"A METHOD OF INFILTRATION MEASUREMENT IN THE SOIL"

BY

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ABSTRACT

The primary objective of this research was to develop and evaluate an acceptable instrument for field measurement of infiltration.

Many situations arise in civil engineering, irrigation and hydrology where it is desirable to evaluate infiltration of water into the soil under either ponded or rainfall conditions. An example is in the prediction of the rate of surface runoff. During a given storm rainfall intensities in excess of infiltration rates give rise to surface runoff. Since a large percentage of the rainfall infiltrates into the soil, the accuracy with which the surface runoff can be predicted is therefore dependent on the evaluation of infiltration.

Infiltration is the movement of water through the soil surface and into the soil and is distinguished from percolation, which is the movement of water through the soil profile. It is the source of soil moisture needed to sustain the growth of vegetation and of the groundwater supplies of wells, springs, and streams. Through infiltration the soil surface divides rainfall into overland flow, and soil moisture and groundwater. Some of the sources of water are: rain, dew, frost and irrigation.

The maximum rate at which water will enter the soil in a given coalition is known as the infiltration capacity.

The infiltration rate is the rate at which water enters the soil during a rainstorm, and it must equal the infiltration capacity, or the rainfall rata, whichever is least. It has the dimensions of volume per unit time per unit of area. Infiltration rates may be determined experimentally by measuring the surface runoff from a small test plot subject to either natural or simulated rainfall. The most important items influencing rate of infiltration have to do with the physical characteristics of the soil and the cover on the soil surface, but such other factors such as soil moisture, rainfall intensity, temperature are also involved.

A comprehensive review of literature regarding the factors affecting infiltration and the methods of measurement is included in this thesis.

Infiltration measurements have been conducted by different methods in the past by observing runoff from natural or artificial rainfall or by observing the rate of fall of ponded water. The most suitable method of measuring infiltration will depend upon the intended application, the equipment, and other resources available. Since there is no single accepted method for measuring infiltration rate, it is of particular

interest therefore, to derive a standard method of infiltration measurement in the "Local" Soil, However, to find a simple but reliable infiltration measurement many existing methods were examined and due to various reasons stated under chapter II of this thesis two methods were investigated and from the results obtained, it was determined that the buffer cylinder infiltrometer method was the most reliable, and also give the highest degree of accuracy.

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q_{ft} final infiltration

q_i intake discharge

q_{if} initial water infiltration

q_o outflow discharge

R electrical resistance of the material

S function of the initial moisture content of the profile

t time

$t_1 t_2$ temperatures

v, v_i electrical potential

z distance to the wetting zone

ρ density of conductor

θ moisture content of the transmission zone

ψ total water (pressure and gravity)

% porcentage

δ_{to} change in time

α component of a solution

∞ infinity

β constant depending on time

$<$ less than

$>$ greater than

CHAPTER 1

Introduction

1.0. The purpose of this study is to find a method of infiltration measurement in the Local Soil. Therefore, investigation was needed to provide a simple but reliable type of infiltrometer and to use this infiltrometer to determine the infiltration, in the local soils.

There are various ways by which water will penetrate and move through a particular soil. When water is applied to a soil in the form of rainfall or irrigation, the water will move downwards due to the capillary action. The gravitational forces will cause an additional downward movement of the soil water. Similarly, due to evaporation from the soil surface as well as water uptake by plant roots the soil water will move upward as well as in any other direction. Temperature differences in the soil or salt concentration will also cause the movement of soil water. However, for the purpose of this study the term 'Infiltration' will be limited to the vertical downward movement of water into the soil.

The realistic planning of water management and conservation activities requires accurate information regarding the rate at which different soils will take in water under different conditions. The rate of water entry into the soil flouctuates widely between soil types, and also wide differences can be found within a single soil type, depending upon the soil moisture level and the water and soil management practices employed.

It will be shown from the review of past literature that most of the present methods of measuring infiltration in the soils are too difficult and slow to carry out, and often inaccurate. But one thing is certain, and that is, that it is from an understanding of water movement that we can learn how to solve such problems as how to supply crops with adequate water and nutrients.

Finally, water itself is an important part of plants, forming approximately 85% of the fresh weight of growing plants. Thus water is not only a plant constituent, but is also a carrier for mineral nutrients, and gases entering the plant. It is essential therefore, that the optimum rate of supplying water to the plants should be

determined which is governed in turn by the infiltration rate. Therefore, research studies are needed to provide a practical method of infiltration measurement in the soil; Hence the primary objective of this research is to develop and evaluate an acceptable intrument for field measurement of infiltration.

The areas choosen for the experimental programme were at the Ahmadu Bello University, Zaria, and the College of Science and Technology, Kaduna Polytechnic, Kaduna.

Samples of the soil from various depths were examined in the Soil Mechanics Laboratory of the Department of Civil Engineering of the University. Other tests such as soil structure, swelling, moisture content and soil colour were undertaken at the same time to obtain the soil conditions necessary for this study. These are shown under appendix III. As a result of these studies and from a consideration of the methods suggested in the literature, it was decided that the best method to be used was the buffered cylinder infiltrometer. The buffer compartment is to compensate for the lateral subterranean flow of water in the plot.

Further, it became apparent that previous workers had used cylinder infiltrometers with excessive wall thicknesses and from the present experiments it would appear that a wall thickness of 0.042 inch (1/24") is sufficient to provide a light yet robust instrument. Further, these infiltrometers can be manufactured very easily from metal sheets and, therefore, much cheaply than the solid cylinder infiltrometers. They are also much lighter which is an important consideration in field work.

Eleven experimental sites were located for infiltration measurement studies. At each of the eleven sites, two cylinder infiltrometers were buried fifteen feet apart for measurements. At one particular site an attempt was made to use a rainfall simulator as a device of infiltration measurement. However, due to intermittent and sometimes prolonged power failures and the difficulties involved in obtaining water supplies for the experimental plot, it was impossible to carry out this experiments for more than one site within this period before the experiments were shifted to the ground of the College of Science and Technology, Kaduna Polytechnic, Kaduna., for further studies between November, 1969 and June, 1970.

During the period under consideration at the ground of the Polytechnic, soil samples were collected and examined at the soil Mechanics Laboratory of the Polytechnic, and a total number of sixty-six experiments (thirty-six buffered and non-buffered cylinder infiltrometers, eighteen inflow and outflow infiltrometers with the standard sprikler devices, and twelve inflow and outflow infiltrometers with actual rainfall) were carried out. Details are shown under Chapter III of this study.

In addition, a separate bounded plotting results for each of the experiments carried out is made available by the author in the Department of Civil Engineering, Ahmadu Bello University, Zaria.

CHAPTER II

2.0. General Consideration

Infiltration is a process in which water enters, penetrates, or wets the soil. It is caused by rain, irrigation water, liquid waste disposal into the ground, ground-water replenishment or recharge, and by seepage or leakage losses from reservoirs and ditches. It is of great importance to the irrigation engineer, hydrologist, civil engineer and, to some extent, the public health engineer.

In general the problem of characterising infiltration is one of describing the movement of water in an unsaturated soil. Different types of soils will, however, react differently under infiltration measurement.

In a dry soil, entrapped air bubbles will change their volume when water enters the soil, and as infiltration continues some air will be dissolved in the water and a small proportion will be released. The rate of absorption or release of this entrapped air greatly affects the rate of infiltration.

During the infiltration process soil swelling occurs e.g. heavy clay soils on wetting and drying will change their volume. This will be a gradual process.

Finally, in N orthern Nigeria, due to the long period of the dry season, the soil is heavy cracked and the rate of infiltration when the rains begin can be very high. However, this aspect of the problem is not considered in this thesis. During the rainy season when the soil is wetted and rewetted by heavy rainfall, infiltration may cause leaching. The amount of water which must be leached through the root zone to keep a favourable salt balance is an important factor in irrigation infiltration processes.

2.1. Historical Background on Water Infiltration Studies.

Infiltration has received a great deal of attention in the past and many research workers have investigated methods of infiltration measurement with particular reference to agricultural land. Each of these methods has been developed to meet a specific need and is usually not widely adaptable.

A review of literature on infiltration measurement showed that the earliest method was due to R.E. Horton in 1933. He used the transporting properties of the soil surface as they

were affected by the impact energy of falling rain -drops and thus obtained factors fc and kft, which were also dependent on rainfall intensity, for his equation - see equation (7) under this thesis.

Horton stressed the importance of correlating infiltration to rainfall runoff data and concluded that for a given soil, the infiltration rate varied between the maximum value when the soil was dry and a minimum value after wetting and packing. This was the first time that the importance of the study of infiltration rates was realised.

Lewis and Power (1938) enumerated a number of factors affecting infiltration as (a) factors influencing infiltration rate at a given time and point i.e. texture, structure, and organic matter., (b) factors influencing the average infiltration rate over a considerable area and period of time i.e. slope, vegetation, and surface roughness.

About 1939, a study of the influence of vegetative factors on infiltration rates was made by Duley and Rusell.

In the same year Browing discovered that certain soils would change appreciably in volume when subjected to change in moisture content and that the effect would be greater in the surface than in the subsoil.

The effect of the entrapment and escape of air was studied by Free and Palmer (1940).

In 1941, Moore studied the effect of temperature on infiltration in soils. He found that as temperature increased between 5°and 30°C., there was a corresponding increase in infiltration rate. There was a rapid increase in infiltration rate from 30°C to 35°C., after which a rapid decrease occured.

The influence of products of microbial activity on soil structure and infiltration was investigated in 1942 by Mc Calla, who determined that the addition of microbial decomposition products of plant residues resulted in a marked increase in the water stability of the soil structure which increased the infiltration rate of these soils.

All these researchers used cylinder infiltrometers

except Duley and Domingo (1943) who used a sprinkling infiltrometer device to determine the effect of decomposition products and microorganisms on the rate of infiltration of a layer of soil. They observed that microbial by-products would increase infiltration in the soil.

Around the same time Bodman and Coleman made their experiments on infiltration using metal cylinders which they filled with dry soil. They obtained distribution curves for different zones - see figure number 1.

Zone 1 - this is the saturated zone in which the curve is formed at the initial stages of the infiltration process and the depth does not increase as infiltration progresses.

Zone 2 - this zone is characterised by a sharp decrease in the moisture content with depth.

Zone 3 - this is the zone in which the moisture content remains constant with depth.

Zone 4 - this is the zone in which the moisture content decreases rapidly with depth.

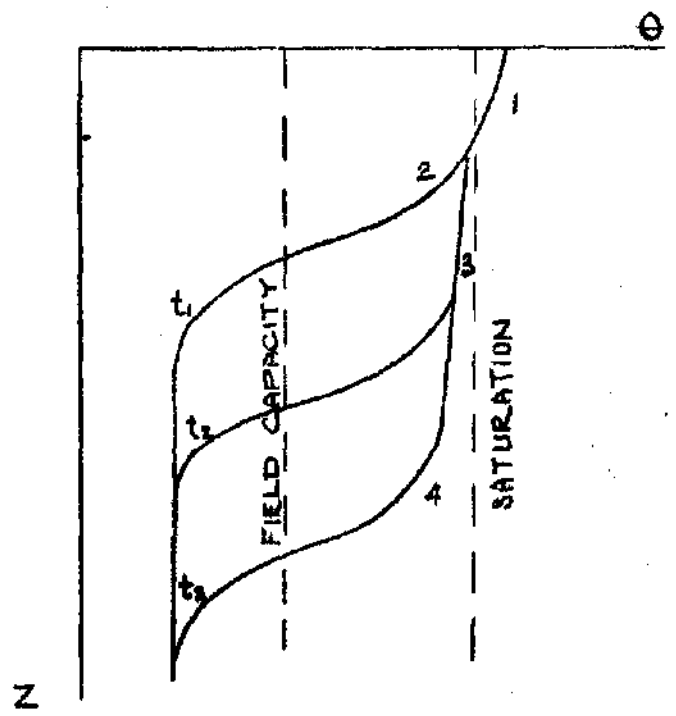


FIG. 1.
BORDMAN AND COLEMAN DISTRIBUTION CURVES.
where θ – the moisture content of the transmission zone
z – the distance to the wetting zone
t – the time

Zone 5 - this is the zone in which the change from wet soil to dry soil takes place over a very short distance. However, it must be remembered that these results were obtained for thoroughly disturbed soils.

In 1945, Phillsbury and Appleman studied the effect of organic matter on the surface soil infiltration.

A study of the influence of earth worms on infiltration was made by Hopp and Slater (1948). They discovered that earthworms will increase infiltration.

It was in 1952 that Richards defined infiltration of a soil as the maximum rate at which a soil, in a given condition, at a given time, will absorb water impounded on the surface at a shallow depth when an adequate border is made.

Pillsbury and Richards (1954) investigated the effect of the addition of different amounts of ammonium sulphate and organic matter on the infiltration of a soil. They discovered that when a moderate application of ammonium sulphate was made, it resulted in a significantly higher infiltration rates.

Conclusion.

In conclusion, there are many factors affecting infiltration of a soil which may either increase or

decrease the rate of infiltration e.g. chemical leaching and deposition, air pockets, the weather, the activities of man, plants, animals, insects, and microorganisms. It is therefore, in our present state of knowledge, not possible to predict infiltration rate from ordinary soil mechanics analysis and therefore it is essential that ptactical measurements are made in each area to determine infiltration capacity and rate.

2.2. Measurements for Water Infiltration.

(i) Historical Background.

The role of infiltration measurements for infiltration of water into the soils have long been recognised by research worker.

In 1928, Lewis and Neal studied the infiltration of water into soils using a series of galvanized iron tanks 36 inches deep and between 3 - 20 inches in diameter. The water tank was provided with an outlet pipe and a set of gauges for obtaining the soil surface elevation. No uniformity in the rate of infiltration was obtained by this method, even after repeated applications of water.

The studies of infiltration characteristics of forest soils was made by Auten in 1933 using rings, 2 inches deep and 12 inches in diameter, buried in the ground. He found that water absorption was most rapid at 1 inch depth and gradually decreased with depth; but this is not indicative of the full infiltration process since as described on section 2.1 - there is a great change in water content with depth, etc.

Pearse and Wooley (1936) investigated the effect of plant cover on infiltration using 1sq. ft. metal frames placed in the soil. They allowed water from a reservoir to flow from the upper edge over the plot, collecting the runoff at the lower edge, and thereby noting the difference between application and runoff which was assumed to have been absorbed as infiltration. It was eventually evident that the plot was too small to evaluate accurate infiltration rates under these conditions.

Lewis (1937) performed experiments on infiltration of water in the soil using metal cylinders pressed 4 inches into the soil with a closely packed soil around the outside of the cylinder. A weighed amount of water was poured into the rings and the time it took to disappear

was noted. He observed a definite relationship between infiltration and moisture content of the top foot of soil.

Nelson and Muckenhein (1941) used 8 inch diameter rings buried 2 inches into the ground with a 16 inches diameter buffer rings. They maintained a $\frac{1}{4}$ inch content head of water, and water intake was measured only in the centre ring, the outer ring thus providing a buffer area.

The effect of lateral movement of water infiltration was investigated by Marchall and Stirk (1950). Using both buffered and unbuffered rings between 1 to 10ft. in diameter, they discovered that the minimum infiltration of a given soil will decrease with the increasing size of plot, and that buffered plots gave more consistent results.

Tisdall (1951) used 12 inches diameter ring infiltrometers to investigate soil moisture as it affects infiltration. He found that the lower the initial soil moisture, the higher the infiltration, and that the longer the time of water application, the less would be the change in soil moisture.

Recently Wilkinson and Kowal *(1968) carried out field measurements on infiltration rates. Their results indicated that the infiltration rate varies from 0.12 to

1.5 inches per hour under similar conditions. The experiments performed on two different sites did not provide enough data to bring out the usefullness of this method of a practical approach to the infiltration method of measurement. Only a limited area was investigated. See appendix I. Therefore, tests are needed at several areas and a continuation of infiltrometer method is followed in this research.

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(ii) Existing Methods of Measurements.

Due to the great number of factors affecting the infiltration process, infiltration capacity (the maximum rates, usually expressed in inches per hour, feet per day, or cubic feet per second per acre, at which infiltration can occur at the land surface) cannot be predicted with much accuracy unless prediction are based on field measurements of infiltration under various conditions. Most of the methods being used for the determination of infiltration are included in the following list of methods:

(a) measurement of differences in soil moisture

(b) measurement of the rise in the water table.

(c) measurement of the surface inflow and outflow for a catchment area and noting the infiltration capacity from the differences between the two. The water can be applied artificially or naturally from actual rainfall.

(d) the application of sprinkling devices or ponded water to an experimental plot in measured quantities and noting the inflow and outflow, and thereby computing the rate of infiltration. A special form of this is the simple buffer cylinder infiltrometer.

(e) the placement of a catch-basin called a lysimeter under a laboratory sample or at some depth below the land surface to measure the infiltrating water at that point.

(f) the use of a general solution of the infiltration equations for an area.

(g) the use of water-shed hydrograph methods.

(a) Measurement of Differences in Soil Moisture:

At the end of the 19th century the capillary tube method of measuring the rise of water was introduce. In 1907, Buckingham argued that the flow of water through soil is basically the same as the flow of electricity in a wire, and concluded that the driving force for water flow in soils is the difference in the attractive forces between water and soil at various points in the soil.

Other people connected with this work are:- Gardner and Richards (1920); Gardner and Widstoe (1921); Richards (1931); Bodman and Coleman (1943); Childs and Collis - George (1950); Klute (1952); Taylor and Henser (1953); Miller and Miller (1955, 1956); Philips (1955); Day and Luthin (1956); Gardner (1956); Bruce and Kluto (1956); Philip (1956); Gardner and Mayhugh (1958). The effect of their investigations resulted in the method of measuring infiltration for the vertical one-dimensional system. In general, the method adopted was in relation to water movement into soil profiles. The most important thing in water flow in soil is that there is a major difference between saturated and unsaturated flow. When a soil is saturated, gravity causes water movement.

Water columns under the influence of gravity push water through the pore spaces in the soil. Here, the larger the pore the faster the flow for a given size of moving force.

When soils are not completely wetted, although gravity is always acting, the major forces are due to adhesion and cohesion. Under these circumstances the degree to which columns are filled with water is as important to flow as is the moving force. The direction of flow is determined by the direction of the moving force - water moves in all directions into dryer soil. Hence the limitation on the use of this method for field measurement of infiltration.

(b) Measurement of the rise in the Water Table.

The effect of the water table is of great importance in soil infiltration. A loose, permeable soil will have a higher infiltration capacity than a tight clay soil. If much of the pore spare is filled with water, infiltration capacity is usually less than when the soil is relatively dry. If the pore space of the surface soil is completely filled with water, further downward movement of moisture is controlled by the subsoil permeability. If the water

table is low with uniform root zones containing the ordinary initial amount of soil water, the distance to the water table may mean only a small change in the initial infiltration rate, and the effect of the surface layer will be to control the infiltration capacity.

In 1957 Youngs compared the moisture profiles for constant water infiltration into columns draining to a water table with those predicted by equation used by Philip in 1955. He found that his theoretical and experimental profiles agreed to a moderate degree.

From the above, the distance to the water table is of little or no consequence, but an increase in ponded depth may materially increase both initial and ultimate infiltration rates; hence the method cannot be widely adopted for field infiltration measurements.

(c) Measurement of the surfaces inflow and outflow for a catchment area and noting the infiltration capacity from the differences between the two using sprinkler.

The water infiltration of the soil may be determined through measurements of the flow into and out of a level area under consideration. If the intake rate is uniform

through the catchment area, the absorption of water by the soil will be uniform for equal periods of time. The amount of water flowing into and out of the area must be properly recorded and controlled. When direct measurements are not feasible, intake cylinders can be used with success.

The following are the research workers who have been engaged on this topic: Laws and Parson (1943), Mayer (1958), and Bertrand and Parr (1961), alternatively, it is suggested that a ponding area can be constructed in the field and actual measurement made of the runoff which will be subtracted from the rainfall to provide infiltration. However, this method is very difficult to control and also it is difficult to make measurement in the open in the rain, due to the discomfort of the situation.

In most of the studies, commercial spray nozzles were tested for rainfall drop size, drop distribution, and kinetic energy at various combinations of pressure and height. One of the major problems is to design a sprinkler which may provide similar characteristics to those of natural rainfall.

Sprinklers have been found to provide reasonable results in producing infiltration. They still have to be developed further for different types of soils and surface roughness, etc., if they are to be accepted as a standard item of equipment in this method of measurement.

(d) The application of sprinkling devices or ponded water to an experimental plot in measured quantities and noting the inflow and outflow, and thereby computing the rate of infiltration.

(i) Applying sprinkling device.

Simulated rainfall or water applied in a form similar to natural rainfall, has become an effective means of applying water in the investigations of water infiltration measurement.

Sprinkling devices are generally used to simulate rainfall and have been studied and used in the past. Some of the early methods were quite primitive, and many rainfall simulators failed to produce natural rainfall-type storms.

In 1930, Lodermilk investigated the influence of forest litter on runoff, percolation, etc., using

artificial rainfall from nozzles that sprayed upward and allowed the rain to fall upon the experimental plot.

Further studies were conducted by different people at different times. Among them were Duley and Hays (1932); Diseker and Yoder (1936); Neal (1938); Woodruff et al. (1938); Sharp and Heltan (1940); and Duley and Domingo (1943). In most of their experiments, it was discovered that direct rainfall energy relationships would be practically impossible to calculate. The drip tower and drip screen rainfall applications were later used for infiltration measurements by Ellison and Pomeranz (1944); Ellison and Slater (1945); and Ellison (1947). The method adopted was to use a tank with holes drilled at about 4 inch centres. Water was supplied to the drip tower. A screen of 1 inch mesh chicken wire was placed directly below the tank and cheese cloth was spread loosely over the wire so that it would be pressed into the opening. A short piece of yarn was hung from each pocket to form water drops of uniform diameters.

Different yarn sizes were used to obtain various uniform drop sizes. They found that natural rainfall characteristics were not well simulated.

A good portable rainfall simulator was developed recently at Purdue University (U.S.A.) to produce artificial storms of approximately the kinetic energy of high intensity natural rainfall. The simulator is used to compare the soil loss, water loss, and infiltration rates of treatments on standard size rectangular runoff plots. This is strictly a laboratory method and would take time to install.

Advantages of Simulated Rainfall

Control - Plots and equipment can be inspected and where necessary corrected prior to and during operation, in contrast to natural rainfall studies when rainfall time and period cannot be predicted.

Various measurements and observations which are difficult or impossible during natural rainstorms may be readily obtained during simulated storms.

Simulated rainfall may be applied at selected intensities for selected durations, and at selected treatment conditions. Such control is much greater than with natural rainfall.

Adaptability - Simulated rainfall is readily adaptable to laboratory research. Such studies will present the possibility for major advances in the understanding of basic processes.

Characteristics of Natural and Artificial Rain Drops.

The effects of drop size on infiltration were evaluated by Laws (1941) and Levine (1952). The results were determined in terms of apparent drop diameter. The apparent drop diameter was a function of the actual drop diameter, the angle of impact, and the velocity of the drop . Hence no simple relationship exists between apparent diameter and actual drop diameter. Although the applicability of the results is limited, they are still useful in comparing the effects of the various operating conditions. It was found that drop diameters decreased with increasing pressure and to

some extent with decreasing nozzle diameter. It was observed that increasing the drop size resulted in a statistically significant decrease in infiltration capacity for the soil tested. They concluded that the decrease in infiltration capacity that resulted was due in part to a physical compaction of the surface soil, and in part to a sealing of the surface layer. These methods are, however, not easily applied in the field.

(ii) Ponded Water Applied to an Experimental Plot

Various types of ponded water, in the form of cylinder infiltrometers, have been used in the study of water infiltration of soils. Usually, metal rings or compartments were driven into the soil to depths ranging from a few inches to more than a foot, so that lateral flow of water from the rings could be held to a minimum. The methods of adding water to these cylinders included such principles as constant heads, falling heads, and sprinkling application. In the earlier studies only single rings were employed and much of the data indicated a high degree of variability, probably due in part to the uncontrolled lateral movement of water from the ring.

In later studies double-ring or multi-ring devices were used so that lateral or divergent flow could be minimised by means of a buffer area surrounding the central compactment. The double ring device system is usually accepted as a good compromise between the requirements of accuracy and ease of use. They are generally refered to as buffer cylinder infiltrometers which is the term adopted for this thesis. Measurements of water infiltration in the centre were supposed to be indicative of the vertical component of flow.

Some of the earlier research works have been mentioned under chapter 2.2. of this thesis.

Limitations

Method of Placement in the Soil - most of the methods of placement cause a certain degree of disturbance of natural structural conditions, and the resulting disturbances manifested as shattering or compaction may cause a large variation in water infiltration between applicated runs.

The Interface between the soil and the side of the metal ring may cause unnatural seepage planes which may result in abnormally high water infiltration.

Variability of Data caused by ring placement could be overcome

by leaving the rings in place over an extended period, beore, or during a series of measurements.

The Problem of Entrapped Air inside the soil column, caused when a constant head of water is applied upon the surface and the inability of air to escape from the soil under conditions of saturated flow usually creates an internal air cushion which results in a impeded downward flow movement.

Advantages

Buffers are used to absorb or to reduce the effect of lateral flow on infiltration, so that the outflow from the inner cylinder is a more accurate measure of the vertical infiltration capacity of the soil.

The equipment can be developed rapidly. The procedure in the field is simple. It can be accurately installed and readings quickly made.

It can be used to determine the infiltration characteristics of irrigated soils with a good accuracy.

Thus practical applications are possible.

The records can be kept in a permanent form for future use where necessary.

(e) <u>The placement of a catch-basin, called a Lysimeter, under a laboratory sample or at the same depth below the land surface to measure the Infiltrating Water at that point</u>.

This method is similar to the large ring devices; however, larger areas are utilized. Plots usually range in area from 10 sq.ft. up to $\frac{1}{4}$ acre, and are provided with a border arrangement so that water can be applied to the basin, providing an impounded condition. A given amount of water is applied to the basin, and the water infiltration is recorded.

Huberty and Pillsbury (1941) and Parker and Jenny (1945) found that small basins have similar limitations in the accurate evaluation of water infiltration as found with cylinder infiltrometer. The larger basins have this

same limitation, and in addition they are not practical because of the large amounts of water needed for infiltration measurements, and the required topography of the experimental area.

(f) The use of a general solution of the Infiltration equations for an area.

Since the infiltration process is a fact finding one, practically all the existing equations which attempt to describe the infiltration process relate the water infiltration to some fractional power of time as indicated in chapter IV (b).

Many research workers have derived numerical techniques for the solution of the governing equations for the rate of infiltration.

Many review articles discussing the advances in modern infiltration theory have been published by Swatzendruber (1966), Gardener (1967) and Skaggs, Huggins, Monke and Foster (1968). But the techniques for the solution of these equations and the characterisation of infiltration are not yet

Therefore, many years are necessary before adequate data can be obtained for accurate water infiltration measurement using this method. And also from the above, it can be seen that the method will be greatly influenced by changes in soils and vegetaion, thus giving rise to many soil parameters which will be very difficult to obtain under field conditions.

CHAPTER III

3.0. A method of water infiltration measurement in the soil.

Various researchers have developed methods and equipment for the determination of reliable infiltration rates for different soil conditions. Useful information has been obtained to correlate, in particular, the effect of duration of water application to physical changes in soil moisture content. It is the writer's intention, therefore, to derive a simple but reliable standard method of infiltration rate measurements. Hence after a comprehensive review of the different methods of measuring water infiltration in the soils, it is considered that a continuation of Wilkinson's work should be followed and buffer cylinder infiltrometer methods of measurement be adopted for the project. As a comparison, a rainfall simulator was also used on an experimental plot to determine infiltration capacity.

The main reason for choosing the buffer cylinder infiltrometer was because of slight differences and difficulties that might arise in the use of other methods. Some of these difficulties have been listed under chapter 2.2.(ii) of this study.

Further, after considering its limitations and the great advantages which this method has over other existing ones, it is considered that this method is the best.

This method may not give values which are close to actual infiltration values as measured under natural field conditions, but consistent results can be obtained easily and the results can be interpreted to provide the kind of information that is required on infiltration.

It is suggested that a future programme of the study should be devised to compare the results of buffer cylinder

infiltrometers with actual infiltration rates. However, at the moment it would not appear that any of the existing methods which are available provide results which are reliable. Therefore, for the moment, cylinder infiltrometer results have to be accepted. It is also suggested that as a further programme the electrical methods of determining infiltration rates at different soil depths should be investigated.

3.1 A. Experiments carried out at the Ahmadu Bello University Zaria.

(i) Location and extent of area of study

At the initial stage, the area of the study covers approximately 550 acres of the total Ahmadu Bello University property and it is situated approximately 5 miles from the town of Zaria lying between the Federal Building Research - Works Division and the extremity of the Zaria airfield, mile 4, and the South Eastern boundary of the present Ahmadu Bello University site, mile 6.

To the South West the Kubani River forms a natural boundary, while to the North East the area is demarcated by the main Funtua - Zaria road. It is located approximately at Latitude 11° 10' N and Longitude 7° 40'E and most of its elevation lies at about 2195 feet above mean sea level.

(ii) Physical environment

Climate - The average annual rainfall for Samaru in the period 1954-61 was recorded at the Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria., as 43.63 inches, occuring mainly between the months of June and September; but usually variable with a well marked dry season between November and March. Average humidities varied between 13.7% in January to 90.6% in August. The maximum air temperatures varies from a mean minimum of 57.7°F in January to a mean maximum of 97.5°F in April. The annual mean maximum temperature for the period 1954 - 61 was recorded as 77.2°F.

Geology - The area under consideration is entirely underlain by variable granite gneiss, outcrops of which are

apparent to the East and also in valley bottoms. Also occuring along the rock are narrow banks of finer grained material and veins of quartz, in some cases up to 18 inches thick.

Topography - The major portion of the area has a gentle slope running South Westwards from the Kaura Namoda railway line to the Kubani river with the angle of slope increasing rapidly as the river itself is approached. The secondary slopes occur regularly throughout the area into the main valley system which feeds the Kubani river.

(iii) Site Locations

Preliminary inspection was made by walking over the area looking for signs of unusual surface disturbance and stones that might damage the cylinders.

A rough sketch of the area was made and offset measurements were taken to locate the infiltration stations, as shown in appendix IV.

(iv) Soil Characteristics of the area

Vine described the soil material as consisting of several feet of deposited silty sand overlying sedentary decomposed rock (usually granitic gneiss), and illustrated the group by reference to a profile. This consisted of 2 feet of greyish brown sandy loam overlying 3 feet of pale brownish yellow sandy loam with a mixture of loamy material at $5\frac{1}{2}$ feet with a little granitic grit, slightly worn quartz stones and occasionally ironstone concretions marking the base of the transported layer, lying above the sedentary disintegrated granite. The soil types were described as Jamaa and Jama series, Yelwa series, Funtua series, Yagun series, Ironpan soils and true alluvial soils.

(v) Equipment.

Equipment used for the experiments are:-

(a) Cylinder Infiltrometers

Cylinder infiltrometers with ponded water will be used in these experiments for measurements of water infiltration and buffer - area would be provided so that lateral flow could be minimised during the operation.

(i) Equipment used for cylinder infiltrometer experiments

Metal - Cylinders. Metal cylinders were constructed of smooth steel to minimize skin friction. A sharpened cutting edge was provided at the base of each cylinder. The cylinders were made to the following dimensions:

Internal diameter of cylinder	12 inches
Height of cylinder	12 "
Plate thickness	$\frac{1}{4}$ "
Splay cutting edge of cylinder	$\frac{1}{2}$ "

Water and water bucket. Water was obtained from the stand pipes previously located around the project area.

A bucket of 14 pints capacity was used to obtain water for both the intake cylinders and their buffered zones.

Timing device. A stop clock and a table clock were provided at the site of the experiment as timing devices.

Driving plate and hammer. A metal plate and a 16lbs. sledge hammer were used as tamping devices to drive the metal cylinders into the ground.

Spirit level. A spirit level was provided as a levelling device while tamping the intake cylinder into the ground.

Micrometer screw gauge. A micrometer screw gauge was fixed to a metal plate and placed over each of the cylinders to obtain the necessary readings for the intake data.

Installation of Cylinders.

The exact location for each cylinder was examined carefully to see that there was no surface disturbance. At each infiltration site, two metal cylinders were set in place fifteen feet apart and they were pressed firmly into the soil. A driving plate was then placed on top of each cylinder. The plate was then tamped with the sledge hammer to drive the cylinder into the soil.

The spirit level was then used to plumb the cylinder top as tamping continued until the cylinder reached the desired depth of 7 inches.

A buffer pond was then constructed by building up a 6 inches dike around the cylinder.

After driving in the metal cylinder, a period of at least two days was left before operation so that the effects of soil disturbance were minimised.

(ii) Field method measurement

The following methods of operation were carried out:

The buffer pond was filled with water to a depth of 3 inches on each of the cylinders, and the depth was maintained throughout the observation period.

Burlap was placed inside the intake cylinder as a puddling protection on the soil.

The intake cylinder was then filled with water to a depth just touching the sharp-end-point of the micrometer screw gauge previously set in place at the top of each cylider.

The puddling protection device was then removed from each of the intake cylinders.

The measurement of the water surface elevation of each of the cylinders was then noted.

Subsequent micrometer gauge readings and the time at which the observations were made were then recorded. Also, additional measurements at periodic intervals were recorded as shown on Table Numbers 2 to 7 cylinder infiltrometer test data from which the results obtained in Table Number 2 were plotted as shown on graph sheet Numbers ZABUC 1(a) - 2(b). In order to solve equation (5) under this study, the same data were replotted on semi-logarithmic - scale sheet numbers ZABUS 1(ia) - 2(ib) as shown under chapter 4.0 (B) of this thesis.

The rest of the data sheets were listed in table numbers 3 to 7 i.e. ZABUS 3(a) - ZABUS 11(b) and they were included in appendix VI of this thesis.

Table No. 2

Cylinder Infiltrometer data ZABUC 1(a) - 2(b)

1(a) 1(b)

Observed Time	Elapsed Time (Minutes). Since last read.	Elapsed Time (Minutes). since beg. of test	Micrometer hook gauge reading. (depth ins.).	INTAKE Ins.	INTAKE Cumm. depth	INTAKE Depth Ins/hr	Micrometer hook gauge reading (depth ins.)	INTAKE Ins.	INTAKE Cumm. depth	INTAKE Depth Ins/hr
8.00	-	-	5.86	-	-	-	5.86	-	-	-
8.05	5	5	5.76	0.10	0.10	1.20	5.75	0.11	0.11	1.32
8.10	5	10	5.69	.07	.17	0.84	5.68	.07	0.18	0.84
8.20	10	20	5.59	.10	.27	.60	5.57	.11	.29	.66
8.30	10	30	5.57	.12	.39	.72	5.48	.09	.38	.54
8.45	15	45	5.43	.14	.53	.56	5.36	.12	.50	.48
9.00	15	60	5.29	.14	.67	.56	5.26	.10	.60	.40
9.30	30	90	5.03	.26	.93	.52	5.02	.24	.84	.48
10.00	30	120	4.78	.25	1.18	.50	4.82	.20	1.04	.40
11.00	60	180	4.35	.43	1.61	.43	4.47	.35	1.39	.35
12.00	60	240	3.92	.43	2.04	.43	4.14	.33	1.72	.33
1.00	60	300	3.49	.43	2.47	.43	3.81	.33	2.05	.33
2.00	60	360	3.06	.43	2.90	.43	3.48	.33	2.38	.33

2(a) 2(b)

8.00	-	-	5.86	-	-	-	5.86	-	-	-
8.05	5	5	5.74	0.12	0.12	1.44	5.72	0.14	0.14	1.68
8.10	5	10	5.65	.09	.21	1.08	5.59	.13	.27	1.56
8.20	10	20	5.50	.15	.36	.90	5.42	.17	.44	1.02
8.30	10	30	5.35	.15	.51	.90	5.27	.15	.59	0.90
8.45	15	45	5.17	.18	.69	.72	5.10	.17	.76	.68
9.00	15	60	4.98	.19	.88	.76	4.93	.17	.93	.68
9.30	30	90	4.73	.25	1.13	.50	4.67	.26	1.19	.52
10.00	30	120	4.49	.24	1.37	.48	4.42	.25	1.44	.50
11.00	60	180	4.07	.42	1.79	.42	4.05	.37	1.81	.37
12.00	60	240	3.68	.39	2.18	.39	3.61	.34	2.15	.34
1.00	60	300	3.32	.36	2.54	.36	3.29	.32	2.47	.32
2.00	60	360	2.96	.36	2.90	.36	2.97	.32	2.79	.32

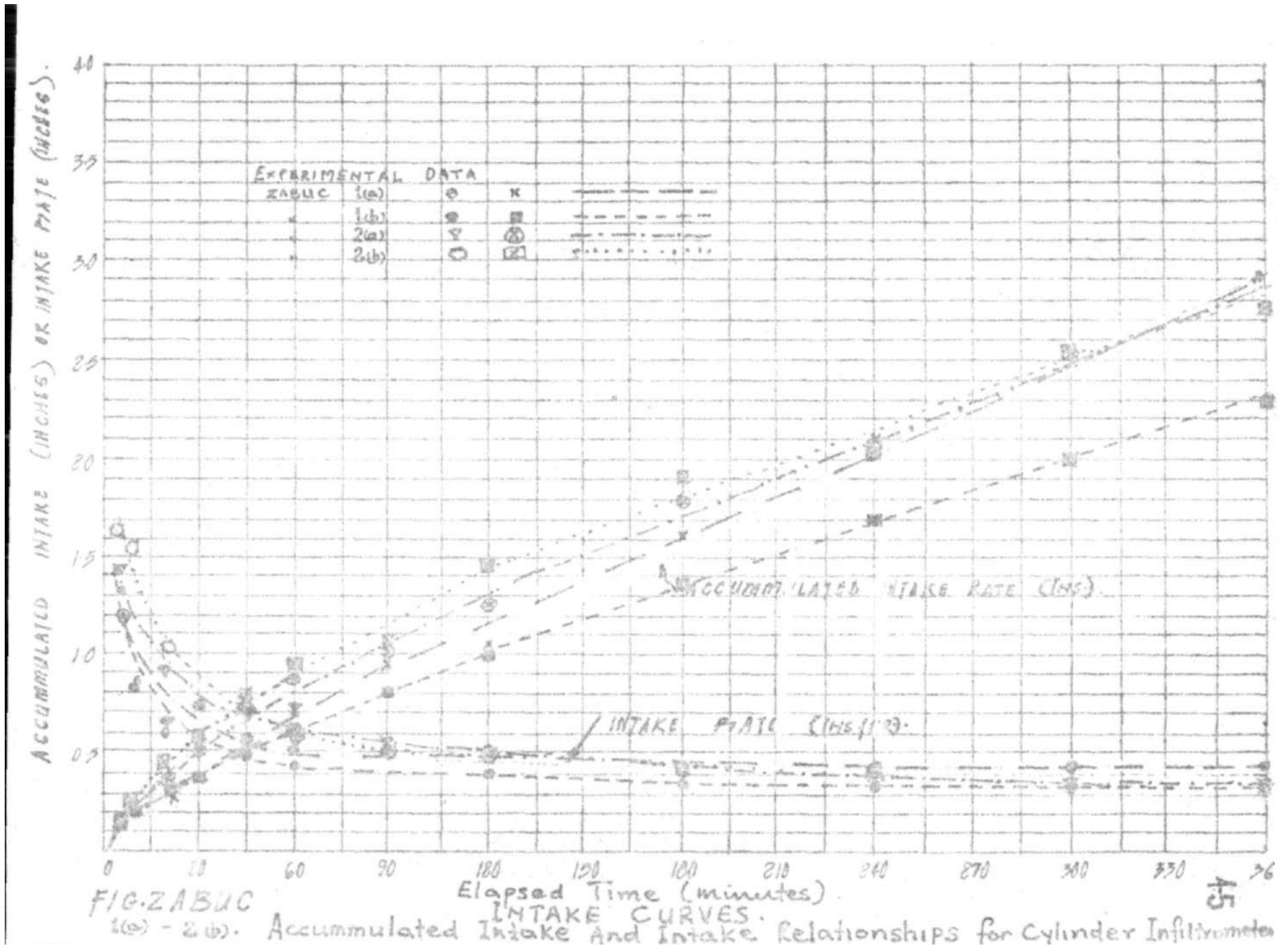


FIG. ZABUC
INTAKE CURVES.
1(a) - 2(b). Accummulated Intake And Intake Relationships for Cylinder Infiltrometer

(iii) Results of the experiments using cylinder infiltrometers at the Ahmadu Bello University, Zaria

The results obtained from the curves under the experiments using cylinder infiltrometers at the Ahmadu Bello University, Zaria are as follows:-

Table No. 7 (i).

Tabulation of the results using cylinder infiltrometers at the Ahmadu Bello University, Zaria.

Table No	Particulars	Initial Rate (Avg.) Ins/hr.	Final Rate (Avg.) Ins/hr
2	ZABUC 1(a) - 2(b)	1. 41	0.38
3	ZABUC 3(a) - 4(b)	2. 13	0.28
4	ZABUC 5(a) - 6(b)	1. 80	0.49
5	ZABUC 7(a) - 8(b)	1. 74	0.18
6	ZABUC 9(a) -10(b)	1. 70	0.23
7	ZABUC,11(a) -11(b)	1. 62	0.14

From the above table, it may be observed that all the six infiltration rates are similar except in the case of tables numbers 2 and 3 where the highest average final rate of 0.38 inch per hour and the highest average initial rate of 2.13 inch per hour was recorded respectively.

This discrepancy is due to the initial moisture content of the soils because the experiments performed under these two tables were conducted during the hot month of May as against the rest of the experiments conducted in the months of June and July when the rainy season was just started.

(b) Sprinklers - Inflow and outflow infiltrometers.

A sprinkling device in the form of a bath-shower sprayer will be used as a standard item of equipment to simulate rainfall and to permit the inflow and outflow on an experimental plot, and thereby computing the rate of infiltration.

(i) Selection of sprinkling device

A bath-shower sprayer was selected after careful consideration for its uniform drop distribution over the plot area, and its rainfall intensity range was similar to natural rainfall.

(ii) Design and construction of the infiltrometer

After the selection of the sprayer, the next part of the research was to design and construct a suitable infiltrometer.

The size of the infiltrometer was dictated by the operational characteristics of the sprayer at a head of 6ft. 3 inches. Therefore, a metal plot frame 4'0"x 4'-0"x 4" in depth was designed bearing in mind that it must be portable, practical, economical in construction, easily installed and for successive application on different sites.

The plot frame was equipped with a flume disigned for measuring the discharge by measuring the loss in head caused by forcing a stream of water through the throat of the flume.

Design of flume

After consideration of the actual rainfall at the Institute of Agriculture, Ahmadu Bello University, Zaria, the following assumptions were made in order to design the flume:

(a) a maximum rainfall intensity of 1 inch per hour.

(b) a maximum infiltration of 0.4 inch per hour at maximum runoff.

Therefore, the maximum runoff will be

1.0 - 0.4 = 0.6 inch per hour.

Taking a metal plot area of 16 sq.ft., we can now find the volume of water discharge per hour in cusecs as

$$\frac{0.6}{12} \times \frac{16}{3600} = 0.0002 \text{ cusecs.}$$

Using table 6.9* it is now possible to read the upper head, Ha = $1\frac{3}{16}$ inch and this gives the minimum throat width of 1 inch for a minimum discharge of 0.009 cusecs; this head is considered quite adequate for this case.

(iii) Water and water connection.

Well water was used for the experiment and the water was pumped directly by a Beressford submersible pump fitted to a $1\frac{1}{4}$ inch galvanised iron pipe. The pipe was reduced and connected to the $\frac{3}{4}$ inch near the sprayer, at which it was reduced and connected to the $\frac{1}{2}$ inch end of the sprayer. A $1\frac{1}{2}$ inch end type flow meter was installed for recording the inflow from the well into the frame plot.

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*Table 6.9- Irrigation Principle and Practice by J. Israelsen and V. E. Hansen refers.

The whole operation was controlled electrically by a Sumo hand auto starter, type AB 742/1^{E}., H.P. 0.3., Amps. 2.2., cycle 50., and volt. 250.

(iv) Field method of measurement.

The metal frame was driven flush with the top of the soil using a tapper to a depth of 2 inches so that no leakage could occur during the run with the runoff flume attached to the slotted front of the plot frame.

The ground which had been made level was checked to see that the area bounded was perfectly level and had no disturbance of any type.

The sprayer was centered over the metal frame with the spray from the sprayer directed on the plot and the surrounding border - area. The drops of this unit are rather large and fall a distance of about 6 ft. 3 ins.

Evaporation was considered negligible.

A polythene tent was mounted in position to protect the sprayer from wind and to reduce evaporation during the flow measurements.

Data obtained from the measurments are recorded for computation in the inflow and outflow infiltrometer data sheet - Table No 8 ZABUS (1 - 6) and are plotted as shown in the preceding graph sheet.

Table No. 8: ZABUS(1 - 6)

Inflow and Outflow Infiltrometer data.

I - Infiltration rate (in/hr.)
q_i - the intake discharge.
q_o - the outflow discharge.
t_o - time in minutes.
Avg.- the average time in minutes
In/hr - Inches per hour

Observed Time	ELAPSED TIME t_o Minutes	16 Sq.ft.	Avg. Mins.	q_i Ins/hr	q_o Ins./hr.	(1) $(q_i - q_o)$ Ins/hr. per 16sqft	q_i Ins/hr	q_o Ins/hr	(2) $(q_i - q_o)$ Ins/hr. per 16sq. ft.	q_i Ins/hr	q_o Ins/hr	(3) $(q_i - q_o)$ Ins/hr per 16sq. ft
8.02	Start	-	-	-		-	-	-	-	-	-	-
8.24	22	0	-	0.83	-	-	0.83	-	-	0.83	-	-
8.27	25	3	14	,,	0.03	0.80	,,	0.07	0.76	,,	0.03	0.80
8.50	48	26	37	,,	0.19	0.64	,,	0.21	0.62	,,	0.11	0.72
9.20	78	56	67	,,	0.28	0.55	,,	0.30	0.53	,,	0.17	0.66
10.04	118	96	107	,,	0.34	0.49	,,	0.36	0.47	,,	0.21	0.62
11.10	188	166	177	,,	0.43	0.40	,,	0.42	0.41	,,	0.32	0.51
12.30	268	246	257	,,	0.43	0.40	,,	0.45	0.38	,,	0.34	0.49
14.10	358	336	347	,,	0.43	0.40	,,	0.45	0.38	,,	0.34	0.49
16.10	478	456	467	0.83	0.43	0.40	0.83	0.45	0.38	0.83	0.34	0.49

						(4)			(5)			(6)
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.24	22	0	-	0.83	-	-	0.83	-	-	0.83	-	-
8.27	25	3	14	,,	0.01	0.82	,,	0.05	0.78	,,	0.08	0.75
8.50	48	26	37	,,	0.11	0.72	,,	0.17	0.66	,,	0.19	0.64
9.20	78	56	67	,,	0.16	0.67	,,	0.28	0.55	,,	0.28	0.55
10.04	118	96	107	,,	0.22	0.61	,,	0.35	0.48	,,	0.34	0.49
11.10	188	166	177	,,	0.28	0.55	,,	0.42	0.41	,,	0.41	0.42
12.30	268	246	257	,,	0.30	0.53	,,	0.43	0.40	,,	0.43	0.40
14.10	358	336	347	,,	0.30	0.53	,,	0.43	0.40	,,	0.43	0.40
16.10	478	456	467	0.83	0.30	0.53	0.83	0.43	0.40	0.83	0.43	0.40

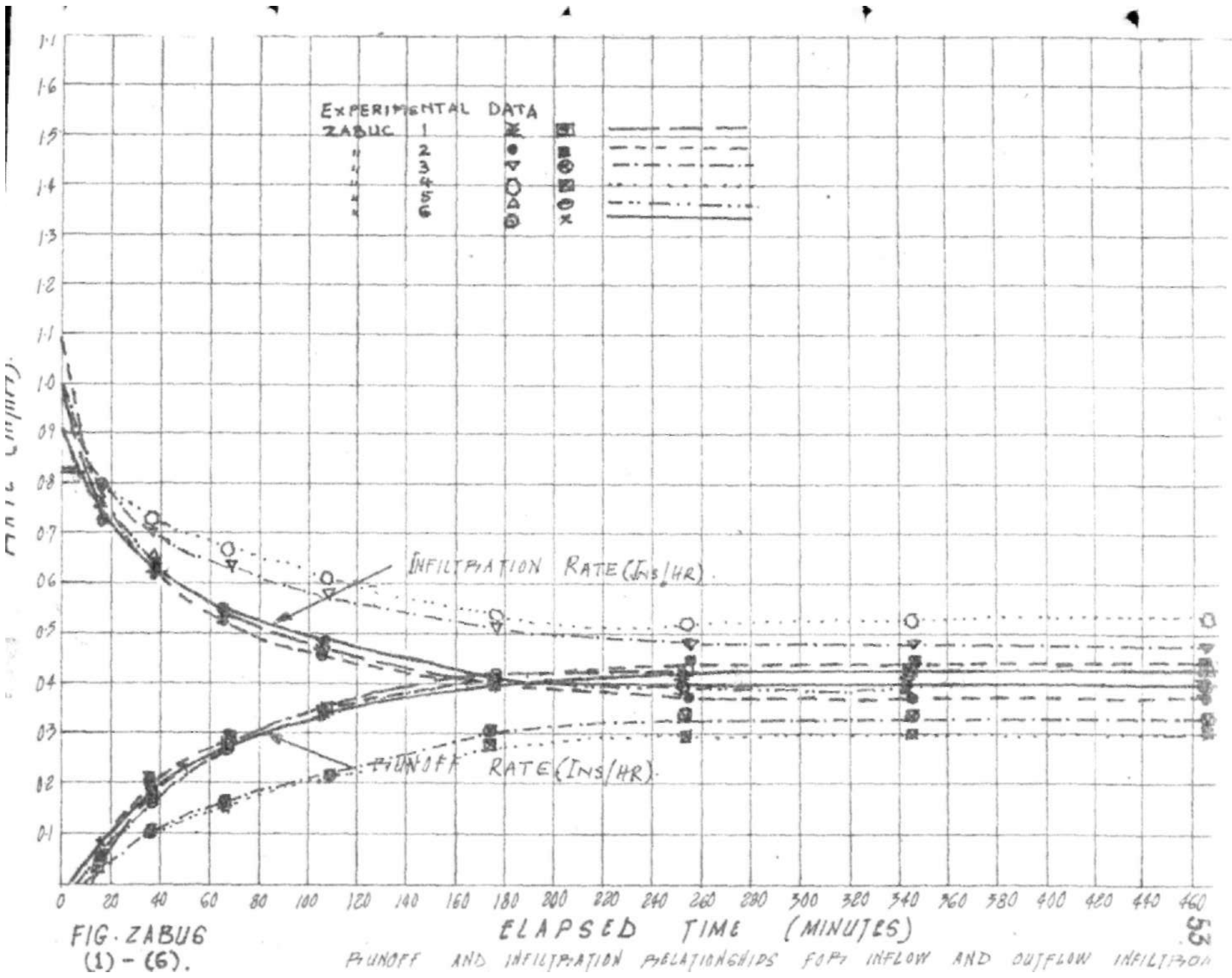


FIG. ZABUG (1) - (6).

RUNOFF AND INFILTRATION RELATIONSHIPS FOR INFLOW AND OUTFLOW INFILTRATION

(v) Results of the experiments using sprinklers at the Ahmadu Bello University, Zaria.

In view of the limited water application upon the experimental plot, the author has been limited to six experiments for this area. However, the results obtained are included herewith in order that the data might be made available to other research workers.

It can be seen from the results that the infiltration at any given time depends on the water available for infiltration and on the infiltration capacity of the soil. If the effective rainfall is greater than the infiltration capacity, the excess fills depressions and flows over the land surface.

During a storm, the f-capacity is not constant.

The average initial infiltration rate is 0.78 inch per hour and the average final rate is 0.45 inch per hour.

Therefore, an experimental infiltration rate - time relationship can be obtained from sprinkler data.

3.1. B. Experiments carried out at the Kaduna Polytechnic, Kaduna.

With reference to verbal instructions from the Head of the Department of Civil Engineering, Ahmadu Bello University, Zaria., a further study of this method was carried out at the ground of the College of Science and Technology, Kaduna polytechnic, Kaduna., between November, 1969., and June, 1970.

(i) Description of the Site

The College of Science and Technology is on a latitude 10^{o}- 32' North and longitude 07^{o} - 26' East on the Northern side of the town of Kaduna to the West of the main Lagos - Kano railway line. The area is fairly smooth and has small slope towards the South until it reaches a deeply and irregularly qullied valley with progressively larger marks of scouring and erosing clearly showing heavy runoff toward the stream which joins the River Kaduna, to the South approximately two miles away.

The site is bounded on the Northern side by the land containing the house of the North Central State Military Governor, and by the Military Hospital and depot. The boundary along the Eastern side runs 3000 feet from, and parallel to, the main railway line. And on the South and West is bounded by the residential areas of Tudun Wada and Sabon Gari. The average elevation of the site is 2010 feet above mean sea level.

The average annual rainfall in the period 1965 - 69 was recorded as 56.93 inches., occuring mainly between the month of March and September., but usually variable with a well marked dry season between November and February.

(ii) Soils and test results

Field work was carried out by using anger method to seven feet below the ground surface. Undisturbed soil samples were collected for testing in the College of Science and Technology laboratory. The section shown on figure Number 3 includes the descriptions of the encountered soils.

(iii) Current Field Experiments

In Chapter 2.2(ii) references have been made to field experiments suitable for the measurement of infiltration rate. Therefore, cylinder infiltrometer and inflow and outflow infiltrometer experiments will be continued in the ground of the Kaduna Polytechnic by the author.

(iv) Experiment and tests.

(a) Cylinder Infiltrometers

An experimental test was performed on the site to find

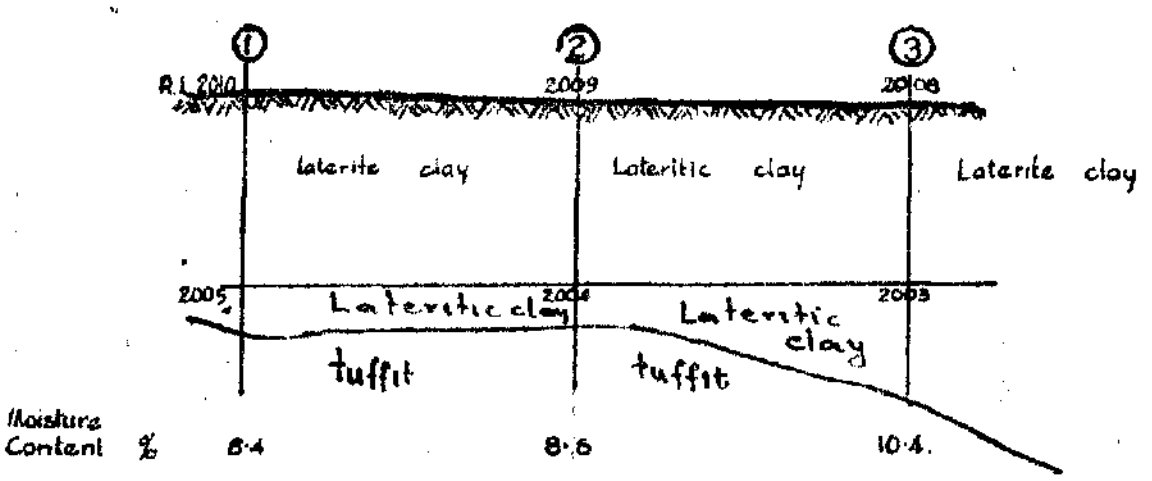


Fig 3. Section showing the Description of the encountered Soil and Moisture Content % of the Ground at the Kaduna Polytechnic.

SCALE { Vertical 1" = 5'
Horizontal 1' = 200'

out whether a metal cylinder with $\frac{1}{24}$ inch thick walls could be suitable as against the $\frac{1}{4}$ inch wall thickness used for the first cylinder infiltrometer tests. The result of this test was favourable, and therefore, a metal cylinder with $\frac{1}{24}$ inch wall thickness was adopted for the later experiments.

Gauges.

Five hook gauges that can be read to 0.05 inch were designed and used for the tests instead of the micrometer screw gauges used in the first experiments. This was made possible by making a triangular engineer's scale and a piece of welding rod with a flat brass soldered to the rod about 3 inches from the other end to prevent the gauge from turning in the groove and to serve as the measuring index point. Detains are shown in figure 4.

Tests.

A total number of twenty-four cylinders were made to cover the thirty-six cylinder infiltrometer tests.

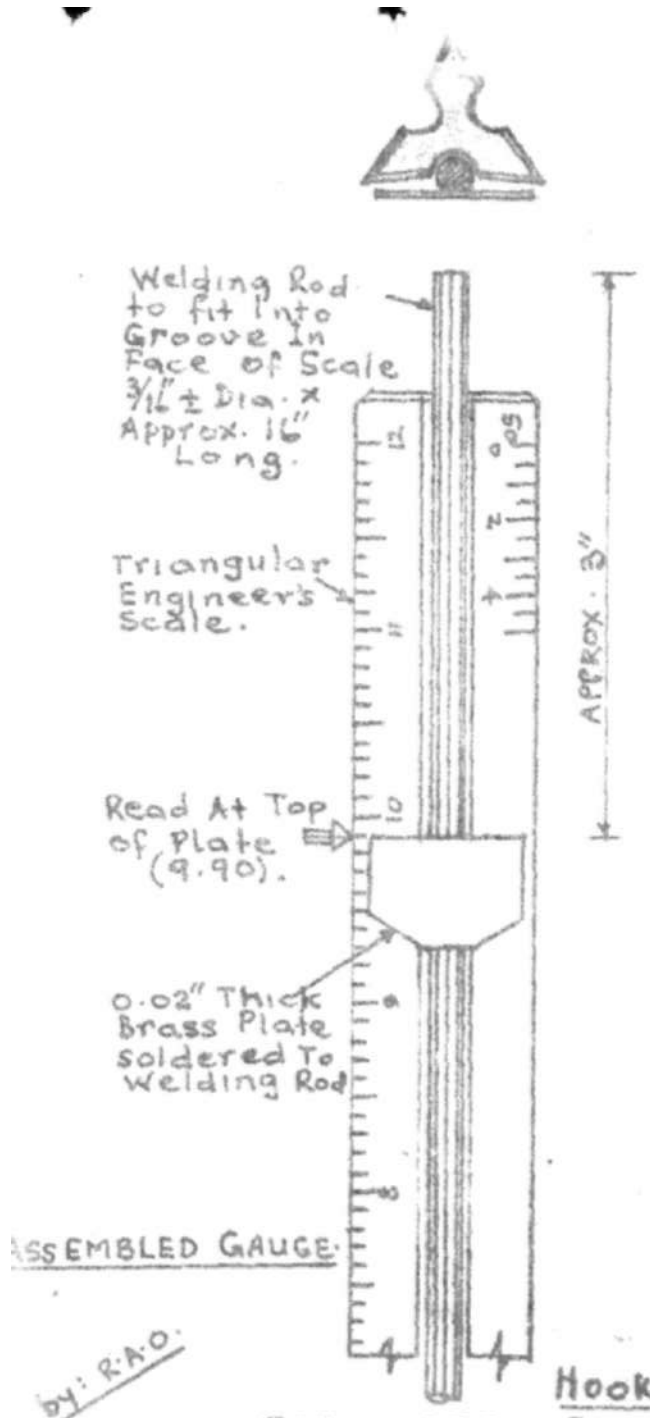
The tests were made as follow:-

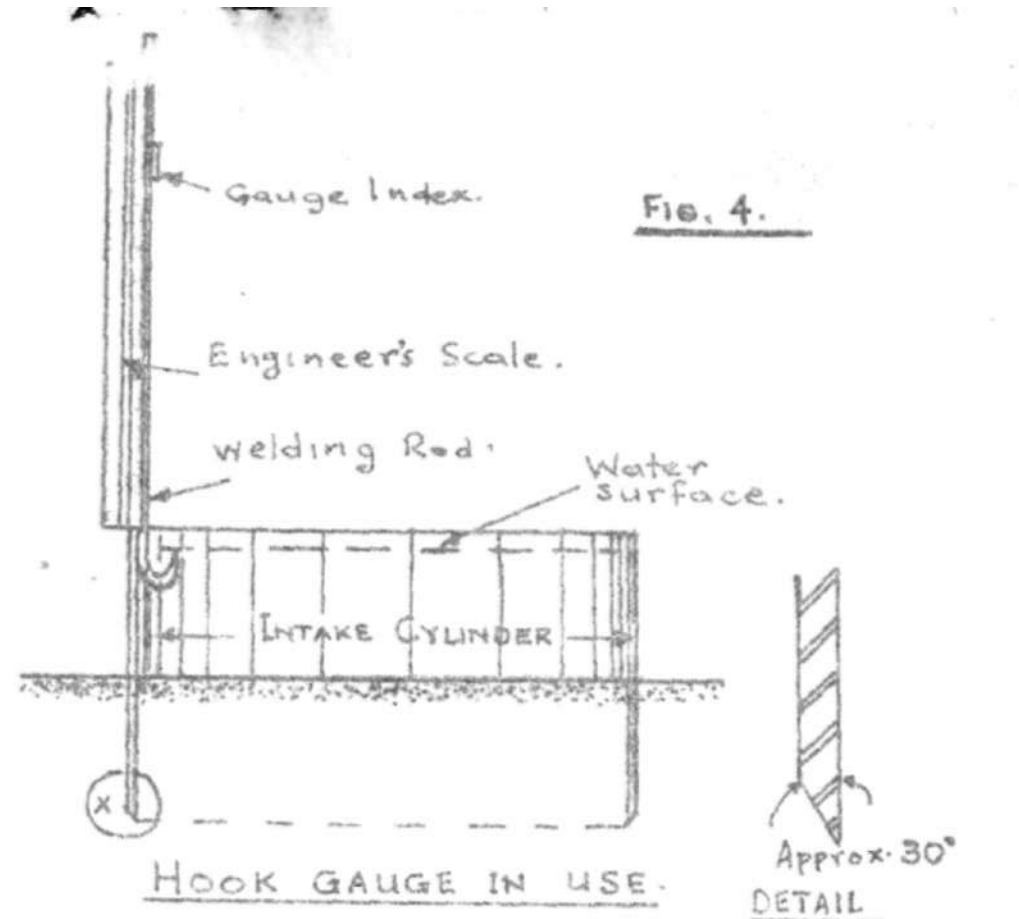
Buffered and non-buffered cylinder infiltrometer tests at a depth of 12 inches repeated seven and eight times respectively.

Ten buffered tests were repeated at increasing depth of cylinder penetration of 1", 2", 3", 4", 5", 6", 9", 12", 15", and 18".

The test was repeated three times at the optimum depth of 6 inches .

Five tests using the center cylinder at the same optimum depth and increasing the diameter of the outer cylinder (15", 18", 24", 30", and 36").





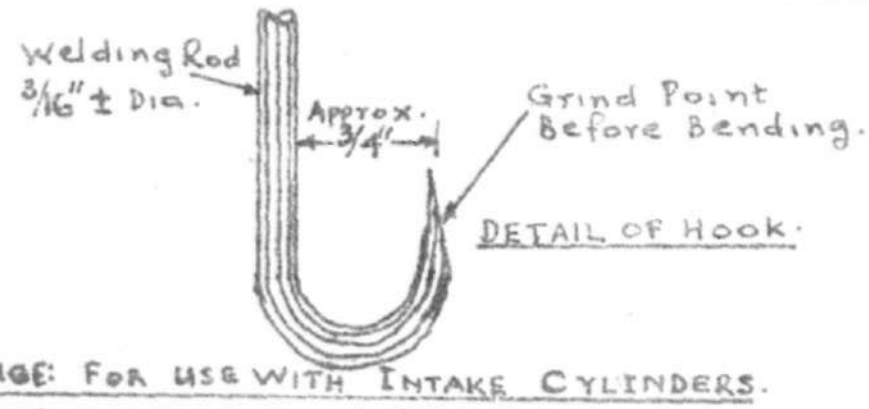


FIG. 4.

HOOK GAUGE: FOR USE WITH INTAKE CYLINDERS.

CYLINDER INFILTROMETER APPARATUS.

Three buffered tests at the optimum depth with varied head of water.

Table No. 9

Cylinder Infiltrometer data.(Non-buffered)

NBK(1) - (*u*)

Observed Time	Elapsed Time (Minutes) Since last readg.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins)	INTAKE Ins.	Cumm. depth(Ins	Depth Ins/ hr	Micrometer hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.
8.00	-	-	12.00	-	-	-	12.00	-	-	-
8.05	5	5	11.875	0.125	0.125	1.50	11.913	0.087	0.087	1.04
8.10	5	10	10.792	.083	.208	1.00	11.847	.066	.153	.80
8.20	10	20	10.667	.125	.333	.75	11.737	.11	.263	.66
8.30	10	30	10.579	.088	.421	.53	11.647	.09	.353	.55
8.45	15	45	10.472	.107	.528	.43	11.537	.11	.463	.45
9.00	15	60	10.385	.087	.615	.35	11.437	.10	.563	.40
9.30	30	90	10.260	.125	.740	.25	11.272	.165	.728	.33
10.00	30	120	10.145	.115	.855	.23	11.147	.125	.853	.25
11.00	60	180	10.015	.13	.985	.13	10.972	.175	1.028	.175
12.00	60	240	9.915	.10	1.085	.10	10.802	.17	1.198	.17
1.00	60	300	9.815	.10	1.185	.10	10.652	.15	1.348	.15
2.00	60	360	9.715	.10	1.285	.10	10.502	.15	1.498	.15
			1				2			
8.00	-	-	12.00	-	-	-	12.00	-	-	-
8.05	5	5	11.917	0.083	0.083	1.00	11.894	0.106	0.106	1.27
8.10	5	10	11.855	.062	.145	.75	11.807	.087	.193	1.05
8.20	10	20	11.755	.10	.245	.60	11.671	.136	.329	.82
8.30	10	30	11.672	.083	.328	.52	11.558	.113	.442	.70
8.45	15	45	11.562	.11	.438	.45	11.406	.152	.594	.61
9.00	15	60	11.462	.10	.538	.40	11.271	.135	.729	.54
9.30	30	90	11.292	.17	.708	.34	11.046	.225	.954	.45
10.00	30	120	11.142	.15	.858	.30	10.851	.195	1.149	.39
11.00	60	180	10.898	.244	1.102	.244	10.521	.33	1.479	.33
12.00	60	240	10.698	.20	1.302	.20	10.271	.25	1.729	.25
1.00	60	300	10.498	.20	1.502	.20	10.071	.20	1.929	.20
2.00	60	360	10.298	.20	1.702	.20	9.871	.20	2.129	.20
			3				4.			

Table No. 9. NBK 5 - 7

Observed Time	Elapsed Time (Mins.) Since last reading	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/hr	Micrometer/ hook gauge reading (depth Ins.)	INTAKE INS.	Cumm. depth (Ins.)	Depth Ins/hr.
8.00	-	-	12.00	-	-	-	12.00	-	-	-
8.05	5	5	11.923	0.077	.077	.92	11.904	0.096	0.096	1.15
8.10	5	10	11.868	0.055	.132	.66	11.829	.075	.171	.90
8.20	10	20	11.785	.083	.215	.50	11.719	.11	.281	.67
8.30	10	30	11.719	.066	.281	.40	11.629	.09	.371	.55
8.45	15	45	11.631	.088	.369	.35	11.511	.118	.489	.475
9.00	15	60	11.556	.075	.444	.30	11.411	.10	.589	.40
9.30	30	90	11.432	.124	.568	.248	11.248	.163	.752	.325
10.00	30	120	11.325	.107	.675	.215	11.120	.128	.880	.255
11.00	60	180	11.150	.175	.850	.175	11.895	.225	1.105	.225
12.00	60	240	11.005	.15	1.00	.15	11.720	.175	1.280	.175
1.00	60	300	10.85	.15	1.15	.15	11.57	.15	1.43	.15
2.00	60	360	10.70	.15	1.30	.15	11.40	.15	1.58	.15

5 6

12.00	-	-	-
11.875	0.125	0.125	1.50
11.787	.088	.213	1.06
11.654	.133	.346	.80
11.546	.108	.454	.65
11.416	.13	.584	.52
11.316	.10	.684	.40
11.151	.165	.849	.33
11.011	.14	.989	.28
10.763	.248	1.237	.248
10.553	.21	1.447	.21
10.383	.17	1.617	.17
10.213	.17	1.787	.17

7

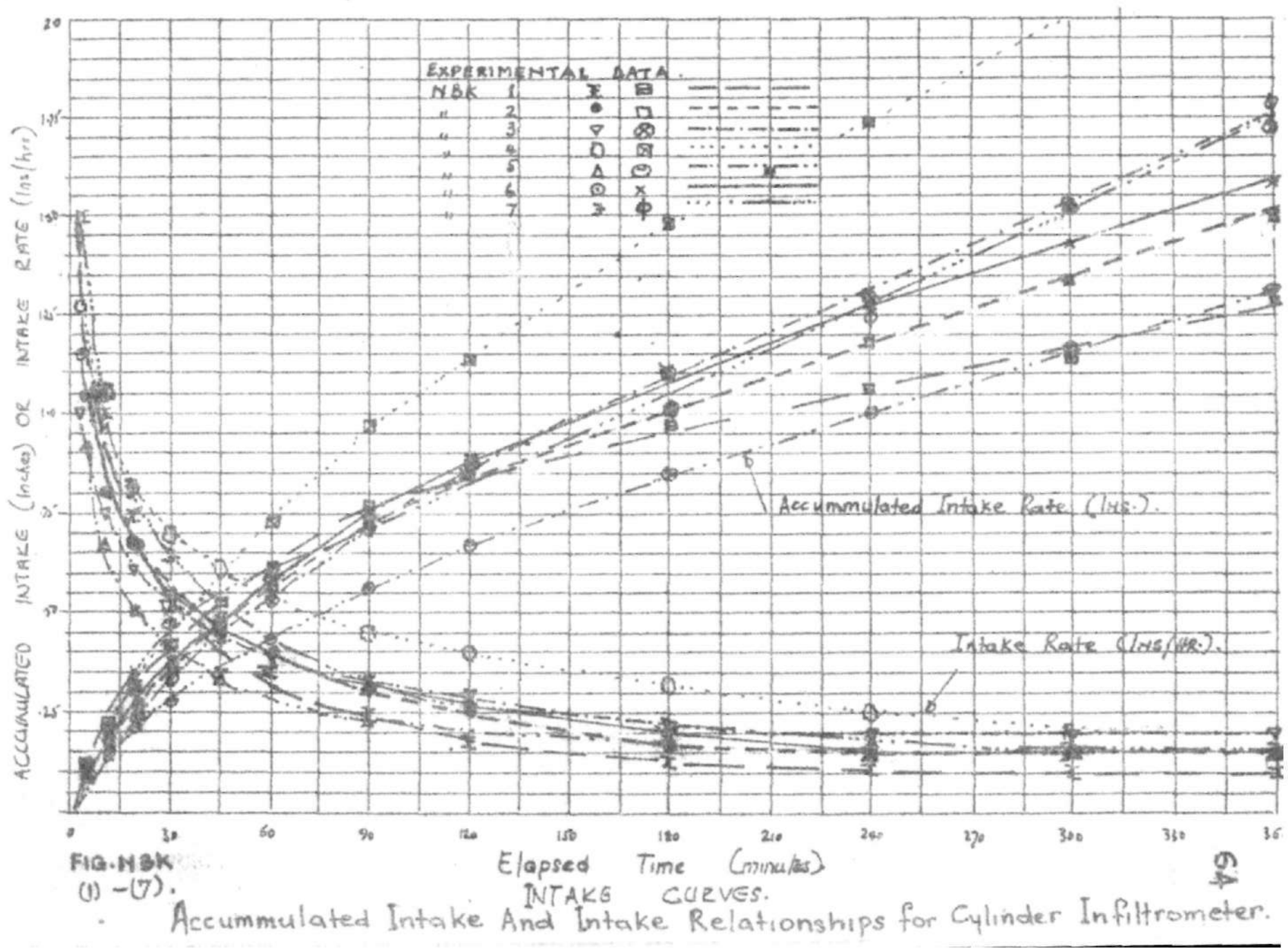


FIG. NBK (1) -(7).
INTAKE CURVES.

Accummulated Intake And Intake Relationships for Cylinder Infiltrometer.

Table No. 10

Cylinder Infiltrometer data. (Buffered) BK(1) - (9)

Observed Time	Elapsed Time (Minutes) Since last readr.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/hr.	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.
8.00	-	-	12.00	-	-	-	12.00	-	-	-
8.05	5	5	11.854	0.146	0.146	1.75	11.904	0.096	0.096	1.15
8.10	5	10	11.752	.102	.248	1.23	11.835	.069	.165	.825
8.20	10	20	11.622	.13	.378	.78	11.710	.125	.290	.75
8.30	10	30	11.522	.10	.478	.60	11.620	.09	.380	.55
8.45	15	45	11.422	.10	.578	.40	11.514	.106	.486	.425
9.00	15	60	11.335	.087	.665	.35	11.426	.088	.574	.35
9.30	30	90	11.235	.10	.765	.20	11.313	.113	.687	.225
10.00	30	120	11.184	.051	.816	.102	11.245	.068	.755	.135
11.00	60	180	11.083	.101	.917	.101	11.143	.102	.857	.102
12.00	60	240	10.983	.10	1.017	.10	11.043	.100	.957	.10
1.00	60	300	10.883	.10	1.117	.10	10.943	.10	1.057	.10
2.00	60	360	10.783	.10	1.217	.10	10.843	.10	1.157	.10

1 2

8.00	-	-	12.00	-	-	-	12.00	-	-	-
8.05	5	5	11.877	0.123	0.123	1.475	11.883	0.117	0.117	1.40
8.10	5	10	11.791	.086	.209	1.025	11.780	.103	.220	1.23
8.20	10	20	11.651	.14	.349	.85	11.626	.154	.374	.925
8.30	10	30	11.526	.125	.474	.75	11.493	.133	.507	.80
8.45	15	45	11.395	.131	.605	.525	11.343	.15	.657	.60
9.00	15	60	11.295	.10	.705	.40	11.218	.125	.782	.50
9.30	30	90	11.170	.125	.830	.25	11.043	.175	.957	.35
10.00	30	120	11.070	.10	.930	.20	10.918	.125	1.082	.25
11.00	60	180	10.945	.125	1.055	.125	10.743	.175	1.257	.175
12.00	60	240	10.820	.125	1.180	.125	10.593	.15	1.407	.15
1.00	60	300	10.695	.125	1.305	.125	10.443	.15	1.557	.15
2.00	60	360	10.570	.125	1.430	.125	10.293	.15	1.707	.15

3 4

Table No. 10

BK 5 - 7.

Observed Time	Elapsed Time (Minutes) Since last reade.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	DEPTH INS./ HR.
8.00	-	-	12.00	-	-	-	12.00	-	-	-
8.05	5	5	11.833	0.167	0.167	2.00	11.897	0.103	0.103	1.24
8.10	5	10	11.717	.116	.283	1.40	11.814	.083	.186	1.00
8.20	10	20	11.551	.166	.449	1.00	11.701	.113	.299	.70
8.30	10	30	11.426	.125	.574	.75	11.611	.09	.389	.55
8.45	15	45	11.276	.15	.724	.60	11.501	.11	.499	.45
9.00	15	60	11.164	.112	.836	.45	11.416	.085	.584	.34
9.30	30	90	11.039	.125	.961	.25	11.293	.123	.707	.215
10.00	30	120	10.951	.08	1.041	.16	11.213	.08	.787	.16
11.00	60	180	10.821	.13	1.171	.13	11.093	.12	.907	.12
12.00	60	240	10.711	.11	1.281	.11	10.983	.11	1.017	.11
1.00	60	300	10.601	.11	1.391	.11	10.883	.10	1.117	.10
2.00	60	360	10.491	.11	1.401	.11	10.783	.10	1.217	.10

5 6

8.00	-	-	12.00	-	-	-
8.05	5	5	11.885	0.115	0.115	1.38
8.10	5	10	11.789	.096	.211	1.15
8.20	10	20	11.619	.17	.381	1.02
8.30	10	30	11.489	.13	.511	.79
8.45	15	45	11.314	.175	.686	.70
9.00	15	60	11.177	.137	.823	.55
9.30	30	90	10.987	.19	1.013	.38
10.00	30	120	10.862	.125	1.138	.25
11.00	60	180	10.682	.18	1.318	.18
12.00	60	240	10.532	.15	1.468	.15
1.00	60	300	10382	.15	1.618	.15
2.00	60	360	10.232	.15	1.768	.15

7

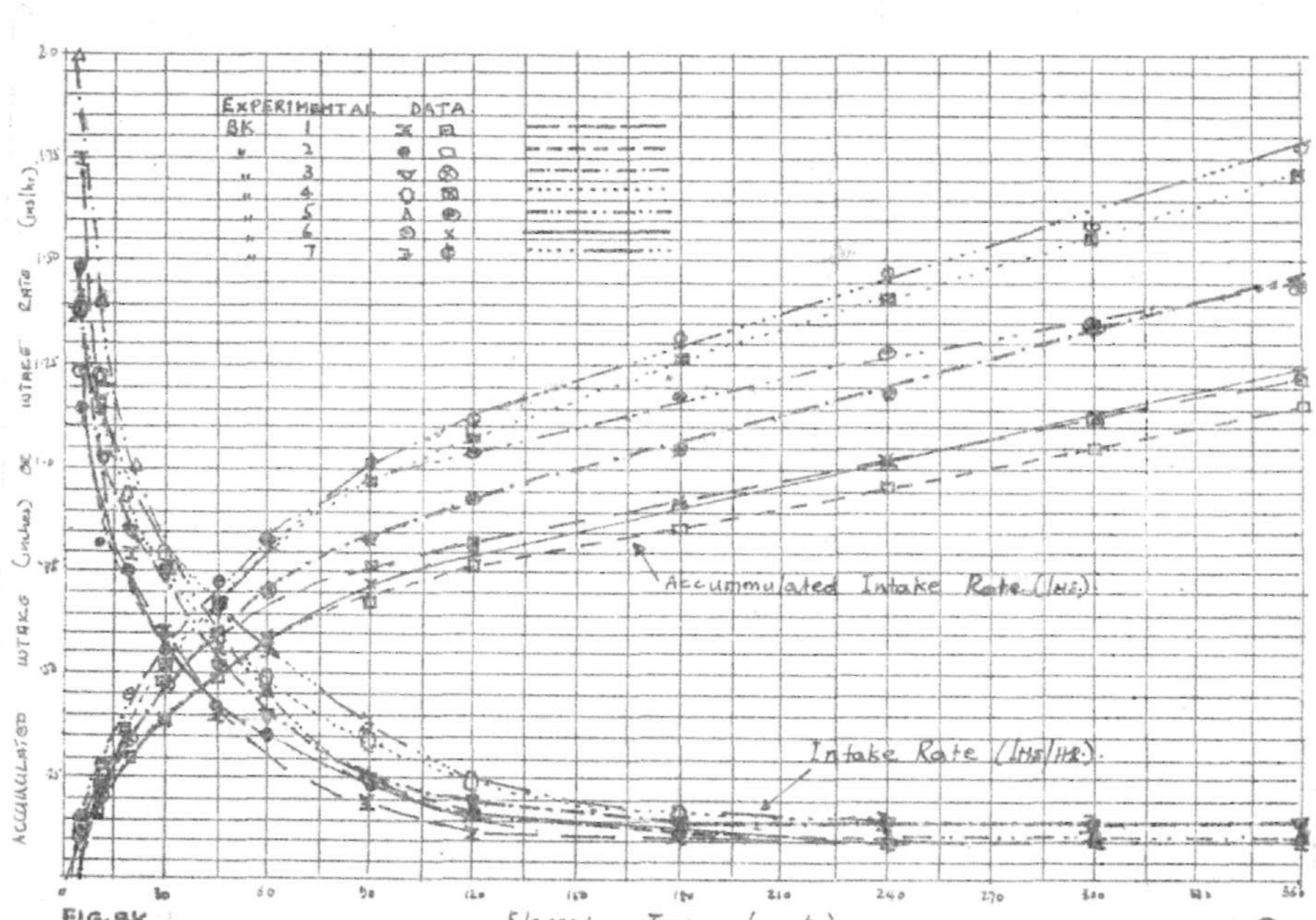


FIG-8K
(1) - (7).

INTAKE CURVES.

Accummulated Intake And Intake Relationships for Cylinder Infiltrometer.

Table No. 12

Cylinder Infiltrometer data: (Buffered with increasing depth of penetration)

BI/DK 1 - 3

Observed Time	Elapsed Time (Mins.)		Micrometer/ hook gauge reading (depth Ins.)	INTAKE			Micrometer/ hook gauge reading (depth Ins.)	INTAKE		
				Ins.	Cumm. depth (Ins.)	Depth Ins/hr		Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.
8.00	-	-	11.00	-	-	-	11.00	-	-	-
8.05	5	5	10.95	0.05	0.05	0.60	10.90	0.10	0.10	1.20
8.10	5	10	10.90	.05	.10	.60	10.83	.07	.17	0.84
8.20	10	20	10.80	.10	.20	.60	10.73	.10	.27	.60
8.30	10	30	10.75	.05	.25	.30	10.63	.10	.37	.60
8.45	15	45	10.70	.05	.30	.20	10.53	.10	.47	.40
9.00	15	60	10.55	.15	.45	.60	10.39	.14	.61	.56
9.30	30	90	10.50	.05	.50	.10	10.02	.32	.93	.64
10.00	30	120	10.20	.30	.80	.60	11.00 10.62	.38	1.31	.76
11.00	60	180	10.00	.20	1.00	.20	9.97	.65	1.96	.65
12.00	60	240	9.83	.17	1.17	.17	11.00 10.23	.77	2.73	.77
1.00	60	300	9.68	.15	1.32	.15	11.00 10.24	.76	3.49	.76
2.00	60	360	9.55	.13	1.45	.13	9.60	.64	4.13	.64

1 2

8.00	-	-	11.00	-	-	-
8.05	5	5	11.80	0.20	0.20	2.40
8.10	5	10	10.70	.10	.30	1.20
8.20	10	20	10.65	.05	.35	.30
8.30	10	30	10.60	.05	.40	.30
8.45	15	45	10.55	.05	.45	.20
9.00	15	60	10.48	.07	.52	.28
9.30	30	90	10.40	.08	.60	.16
10.00	30	120	10.33	.07	.67	.14
11.00	60	180	10.20	.13	.80	.13
12.00	60	240	10.08	.12	.92	.12
1.00	60	300	9.97	.11	1.03	.11
2.00	60	360	9.87	.10	1.13	.10

3

Table No. 11

BI/DK 4 - 5

Observed Time	Elapsed Time (Minutes) Since last readg.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr	Micrometer/ hook gauge reading (depth Ins.	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr
8.00	-	-	11.00	-	-	-	11.00	-	-	-
8.05	5	5	10.90	0.10	0.10	1.20	10.93	.07	0.07	0.84
8.10	5	10	10.88	.02	.12	.24	10.85	.08	.15	.60
8.20	10	20	10.86	.02	.14	.12	10.80	.05	.20	.30
8.30	10	30	10.84	.02	.16	.12	10.78	.02	.22	.12
8.45	15	45	10.81	.03	.19	.12	10.75	.03	.25	.12
9.00	15	60	10.79	.02	.21	.08	10.70	.05	.30	.20
9.30	30	90	10.60	.19	.40	.38	10.61	.09	.39	.18
10.00	30	120	10.52	.08	.48	.16	10.55	.06	.45	.12
11.00	60	180	10.43	.09	.57	.09	10.47	.08	.55	.08
12.00	60	240	10.35	.08	.65	.08	10.40	.07	.60	.07
1.00	60	300	10.28	.07	.72	.07	10.34	.06	.66	.06
2.00	60	360	10.21	.07	.79	.07	10.28	.06	.72	.06

Table No. 11

B1/DK 6 - 7.

Observed Time	Elapsed Time (Min.) Since last read.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/hr
8.00	-	-	11.00	-			11.00	-	-	-
8.05	5	5	10.833	0.167	0.167	2.00	10.892	0.108	0.108	1.30
8.10	5	10	10.696	.137	.304	1.65	10.817	.075	.185	.90
8.20	10	20	10.488	.208	.512	1.25	10.690	.127	.312	.76
8.30	10	30	10.322	.166	.678	1.00	10.589	.101	.413	.61
8.45	15	45	10.135	.187	.865	.75	10.464	.125	.538	.50
9.00	15	60	9.973	.162	1.027	.65	10.359	..105	.643	.42
9.30	30	90	9.753	.22	1.247	.40	10.204	.155	.798	.31
10.00	30	120	9.603	.15	1.397	.30	10.08	.124	.922	.249
11.00	60	180	9.353	.25	1.647	.25	9.88	.20	1.122	.20
12.00	60	240	9.203	.15	1.797	.15	9.723	.157	1.279	.157
1.00	60	300	9.103	.10	1.897	.10	9.573	.15	1.429	.15
2.00	60	360	9.003	.10	1.997	.10	9.423	.15	1.579	.15

6 7

Table No. 11

BI/DK 8 - 10

Observed Time	Elapsed Time (Minutes) Since last readg.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.	INTAKE Ins	Cumm. depth (Ins.)	Depth Ins/ hr.	Micrometer/ hook gauge reading (depth Ins.	INTAKE Ins	Cumm. depth (Ins.)	Depth Ins/ hr.
8.00	-	-	11.00	-	-	-	11.00	-	-	-
8.05	5	5	10.909	0.091	0.091	1.10	10.875	0.125	0.125	1.50
8.10	5	10	10.817	.082	.173	.98	10.779	.096	.221	1.1
8.20	10	20	10.677	.14	.313	.85	10.639	.14	.361	.84
8.30	10	30	10.56	.117	.430	.70	10.519	.12	.481	.72
8.45	15	45	10.422	.138	.568	.554	10.369	.15	.631	.60
9.00	15	60	10.30	.122	.690	.49	10.244	.125	.756	.5
9.30	30	90	10.11	.19	.880	.38	10.064	.18	.936	.36
10.00	30	120	9.955	.155	1.035	.31	9.924	.14	1.076	.28
11.00	60	180	9.707	.248	1.283	.248	9.694	.23	1.506	.23
12.00	60	240	9.509	.198	1.481	.198	9.494	.20	1.706	.20
1.00	60	300	9.404	.105	1.586	.105	9.294	.20	1.906	.20
2.00	60	360	9.299	.105	1.691	.105	9.094	.20	2.106	.20

.8 9

11.00	-	-	-
10.853	0.147	0.147	1.75
10.743	.11	.257	1.34
10.568	.175	.432	1.05
10.428	.14	.572	.85
10.253	.175	.747	.70
10.108	.145	.892	.58
9.888	.22	1.112	.44
9.713	.175	1.287	.35
9.460	.253	1.54	.253
9.240	.22	1.760	.22
9.04	.20	1.96	.20
8.84	.20	2.16	.20

10

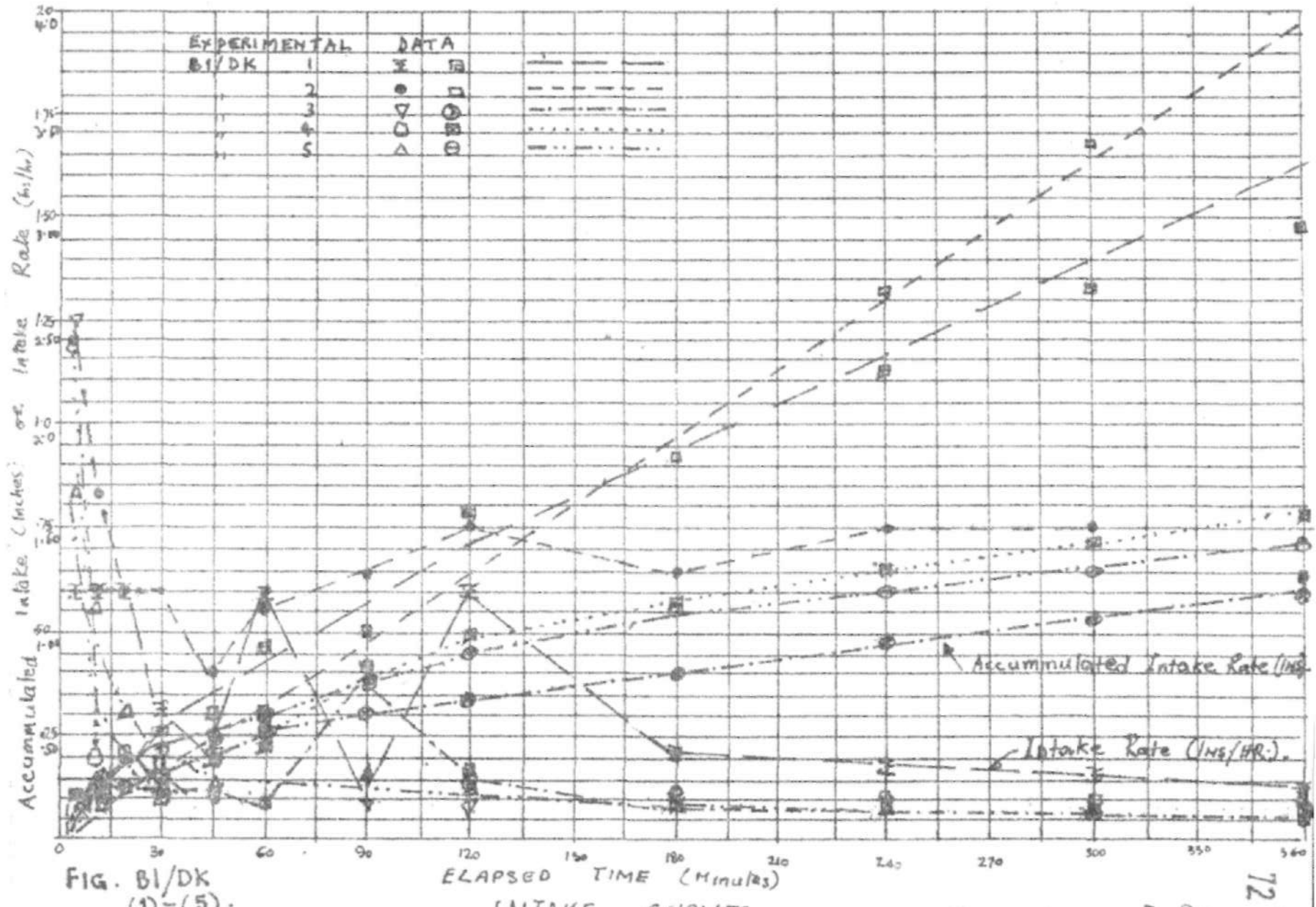


FIG. B1/DK (1)-(5).

INTAKE CURVES.
Accummulated Intake And Intake Relationships for Cylinder Infiltrometer

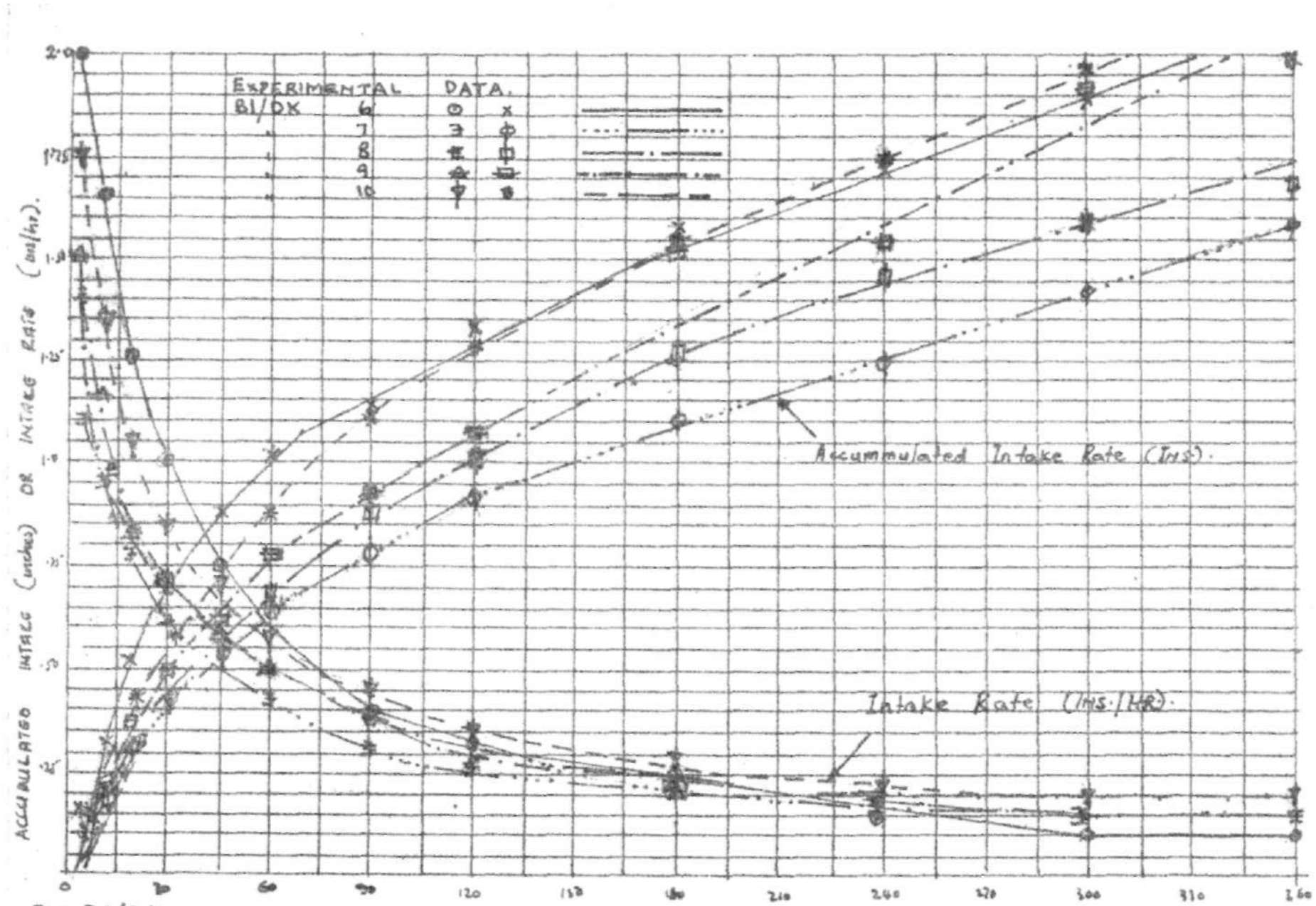


FIG. B1/DK (6)-(10). INTAKE CURVES.

Accummutated Intake And Intake Relationships for Cylinder Infiltrometer.

Table No. 12

Cylinder Infiltrometer data

(Buffered with the optimum depth of penetration and constant head)
SO/DK (1) - (3)

Observed Time	Elapsed Time (Minutes)		Micrometer/ hook gauge reading (depth Ins.)	INTAKE			Micrometer/ hook gauge reading (depth Ins.)	INTAKE		
	Since last read.	Since beg. of test		Ins.	Cumm. depth (Ins.)	Depth Ins./ hr		Ins.	Cumm. depth (Ins.)	Depth Ins./ hr
8.00	-	-	11.00	-	-	-	11.00	-	-	-
8.05	5	5	10.937	0.063	0.063	0.75	10.94	0.06	0.06	.72
8.10	5	10	10.887	.05	.113	0.60	10.89	.05	.11	.60
8.20	10	20	10.812	.075	.188	0.45	10.82	.07	.18	.43
8.30	10	30	10.747	.065	.253	.39	10.76	.06	.24	.36
8.45	15	45	10.675	.072	.325	.29	10.685	.075	.315	.30
9.00	15	60	10.605	.07	.375	.28	10.623	.62	.377	.25
9.30	30	90	10.485	.125	.50	.25	10.513	.11	.487	.22
10.00	30	120	10.365	.12	.62	.24	10.423	.09	.577	.18
11.00	60	180	10.135	.23	.85	.23	10.253	.17	.747	.17
12.00	60	240	9.905	.23	1.08	.23	10.103	.15	.897	.15
1.00	60	300	9.675	.23	1.31	.23	9.953	.15	1.047	.15
2.00	60	360	9.445	.23	1.54	.23	9.803	.15	1.197	.15

1 2

8.00	-	-	11.00	-	-	-
8.05	5	5	10.95	0.05	0.05	.61
8.10	5	10	10.909	.041	.091	.50
8.20	10	20	10.846	.063	.154	.38
8.30	10	30	10.795	.051	.205	.31
8.45	15	45	10.730	.065	.270	.26
9.00	15	60	10.675	.055	.325	.22
9.30	30	90	10.590	.085	.410	.17
10.00	30	120	10.51	.08	.490	.16
11.00	60	180	10.36	.15	.64	.15
12.00	60	210	10.21	.15	.79	.15
1.00	60	300	10.06	.15	.94	.15
2.00	60	360	[illegible]91	.15	1.09	.15

3

Table No. 13

Cylinder Infiltrometer data.
(Buffered with the optimum depth of penetration and varying depth)
/DVK (1) - (3)

Micrometer/ hook gauge reading (depth Ins.	INTAKE		
	Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.
12.00	-	-	-
11.942	0.058	0.058	0.70
11.892	.05	.108	.60
11.817	.075	.183	.45
11.759	.058	.241	.35
11.684	.075	.316	.30
11.622	.062	.378	.25
11.522	.10	.478	.20
11.435	.087	.565	.175
11.285	.15	.715	.15
11.160	.125	.840	.125
11.035	.125	.965	.125
10.910	.125	1.090	.125

1

Observed Time	Elapsed Time(Mins.)		Micrometer/ hook gauge reading (depth Ins	INTAKE		
	Since last readg.	Since beg. of test		Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.
8.00	-	-	10.50	-	-	-
8.05	5	5	10.417	0.083	0.083	1.66
8.10	5	10	10.359	.058	.141	.70
8.20	10	20	10.266	.093	.234	.56
8.30	10	30	10.20	.066	.300	.40
8.45	15	45	10.11	.09	.39	.36
9.00	15	60	10.041	.069	.459	.276
9.30	30	90	9.916	.125	.584	.25
10.00	30	120	9.803	.113	.697	.225
11.00	60	180	9.603	.20	.897	.20
12.00	60	240	9.496	.107	1.004	.107
1.00	60	300	9.390	.106	1.110	.106
2.00	60	360	9.284	.106	1.216	.106

2

Micrometer/ hook gauge reading (depth Ins	INTAKE		
	Ins.	Cumm. depth (Ins.)	Depth Ins./ hr.
10.00	-	-	-
9.904	0.096	0.096	1.15
9.822	.082	.178	.99
9.712	.11	.288	.[illegible]
9.629	.083	.371	.50
9.537	.092	.463	.37
9.462	.075	.538	.30
9.349	.113	.651	.225
9.264	.085	.736	.17
9.159	.105	.841	.105
9.054	.105	.946	.105
8.949	.105	1.051	.105
8.844	.105	1.156	.105

3

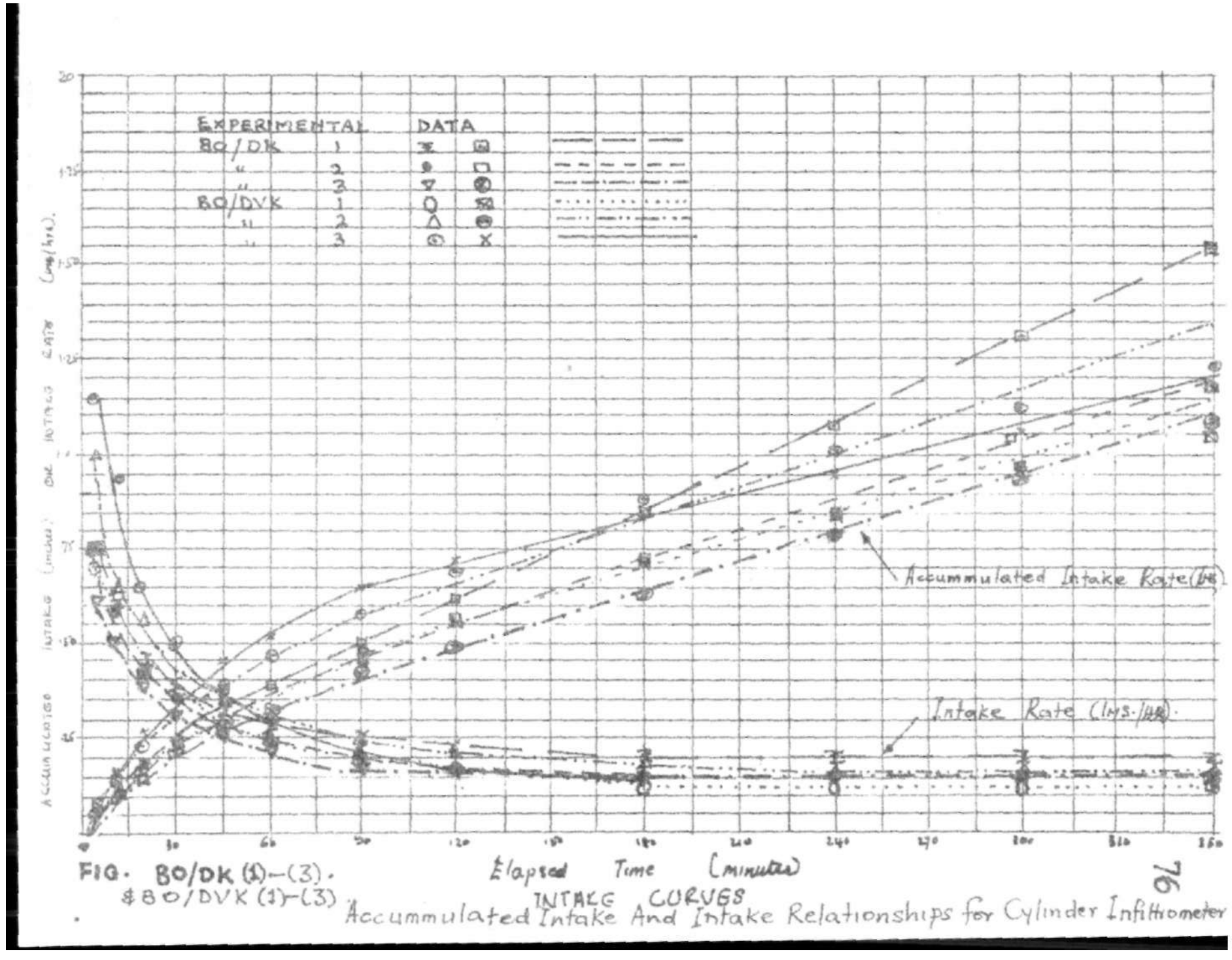


FIG. BO/DK (1)–(3).
BO/DVK (1)–(3)

Accummulated INTAKE CURVES And Intake Relationships for Cylinder Infiltrometer

Table No. 14

Cylinder Infiltrometer data.

(Enlarging the buffer area with inner cylinder at the optimum depth of penetration and using varied water heads).

EBO/DK 1 - 3 .

Observed Time	Elapsed Time (Min.) Since last read.	Since beg. of test.	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr.
8.00	-	-	12.00	-	-	-
8.05	5	5	11.93	0.07	0.07	0.84
8.10	5	10	11.85	0.05	0.12	.60
8.20	10	20	11.792	.058	.178	.35
8.30	10	30	11.751	.041	.219	.25
8.45	15	45	11.694	.057	.276	.23
9.00	15	60	11.644	.05	.326	.20
9.30	30	90	11.564	.08	.406	.16
10.00	30	120	11.494	.07	.476	.14
11.00	60	180	11.394	.10	.576	.10
12.00	60	240	11.294	.10	.676	.10
1.00	60	300	11.194	.10	.776	.10
2.00	60	360	11.094	.10	.876	.10

1

Observed Time	Elapsed Time(Minutes Since last read.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins./ hr.
8.00	-	-	10.60	-	-	-
8.05	5	5	10.598	0.102	0.102	1.23
8.10	5	10	10.515	.083	.185	1.00
8.20	10	20	10.374	.141	.326	.85
8.30	10	30	10.264	.11	.436	.70
8.45	15	45	10.127	.137	.573	.55
9.00	15	60	10.015	.112	.685	.45
9.30	30	90	9.865	.15	.835	.30
10.00	30	120	9.740	.125	.960	.25
11.00	60	180	9.540	.20	1.160	.20
12.00	60	240	9.433	.107	1.267	.107
1.00	60	300	9.327	.106	1.373	.106
2.00	60	360	9.221	.106	1.479	.106

2

Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/ hr
10.60	-	-	-
10.509	0.091	0.091	1.10
10.428	.071	.162	.86
10.32	.108	.270	.65
10.236	.084	.354	.503
10.126	.11	.464	.45
10.034	.092	.556	.37
9.889	.145	.701	.29
9.764	.125	.826	.25
9.534	.23	1.056	.23
9.324	.21	1.266	.21
9.124	.20	1.166	.20
8.924	.20	1.666	.20

3

Table No. 11

EDO/DK 4 - 5.

Observed Time	Elapsed Time(Minutes). Since last readg.	Since beg. of test	Micrometer hook gauge reading (depth Ins.	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins./hr
8.00	-	-	10.00	-	-	-
8.05	5	5	9.90	0.10	0.10	1.20
8.10	5	10	9.82	.08	.18	.95
8.20	10	20	9.679	.141	.321	.85
8.30	10	30	9.571	.108	.429	.65
8.45	15	45	9.446	.125	.554	.50
9.00	15	60	9.346	.10	.654	.40
9.30	30	90	9.196	.15	.804	.30
10.00	30	120	9.081	.115	.919	.23
11.00	60	180	8.974	.107	1.026	.107
12.00	60	240	8.869	.105	1.131	.105
1.00	60	300	8.764	.105	1.236	.105
2.00	60	360	8.659	.105	1.341	.105

4

8.00	-	-	9.80	-	-	-
8.05	5	5	9.717	0.083	0.083	1.00
8.10	5	10	9.635	.082	.165	.99
8.20	10	20	9.508	.127	.292	.76
8.30	10	30	9.400	.108	.400	.65
8.45	15	45	9.274	.126	.526	.503
9.00	15	60	9.159	.115	.641	.46
9.30	30	90	8.996	.163	.804	.325
10.00	30	120	8.866	.13	.934	.26
11.00	60	180	8.666	.20	1.134	.20
12.00	60	240	8.491	.175	1.309	.175
1.00	60	300	8.316	.175	1.484	.175
2.00	60	360	8.141	.175	1.659	.175

5

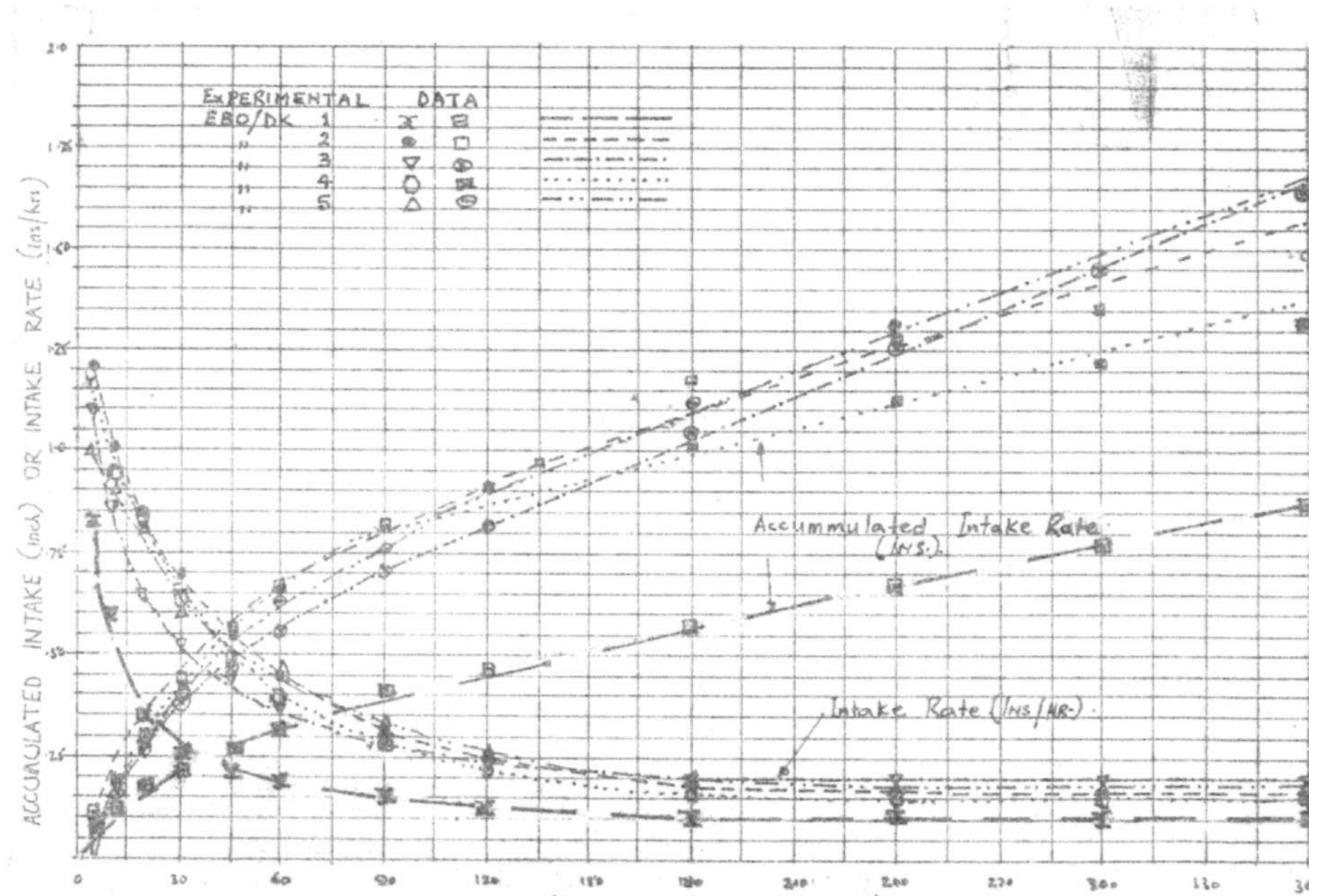


FIG. EBO/DK (1) – (5). INTAKE CURVES.

(1) Results of the experiments using cylinder infiltrometers at the Kaduna Polytechnic, Kaduna.

The results obtained from the curves under the experiments using cylinder infiltrometers at the Kaduna Polytechnic, Kaduna., are as follows:-

Table No. 15.

Tabulation of the results using cylinder infiltrometers at the Kaduna Polytechnic, Kaduna.

Table No.	Particulars	Initial Rate (Avg).Ins/hr	Final Rate (Avg).Ins/hr.
10	NBK 1 - 7	1.20	0.16
11	BK 1 - 7	1.50	0.12
12	BI/DK 1 -10	1.39	0.18
13 & 14	BO/DK 1 - 3	0.82	0.15
1	BO/DVK 1 - 3		
15	EBO/DK 1 - 5	1.07	0.14

As illustrated above, it may be observed that all the five infiltration rates are similar, the highest average initial infiltration rate is 1.50 inch per hour, and the highest average final rate is 0.18 inch per hour. The slight discrepancy is due to the initial moisture content of the soils e.g. the lower the initial soil moisture, the higher the infiltration rate. During these tests, the author determined the optimum depth of

penetration when increasing the depth of cylinder penetration from one inch to eighteen inches. The depths of penetration between one inch and four inches indicated that lateral movement of water in the soils could not be controlled and the infiltration rates flouctuated widely during the experiment, e.g. in many cases the rates were constant for either the early or later periods of the experiment and never reached their steady states.

Further observations indicated that between five and seven inches penetration the rates were constant over the entire test of 360 minute duration and reached their steady states. It was also evident that increasing the depth of penetration from five inches had no effect on the infiltration rates. Hence, an average depth of 6 inches was choosen as the optimum depth of penetration. Also, 12 inches diameter was choosen for the same reason.

Finally, an experimental infiltration rate--time relationship can be obtained from the cylinder infiltrometer data.

(b) Sprinklers - Inflow and Outflow infiltrometers.

The simulated rainfall experiments were repeated using the former standard sprinkler device on a standard plot, and altering

the rates of water application.

In these experiments, eighten tests were carried out using the rates of application of 1.20 inch per hour, 1.00 inch per hour, and 0.83 inch per hour.

Finally, during the raining season, the actual rainfall rates of 1.20 inch per hour, 1.00 inch per hour, 0.95 inch per hour, 0,85 inch per hour, 0.82 inch per hour, and 0.80 inch per hour., were used for the data obtained on Table number 19.

The following rainfall rates were used for the data obtained on Table number 20:-

0.95 inch per hour, 0.98 inch per hour, 1.30 inch per hour, 0.80 inch per hour, 1.00 inch per hour, and 1.10 inch per hour.

Table No. 16

Inflow and Outflow Infiltrometers

(Rate of water application 1.00 in/hr)

KPSN (1) - (6)

Observed Time	Elapsed Time: t o o Minutes	16 sq.ft	AVG Minutes	(1) q_i Ins/hr	(1) q_o Ins/hr	(1) q_i-q_o 1 Ins/hr per 16 sq ft	(2) q_i Ins/hr	(2) q_o Ins/hr	(2) q_i-q_o 1 Ins/hr per 16 sq ft	(3) q_i Ins/hr	(3) q_o Ins/hr	(3) q_i-q_o 1 Ins/hr per 16 sq ft.
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.24	22	0	-	1.00	-	-	1.00	-	-	1.00	-	-
8.27	25	3	14	,,	0.42	0.58	,,	0.18	0.82	,,	0.33	0.67
8.50	48	26	37	,,	0.60	0.40	,,	0.47	0.53	,,	0.61	0.39
9.20	78	56	67	,,	0.70	0.30	,,	0.58	0.42	,,	0.70	0.30
10.04	118	96	107	,,	0.76	0.24	,,	0.64	0.36	,,	0.74	0.26
11.10	188	166	177	,,	0.79	0.21	,,	0.68	0.32	,,	0.76	0.24
12.30	268	245	257	,,	0.80	0.20	,,	0.70	0.30	,,	0.77	0.23
14.10	358	336	347	,,	0.80	0.20	,,	0.70	0.30	,,	0.77	0.23
16.10	478	456	467	1.00	0.80	0.20	1.00	0.70	0.30	1.00	0.77	0.23

Observed Time	Elapsed Time: t o o Minutes	16 sq.ft	AVG Minutes	(4) q_i Ins/hr	(4) q_o Ins/hr	(4) q_i-q_o 1 Ins/hr per 16 sq ft	(5) q_i Ins/hr	(5) q_o Ins/hr	(5) q_i-q_o 1 Ins/hr per 16 sq ft	(6) q_i Ins/hr	(6) q_o Ins/hr	(6) q_i-q_o 1 Ins/hr per 16 sq ft.
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.24	22	0	-	1.00	-	-	1.00	-	-	1.00	-	-
8.27	25	3	14	,,	0.22	0.78	,,	0.27	0.73	,,	0.38	0.62
8.50	48	26	37	,,	0.51	0.49	,,	0.50	0.50	,,	0.52	0.48
9.20	78	56	67	,,	0.65	0.35	,,	0.60	0.40	,,	0.59	0.41
10.04	118	96	107	,,	0.73	0.27	,,	0.66	0.34	,,	0.63	0.37
11.10	188	166	177	,,	0.77	0.23	,,	0.69	0.31	,,	0.65	0.35
12.30	268	246	257	,,	0.79	0.21	,,	0.72	0.28	,,	0.68	0.32
14.10	358	336	347	,,	0.79	0.21	,,	0.72	0.28	,,	0.68	0.32
16.10	478	456	467	1.00	0.79	0.21	1.00	0.72	0.28	1.00	0.68	0.32

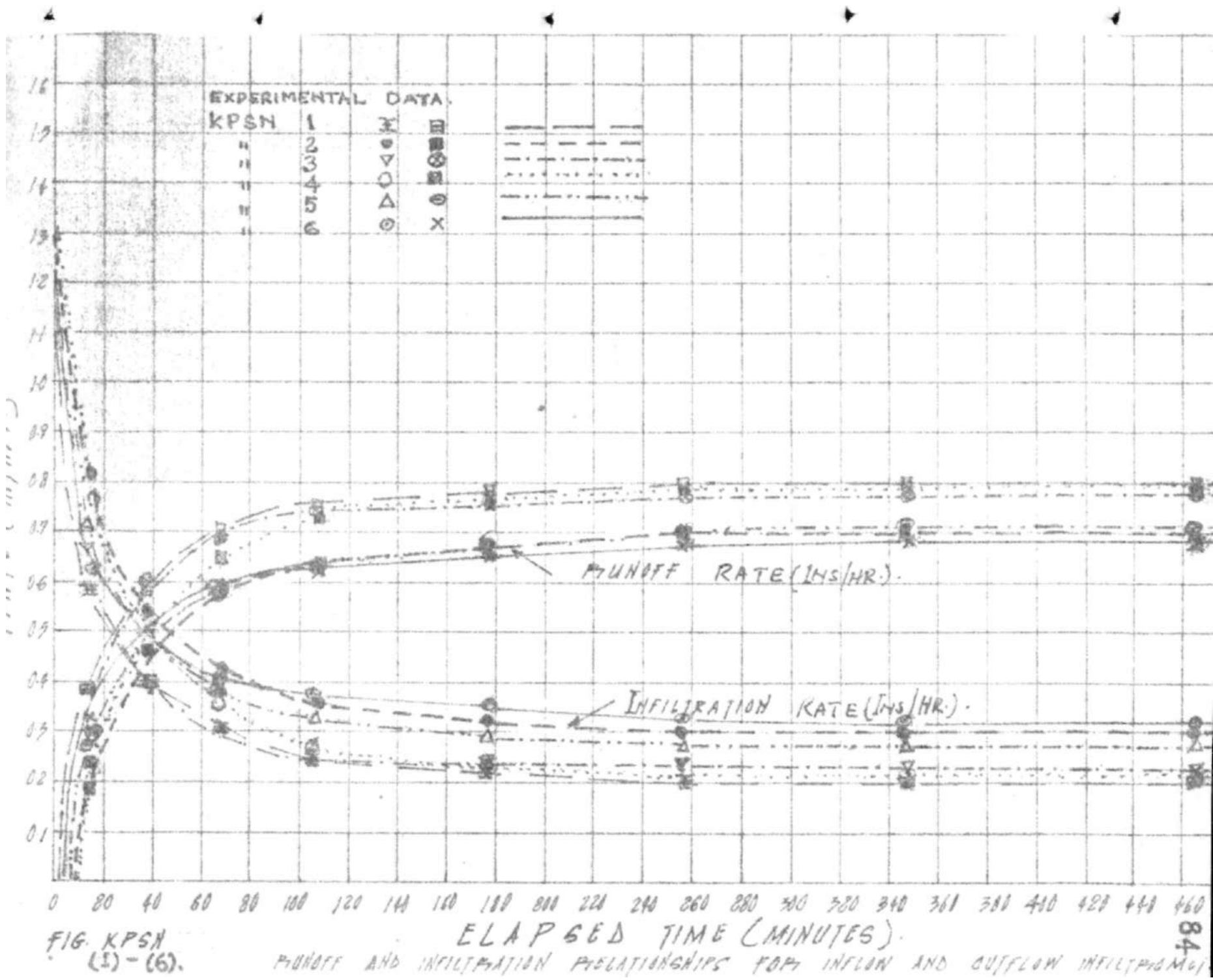


FIG. KPSN (1) - (6). RUNOFF AND INFILTRATION RELATIONSHIPS FOR INFLOW AND OUTFLOW INFILTROMETERS.

Table No.17

Inflow and Outflow Infiltrometers

(Rate of water application 0.83 in./hr)

KPSJ (1) - (6)

Observed Time	ELAPSED TIME Minutes	16 SQ ft	AVG Minutes	(1) q_i Ins/hr	(1) q_o Ins/hr	(1) (q_i-q_o) Ins/hr per 16 Sq.ft	(2) q_i Ins/hr	(2) q_o Ins/hr	(2) (q_i-q_o) Ins/hr per 16 sq ft	(3) q_i Ins/hr	(3) q_o Ins/hr	(3) (q_i-q_o) Ins/hr per 16 Sq ft.
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.24	22	0	-	0.83	-	-	0.83	-	-	0.83	-	-
8.27	25	3	14	,,	0.07	0.76	,,	0.21	0.62	,,	0.14	0.69
8.50	48	26	37	,,	0.29	0.54	,,	0.31	0.52	,,	0.27	0.56
9.20	78	56	67	,,	0.41	0.42	,,	0.37	0.46	,,	0.39	0.44
10.04	118	96	107	,,	0.50	0.33	,,	0.41	0.42	,,	0.48	0.35
11.10	188	166	177	,,	0.55	0.28	,,	0.45	0.38	,,	0.53	0.30
12.30	268	246	257	,,	0.56	0.27	,,	0.47	0.36	,,	0.55	0.28
14.10	358	336	347	,,	0.56	0.27	,,	0.49	0.34	,,	0.56	0.27
16.10	478	456	467	0.83	0.56	0.27	0.83	0.49	0.34	0.83	0.56	0.27

Observed Time	ELAPSED TIME Minutes	16 SQ ft	AVG Minutes	(4) q_i Ins/hr	(4) q_o Ins/hr	(4) (q_i-q_o) Ins/hr per 16 Sq.ft	(5) q_i Ins/hr	(5) q_o Ins/hr	(5) (q_i-q_o) Ins/hr per 16 sq ft	(6) q_i Ins/hr	(6) q_o Ins/hr	(6) (q_i-q_o) Ins/hr per 16 Sq ft.
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.04	22	0	-	0.83	-	-	0.83	-	-	0.83	-	-
8.27	25	3	14	,,	0.17	0.66	,,	0.23	0.60	,,	0.17	0.66
8.50	48	26	37	,,	0.28	0.55	,,	0.36	0.47	,,	0.31	0.52
9.20	78	56	67	,,	0.34	0.49	,,	0.44	0.39	,,	0.39	0.44
10.04	118	96	107	,,	0.38	0.45	,,	0.50	0.33	,,	0.44	0.39
11.10	188	166	177	,,	0.42	0.41	,,	0.52	0.31	,,	0.47	0.36
12.30	268	246	257	,,	0.45	0.38	,,	0.53	0.30	,,	0.50	0.33
14.10	358	336	347	,,	0.46	0.37	,,	0.53	0.30	,,	0.51	0.32
16.10	478	456	467	0.83	0.46	0.37	0.83	0.53	0.30	0.83	0.51	0.32

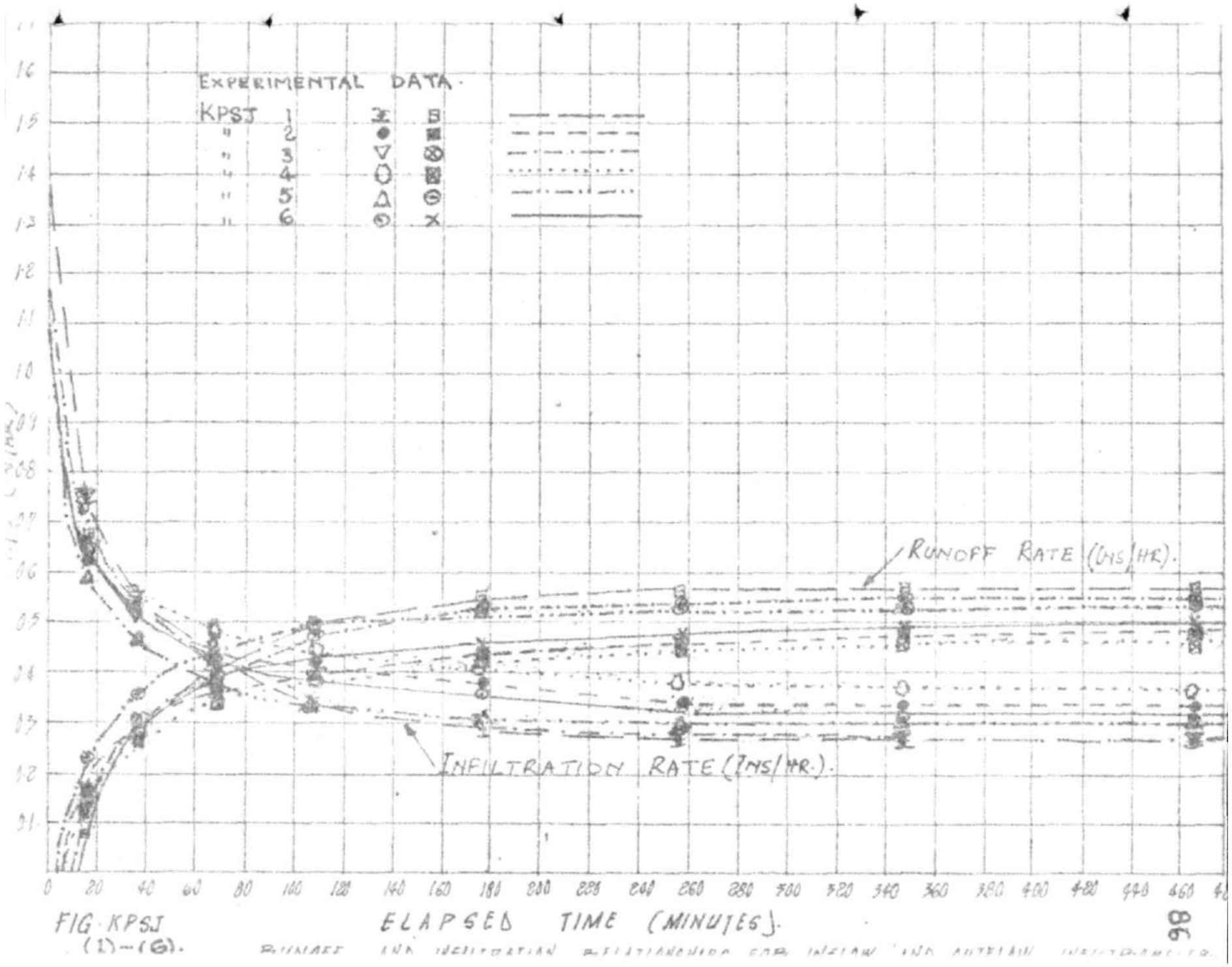


FIG. KPSJ (1)-(6). RUNOFF AND INFILTRATION RELATIONSHIP FOR INFLOW AND OUTFLOW INFILTROMETER

Table No. 18

Inflow and Outflow Infiltrometers

(Rate of water application 1.20 in./hr.)

KPSF (1) - (6)

Observed Time	ELAPSED TIME t o o Minutes	16 sq. ft	AVG Minutes	(1) q_i Ins/hr	q_o Ins/hr	(q_i-q_o) I Ins/hr per 16 Sq. ft.	(2) q_i Ins/hr	q_o Ins/hr.	(q_i-q_o) I Ins/hr per 16 sq. ft	(3) q_i Ins/hr	q_o Ins/hr	(q_i-q_o) I Ins/hr per 16sq. ft.
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.24	22	0	-	1.20	-	-	1.20	-	-	1.20	-	-
8.27	25	3	14	,,	0.51	0.69	,,	0.56	0.64	,,	0.46	0.74
8.50	48	26	37	,,	0.63	0.57	,,	0.66	0.54	,,	0.63	0.57
9.20	78	56	67	,,	0.72	0.48	,,	0.72	0.48	,,	0.71	0.49
10.04	118	96	107	,,	0.77	0.43	,,	0.78	0.42	,,	0.75	0.45
11.10	188	166	177	,,	0.80	0.40	,,	0.82	0.38	,,	0.79	0.41
12.30	268	246	257	,,	0.82	0.38	,,	0.83	0.37	,,	0.80	0.40
14.10	358	336	347	,,	0.82	0.38	,,	0.83	0.37	,,	0.80	0.40
16.10	478	456	467	1.20	0.82	0.38	1.20	0.83	0.37	1.20	0.80	0.40

				(4)			(5)			(6)		
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8 24	22	0	-	1.20	-	-	1.20	-	-	1.20	-	-
8.27	25	3	14	,,	0.51	0.69	,,	0.46	0.74	,,	0.49	0.71
8.50	48	26	37	,,	0.61	0.59	,,	0.58	0.62	,,	0.59	0.61
9.20	78	56	67	,,	0.70	0.50	,,	0.65	0.55	,,	0.69	0.51
10.04	118	96	107	,,	0.74	0.46	,,	0.70	0.50	,,	0.75	0.45
11.10	188	166	177	,,	0.77	0.43	,,	0.74	0.46	,,	0.77	0.43
12.30	268	246	257	,,	0.80	0.40	,,	0.76	0.44	,,	0.78	0.42
14.10	358	336	347	,,	0.80	0.40	,,	0.77	0.43	,,	0.78	0.42
16.10	478	456	467	1.20	0.80	0.40	1.20	0.77	0.43	1.20	0.78	0.42

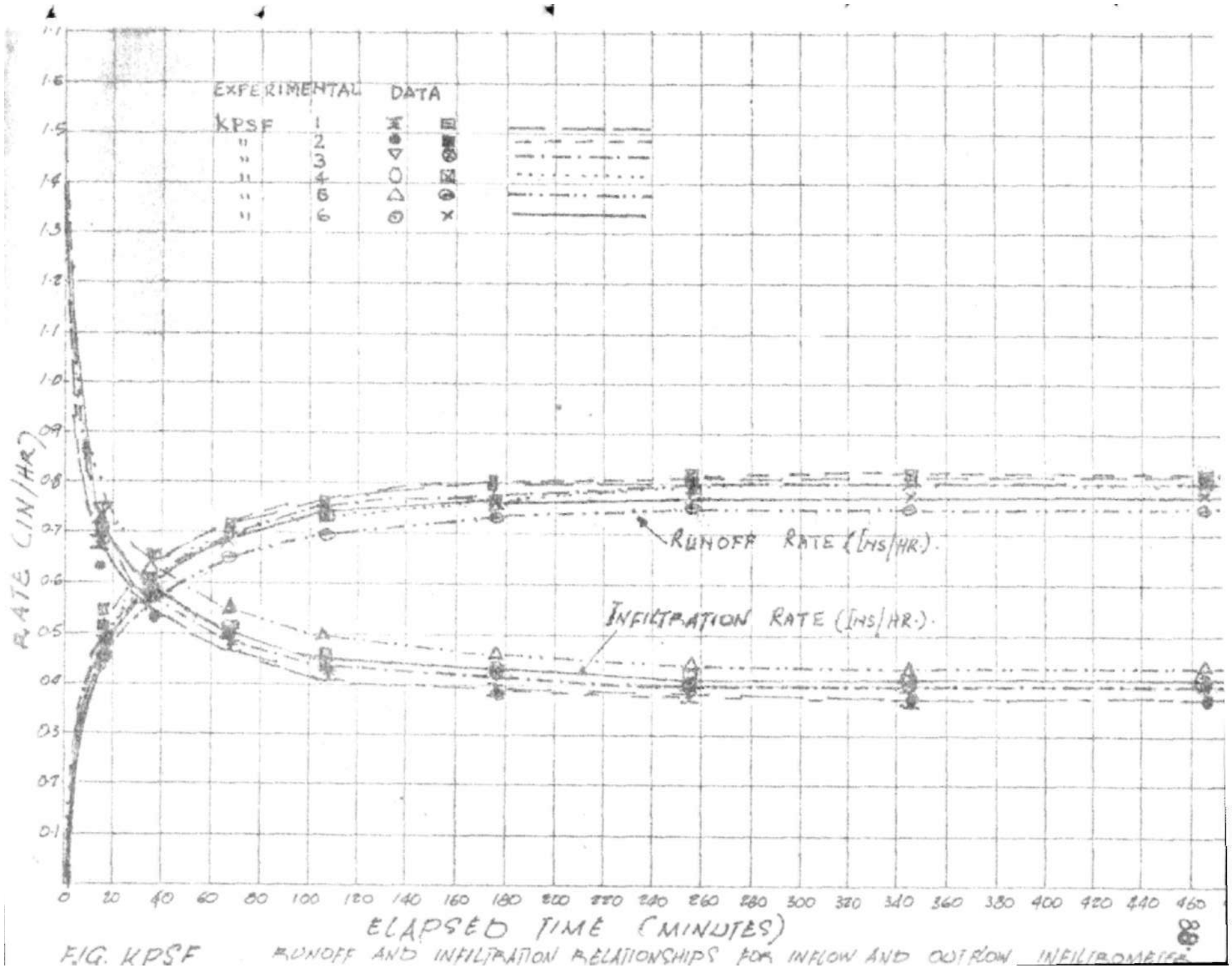


FIG. KPSF RUNOFF AND INFILTRATION RELATIONSHIPS FOR INFLOW AND OUTFLOW INFILTROMETER

Table No.19

Inflow and Outflow Infiltrometers

(Actual rainfall rate.- 1.20, 0.82., 0.85., 1.00., 0.80 and 0.90 ins/hr.
KPR (1) - (6)

Observed Time	ELAPSED TIME t o o Minutes	16 sq.ft	AVG Minutes	(1) q_i Ins/hr	q_o Ins/hr	q_i-q_o I Ins/hr. per16 sq.ft	(2) q_i Ins/hr.	q_o Ins/hr	q_i-q_o I Ins/hr. per16 sq.ft	(3) q_i Ins/hr	q_o Ins/hr	q_i-q_o IIins/hr per 16 sq. ft.
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.24	22	0	-	1.20	-	-	0.82	-	-	0.85	-	-
8.27	25	3	14	,,	0.40	0.80	,,	0.11	0.71	,,	0.11	0.74
8.50	48	26	37	,,	0.72	0.48	,,	0.37	0.45	,,	0.30	0.55
9.20	78	56	67	,,	0.86	0.34	,,	0.52	0.30	,,	0.48	0.37
10.04	118	96	107	,,	0.95	0.25	,,	0.59	0.23	,,	0.58	0.27
11.10	188	166	177	,,	1.02	0.18	,,	0.62	0.20	,,	0.64	0.21
12.30	268	246	257	,,	1.03	0.17	,,	0.64	0.18	,,	0.65	0.20
14.10	358	386	347	,,	1.03	0.17	,,	0.64	0.18	,,	0.66	0.19
16.10	478	456	467	1.20	1.03	0.17	0.82	0.64	0.18	0.85	0.66	0.19
				(4)			(5)			(6)		
8.02	Start	-	-	-	-	-	-	-	-	-	-	-
8.21	22	-	-	1.00	-	-	0.80	-	-	0.90	-	-
8.27	25	3	14	,,	0.20	0.80	,,	0.10	0.70	,,	0.15	0.75
8.50	48	26	37	,,	0.50	0.50	,,	0.26	0.54	,,	0.41	0.49
9.20	78	56	67	,,	0.64	0.36	,,	0.29	0.41	,,	0.53	0.37
10.04	118	96	107	,,	0.71	0.29	,,	0.48	0.32	,,	0.60	0.30
11.10	188	166	177	,,	0.72	0.28	,,	0.53	0.27	,,	0.63	0.27
12.30	268	246	257	,,	0.78	0.22	,,	0.56	0.24	,,	0.64	0.26
14.10	358	336	347	,,	0.79	0.21	,,	0.56	0.24	,,	0.65	0.25
16.10	478	456	467	1.00	0.79	0.21	0.80	0.56	0.24	0.90	0.65	0.25

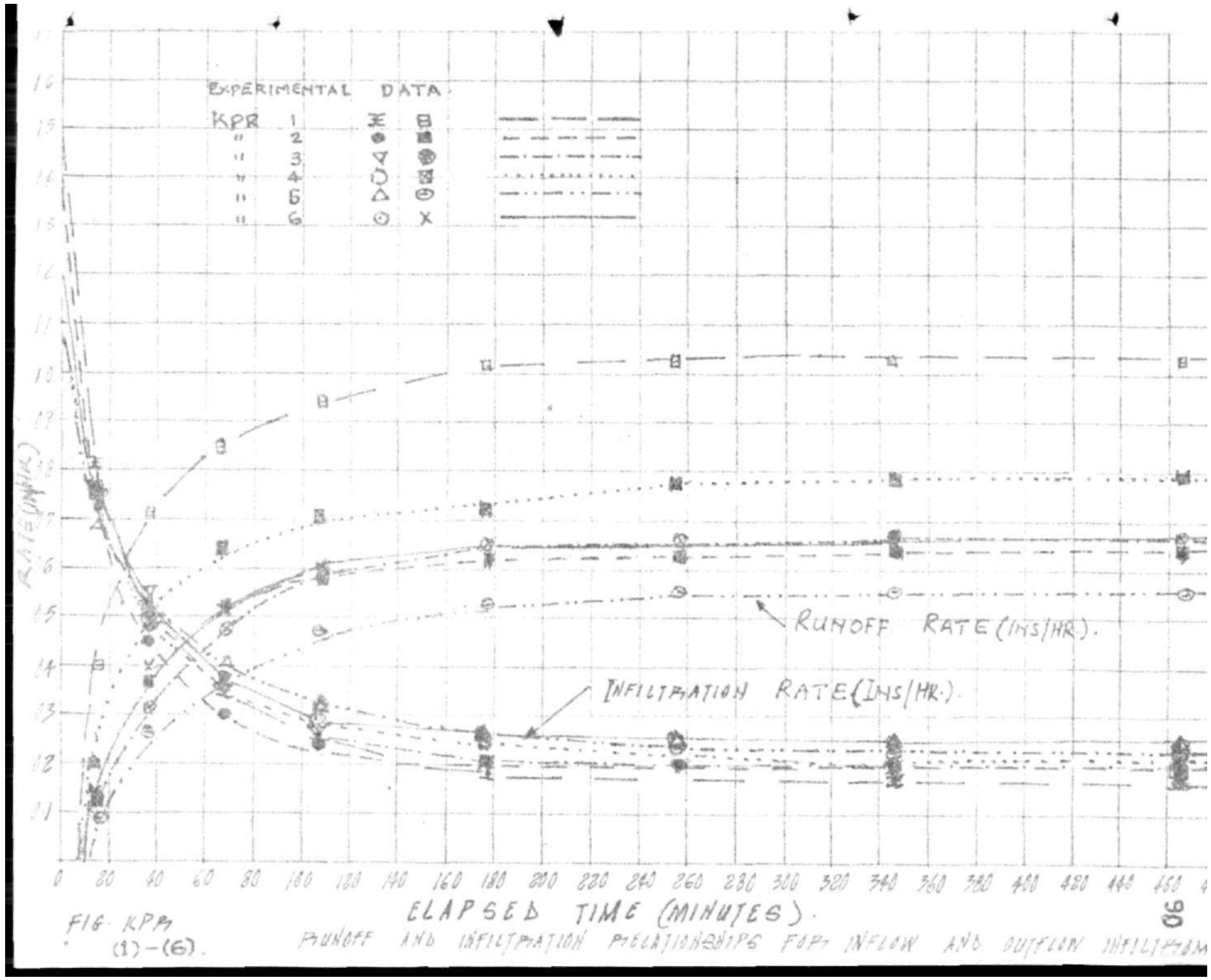


FIG. KPR (1)-(6).

RUNOFF AND INFILTRATION RELATIONSHIPS FOR INFLOW AND OUTFLOW INFILTROM

Table No. 20.

Inflow and Outflow Infiltrometers

(rainfall rates - 0.95., 0.98., 1.30., 0.80., 1.00., and 1.10 ins/hr)

KPR 1 (a) - 6 (a).

1(a) 2(a) 3(a)

Observed Time	ELAPSED TIME to Minutes	16 SQ. ft.	Avg. Minutes	q_i Ins/hr.	q_o Ins/hr.	$q_i - q_o$ Ins/hr per 16 sq. ft.	q_i Ins/hr	q_o Ins/hr	$q_i - q_o$ Ins/hr per 16 sq. ft.	q_i Ins/hr	q_o Ins/hr	$q_i - q_o$ Ins/hr per 16sq. ft.
8.02	Start	-	-	-	- -	- -	-	- -	--	-	--	-
8.24	22	0	-	0.9	- -	-	0.98	-	-	1.30	-	-
8.27	25	3	14	"	0.37	0.58	"	0.38	0.60	"	0.42	0.88
8.50	48	26	37	"	0.54	0.41	"	0.50	0.48	"	0.67	0.63
9.20	78	56	67	"	0.64	0.31	"	0.71	0.27	"	0.90	0.40
10.04	118	96	1 7	"	0.72	0.23	"	0.78	0.20	"	0.98	0.32
11.10	188	166	177	"	0.75	0.20	"	0.80	0.18	"	1.04	0.26
12.30	268	246	257	"	0.77	0.18	"	0.82	0.16	"	1.08	0.22
14.10	358	336	347	"	0.77	0.18	"	0.82	0.16	"	1.08	0.22
16.10	478	456	467	0.95	0.77	0.18	0.98	0.82	0.16	1.30	1.08	0.22

4(a) 5(a) 6(a)

7.58	Start	-	-	-	-	-	-	-	-	-	-	-
8.04	22	0	-	0.80	-	-	1.00	-	-	1.10	-	-
8.27	25	3	14	"	0.17	0.63	"	0.20	0.80	"	0.38	0.72
8.50	48	26	37	"	0.34	0.46	"	0.38	0.63	"	0.49	0.51
9.20	78	56	67	"	0.47	0.33	"	0.57	0.43	"	0.68	0.42
10.04	118	96	1o7	"	0.54	0.26	"	0.68	0.32	"	0.77	0.33
11.10	188	166	177	"	0.60	0.20	"	0.73	0.27	"	0.80	0.30
12.30	268	246	257	"	0.63	0.17	"	0.77	0.23	"	0.83	0.27
14.10	358	336	347	"	0.63	0.17	"	0.77	0.23	"	0.83	0.27
16.10	478	456	467	0.80	0.63	0.17	1.00	0.77	0.23	1.10	0.83	0.27

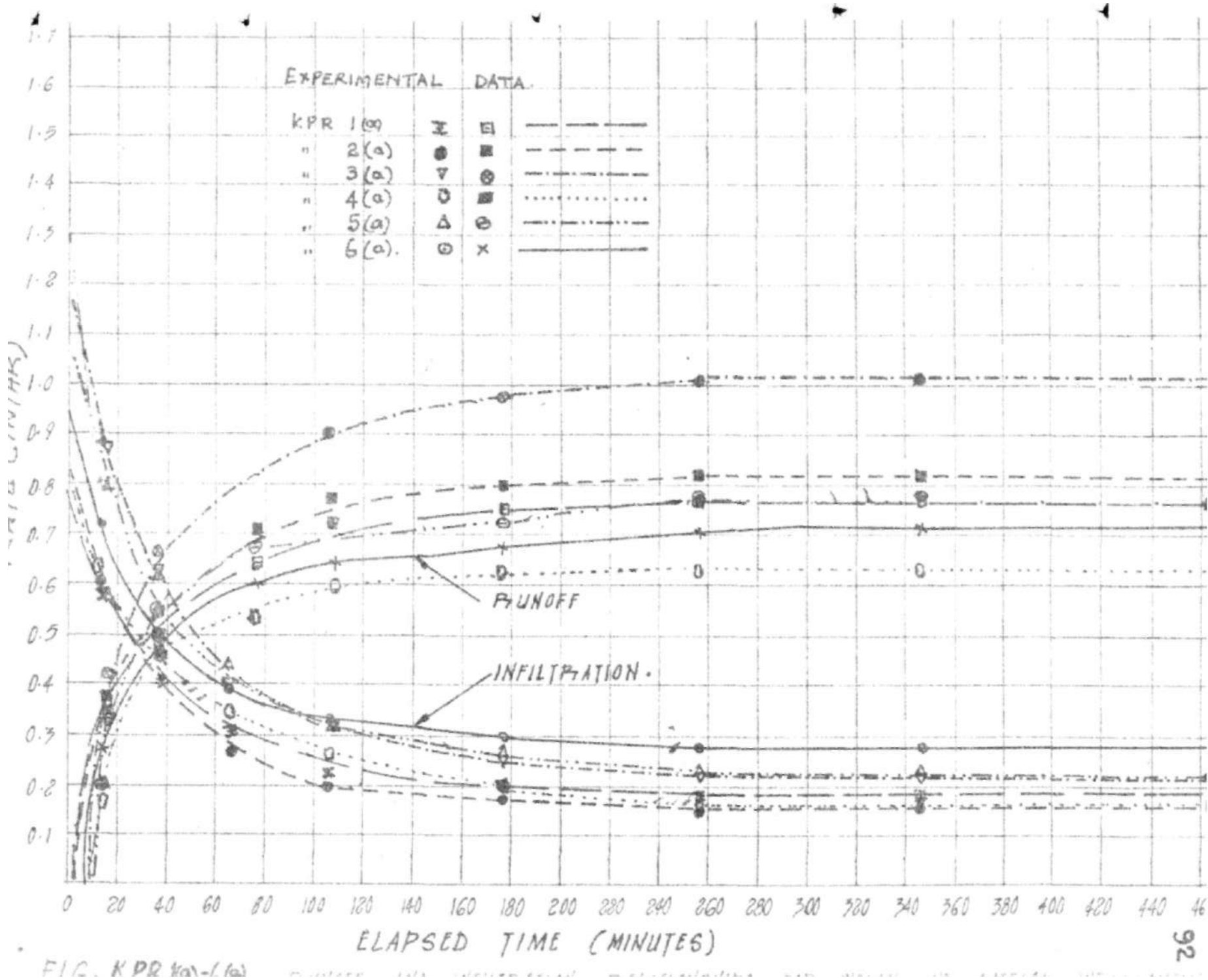

EXPERIMENTAL DATA.
KPR 1(a)
" 2(a)
" 3(a)
" 4(a)
" 5(a)
" 6(a).
RUNOFF
INFILTRATION.
ELAPSED TIME (MINUTES)

FIG. KPR 1(a)-6(a)

Results of the experiments using sprinklers and actual rainfall rates at the Kaduna Polytechnic.

The results obtained from the curves under the experiments using sprinklers and the actual rainfall rates at the Kaduna Polytechnic, Kaduna., are as follows:-

Table No. 21.

Tabulation of the results using sprinklers and actual rainfall rates at the Kaduna Polytechnic, Kaduna.

Table No.	Particulars .	Initial Rate (Avg) Ins/hr.	Final Rate (Avg) Ins/hr.
16	KPSN 1 - 6	0.70	0.26
17	KPSJ 1 - 6	0.65	0.31
18	KPSF 1 - 6	0.67	0.40
19	KPR 1 - 6	0.75	0.21
20	KPR (1a) -(6a)	0.70	0.21

From the above, it may be observed that all the five infiltration capacities are similar. The slight discrepancy between the values obtained for the actual rainfall rates i.e. KPR 1-6 and KPR 1 (a) - 6 (a), and those obtained for the rest, from the sprinklers, is due to the rain drop impact upon the experimental plot.

Furthermore, it can be seen that simulated rainfall compares

favourable with the actual rainfall and in fact is a valuable research tool having the potential to greatly increase our knowledge of soil infiltration. It is generally more efficient, controlled, and adaptable than natural rainfall. It can therefore replace natural rainfall.

(C) Conclusions to the experiments carried out at the Ahmadu Bello University, Zaria., and the Kaduna Polytechnic, Kaduna.

Experiments were conducted using the cylinder infiltrometer methods, actual rainfall, and sprinkling devices were used for inflow and outflow infiltrometers on different sites at the Ahmadu Bello University, Zaria., and the Kaduna Polytechnic, Kaduna.

From the results of the above experiments, it is evident that the results obtained for the cylinder infiltrometers and sprinklers (inflow and outflow infiltrometers) are very different i.e. the results for the cylinder infiltrometers are too high; but from the limited literature so far, it is possible to say that one can use the correction factor on the results obtained for the cylinder infiltrometers; Hence to get the correction factor, the results obtained for

the cylinder infiltrometers, sprinklers, and the actual rainfall rates were compared. It was found that the correction factor was constant i.e. the curves have a linear relationship.

Therefore, assuming that the values obtained for the actual rainfall rates are correct, and taking an average value from figures KPR (1) - (6) and KPR 1 (a) - 6 (a)., we have an average initial infiltration rate of 0.73 inch per hour, and an average final rate of 0.21 inch per hour used in the following analysis:

Table No 22

Analysis for correction factor on cylinder infiltrometer results for the experiments carried out at the Ahmadu Bello University, Zaria., and the Kaduna Polytechnic, Kaduna.

I_c - Cylinder Infiltrometer.

I_R - Actual Rainfall

A. Analysis for correction factor on cylinder infiltrometer results for the experiments carried out at the Ahmadu Bello University, Zaria.

Figure No.	Initial Rate			Final Rate		
	I_c Ins/hr.	I_R Ins/hr.	Approx. I_c/I_R	I_c Ins/hr.	I_R Ins/hr.	Approx. I_c/I_R
ZAUC 1(a)	1.20	0.73	0.61	0.43	0.21	0.49
" 1(b)	1.32	"	0.55	0.33	"	0.64
" 2(a)	1.44	"	0.51	0.36	"	0.58
" 2(b)	1.68	"	0.44	0.32	"	0.66
" 3(a)	1.80	"	0.41	0.36	"	0.58
" 3(b)	1.56	"	0.47	0.37	"	0.57
" 4(a)	2.52	"	0.29	0.24	"	0.88
" 4(b)	2.64	"	0.28	0.16	"	0.31
" 5(a)	1.92	"	0.38	0.16	"	1.31
" 5(b)	2.04	"	0.36	0.21	"	1.00
" 6(a)	1.44	"	0.51	0.25	"	0.84
" 6(b)	1.80	"	0.41	0.13	"	1.62
" 7(a)	2.16	"	0.34	0.12	"	1.75
" 7(b)	1.92	"	0.38	0.17	"	1.24
" 8(a)	1.32	"	0.55	0.25	"	0.84
" 8(b)	1.56	"	0.47	0.28	"	0.75
" 9(a)	1.56	"	0.47	0.28	"	0.75
" 9(b)	1.44	"	0.51	0.21	"	1.00
"10(a)	2.04	"	0.36	0.24	"	0.88
"10(b)	1.80	"	0.41	0.19	"	1.11
"11(a)	1.56	"	0.47	0.15	"	1.40
"11(b)	1.68	"	0.44	0.13	"	1.61
			9.72			21.81
	Avg.		0.44			0.99

B. Analysis for correction factor on cylinder infiltrometer results for the experiments carried out at the Kaduna Polytechnic, Kaduna.

Figure No.		Initial Rate			Final Rate		
		I_c Ins/hre.	I_R Ins/hr.	Approx. I_c/I_R	I_c Ins/hr.	I_R Ins/hr.	Approx. I_c/I_R
NBK	1	1.50	0.73	0.49	0.10	0.21	2.10
"	2	1.04	"	0.70	0.15	"	1.40
"	3	1.00	"	0.73	0.20	"	1.05
"	4	1.27	"	0.57	0.20	"	1.05
"	5	0.92	"	0.79	0.15.	"	1.40
"	6	1.10	"	0.64	0.15	"	1.40
"	7	1.50	"	0.49	0.17	"	1.24
BK	1	1.75	"	0.42	0.10	"	2.10
"	2	1.15	"	0.64	0.10	"	2.10
"	3	1.48	"	0.49	0.13	"	1.61
"	4	1.40	"	0.52	0.15	"	1.40
"	5	2.00	"	0.37	0.11	"	1.91
"	6	1.24	"	0.59	0.10	"	2.10
"	7	1.38	"	0.53	0.15	"	1.40
BK/DK	1	0.60	"	1.20	0.13	"	1.61
"	2	1.20	"	0.61	0.64	"	0.33
"	3	2.40	"	0.31	0.10	"	2.10
"	4	1.20	"	0.61	0.07	"	3.00
"	5	0.84	"	0.87	0.06	"	3.50
"	6	2.00	"	0.37	0.10	"	2.10
"	7	1.30	"	0.56	0.15	"	1.40
"	8	1.10	"	0.66	0.11	"	1.91
"	9	1.50	"	0.49	0.20	"	1.05
"	10	1.75	"	0.42	0.20	"	1.05
BO/DK	1	0.75	"	0.97	0.23	"	0.91
"	2	0.72	"	1.01	0.15	"	1.40
"	3	0.61	"	1.20	0.15	"	1.40
BO/DVK	1	0.70	"	1.04	0.13	"	1.61
"	2	1.00	"	0.73	0.11	"	1.91
"	3	1.15	"	0.64	0.11	"	1.91
EBO/DK	1	0.84	"	0.87	0.10	"	2.10
"	2	1.23	"	0.59	0.11	"	1.91
"	3	1.10	"	0.66	0.20	"	1.05
"	4	1.20	"	0.62	0.11	"	1.91
"	5	1.00	"	0.73	0.18	"	1.17
				23.12			57.59
		Avg.		0.66			1.65

From the foregoing analysis, the author has determined the correction factors by which cylinder infiltrometers have to be multiplied for the soils at the Ahmadu Bello University, Zaria., and the Kaduna Polytechnic, Kaduna.

It may be observed that the correction factor for the soils at the Kaduna Polytechnic, Kaduna is slightly higher than that obtained for the soils at the Ahmadu Bello University, Zaria., which may be due to differences in the moisture contents of the soils e.g. the lower the initial soil moisture, the higher the infiltration, and that the longer the time of water application, the less would be the change in soil moisture.

CHAPTER IV

4.0. Theoretical Considerations

A. The flow of water through soils.

In chapter 2.2.(ii) of this thesis the author has listed past research workers who have been connected with the flow of water through the soil. They used the capillary tube method to measure the rise of water in the soil. It was found that the capillary rise experiments with dry soil behaves quite differently from water in glass tubes. At the same time the following classification for soil water was made without physical meaning: capillary water, gravitational water, and hygroscopic water. Later the capillary flow phenomena was used to obtain the physical laws.

Therefore, it is important to discuss the physical laws which discribe the transport of matter and energy through space.

The physical laws for the flow of water through soil are listed below:

(a) Physical Laws

Ohm's law for the flow of electricity.

$$I_e = A_c R/\rho \quad \frac{V_1 - V_2}{L} \qquad \text{----------(1)}$$

where I_e - the electrical flux.

A_c - the cross sectional area of the conductor

ρ - the density of conductor

V_1 and V_2 - the electrical potential at two points

L - the distance between these points

R - the electrical resistance of the material

Fourier's law of heat conductivity.

$$q = A_c D \quad \frac{t_1 - t_2}{L} \qquad \text{----------(2)}$$

where q - the heat flux,

A_c - the cross sectional area

D - the thermal diffusivity,

t_1 & t_2 - the temperatures at two points of distance

L from each other.

Fricks law of diffusion

$$q_d = A_c D \quad \frac{C_1 C_2}{L} \qquad \text{----------(3)}$$

where q_d - the flux of the diffusing material

A_c - the cross sectional area

C1&C2 - the concentrations of the diffusing

material at two points and

L - the distance between the two points

D - the thermal diffusivity.

Darcy's Formular.

A century ago the French sanitary engineer Hency Darcy investigated the flow of water through saturated sands for the water supply of Dijon. He published (1856) his experimental formular -

$$q = -AK\frac{\Phi_1 - \Phi_2}{L} \quad \ldots\ldots\ldots(4)$$

where q - the flux of water through the material

A - the cross sectional area of the porous sand

K - the water conductivity of the material

Φ_1 and Φ_2 - the total water (pressure and gravity) at two points.

The sign is negative since the flow takes place in the opposite direction.

The important physical principle common to all above empirical laws is the general transport law which states that the flux of matter or energy is equal to the product of a conductivity (or resistance) term and a driving force term. The driving force can be a potential gradient ($\frac{V_1 - V_2}{L}$), a pressure gradient ($\frac{P_1 - P_2}{L}$), a concentration gradient ($\frac{C_1 - C_2}{L}$), or a temperature gradient ($\frac{t_1 - t_2}{L}$). It is important therefore, to state than no flow problem can be properly analyzed without considering both the conductivity and potential gradient.

B. Infiltration of water through soils

Many attempts had been made in the past to evaluate infiltration capacity and rates with a number of input parameters. Often these parameters are the coefficients of algebraic equations which relate the infiltration capacity to time or soil moisture content.

Under this chapter, a number of infiltration equations are listed. From the list, the choice appears to be between a potentially accurate but difficult to compute method and a simplified but apparently reasonably accurate method for which input information is much more easily obtained. Practical considerations often favour the latter. Therefore, equations (5) and (7) were solved.

In solving the equations, the author has attempted to evaluate the two equations on the basis of experimental data from the experiments carried out under this study to obtain numerical values for the parameters in the simplest form.

(a) Infiltration Equations

The Infiltration equations are

Kotiakov (1932) equation

Kotiakov suggested

$$I = \beta t^{-\alpha} \text{----------(5)}$$

where I - total infiltration, inches per hour.

t - time, hour

β - a constant depending on time t.

α - a component of a solution.

In 1958, Swatzendruber and Hubeats found that this formula fits experimental data but will fail unless one assumes β, α, to be functions of time ($\alpha = \frac{1}{2}$, at $t \to 0$), ($\alpha = 1$, at $t \to \infty$).

Horton's equation (1940).

$$I = \int_{t=0}^{t} q\,dt = q_{ft}\,t + \frac{1}{\beta}(q_{if} - q_{ft})\left[1 - e_i^{-\beta t}\right] \text{-----(6)}$$

where I - total infiltration, inches per hour.

q_{ft} - final infiltration, inches per hour

q_{if} - the initial water infiltration

β - a constant depending on time t.

e_i - effective 'void ratio

t - time, hour.

This equation works quite well if the time period , t, is considerate but, requires the determination of too many parameters for its easy solution.

Horton's Equation (1943).

$$f = f_c + (f_o - f_c') e^{-k_{ft}} t \quad \ldots\ldots\ldots\ldots(7)$$

where f - the infiltration capacity at time, t,

f_o - the infiltration capacity at time, t=o.

f_c - the infiltration capacity at steady state,

k_{ft} - the rate of decrease in f-capacity dependent on the soil and its surface conditions,

e - the natural-log base, usually 2.72

t - the time.

when $t = \infty$, $K_{ft} = \frac{f_o - f_c}{F_c}$ .....(71)

where F_c - the mass infiltration in excess of that at the f_c rate.

Philip Equation (1954 - 60).

This equation is generally known as the 'Algebraic infiltration equation' and it appears quite reliable. The equation bears little resemblance to the Horton equation; but fits the Kotinkov (1932) equation quite well.

The equation for total infiltration -

$$I = St^{\frac{1}{2}} + At \quad \text{.....(8)}$$

where S - the function of the initial moisture content of the profile,

A - the constant related to permeability and length in the one-dimensional system,

t - the time, hour.

Van duin Equation (1955, 1956).

Van duin correctly assumed that the transmission zone is the one which controls the infiltration process. The moisture content of this zone is constant with time and depth, and so is the unsaturated conductivity (k).

He further assumed that the soil water at the edge of the wetting zone (zone 5) is constant with time and he neglected the existence of free water at the surface. The only component of the total potential is the gravity.

The equation for the total infiltration -

$$I = \theta a \left(\frac{kt}{a}\right)^{0.55} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where θ - the moisture content of the transmission zone,

a - the soil constant,

t - the time, hour

k - the unsaturated conductivity.

(i) Theoretical analysis using cylinder infiltrometers at the Ahmadu Bello University, Zaria.

The author is hereby considering the use of analysis to solve equation (5) of this study using the data obtained from the experiments carried out at the Ahmadu Bello University, Zaria.

Infiltration rates are plotted on semi-logarithmic-scale papers on the vertical axis and time on the horizontal axis.

The resultant curves are represented by straight lines as shown under figures ZABUC 1 (ia) to ZABUC 2 (ib). Therefore, the infiltration rate I in inches per hour can now be found by applying the Kotiakov (1932) infiltration equation. Thus, by applying equation (5), we have -

$$I = \beta t^{-\alpha}$$

where β - a constant depending on time (t)

t - time in hour

α - a component of a sclution.

In the following analysis, constant (β) is found as the intercept made by the infiltration rate line at unit time, amd (α) is the slope of the line.

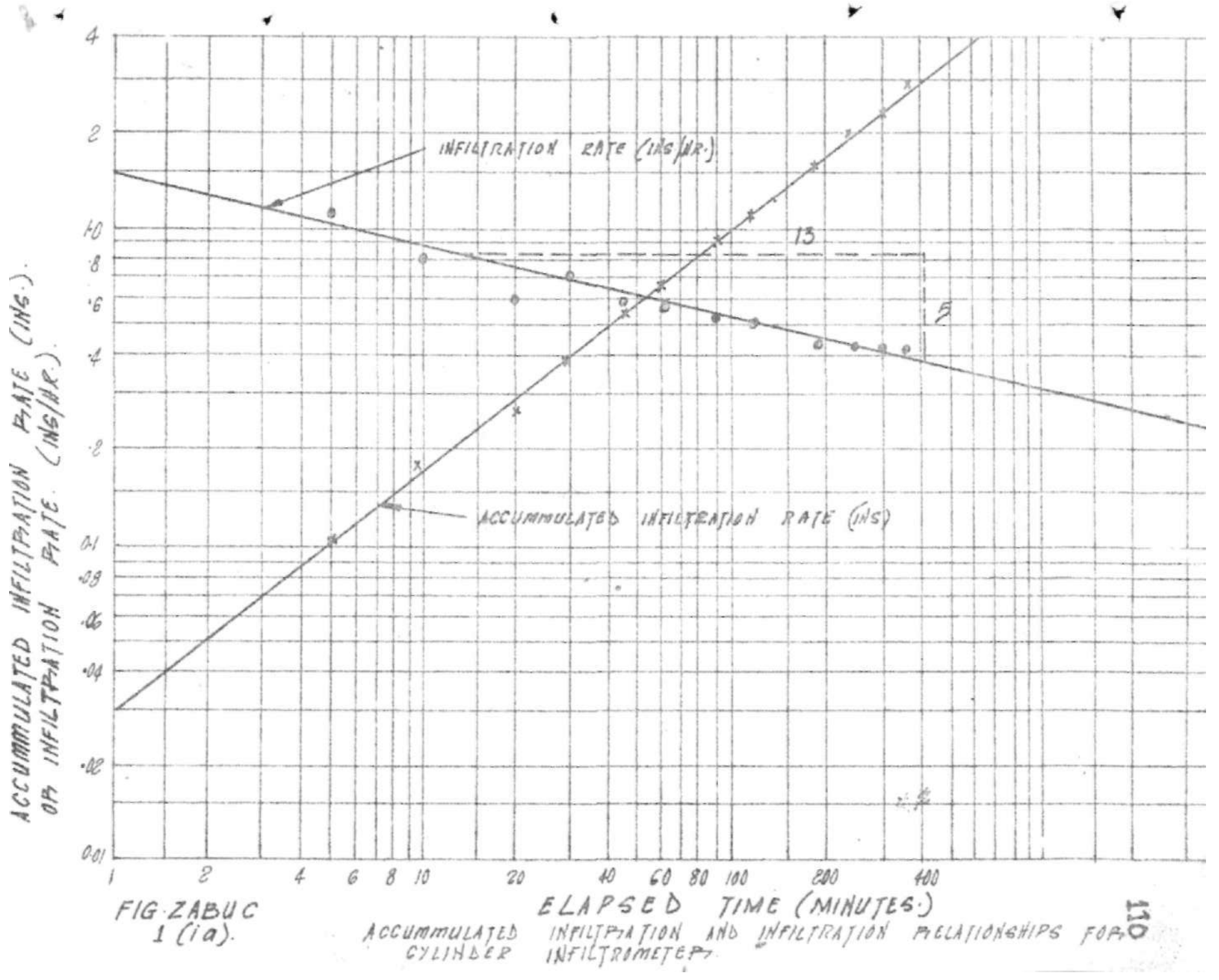


FIG ZABUC 1 (ia). ACCUMMULATED INFILTRATION AND INFILTRATION RELATIONSHIPS FOR CYLINDER INFILTROMETER.

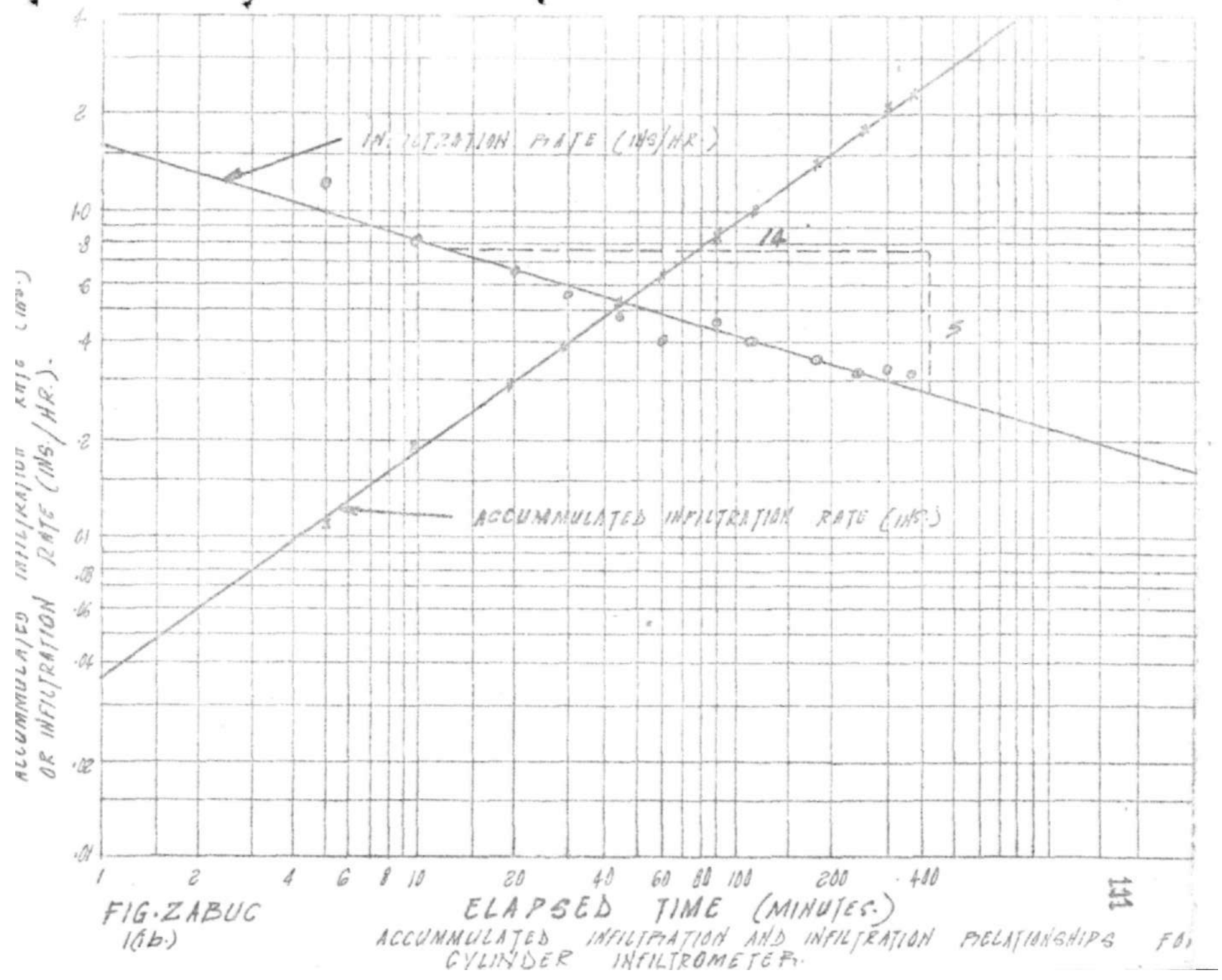
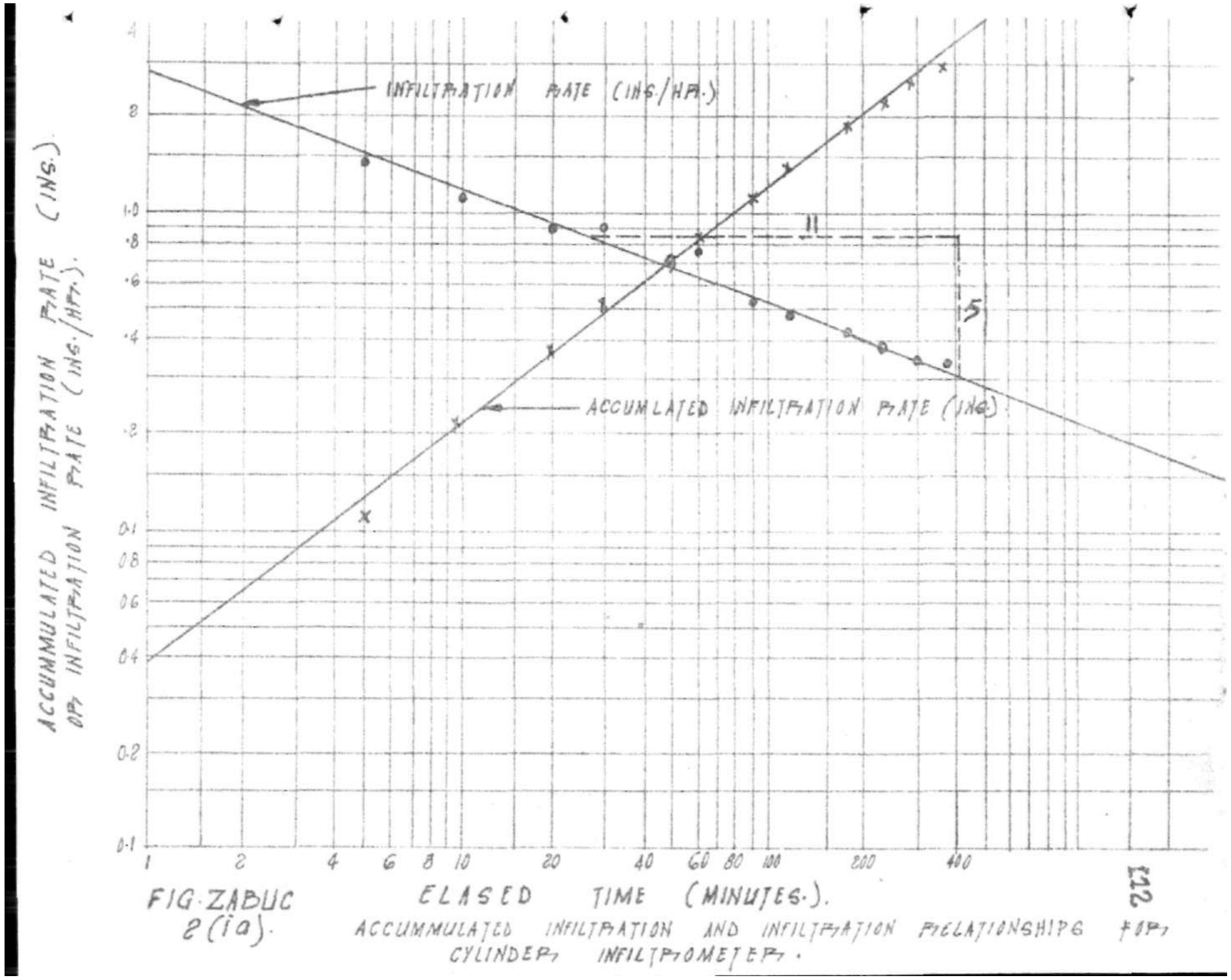


FIG. 2ABUC
1(b.)

ACCUMMULATED INFILTRATION AND INFILTRATION RELATIONSHIPS FOR CYLINDER INFILTROMETER.



FIG·ZABUC 2(ia).

ACCUMMULATED INFILTRATION AND INFILTRATION RELATIONSHIPS FOR CYLINDER INFILTROMETER.

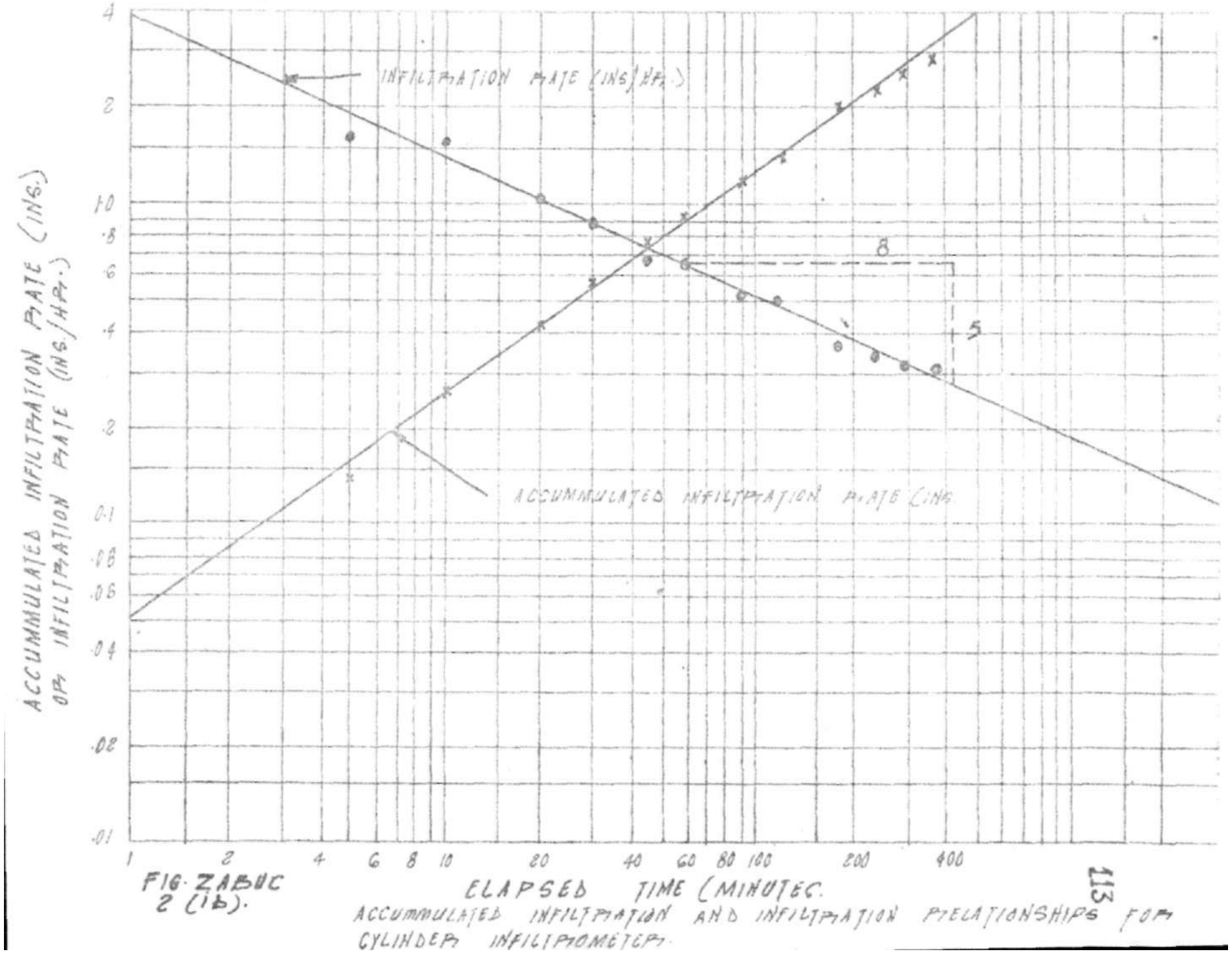


FIG. ZABUC 2 (1b).

ACCUMMULATED INFILTRATION AND INFILTRATION RELATIONSHIPS FOR CYLINDER INFILTROMETER.

(ii) Results of the experiments using theoretical analysis to determine infiltration rates on the data obtained from cylinder infiltrometers at the Ahmadu Bello University, Zaria.

Table No. 23.

Cylinder Infiltrometer Analysis for infiltration rate.

Figure No.	β Ins./hr.	t hour	α	I inches per hour
ZABUC 1 (ia)	1.50	t	0.385	$1.5t^{-0.385}$
" 1 (ib)	1.60	"	0.356	$1.6t^{-0.356}$
" 2 (ia)	2.70	"	0.454	$2.7t^{-0.454}$
" 2 (ib)	3.80	"	0.625	$3.8t^{-0.625}$

Therefore, from the foregoing, the value of the infiltration rate, I in inches per hour at time (t) can be found if the values of β and α are known.

Conclusions to analysis using cylinder infiltrometer data.

The data for the infiltration rates of variour areas around the Main Campus of the Ahmadu Bello University, Zaria, were shown in Tables numbers 2 to 8. It is hereby concluded that the results obtained from the above analysis indicated close comparison with those obtained from field experiments.

(iii) Theoretical analysis using Sprinklers -

Inflow and Outflow infiltrometers, at the

Kaduna Polytechnic, Kaduna.

In order to solve equation (7) of this study, the author has used the results obtained by plotting the data in Tables 16 to 19 (inflow and outflow infiltrometers) to obtain the necessary analysis shown in Tables 24 to 27 for the infiltration capacity for the ground of the Kaduna Polytechnic, Kaduna.

The equation is as follows:-

$$f = f_c + (f_o - f_c)\, e^{-k_{ft}t}$$

where f - the infiltration capacity at time, $t = o$,

f_c - the infiltration capacity at steady state,

k_{ft} - the rate of decrease in f-capacity dependent on the soil and its surface conditions

e - the natural - log base,

t - the time.

From the curves obtained by plotting the above mentioned data, the only unknown therefore, is F_c which is the mass infiltration in excess of that at the f_c rate.

Therefore, from equation (7i), we have -

$$K_{ft} = \frac{f_o - f_c}{F_c}$$

from which

$$F_c = \frac{f_o - f_c}{K_{ft}} .$$

Table No.24

Inflow and Outflow Infiltrometer analysis - Infiltration capacity (KPSN).

Formula	KPSN (1)	KPSN (2)	KPSN (3)	KPSN (4)	KPSN (5)	KPSN (6)
fc	0.20	0.30	0.23	0.21	0.28	0.32
fo	1.10	1.30	1.30	1.40	1.30	1.30
Fc	2.70	3.00	3.21	3.69	3.06	3.04
e^{-kft}	$e^{-0.33t}$	$e^{-0.33t}$	$e^{-0.33t}$	$e^{-0.32t}$	$e^{-0.33t}$	$e^{-0.32t}$
$f=fc+(fo-fc)e^{-kft}$	$0.20+\frac{0.90}{e^{0.33t}}$	$0.30+\frac{1.0}{e^{0.33t}}$	$0.23+\frac{1.07}{e^{0.33t}}$	$0.21+\frac{1.19}{e^{0.32t}}$	$0.28+\frac{1.02}{e^{0.33t}}$	$0.32+\frac{0.98}{e^{0.32}}$

Table No.25

Inflow and Outflow Infiltrometer analysis - Infiltration capacity (KPSJ).

Formula	KPSJ (1)	KPSJ (2)	KPSJ (3)	KPSJ (4)	KPSJ (5)	KPSJ (6)
fc	0.27	0.34	0.27	0.37	0.30	0.32
fo	1.40	1.10	1.20	1.10	1.10	1.20
Fc	3.50	2.28	2.98	2.19	2.40	2.64
e^{-kft}	$e^{-0.32t}$	$e^{-0.33t}$	$e^{-0.31t}$	$e^{-0.33t}$	$e^{-0.33t}$	$e^{-0.33t}$
$f=fc+(fo-fc)e^{-kft}$	$0.27+\frac{1.13}{e^{0.32t}}$	$0.34+\frac{0.76}{e^{0.33t}}$	$0.27+\frac{0.93}{e^{0.31t}}$	$0.37+\frac{0.73}{e^{0.33t}}$	$0.30+\frac{0.80}{e^{0.33t}}$	$0.32+\frac{0.88}{e^{0.33t}}$

Table No.26

Inflow and Outflow Infiltrometer analysis - Infiltration apacity (KPSF)

Formula	KPSF (1)	KPSF (2)	KPSF (3)	KPSF (4)	KPSF (5)	KPSF (6)
fc	0.38	0.37	0.40	0.40	0.43	0.42
fo	1.50	1.40	1.40	1.30	1.40	1.30
Fc	3.36	3.09	3.00	2.70	2.91	2.64
e^{-kft}	$e^{-0.33t}$	$e^{-0.33t}$	$e^{-0.33t}$	$e^{-0.33t}$	$e^{-0.33t}$	$e^{-0.33t}$
$f=fc+(fo-fc)e^{kft}$	$0.38+\frac{1.12}{e^{0.33t}}$	$0.37+\frac{1.03}{e^{0.33t}}$	$0.40+\frac{1.0}{e^{0.33t}}$	$0.40+\frac{0.90}{e^{0.33t}}$	$0.43+\frac{0.97}{e^{0.33t}}$	$0.42+\frac{0.88}{e^{0.33t}}$

Table 27

Inflow and Outflow Infiltrometer analysis - Infiltration capacity (KPR).

Formula	KPR (1)	KPR (2)	KPR (3)	KPR (4)	KPR (5)	KPR (6)
fc	0.17	0.18	0.19	0.21	0.24	0.25
fo	1.50	1.40	1.10	1.40	1.10	1.20
Fc	3.99	3.80	2.82	3.69	2.67	2.94
e^{-kft}	$e^{-0.33t}$	$e^{-0.32t}$	$e^{-0.32t}$	$e^{-0.32t}$	$e^{-0.31t}$	$e^{-0.32t}$
$f=fc+(fo-fc)e^{-kft}$	$0.17+\frac{1.33}{e^{0.33t}}$	$0.18+\frac{1.22}{e^{0.32t}}$	$0.19+\frac{0.91}{e^{0.32t}}$	$0.21+\frac{1.19}{e^{0.32t}}$	$0.24+\frac{0.86}{e^{0.31t}}$	$0.25+\frac{0.95}{e^{0.32t}}$

(iV) Results and Conclusions to analysis using Sprinklers - Inflow and Outflow infiltrometer data at the Kaduna Polytechnic, Kaduna.

The analysis obtained by plotting the data in Tables 16 - 19 (inflow and outflow infiltrometers) are shown in Tables 24 - 27. Thus, the infiltration capacity in inches per hour was determined for each test by applying the Horton (1943) infiltration equation— see equation (7) under this study.

The initial moisture contents were not equal for all cases; also the difference in the curves is highly dependent on surface conditions. Thus, the differences in surface conditions; are also reflected in the equations.

At least for theoretical consideration, the analysis appeared to be the best method of determining the ability of the infiltration equations using the experimental data and to determine values for the infiltration capacity for different soils and conditions.

CHAPTER V.

5.0 Conclusions to the experiments carried out at the Ahmadu Bello University, Zaria., and the Kaduna Polytechnic, Kaduna.

The experiments from different sites indicated the infiltration rates in inches per hour using cylinder infiltrometers and the rate of inflow and outflow on a standard plot. In the latter case, each intensity was continued sufficiently long for the rate of runoff to become sensibly constant.

The lateral position of the curves depend mainly on the intial soil moisture and the general shape of the curves depend on the soil type, and other conditions such as cover, etc.

It was difficult to control lateral subterranean flow of water between the depth of penetration of one inch and four inches. This problem however, did not affect the depth of penetration from five inches upwards.

The optimum depth of cylinder penetration was determined and this occured at 6 inches depth of penetration.

Buffered cylinders reached their steady states at a period earlier than non-buffered cylinders.

It was observed that varying the head of water inside the inner cylinder produces little or no change in the amount of water intake of the soils under consideration.

At the beginning of each test the rate of infiltration was consistently high; but at later periods it became constant at a lower rate. This may be due to the soils nearing their saturation point.

In most of the tests, the infiltration rates reach their steady states between 4 and 5 hours.

The initial infiltration rate ranges between 0.90 and 1.50 inches per hour., and between 0.17 and 0.32 inches per hour for the rate at the steady state. The latter compares favourably with those obtained by Dr. Guy E. Wilkinson under Appendix 1. The soils achieved nearly complete saturation, since the final f-capacity curves level off at about the same point for most of the experiments. The original moisture content was found to have no significant effect on the rates at the steady states, but the moisture content does affect the initial infiltration rate, e.g. the higher the moisture content the lower the initial infiltration rate. Thus, the infiltration capacity is lower during the rainy season than the dry season.

It was found that the greater the rainfall / water application, the less the rate of infiltration., and the greater the rate of application, the greater the proportion of the runoff.

An investigation was conducted to experimentally evaluate infiltration equations proposed by kotiakov and Horton. Experimental data were obtained from recent field studies conducted by the author for this thesis. On the basis of the results, the author found that adequate predictions of infiltration rates can be obtained from either of the two equations, but the analysis obtained by using Horton's equation appears to be more reliable and can be used to determine the infiltration capacity, which is the maximum rate at which infiltration can occure at the land surface. Also very good representations of the infiltration capacity - time relationship can be obtained by using the sprinklers to obtain data for use with Horton's equation.

Finally, the two equations predict steady state infiltration rates and capacity that agree closely with experimental values.

CHAPTER VI.

6.0 A. SUMMARY.

The brief studies reported here point to the usefulness of specific information on the infiltration characteristics of specific local sites.

Characteristics of infiltration rates and the response of different sites under various conditions are so varied that no uniform relationship could be categorically stated.

Studies of infiltration rates of various areas should include a knowledge of how soil depth, soil moisture, soil cover, soil texture, soil structure, soil swelling, and seasonal changes in physical conditions affect infiltration.

Experiments were conducted using the cylinder infiltrometer method. Later experiments were performed in which sprinkling devices for inflow and outflow infiltrometers were used on different sites.

As a result of the experiment, it was evident that the optimum depths of penetration had a range of 5 - 7 inches with a mean of 6 inches. The effective optimum depth was dependent on the condition of the surface and the type of soil.

It was evident from the results that infiltration only starts when the soil is wetted, and that the

infiltration rates decrease with time after wetting, i.e. the rate of water infiltration gradually drops until it approaches a constant value. Also, it was shown that only during those portions of the infiltration rate when the runoff is constant, and after satisfactory soil saturation, can the infiltration rate be determined directly and with a degree of accuracy.

In the studies, the author has considered the theoretical analysis of infiltration rate using the simple knowledge of overland flow. Experimental data for the solution of Kotiakov and Horton equations were obtained from the experiments conducted by cylinder infiltrometers and sprinklers.

Numerical techniques for the solution of two equations and the characterisation of infiltration as proposed by the author can now be applied to field scale problems. Perhaps a greater barrier to numerical solution for applied problems is the large amount of computation time necessary to determine infiltration for the variable conditions existing within a catchment area. This barrier could be overcome by the use of infiltration data such as those used in this study.

The author has also considered the method of eliminating the error which may result from the effect of water pressure on the infiltration rate by using buffered zone.

It was evident from the results that infiltration capacity varies from time to time, according to the complex interaction of a large number of variables. The influencing factors can be broadly classified as for example through a storm, or through a series of rainfalls as short term variations and those whose main effects are upon the longer term variations of infiltration capacity from one season of the year to another. Thus, it is difficult to assess their individual quantitative effect.

B. Conclusions and Recommentations.

On the basis of the results obtained from this study the following conclusions were formulated:

A knowledge of how the accummulated amount of infiltration varies with time has been derived out of the cylinder infiltrometer method. This method can be used to predict the rainfall - runoff relationship of a water-shed area.

In surface irrigation, for example, it is desiratble to know the relationship between accummulated infiltration and time to determine how much variation in innudation time can be permitted within a certain agricultural field to maintain irrigation efficiency over a given period of time. Also, it is the relationship between rainfall intensity and the infiltration capacity which determines how much of the falling rain will flow directly over the ground surface into streams and rivers, and how much will enter the soil where it will be retained for some period of time before being either passed downwards as percolation, or returned to the atmosphere by the processes of evaporation and transpiration. The infiltration capacity should be as great as possible, to avoid soil erosion, to build up ground-water supplies, and to alleviate surface drainage problems. Conversely, the infiltration capacity should be as small as possible, so that the greatest possible runoff will occur to fill surface reservoirs. It will also

be of great use in all types of engineering works such as sewage disposal works, etc.

It was found that the best cylinder infiltrometer suitable for the experiment was that of 12 inches diameter and having an overall height of 12 inches which can be buried at least 6 inches into the ground. The cylinder made with 0.042 inch thick -ness gave good results. It is therefore, the opinion of the author that some economical benefits can be obtained in the standardization of infiltration measurement by using a cylinder of this thickness as against the one made of 0.25 inch in thickness

As a result of this experiment it was evident that the cylinder infiltrometer method of measurement is the simplest as it requires simple experimental instruments. It is further evident that the buffered cylinder infiltrometer is better than the non-buffered cylinder infiltrometer.

In comparing the best cylinder infiltrometer with the best inflow and outflow infiltrometer, the author found that the best cylinder infiltrometer was more adaptable and under normal conditions would give better results. Also it was found that for practical reasons the best inflow and outflow infil-trometer with the standard sprinkler device showed better application and adaptability than that with natural rainfall, because of the general experimental control and other factors which must be considered before a reliable result can be obtained. Also, rainfall time and period can not be predicted.

Furthermore, it would appear that for the lateritic soil

of Zaria and Kaduna, the cylinder infiltrometer correction factors may be used as a guide and for good results, the correction factor of 0.44 for initial and 0.99 for final rates would apply for Zaria, and the correction factor of 0.66 for initial and 1.65 for final rates would apply for Kaduna. However, it must be emphasised that these results can only be accepted for the Zaria and Kaduna lateritic soils. The correction factor for other soils such as the fiky soils of Lake Chad or the alluvial plain of Basita must be determined experimentally.

It is suggested that previous results obtained using ring (cylinder) infiltrometers might benefit from the application of a similar correction factor, in view of their apparently high value

On the basis of the results obtained from the theoretical analysis of this study the following conclusions were made:-

Assuming a homogeneous, deep soil with a uniform initial moisture content, the infiltration rate and capacity can be predicted from the result of experiment and by using equations (5) and (7) under this thesis.

For equation (5) three parameters must be determined. They are:-

a constant depending on time (β), time (t), and the slope of the line (α).

Similarly, for equation (7) also, three parameters must be known. These are:-

a constant dependent on the soil and its surface conditions (K_{ft}), time (t), and rainfall intensity.

It may be observed that the two equations give adequate fits to the infiltration data. An indication of the comparative ability of the equations to fit the experimental data is given by the infiltration analysis in table 23 and tables 24 to 27.

Finally, in America, we have had designs of infiltrometers for over 30 years, but there has never been a standard design. The author favours standardization covering minimum requrements and hereby advocates one standard design - the 0.042 inch thick cylinder infiltrometer, with an internal diameter of 12 inches and overall height of 12 iches. In particular, the standard infiltrometer should be consistent with good practice, and should be able to be erected at the lowest possible cost, whcih is desirable and necessary for all projects where initial cost is of primary importance.

Appendix 1.

Table No. 28.

The index of physical condition as the wet-run infiltration

By DR. Guy E. Wilkinson.

Length of gamba fallow and water infiltration(gamba fallow rotations-groundnuts).

Fallow	Crop	Block 1 Ins/hr	Block 2 Ins/hr	Block 3 Ins/hr	Block 4 Ins/hr	TOTAL.
2 yrs.	1	0.24	0.28	0.38	0.12	
	2	0.16	0.20	0.34	0.10	
	3	0.21	0.28	0.31	0.17	
		0.61	0.76	1.03	0.39	2.79
3 yrs.	1	0.25	0.38	0.31	0.24	
	2	0.28	0.59	0.41	0.35	
	3	0.23	0.56	0.46	0.32	
		0.76	1.53	1.18	0.91	4.38
6 yrs	1	0.73	0.29	0.39	0.23	
	2	0.31	0.27	0.30	0.27	
	3	0.16	0.30	0.42	0.22	
		1.20	0.86	1.11	0.72	3.89
		2.57	3.15	3.32	2.02	11.06

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Appendix 111.

Soil Characteristic as it affects Infiltration Measurements.

Those characteristics that directly affect infiltration are soil texture, soil structure, soil structure and soil moisture content. Other factors influencing infiltration are soil swelling and soil colour.

They are as follows:-

(i) Soil Texture

This is the grading of the size particles in a soil. The particles range in size from fine gravel to clay. Generally, the range is between certain limits which have been fixed at diameters and classified as follows:

Clay		<	0.002 mm.
Silt	0.002	-	0.05 ,,
Sand	0.05	-	2.0 ,,
Gravel		>	2.0 ,,

The texture of a soil has a very important influence on the flow of soil water and also determines the depth of soil water it can store in a given depth of soil.

Soil may be separated for textural classification by the following methods:

Sieving - this method is used to separate coarse sand. 0.2 mm sieve is used for this purpose.

Pippette or hydrometer.- for obtaining fine fractions such as silt and clay.

Decantation - for use on fine samples such as fine sand.

The amount of water transfer to plants is greater in moderately fine tecture than in coarse tecture soils, expecially in humid regions.

The textural classification chart is used after the mechanical analysis to obtain the textural grade and the results obtained are shown in table number 1.

Table No. 1

Soil Characteristic as it affects infiltration measurements.

Site No.	Depth (ft)	Clay	Silt	Sand	Soil Texture	Soil Structure	Soil Colour	Moisture content %	Soil Swelling %
1	1	8	4	88	Sand	Blocklike	Pale brown	7.50	46.0
	2	16	6	78	Sandy loam				
	3	20	4	76	Sandy loam		Pale brown/ vague red		
	4	30	6	64	Sandy loam		vague red/ reddish yellow		
	5	28	2	70	Sandy clay loam				
	6	26	16	58	Sandy loam				
2	1	6	5	89	Sand	Blocklike	Pale brown	7.18	42.0
	2	20	5	75	Sandy loam				
	3	18	9	73	Loam sand		Pale brown/ vague red		
	4	17	12	71	Sandy loam		vague red/ reddish yellow		
	5	27	4	69	Sandy clay loam				
	6	26	2	72	Sandy loam				
3	1	5	8	87	Sand	Column/ Blocklike	Pale brown	7.23	44.0
	2	7	3	90	Sand				
	3	12	6	82	Loam sand		Pale brown/ greyish white		
	4	16	3	81	Loam sand		Greyish yellow		
	5	25	10	65	Sandy Clay loam				
	6	23	8	69	Sandy loam				
4	1	10	2	90	Sand	Blocklike	Pale brown	7.40	44.6
	2	17	13	70	Sandy loam				
	3	21	8	71	Sandy loam		Pale brown/ vague red		
	4	24	6	70	Sandy loam		Vague red		
	5	27	4	69	Sandy clay loam				
	6	25	4	71	Sandy clay loam				
5	1	12	10	78	Loam sand	Plate/ Column	Greyish white	7.20	40.0
	2	18	10	70	Sandy loam				
	3	20	5	75	Sandy loam		Greyish white		
	4	22	10	68	Sandy loam				
	5	28	4	68	Sandy clay loam		Grey		
	6	30	6	64	Sandy clay loam				
6	1	9	2	89	Sand	Blocklike	Pale brown	7.22	43.3
	2	16	8	76	Sandy loam				
	3	20	6	74	Sandy loam		Pale brown/ vague red		
	4	28	12	60	Sandy loam				
	5	27	10	63	Sandy loam		Vague red		
	6	28	5	77	Sandy clay loam				

The above results indicated a favourable comparison with those described by Vine.



TEXTURAL CLASSIFICATION CHART. (BYRAM)

(ii) Soil Structure.

Soil structure is the breaking down of soil into structural units, and refers to the degree to which individual soil particles are grouped together to form aggregates. It is built by wetting and drying, freezing and thawing, or by combinations of these conditions. Also penetrating roots build soil structure by removing water from the soil, which causes drying and permits subsequent wetting. The grouping of particles into structural units occurs in all soils. Fine materials have no structures since structure is the way soil is divided into pieces or particles.

Soils in which the particles are uniform in size will have large spaces between the particles, but those in which the size of the grain varies greatly will be more closely packed, and therefore, the volume of pore spaces between the grains will be restricted. Hence the overall structure is a resultant of the arrangement and bonding of individual soil particles into structural units. Soils with good structure will have a high porosity.

Characteristic structural units may be platelike, prisin-like, blocklike, column, spherical, mathy, and berechy.

Finally, aggregation has a great effect on infiltration, and the presence of large aggregates increases the amount of pore space in the soil, which is desirable in agricultural soils.

The results obtained from the laboratory observations for samples collected were listed in Table Number 1, which indicated that the soil structure is mostly blocklike, and of a good structure.

(iii) Soil Colour.

Soil profiles which differ in their mineral constituents will also normally differ in their colour and reflectivity. This difference may be found by field observation.

The colour must select, indentify and generalize the soil in which it is related before one can describe and make comparison between different soil types. Also it will indicate the limits of one type of soil to the other and the area covered. Thus, colour can be employed effectively in soil interpretation.

The results obtained from the field observations on the samples collected were listed in Table Number 1., and these add to the clarity of the soil types under different stages.

(iv) Soil moisture content.

Soil moisture will reduce or limit the infiltration rate. The reduction is due to the fact that moisture causes soil swelling and thereby reduces both the pore space and the rate of water movement.

Soil moisture may be classified as hydroscopic, capillary, or gravitational moisture.

Hydroscopic moisture - water held tightly to the surface of soil particles by cohesive forces.

Capillary moisture - water held by forces of surface tension as continuous films around particles and in the capillary spaces.

Gravitational moisture - water that moves freely in response to gravity and drains out of the soil.

Measurement of soil moisture can be done by direct weighing, neutron scattering, and tensiometers.

The soil moisture contents determined under laboratory tests were listed in Table Number 1.

(v) Soil swelling

Soil materials such as clays swell while absorbing water and shrink upon drying. This is due to the expanding micropores when enlarged by inflow of water caused by a gradient of free energy. They receive water by surface absorbtion or capillarity. The swelling effect on the soil particles will reduce the rate of water movement into the soil; this is because upon swelling under confined conditions, the larger pores are narrowed and gases may also temporarily clog the soil pores.

The soil samples collected for laboratory experiments gave the results shown in Table Number 1.

Appendix IV.

Site Location for the experiments at the Ahmadu Bello University, Zaria.

The site location for the experiments at the Ahmadu Bello University, Zaria., has been discussed under Chapter 3.0 (iii) of this study.

The necessary drawing is shown on the following page - see drawing number 1.

TRUE N

TO ZARIA

I·S·1 I·S·2 I·S·3 I·S·4 I·S·5 I·S·6 I·S·7 I·S·8 I·S·9 I·S·10 I·S·11

E·S·1-6

W4 RL2202
W5 RL2200
W6 RL2181
W8 RL2187
W9 RL2185
W10 RL2185
W14 RL2187
W3 RL2196
RG3 RL2199
RG5 RL2165

SWIMMING POOL
POST OFFICE
POLICE POST
SURGERY
CHAPEL
WOMEN HOSTEL
ESTATE DEPT.
STUDENT HOSTEL
WATER TOWER
FACULTY OF ENGINEERING
ZOOLOGY
PHYSICS
GEOGRAPHY
FINE ARTS
SEWAGE WORKS
CATERING FLATS
STAFF SCHOOL
SWIMMING POOL
VICE CHANCELLORS HOUSE
BOTANICAL GARDEN

Appendix V.

Sit Location for the xeperiments at the Kaduna Polytechni, Kaduna.

The site location for the experiments at the Kaduna Polytechnic, Kaduna., has been discussed under Chapter 3.1. B. of this study.

The necessary drawing is shown on the following page - see drawing number 2.

Appendix VI

Table No. 3

Cylinder Infiltrometer data ZABUC 3(a) - 4(b)

			3(a)				3(b)			
Observed Time	Elapsed Time (Minutes). Since last readg.	Since beg. of test	Micrometer/ hook gauge reading (depth ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/hr	Micrometer/ hook gauge reading depth(Ins.)	INTAKE Ins	Cumm. depth (Ins.)	Depth Ins/hr.
8.00	-	-	5.86	-	-	-	5.86	-	-	-
8.05	5	5	5.71	0.15	0.15	1.80	5.73	0.13	0.13	1.56
8.10	5	10	5.56	.15	.30	1.80	5.60	.13	.26	1.56
8.20	10	20	5.43	.13	.43	0.78	5.44	.16	.42	0.96
8.30	10	30	5.27	.16	.59	.96	5.27	.17	.59	1.02
8.45	15	45	5.13	.14	.73	.56	5.08	.19	.78	0.76
9.00	15	60	4.98	.15	.88	.60	4.88	.20	.98	.80
9.30	30	90	4.73	.25	1.13	.50	4.53	.35	1.32	.70
10.00	30	120	4.37	.26	1.39	.52	4.18	.34	1.66	.68
11.00	60	180	3.92	.45	1.84	.45	3.73	.45	2.11	.45
12.00	60	240	3.51	.41	2.25	.41	3.32	.41	2.52	.41
1.00	60	300	3.15	.36	2.61	.36	2.95	.37	2.89	.37
2.00	60	360	2.79	.36	2.97	.36	2.58	.37	3.26	.37

			4(a)				4(b)			
8.00	-	-	5.86	-	-	-	5.86	-	-	-
8.05	5	5	5.65	0.21	0.21	2.52	5.64	0.22	0.22	2.64
8.10	5	10	5.45	.20	.41	2.40	5.43	.21	.43	2.52
8.20	10	20	5.16	.29	.70	1.74	5.08	.35	.78	2.10
8.30	10	30	4.92	.24	.94	1.44	4.76	.32	1.10	1.92
8.45	15	45	4.60	.30	1.24	1.20	4.51	.25	1.35	1.00
9.00	15	60	4.60	.30	1.54	1.20	4.26	.25	1.60	1.00
9.30	30	90	4.26	.34	1.88	0.68	3.95	.31	1.91	0.62
10.00	30	120	3.93	.32	2.21	.64	3.65	.30	2.21	.60
11.00	60	180	3.57	.36	2.57	.36	3.30	.35	2.56	.35
12.00	60	240	3.26	.31	2.88	.31	3.03	.27	2.03	.27
1.00	60	300	3.02	.24	3.12	.24	2.87	.16	2.99	.16
2.00	60	360	2.78	.24	3.36	.24	2.71	.16	3.15	.16

Table No.4

Cylinder Infiltrometer data ZABUC 5(a) - 6(b)

5(a)

Observed Time	Elapsed Time (Minutes.) Since last reading.	Since beg. of test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumulative depth (Ins.	Depth Ins/hr.
8.00	-	-	5.86	-	-	-
8.05	5	5	5.70	0.16	0.16	1.92
8.10	5	10	5.55	.15	.31	1.80
8.20	10	20	5.27	.28	.59	1.68
8.30	10	30	5.01	.26	.85	1.56
8.45	15	45	4.66	.35	1.20	1.40
9.00	15	60	4.32	.34	1.54	1.36
9.30	30	90	3.99	.33	1.87	0.66
10.00	30	120	3.67	.32	2.19	.64
11.00	60	180	3.28	.39	2.58	.39
12.00	60	240	3.08	.20	2.78	.20
1.00	60	300	2.92	.16	2.94	.16
2.00	60	360	2.76	.16	3.10	.16

5(b)

Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins	Cumulative depth(Ins.)	Depth Ins/hr.
5.86	-	-	-
5.69	0.17	0.17	2.04
5.53	.16	.33	1.92
5.33	.20	.53	1.20
5.14	.19	.72	1.14
4.86	.28	1.00	1.12
4.59	.27	1.27	1.08
4.29	.30	1.57	0.60
3.99	.30	1.87	.60
3.63	.36	2.23	.36
3.29	.34	2.57	.34
3.08	.21	2.78	.21
2.77	.21	2.99	.21

6(a)

8.00	-	-	5.86	-	-	-
8.05	5	5	5.74	0.12	0.12	1.44
8.10	5	10	5.63	.11	.23	1.32
8.20	10	20	5.43	.20	.43	1.20
8.30	10	30	5.25	.18	.61	1.08
8.45	15	45	5.00	.25	.86	1.00
9.00	15	60	4.77	.23	1.09	0.92
9.30	30	90	4.46	.31	1.40	.62
10.00	30	120	4.17	.29	1.69	.58
11.00	60	180	3.77	.40	2.09	.40
12.00	60	240	3.44	.33	2.42	.33
1.00	60	300	3.19	.25	2.67	.25
2.00	60	360	2.94	.25	2.92	.25

6(b)

5.86	-	-	-
5.71	0.15	0.15	1.80
5.58	.13	.28	1.56
5.36	.22	.50	1.32
5.16	.20	.70	1.20
4.87	.29	.99	1.16
4.61	.26	1.25	1.04
4.23	.38	1.63	0.76
3.88	.35	1.98	.70
3.42	.46	2.44	.46
3.09	.33	2.77	.33
2.86	.13	2.90	.13
2.73	.13	3.03	.13

Table No. 5

Cylinder Infiltrometer data. ZABUC 7(a) - 8(b)

			7(a)				7(b)			
Observed Time	Elapsed Time (Minutes). Since last reading	Since beg. of test	Micrometer/hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. Depth (Ins.)	Depth Ins/hr	Micrometer/hook gauge reading (depth)	INTAKE Ins.	Cumm. Depth (Ins.)	Depth Ins/hr
8.00	-	-	5.86	-	-	-	5.86	-	-	-
8.05	5	5	5.68	0.18	0.18	2.16	5.70	0.16	0.16	1.92
8.10	5	10	5.52	.16	.34	1.92	5.53	.17	.33	2.04
8.20	10	20	5.28	.24	.58	1.44	5.31	.22	.55	1.32
8.30	10	30	5.05	.23	.81	1.26	5.11	.20	.75	1.20
8.45	15	45	4.65	.40	1.21	1.60	4.76	.35	1.10	1.40
9.00	15	60	4.28	.37	1.58	1.48	4.45	.31	1.41	1.24
9.30	30	90	3.86	.42	2.00	0.84	4.08	.37	1.78	0.74
10.00	30	120	3.47	.36	2.36	.72	3.73	.35	2.13	.70
11.00	60	180	3.07	.40	2.76	.40	3.34	.39	2.52	.39
12.00	60	240	3.02	.05	2.81	.05	3.06	.28	2.80	.28
1.00	60	300	3.00	.02	2.83	.02	2.89	.17	2.97	.17
2.00	60	360	2.98	.02	2.85	.02	2.72	.17	3.14	.17
			8(a)				8(b)			
8.00	-	-	5.86	-	-	-	5.86	-	-	-
8.05	5	5	5.75	0.11	0.11	1.32	5.76	0.13	0.13	1.56
8.10	5	10	5.65	.10	.21	1.20	5.65	.11	.24	1.32
8.20	10	20	5.48	.17	.38	1.02	5.46	.19	.43	1.14
8.30	10	30	5.33	.15	.53	0.90	5.28	.18	.61	1.08
8.45	15	45	5.11	.22	.75	.88	5.04	.24	.85	0.96
9.00	15	60	4.91	.20	.95	.80	4.82	.22	1.07	.88
9.30	30	90	4.58	.33	1.28	.66	4.47	.35	1.42	.70
10.00	30	120	4.27	.31	1.59	.62	4.16	.31	1.73	.62
11.00	60	180	3.89	.38	1.97	.38	3.76	.40	2.13	.40
12.00	60	240	3.59	.30	2.27	.30	3.41	.35	2.48	.35
1.00	60	300	3.34	.25	2.52	.25	3.13	.28	2.76	.28
2.00	60	360	3.09	.25	2.77	.25	2.85	.28	3.04	.28

Table No.6

Cylinder Infiltrometer data. ZABUC 9(a) - 10(b)

9(a)

Observed Time	Elapsed Time (Minutes.) Since last read.	Since beg. test	Micrometer/ hook gauge reading (depth Ins.)	INTAKE Ins.	Cumm. depth (Ins.)	Depth Ins/hr.
8.00	-	-	5.86	-	-	-
8.05	5	5	5.73	0.13	0.13	1.56
8.10	5	10	5.65	.10	.23	1.20
8.20	10	20	5.46	.19	.40	1.14
8.30	10	30	5.27	.19	.59	1.14
8.45	15	45	5.02	.25	.84	1.00
9.00	15	60	4.78	.24	1.08	0.96
9.30	30	90	4.42	.36	1.44	.72
10.00	30	120	4.09	.33	1.77	.66
11.00	60	180	3.68	.41	2.18	.41
12.00	60	240	3.32	.36	2.54	.36
1.00	60	300	3.04	.28	2.82	.28
2.00	60	360	2.76	.28	3.10	.28

9(b)

Micrometer/ hook gauge depth Ins.	INTAKE Ins.	Cumm. depth	Depth Ins/hr
5.86	-	-	-
5.74	0.12	0.12	1.44
5.62	.12	.24	1.44
5.42	.20	.40	1.20
5.23	.19	.63	1.14
4.96	.27	.90	1.08
4.72	.24	1.14	0.96
4.28	.44	1.58	.98
3.87	.41	1.99	.82
3.51	.36	2.35	.36
3.21	.30	2.65	.30
3.00	.21	2.86	.21
2.79	.21	3.07	.21

10(a)

8.00	-	-	5.86	-	-	-
8.05	5	5	5.69	0.17	0.17	2.04
8.10	5	10	5.53	.16	.33	1.92
8.20	10	20	5.31	.22	.55	1.32
8.30	10	30	5.11	.20	.75	1.20
8.45	15	45	4.87	.24	.99	0.96
9.00	15	60	4.66	.21	1.20	.84
9.30	30	90	4.34	.32	1.52	.64
10.00	30	120	4.03	.31	1.83	.62
11.00	60	180	3.60	.43	2.26	.43
12.00	60	240	3.25	.35	2.61	.35
1.00	60	300	3.01	.24	2.85	.24
2.00	60	360	2.77	.24	3.09	.24

10(b)

5.86	-	-	-
5.71	0.15	0.15	1.80
5.58	.13	.28	1.56
5.36	.22	.50	1.32
5.15	.21	.71	1.26
4.85	.30	1.01	1.20
4.58	.27	1.28	1.08
4.20	.38	1.66	0.76
3.85	.35	2.01	.70
3.49	.36	2.37	.36
3.22	.27	2.64	.27
3.03	.19	2.83	.19
2.84	.19	3.02	.19

Table No. 7

Cylinder Infiltrometer data. ZABUC 11(a) - 11(b)

Observed Time	Elapsed Time (Minutes.) Since last read.	Since beg. of test	11(a) Micrometer/ hook gauge reading (depth Ins.)	11(a) INTAKE Ins.	11(a) Cumm. depth (Ins.)	11(a) Depth Ins/hr.	11(b) Micrometer/ hook gauge reading (depth Ins.)	11(b) INTAKE Ins.	11(b) Cumm. depth (Ins.)	11(b) Depth Ins/hr.
8.00	-	-	5.86	-	-	-	5.86	-	-	-
8.05	5	5	5.73	0.13	0.13	1.56	5.72	0.14	0.14	1.68
8.10	5	10	5.61	.12	.25	1.44	5.59	.12	.26	1.44
8.20	10	20	5.37	.24	.49	1.44	5.36	.23	.49	1.38
8.30	10	30	5.16	.21	.70	1.26	5.14	.22	.71	1.32
8.45	15	45	4.86	.30	1.00	1.20	4.72	.32	1.03	1.28
9.00	15	60	4.58	.28	1.28	1.12	4.43	.29	1.32	1.16
9.30	30	90	4.18	.40	1.68	0.80	4.01	.42	1.74	0.84
10.00	30	120	3.80	.38	2.06	.76	3.63	.38	2.12	.76
11.00	60	180	3.34	.46	2.52	.46	3.23	.40	2.52	.40
12.00	60	240	3.01	.33	2.85	.33	2.97	.26	2.78	.26
1.00	60	300	2.86	.15	3.00	.15	2.84	.13	2.91	.13
2.00	60	360	2.71	.15	3.15	.15	2.71	.13	3.04	.13

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