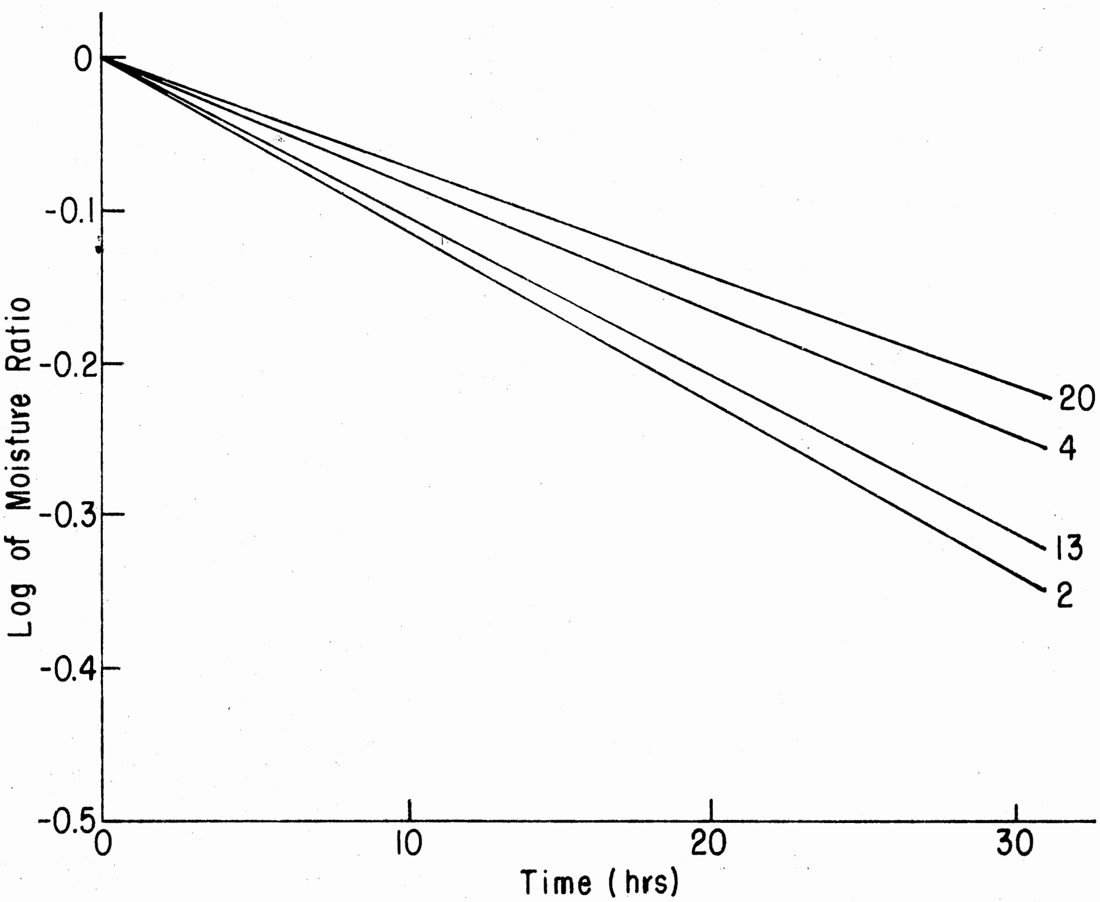


Figure 25. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Depth of 6.4 cm

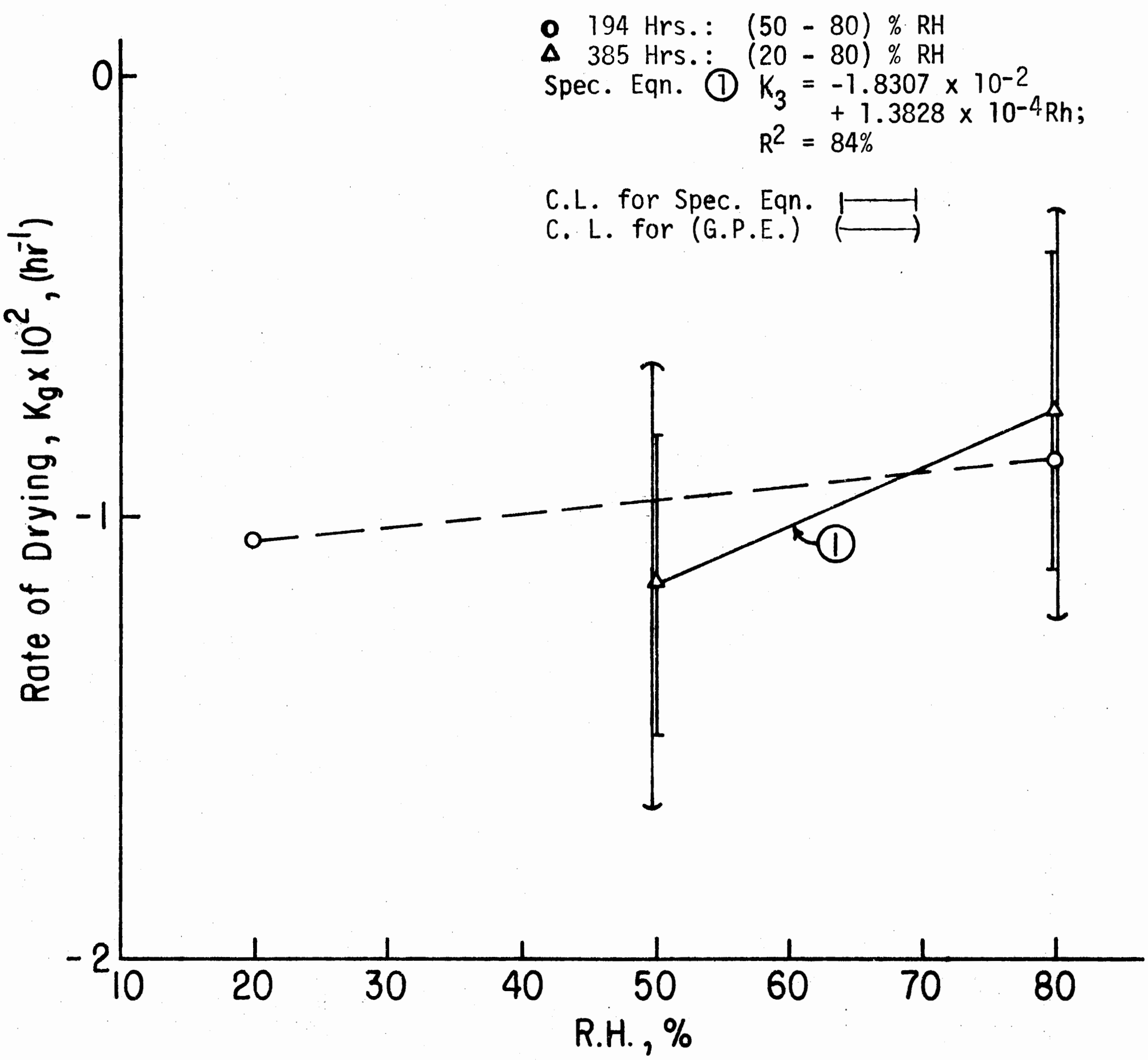


Figure 26. Rate of Drying of CPC as a Function of Relative Humidity for Depth of 6.4 cm and Ages of 194 and 388 Hrs.

the rate of drying between samples processed at the 20% and 80% level of relative humidities. This variation in the rates of drying between these two levels of relative humidity is not significant at the LSD (0.05) test for comparison of the mean rate of drying of samples of CPC at these two levels of relative humidity at the relevant age location and depth.

With respect to the change in the rates of drying of CPC for the 50% level of relative humidity and 80% level of relative humidity for age location of 194 hours, a large change in the drying rate resulted from the comparison of mean drying rate of samples of CPC. Run No. 02 is associated with the 50% level of relative humidity whereas run No. 20 is for the 80% level of relative humidity. The rate of drying of samples for the 50% level of relative humidity is much faster than that for the 80% level of relative humidity. The variation between the rates of drying for these two levels is 57.2% and is statistically significant at LSD (0.05). Figures 25 and 26 provide a good picture of this difference. The type of variation in these two drying rates is linear, and this is substantiated by fitting a least square regression equation between the values of drying rates at the above mentioned levels. The specific equation for the change in the rate of drying of samples of CPC from the 50% relative humidity to the 80% level of relative humidity for depth 6.4 cm and age location of 194 hours is

$$K_3 = -1.8307 \times 10^{-2} + 1.3823 \times 10^{-4} \text{ Rh} \qquad [22]$$

This specific equation [22] was not able to account for 16% of the total sums of squares. The other relevant variables involved in aiding the execution of this analysis on the 6.4 cm level of depth for the effect of relative humidity on the rate of drying for CPC is shown on

Table II.

Effect of Relative Humidity for
a Depth of 2.5 cm

Both the depth of 2.5 cm and the age location of 97 hours are held constant in order to compare relative humidity 50% and 80%, respectively. The relevant experimental run numbers are Nos. 01 and 19. The average change in the rate of drying for samples processed under these specific conditions is 2.47%. Such a difference is not statistically significant at LSD (0.05). The implication of this small change in the rate of drying for these samples essentially is that all these relevant samples dried at the same rate, at these two separate humidities. Figures 27 and 28 provide a picture for such an insignificant change.

Holding depth 2.5 cm as well as age location 697 hours constant, relative humidities 20% and 80% are compared for their effect on the change in the rate of drying of samples of CPC for those prescribed conditions. Upon comparing the overall mean drying rates values for these relevant samples, an 80.6% overall difference is observed. Run No. 25 is associated with the 20% level of relative humidity whereas run No. 16 is for the 80% level of relative humidity. Both Figures 27 and 28 provide a visual for this large variation in drying rates for samples of CPC investigated under these specific conditions. Samples of CPC dried at the 20% relative humidity did so at a much faster rate than those investigated at relative humidity 80%. This variation in drying rates for these two relative humidities is statistically significant at LSD (0.05), when the mean drying rates for relevant samples of CPC were compared. Upon making linear contrasting on this change in

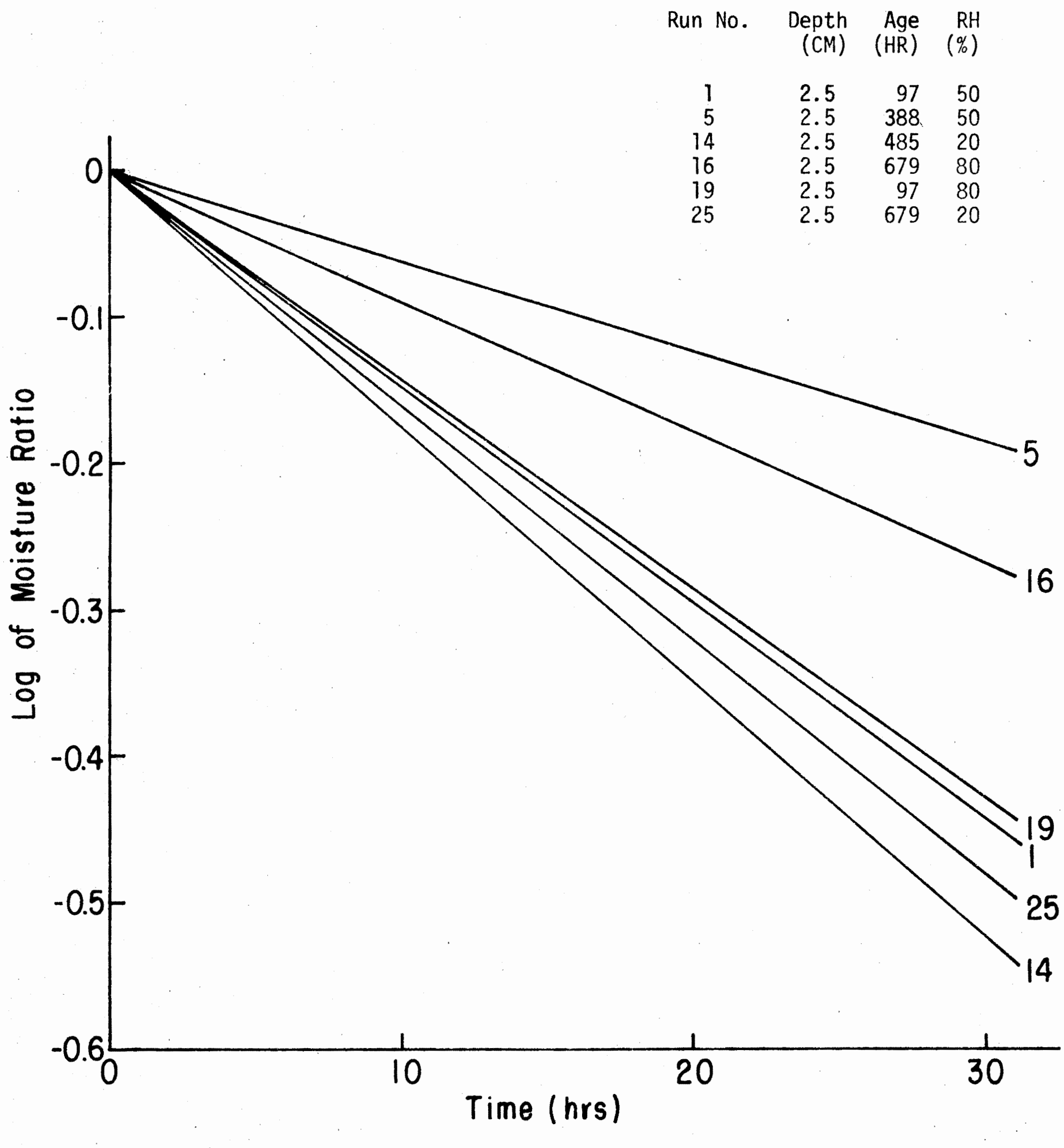


Figure 27. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Depth of 2.5 cm

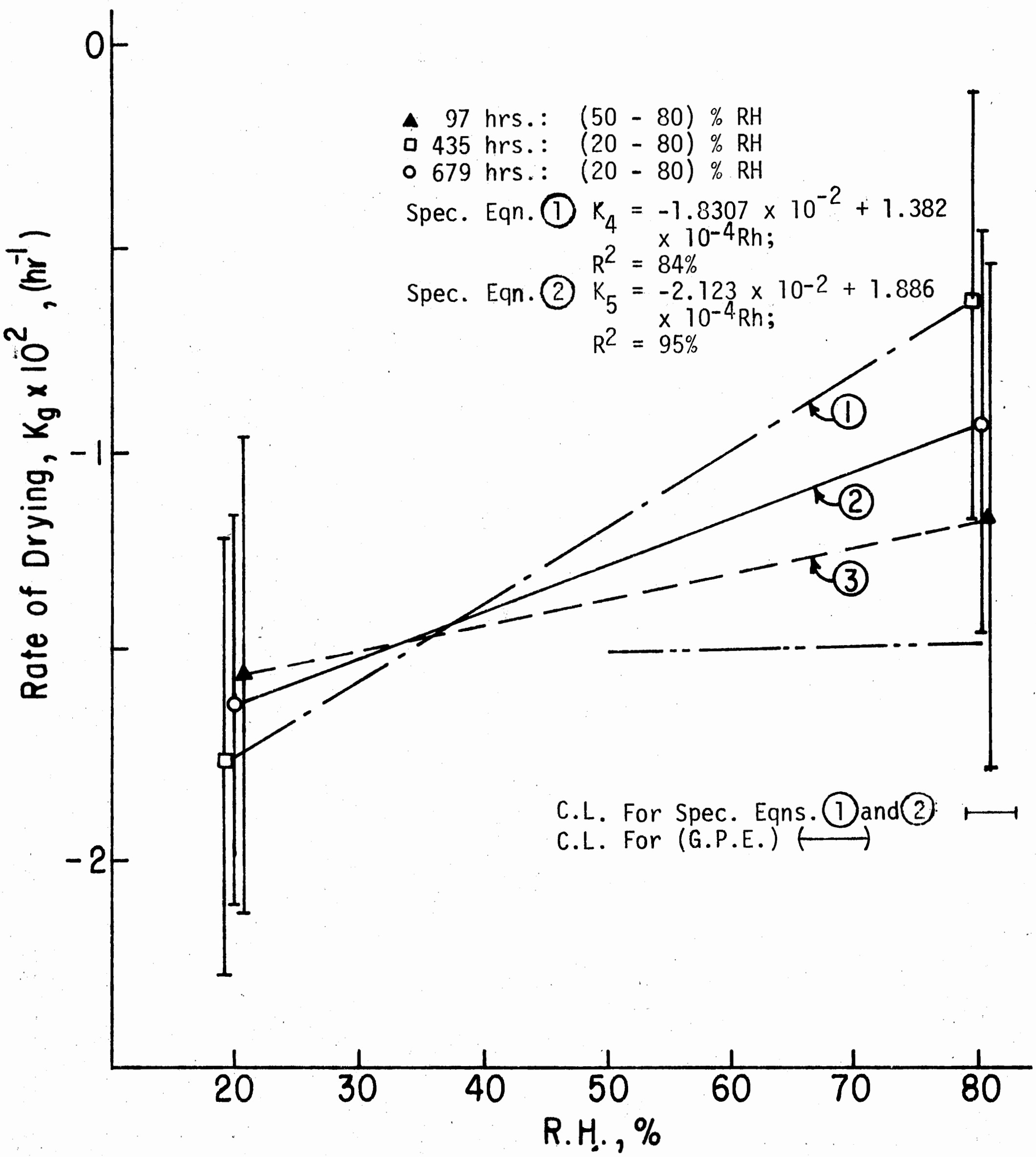


Figure 28. Rate of Drying of CPC as a Function of Relative Humidity for Depth of 2.5 cm and Ages of 97, 485 and 679 Hrs.

the rate of drying for samples of CPC which is 80%, a linear change resulted and effected the specific equation.

$$K_4 = -1.8307 \times 10^{-2} + 1.382 \times 10^{-4}\ Rh \qquad [23]$$

The regression coefficient which describes essentially how well the equation represents the data involved for this portion of the analysis is 83.7%. The limits of the end points of the graph of equation [23] fall well within the limits of the end points of the general equation as shown on Figure 29.

Age location of 485 hours is held fixed along the depth 2.5 cm, as relative humidity 20% and 80% is compared for differences in rate of drying of samples of CPC under those conditions. Run No. 14 is associated with relative humidity 20% whereas run No. 05 for relative humidity 80%. The mean rates of drying for samples of CPC associated with this portion of the analysis was compared and a 184.3% variation resulted. Such a variation is statistically significant at LSD (0.05), signifying that the variation represented by Figures 27 and 28 for this investigation is valid. With respect to the type of variation seen here, it is linear, and the specific equation to describe the change in the rate of drying for these relevant conditions is

$$K_5 = -2.123 \times 10^{-2} + 1.8863 \times 10^{-4}\ Rh \qquad [24]$$

This specific equation was not able to describe 5.3% of the total sums of squares of the data available for this portion of the analysis.

The limits of the end points of the graph of equation [24] fall well within the limits of the end points of the general equation as shown in Figure 28. All other factors associated with this analysis on the 2.5 cm level of depth, for the effect of relative humidity on the rate of drying for CPC is shown on Table II.

Effect of Age

With relative humidity fixed, it was possible to determine the effect of age on the change in the rate of drying of CPC for a fixed depth. Table III provides a picture for the specific areas of discussion in this section.

TABLE III

AGE WITHIN DEPTH WITHIN RELATIVE HUMIDITY

RH %	DEPTH (CM)		AGE HRS.	
20	2.5	485	679	776
	6.4	388	679	776
	10.2	582	679	873
50	2.5	97	291	388
	6.4	97	194	485
	10.2	194	291	582
80	2.5	97	485	679
	6.4	194	388	873
	10.2	291	582	776

To aid in the analysis in this section computer programme No. 8 was designed. The comparison of the differences in the rate of drying of samples of CPC as age changes for fixed depths and relative humidities is considered the main function of this computer programme.

It also performs the check on the values obtained by the hand calculated values associated with computer programme No. 5. The generation of relevant values for the least square regression equations, after comparison or contrasting has been made on pertinent rates of drying of relevant samples' values, is also performed by this computer programme.

Effect of Age for 20% Relative Humidity and Depth of 10.2 cm

Holding both relative humidity at 20% and depth at 10.2 cm constant, the effect of age on the rate of drying of samples of CPC for levels of age at 582 hours and 873 hours was investigated. Run No. 09 was associated with age 873 hours whereas run No. 15 with age 582 hours.

The average rate of drying of samples of CPC at the 873 hours level is -1.28×10^{-2} hr^{-1} and that for the 582 hours level is -1.068×10^{-2} hr^{-1}. The variation in the rate of drying of these samples of CPC between these two levels of age is 0.002 hr^{-1} (19.9%). Figures 29 and 30 provide a picture for this variation and substantiate that the rate of drying of samples of CPC is apparently faster at the 873 hours level than at the 852 hour level. But this variation is not statistically significant at LSD (0.05). This implies that there is essentially no difference in the rate of drying of samples of CPC for the above mentioned conditions for levels of age 582 hours and 873 hours.

With respect to the 582 hours level of age and the 673 hours level of age, holding relative humidity and depth fixed at 20% and 10.2 cm, respectively; the average rate of drying of samples of CPC for 582 hours level of age is -1.0677×10^{-2} hr^{-1} and that for the 872 hours

Run No.	Depth (CM)	Age (HR)	RH (%)
9	10.2	873	20
15	10.2	582	20
27	10.2	873	20

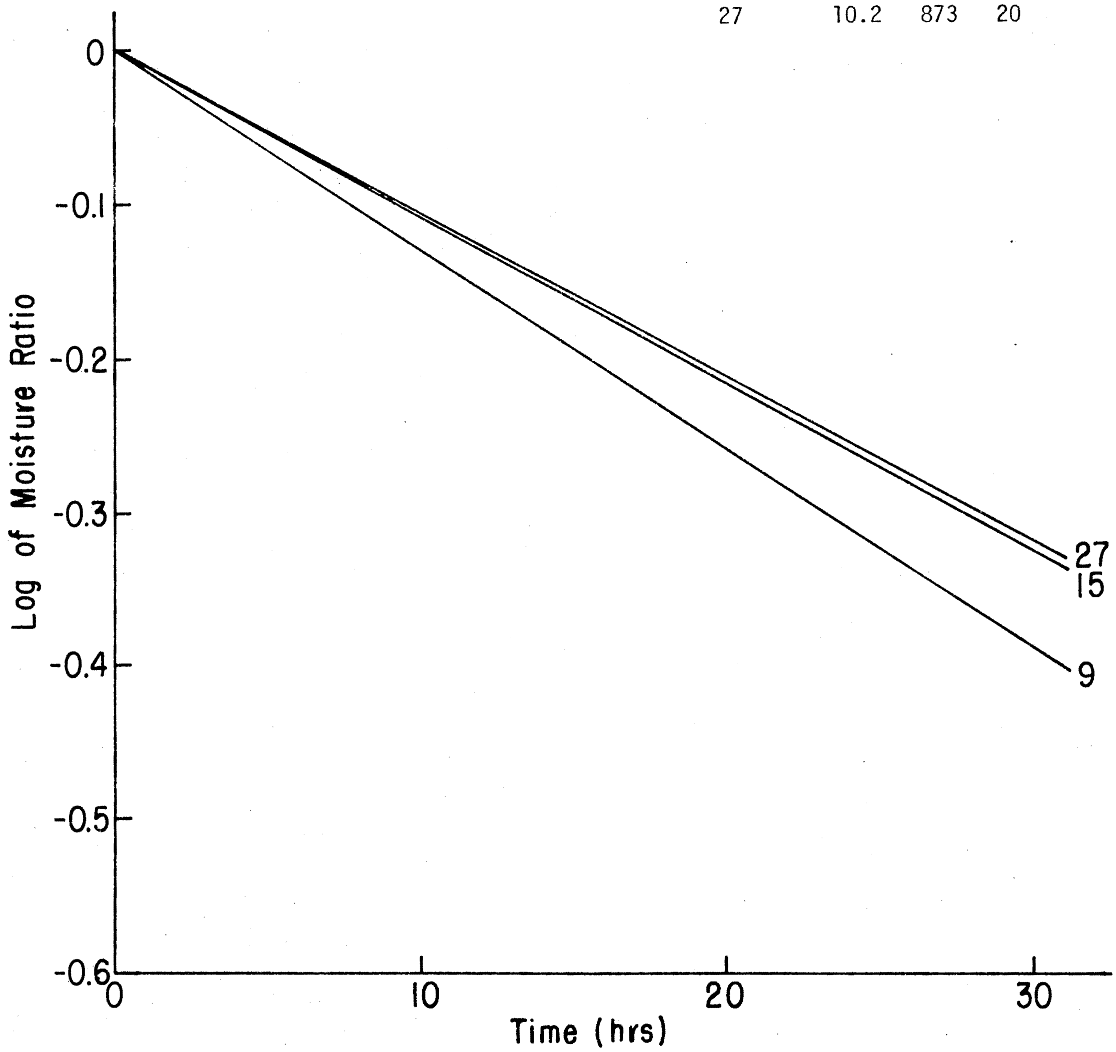


Figure 29. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 20% and Depth of 10.2 cm

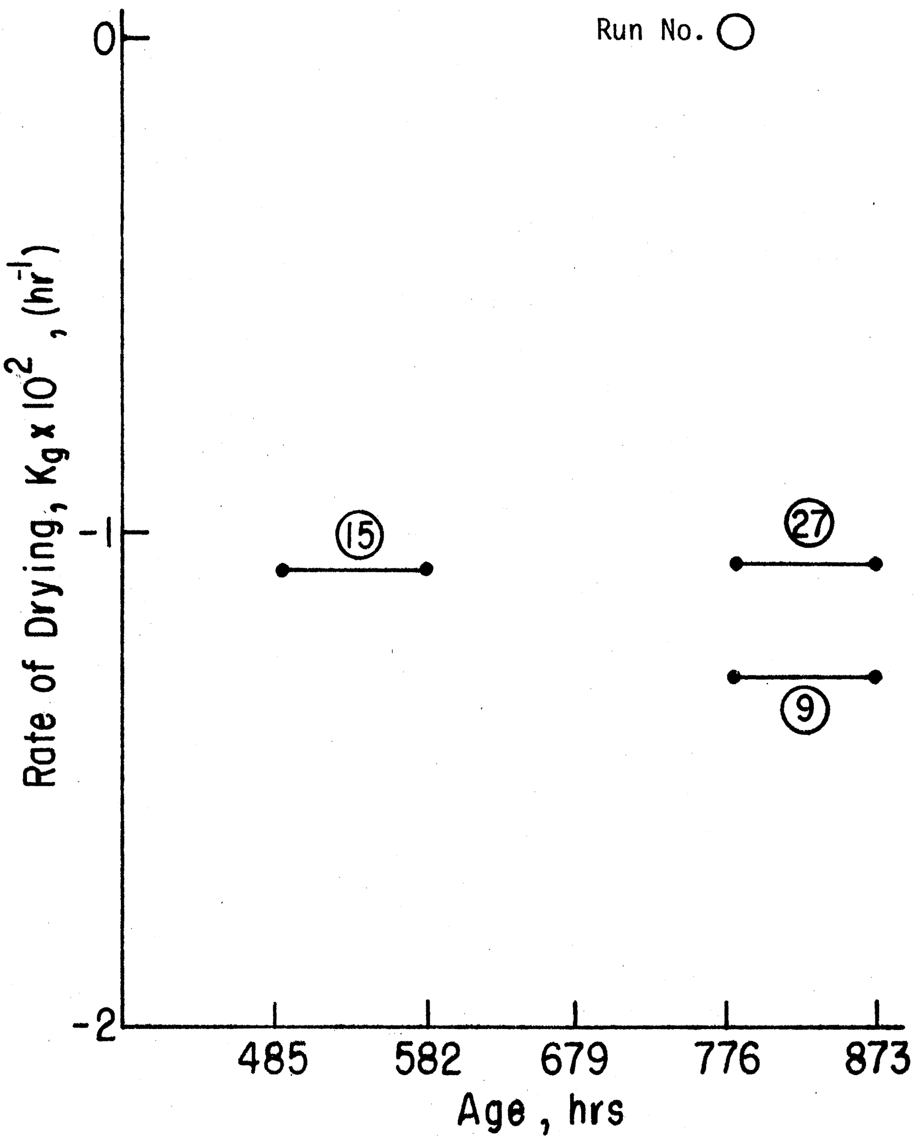


Figure 30. Rate of Drying of CPC as a Function of Age for Relative Humidity of 20% and Depth of 10.2 cm

level -1.058×10^{-2} hr^{-1}. The experimental run number associated with the 582 hours level of age is No. 15 and that for the 872 hours level is No. 27. The difference in the average rate of drying of samples of CPC for these two levels at these conditions is 8.9×10^{-2} hr^{-1}. Figures 29 and 30 provide a visual for both the rate of drying of the relevant samples of CPC and the change in the rate of drying associated with them for levels of age of 582 hours and 873 hours. A variation of 8.9×10^{-2} hr^{-1} is relatively small and is not statistically significant at LSD (0.05). In effect, there is essentially no difference in the rate of drying of samples of CPC for fixed depth of 10.2 cm and fixed relative humidity of 20% for levels of age 582 hours and 873 hours, respectively.

Effect of Age for 20% Relative Humidity and Depth of 6.4 cm

The levels of age of CPC are 679 hours and 388 hours, respectively. The experimental run number associated with the former age level is No. 7 and that for the latter is No. 13. The variables held constant are 20% level of relative humidity and 6.4 cm level of depth. The rate of drying of samples of CPC for age level at 388 hours is -1.04886×10^{-2} hr^{-1} and that for the 679 hours age level is -1.12489×10^{-2} hr^{-1}. The difference between these two rates of drying of samples of CPC is 2×10^{-2} hr^{-1} (19.08%) and such a variation could be seen in Figure 31. Samples of CPC dried at the 388 hours level of age seemed to dry faster than those dried at the 679 hours level of age. But there is essentially no difference in the rates of drying of the relevant samples of CPC at the 388 hours level and the 679 hours level. The test for

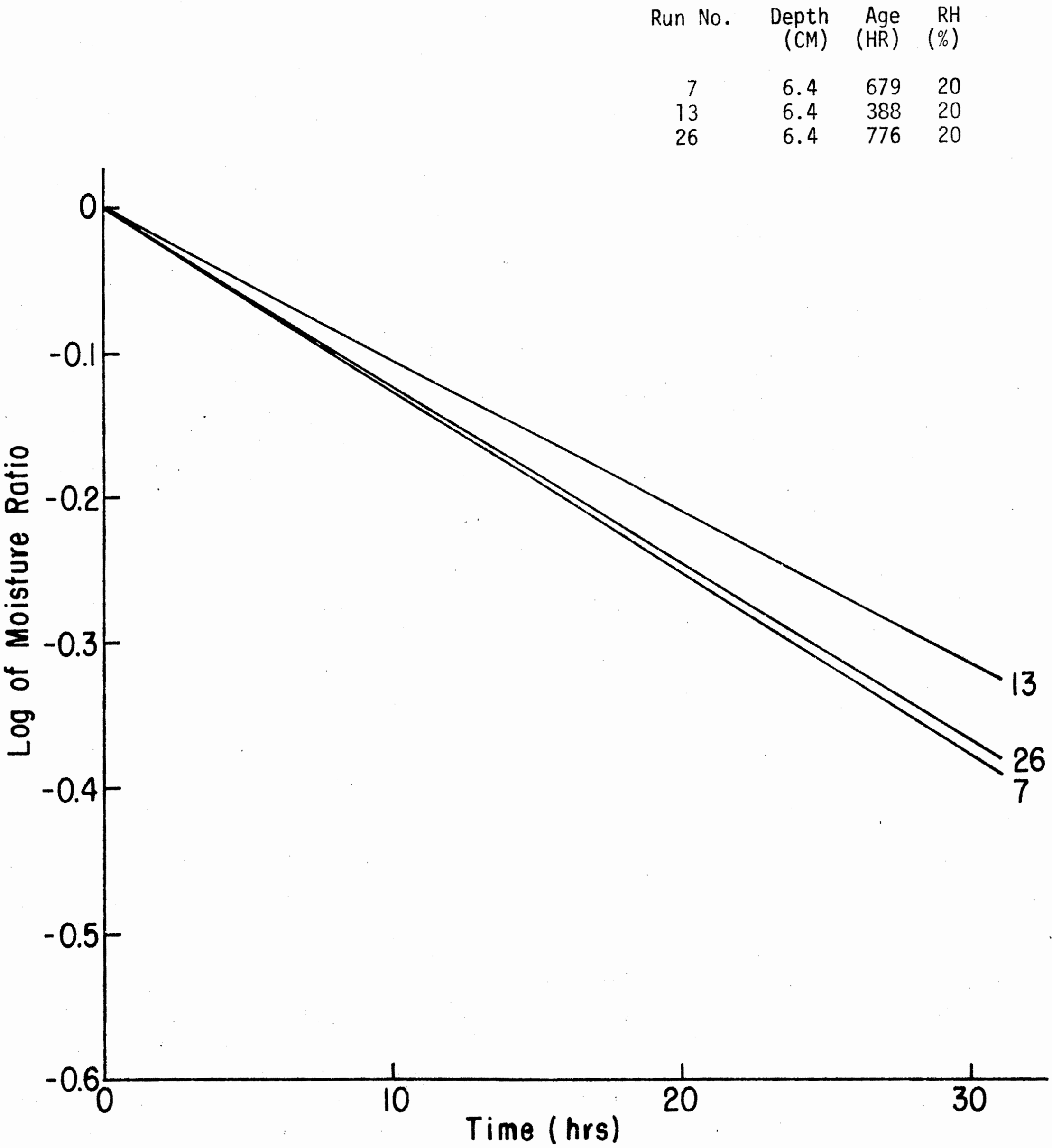


Figure 31. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 20% and Depth of 6.4 cm

comparison between these two average rates of drying of samples of CPC at age level of 388 hours and 679 hours is done at an LSD (0.05), and it was not statistically significant.

The variables that are held constant are relative humidity 20% and depth 6.4 cm. The two levels of age considered are 679 hours and 776 hours. Run No. 07 is associated with age level of 679 hours and run No. 26 with 776 hours age level. The rate of drying of samples for age level of 679 hours is -1.24898×10^{-2} hr^{-1} and that for 776 age level is -1.21159×10^{-2} hr^{-1}; generating a change of 3.7×10^{-3} hr^{-1}. Such a change could be seen in Figure 32. This change in the rates of drying of samples of CPC when age levels 679 hours and 776 hours are compared for the constraints mentioned earlier in this paragraph, is not statistically significant at LSD (0.05). The interpretation of the latter statement is that there is no change in the drying rates for samples of CPC dried at age levels 679 hours and 776 hours, for relative humidity 20% and depth 6.4 cm.

With relative humidity of 20% and depth 6.4 cm held constant, the two levels of age of CPC scrutinized here are 388 hours and 776 hours. Run No. 13 is associated with the 388 hours level of age of CPC whereas run No. 26 with the 776 hours age level. The rate of drying of samples of CPC for the age level of 388 hours is -1.04886×10^{-2} hr^{-1} whereas that for the 776 hours age level is -1.21159×10^{-2} hr^{-1}; producing a difference of 1.63×10^{-3} hr^{-1}. This difference could be seen on Figure 31. Upon using this difference of 1.63×10^{-3} hr^{-1} in the comparison test with LSD (0.05) value at 3.046×10^{-3} hr^{-1}, it became clear that there exists no difference in the rate of drying of samples of CPC for the conditions mentioned in this paragraph when CPC is 388

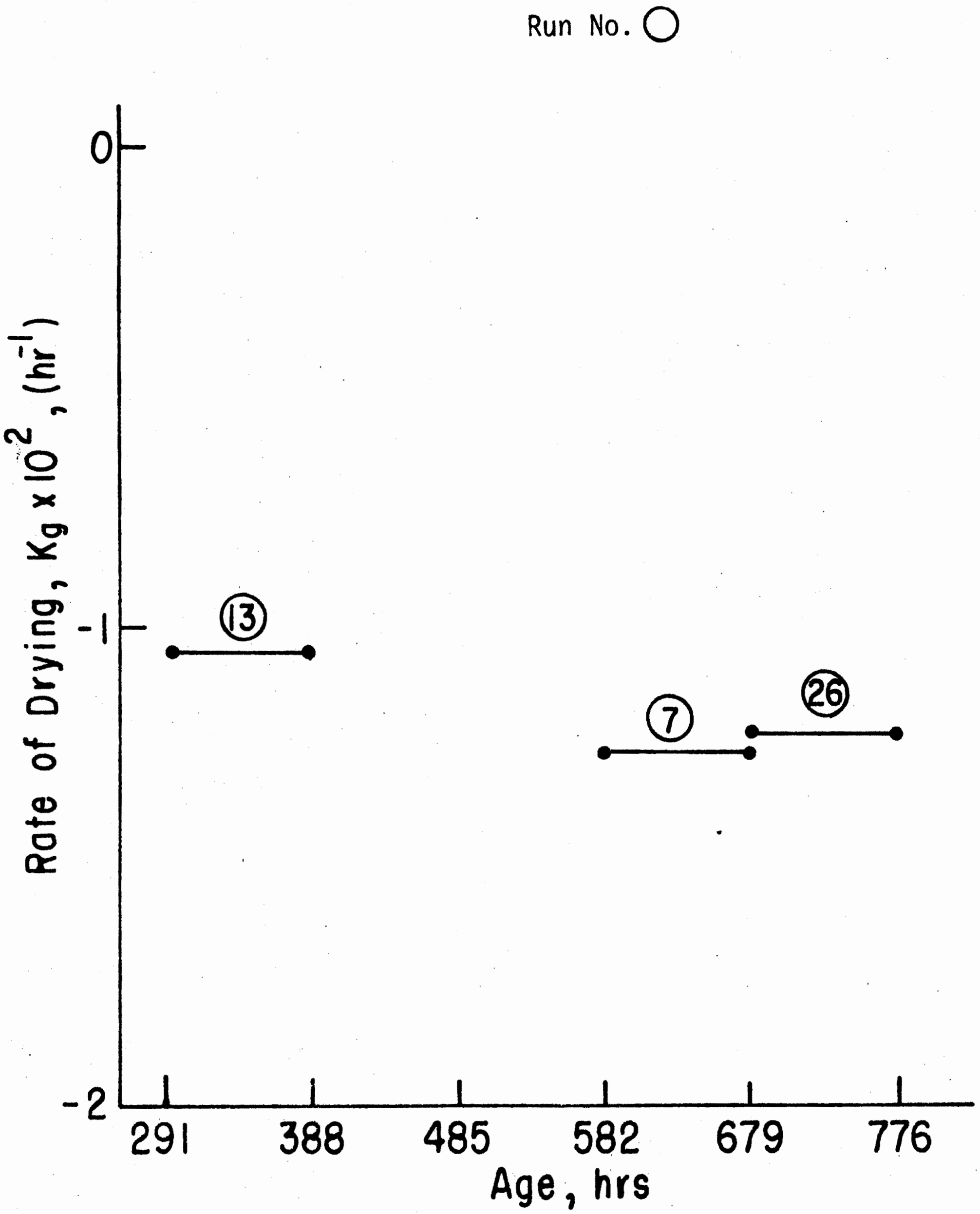


Figure 32. Rate of Drying of CPC as a Function of Age for Relative Humidity of 20% and Depth of 6.4 cm

hours old or 776 hours old. Figure 32 provides a means of viewing the rates of drying of samples of CPC for runs Nos. 7, 13, and 26.

Effect of Age for 20% Relative Humidity and Depth of 2.5 cm

The factors held constant in this part of the analysis is depth at 2.5 cm level and relative humidity at 20% level. The two levels of age investigated is 485 hours and 776 hours, respectively. Associated with the first of the two levels of age is run No. 08 and run No. 14 with the second. The rate of drying of samples of CPC for level of age of 485 hours is -1.7458×10^{-2} hr^{-1} and that for age level 776 hours is -1.57335×10^{-2} hr^{-1}. The difference between these two rates is 1.7×10^{-3} hr^{-1} (10.97%), which is essentially not statistically significant as LSD (0.05). The implication of this significance test is that there is no difference in the rates of drying of samples of CPC irrespective of the age of CPC being 485 hours old or 776 hours.

Figure 33 illustrates the extremely small change in the rates of drying of samples at age level 485 hours and 776 hours for depth of 2.5 cm.

Attention is diverted towards investigating the two new levels of age of CPC at 679 hours and 776 hours, respectively, for fixed relative humidity of 20% and fixed depth of 2.5 cm. The rate of drying of samples of CPC at age level of 679 hours is -1.6059×10^{-2} hr^{-1} and that for age level of 776 hours is -1.57335×10^{-2} hr^{-1}; producing a variation of 3.3×10^{-4} hr^{-1} (2.07%). Figure 34 provides good visual for this change in drying rate of CPC. This change in the rate of drying of CPC between these two levels is not statistically significant at LSD

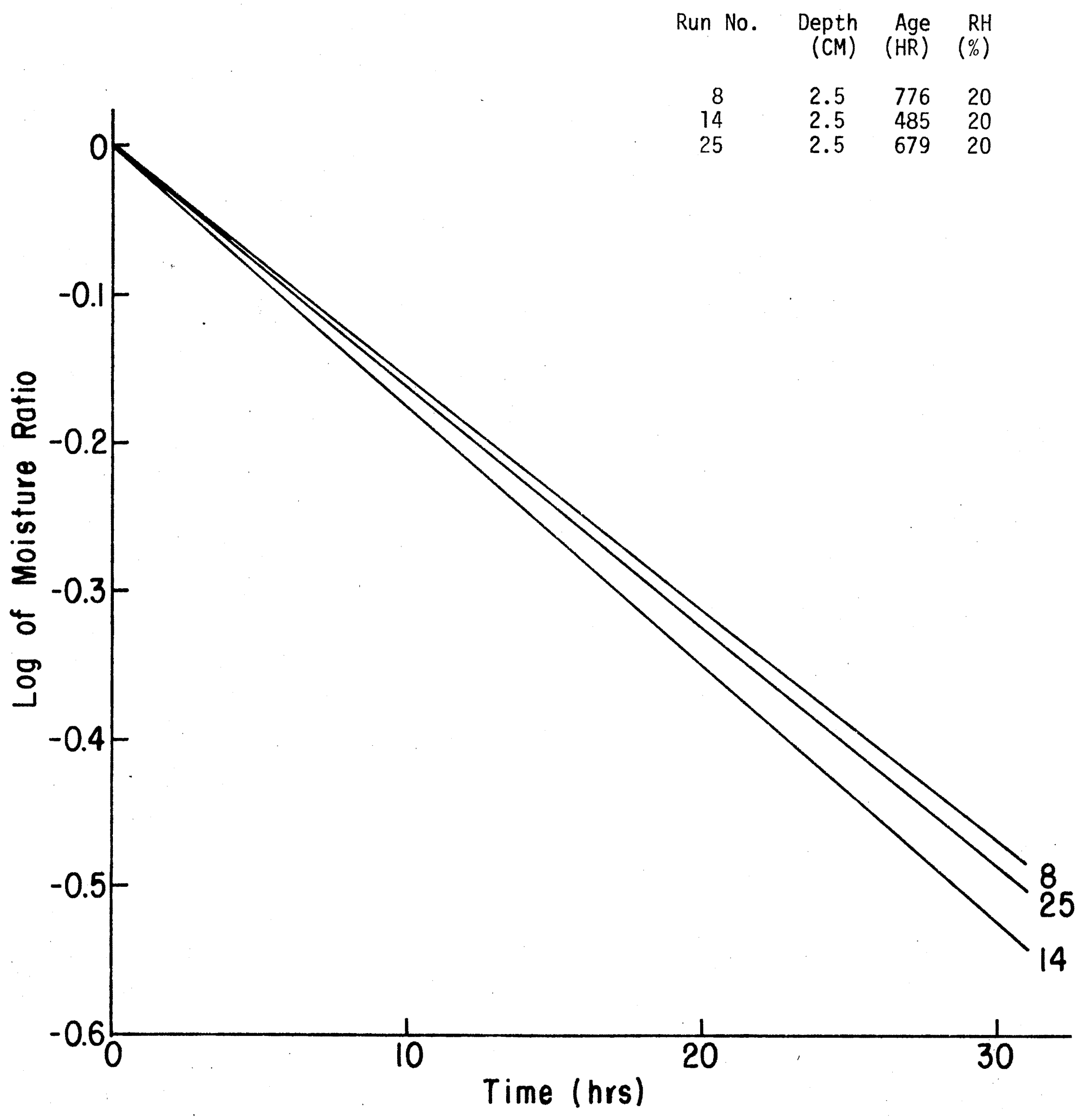


Figure 33. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 20% and Depth of 2.5 cm

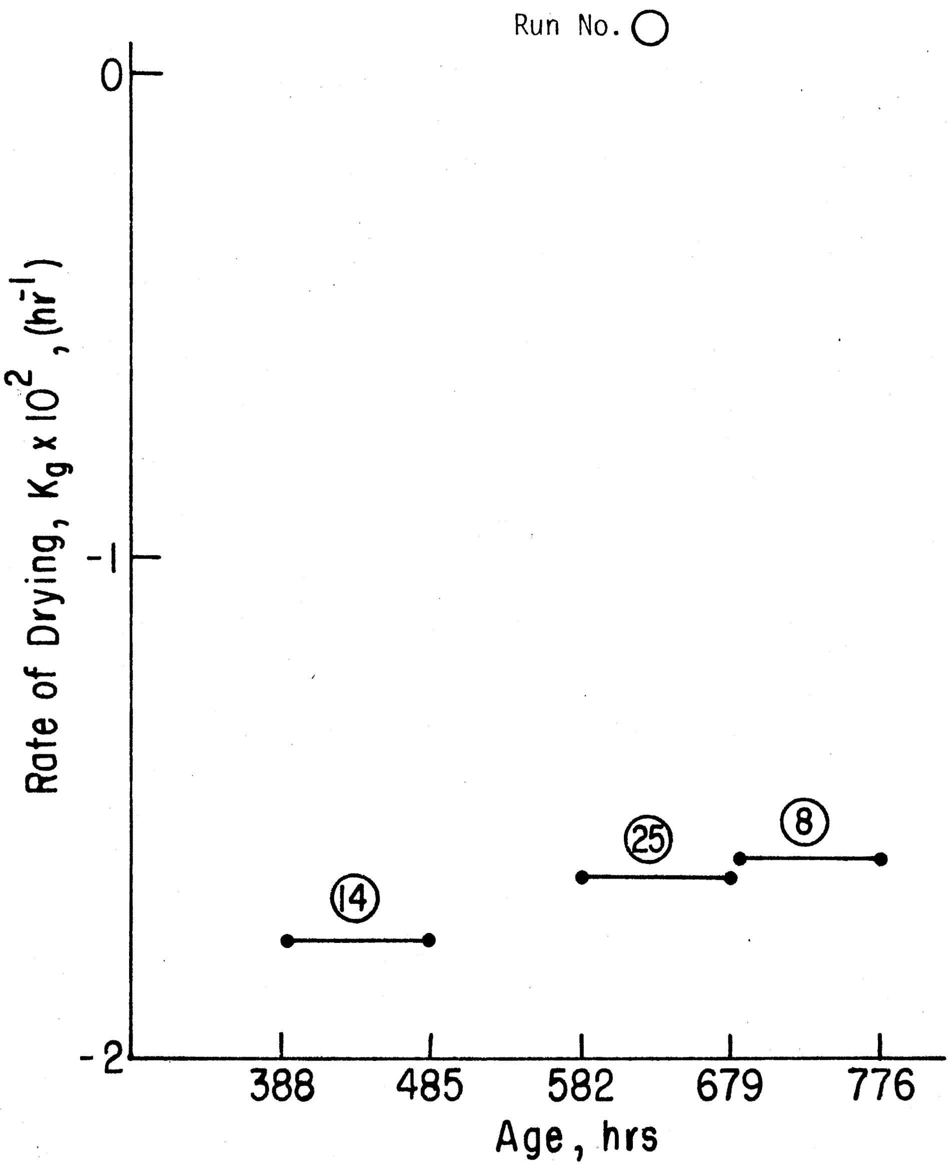


Figure 34. Rate of Drying of CPC as a Function of Age for Relative Humidity of 20% and Depth of 2.5 cm

(0.05); and suggested that the rate of drying of CPC 679 hours old is the same as the rate of drying of CPC 776 hours old for relative humidity 20% and depth 2.5 cm.

The situation is investigated in which the levels of age of CPC are 485 hours and 679 hours, with that for fixed relative humidity is 20%, and fixed depth is 2.5 cm. The rate of drying of samples of CPC for age level of 485 hours is -1.74579×10^{-2} hr^{-1} and that for the 679 hours level is -1.60598×10^{-2} hr^{-1}. The difference between these two drying rates of samples of CPC is 1.4×10^{-3} hr^{-1} (8.7%). Run No. 14 is associated with age location of 485 hours whereas run No. 25 for 679 hours age location.

Figure 34 provides good illustration for visualizing the type of change 1.4×10^{-3} hr^{-1} really is. This change in drying rate for samples of CPC processed when the samples of CPC are 485 hours and 679 hours old — essentially at fixed relative humidity of 20% and depth of 2.5 cm — is not statistically significant at LSD (0.05). So, in effect, the rate of drying of samples of CPC is the same irrespective of if the CPC is 485 hours old or 679 hours old. The latter statement holds true for this specific test if the relative humidity is held constant at 20% and the fixed depth of CPC is 2.54 cm.

A summary of the analysis of the effect of age on the change in the rate of drying of samples of CPC at relative humidity 20% and depth 2.5 cm is shown on Table II.

Effect of Age for 50% Relative Humidity and Depth of 2.5 cm

Relative humidity is fixed at 50% along with fixed depth of 2.5 cm.

The two levels of age considered here are 97 hours and 291 hours. Run No. 01 is associated with the first level of age while run No. 12 with the second level of age. The rate of drying of samples of CPC for level of age at 97 hours is -1.45764 x 10^{-2} hr^{-1} and that for level of age at 291 hours is -1.083876 x 10^{-2} hr^{-1}. The difference between these two drying rates is 3.74 x 10^{-3} hr^{-1} (34.5%). A visual representation of this change is seen on Figures 35 and 36. The rate of drying of samples associated with the age level of 97 hours is much faster than the rate of drying of samples from the age level 291 hours. The variation in the rates of drying of samples of CPC from these two levels is statistically significant at LSD (0.05). A relevant interpretation is that the rate of drying of samples taken from CPC within 97 hours old dried faster than that taken at 291 hours old, providing the relative humidity is fixed at 50% and the depth of CPC is 2.5 cm.

Depth is fixed at 2.5 cm as well as relative humidity is also fixed at 50%. Of the two levels of age of CPC considered one is at 98 hours and the other is at 388 hours. Run No. 01 is concommitant with level of age 97 hours, whereas run No. 22 with level of age 388 hours. The rate of drying of samples of CPC at the level of age of 97 hours is -1.14576 x 10^{-2} hr^{-1} and that for level of age at 388 hours is -9.5994 x 10^{-3} hr^{-1}, generating a difference between these two rates of drying of samples of CPC of 4.97 x 10^{-3} hr^{-1} (51.9%). This difference in the rate of drying of samples of CPC for these appropriate levels of age could be visually perceived on Figures 35 and 36. This change in the rate of drying of samples of CPC between these two levels of age for the restrictions mentioned in this paragraph is statistically significant at LSD (0.05). Samples of CPC from level of age of 97 hours dries much faster

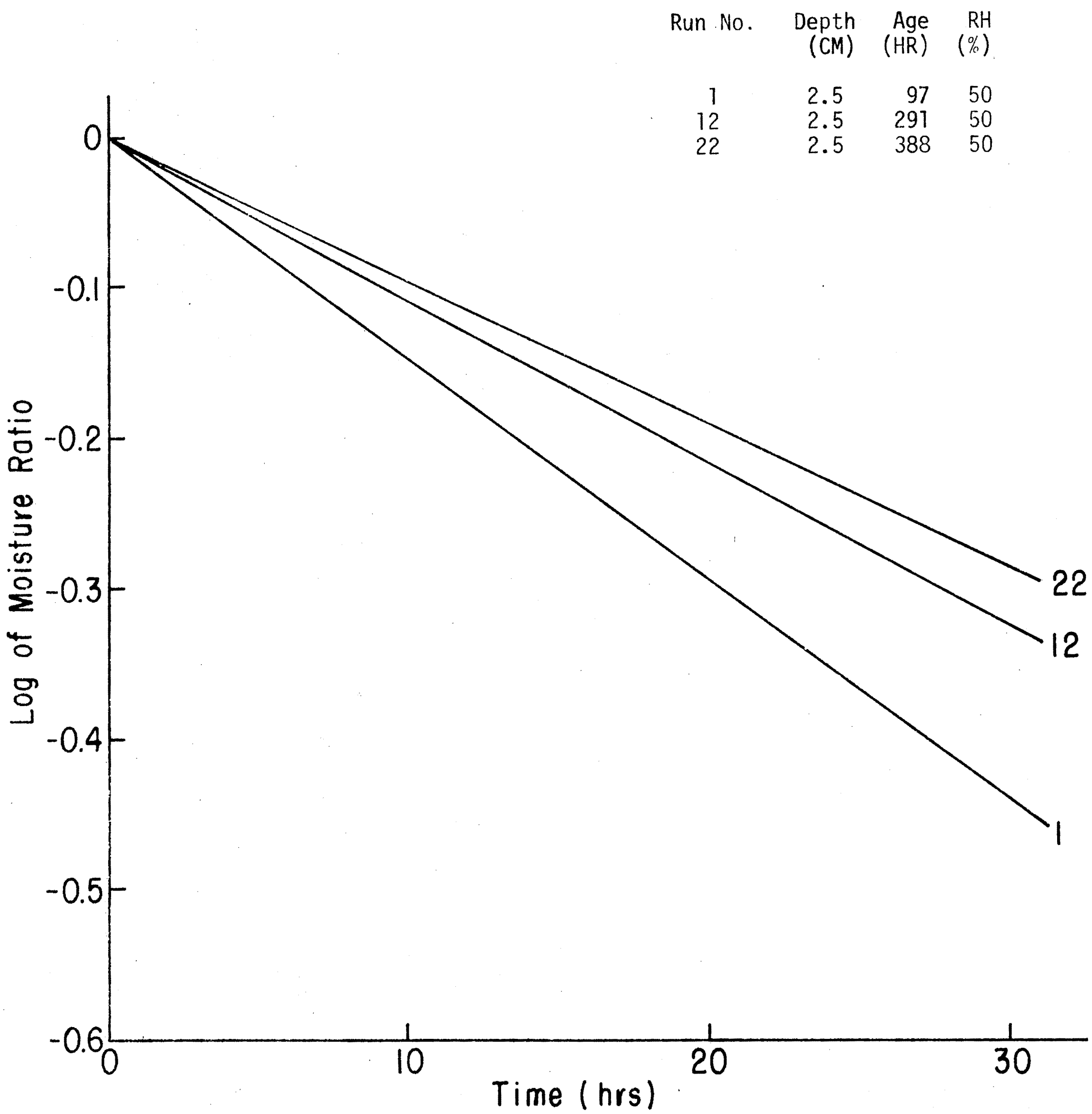


Figure 35. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 50% and Depth of 2.5 cm

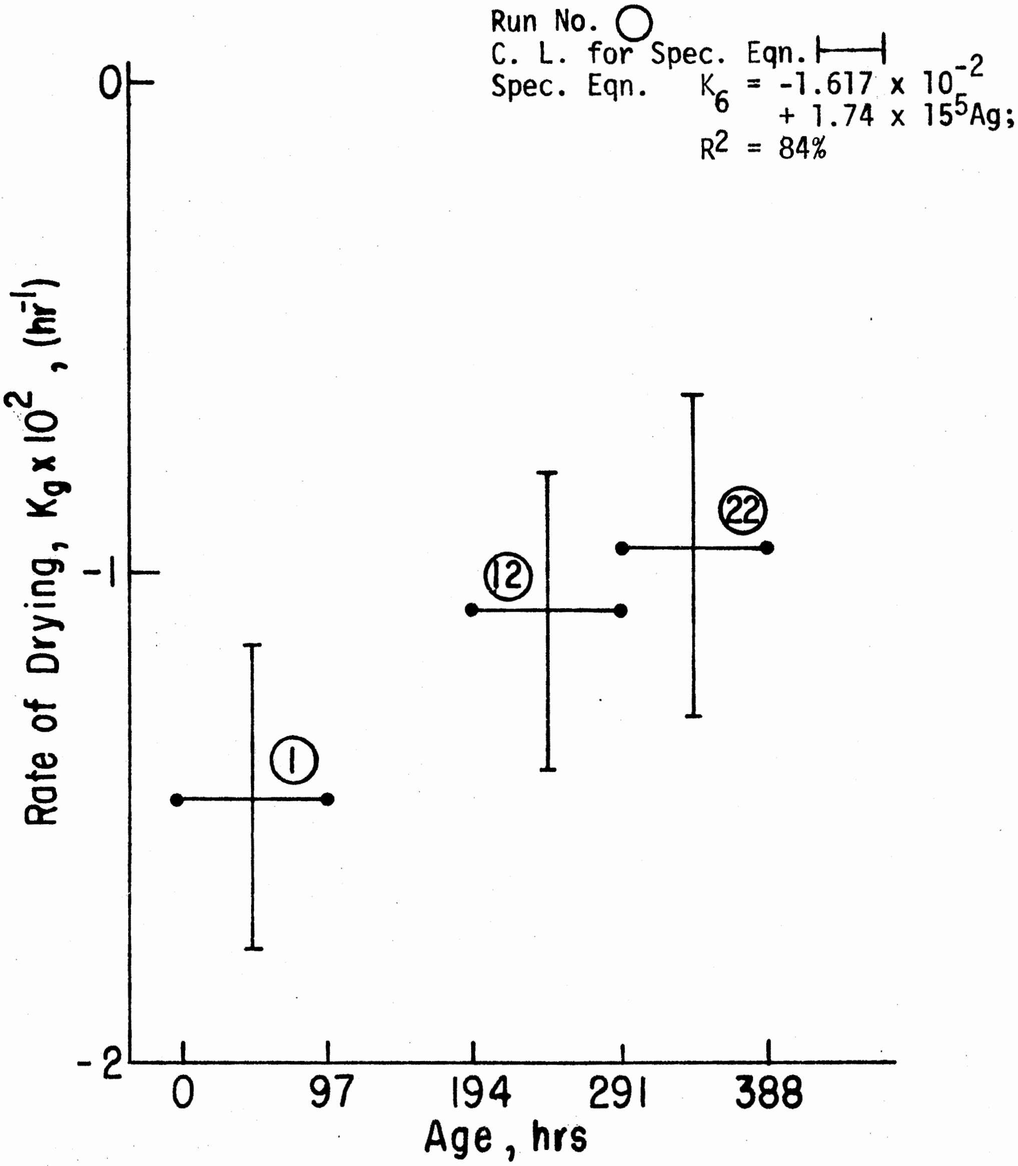


Figure 36. Rate of Drying of CPC as a Function of Age for Relative Humidity of 50% and Depth of 2.5 cm

than those taken at the level of age of 388 hours.

With respect to fixed depth of 2.5 cm, and relative humidity fixed at 50%, the two levels of age viewed attentively here is 291 hours and 388 hours. Run No. 12 is related to level of age of 291 hours and run No. 22 with level of age of 388 hours. Samples dried from levels of age of CPC at 291 hours did so at a rate of $-1.0839 \times 10^{-2}\ hr^{-1}$ whereas those from the level of age at 388 hours dried at $-9.5994 \times 10^{-3}\ hr^{-1}$, procreating a difference of $1.23 \times 10^{-3}\ hr^{-1}$. This change in the rate of drying of samples of CPC with the restraints attached to the levels of age contemplated upon, in this paragraph is not statistically significant at LSD (0.05).

Throughout the analysis of the effect of age on the change in the rate of drying of CPC for 50% relative humidity, it is necessary to mention that depth was fixed at 2.5 cm as well as relative humidity fixed at 50%. When the levels of age were 97 hours and 291 hours, a difference of rate of drying of samples from these levels was calculated to be $3.74 \times 10^{-3}\ hr^{-1}$ (35.5%). With reference to the levels of age of 97 hours and 388 hours, a relative difference of rate of drying of samples from these levels was $4.97 \times 10^{-3}\ hr^{-1}$ (51.9%). The difference in the rate of drying of samples taken from levels of age at 291 hours and 388 hours is $1.23 \times 10^{-2}\ hr^{-1}$ (12.9%). In order to find out what major type of differences in a group of differences presenting itself here on what type of overall changes in the rate of drying for samples taken from these three independent groups of level of ages, a least square regression analysis was performed on the rates of drying grouped together. The major type of change in the rates of drying for these relevant samples under consideration is linear and the specific equation for this change is

$$K_6 = -1.617 \times 10^{-2} + 1.741 \times 10^{-5} (Ag) \qquad [25]$$

This equation was able to describe 84% of the total available sums of squares for the regression analysis. Figures 35 and 36 essentially provide a means of observing the change in the rate of drying of samples of CPC at fixed relative humidity of 50%; fixed depth of 2.5 cm and levels of ages of 97, 291, and 388 hours.

Effect of Age on 50% Relative Humidity and Depth of 6.4 cm

For this entire section, the only source of variation encountered is in age of CPC. Of the three different levels of age encountered, analysis is performed on all possible combinations of levels of age taken two at a time. The levels of age in this section are 97 hours, 194 hours and 485 hours.

Run No. 10 is associated with level of age at 97 hours, whereas run No. 02 with level of age at 194 hours, and run No. 23 with level of age at 485 hours. The rate of drying of samples of CPC at the level of age at 97 hours is -1.71269×10^{-2} hr^{-1}, that at 194 hours is -1.13954×10^{-2} hr^{-1} and that for 485 hours is -4.71549×10^{-3} hr^{-1}. The difference between the rate of drying of samples of CPC at the level of age of 97 hours and 194 hours is 5.73×10^{-3} hr^{-1} (50.3%); that between levels of age at 97 hours and 485 hours is 6.68×10^{-3} hr^{-1} (141.7%). These respective different and separate changes in the rates of drying of samples of CPC for these levels of age could be visually perceived on Figures 37 and 38.

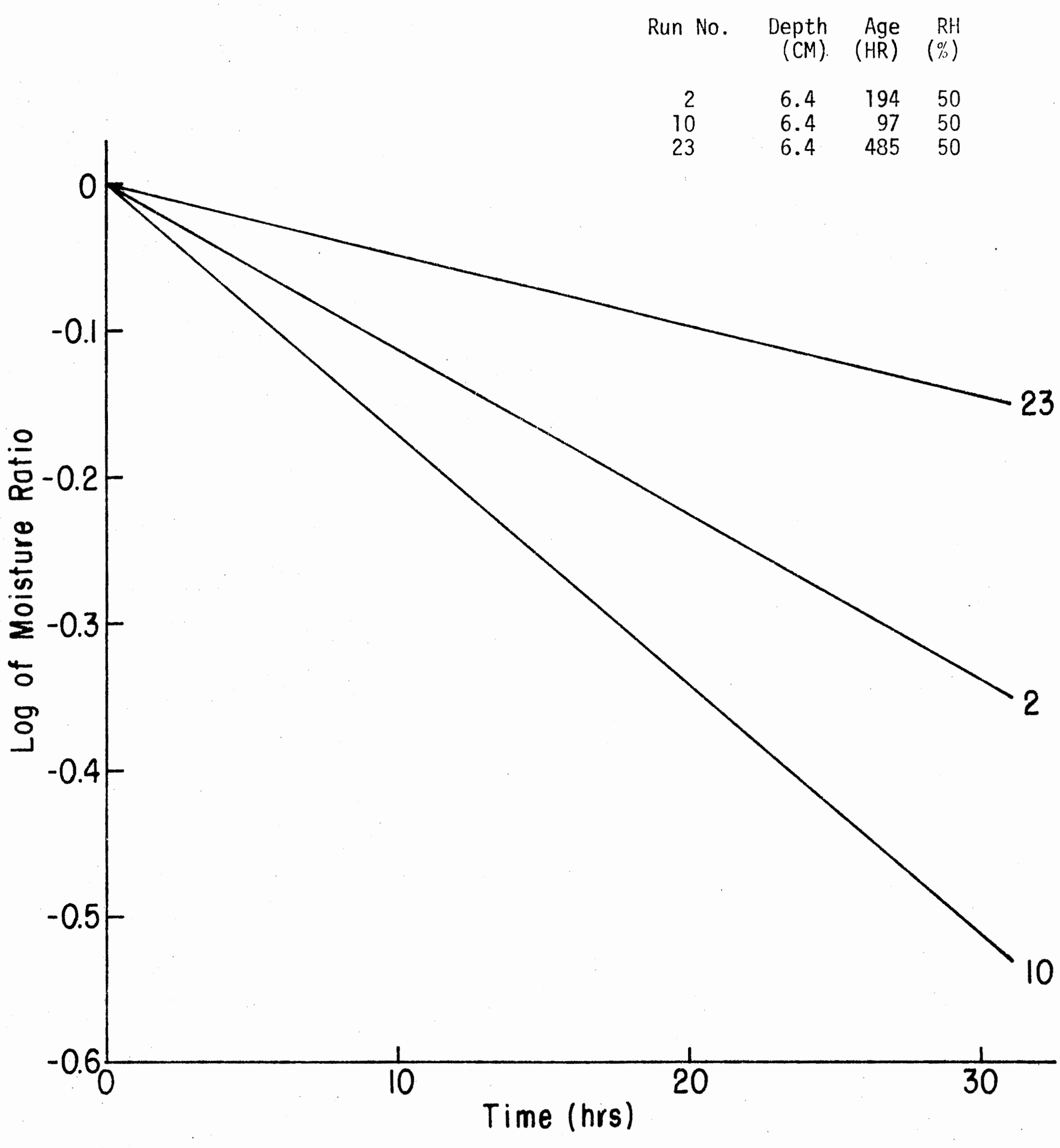


Figure 37. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 50% and Depth of 6.4 cm

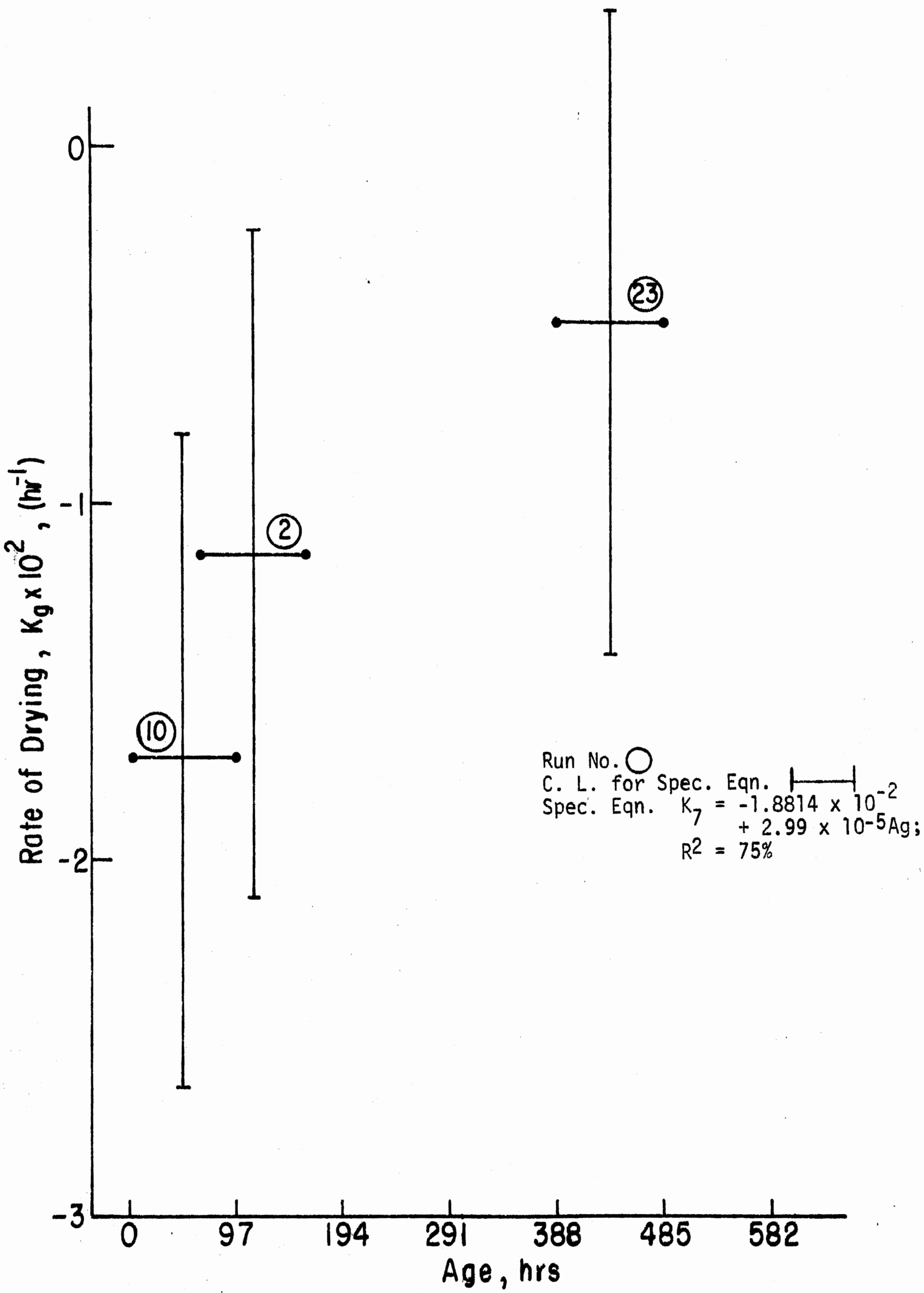


Figure 38. Rate of Drying of CPC as a Function of Age for Relative Humidity of 50% and Depth of 6.4 cm

With respect to the levels of age of CPC at 97 hours and 194 hours, the rate of drying of samples of CPC taken from the level at 97 hours is much faster than that for samples taken at the level of age of CPC at 194 hours. In a similar manner of comparison for the level of age at 194 hours and 488 hours, the rate of drying of samples taken from the level of age at 194 hours is very much faster than those from the 485 hours.

For the situation for those samples associated with levels of age at 97 hours and 485 hours, the rate of drying for the samples at level of age of 97 hours is extremely faster than those taken at the level of age of 485 hours. All differences or changes in the rates of drying of samples of CPC for these relevant levels of age compared previously in this section are statistically significant at LSD (0.05). The type of overall major change in the rate of drying of samples taken at each of these levels is linear based upon the method of least square analysis on the relevant regression model. The specific equation describing these changes is

$$K_7 = -1.8814 \times 10^{-2} + 2.99 \times 10^{-5}\ Ag \qquad [26]$$

This equation was not able to describe 25.7% of the total sums of squares available for the analysis of regression.

Effect of Age on 50% Relative Humidity and Depth of 10.2 cm

Since the relative humidity is fixed at 50%, depth fixed at 10.2 cm, and there are three different levels of age reflected in this section of the analysis, it is intended that this analysis will compare basically the comparison between average rates of drying of samples of

CPC. Such comparisons, will be made on all possible combinations of levels of age mentioned in this section taken two at a time.

The levels of age are 194 hours, 291 hours, and 582 hours and the respective run number to which they are associated are Nos. 11, 03, and 24, respectively.

The respective rates of drying of samples of CPC processed from levels of age of 194 hours, 291 hours, and 582 hours are -1.54009 $\times 10^{-2}$ hr^{-1}, -0.98820 $\times 10^{-3}$ hr^{-1} and -8.6457 $\times 10^{-3}$ hr^{-1}, respectively. The difference in the rate of drying of samples taken at the level of age of 291 hours and those from the level of age of 582 hours is 3.43 $\times 10^{-4}$ hr^{-1}. The difference in the rate of drying of samples of CPC taken at the level of age of 291 hours and that from the level of age of 582 hours is 3.43 $\times 10^{-4}$ hr^{-1} (0.9%). That for level of age of 194 hours and 582 hours is 6.7 $\times 10^{-3}$ hr^{-1} (78%). A magnitude of 6.4 $\times 10^{-3}$ (73%) is the difference in the rate of drying of samples of CPC between level of age of 291 hours and that taken at level of age of 194 hours.

These three separate changes in the rate of drying of CPC could be appreciated from viewing Figures 39 and 40. The two larger of the three separate changes (6.7 $\times 10^{-3}$ hr^{-1} and 6.4 $\times 10^{-3}$ hr^{-1}) in the rates of drying for samples taken at these above mentioned levels of age are statistically significant at LSD (0.05).

There is essentially no difference in the rates of drying of samples of CPC taken at the level of age of 291 hours and those taken when the level of age of CPC is 582 hours. The rate of drying of samples taken at the level of age of 194 hours is faster than the rates of drying of any of those samples taken at the two other levels of age ; i.e., 291 and 582 hours. respectively. The next in turn as far as

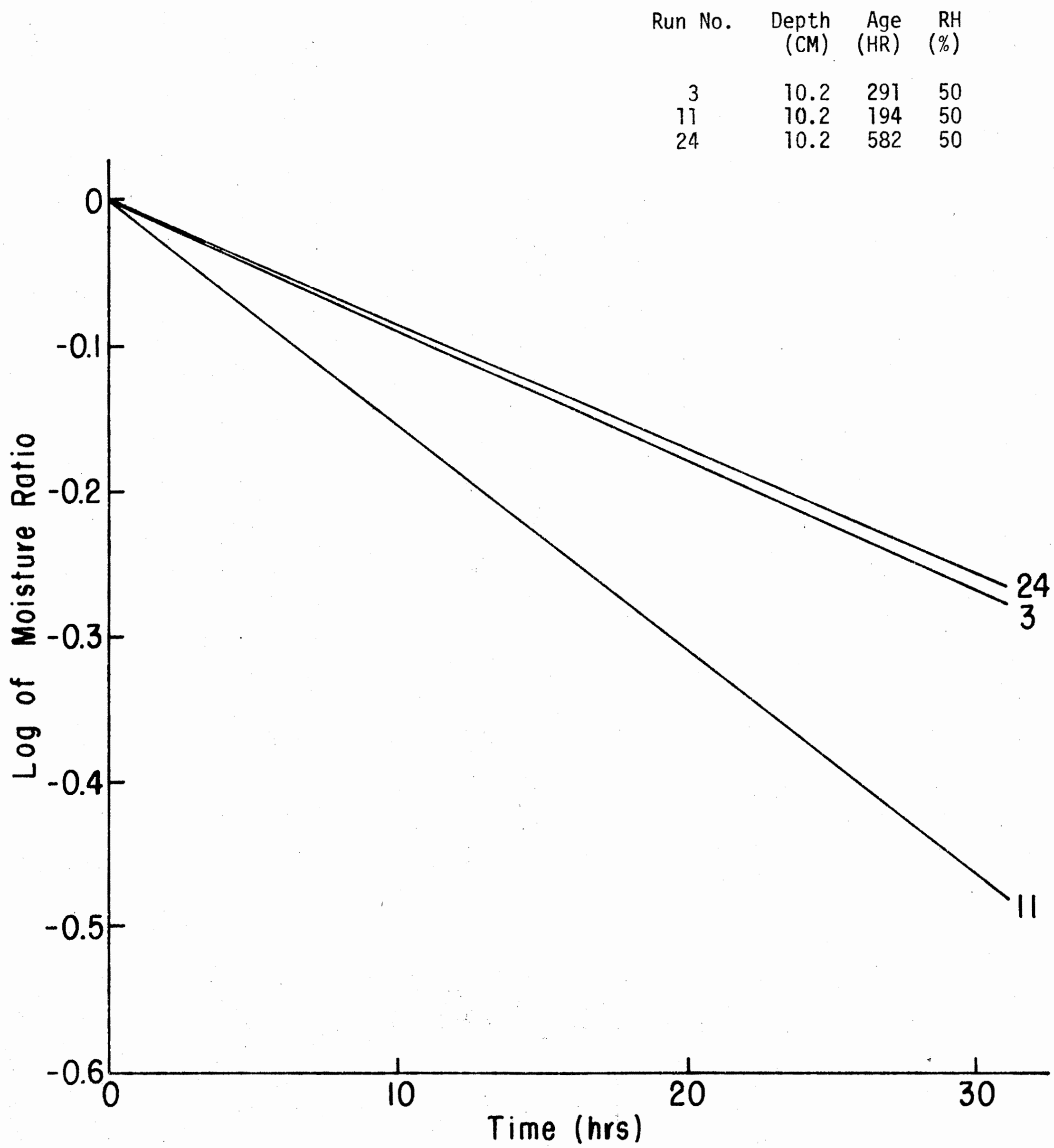


Figure 39. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 50% and Depth of 10.2 cm

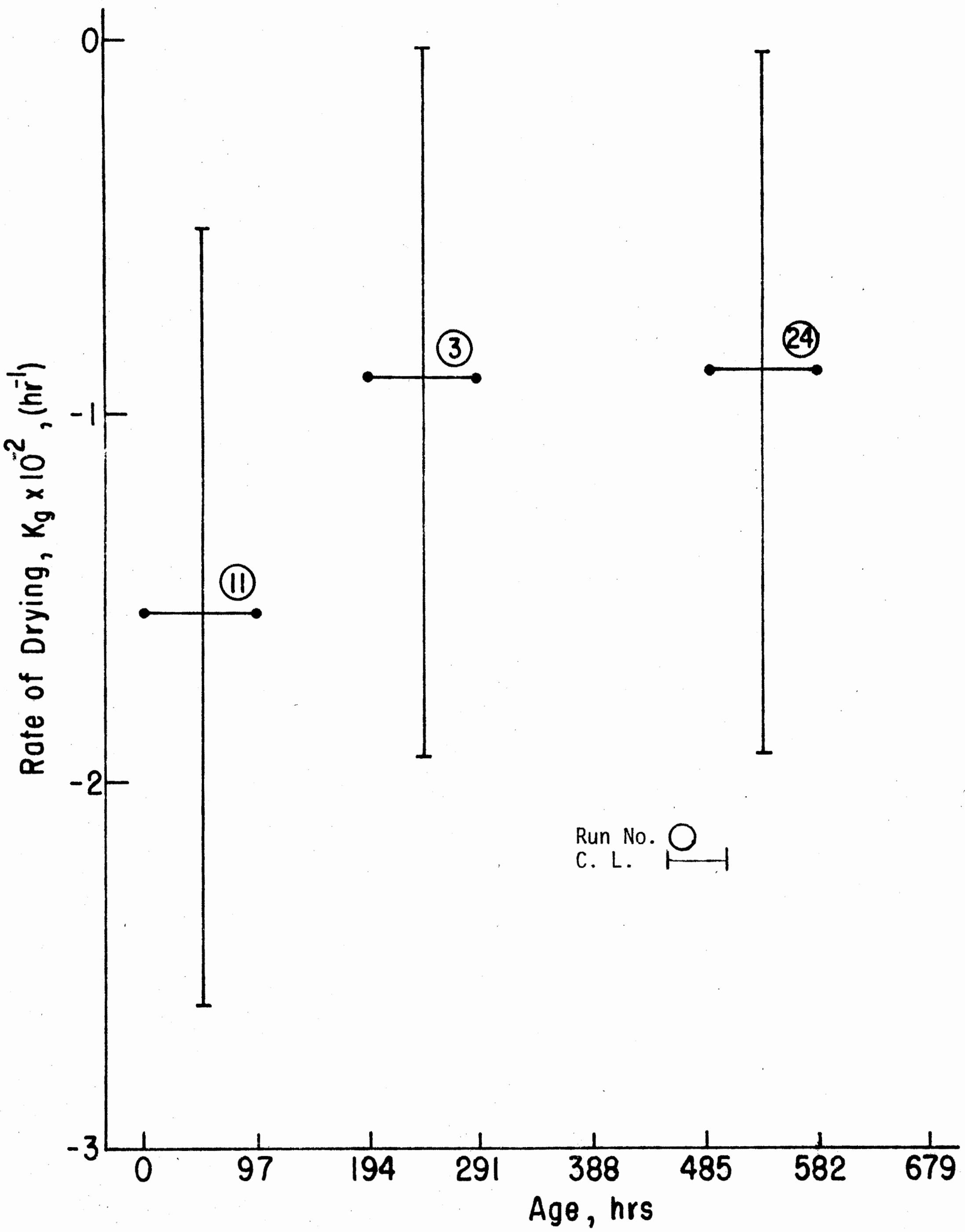


Figure 40. Rate of Drying of CPC as a Function of Age for Relative Humidity of 50% and Depth of 10.2 cm

intensity or speed of drying is concerned, samples taken from levels of age 291 hours fits this category. The overall major type of change in the rate of drying of samples of CPC for these three levels of age is neither linear nor quadratic. This fact is based upon the least square regression analysis for the observed values of the rate of drying of samples at these three levels of age of CPC. So, in effect, the major change in the rate of drying of samples of CPC at the levels of age 194 hours, 291 hours, and 582 hours is essentially zero.

Effect of Age for 80% Relative Humidity and Depth of 2.5 cm

The levels of age of CPC are analyzed in this section in the following pairs: levels of age of CPC at 485 hours and 697 hours with respective runs Nos. 05 and 16; 485 hours and 97 hours with respective runs Nos. 05 and 19; and 97 hours and 679 hours with respective runs Nos. 16 and 19.

The rate of drying of samples of CPC for levels of age at 485 hours is $-6.1403 \times 10^{-3}\ hr^{-1}$; and that for level of age of 679 hours is $-8.89415 \times 10^{-3}\ hr^{-1}$; thus generating a difference in the rate of drying of samples of CPC for these two levels of age of $3.0 \times 10^{-3}\ hr^{-1}$ (30.96%). For the level of age at 97 hours the rate of drying of samples of CPC is $-6.1403 \times 10^{-3}\ hr^{-1}$. The difference in the rates of drying of samples of CPC at the levels of age of 97 hours and 679 hours effected a difference of $5.33 \times 10^{-3}\ hr^{-1}$ (59.93%).

Figures 41 and 42 are intended to provide a visual feel for these changes in the relevant comparative rates of drying of samples of CPC for levels of age of 97 hours, 485 hours, and 697 hours.

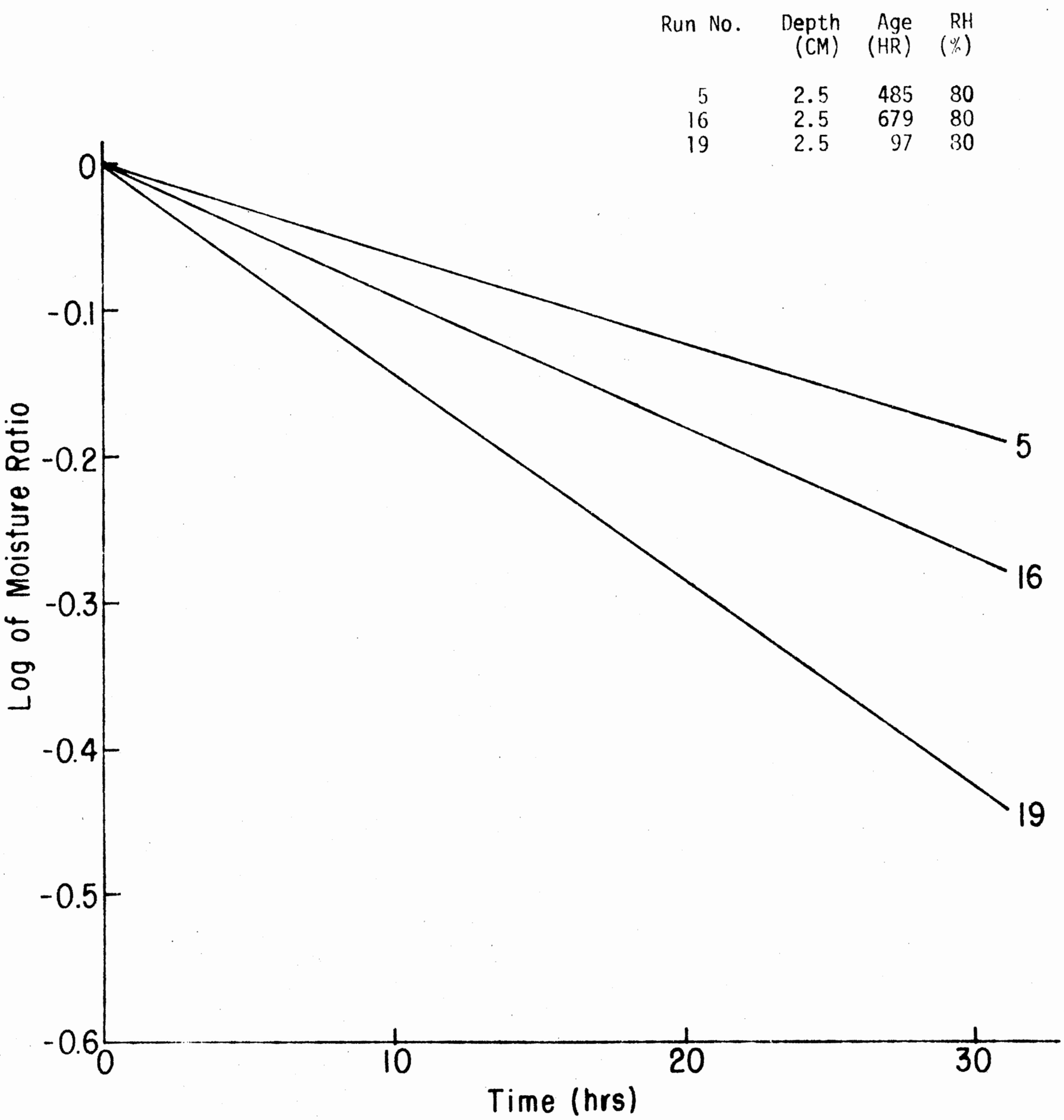


Figure 41. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 80% and Depth of 2.5 cm

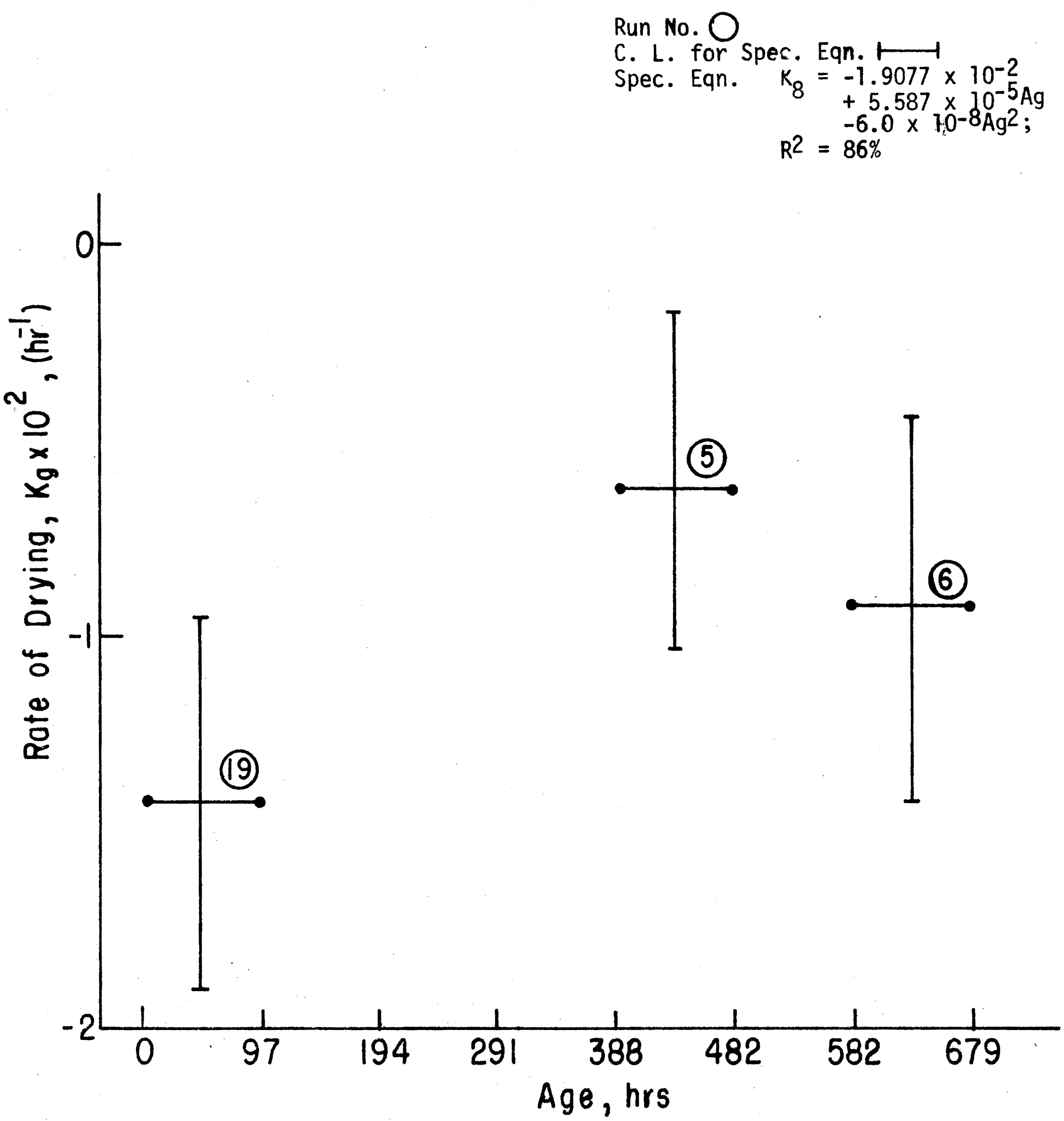


Figure 42. Rate of Drying of CPC as a Function of Age for Relative Humidity of 80% and Depth of 2.5 cm

The change in the rates of drying of samples of CPC for levels of age of 485 hours and 679 hours — 3.0×10^{-3} hr^{-1} (30.96%) — is statistically significant at LSD (0.05); that for levels of age of 97 hours and 485 hours — 8.1×10^{-3} hr^{-1} (131.60%) — is statistically significant at LSD (0.05); and that for levels of age of 97 hours and 679 hours — 5.33×10^{-3} hr^{-1} (59.93%) — is also statistically significant at LSD (0.05).

Upon comparing which of these three levels of age produce the fastest rate of drying of samples of CPC, it is evident that level of age at 97 hours dried fastest, followed by levels of age 697 hours and 485 hours, respectively; in the order of faster rates of drying. Figure 42 seems to substantiate this fact.

In order to find out the overall major type of change presented by the three different magnitudes of changes in rates of drying of samples of CPC for levels of age 97 hours, 485 hours and 679 hours; a least square regression analysis was performed on these deduced relevant rates of drying of samples of CPC.

The regression analysis effected the conclusion that the major type of change is quadratic in nature. The relevant specific equation for such a change is

$$K_8 = -1.90771 \times 10^{-2} + 5.587 \times 10^{-5} (Ag) - 6.0 \times 10^{-8} (Ag)^2 \qquad [27]$$

This equation described 86% of the total available sums of squares for the regression analysis.

Effect of Age for 80% Relative Humidity and Depth of 6.4 cm

The three levels of age involved in this portion of analysis are 194 hours, 388 hours, and 873 hours. Runs Nos. 20, 04, and 18 are associated with these respective levels of age.

The rate of drying of samples of CPC at the level of age of 194 hours is -7.2485×10^{-3} hr^{-1} whereas for the level of age of 388 hours it is -8.37055×10^{-3} hr^{-1}. With respect to the level of age of 873 hours, the rate of drying of samples of CPC is -2.21306×10^{-2} hr^{-1}. The change in the rate of drying of samples of CPC between the levels of age 388 hours and 873 hours is 1.38×10^{-2} hr^{-1} (164.38%); that for levels of age 194 hours and 388 hours is 1.1×10^{-3} hr^{-1} (15.47%); and for levels of age 194 hours and 873 hours it is 1.488×10^{-2} hr^{-1} (205.31%). Figures 43 and 44 provide an illustration for these changes in the rates of drying of samples of CPC at these three levels of age .

From the values of the three rates of drying of samples of CPC mentioned in this section, (i.e. for 80% relative humidity and depth of 6.4 cm) samples processed at the level of age of 873 hours dried the fastest, followed by samples processed at the level of age of 194 hours. The slowest drying samples of CPC were those observed at level of age of 388 hours.

Both of the changes in the rates of drying of samples of CPC between the levels of age 388 hours and 873 hours and for levels of age 194 hours and 873 hours are statistically significant at LSD (0.05). The change in the rates of drying of samples of CPC between the levels of age 194 hours and 388 hours is not statistically significant at

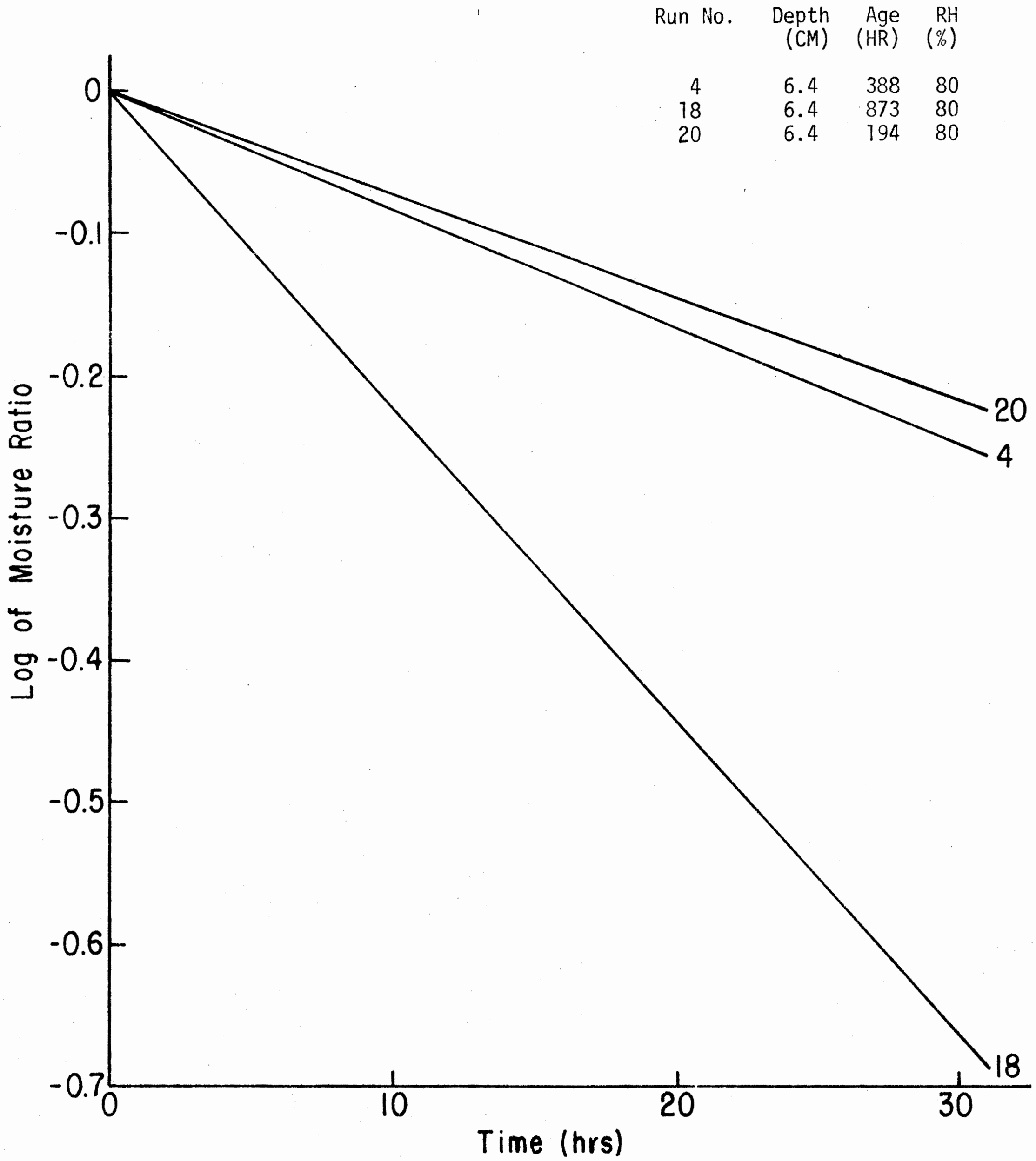


Figure 43. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 80% and Depth of 6.4 cm

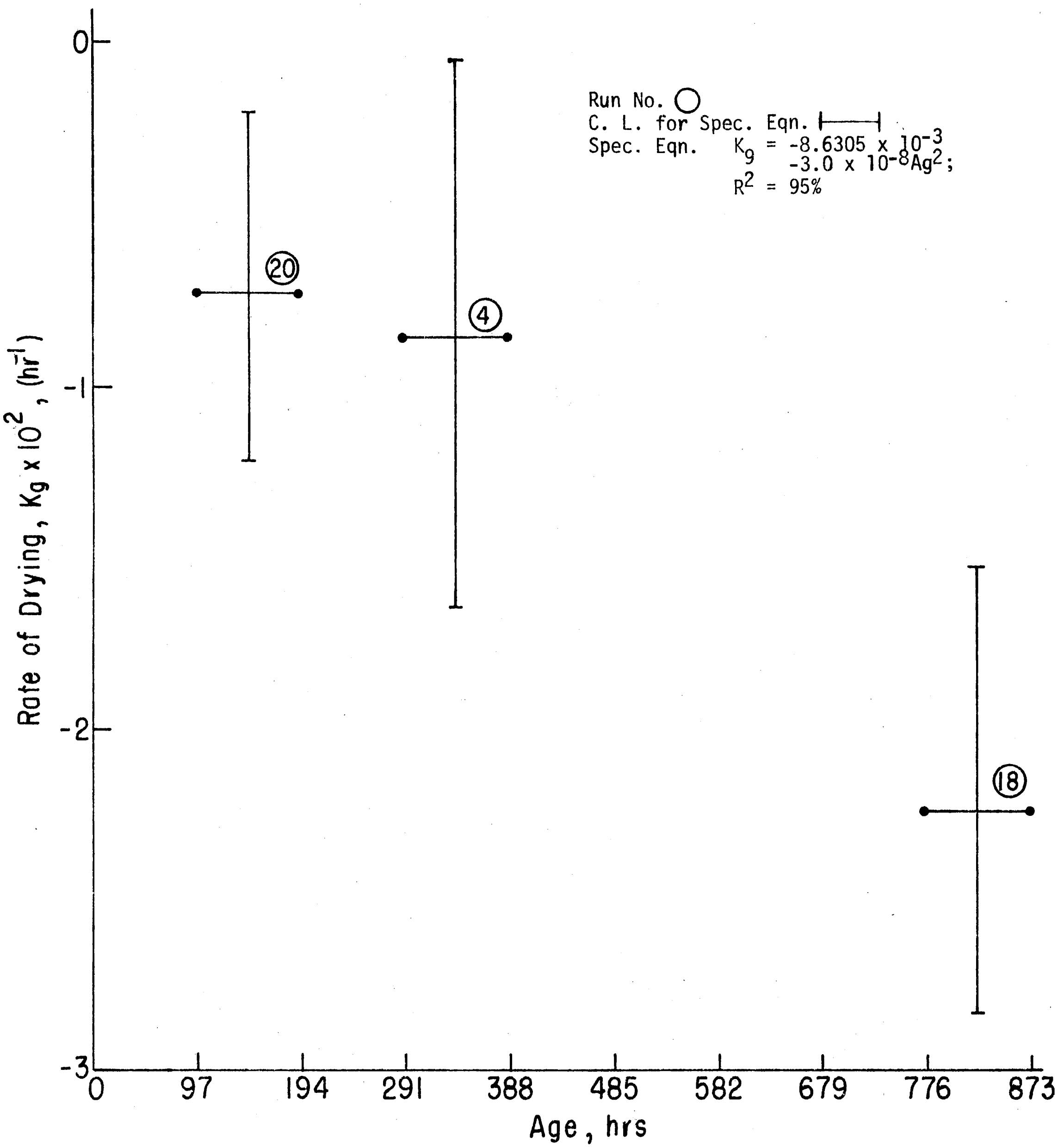


Figure 44. Rate of Drying of CPC as a Function of Age for Relative Humidity of 80% and Depth of 6.4 cm

LSD (0.05).

With respect to the major type of change in the rates of drying of samples of CPC viewed for these three levels of age, a least square regression analysis was performed on the deduced values of rates of drying of the relevant samples of CPC involved. In effect, a quadratic type of change is seen among the large variation of rates of drying of samples of CPC as substantiated by the results from the regression analysis. The specific equation to describe such a change in the rates of drying of samples of CPC for levels of age at 194 hours, 388 hours, and 873 hours is

$$K_9 = -8.6305 \times 10^{-3} - 3.0 \times 10^{-8} (Ag)^2 \qquad [28]$$

The R^2 values for this equation is 95%.

Effect of Age for 80% Relative Humidity and Depth of 10.2 cm

The experimental runs analyzed in this part of the analysis are Nos. 06, 17, and 21. The relevant levels of age of CPC relating to these runs Nos. are 582 hours, 776 hours, and 291 hours, respectively.

The rates of drying of samples of CPC for level of age 582 hours is -7.9638×10^{-3} hr^{-1}, for the level of age of 776 hours it is -1.86114×10^{-2} hr^{-1}; and that for the level of age of 291 hours is -7.6247×10^{-2} hr^{-1}. The difference in the rates of drying of samples of CPC for levels of age at 582 hours and 776 hours is 1.06×10^{2} hr^{-1}; similarly that for levels of age 582 hours and 291 hours is -3.4×10^{-4} hr^{-1}.

A magnitude of 1.1×10^{-2} hr^{-1} is the difference in the rates of drying of samples of CPC when the levels of age compared are 291 hours and 776 hours, respectively. Of the three levels of age considered here, samples of CPC associated with the 291 hours dried the slowest. Samples of CPC related to the level of age of 776 hours seemed to dry the fastest, with samples associated with the 582 hours level of age of CPC took the intermediate position.

The change in the rates of drying of samples of CPC for levels of age 582 hours and 776 hours is statistically significant at LSD (0.05). By a similar token, that for levels of age of 291 hours and 776 hours is also statistically significant at LSD (0.05). No statistical significance at LSD (0.05) was observed for the change in the rates of drying of samples of CPC for levels of age 291 hours and 582 hours, respectively.

The overall major type of change observed in the rates of drying of samples of CPC for these three levels of age is quadratic in nature. This claim is substantiated by a least square regression analysis on the observed values of the rates of drying of samples of CPC at these three pertinent levels of age. The specific equation obtained from the regression analysis is

$$K_{10} = -2.60443 \times 10^{-2} + 9.553 \times 10^{-5} \, Ag - 1.1 \times 10^{-7} \, Ag^2 \qquad [29]$$

This specific equation was able to describe 85% of the total available sums of squares for regression analysis.

Figures 45 and 46 essentially provide a means of perceiving the different changes in the rate of drying of samples of CPC at relative humidity 80% and depth of 10.2 cm.

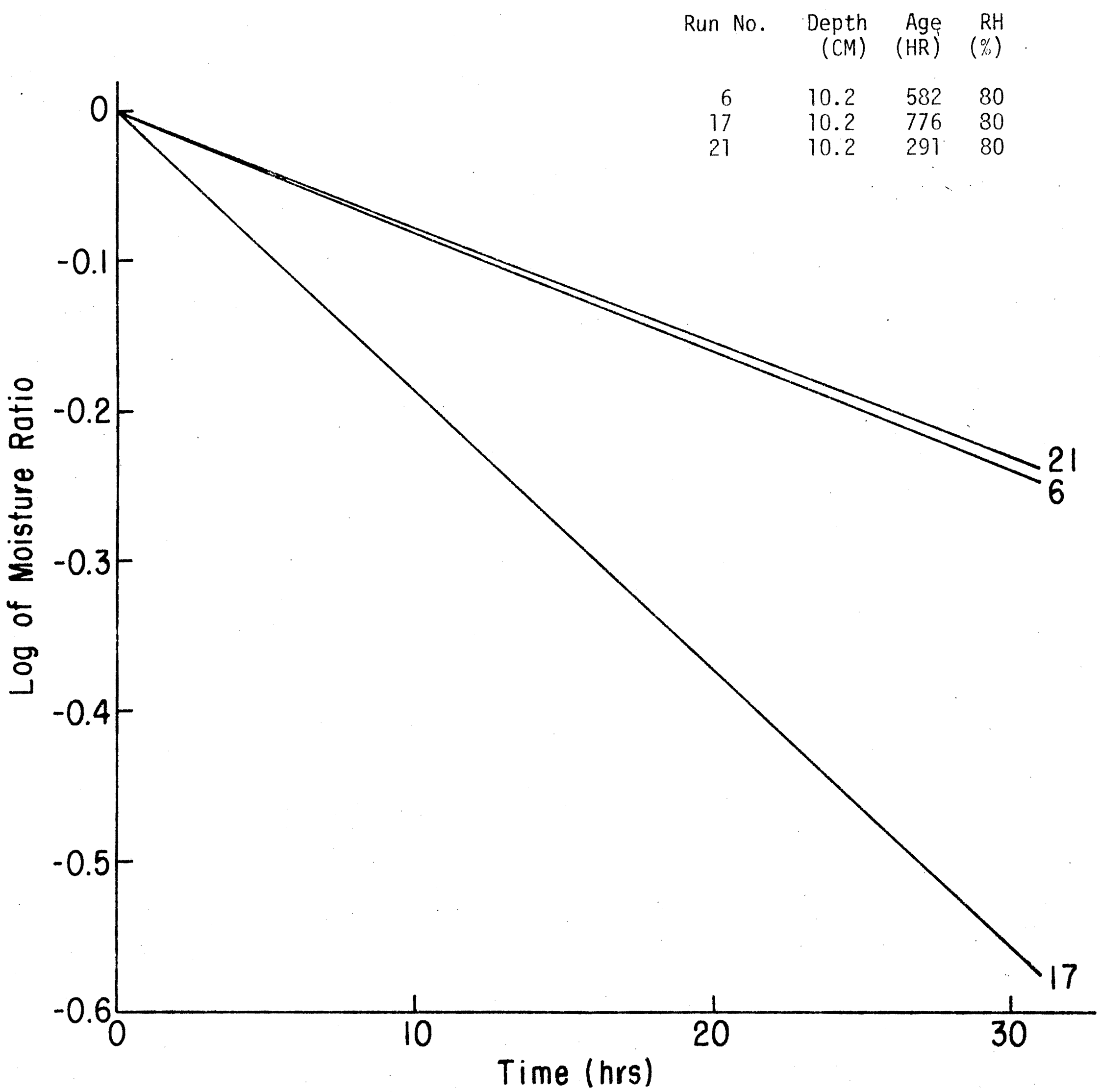


Figure 45. Regression Lines of Log-Moisture Ratio as a Function of Drying Time for Relative Humidity of 80% and Depth of 10.2 cm

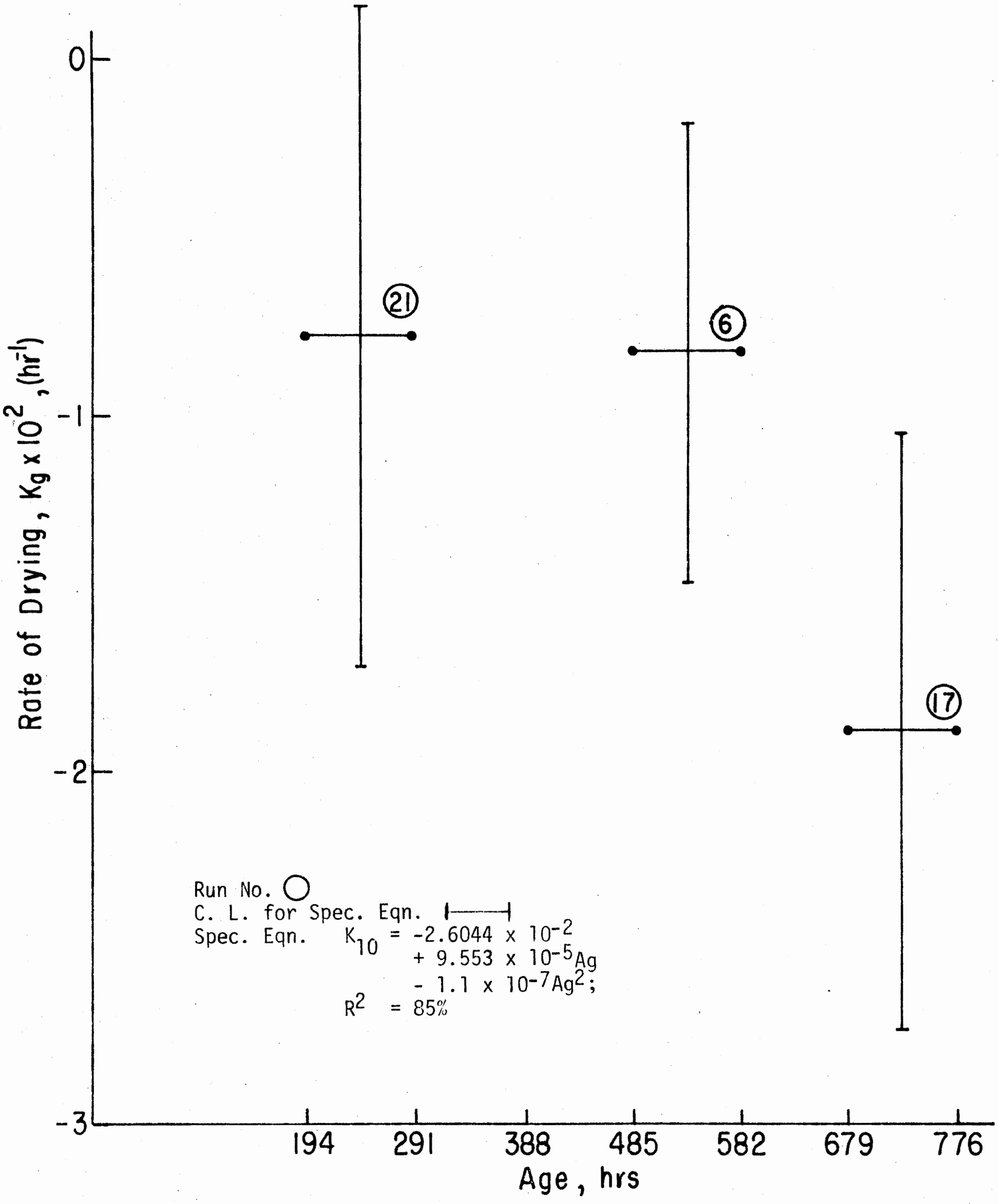


Figure 46. Rate of Drying of CPC as a Function of Age for Relative Humidity of 80% and Depth of 10.2 cm

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

The objective of this study is to determine the rate of drying of CPC as a function of relative humidity, depth and age of CPC.

CPC was obtained from Ralph's Meat Packing Company and stored in stainless steel can containers which were placed in the same room that the experimental equipment was located. Samples of CPC were placed in relevant drying pans, that already have their weights recorded. The weight of the samples was determined and recorded.

The specific drying conditions are set with the aid of the constant temperature - humidity air conditioning unit. The relevant samples of CPC were then placed in the drying compartment, relevant temperatures recorded, as well as pressure readings taken from the micro-manometer. Weights of these samples were obtained at 0, 1, 3, 7, 15, 31 and 88 hours, respectively. The final weights of the samples were obtained by placing the samples in an oven for 24 hours then weighing the bone dry samples on a Sartorious balance. All weight readings were obtained from the Sartorious balance. All observations were recorded. The same procedure was repeated for all experimental designed conditions which is shown on the treatment matrix layout in Appendix A.

The two experimental designs utilized in this study are a latin square design over time to investigate if there is any row or column effect affecting the drying operation. A 3 x 3 matrix arrangement was set up in the drying compartment. The matrix comprised triplicate subsamples for each of three cows. The drying conditions utilized in this study were 20%, 50%, and 80% relative humidity over depth. Seven runs were investigated. The results of this investigation indicated that there was no row or column effect in the drying compartment during drying. This information suggested that there was no need to consider the effects of row or column in the final experimental design.

The major experimental design was a 3 x 3 factorial run in a split plot design over time with age as location. The levels of factor depth were 2.5, 6.4, and 10.2 cm, respectively. The levels of factor relative humidity were 20%, 50%, and 80%, respectively. The levels of age were 97, 194, 291, 388, 485, 582, 679, 776, and 873 hours, respectively. A level of age was applied to each run for each drying condition within a replicate. The variation among cows was used as experimental error in analysis. The variation among cows was used to establish confidence limits on the rate of drying of CPC.

At all times the response variable of the raw data was weight in grams. The reduced response variable for the analysis of data in the major experimental design was the rate of drying of samples of CPC. The final analysis for obtaining the general equation in which the rate of drying of samples of CPC was expressed as a function of relative humidity, depth and age of CPC; was performed on eighty-one rates of drying of CPC values.

The general polynomial equation that was deduced in this study is

$$K_g = -5.0233 \times 10^{-2} + 6.8151 \times 10^{-4}\ Rh + 1.124 \times 10^{-5}\ D + 8.017 \times 10^{-5}\ Ag - 2.86 \times 10^{-6}\ (Rh)^2$$

$$-6.0 \times 10^{-8} (Ag)^2 - 1.8 \times 10^{-7} (Rh)(D)$$
$$- 4.2 \times 10^{-7} (Rh)(Ag)$$

The regression coefficient for this equation is 66%.

Conclusions

1. The rate of drying of CPC is expressed as a second degree polynomial function of relative humidity, age and depth.
2. There were interaction effects which were as significant as the main effects.
3. The order of magnitude of most effect on the rate of drying of CPC was age, relative humidity, and depth.
4. To achieve highest drying rate, dry samples of CPC at 4-7 cm thick in 20-50% relative humidity environment for high age.
5. Slowest drying rates are achieved for depth of about 10 cm for fresh CPC and relative humidity of drying environment at 80%.
6. Irrespective of depth of samples of CPC, the rate of drying of CPC is the same for medium and old ages of CPC for fast drying potential.
7. For the thickest depth investigated within the medium ranges of age of CPC, the rate of drying of samples of CPC is essentially the same irrespective of slow, medium or fast drying potential.
8. With medium drying potential for thin and medium depth, medium aged samples of CPC seem to dry faster than fresh samples of CPC taken from the same source. There is a constant change in the rate of drying for these constraints.
9. When very thick depth samples of CPC are dried in medium range drying potential, the rate of drying of CPC is the same irrespective of

fresh or medium age of CPC.

10. With slow drying potential and irrespective of the depth of samples of CPC, the older the CPC, the faster is the drying rate. There is a progressive change in the rate of drying for these conditions.
11. When old ages of samples of CPC are taken from the same source and dried in a fast drying potential medium, the rate of drying for thin depth samples is higher than for medium depth.
12. For fresh CPC there is no change in the rate of drying of CPC for medium drying potential, irrespective of the depth of CPC.

Recommendations for Future Study

The following recommendations for future study are suggested:

1. Experimental determination into the nature of the water bonding properties of the basic structure of CPC.
2. Experimental investigation into the shrinkage and plastic behaviour of CPC.
3. Determination of the mechanism which is responsible for moisture release at different periods during drying at various controlled conditions. Such a study is to be performed in two stages. The investigation into whether diffusion mechanism is controlling moisture transfer is to be conducted in the first stage. For the second stage, the study should be confined to the determination of suction potentials or internal frictional resistance to moisture flow through CPC.
4. Determination of the rates of drying of CPC with consideration to age as the most important variable.

SELECTED BIBLIOGRAPHY

1. Anthony, W. B. "Feeding Value of Cattle Manure for Cattle." Journal of Animal Science, 30, 274-277, 1970.

2. ASHRAE Handbook of Fundamentals. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1972.

3. Bartee, E. M. Engineering Experiment Design Fundamentals. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1970.

4. Baumann, D. J. "Elimination of Water Pollution by Packinghouse Animal Paunch and Blood." EPA Water Pollution Control Research Series Report No. 12060, FDS 11/71, 1971.

5. Boruff, C. S. "Stabilization of Paunch Manures and Packinghouse Screenings." Industrial and Engineering Chemistry, 25, 703-6, June, 1933.

6. Carrier, W. H. "The Theory of Atmospheric Evaporation - with Special Reference to Compartment Dryers." Industrial Engineering Chemistry, 13, 432, 1921.

7. Chancery, No. G19, 425 Illinois Circuit Court. "Winnebago County Versus Fluegal." Winnebago Co., January 31, 1970.

8. Coddling, J. H. "Treatment of Abattoir Wastes." Nature, 146, 9-12, (1040) July, 1940.

9. Draper, N. R., and H. Smith. Applied Regression Analysis. John Wiley and Sons, Inc., New York, 1966.

10. Eldridge, E. F. Industrial Waste Treatment Practices. 265-82, McGraw-Hill Book Co., Inc., New York, 1942.

11. Farmer, D. M., and S. C. Yin. "Problems, Properties, Disposal Practices, and Potential Uses of Cattle Paunch Manure." ASAE Paper No. 73-403, 1973.

12. Hammond, J. C. "Cow Manure as a Source of Certain Vitamins for Growing Chickens." Poultry Science, 21, 554-559, 1942.

13. Henderson, S. M., and R. L. Perry. Agricultural Process Engineering. Bros. Inc., Ann Arbor, MI, 1966.

14. Kirkwood, K. C., and T. J. Mitchell. "Predictions of the Drying Times of Porous Granular and Fibrous Materials." Journal of Applied Chemistry, 256, June 15, 1956.

15. McQuiston, F. C., and J. D. Parker. Heating, Ventilating, and Air Conditioning Analysis and Design. John Wiley and Sons, Inc., New York, 1977.

16. Nells, J. H., and P. R. Krige. "The Disposal of Solid Abattoir Waste by Composting." Water Research Pergamon Press, 5, 1177-1189, Britain, 1971.

17. Perry, R. H., and C. H. Chilton. Chemical Engineers' Handbook. McGraw-Hill Book Co., Inc., New York, 1973.

18. S. W. 2nd. 784; MO. Bower Versus Hog Builders Inc., 461, 1970.

19. Sherwood, T. K. "Mechanism of the Drying of Pulp and Paper." Industrial Engineering Chemistry, 22, 132, 1930.

20. Sherwood, T. K. "The Drying of Solids - I." Industrial Engineering Chemistry, 21, 12, 1929.

21. Sherwood, T. K. "Application of Diffusion Equations." Industrial Engineering Chemistry, 24, 307, 1932.

22. Schultz, K. L. "Continuous Thermophylic Composting." Compost. Sci., 3(1), 22-34, 1962.

23. Simmonds, W. H. C., G. T. Ward, and E. McEwen. "The Drying of Wheat Grain, Part II, Through Drying of Deep Beds." Trans. Instu. Chem. Engr., 31, 265, 1953.

24. Smith, J. L., and Gold, R. C. "Development of a Sub-surface Injector for Total Recycling of Sewage Sludge." Experiment Station Report No. PR-72-42, Colorado State University, November, 1972.

25. Snedecor, G. W., and W. Cochran. Statistical Methods. Iowa State University Press, Ames, Iowa, 1966.

26. Summerfelt, R. C., and S. C. Yin. "Paunch Manure as a Feed Supplement in Channel Catfish Farming." EPA Environmental Technology Series, EPA - 660/2-74-046, May, 1974.

27. Steel, R. G. D., and J. H. Torrie. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York, 1960.

28. Steffen, A. J. "What to Do About Paunch Wastes." Proceedings of the Third Industrial Waste Conference, 268-71, Purdue University, Lafayette, Indiana, 1947.

29. Unger, A. G. "Energy Utilization in the Leading Energy Consuming Food Processing Industries." Food Technology, 29, 33-45, 1975.

30. Wells, E. D., M. L. Esmay, and F. W. Bakker-Arkema. "Constant Rate Drying of Chicken Excreta." ASAE Paper No. 73-409, 1973.

31. Witherow, J. L. A Method of Manure Disposal for a Beef Packing Operation. First Interim Technical Report by Procedyne Corporation, 221 Somerset St., New Brunswick, New Jersey 08903, Project 120600 EOF, EPA, 1977.

32. Witherow, J. L., S. C. Yin, and D. M. Farmer. "National Meat Packing Waste Management Research and Development Program." Environmental Protection Technology Series, EPA-R2-73-178, 33, 1973.

33. Witherow, J. L. "Paunch Handling and Processing." PNERL Working Paper No. 13, Industrial Wastes Branch, Pacific Northwest Environmental Research Laboratory, National Environmental Research Center, Corvallis, Oregon 97330, EPA, July, 1974.

34. Yin, S. C., and J. L. Witherow. "Cattle Paunch Contents as Fish Feed Supplement: Feasibility Studies." Proceedings of Third National Symposium on Food Processing Wastes, Environmental Protection Technology Series, EPA-72-018, 401-408, 1972.

APPENDIX A

TREATMENT APPLICATION MATRIX

TABLE IV

TREATMENT APPLICATION MATRIX

RH (%) \ DEPTH (cm)	2.5			6.4			10.2		
	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW
20	08	776	1 2 3	07	679	1 2 3	09	873	1 2 3
	14	485	4 5 6	13	388	4 5 6	15	582	4 5 6
	25	679	7 8 9	26	776	7 8 9	27	873	7 8 9
50	01	97	1 2 3	02	194	1 2 3	24	582	7 8 9
	12	291	4 5 6	10	97	4 5 6	03	291	1 2 3
	22	388	7 8 9	23	485	7 8 9	11	194	4 5 6
80	05	485	1 2 3	04	388	1 2 3	06	582	1 2 3
	16	679	4 5 6	18	873	4 5 6	17	776	4 5 6
	19	97	7 8 9	20	194	7 8 9	21	291	7 8 9

APPENDIX B

COMPUTER PROGRAMS AND RELEVANT PRINTOUTS

COMPUTER PROGRAMME NO. 1

```
TITLE'DRYING CPC USING LATIN SQUARE DESIGN OVER TIME';
LATIN  SQUARE DESIGN OVER TIME';
DATA WIFE; INPUT NAME $ 1-4 DEPT $ 6-9 AFS $ 11-13 ROW 15 COW 16 COL 18
RUN 20 RH 22-23 DEPTH $ 25-27 THKNS 25-27 SAMP 29 CARD 31 CONT 33-37 2
INWT 39-43 2 WTHR1 46-50 2 WTHR3 52-56 2 WTHR7 58-62 2 WTHR15 64-68 2
WTHR31 70-74 2 WTHR63 76-80 2  #2 ROW2 15 COW2 16 COL2 18 RUN2 20
RH2 22-23 DEPTH2 $ 25-27 THKNS2 25-27 SAMP2 29 CARD2 31 DAY 33-34 MTH 36-37
YR 39-40
AGE  42-47 2 CONTWT 49-52 2 ORGWT  54-58 2 FNLWT 60-64 2  AIR TEMP  72-74 1
AIRFLW 76-77 ;
IF RUN¬= RUN2 OR RH¬=RH2 OR DEPTH¬=DEPTH2 OR SAMP¬=SAMP2 OR CARD¬=1 OR CARD2¬=2
OR ROW¬=ROW2 OR COL¬=COL2 OR COW¬=COW2
THEN PUT RUN RUN2 RH RH2 DEPTH DEPTH2 SAMP SAMP2 CARD CARD2
ROW ROW2 COW COW2 COL COL2;
HR1 = AGE;  HR2 = HR1*HR1;
SMPWT = INWT-CONT ;
MOIST = ORGWT-FNLWT;  WET_SMP=ORGWT-CONTWT;
DRY_SMP = WET_SMP - MOIST;
MC_WB = 100*MOIST/WET_SMP;  MC_DB = 100*MOIST/DRY_SMP;
INWT = INWT-CONT;  WTHR1 = WTHR1-CONT;  WTHR3=WTHR3-CONT;  WTHR7 = WTHR7-CONT;
WTHR15 = WTHR15-CONT;  WTHR31 = WTHR31-CONT;  WTHR63 = WTHR63-CONT;
MCIN = MC_WB;
MC_IN=((MCIN*100)/(100-MCIN));
MCHR01=    MC_WB-(100*(INWT-WTHR1   ))/INWT;
MCHR03=    MC_WB-(100*(INWT-WTHR3   ))/INWT;
MCHR07=    MC_WB-(100*(INWT-WTHR7   ))/INWT;
MCHR15=    MC_WB-(100*(INWT-WTHR15  ))/INWT;
MCHR31=    MC_WB-(100*(INWT-WTHR31  ))/INWT;
MCHR63=    MC_WB-(100*(INWT-WTHR63  ))/INWT;
MCH_63=(MC_HR63-(0.0165*MC_HR63));
MRHR00=((MC_IN-MCH_63)/(MC_IN-MCH_63));
MRHR01=((MC_HR01-MCH_63)/(MC_IN-MCH_63));
MRHR03=((MC_HR03-MCH_63)/(MC_IN-MCH_63));
MRHR07=((MC_HR07-MCH_63)/(MC_IN-MCH_63));
MRHR15=((MC_HR15-MCH_63)/(MC_IN-MCH_63));
MRHR31=((MC_HR31-MCH_63)/(MC_IN-MCH_63));
MRHR63=((MC_HR63-MCH_63)/(MC_IN-MCH_63));
T=0  ;MR=MRHR00;LGMR=LOG10(MRHR00+0.001);  T2=T*T; LGT=.; LGT2=.; TIME='00';
OUTPUT;
T=1  ;MR =MRHR01;LGMR=LOG10(MRHR01);  T2=T*T; LGT=.; LGT2=.; TIME='01';OUTPUT;
T=3  ;MR =MRHR03;LGMR=LOG10(MRHR03);  T2=T*T; LGT=.; LGT2=.; TIME='03';OUTPUT;
T=7  ;MR =MRHR07;LGMR=LOG10(MRHR07);  T2=T*T; LGT=.; LGT2=.; TIME='07';OUTPUT;
T=15;MR =MRHR15;LGMR=LOG10(MRHR15);  T2=T*T;LGT=.; LGT2=.; TIME='15';OUTPUT;
T=31;MR =MRHR31;LGMR=LOG10(MRHR31);  T2=T*T;LGT=.; LGT2=.; TIME='31';OUTPUT;
T=63;MR =MRHR63;LGMR=LOG10(MRHR63);  T2=T*T;LGT=.; LGT2=.; TIME='63';OUTPUT;
CARDS;
PROC SCATTER DATA=WIFE; BY ROW COW;
PLOT MR*T=ROW;
PLOT LGMR*T=ROW;
PLOT LGMR*LGT=ROW;
PLOT MR*LGT=ROW;
PROC SAS 72 DATA=WIFE;
PARMCARDS4;
DATA ONE;
SET PASS;
PROC SORT DATA=ONE; BY RUN TIME;
PROC ANOVA DATA=ONE; CLASSES ROW COL COW TIME; BY RUN;
MODEL MR LGMR= ROW|COL COW TIME COW*TIME ROW*TIME COL*TIME ROW*COL*TIME;
POOL 'ROW*COL-COW' ROW*COL-COW;
POOL 'ROW*COL*TIME-COW*TIME' ROW*COL*TIME-COW*TIME;
DATA TWO; SET ONE; IF RUN ¬= 1 THEN DELETE;
PROC ANOVA DATA=TWO; CLASSES ROW COL COW; BY RUN TIME;
MODEL MR LGMR = ROW|COL COW ;POOL 'ROW*COL-COW' ROW*COL-COW;
;;;;
$ENDLIST
```

COMPUTER PROGRAMME NO. 2

```
TITLE'PRELIMINARY RUN TO TEST VARIABLES AND A 7_LAG OPERATION';
CARDS;
PROC PRINT DATA = WIFE;
VARIABLES RNO CWNO SSPLE DRTM FNLWT MC_EQ MC_DB MC_DB_00 MC_DB_01 MC_DB_03
MC_DB_07 MC_DB_15 MC_DB_31; MC_DB_63;
DATA WIFE2;
SET WIFE; IF DRTM LT 63 THEN DELETE;
HRS='00'; TIME='00'; M_RATIO=(MC_DB_01-MC_EQ)/(MC_DB_01-MC_EQ);
LG_MR=LOG(M_RATIO); MCDB=MC_DB_01; LG_MCDB=LOG(MCDB); OUTPUT;
HRS='00'; TIME='01'; M_RATIO=(MC_DB_03-MC_EQ)/(MC_DB_01-MC_EQ);
LG_MR=LOG(M_RATIO); MCDB=MC_DB_03; LG_MCDB=LOG(MCDB); OUTPUT;
HRS ='00'; TIME='03'; M_RATIO=(MC_DB_07-MC_EQ)/(MC_DB_01-MC_EQ);
LG_MR=LOG(M_RATIO); MCDB=MC_DB_07; LG_MCDB=LOG(MCDB); OUTPUT;
HRS='00'; TIME='07'; M_RATIO=(MC_DB_15-MC_EQ)/(MC_DB_01-MC_EQ);
LG_MR=LOG(M_RATIO); MCDB=MC_DB_15; LG_MCDB=LOG(MCDB);OUTPUT;
HRS='00'; TIME='15'; M_RATIO=(MC_DB_31-MC_EQ)/(MC_DB_01-MC_EQ);
LG_MR=LOG(M_RATIO); MCDB=MC_DB_31; LG_MCDB=LOG(MCDB); OUTPUT;
HRS='00'; TIME='31'; M_RATIO=(MC_DB_00-MC_EQ)/(MC_DB_01-MC_EQ);
LG_MR=LOG(M_RATIO); MCDB=MC_DB_63; LG_MCDB=LOG(MCDB); OUTPUT;
PROC PRINT DATA = WIFE2;
VARIABLES RH DEPTH AGML RNO CWNO SSPLE DRTM HRS TIME M_RATIO LG_MR MCDB LG_MCDB
Q;
$ENDLIST
```

COMPUTER PROGRAMME NO. 3

```
TITLE 'CALCULATING VALUES OF SLOPES OF LOG OF MOISTURE RATIO VERSUS DRYING TIME
DATA WIFE;INPUT NAME $ DEPT  $ 6-9 AES $ 11-13 YR 15-16 MTH 18-19 DAY 21-22
#1 SSPLE 24-25 DRTM 27-28 RNO 30-31 CRDNO 33-34 RH 36-37 CWNO 10    CL 42-43
#1 RW 45-46 AGML 48-50 DEPTH 52-55 2 CONWT 57-61 2 FNLWT 63-67 2 EQWT 69-73 2
#1 TW5 75-76 TW6 78-79
#2 YR2 15-16 MTH2 18-19 DAY2 21-22 SSPLE2 24-25 DRTM2 27-28 RNO2 30-31
#2 CRDNO2 33-34 BP 36-39 2 TW7 41-42 TW8 44-45 TW11 47-48 TA3 50-51 TA9 53-54
#2 TA10 56-57 TA14 59-60 RHDCT 62-63 RHCHB 65-66 RHRM 68-69 MPD1 71-74 3
#2 MPD2 76-79 3 CWNO2 10
#3 YR3 15-16 MTH3 18-19 DAY3 21-22 SSPLE3 24-25 DRTM3 27-28 RNO3 30-31
#3 CRDNO3 33-34 MPD3 36-39 3 MPD4 41-44 3 MPD5 46-49 3 MPD6 51-54 3 MPD7 56-59 3
#3 MPD8 61-64 3 MPD9 66-69 3 MPD10 71-74 3 MPD11 76-79 3 CWNO3 10
#4 YR4 15-16 MTH4 18-19 DAY4 21-22 SSPLE4 24-25 DRTM4 27-28 RNO4 30-31
#4 YR ¬=YR2 OR YR¬=YR3 OR YR¬=YR4 OR MTH¬=MTH2 OR MTH¬=MTH3 OR MTH¬=MTH4 OR
DAY¬=DAY2 OR DAY¬= DAY3 OR DAY¬=DAY4 OR SSPLE¬=SSPLE2 OR SSPLE¬=SSPLE3 OR
SSPLE¬=SSPLE4 OR DRTM¬=DRTM2 OR DRTM¬=DRTM3 OR DRTM¬=DRTM4 OR RNO¬=RNO2 OR
RNO¬=RNO3 OR RNO¬=RNO4 OR CRDNO¬=1 OR CRDNO2¬=2 OR CRDNO3¬=3 OR CRDNO4¬=4 OR
CWNO¬=CWNO2 OR CWNO¬=CWNO3 OR CWNO¬=CWNO4
THEN PUT YR YR2 YR3 YR4 MTH MTH2 MTH3 MTH4 DAY DAY2 DAY3 DAY4 SSPLE SSPLE2
SSPLE3 SSPLE4 DRTM DRTM2 DRTM3 DRTM4 RNO RNO2 RNO3 RNO4 CRDNO CRDNO2 CRDNO3
CRDNO4 CWNO CWNO2 CWNO3 CWNO4;
DROP YR2 YR3 YR4 MTH2 MTH3 MTH4 DAY2 DAY3 DAY4 SSPLE2 SSPLE3 SSPLE4 DRTM2 DRTM3
DRTM4 RNO2 RNO3 RNO4 CRDNO2 CRDNO3 CRDNO4 CWNO2 CWNO3 CWNO4;
TAVA=((((TA3+TA9+TA10+TA14)/4)*9)/5)+32;A01=0.15342;A02=0.26843;A03=0.21729;
TAWA=((((TW5+TW6+TW7+TW8+TW11)/5)*9)/5)+32;A04=0.16616;A05=0.01158;A06=0.0783;
GCST= ((RH=20)+(RH=50))*53.349+(RH=80)*85.780;
DSTY=((BP*0.491*144)/(GCST*(TAVA+460)));
A12=A01;A11=A02;A10=A03;A09=A04;A08=A05;A07=A06;
Q01=A01*(1096.5*SQRT(MPD1  /DSTY));Q02=A02*(1096.5*SQRT(MPD2  /DSTY));
Q03=A03*(1096.5*SQRT(MPD3  /DSTY));Q04=A04*(1096.5*SQRT(MPD4  /DSTY));
Q05=A05*(1096.5*SQRT(MPD5  /DSTY));Q06=A06*(1096.5*SQRT(MPD6  /DSTY));
Q07=A07*(1096.5*SQRT(MPD7  /DSTY));Q08=A08*(1096.5*SQRT(MPD8  /DSTY));
Q09=A09*(1096.5*SQRT(MPD9  /DSTY));Q10=A10*(1096.5*SQRT(MPD10/DSTY));
Q11=A11*(1096.5*SQRT(MPD11/DSTY));Q12=A12*(1096.5*SQRT(MPD12/DSTY));
Q=((Q01+Q02+Q03+Q04+Q05+Q06+Q07+Q08+Q09+Q10+Q11+Q12)*0.025)/12;
WETWT= SMPWT-CONWT;DRYWT=FNLWT-CONWT;MOIST=WETWT-DRYWT;MOIS_EQ=EQWT-FNLWT;
MC_DB=100*MOIST/DRYWT;EQ_WT=EQWT-CONWT;
EQD_WT=EQ_WT-MOIS_EQ;
MC_EQ=100*MOIS_EQ/EQD_WT;
MC_DB_00=MC_DB;
RETAIN MC_DB_63 MC_DB_31 MC_DB_15 MC_DB_07 MC_DB_03 MC_DB_01 MC_DB_00 MC_DB;
OUTPUT;
MC_DB_00=MC_DB_01; MC_DB_01=MC_DB_03; MC_DB_03=MC_DB_07; MC_DB_07=MC_DB_15:
MC_DB_15=MC_DB_31; MC_DB_31=MC_DB_63;
MC_DB_63 = MC_DB;
CURVES';
HRS='00',TIME=00;      M_RATIO=(MC_DB_01-MC_EQ)/(MC_DB_01-MC_EQ);T2=TIME*TIME;
LG_MR=LOG10(M_RATIO); MCDB=MC_DB_01; LG_MCDB=LOG10(MCDB);
LG_TIME=LOG10(TIME+0.001); LG_T2=LOG10(T2+0.001);OUTPUT;
HRS='01'; TIME= 01 ; M_RATIO=(MC_DB_03-MC_EQ)/(MC_DB_01-MC_EQ); T2=TIME*TIME;
LG_MR=LOG10(M_RATIO); MCDB=MC_DB_03; LG_MCDB=LOG10(MCDB);
LG_TIME=LOG10(TIME+0.001); LG_T2=LOG10(T2); OUTPUT;
HRS='03'; TIME= 03 ; M_RATIO=(MC_DB_07-MC_EQ)/(MC_DB_01-MC_EQ); T2=TIME*TIME;
```

COMPUTER PROGRAMME NO. 3 (CONT'D)

```
LG_MR=LOG10(M_RATIO); MCDB=MC_DB_07; LG_MCDB=LOG10(MCDB);
LG_TIME=LOG10(TIME+0.001); LG_T2=LOG10(T2); OUTPUT;
HRS='07'; TIME= 07 ; M_RATIO=(MC_DB_15-MC_EQ)/(MC_DB_01-MC_EQ); T2=TIME*TIME;
LG_MR=LOG10(M_RATIO); MCDB=MC_DB_15; LG_MCDB=LOG10(MCDB);
LG_TIME=LOG10(TIME+0.001); LG_T2=LOG10(T2); OUTPUT;
HRS='15'; TIME= 15 ; M_RATIO=(MC_DB_31-MC_EQ)/(MC_DB_01-MC_EQ); T2=TIME*TIME;
LG_MR=LOG10(M_RATIO); MCDB=MC_DB_31; LG_MCDB=LOG10(MCDB);
LG_TIME=LOG10(TIME+0.001); LG_T2=LOG10(T2); OUTPUT;
HRS='31'; TIME= 31 ; M_RATIO=(MC_DB_63-MC_EQ)/(MC_DB_01-MC_EQ); T2=TIME*TIME;
LG_MR=LOG10(M_RATIO); MCDB=MC_DB_63; LG_MCDB=LOG10(MCDB);
LG_TIME=LOG10(TIME+0.001); LG_T2=LOG10(T2); OUTPUT;
CARDS
PROC SORT DATA=WIFE2; BY RH DEPTH RNO AGML CWNO;
PROC GLM DATA=WIFE2;                          BY RH DEPTH RNO AGML CWNO;
MODEL LG_MR  =        TIME / NOINT SOLUTION;
PROC GLM DATA=WIFE2;                          BY RH DEPTH RNO AGML CWNO;
MODEL LG_MR  =        TIME T2 / NOINT SOLUTION;
$ENDLIST
```

COMPUTER PROGRAMME NO. 4

```
TITLE 'ANALYSIS TO FIND THE OVERALL PREDICTION EQUATION FROM 81 B1 VALUES EACH
OF WHICH WAS OBTAINED FROM THE SLOPE OF LOG_MR AS A FUNCTION OF TIME';
DATA WIFE; INPUT NAME $ 1-4 DEPT $ 6-9 AES $ 11-13 YR 15-16 MTH 18-19 DAY 21-22
RH 24-25 DEPTH 27-30 RNO 32-33 AGML 35-37 CWNO 39 COW 41 CRDNO 43 B1 45-55
A1 57-67 A2 69-79 REP 80;
CARDS;

PROC GLM DATA=WIFE;
MODEL B1=RH DEPTH AGML RH*RH AGML*AGML RH*DEPTH RH*AGML  / SOLUTION P CLI;
ID RH DEPTH AGML CWNO;
```

COMPUTER PROGRAMME NO. 4 (CONT'D)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	0.00108159	0.00015451	19.94	0.0001	0.656617	23.4200
ERROR	73	0.00056563	0.00000775		STD DEV		B1 MEAN
CORRECTED TOTAL	80	0.00164721			0.00278358		-0.01188545

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00004932	6.37	0.0138	1	0.00021580	27.85	0.0001
DEPTH	1	0.00002490	3.21	0.0771	1	0.00016804	21.69	0.0001
AGML	1	0.00003859	4.98	0.0287	1	0.00074747	96.47	0.0001
RH*RH	1	0.00000019	0.02	0.8752	1	0.00006131	7.91	0.0063
AGML*AGML	1	0.00044484	57.41	0.0001	1	0.00076656	98.93	0.0001
RH*DEPTH	1	0.00024866	32.09	0.0001	1	0.00013953	18.01	0.0001
RH*AGML	1	0.00027508	35.50	0.0001	1	0.00027508	35.50	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.05023308	-10.76	0.0001	0.00466905
RH	0.00068151	5.28	0.0001	0.00012914
DEPTH	0.00001124	4.66	0.0001	0.00000241
AGML	0.00008017	9.82	0.0001	0.00000816
RH*RH	-0.00000286	-2.81	0.0063	0.00000102
AGML*AGML	-0.00000006	-9.95	0.0001	0.00000001
RH*DEPTH	-0.00000018	-4.24	0.0001	0.00000004
RH*AGML	-0.00000042	-5.96	0.0001	0.00000007

OBSERVATION	RH	DEPTH	AGML	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	50	254	97	-0.01424331	-0.01757739	0.00333408	-0.02340928	-0.01174551
2	50	254	97	-0.01352840	-0.01757739	0.00404899	-0.02340928	-0.01174551
3	50	254	97	-0.01595741	-0.01757739	0.00161998	-0.02340928	-0.01174551
4	50	635	194	-0.01059584	-0.01269953	0.00210369	-0.01836730	-0.00703176
5	50	635	194	-0.01041867	-0.01269953	0.00228086	-0.01836730	-0.00703176
6	50	635	194	-0.01317161	-0.01269953	-0.00047208	-0.01836730	-0.00703176
7	50	1016	291	-0.00986691	-0.00894383	-0.00092308	-0.01465671	-0.00323096
8	50	1016	291	-0.00844334	-0.00894383	0.00050049	-0.01465671	-0.00323096
9	50	1016	291	-0.00865453	-0.00894383	0.00028930	-0.01465671	-0.00323096
10	80	635	388	-0.00985222	-0.00698429	-0.00286793	-0.01269237	-0.00127620
11	80	635	388	-0.00733433	-0.00698429	-0.00035004	-0.01269237	-0.00127620
12	80	635	388	-0.00792509	-0.00698429	-0.00094080	-0.01269237	-0.00127620
13	80	254	485	-0.00705382	-0.00623792	-0.00081590	-0.01208793	-0.00038791
14	80	254	485	-0.00550763	-0.00623792	0.00073029	-0.01208793	-0.00038791
15	80	254	485	-0.00585948	-0.00623792	0.00037844	-0.01208793	-0.00038791

COMPUTER PROGRAMME NO. 4 (CONT'D)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

OBSERVATION	RH	DEPTH	AGML	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
16	80	1016	582	-0.00886418	-0.01041446	0.00155028	-0.01620544	-0.00462349
17	80	1016	582	-0.00828743	-0.01041446	0.00212703	-0.01620544	-0.00462349
18	80	1016	582	-0.00673990	-0.01041446	0.00367456	-0.01620544	-0.00462349
19	20	635	679	-0.01261176	-0.01166061	-0.00095115	-0.01731803	-0.00600319
20	20	635	679	-0.01208545	-0.01166061	-0.00042484	-0.01731803	-0.00600319
21	20	635	679	-0.01277221	-0.01166061	-0.00111160	-0.01731803	-0.00600319
22	20	254	776	-0.01530514	-0.01600708	0.00070194	-0.02188032	-0.01013383
23	20	254	776	-0.01497923	-0.01600708	0.00102785	-0.02188032	-0.01013383
24	20	254	776	-0.01691602	-0.01600708	-0.00090894	-0.02188032	-0.01013383
25	20	1016	873	-0.01464989	-0.01279046	-0.00185943	-0.01665543	-0.00892549
26	20	1016	873	-0.01317228	-0.01279046	-0.00038182	-0.01665543	-0.00892549
27	20	1016	873	-0.01058055	-0.01279046	0.00220991	-0.01665543	-0.00892549
28	50	635	97	-0.01334397	-0.01676331	0.00341934	-0.02256296	-0.01096365
29	50	635	97	-0.02307589	-0.01676331	-0.00631258	-0.02256296	-0.01096365
30	50	635	97	-0.01496084	-0.01676331	0.00180247	-0.02256296	-0.01096365
31	50	1016	194	-0.00971559	-0.01186545	0.00214986	-0.01761892	-0.00615198
32	50	1016	194	-0.01969577	-0.01186545	-0.00781032	-0.01761892	-0.00615198
33	50	1016	194	-0.01679130	-0.01186545	-0.00492585	-0.01761892	-0.00615198
34	50	254	291	-0.00954603	-0.01057200	0.00102597	-0.01628228	-0.00486172
35	50	254	291	-0.01112342	-0.01057200	-0.00055142	-0.01628228	-0.00486172
36	50	254	291	-0.01184684	-0.01057200	-0.00127484	-0.01628228	-0.00486172
37	20	635	388	-0.00843468	-0.01403944	0.00560476	-0.01909439	-0.00898449
38	20	635	388	-0.01190006	-0.01403944	0.00213938	-0.01909439	-0.00898449
39	20	635	388	-0.01113119	-0.01403944	0.00290825	-0.01909439	-0.00898449
40	20	254	485	-0.01939272	-0.01501941	-0.00437331	-0.02086214	-0.00917668
41	20	254	485	-0.01511424	-0.01501941	-0.00009483	-0.02086214	-0.00917668
42	20	254	485	-0.01766694	-0.01501941	-0.00264753	-0.02086214	-0.00917668
43	20	1016	582	-0.00760328	-0.00843630	0.00083302	-0.01434254	-0.00253006
44	20	1016	582	-0.01162540	-0.00843630	-0.00318910	-0.01434254	-0.00253006
45	20	1016	582	-0.01280321	-0.00843630	-0.00436691	-0.01434254	-0.00253006
46	80	254	679	-0.00667338	-0.01064551	0.00397213	-0.01652768	-0.00476334
47	80	254	679	-0.00950638	-0.01064551	0.00113913	-0.01652768	-0.00476334
48	80	254	679	-0.01050269	-0.01064551	0.00014282	-0.01652768	-0.00476334
49	80	1016	776	-0.01392985	-0.01706638	0.00313653	-0.02295290	-0.01117987
50	80	1016	776	-0.02109327	-0.01706638	-0.00402689	-0.02295290	-0.01117987
51	80	1016	776	-0.02081099	-0.01706638	-0.00374461	-0.02295290	-0.01117987
52	80	635	873	-0.01918199	-0.02080868	0.00162669	-0.02683674	-0.01478061
53	80	635	873	-0.02209108	-0.02080868	-0.00128240	-0.02683674	-0.01478061
54	80	635	873	-0.02511566	-0.02080868	-0.00430698	-0.02683674	-0.01478061
55	80	254	97	-0.01621246	-0.01088872	-0.00532374	-0.01685470	-0.00492275
56	80	254	97	-0.01249288	-0.01088872	-0.00160416	-0.01685470	-0.00492275
57	80	254	97	-0.01396796	-0.01088872	-0.00307924	-0.01685470	-0.00492275
58	80	635	194	-0.00704693	-0.00930969	0.00226276	-0.01509011	-0.00352927
59	80	635	194	-0.00768456	-0.00930969	0.00162513	-0.01509011	-0.00352927
60	80	635	194	-0.00701405	-0.00930969	0.00229564	-0.01509011	-0.00352927
61	80	1016	291	-0.00554904	-0.00885282	0.00330378	-0.01473377	-0.00297187
62	80	1016	291	-0.00943136	-0.00885282	-0.00057854	-0.01473377	-0.00297187
63	80	1016	291	-0.00789379	-0.00885282	0.00095903	-0.01473377	-0.00297187

COMPUTER PROGRAMME NO. 4 (CONT'D)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

OBSERVATION	RH	DEPTH	AGML	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
64	50	254	388	-0.00969757	-0.00875256	-0.00094501	-0.01451576	-0.00298935
65	50	254	388	-0.01039105	-0.00875256	-0.00163849	-0.01451576	-0.00298935
66	50	254	388	-0.00870982	-0.00875256	0.00004274	-0.01451576	-0.00298935
67	50	635	485	-0.00583622	-0.00724119	0.00140497	-0.01299092	-0.00149146
68	50	635	485	-0.00504763	-0.00724119	0.00219356	-0.01299092	-0.00149146
69	50	635	485	-0.00326261	-0.00724119	0.00397858	-0.01299092	-0.00149146
70	50	1016	582	-0.01253417	-0.00685199	-0.00568218	-0.01266121	-0.00104276
71	50	1016	582	-0.00752847	-0.00685199	-0.00067648	-0.01266121	-0.00104276
72	50	1016	582	-0.00587454	-0.00685199	0.00097745	-0.01266121	-0.00104276
73	20	254	679	-0.01630119	-0.01455569	-0.00174550	-0.02034453	-0.00876685
74	20	254	679	-0.01549066	-0.01455569	-0.00093497	-0.02034453	-0.00876685
75	20	254	679	-0.01638758	-0.01455569	-0.00183189	-0.02034453	-0.00876685
76	20	635	776	-0.01182893	-0.01311199	0.00128306	-0.01879714	-0.00742684
77	20	635	776	-0.01225946	-0.01311199	0.00085253	-0.01879714	-0.00742684
78	20	635	776	-0.01225946	-0.01311199	0.00085253	-0.01879714	-0.00742684
79	20	1016	873	-0.01122865	-0.01279046	0.00156181	-0.01865543	-0.00692549
80	20	1016	873	-0.01033906	-0.01279046	0.00245140	-0.01865543	-0.00692549
81	20	1016	873	-0.01019511	-0.01279046	0.00259535	-0.01865543	-0.00692549

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00056563
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	0.13657646
DURBIN-WATSON D	1.69959826

COMPUTER PROGRAMME NO. 5

```
TITLE 'ANOVA ON THE 81 B1 VALUES';
DATA WIFE; INPUT NAME $ 1-4 DEPT $ 6-9 AES $ 11-13 YR 15-16 MTH 18-19 DAY 21-22
RH 24-25 DEPTH 27-30 RNU 32-33 AGML 35-37 CWNU 39 COW 41 CRDNO 43 B1 45-55
A1 57-67 A2 69-79 REP 80;
CARDS
```

```
  81 OBSERVATIONS IN DATA SET WIFE          17  VARIABLES
```

```
PROC ANOVA DATA = WIFE; CLASSES REP AGML COW;
MODEL B1 = REP|AGML COW(REP) AGML*COW(REP);
MEANS REP|AGML COW(REP);
POOL 'R*A' REP*AGML/AGML;
POOL 'A*C(R)' AGML*COW(REP)/REP*AGML;
```

DATA SET WIFE

CLASSES	VALUES
REP	1 2 3
AGML	97 194 291 388 485 582 679 776 873
COW	1 2 3

MEANS

AGML	N	B1
97	9	-0.015309236
194	9	-0.011348258
291	9	-0.009150584
388	9	-0.009486221
485	9	-0.009437921
582	9	-0.009095620
679	9	-0.012481256
776	9	-0.015486928
873	9	-0.015173030
REP		
1	27	-0.010939875
2	27	-0.014625172
3	27	-0.010091304
OVERALL MEANS	81	-0.011885450

COMPUTER PROGRAMME NO. 5 (CONT'D)

MEANS

REP	COW	N	B1
1	1	9	-0.011449230
1	2	9	-0.010417418
1	3	9	-0.010952978
2	1	9	-0.011980163
2	2	9	-0.016136166
2	3	9	-0.015759184
3	1	9	-0.010692796
3	2	9	-0.010073903
3	3	9	-0.009507213

REP	AGML		
1	97	3	-0.014576373
1	194	3	-0.011395373
1	291	3	-0.008986260
1	388	3	-0.008370547
1	485	3	-0.006140310
1	582	3	-0.007963837
1	679	3	-0.012489807
1	776	3	-0.015733463
1	873	3	-0.012800907
2	97	3	-0.017126900
2	194	3	-0.015400887
2	291	3	-0.010838763
2	388	3	-0.010488637
2	485	3	-0.017457967
2	582	3	-0.010677297
2	679	3	-0.008894150
2	776	3	-0.016611370
2	873	3	-0.022130577
3	97	3	-0.014224433
3	194	3	-0.007245513
3	291	3	-0.007624730
3	388	3	-0.009599480
3	485	3	-0.004715487
3	582	3	-0.008645727
3	679	3	-0.016059810
3	776	3	-0.012115950
3	873	3	-0.010587607

ANALYSIS OF VARIANCE FOR VARIABLE B1 MEAN -0.011885450

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	LSD .01	LSD .05	DIVISOR
REP	2	0.00031371697	0.00015685849			
AGML	8	0.00056838627	0.00007104828			
REP*AGML	16	0.00049364550	0.00003085284			
COW(REP)	6	0.00010620896	0.00001770149			
AGML*COW(REP)	48	0.00016525728	0.00000344286			
R*A	16	0.00049364550	0.00003085284	0.00764789805	0.00555079430	9
A*C(R)	48	0.00016525728	0.00000344286	0.00406355411	0.00304611190	3
CORRECTED TOTAL	80	0.00164721498	0.00002059019			

COMPUTER PROGRAMME NO. 6

```
TITLE 'COMPARING B1 VALUES AS DEPTH CHANGES FOR FIXED RH AND FIXED AGML';
DATA WIFE; INPUT NAME $ 1-4 DEPT $ 6-9 AES $ 11-13 YR 15-16 MTH 18-19 DAY 21-22
RH 24-25 DEPTH 27-30 RNO 32-33 AGML 35-37 CWNO 39 COW 41 CRDNO 43 B1 45-55
A1 57-67 A2 69-79 REP 80;
IF RNO=09 OR RNO=14 OR RNO=13 OR RNO=15 OR RNO=27 OR RNO=24 OR RNO=22 OR RNO=23
OR RNO=05 OR RNO=04 OR RNO=06 OR RNO=16 OR RNO=18 OR RNO=17 OR RNO=19 OR RNO=20
OR RNO=21 THEN DELETE;
CARDS;

PROC SORT DATA=WIFE; BY RH AGML;

PROC GLM DATA=WIFE; BY RH AGML;
MODEL B1=DEPTH / SOLUTION P CLI; ID DEPTH CWNO RNO;
```

RH=20 AGML=679

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00001912	0.00001912	102.27	0.0005	0.962358	3.0289
ERROR	4	0.00000075	0.00000019		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00001987			0.00043236		-0.01427481

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
DEPTH	1	0.00001912	102.27	0.0005	1	0.00001912	102.27	0.0005

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01843981	-41.15	0.0001	0.00044809
DEPTH	0.00000937	10.11	0.0005	0.00000093

OBSERVATION	DEPTH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	635	1	7	-0.01261176	-0.01248981	-0.00012195	-0.01387593	-0.01110368
2	635	2	7	-0.01208545	-0.01248981	0.00040436	-0.01387593	-0.01110368
3	635	3	7	-0.01277221	-0.01248981	-0.00028240	-0.01387593	-0.01110368
4	254	7	25	-0.01630119	-0.01605981	-0.00024136	-0.01744594	-0.01467368
5	254	8	25	-0.01549066	-0.01605981	0.00056915	-0.01744594	-0.01467368
6	254	9	25	-0.01638758	-0.01605981	-0.00032777	-0.01744594	-0.01467368

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000075
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	0.00000000
DURBIN-WATSON D	2.95784127

RH=20 AGML=776

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00001963	0.00001963	34.52	0.0042	0.896168	5.4152
ERROR	4	0.00000227	0.00000057		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00002190			0.00075405		-0.01392471

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
DEPTH	1	0.00001963	34.52	0.0042	1	0.00001963	34.52	0.0042

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01814514	-23.22	0.0001	0.00078147
DEPTH	0.00000949	5.88	0.0042	0.00000162

OBSERVATION	DEPTH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	254	1	8	-0.01530514	-0.01573346	0.00042832	-0.01815087	-0.01331605
2	254	2	8	-0.01497923	-0.01573346	0.00075423	-0.01815087	-0.01331605
3	254	3	8	-0.01691602	-0.01573346	-0.00118256	-0.01615087	-0.01331605
4	635	7	26	-0.01182693	-0.01211595	0.00028702	-0.01453336	-0.00969854
5	635	8	26	-0.01225946	-0.01211595	-0.00014351	-0.01453336	-0.00969854
6	635	9	26	-0.01225946	-0.01211595	-0.00014351	-0.01453336	-0.00969854

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000227
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	-0.42790073
DURBIN-WATSON D	2.72711427

COMPUTER PROGRAMME NO. 7

```
TITLE 'COMPARING B1 VALUES AS AGE CHANGES FOR FIXED DEPTH AND RH';
DATA WIFE; INPUT NAME $ 1-4 DEPT $ 6-9 AES $ 11-13 YR 15-16 MTH 18-19 DAY 21-22
RH 24-25 DEPTH 27-30 RNO 32-33 AGML 35-37 CWNO 39 COW 41 CRDNO 43 B1 45-55
A1 57-67 A2 69-79 REP 80;
CARDS;

PROC SORT DATA=WIFE; BY RH DEPTH;

PROC GLM DATA=WIFE; BY RH DEPTH;
MODEL B1=AGML AGML*AGML / SOLUTION P CLI;  ID AGML CWNO RNO;

PROC GLM DATA=WIFE; BY RH DEPTH;
MODEL B1=AGML / SOLUTION P CLI; ID AGML CWNO RNO;
```

```
COMPARING B1 VALUES AS AGE CHANGES FOR FIXED DEPTH AND RH     23:17 SUNDAY, AUGUST 27, 1978     8
                               RH=80    DEPTH=635

                        GENERAL LINEAR MODELS PROCEDURE
```

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	2	0.00041207	0.00020604	57.83	0.0001	0.950680	15.0007
ERROR	6	0.00002138	0.00000356		STD DEV		B1 MEAN
CORRECTED TOTAL	8	0.00043345			0.00188758		-0.01258321

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AGML	1	0.00039361	110.47	0.0001	1	0.00000248	0.69	0.4364
AGML*AGML	1	0.00001846	5.18	0.0631	1	0.00001846	5.18	0.0631

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.00863047	-2.52	0.0455	0.00342973
AGML	0.00001358	0.83	0.4364	0.00001629
AGML*AGML	-0.00000003	-2.28	0.0631	0.00000001

OBSERVATION	AGML	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	388	1	4	-0.00985222	-0.00837055	-0.00148167	-0.01370380	-0.00303729
2	388	2	4	-0.00733433	-0.00837055	0.00103622	-0.01370380	-0.00303729
3	388	3	4	-0.00792509	-0.00837055	0.00044546	-0.01370380	-0.00303729
4	873	4	18	-0.01918199	-0.02213058	0.00294659	-0.02746383	-0.01679732
5	873	5	18	-0.02209108	-0.02213058	0.00003950	-0.02746383	-0.01679732
6	873	6	18	-0.02511866	-0.02213058	-0.00298808	-0.02746383	-0.01679732
7	194	7	20	-0.00704693	-0.00724851	0.00020158	-0.01258177	-0.00191526
8	194	8	20	-0.00768456	-0.00724851	-0.00043605	-0.01258177	-0.00191526
9	194	9	20	-0.00701405	-0.00724851	0.00023446	-0.01258177	-0.00191526

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00002138
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.02740886
DURBIN-WATSON D	1.94659443

COMPUTER PROGRAMME NO. 7 (CONT'D)

COMPARING B1 VALUES AS AGE CHANGES FOR FIXED DEPTH AND RH   23:17 SUNDAY, AUGUST 27, 1978   7
RH=80   DEPTH=254

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	2	0.00010135	0.00005067	18.74	0.0026	0.862009	16.8604
ERROR	6	0.00001622	0.00000270		STD DEV		B1 MEAN
CORRECTED TOTAL	8	0.00011757			0.00164438		-0.00975296

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AGML	1	0.00006176	22.84	0.0031	1	0.00005873	21.72	0.0035
AGML*AGML	1	0.00003959	14.64	0.0087	1	0.00003959	14.64	0.0087

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01907709	-11.48	0.0001	0.00166237
AGML	0.00005587	4.66	0.0035	0.00001199
AGML*AGML	-0.00000006	-3.83	0.0087	0.00000002

OBSERVATION	AGML	CWNO	RNU	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	485	1	5	-0.00705382	-0.00614031	-0.00091351	-0.01078644	-0.00149418
2	485	2	5	-0.00550763	-0.00614031	0.00063268	-0.01078644	-0.00149418
3	485	3	5	-0.00585948	-0.00614031	0.00028083	-0.01078644	-0.00149418
4	679	4	16	-0.00667338	-0.00889415	0.00222077	-0.01354028	-0.00424802
5	679	5	16	-0.00950638	-0.00889415	-0.00061223	-0.01354028	-0.00424802
6	679	6	16	-0.01050269	-0.00889415	-0.00160854	-0.01354028	-0.00424802
7	97	7	19	-0.01621246	-0.01422443	-0.00198803	-0.01887056	-0.00957831
8	97	8	19	-0.01249288	-0.01422443	0.00173155	-0.01887056	-0.00957831
9	97	9	19	-0.01396796	-0.01422443	0.00025647	-0.01887056	-0.00957831

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00001622
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	0.00304979
DURBIN-WATSON D	1.93858084

COMPUTER PROGRAMME NO. 7 (CONT'D)

COMPARING B1 VALUES AS AGE CHANGES FOR FIXED DEPTH AND RH   23:17 SUNDAY, AUGUST 27, 1978   9
RH=80   DEPTH=1016

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	2	0.00023419	0.00011710	16.35	0.0037	0.844955	23.4757
ERROR	6	0.00004297	0.00000716		STD DEV		B1 MEAN
CORRECTED TOTAL	8	0.00027716			0.00267622		-0.01139998

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AGML	1	0.00015702	21.92	0.0034	1	0.00005109	7.13	0.0370
AGML*AGML	1	0.00007717	10.77	0.0168	1	0.00007717	10.77	0.0168

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.02604426	-3.10	0.0210	0.00838929
AGML	0.00009553	2.67	0.0370	0.00003577
AGML*AGML	-0.00000011	-3.28	0.0168	0.00000003

OBSERVATION	AGML	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	582	1	6	-0.00866418	-0.00796384	-0.00070034	-0.01552537	-0.00040231
2	582	2	6	-0.00828743	-0.00796384	-0.00032359	-0.01552537	-0.00040231
3	582	3	6	-0.00673990	-0.00796384	0.00122394	-0.01552537	-0.00040231
4	776	4	17	-0.01392985	-0.01861137	0.00468152	-0.02617290	-0.01104984
5	776	5	17	-0.02109327	-0.01861137	-0.00248190	-0.02617290	-0.01104984
6	776	6	17	-0.02081099	-0.01861137	-0.00219962	-0.02617290	-0.01104984
7	291	7	21	-0.00554904	-0.00762473	0.00207569	-0.01518626	-0.00006320
8	291	8	21	-0.00943136	-0.00762473	-0.00180663	-0.01518626	-0.00006320
9	291	9	21	-0.00789379	-0.00762473	-0.00026906	-0.01518626	-0.00006320

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00004297
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.19666899
DURBIN-WATSON D	2.36873406

COMPUTER PROGRAMME NO. 7 (CONT'D)

COMPARING B1 VALUES AS AGE CHANGES FOR FIXED DEPTH AND RH   23:17 SUNDAY, AUGUST 27, 1978   11

RH=20   DEPTH=635

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00000567	0.00000567	4.88	0.0629	0.410739	9.2129
ERROR	7	0.00000813	0.00000116		STD DEV		B1 MEAN
CORRECTED TOTAL	8	0.00001380			0.00107774		-0.01169813

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AGML	1	0.00000567	4.88	0.0629	1	0.00000567	4.88	0.0629

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.00874122	-6.31	0.0004	0.00138600
AGML	-0.00000481	-2.21	0.0629	0.00000218

OBSERVATION	AGML	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	679	1	7	-0.01261176	-0.01200939	-0.00060237	-0.01471630	-0.00930247
2	679	2	7	-0.01208545	-0.01200939	-0.00007606	-0.01471630	-0.00930247
3	679	3	7	-0.01277221	-0.01200939	-0.00076282	-0.01471630	-0.00930247
4	388	4	13	-0.00843466	-0.01060874	0.00217408	-0.01353728	-0.00768020
5	388	5	13	-0.01190006	-0.01060874	-0.00129132	-0.01353728	-0.00768020
6	388	6	13	-0.01113119	-0.01060874	-0.00052245	-0.01353728	-0.00768020
7	776	7	26	-0.01182893	-0.01247627	0.00064734	-0.01528878	-0.00966375
8	776	8	26	-0.01225946	-0.01247627	0.00021681	-0.01528878	-0.00966375
9	776	9	26	-0.01225946	-0.01247627	0.00021681	-0.01528878	-0.00966375

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000813
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.48436973
DURBIN-WATSON D	2.89372626

COMPUTER PROGRAMME NO. 7 (CONT'D)

COMPARING B1 VALUES AS AGE CHANGES FOR FIXED DEPTH AND RH   23:17 SUNDAY, AUGUST 27, 1978   13
RH=50   DEPTH=254

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00003994	0.00003994	36.53	0.0005	0.839197	8.9581
ERROR	7	0.00000765	0.00000109		STD DEV		B1 MEAN
CORRECTED TOTAL	8	0.00004759			0.00104555		-0.01167154

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AGML	1	0.00003994	36.53	0.0005	1	0.00003994	36.53	0.0005

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01617538	-19.66	0.0001	0.00082263
AGML	0.00001741	6.04	0.0005	0.00000288

OBSERVATION	AGML	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	97	1	1	-0.01424331	-0.01448644	0.00024313	-0.01731566	-0.01165722
2	97	2	1	-0.01352840	-0.01448644	0.00095804	-0.01731566	-0.01165722
3	97	3	1	-0.01595741	-0.01448644	-0.00147097	-0.01731566	-0.01165722
4	291	4	12	-0.00954603	-0.01110856	0.00156253	-0.01372394	-0.00849318
5	291	5	12	-0.01112342	-0.01110856	-0.00001486	-0.01372394	-0.00849318
6	291	6	12	-0.01184684	-0.01110856	-0.00073828	-0.01372394	-0.00849318
7	388	7	22	-0.00969757	-0.00941962	-0.00027795	-0.01217060	-0.00666864
8	388	8	22	-0.01039105	-0.00941962	-0.00097143	-0.01217060	-0.00666864
9	388	9	22	-0.00870982	-0.00941962	0.00070980	-0.01217060	-0.00666864

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000765
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.50238746
DURBIN-WATSON D	2.89381371

COMPUTER PROGRAMME NO. 7 (CONT'D)

RH=50 DEPTH=635

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00021876	0.00021876	20.32	0.0028	0.743738	29.6179
ERROR	7	0.00007538	0.00001077		STD DEV		B1 MEAN
CORRECTED TOTAL	8	0.00029413			0.00328144		-0.01107925

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AGML	1	0.00021876	20.32	0.0028	1	0.00021876	20.32	0.0028

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01881431	-9.25	0.0001	0.00203506
AGML	0.00002990	4.51	0.0028	0.00000663

OBSERVATION	AGML	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	194	1	2	-0.01059584	-0.01301302	0.00241718	-0.02125486	-0.00477118
2	194	2	2	-0.01041867	-0.01301302	0.00259435	-0.02125486	-0.00477118
3	194	3	2	-0.01317161	-0.01301302	-0.00015859	-0.02125486	-0.00477118
4	97	4	10	-0.01334397	-0.01591367	0.00256970	-0.02447704	-0.00735029
5	97	5	10	-0.02307589	-0.01591367	-0.00716222	-0.02447704	-0.00735029
6	97	6	10	-0.01496084	-0.01591367	0.00095283	-0.02447704	-0.00735029
7	485	7	23	-0.00583622	-0.00431108	-0.00152514	-0.01322772	0.00460557
8	485	8	23	-0.00504763	-0.00431108	-0.00073655	-0.01322772	0.00460557
9	485	9	23	-0.00326261	-0.00431108	0.00104847	-0.01322772	0.00460557

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00007538
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.29053338
DURBIN-WATSON D	2.46190724

COMPUTER PROGRAMME NO. 7 (CONT'D)

RH=80 DEPTH=635

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00039361	0.00039361	69.16	0.0001	0.908084	18.9594
ERROR	7	0.00003984	0.00000569		STD DEV		B1 MEAN
CORRECTED TOTAL	8	0.00043345			0.00238570		-0.01258321

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AGML	1	0.00039361	69.16	0.0001	1	0.00039361	69.16	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.00135125	-0.66	0.4172	0.00156736
AGML	-0.00002316	-8.32	0.0001	0.00000278

OBSERVATION	AGML	CWHO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	388	1	4	-0.00985222	-0.01033682	0.00048460	-0.01631750	-0.00435614
2	388	2	4	-0.00733433	-0.01033682	0.00300249	-0.01631750	-0.00435614
3	388	3	4	-0.00792509	-0.01033682	0.00241173	-0.01631750	-0.00435614
4	873	4	18	-0.01918199	-0.02156878	0.00238679	-0.02804093	-0.01509664
5	873	5	18	-0.02209108	-0.02156878	-0.00052230	-0.02804093	-0.01509664
6	873	6	18	-0.02511866	-0.02156878	-0.00354988	-0.02804093	-0.01509664
7	194	7	20	-0.00704693	-0.00584403	-0.00120290	-0.01209164	0.00040357
8	194	8	20	-0.00748456	-0.00584403	-0.00164053	-0.01209164	0.00040357
9	194	9	20	-0.00701405	-0.00584403	-0.00117002	-0.01209164	0.00040357

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00003984
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	0.60708617
DURBIN-WATSON D	0.77013659

COMPUTER PROGRAMME NO. 8

```
TITLE 'COMPARING B1 VALUES AS RH CHANGES, DEPTH AND AGML BEING FIXED';
DATA WIFE; INPUT NAME $ 1-4 DEPT $ 6-9 AES $ 11-13 YR 15-16 MTH 18-19 DAY 21-22
RH 24-25 DEPTH 27-30 RNO 32-33 AGML 35-37 CWNO 39 COW 41 CRONO 43 B1 45-55
A1 57-67 A2 69-79 REP 80;
IF RNO=08 OR RNO=12 OR RNO=22 OR RNO=07 OR RNO=26 OR RNO=10 OR RNO=23
OR RNO=18 OR RNO=09 OR RNO=27 OR RNO=11 OR RNO=17 THEN DELETE;
CARDS;
PROC SORT DATA=WIFE; BY DEPTH AGML;
PROC GLM DATA =WIFE; BY DEPTH AGML;
MODEL B1=RH / SOLUTION  P CLI; ID RH CWNO RNO;
PROC GLM DATA=WIFE; BY DEPTH AGML;
MODEL B1=RH RH*RH / SOLUTION P CLI ; ID RH CWNO RNO;
```

10:58 MONDAY, AUGUST 28, 1978

DEPTH=254 AGML=085

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00019213	0.00019213	71.71	0.0011	0.947167	13.8727
ERROR	4	0.00001072	0.00000268		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00020285			0.00163686		-0.01179914

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00019213	71.71	0.0011	1	0.00019213	71.71	0.0011

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.02123052	-16.35	0.0001	0.00129883
RH	0.00016863	8.47	0.0011	0.00002227

OBSERVATION	RH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	80	1	5	-0.00705382	-0.00614031	-0.00091351	-0.01138795	-0.0008[illegible]
2	80	2	5	-0.00550763	-0.00614031	0.00063268	-0.01138795	-0.0008[illegible]
3	80	3	5	-0.00585948	-0.00614031	0.00028083	-0.01138795	-0.0008[illegible]
4	20	4	14	-0.01939272	-0.01745797	-0.00193475	-0.02270560	-0.0122[illegible]
5	20	5	14	-0.01511424	-0.01745797	0.00234373	-0.02270560	-0.0122[illegible]
6	20	6	14	-0.01786694	-0.01745797	-0.00040897	-0.02270560	-0.0122[illegible]

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00001072
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.63037262
DURBIN-WATSON D	3.10771033

10:58 MONDAY, AUGUST 28, 1978

DEPTH=254 AGML=679

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00007702	0.00007702	36.75	0.0037	0.901835	11.6032
ERROR	4	0.00000838	0.00000210		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00008540			0.00144773		-0.01247698

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00007702	36.75	0.0037	1	0.00007702	36.75	0.0037

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01844836	-16.06	0.0001	0.00114876
RH	0.00011943	6.06	0.0037	0.00001970

OBSERVATION	RH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	80	4	16	-0.00667333	-0.00889415	0.00222077	-0.01353545	-0.00425285
2	80	5	16	-0.00950638	-0.00889415	-0.00061223	-0.01353545	-0.00425285
3	80	6	16	-0.01050269	-0.00889415	-0.00160854	-0.01353545	-0.00425285
4	20	7	25	-0.01630119	-0.01605981	-0.00024138	-0.02070111	-0.01141851
5	20	8	25	-0.01549066	-0.01605981	0.00056915	-0.02070111	-0.01141851
6	20	9	25	-0.01638758	-0.01605981	-0.00032777	-0.02070111	-0.01141851

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000838
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.05809006
DURBIN-WATSON D	1.47299046

COMPUTER PROGRAMME NO. 8 (CONT'D)

10:58 MONDAY, AUGUST 28, 1978

DEPTH=635 AGML=194

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00002579	0.00002579	20.50	0.0106	0.836711	12.0342
ERROR	4	0.00000503	0.00000126		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00003083			0.00112182		-0.00932194

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00002579	20.50	0.0106	1	0.00002579	20.50	0.0106

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01830681	-8.99	0.0008	0.00203675
RH	0.00013823	4.53	0.0106	0.00003053

OBSERVATION	RH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	50	1	2	-0.01059584	-0.01139537	0.00079953	-0.01499185	-0.00779889
2	50	2	2	-0.01041867	-0.01139537	0.00097670	-0.01499185	-0.00779889
3	50	3	2	-0.01317161	-0.01139537	-0.00177624	-0.01499185	-0.00779889
4	80	7	20	-0.00704693	-0.00724851	0.00020158	-0.01084499	-0.00365203
5	80	8	20	-0.00768456	-0.00724851	-0.00043605	-0.01084499	-0.00365203
6	80	9	20	-0.00701405	-0.00724851	0.00023446	-0.01084499	-0.00365203

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000503
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	-0.32112652
DURBIN-WATSON D	2.45889570

COMPUTER PROGRAMME NO. 8 (CONT'D)

10:58 MONDAY, AUGUST 28, 1978

DEPTH=254 AGML=485

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00019213	0.00019213	71.71	0.0011	0.947167	13.9727
ERROR	4	0.00001072	0.00000268		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00020285			0.00163686		-0.0117[illegible]

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00019213	71.71	0.0011	0	0.00000000	.	.
RH*RH	0	0.00000000	.	.	0	0.00000000	.	.

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.02123052 B	-16.35	0.0001	0.00129883
RH	0.00018863 B	8.47	0.0011	0.00002227
RH*RH	0.00000000 B	.	.	.

NOTE: AN INFINITE NUMBER OF SOLUTIONS TO THE NORMAL EQUATIONS EXIST. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED. REFER TO THE GENERAL FORM OF ESTIMABLE FUNCTIONS TO SEE WHAT THE EXPECTED VALUE OF THE BIASED ESTIMATORS ARE.

OBSERVATION	RH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	80	1	5	-0.00705382	-0.00614031	-0.00091351	-0.01138795	-0.00089267
2	80	2	5	-0.00550763	-0.00614031	0.00063268	-0.01138795	-0.00089267
3	80	3	5	-0.00585948	-0.00614031	0.00028083	-0.01138795	[illegible]
4	20	4	14	-0.01939272	-0.01745797	-0.00193475	-0.02270560	-0.01221[illegible]
5	20	5	14	-0.01511424	-0.01745797	0.00234373	-0.02270560	-0.01221[illegible]
6	20	6	14	-0.01786694	-0.01745797	-0.00040897	-0.02270560	-0.01221033

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00001072
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.63037262
DURBIN-WATSON D	3.10771033

DEPTH=254 AGML=679

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00007702	0.00007702	36.75	0.0037	0.901835	11.6032
ERROR	4	0.00000838	0.00000210		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00008540			0.00144773		-0.01247595

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00007702	36.75	0.0037	0	0.00000000	.	.
RH*RH	0	0.00000000	.	.	0	0.00000000	.	.

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01844836 B	-16.06	0.0001	0.00114876
RH	0.00011943 B	6.06	0.0037	0.00001970
RH*RH	0.00000000 B	.	.	.

NOTE: AN INFINITE NUMBER OF SOLUTIONS TO THE NORMAL EQUATIONS EXIST, ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED.
REFER TO THE GENERAL FORM OF ESTIMABLE FUNCTIONS TO SEE WHAT THE EXPECTED VALUE OF THE BIASED ESTIMATORS ARE.

OBSERVATION	RH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	80	4	16	-0.00667338	-0.00889415	0.00222077	-0.01353545	-0.00425285
2	80	5	16	-0.00950638	-0.00889415	-0.00061223	-0.01353545	-0.00425285
3	80	6	16	-0.01050269	-0.00889415	-0.00160854	-0.01353545	-0.00425285
4	20	7	25	-0.01630119	-0.01605981	-0.00024138	-0.02070111	-0.01141851
5	20	8	25	-0.01549066	-0.01605981	0.00056915	-0.02070111	-0.01141851
6	20	9	25	-0.01638756	-0.01605981	-0.00032777	-0.02070111	-0.01141851

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000838
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.05809006
DURBIN-WATSON D	1.47299046

COMPUTER PROGRAMME NO. 8 (CONT'D)

DEPTH=635 AGML=194

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.00002579	0.00002579	20.50	0.0106	0.836711	12.0342
ERROR	4	0.00000503	0.00000126		STD DEV		B1 MEAN
CORRECTED TOTAL	5	0.00003083			0.00112182		-0.00932194

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00002579	20.50	0.0106	0	0.00000000	.	.
RH*RH	0	0.00000000	.	.	0	0.00000000	.	.

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.01830681 B	-8.99	0.0008	0.00203675
RH	0.00013823 B	4.53	0.0106	0.00003053
RH*RH	0.00000000 B	.	.	.

NOTE: AN INFINITE NUMBER OF SOLUTIONS TO THE NORMAL EQUATIONS EXIST. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED. REFER TO THE GENERAL FORM OF ESTIMABLE FUNCTIONS TO SEE WHAT THE EXPECTED VALUE OF THE BIASED ESTIMATORS ARE.

OBSERVATION	RH	CWNO	RNO	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	50	1	2	-0.01059584	-0.01139537	0.00079953	-0.01499185	-0.00779889
2	50	2	2	-0.01041867	-0.01139537	0.00097670	-0.01499185	-0.00779889
3	50	3	2	-0.01317161	-0.01139537	-0.00177624	-0.01499185	-0.00779889
4	80	7	20	-0.00704693	-0.00724851	0.00020158	-0.01084499	-0.00365203
5	80	8	20	-0.00768456	-0.00724851	-0.00043605	-0.01084499	-0.00365203
6	80	9	20	-0.00701405	-0.00724851	0.00023446	-0.01084499	-0.00365203

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00000503
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	-0.32112652
DURBIN-WATSON D	2.45889570

COMPUTER PROGRAMME NO. 9

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TITLE 'ANALYSIS TO FIND THE OVERALL PREDICTION EQUATION FROM 81 B1 VALUES EACH
OF WHICH WAS OBTAINED FROM THE SLOPE OF LOG_MR AS A FUNCTION OF TIME';
DATA WIFE; INPUT NAME $ 1-4 DEPT $ 6-9 AES $ 11-13 YR 15-16 MTH 18-19 DAY 21-22
RH 24-25 DEPTH 27-30 RND 32-33 AGML 35-37 CWNO 39 COW 41 CRDNO 43 B1 45-55
A1 57-67 A2 69-79 REP 80;
CARDS;
PROC GLM DATA=WIFE;
MODEL B1=RH DEPTH AGML RH*RH DEPTH*DEPTH AGML*AGML RH*DEPTH RH*AGML DEPTH*AGML
 / SOLUTION P CLI; ID RH DEPTH AGML CWNO;
```

COMPUTER PROGRAMME NO. 9 (CONT'D)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.00110901	0.00012322	16.26	0.0001	0.673261	23.1649
ERROR	71	0.00053821	0.00000758		STD DEV		B1 MEAN
CORRECTED TOTAL	80	0.00164721			0.00275325		-0.01188545

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
RH	1	0.00004932	6.51	0.0129	1	0.00022879	30.18	0.0001
DEPTH	1	0.00002490	3.29	0.0741	1	0.00006767	8.93	0.0039
AGML	1	0.00003859	5.09	0.0271	1	0.00074948	93.87	0.0001
RH*RH	1	0.00000019	0.03	0.8739	1	0.00007165	9.45	0.0030
DEPTH*DEPTH	1	0.00000000	0.00	0.9860	1	0.00002575	3.40	0.0695
AGML*AGML	1	0.00044692	58.96	0.0001	1	0.00072208	95.26	0.0001
RH*DEPTH	1	0.00024950	32.91	0.0001	1	0.00010835	14.29	0.0003
RH*AGML	1	0.00029465	38.87	0.0001	1	0.00029437	38.83	0.0001
DEPTH*AGML	1	0.00000491	0.65	0.4235	1	0.00000491	0.65	0.4235

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.05328997	-10.00	0.0001	0.00532787
RH	0.00071410	5.49	0.0001	0.00012998
DEPTH	0.00001950	2.99	0.0039	0.00000653
AGML	0.00008228	9.94	0.0001	0.00000827
RH*RH	-0.00000312	-3.07	0.0030	0.00000102
DEPTH*DEPTH	-0.00000001	-1.84	0.0695	0.00000000
AGML*AGML	-0.00000006	-9.76	0.0001	0.00000001
RH*DEPTH	-0.00000017	-3.78	0.0003	0.00000004
RH*AGML	-0.00000044	-6.23	0.0001	0.00000007
DEPTH*AGML	0.00000000	0.81	0.4235	0.00000000

OBSERVATION	RH	DEPTH	AGML	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
1	50	254	97	-0.01424331	-0.01779265	0.00354934	-0.02366493	-0.01192036
2	50	254	97	-0.01352840	-0.01779265	0.00426425	-0.02366493	-0.01192036
3	50	254	97	-0.01595741	-0.01779265	0.00183524	-0.02366493	-0.01192036
4	50	635	194	-0.01059584	-0.01203543	0.00143959	-0.01769939	-0.00637096
5	50	635	194	-0.01041867	-0.01203543	0.00161676	-0.01769939	-0.00637096
6	50	635	194	-0.01317161	-0.01203543	-0.00113618	-0.01769939	-0.00637096
7	50	1016	291	-0.00986691	-0.00966735	-0.00019956	-0.01540019	-0.00393451
8	50	1016	291	-0.00844334	-0.00966735	0.00122401	-0.01540019	-0.00393451
9	50	1016	291	-0.00865453	-0.00966735	0.00101282	-0.01540019	-0.00393451
10	80	635	388	-0.00985222	-0.00604345	-0.00380877	-0.01177994	-0.00030696
11	80	635	388	-0.00733433	-0.00604345	-0.00129088	-0.01177994	-0.00030696

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

OBSERVATION	RH	DEPTH	AGML	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
12	80	635	388	-0.00792509	-0.00604345	-0.00188164	-0.01177994	-0.00030696
13	80	254	485	-0.00705382	-0.00662960	-0.00042422	-0.01243350	-0.00082570
14	80	254	485	-0.00550763	-0.00662960	0.00112197	-0.01243350	-0.00082570
15	80	254	485	-0.00585948	-0.00662960	0.00077012	-0.01243350	-0.00082570
16	80	1016	582	-0.00886418	-0.01049363	0.00162945	-0.01627389	-0.00471338
17	80	1016	582	-0.00828743	-0.01049363	0.00220620	-0.01627389	-0.00471338
18	80	1016	582	-0.00673990	-0.01049363	0.00375373	-0.01627389	-0.00471338
19	20	635	679	-0.01261176	-0.01081516	-0.00179660	-0.01648991	-0.00514040
20	20	635	679	-0.01208545	-0.01081516	-0.00127029	-0.01648991	-0.00514040
21	20	635	679	-0.01277221	-0.01081516	-0.00195705	-0.01648991	-0.00514040
22	20	254	776	-0.01530514	-0.01668001	0.00137487	-0.02259669	-0.01076333
23	20	254	776	-0.01497923	-0.01668001	0.00170078	-0.02259669	-0.01076333
24	20	254	776	-0.01691602	-0.01668001	-0.00023601	-0.02259669	-0.01076333
25	20	1016	873	-0.01464989	-0.01292254	-0.00172735	-0.01875009	-0.00709499
26	20	1016	873	-0.01317228	-0.01292254	-0.00024974	-0.01875009	-0.00709499
27	20	1016	873	-0.01058055	-0.01292254	0.00234199	-0.01875009	-0.00709499
28	50	635	97	-0.01334397	-0.01635424	0.00301027	-0.02213984	-0.01056863
29	50	635	97	-0.02307589	-0.01635424	-0.00672165	-0.02213984	-0.01056863
30	50	635	97	-0.01496084	-0.01635424	0.00139340	-0.02213984	-0.01056863
31	50	1016	194	-0.00971559	-0.01295132	0.00323573	-0.01882721	-0.00707544
32	50	1016	194	-0.01969577	-0.01295132	-0.00674445	-0.01882721	-0.00707544
33	50	1016	194	-0.01679130	-0.01295132	-0.00383998	-0.01882721	-0.00707544
34	50	254	291	-0.00954603	-0.01062460	0.00107857	-0.01632744	-0.00492176
35	50	254	291	-0.01112342	-0.01062460	-0.00049882	-0.01632744	-0.00492176
36	50	254	291	-0.01184684	-0.01062460	-0.00122224	-0.01632744	-0.00492176
37	20	635	388	-0.00843466	-0.01345549	0.00502083	-0.01938016	-0.00753083
38	20	635	388	-0.01190006	-0.01345549	0.00155543	-0.01938016	-0.00753083
39	20	635	388	-0.01113119	-0.01345549	0.00232430	-0.01938016	-0.00753083
40	20	254	485	-0.01939272	-0.01534635	-0.00404637	-0.02117286	-0.00951985
41	20	254	485	-0.01511424	-0.01534635	0.00023211	-0.02117286	-0.00951985
42	20	254	485	-0.01786694	-0.01534635	-0.00252059	-0.02117286	-0.00951985
43	20	1016	582	-0.00760328	-0.00891910	0.00131582	-0.01479115	-0.00304705
44	20	1016	582	-0.01162540	-0.00891910	-0.00270630	-0.01479115	-0.00304705
45	20	1016	582	-0.01280321	-0.00891910	-0.00388411	-0.01479115	-0.00304705
46	80	254	679	-0.00667338	-0.01146020	0.00478682	-0.01740439	-0.00551551
47	80	254	679	-0.00950638	-0.01146020	0.00195382	-0.01740439	-0.00551551
48	80	254	679	-0.01050269	-0.01146020	0.00095751	-0.01740439	-0.00551551
49	80	1016	776	-0.01392985	-0.01710409	0.00317424	-0.02303593	-0.01117225
50	80	1016	776	-0.02109327	-0.01710409	-0.00398918	-0.02303593	-0.01117225
51	80	1016	776	-0.02081099	-0.01710409	-0.00370690	-0.02303593	-0.01117225
52	80	635	873	-0.01918199	-0.02034477	0.00116278	-0.02637027	-0.01431927
53	80	635	873	-0.02209108	-0.02034477	-0.00174631	-0.02637027	-0.01431927
54	80	635	873	-0.02511866	-0.02034477	-0.00477389	-0.02637027	-0.01431927
55	80	254	97	-0.01621246	-0.01112544	-0.00508702	-0.01707352	-0.00517735
56	80	254	97	-0.01249288	-0.01112544	-0.00136744	-0.01707352	-0.00517735
57	80	254	97	-0.01396796	-0.01112544	-0.00284252	-0.01707352	-0.00517735
58	80	635	194	-0.00704693	-0.00858119	0.00153426	-0.01436937	-0.00279302
59	80	635	194	-0.00768456	-0.00858119	0.00089663	-0.01436937	-0.00279302

COMPUTER PROGRAMME NO. 9 (CONT'D)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: B1

OBSERVATION	RH	DEPTH	AGML	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
60	80	635	194	-0.00701405	-0.00858119	0.00156714	-0.01436937	-0.00279302
61	80	1016	291	-0.00554904	-0.00942610	0.00387706	-0.01528585	-0.00356634
62	80	1016	291	-0.00943136	-0.00942610	-0.00000526	-0.01528585	-0.00356634
63	80	1016	291	-0.00789379	-0.00942610	0.00153231	-0.01528585	-0.00356634
64	50	254	388	-0.00969757	-0.00881020	-0.00083737	-0.01453680	-0.00308361
65	50	254	388	-0.01039105	-0.00881020	-0.00158085	-0.01453680	-0.00308361
66	50	254	388	-0.00870982	-0.00881020	0.00010038	-0.01453680	-0.00308361
67	50	635	485	-0.00583622	-0.00615751	0.00032129	-0.01196190	-0.00035311
68	50	635	485	-0.00504763	-0.00615751	0.00110988	-0.01196190	-0.00035311
69	50	635	485	-0.00326261	-0.00615751	0.00289490	-0.01196190	-0.00035311
70	50	1016	582	-0.01253417	-0.00689395	-0.00564022	-0.01265722	-0.00113069
71	50	1016	582	-0.00752847	-0.00689395	-0.00063452	-0.01265722	-0.00113069
72	50	1016	582	-0.00587454	-0.00689395	0.00101941	-0.01265722	-0.00113069
73	20	254	679	-0.01630119	-0.01505570	-0.00124549	-0.02081535	-0.00929606
74	20	254	679	-0.01549066	-0.01505570	-0.00043496	-0.02081535	-0.00929606
75	20	254	679	-0.01638758	-0.01505570	-0.00133188	-0.02081535	-0.00929606
76	20	635	776	-0.01182893	-0.01229455	0.00046562	-0.01800850	-0.00658061
77	20	635	776	-0.01225946	-0.01229455	0.00003509	-0.01800850	-0.00658061
78	20	635	776	-0.01225946	-0.01229455	0.00003509	-0.01800850	-0.00658061
79	20	1016	873	-0.01122865	-0.01292254	0.00169389	-0.01875009	-0.00709499
80	20	1016	873	-0.01033906	-0.01292254	0.00258348	-0.01875009	-0.00709499
81	20	1016	873	-0.01019511	-0.01292254	0.00272743	-0.01875009	-0.00709499

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.00053821
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	0.11691708
DURBIN-WATSON D	1.72936730

APPENDIX C

STATISTICAL CONTRASTS IDENTIFICATION FORMAT

TABLE V

EFFECT OF DEPTH BY RELATIVE HUMIDITY BY AGE*

DEPTH (cm) / RH (%)	2.5			6.4			10.2		
	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW
20	08	776 ○	1 2 3	07	679 ⊖	1 2 3	09	873	1 2 3
	14	485	4 5 6	13	388	4 5 6	15	582	4 5 6
	25	679 ⊖	7 8 9	26	776 ○	7 8 9	27	873	7 8 9
50	01	97 ⊗	1 2 3	02	194 ◕	1 2 3	24	582	7 8 9
	12	291 ⊕	4 5 6	10	97 ⊗	4 5 6	03	291 ⊕	1 2 3
	22	388	7 8 9	23	485	7 8 9	11	194 ◕	4 5 6
80	05	485	1 2 3	04	388	1 2 3	06	582	1 2 3
	16	679	4 5 6	18	873	4 5 6	17	776	4 5 6
	19	97	7 8 9	20	194	7 8 9	21	291	7 8 9

*Matching symbols signifying comparable Age.

TABLE VI

EFFECT OF AGE BY RELATIVE HUMIDITY BY DEPTH*

DEPTH (cm) / RH (%)	2.5			6.4			10.2		
	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW
20	08	776 ○	1 2 3	07	679 ⊗	1 2 3	09	873 ∅	1 2 3
	14	485 ○	4 5 6	13	388 ⊗	4 5 6	15	582 ∅	4 5 6
	25	679 ○	7 8 9	26	776 ⊗	7 8 9	27	873 ∅	7 8 9
50	01	97 ⦶	1 2 3	02	194 ⊙	1 2 3	24	582 ◕	7 8 9
	12	291 ⦶	4 5 6	10	97 ⊙	4 5 6	03	291 ◕	1 2 3
	22	388 ⦶	7 8 9	23	485 ⊙	7 8 9	11	194 ◕	4 5 6
80	05	485 ⊕	1 2 3	04	388 ⊘	1 2 3	06	582 ◓	1 2 3
	16	679 ⊕	4 5 6	18	873 ⊘	4 5 6	17	776 ◓	4 5 6
	19	97 ⊕	7 8 9	20	194 ⊘	7 8 9	21	291 ◓	7 8 9

*Matching symbols signifying comparable Relative Humidity and Depth.

TABLE VII

EFFECT OF RELATIVE HUMIDITY BY DEPTH BY AGE*

DEPTH (cm) / RH (%)	2.5			6.4			10.2		
	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW	RUN	AGE (HRS)	COW
20	08	776	1 2 3	07	679	1 2 3	09	873	1 2 3
	14	485 ○	4 5 6	13	388 ⊙	4 5 6	15	582 ◓	4 5 6
	25	679 ⦶	7 8 9	26	776	7 8 9	27	873	7 8 9
50	01	97 ⊖	1 2 3	02	194 ◒	1 2 3	24	582 ◓	7 8 9
	12	291	4 5 6	10	97	4 5 6	03	291 ⊗	1 2 3
	22	388	7 8 9	23	485	7 8 9	11	194	4 5 6
80	05	485 ○	1 2 3	04	388 ⊙	1 2 3	06	582 ◓	1 2 3
	16	679 ⦶	4 5 6	18	873	4 5 6	17	776	4 5 6
	19	97 ⊖	7 8 9	20	194 ◒	7 8 9	21	291 ⊗	7 8 9

*Matching symbols signifying comparable Age and Depth.

APPENDIX D

AIRFLOW

AIRFLOW BACKGROUND

The duct is designed for turbulent airflow. This random convulsive behaviour adds more to the definition of turbulence than just disturbed airflow patterns. Because of such nonsequential perturbations in the air stream, the velocity of such a flow changes relative to location and time. Heat, mass, and momentum transfer could be categorized as properties of turbulence in the flow.

It is accepted in theory that the pitot-tube which is connected to a micromonometer is used to make velocity pressure transverse across a known diameter of the circular duct. The relevant change in velocity pressure could be used in

$$V = \frac{1096.5\ (h_w)^{1/2}}{(\rho_a)^{1/2}} \qquad [30]$$

to obtain the relevant velocity at that location. The velocity pressure is measured in ins. of water as indicated by the micromonometer. A series of such velocity measurements at known distances along the chosen diameter of the dust is obtained and calculation with the relevant area of assumed concentric flow is performed for the flow rate. An average of the velocity pressure readings within the same annulus is used for the calculation of the velocity within that annulus. These individual airflow rates within the respective annulus are averaged over the twelve stations within the duct to obtain the overall airflow rate.

The density of the air changes whenever there is a change in temperature in the atmosphere. This is substantiated by examining the ideal gas law which is used as

$$P_a = \frac{P_a}{R_a T_a} \quad [31]$$

Care is exercised in using this law. In this experiment, air at 20% RH and 50% RH is considered as relatively dry air.

The equation $R_a = \frac{\overline{R}}{M_a}$ [32]

is used in calculation of the gas constant. Air at 80% RH is considered partially saturated air so

$$R_v = \frac{\overline{R}}{M_v} \quad [33]$$

is used in calculating the gas constant. By partially saturated air it is meant that the medium contains both dry air as well as water vapor. Such a medium is referred to as a moist air medium. Conceptually it is a situation in which there is mutual equilibrium between the moist air and the liquid phase of the water.

Gas constant for air or gas constant for vapor is substituted in [31] from which the density of the air is obtained. The density is substituted into [30] from which the velocity of the air at that location is calculated. If consideration is given to the medium between the point at which the velocity pressure measurement is made and a point shortly before the air comes into contact with the abattoir cow-paunch constituents, it is assumed in this experiment that the density of the air is constant over that distance. The velocity and cross sectional area is substituted into

$$Q = \frac{\Sigma (AV)}{n} \quad [34]$$

for the relevant flow rate.

Airflow Rate Operation

The diameter of 0.1 m I.D. aluminum duct is graduated in 12 sections in such a way that 12 equal cross sectional areas are calculated. A vertical scale is constructed to identify these graduated sections. The Dwyer No. 16 pitot static tube in conjunction with the Dwyer No. 1420 hook gauge micromanometer as seen in Figure 10 was used to obtain the velocity pressure measurements.

A micrometer was attached to the left liquid well of this micromanometer. A pointer or needle was attached to the micrometer. This needle was adjusted by rotating the bottom end of the micrometer until it touches the surface of the liquid inside the liquid well. At the same time the reading on the micrometer scale was zero. A similar process was performed for the right liquid well.

The pitot static tube was placed in a position such that its hemispherical tip was pointed downstream and was perpendicular to the velocity of the airflow; and its static pressure arm was located at position No. 1 on the vertical scale. The right-hand side micrometer was adjusted until the pointer just touches the surface of the liquid in the right liquid well and the relevant departure from zero was read in inches of water and recorded. The pitot tube was moved to location No. 2, the process of adjusting the micrometer until the pointer just touches the surface of the liquid in the right liquid well and relevant departure from zero was read in inches of water and recorded, was repeated.

The constant airflow rate required for this drying operation is 1.2 m^3/sec. The velocity pressure that was necessary for such a flow rate is 1.3×10^{-4} m.

In order to obtain such a velocity pressure the input current into the shaded pole blower model 2C781 was adjusted by the VT4FC ohmitron transformer. The process of adjusting the current to the shaded pole blower model 2C781, as well as the VT4FC ohmitron transformer and obtaining the relevant velocity pressure was repeated until 1.3×10^{-4} m was achieved.

This process of obtaining the velocity pressure (h_w) measurements to calculate the airflow rate through the drying chamber was obtained each time the samples of CPC were removed from the drying compartment to be weighed.

In addition to obtaining the velocity pressure (h_w) measurements, the barometric pressure of the environment in which the experimental equipment was located, was read from the No. 211-B Air guide barometer and recorded. Such readings are taken at each time the velocity pressure (h_w) measurements are obtained. The velocity of the air was calculated by using equations [30] and [7], respectively. The flow rate of the air through the drying compartment was then calculated by using equation [2].

APPENDIX E

DRYING RATE OF PAUNCH CONTENTS IN PRELIMINARY EXPERIMENT

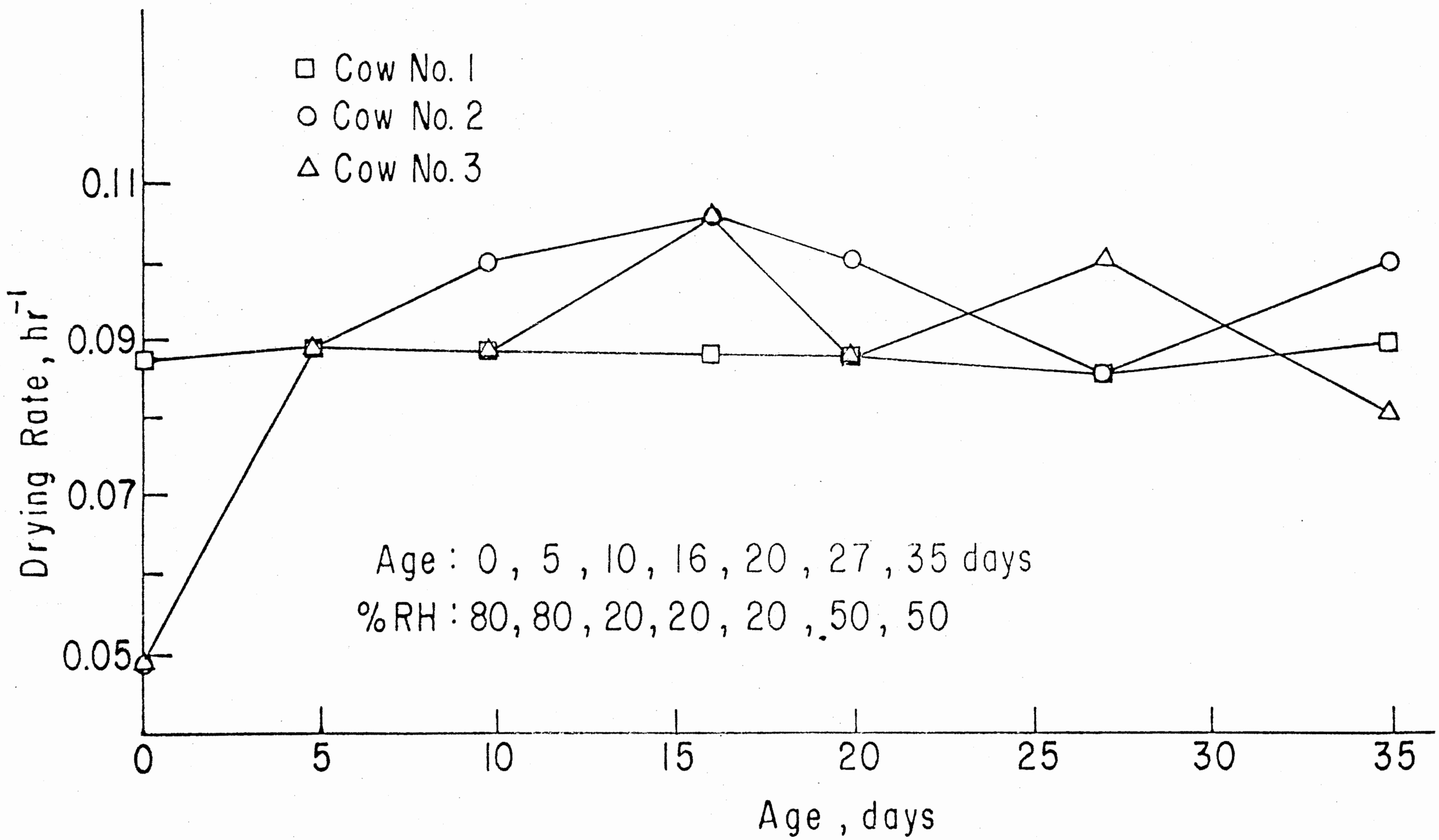

Figure 47. Drying Rate of Paunch Contents in Preliminary Experiment

APPENDIX F

COEFFICIENTS OF REGRESSION MODELS

TABLE VIII

COEFFICIENTS OF REGRESSION MODELS

Variables	No. of Terms in Models							
	3	3	3	4	4	6	8	8
Intercept	-1.72894 $\times10^{-2}$	1.72894$\times10^{-2}$	1.72894 $\times10^{-2}$	-1.7846 $\times10^{-2}$	-1.29845 $\times10^{-2}$	2.32859 $\times10^{-2}$	-5.37$\times10^{-2}$	-5.02331 $\times10^{-2}$
Ag					2.97$\times10^{-6}$	4.489$\times10^{-5}$	8.232$\times10^{-5}$	8.017$\times10^{-5}$
$(Ag)^2$						-4.0$\times10^{-8}$	-6.0$\times10^{-8}$	-6.0$\times10^{-2}$
D					2.24$\times10^{-6}$		1.938$\times10^{-5}$	1.124$\times10^{-5}$
D * Ag			1.0$\times10^{-8}$	1.0$\times10^{-8}$		1.0$\times10^{-8}$		
Rh		4.597$\times10^{-5}$			2.226$\times10^{-5}$		7.089$\times10^{-4}$	6.8151$\times10^{-4}$
$(Rh)^2$						1.64$\times10^{-7}$	-3.07$\times10^{-6}$	-2.86$\times10^{-6}$
Rh * Ag	6.5$\times10^{-7}$	9.3$\times10^{-7}$	6.5$\times10^{-7}$	9.1$\times10^{-7}$			-4.4$\times10^{-7}$	-4.2$\times10^{-7}$
Rh * D				9.0$\times10^{-8}$		-7.0$\times10^{-8}$	-1.7$\times10^{-7}$	-1.8$\times10^{-2}$
Rh * $(Ag)^4$	1.0$\times10^{-8}$							
Correlation Coefficient (R^2)	0.57	0.62	0.57	0.66	0.07	0.56	0.67	0.66

VITA

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Candidate for the Degree of

Master of Science

Thesis: THE DETERMINATION OF THE RATE OF DRYING OF ABATTOIR COW PAUNCH CONTENT (CPC) AS A FUNCTION OF RELATIVE HUMIDITY, DEPTH AND AGE

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