DESIGN AND CONSTRUCTION OF A RAINFALL SIMULATOR

BY

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DECLARATION

I Samson Iliya Anzeega with the matriculation number 2003/14888EA hereby declare that this project titled design and construction of an artificial rainfall simulator, is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications; published and unpublished works of others were duly referenced in the text.

SAMSON ILIYA ANZEEGA 25/02/2009

Name of student   Date

CERTIFICATION

This project entitled " desing and construction of an artificial rainfall simulator" by Samson Iliya Anzeega meets the regulation governing he award of he degree of bachelor of engineering(B. ENG.) of the Federal University of Technology, Minna, and it is approved for it's contribution to the scientific knowledge and literary presentation.

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DEDICATION

I dedicate this Work to God almighty, the dispenser of all knowledge, wisdom, divine understanding, giver of good health and all good things of life, for seeing me trough this program successfully. To my late father, Mr. Iliya Haruna Anzeega, my mother Mrs. Ladi Iliya Haruna Anzeega and to my brothers and Sisters, for supporting me in their various ways. God bless you all.

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My uttermost thanks goes to almighty God for His love, provision, protection and mercy for my life thus far, who made it possible for me to be alive and to graduate this day. I also thank my ever loving and caring mother, Mrs. Ladi Iliya H. Anzeega and my late father I. H. Anzeega, for going through all they did to see that I become whom I am today.

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ABSTRACT

A simple, portable and low cost rainfall simulator was design and constructed. The rainfall simulator was constructed using locally sourced materials which were readily available. Such as mild steel pipe for the support of simulator, copper tube for simulator head, aluminum plate for simulator head cover and a connector which convey water from the reservoir to the water pump and to the spray head. The rainfall simulator constructed is suitable for field and laboratory use in studying soil erosion process. The rainfall simulator has an oscillating spray head which is vertically downward and oscillates at an angle of $+10^0$ forward and -10^0 backward. It functions with the aid of an electric motor, electrically operated pumping machine and a connector which interfaces the reservoir to the electric and to the spray head. The rainfall simulator is of height 3.22m and a catchments area of (1m × 1.5m). The rainfall simulator was satisfactory, since it achieve its objective. It was design and constructed at the cost of #45,930. When compared to the cost of importing the rainfall simulator from abroad. The rainfall simulator was used to simulate the rainfall events of a local area, thus simulated rainfall intensity of 116mm/h, kinetic energy of $3.99Jm^{-2}/h$, erosivity index of 462.84 Jm^2 and soil loss of 0.4253 kg/m^2s. The constructed rainfall simulator can be easily assemble and disassemble which makes it easy to use in soil erosion research.

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CHAPTER ONE

1.0 INTRODUCTION

Rainfall simulator demonstrates the benefit of crop residue management in protecting the topsoil during rainstorm and simulate natural rainfall accurately and precisely Nord, (1991). Accelerate soil erosion is a serious global problem with significant financial and environmental consequences. Soil erosion effect Occur both On site and off site, the effects are particularly important on agricultural land resulting in reduction of cultivable soil depth and fertility decline.

One of the biggest problems in soil erosion research is the need to rely on natural rain fall to observe soil erosion. It is virtually impossible to predict where and when rainfall events are going to take place. The meteorological station only broadcast probabilities rather than certainties of the occurrence of rainfall on any given day at given location. Even if accurate time and location forecasts could be given, this information would not predict whether these events are sufficient in intensity and duration for soil erosion by rainfall as well as generated run-off to occur.

Erosion results into sedimentation on river beds and drainage networks. This reduces their capillarity, increase flooding risk, blocks irrigation canals and shortens the design life of water reservoirs.

Several hydroelectric and irrigation projects have been destroyed as a consequence of erosion. Sediment is also a primary source of pollution and increase the level of nitrogen and phosphorus in water bodies and results in eutrofication (Bryan and Luke, 1981). Before undertaking rainfall simulation studies, common question arise regarding the design, costs, and performance of rainfall simulators as well as the practical problems and scientific advantages associated with them. There is no standard procedure for the evaluation of simulator performance in representing real life, natural rainfall events. Like wise, there are no guide lines as to how accurate the simulation should be in order to produce meaningful and worth while data.

In natural rainfall, no two rainfall events are identical in terms of variation during the storm of intensity, drop size, distribution and kinetic energy, even if when average over the storm as a whole these characteristics are identical.

According to Rickson (1980), comparison of soil losses under different treatments become very difficult as the experimental conditions (bath before, during and later the storm) are never the same. Since rainfall is the major factor initiating soil erosion by water, the lack of rainfall reliability is a major hindrance to sound scientific study of erosion rates and processes.

These problems have generated the need for controllable, reliable and predictable simulated rainfall. Simulated rainfall is controllable in time and space and allows the repetition of many thousands of years of rainfall in very short time period.

1.1 STATEMENT OF THE PROBLEM

Soil erosion continues to be the principal threat to the long term sustainability of agricultural and grazing lands resulting in reduction of cultivable soil depth and fertility decline and the need to rely on natural rainfall to observe soil erosion studies.

Several hydroelectric and irrigation project have been destroyed as a consequence of soil erosion and sediment deposit is the source of water pollution and increase the level of nitrogen and phosphorus in water bodies and results in eutrofication. Bryan and Luk (1981).

1.2 OBJECTIVES

1. The design of rainfall simulator using local materials that will be effective at low cost of production, easy to operate and maintain.

2. To evaluate the efficiency of the rainfall simulator using the natural rainfall data.

1.3 LIMITATIONS OF THE STUDY

The design and fabrication of a rainfall simulator that can be use to simulate natural rainfall accurately and precisely.

1.4 JUSTIFICATION

One of the biggest problems in soil erosion research is the need to rely on the natural rainfall to observe soil erosion. It is virtually impossible to predict where and when rainfall events are going to take place.

The design and fabrication of rainfall simulator for the Department of Agricultural and Bio-resources Engineering F.U.T Minna, would enhance fish and wild life habitat, reduce flooding to communities and croplands and therefore improve economic and recreational opportunities by carrying out appropriate conservation practices that are environmentally friendly.

CHAPTER TWO

LITERATURE REVIEW

2.0 SOIL

This is natural occurring unconsolidated or loose covering of the broken rock particles and decaying organic matter on the surface of the earth capable of supporting life. Soil particles pack loosely, forming a soil structure filled with pore spaces. These pores contain soil solution liquid and air. Nyle and Ray (1999)

2.1 SOIL TYPES

2.11 SANDY SOIL

This type of soil has the biggest particles and the size of the particles does not determine the degree of aeration and drainage that the soil allows. It is granular and consists of rock and mineral particles that are very small. Therefore, the texture is gritty and sandy soil formed by the disintegration and weathering of rock such as limestone, granite, quartz and shale. In a way sandy soil is good for plants since it lets the water go off so that it does not remain near the roots to lead than to decay.

2.12 SILTY SOIL

Silty soil is considered to be one of the most fertile of soils. It can occur in nature as soil or as suspended sediments in water column of a water body on the surface of the earth. It is composed of minerals like quartz and fine organic particles. It is granular like sandy soil but it more nutritious than sandy soil and it also offers better drainage. In case silty soil is dry it has a smoother texture and looks like dark sand. This type of soil can hold more moisture and at time becomes compact.

2.13 CLAY SOIL

Clay soil is a kind of material that occurs naturally and consists of very fine grained material with very less air spaces, that is the reason it is difficult to work with since the drainage in this soil is low, most of the time there is a chance of water logging and harm to the roots of the plants.

2.14 LOAMY SOIL

This soil consists of sand, silt and clay to some extent. It is considered to be the perfect soil. The texture is gritty and retains water very easily, yet the drainage is well. There are various kinds of loamy soil ranging from fertile to very muddy and thick sod. Yet out of all the different kinds of soil, loamy soil is ideal for cultivation.

2.15 PEATY SOIL

This kind of soil is basically formed by the accumulation of dead and decayed organic matter; it naturally contains much more organic matter than most of the soil. It is generally found in marshy areas. Now the decomposition of the organic matter in peaty soil is blocked by logging, but if the soil fertilized well and the drainage of the soil is looked after, it can be ideal for growing plants.

2.16 CHALKY SOIL

Unlike peaty soil, chalky soil is very alkaline in nature and consists of a large number of stones. This kind of soil is prone to dryness and in summer, it is a poor choice for plantation, as the plants would need much watering and fertilizing than on any other type of soil. Nyle and Ray (1999).

2.2 FUNCTION OF SOIL FOR AGRICULTURAL PURPOSES.

Soil resources are critical to the environment, as well as to food and fiber production. Soil provides minerals and water to plants. Soil absorbs rainwater and relcases it later thus preventing floods and drought.

Soil is a medium for plant growth which supplies the plant with physical support, air, water, temperature moderation, protection from toxins and nutrient elements. William et al. (1991).

2.3 SOIL PHYSICAL PROPERTIES

2.3.1 SOIL COLOUR

This is the colour of soil which have little effect on the behavior and the use of soil. An important exception to this statement is the fact that dark colour surface soils absorb more solar energy than lighter colour soil, and therefore may warm up faster. William et al (1991).

2.3.2 SOIL TEXTURE

Soil texture refers to the fineness or coarseness of the mineral particles of the soil and it is commonly define as the relative preposition of sand, silt, and clay. It is perhaps the most fundamental and most permanent soil property affected very little by normal soil management practice. It exerts considerable influence on the capacity of the soil to hold water and to circulate air. Soil texture also critically influences the response of crops to fertilization. William et al (1991)

2.3.3 SOIL STRUCTURE

In most soils, the soil separates do not exist independently as single grains, instead, they are bound together in clusters called aggregates. The smallest aggregate is termed "ped".

The soil separates and the peds may further coalesce to form bigger aggregates of definite shapes which constitute "soil structure".

2.3.4 SOIL DENSITY

Soil particle density, Dp is defined as the mass per unit volume of the soil solid. Particle density is not affected by the pore space, and therefore is not related to particle size or to the arrangement of particles.

2.4 SOIL EROSION

Soil erosion is the carrying away or displacement of solids (sediments, soil, rock and other particles) usually by the agents of erosion such as wind, water or ice by downward or down slope movement in response to gravity or by living organisms (in the case of bio-erosion). Paul et al. (1990).

Soil erosion is a noticeable intrinsic natural process but in many places, it is increased by human land use. Poor land use practice include deforestation, over grazing, unmanaged construction activities and road or buildings. Land that is used for the production of agricultural crops generally experience significant greater rate of erosion than that of land under natural vegetation. However, improved land use practices can limit erosion, using techniques such as terrace- building, conservation tillage practices and tree planting.

2.4.1 FACTORS AFFECTING SOIL EROSION

The rate of erosion depends on many factors.

Climatic factors include the amount and intensity of precipitation, the average temperature as well as the typical temperature range, and seasonality, the wind speed, storm frequency. The geological factors include the sediment or rock types, its porosity and permeability, the slope (gradient) of the land, and if the rocks are tilled, faulted, folded, or weathered. The biological factors include ground cover from vegetation or lack thereof, the type of organism inhabiting the area and the land use Dandekar and Sharma (2005)

In general, given vegetation and ecosystem, you expect area with high intensity precipitation, more frequent rainfall, more wind, or more storms to have more erosion. Sediment with high sand or silt content and area with steep slopes erode more easily, as do area with highly fractured or weathered rock. Porosity and permeability of the sediment or rock affects the speed with which the water can percolates into the ground. If the water move underground, less run- off is generated, reducing the amount of surface erosion. Sediment containing more clay tends to erode less than those with sand or silt. Here, however, the impact of atmospheric sodium on erodibility of clay should be considered. (Dandekar and Sharma, 2005)

2.5 WATER EROSION

They are several types of erosion caused by water such as splash erosion, sheet erosion, rill erosion, gully erosion and valley or stream erosion.

2.5.1 SPLASH EROSION

This is the detachment and air borne movement of small soil particles caused by the impact of rain drops on soil.(Baltimore, 2007)

2.5.2 SHEET EROSION

This is the detachment of soil particles by raindrop impact and their removal down slope by water flowing over land as sheet instead of in definite channels or rills. This impact of rain drop breaks apart the soil aggregate. Particle of clay, silt, sand filled the soil pores and reduce infiltration. After the surface pores are filled with sand, silt, or clay, over land surface flow of water begins due to the lowering of infiltration rates. One, the rate of falling rain is faster than infiltration, run-off takes place.

2.5.3 RILL EROSION

This refers to the development of small, ephemeral concentrated flow paths, which function as both sediment source and sediment delivery system for erosion on hill slopes. Generally where water erosion rates on disturbed up land areas are greatest, rill are active. Where precipitation exceed soil infiltration rate, run-off occur. Surface run-off turbulence can often cause more erosion than the initial rain drop impact.

2.5.4 GULLY EROSION

This results in an action where water flows along a linear depression eroding a trench or gully. This is particularly noticeable in the formation of hollow ways, where prior to be tarmac ked; an old rural road has over many years become significant lower than the surrounding field.

2.5.5 VALLEY OR STREAM EROSION

This occurs with continued water flow along a linear feature. The erosion is both downward deepening the valley, and head ward, extending the valley into the hillside (Baltimore, 2007)

2.6 RUN-OFF

Run-off is the major agent of soil transportation. The power of moving water in carrying materials needs no emphasis. However, splashing by rain drops greatly aid and enhance soil transportation by run-off, the two together accounting for the total soil wash that finally occurs. By splashing soil, the transportation of soil actually initiated by raindrops before run-off takes over. Furthermore, the particles detached by raindrops fill the gaps between the larger particles, sealing the openings of the pore channels, thereby reducing the infiltration of water into the soil and increasing the volume of run-off. The transported soil materials are deposited at the bottom of the slope where the land is level or near and erosion absent (e.g. Fadama) or they end up in rivers and other surface water bodies.

2.7 SOIL EROSION CONTROL MEASURES

Tile drainage systems can also be an effective means of reducing surface run-off. By maintaining the water table at a constant desired level, the soil surface will remain in a drier condition to more effectively accept water without eroding.

Tile drainage system complements surface water control measures such as grassed water ways, water and sediment control basins, terracing and water effective means of maintaining bank stability, decreasing sedimentation, and improving water quality.

In summary, wind and water erosion control practices are based on maintaining a good soil structure, protecting the soil surface and making use of erosion control structures adherence to these practice will do much to enable farmers to continue to maximize crop yields, minimize soil erosion, and enhance the quality of surface water.

2.8 UNIVERSAL SOIL LOSS EQUATION

The universal soil loss equation (USLE) predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system, and management practices. USLE only pre3dicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind, or tillage erosion. (Michael and Ojha 1999)

This erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites. The USLE can be used to compare soil losses from a particular field with a specific crop and management system to "tolerate soil loss" rates. Alternative management and crop systems may also be evaluated to determine the adequacy of conservation measures in farm planning.

Five major factors are used to calculate the soil loss for a given site. Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. Michael and Ojha,(1999)

The Universal soil loss equation presented below (USLE)

$$A=R\ K\ LS\ C\ P \quad \text{...2.1}$$

Where,

A=represents the potential long term average annual soil loss in tons per acre per year. This is the amount which is compared to the tolerable "soil loss" limits.

R= is the rainfall and run-off factor by geographic location

K= is the soil erodibility factor. It is the average soil loss in tons/acre per unit area for a particular soil in cultivated.

SL= Factor represents a ratio of soil loss under given conditions to that at a site with a "standard" slope steepness.

C=is the crop/vegetation and management systems in terms of preventing soil loss.

P= is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water run-off and thus reduce the amount of erosion.

2.8 RAINFALL SIMULATOR

Rainfall simulator applies artificial rainfall to desired areas to study erosion, infiltration, run-off and water quality. Using a rain fall simulator or modified irrigation system specifically designed to reproduce the characteristics of a storm. The advantages of using a rainfall simulation include cost effectiveness, control, portability and educational opportunities. Rainfall simulators allow controlled rain storms to be applied where and when they are desired.

2.8.1 TYPES OF RAINFALL SIMULATORS

The selection of a certain type of rainfall simulator will be determined by many factors. The choice of rainfall simulators will depend on the type of study field or laboratory based - This will influence whether a simulator with a tall fall height will be practical for example:

- Long or short term experiments- this will determine the need for robustness of the simulator;
- Aimed at precise simulation of rainfall characteristics or simply aimed at producing repeatable rainfall characteristics;

Other consideration will be:

- Cost;
- Length of time to order and obtain parts;
- Assembly and disassembly time;
- Availability of parts;
- Ease of maintenance and repairs.

- **2.8.1.1 PRESSURIZED RAINFALL SIMULATORS**

The first rainfall simulators used in erosion studies uses pressurized water flowing through single or multiple nozzles. These early versions were based on irrigation equipment and infiltrometers. The principle behind the use of pressurized water is that drops sprayed out of the nozzle under pressure have an initial velocity imparted to them which should be sufficient for the drops to reach their terminal velocity at considerable less fall height than for drops falling from the skies. This reduction in necessary fall height is a notable advantage for these simulators over those which rely on gravity and freefall of drops to attain terminal velocity (Non-pressurized rainfall simulators). The nozzles are crucial in the character of the drops being simulated, and hence the entire storm. Elwell and Makwanga (1980).

When an initial velocity is imparted to the drops, their fall velocity may exceed their terminal velocity. The following freefall through the air after discharge from the nozzle may effectively reduce fall velocity due to air resistance and drag. Ideally, the velocity should be such that terminal velocity is achieved before the drop makes impact with the target area. It is unlikely that drops falling the low fall height used in pressurized simulators will gain any fall velocity due to gravity over such short fall distances. If initial velocities are so high (due to high water pressure) even air resistance may not decelerate the drops before they reach the target. Hence the drops will fall at a higher velocity than would occur naturally, and hence would be more. A pump is usually used to pressurize the water supply, although, gravity fed systems can work also. The height differential the water source and the plot were sufficient to maintain approximately 69 - 103.5Kpa at the simulator nozzle by the use of small diameter pipes. Bowyer-Bower and Burt (1989).

The pressure of the supplied water will determine the rainfall characteristics simulated. Most pressurized rainfall simulator use a range of pressure between 34.5 - 140 Kpa. Generally, the higher pressure give good drop size distribution (the drop are too large for the intensities simulated) and uniformity of rainfall distribution is also often poor at low pressures. Water pressure also affects the area covered by the rainfall: low pressure reduces the application area, high pressure increases it, but at a lower application rate per unit area. A pressure gauge is used to monitor the pressure throughout an experimental run. They are extremely sensitive pieces of equipment, and their reliability in the field is often affected by their sensitivity to frost and poor handling.

The major disadvantage of early versions of pressurized simulators was the problem that for a realistic drop size distribution (and hence storm kinetic energy), high pressures were used, which gave excessive intensities, without compromising drop size characteristics, measures to interrupt or intercept rainfall so as to reduce application rate on the ground were introduced.

The simplest measure is to orient the nozzle to point upwards, to produce an arc of water Bowyer - Bower and Burt (1989) the drops reach zero velocity at the top of the arc before they begin to fall to the ground. It is then hoped that the fall distance is sufficient for the drops to attain their terminal velocity. This is rarely the case, however, and the advantage of pressurized drops requiring less fall height than non-pressurized drops becomes redundant. Another problem with this approach is the variation in drop size along the length of the arc, as evidenced in a poorly set up rain gun irrigator, where a fine mist is produced in some areas, and heavy large drops in others.

TABLE 2.1 TYPES OF NOZZLES USED IN PRESSURIZED RAINFALL SIMULATORS

Type of Nozzle	Nozzle Orientation	Fall height (m)	Pressure used	Energy supplied
Vee jet 80100	Oscillating	3	41N/m^2	200Kj/ha mm
Veejet 80150	Oscillating	3	41N/m^2	275Kj/ha mm
Veejet 8070	Oscillating	3	41 N/m^2	200 Kj/ha mm
1.5 HH 30	Beneath rotating disc	2.5	50 KPa	27.42 j/m^2
Delavan 33974	Fixed	1.0	0.70 Kg/cm^2	0.98 j/m^2

Source: Rickson, R.J. ;Experimental techniques for erosion studies.

2.8.3 NON-PRESSURIZED RAINFALL SIMULATORS

These rainfall simulators allow simulated raindrops to fall under gravity, ideally in order to approach or even reach their terminal velocities. The major problem with these simulators is the height required for the drops to reach their terminal velocity. The relationships between fall height and fall velocity are investigated in Epema and Riezebos (1983). For example, a 5mm diameter raindrop requires 12 meters of fall height to attain its terminal velocity. This is impractical for field applications, due to the distortions of rainfall application due to even the slightest of breezes (not to mention the stability of a 12 meter high tower on sloping terrain). Thus most non- pressurized rainfall simulators will be found in laboratories although some workers have used them irrespective of whether the drops attaining their terminal velocity.

The principle of these simulators is that water is conveyed to drop formers of small internal diameter, below a header tank of water of constant head. One problem with the constant head is that the intensity of application must increase as the spacing of the drop formers decreases. However, this will be overcome by using a weir device that can change the constant head for different intensity requirements. As soon as the required head of water is achieved, any excess water will be drained away, preferably back to the supply tank for recycling. An increase in the head of water increases the rate of drop formation and hence intensity. Intensity can also be changed by blocking off some of the drop formers, but this can upset uniformity and the question arises as to which droppers should be blocked of, and how many, to achieved the desired intensity.

The head of water above the drop formers will also affect the drop mass. Smaller drops become large as the time taken in formation increases. For large drop, the opposite is true.

Hudson argues that the rate of drop formation should be sufficiently slow; otherwise variations in the size of drops are highly likely. The drops will form when their weight overcomes surface tension forces, due to the effect of gravity. Some very small drops may not overcome these surface tension forces, and will only detach from the drop former if a downward flow of air is provided Gunn and Kinzer (1979). Rates of drop formation may be affected by atmospheric temperature changes as air may enter the drop formers, so reducing the rate at which drop are formed Bowyer -Bower and Burt (1989).

Usually the drops formers are all the same size, so producing a very unrealistic drop size distribution. However, the precision of these drops formed is this way is useful when calibrating methods of determination of raindrop size. As natural rainfall comprises

drops of many different sizes, on-pressurized drops are broken up into a range of drop size, by installing a mesh screen just beneath the drop formers. This has three key purposes. First, it will break the drops into a random, but hopefully, temporally repeatable drop size distributions, as for natural rain fall. Second, the mesh can be used to determine maximum drop size. Thus if the largest drop size of rainfall is 15mm, the aperture of the mesh should be set at 3mm. Finally, if the large diameter drop formers are used, the mesh will break the large drops formed into smaller, more realistic drop sizes. These meshes should be made of galvanized metal or plastic. They should consist of fine wires to avoid storage of drops by surface tension. If a mesh is used, the height at which it is placed must be sufficient for the interrupted drops to reach their terminal velocity. The mesh effectively reduces fall velocities to zero, so full terminal velocity has to be attained below the mesh. However, it must also be remembered that by reducing the effective size of the drops. so their terminal velocities are less, so requiring less fall height for these velocities to be attained. Thus, if a mesh of 5mm is used, this must be placed no less than 12m above the target area for drops of this size to reach their terminal velocity. Larger drops will require even greater fall heights.

The characteristics of the rain fall simulated with non-pressurized apparatus is determined by the type of drop former used, whether a mesh screen is used to intercept drops shortly after they are formed and fall, and the head of water above the drop former. (Gunn and Kinzer, 1989).

2.8.3.1 DROP FORMER USED IN NON-PRESSURIZED RAINFALL SIMULATOR

Hanging yarns have been used as drop formers. The thickness of the yarns determines the size of drops produced. These simulators are also called "thread droppers" with drop formers primary made of cotton or wool fibers. The major drawbacks of these simulators are that the minimum size of drops produced is 4mm in diameter. This is far too large for most natural rainfall, unless a mesh is used to break the drop into smaller, more realistic sizes. (Bowyer - Bower and Burt 1989).

Hypodermic needles are commonly used in non-pressurized rainfall simulators despite their practical dangers! These are not good at producing smaller drops than the two techniques above, although surface tension is a problem for these smaller drop sizes. This can be overcome by blowing a constant air stream over the drops to detach them from the needle, but this can be very complex to set up for most research purposes. Gunn and Kinzer (1989) reported on the use of this technique. They showed that by using a co-axial air stream directed vertically downwards over a single sized hypodermic needle and varying the rate of water flow, they could produce drops in the astonishing range of 0.25-10,000mg. The smallest drops are barely visible to the naked eye.(Gunn and Kinzer, 1989).

2.8.4 COMPARISON OF PRESSURIZED AND NON-PRESSURIZED RAINFALL SIMULATORS

Bowyer-Bower and Burt (1989) make a comprehensive comparison between a spray type (nozzle rainfall simulator) and one that is of drip type design. This includes the logistical difficulties involved in carrying out replication using both simulators. One major practical consideration is the use of water. Spray type simulator often have a higher water consumption as the area receiving rainfall is often beyond the test application area - drop type simulators are more precise in targeting these plots

2.8.5 ADVANTAGES AND DISADVANTAGES OF RAINFALL SIMILATOR.

2.8.5.1 Advantages of Simulated Rainfall

Simulated rainfall, speed up soil erosion research. A standard test can be replicated over and over within a much shorter time scale than would be observed under natural rainfall. Researchers would have to wait years, for the same event to occur, even if such repetition was likely, which is not.

Under natural rainfall, it is extremely difficult to ensure constant starting conditions for different treatments. Bowyer-Bower and Burf (1989) highlight the expense and maintenance required to monitor sites under natural conditions. Simulated rainfall however can be used to wet-up plots to the same degree prior to testing.

Rainfall simulation has lead to newer approaches to soil erosion research as well as improvement to existing techniques.

2.8.5.2 Disadvantages of Simulated Rainfall

The major drawback with rainfall simulators is the scale at which they operated. Rainfall simulators will never completely replicate natural rainfall characteristics. This is partly due to the unpredictable and variable nature of natural rain. It is difficult to quantify natural rain accurately, let alone build a rainfall simulator to replicate it.

Finally, rainfall simulator can be quit demanding on resources; the more sophisticated the rainfall, the more expensive.

2.8.6. RAINFALL SIMULATORS AND WIND TUNNELS

In order to replicate reality as closely as possible, a number of researchers have built a rainfall simulator/wind tunnel combination. This facility will answer the criticism that laboratory based simulators do not account for wind effects, and yet field simulators are often unusable in windy conditions, because of the difficulties in quantifying the effects of wind on the erosivity of the simulated rainfall. The ultimate simulator for erosion studies has been described and used by Nord (1991). This comprises a rainfall simulator, a run-off generator, sunlight simulator/ wind generator and high velocity flume. Even with all these variables, it is unlikely that such equipment is any more realistic of natural conditions than a very simple rainfall simulator, as the compromises to get a realistic interaction between all these components must be enormous.

2.8.7 COMMON COMPONENTS OF RAINFALL SIMULATOR

2.8.7.1 FRAME

Many different materials have been used to support the rainfall simulator head, whether it is a nozzle or drip type. The ideal frame would be made of cheap, robust and light weight material. Dexion is quickly assembled, but is prone to warping, especially is above wind speeds. Angle iron is sturdier but heavier and less suited to field work. Speed train is quickly assembled, but costly, and the joints are relatively weak, and can snap off if not handled with care. Aluminum is light weight, but expensive. A compromise would be to use aluminum ladders as the frame. Here the ladders will support the simulator head, and provide access to climb up to the nozzle to check operating pressure at the head. Nozzle-blockages and so on. These ladders are expensive and should not apart from this scientific one.

Most frames are four sided although tripods have been used. The problem here is the interference with the spray at the top of the simulator. All frames should have telescopic legs if possible so that the simulator will be steady and the nozzle or drop formers vertical. The problem is that on steep slopes, however, upslope drops have less fall distance than the down slope drops, providing the shortest fall height is sufficient for the drops to reach their terminal velocity, then this different will be treated as unimportant.

2.8.7.2 WIND SHIELD

Field experiments with rain simulators are at the mercy of the wind. Ideally, most simulators should work in above average wind conditions, but this only possible if a wind shield is used. Even on apparently calm days, wind shields are essential for field use of rainfall simulators. The best time of the day to avoid wind is very early in the morning. Even laboratory simulator is subject to air currents which may distort the repeatability of distribution between experimental runs. Plastic sheeting can be used in low velocity winds, but because it is not permeable to air currents, it can act as a huge sail, making the whole simulator rig susceptible to blowing over or even taking off! Following the principles of shelter belts for wind erosion control, the wind shield should be slightly porous to allow air flow to be retarded but not resisted altogether. Fabrics such as taffeta and synthetic alternatives or vegetable bags meet these requirements. They also have the advantage of being partially absorbents, so that any stray spray reaching the wind shield is absorbed and drained through the fabric, rather being splashed back, as would occur with plastic. Fabric is also more drape-able, and conforms to the frame used, unlike the more rigid plastic sheeting (Hudson, 1981)

2.8.7.3 WATER SUPPLY

Water supply for rainfall simulation is the biggest practical problem, especially in remote field sites. Not only quantity is a problem, but quality as well. If the water source is a natural source; stream or lake, e.t.c. It is necessary to attach a filter on the end of the input pipe to avoid contamination and blockages. A fine wire mesh is usually sufficient, but this will not filter out any fine particulate material.

Using natural streams and rivers as source of water can be unreliable, and being in valley bottoms, these sources are often found from hill side erosion plots. Large containers such as oil drums can be used, but their portability when full makes this often difficult in the field.

2.8.7.4. PUMPS

A gravity fed system is used; pressurized rainfall simulators require a pump to supply water under pressure to the simulator head. In the laboratory, electrical pumps can be used, but field applications need an independent power source. Petrol or diesel pumps are often used. Often the problem is over-capacity, as many pumps have been used for other water supply experiments, such as irrigation tests. These require much higher pressures than used for rain fall simulation, and this means the pumps used are too large for application rates required. One solution is to use a "bleeder pipe" which recycles a large proportion of the pumped water back to the water reservoir. This helps to keep the water supply to the head itself at a more realistic rate. Bryan (1991). Using an electric pump may have problems in the reliability of electricity, as well as health and safety regulations when electricity is used in close proximity to water. In the field, a generator is often required to run electric pumps, and it is the author's view that the increase in equipment means an increase in the thing that can be unreliable. Petrol and diesel pumps do not require a generator, but may require a lot of fuel for continuous and lengthy experimental work. Whilst fuel supply may be a problem in some remote areas, the fuel has to be carried out in the field, which is bulky and potentially hazardous.(Burt 1984).

2.8.7.5 PIPE WORK

Most rainfall simulators use a variety of pipes from the input supply pipe to that used to supply water to the simulator head. Flexible pipes can be more portable and maneuverable, although coiling may lead to friction losses. Rigid pipes would be too cumbersome to use in the field. Different diameter pipes can be joined by adapters, and quick, snap action coupling joints are useful for simulator that have to be assembled and disassembled rapidly. The actual diameter of the pipe work used will depend on the size of the pump and simulator head used. Even minor changes in the experimental set up such as minor water leaks and coiling of the hoses can affect the temporal performance of a simulator. (Bowyer-Bower and Burt, 1989)

2.8.7.6 MOTOR

Rotating disc and oscillating nozzle rain simulators require an independent motor for motion. This is yet another piece of apparatus and should be treated with caution, as to it reliability. These motors are commonly run on electricity supplied from the mains in the laboratory, or from a generator or 12 volt car battery in the field. As mentioned above, electricity supply may be unreliable, a generator is costly and cumbersome to transport to the field, and a car-battery requires charging at constant intervals (depending on the number of experimental runs carried out). These potential difficulties can be overcome by using the pressure of the discharging water to rotate the nozzle which makes the need for an independent power supply redundant. (Burt 1984)

2.8.8 RAINFALL CHARACTERISTICS TO BE SIMULATED

Rainfall simulators should be capable of simulating the characteristics of natural rainfall. These include

2.8.8.1 Intensity

Rain fall simulators should be able to simulate a number of design storm especially medium to high intensity events, as these are likely to be associated with measurable amount of soil loss.

2.8.8.2 Drop sizes

Simulator storms should represent the drop size of natural rain at the given intensity as this affects the kinetic energy of individual drops and that of the storm as a whole: accurate representation of drop size is also important while simulating specific erosion process such as detachment (Mason and Andrews, 1960)

2.8.8.3 Drop velocity

Simulated drops should fall at their terminal velocity id they are to have the same level of energy as drops of the same size. Terminal velocity can be defined as the velocity at which objects fall without having further acceleration due to gravity. (Dingle and Lee 1972)

2.8.8.4 Kinetic energy of rainfall

If rainfall simulate rainfall intensity drop size and drop velocities accurately, it can be assumed that they will represent natural kinetic energy of rainfall successfully.

2.8.8.5 Angle of application

Under natural conditions, raindrops tend to fall vertically, so rain simulators should be able to reproduce vertical fall of drops. If raindrops fall at an angle to the ground surface there will be more erosive in one direction i.e. more soil will be splashed in the opposite direction to the incidence of rainfall. This incidence will over-estimate the amount of splash detachment and transport in that direction. Although underestimating in the opposite direction. (Moeyerson ,1983)

2.8.8.6 Water quality

Rain water would be the most realistic water source to use as chemical reaction to other source may be different than those experienced under natural rainfall. Tap water often contains chloride fluoride as well as calcium deposits all of which may effect the erosion of the simulated rain. Distilled water may be used as it is assumed to have very little chemical reaction with the soil or erosion control treatment. (Bryan et al., 1984)

2.8.8.7. Water temperature

It has been found that temperature has a minor influence on soil erodibility due to the sensitivity of the chemical and biological reactions in the soil to temperate. (Kamanu 1991). Temperature also affects the viscosity of water and surface tension forces which will both affect the drop formation mechanism in simulated rainfall. (Moeyersons, 1983)

2.8.8.8. Drop cross-section on impact

As natural raindrop fall, their spherical shape becomes distorted due to their air resistance and drag. This deformation affects the erosivity of the drops on contact with the ground surfaces. (Riezebos 1983).

2.8.8.9. Continuous application

Bryan (1991) states that interruption of rainfall application may have significant effects on the accuracy of simulation of surface wash process. This is due to the temporal fluctuations in film of water not produced. Intermittent application results rate of soil detachment and infiltration as reported by Akanro (1983) it is virtually impossible to simulate all these desirable characteristics accurately. Often, an improvement occurs in the representation of one characteristic heads to a proper simulation in another. Therefore emphasis the importance of repeatable results. More advantages can be achieved by standardize use of cheap, portable and readily available simulators, even if they are imperfect than an elusive quest for perfect rain fall production.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Component Parts of the Rainfall Simulator

3.1.1 Frame

The rainfall simulator frame is made of a plate metal used to support the simulator head. It is a four sided frame made of 25mm square pipe which can easily be assembled and dissembled.

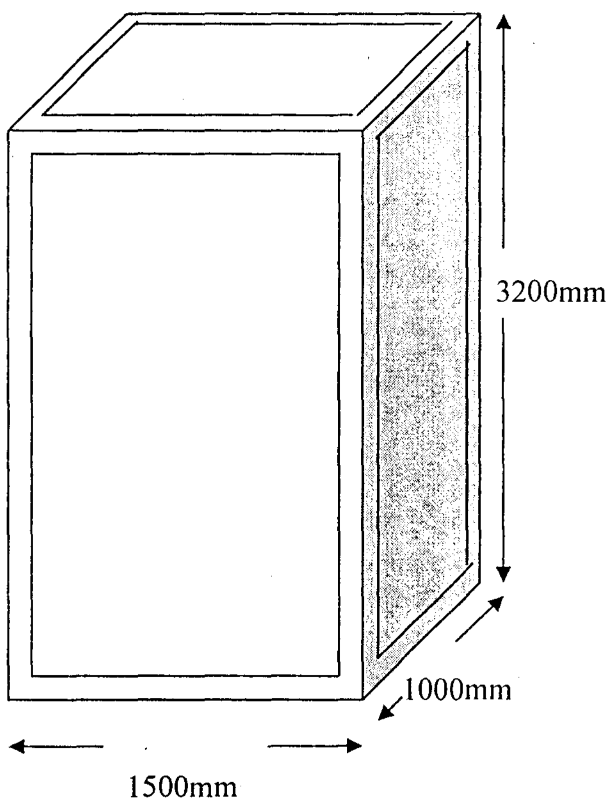


Figure 3.1 Simulator frame

3.1.2 Wind Shield

The wind shield serves as a protective covering for the simulator from external wind current. This enables system isolation which makes it possible for reproducing similar rain patterns. The wind shield is made of transparent polythene leather.

3.1.3 Water Supply tank

Water supply for the simulator is a storage tank which feeds directly to the pump, the tank is made of galvanized metal sheet.

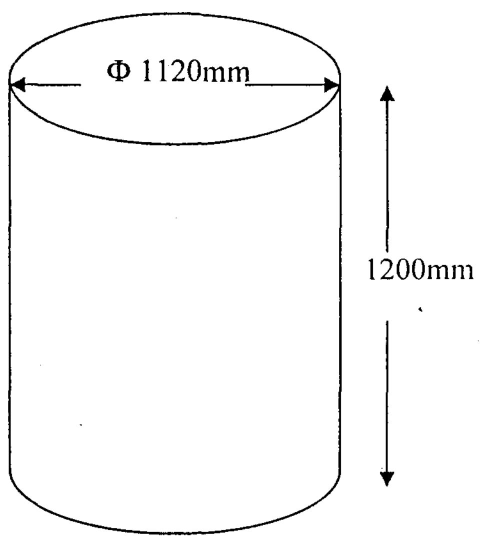


Figure 3.2 Storage tank

3.1.4 Pump

The simulator pump is an electrically powered water pump driven by 220 volts the pump rating is 370 watts and max volume flow rate of 40 litres/min

3.1.5 Oscillating Mechanism

The oscillating mechanism is driven by a geared electric motor with power rating of 30watts and 220 volts A.C. the oscillation is achieved by the conversion of the rotary motion of the electric motor to a to and fro motion on a pivoted lever.

3.1.6 Pipe Channel

The pipe channels are tubes which convey water to the simulator spray head. The pipe channel is PVC pipe and flexible hose tubing all of 30mm diameter.

3.2 Design Analysis

3.2.1 Spray design

The pump used for the simulator is of power rating of 350watts and has a volumetric flow rate of 40lit/min ($0.04m^3$/min $0.00066667m^3$/sec) mass flow rate is gotten by multiplying the volumetric flow rate by water density

$\dot{m} = Q \times \rho$ (Bansal 2005)-- - - - - - 3.1

$\dot{m}$=0.66667kg/s

3.2.2 Pump water velocity

From the law of mass conservation, mass flow rate is given by

$$\dot{m} = \rho \times V \times A_P \qquad - \quad - \quad - \quad - \quad - \quad - \qquad 3.2$$

Where

m = mass flow rate = $0.66667 m^3/sec$

ρ = density of water = $1000 kg/m^3$

V = velocity of flow =?

A_P= Pipe area of cross section of flow

$$V = \frac{\dot{m}}{\rho \times A_P}$$

Given that pipe diameter =30mm

:- r =0.015m

$$A_P = \pi \times r^2$$

$$A_P = \pi \times 0.015^2 = 7.06858 \times 10^{-4} m^2$$

$$V = \frac{0.6667}{1000 \times 7.06858 \times 10^{-4}} = 0.943 m/s$$

3.2.3 Sprayer Outlet

Considering an average diameter of 3mm for the spray head area of outlet is given by

$$A_H = \pi \times r^2 \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad 3.3$$

Where

A_H = Area of hole (m^2)

r = radius of hole (m)

$$A_H = \pi \times r\pi \times 0.0015^2 = 7.06858 \times 10^{-6} m^2$$

3.2.4 Number of Holes

The number of outlet holes on the spray head is given by dividing the pipe area of cross section by hole area of cross section

$$\frac{\text{Pipe area of cross section}}{\text{Hole area of cross section}} \quad - \quad - \quad - \quad - \quad - \quad -3.4$$

$$\frac{7.06858 \times 10^{-4}}{7.06858 \times 10^{-6}} = 100 holes$$

3.2.5 Height of Simulator Head

From the equation of motion below

$$v^2 = u^2 + 2aS \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad -3.5$$

Where

v = final or impact velocity = 8m/s

u = initial or exit velocity = V = 0.943m/s

a = acceleration (9.8m/s^2)

S = height of spray head =?

$$S = \frac{v^2 - V^2}{2a} \quad \text{(Nelkon and Parker 1995)} \quad \text{-3.6}$$

$$S = \frac{64 - 0.8892}{19.6} = 3.22m$$

Height of simulator head =3.22meters

3.2.6 Frame Design

The frame of the rainfall simulator was designed putting into consideration the calculated height of the spray head.

From the force diagram of the frame as shown below

Load supported by frame was determined by weighing

the (simulator head + reciprocating mechanism + maximum water in the spray head)

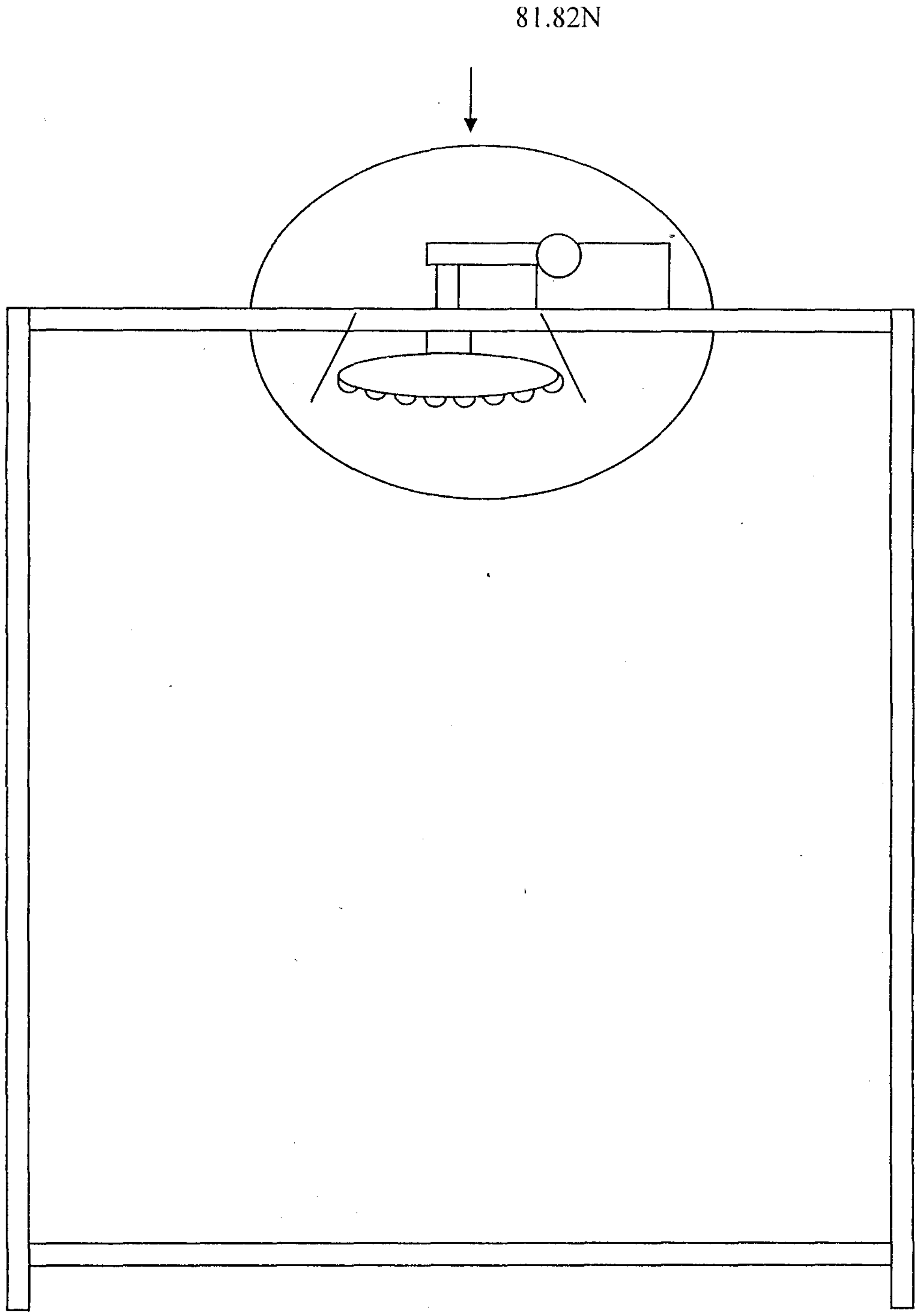


Figure 3.3 Rain simulator

3.2.7 Forces Acting on Frame

Mass of simulator head =4.8kg

Mass of reciprocating mechanism = 3.5 kg

Mass of water in spray head is given by

$M = \rho \times v$

Where

ρ = density of water= 1000kg/m^3

V = volume of water in tube.

$$v = \frac{\pi \times d^2}{4} \times L \qquad - \quad - \quad - \quad - \quad - \quad - \qquad -3.8$$

d = spray head pipe internal diameter = 5mm =0.005m

L = length of pipe = 2.5m

$$v = \frac{\pi \times 0.005^2}{4} \times 2.5 = 0.0000491m^3$$

$M = 1000 \times 0.000049$ =0.0491kg

Load on frame becomes

Mass (m) on frame = 4.8 + 3.5 + 0.049 = 8.349kg

Load on simulator frame = $8.349 \times 9.8 = 81.82N$

The frame is designed with four supports

Load on frame

$$\text{Force acting on each support} = \frac{\text{Load on frame}}{\text{Number of supporting legs}}$$

$$\text{Force acting on each support} = \frac{81.82}{4} = 20.455N$$

3.3.1 Wind Shield Design

The size of the wind shield required is given by the dimensions of the perimeter and height of the simulator.

$$\text{Perimeter (P)} = 2 \times (l + b)$$

Where

L = overall length of the simulator frame =1.5m

b= overall breadth of the simulator frame = 1m

$$\text{Perimeter (P)} = 2 \times (1.5 + 1) = 5\text{m}$$

Height of simulator frame =3.22m

Required dimension of wind shield is 5m /3.22m transparent leather.

3.3.2 Simulator Catchments Area

Area $(A_c) = l \times b$

l = length of simulator = 1.5m

b= breadth of simulator = 1m

Area $(A_c) = 1.5 \times 1 = 1.5m^2$

3.3.3 Reciprocating Mechanism

Area $(A_c) = l \times b$

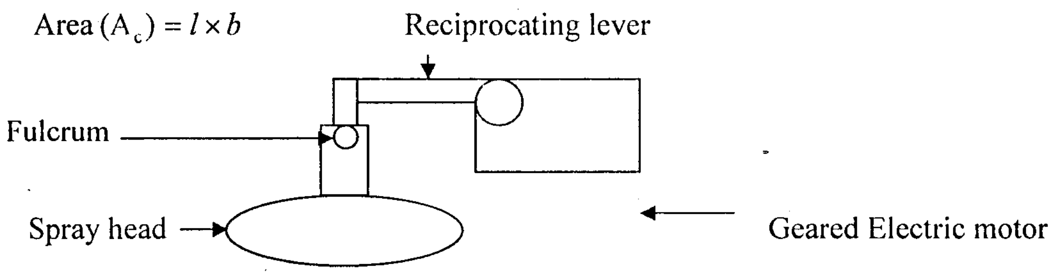


Figure 3.4 Reciprocating Mechanism

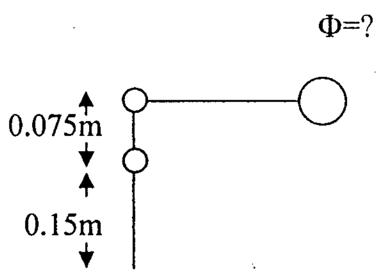


Figure 3.5 Schematic diagram of reciprocating mechanism

Required displacement angle of spray head is -10° and +10°

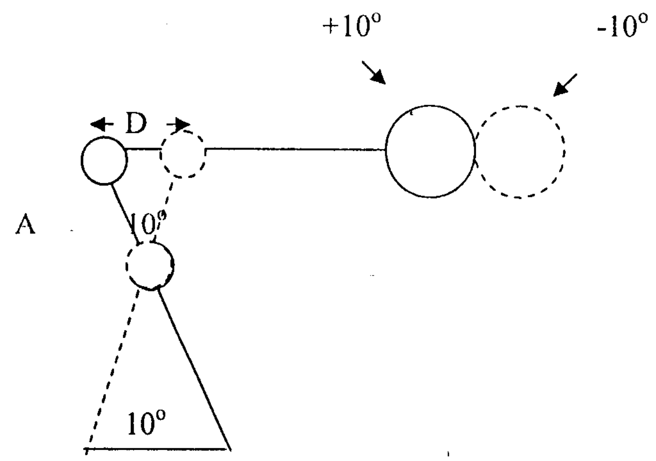
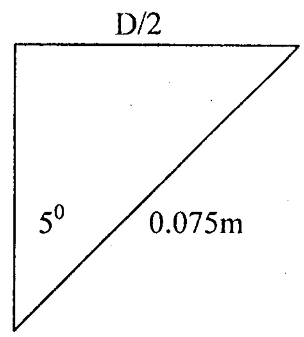


Figure 3.6 Spray head displacement

From triangle A



$$\sin 5 = \frac{0.5D}{0.075}$$

3.3.6 Component Construction and Assembly

Frame

The simulator frame was made using one inch square pipe, then cut to required dimensions of the simulator using hacksaw. Joining of cut pipes was achieved by welding operation (electric arc welding)

Spray Head

The spray head was made using copper pipe of 5mm diameter and the required length of copper pipe then cut using the pipe handheld cutter. The copper pipe was bent into the required rectangular shape for the sprayer, by hand. The rectangular shaped copper pipe was now drilled using electric hand drill to create the required spray holes. The two open ends of the copper pipe were soldered to the inflow pipe by gas welding (soldering).The rectangular copper pipe was fitted onto supporting aluminium plates by riveting.

The Pump

The pump mounting was made by using ¾ inch pipe, the metal pipe cut into required size and joined by welding. The pump mouth was attached to the main frame by welding, and then pipe connectors were fitted onto the inflow and outflow channels of the pump by screwing them into position.11/4 inch tube was then fitted to the connectors using ring clips to fasten them in place for the supply of water to the sprayer.

Oscillating Mechanism

The oscillating mechanism was designed using an AC (Alternating Current).Motor with a gear box attached to reduce the output. The mechanism was now fixed in place by means of bolts and nuts.

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

4.1 Testing

The materials used for testing include rainguage, measuring cylinder storage tank, water and stop watch.

The rainfall simulator was assembled, wind shield attached. The test plot is an area covered with grass. The rain gauge was positioned in the central fall of the spray head. The unit was switched on for 30 minutes and the flow depth was recorded and further calculations were also carried out accordingly.

4.2 Result

Rainfall depth was measured to be 5.8cm which is equal to 58mm.

$$\text{Total kinetic energy of the storm} = \frac{\text{vol of the rainfall}}{\text{Individual drop}} \qquad \text{(Laws, 1941)}$$

4.2.1 Volume of rainfall = depth of rainfall x the surface area

Depth of rainfall = 58mm = 0.058m

Area of the fall = $1.5m^2$

Volume of rainfall = 0.058x 1.5= $0.087m^3$

Volume of individual drop = volume of rainfall

Size of individual drop

$$= \frac{0.087}{4} = 0.0217m^3$$

4.2.2 Total kinetic energy of the storm (E) = 0.0870 / 0.218

= 3.99Jm^{-2} / hr

4.2.3 Intensity of the rainfall = $\frac{\text{rainfall depth}}{\text{Time taken}}$

= 58 / 30 x 60

= 116mm / hr

4.2.4 Soil loss = 0.00094EI_{30} (wischmeier and smith, 1958)

Where E = total storm kinetic energy

I_{30} = maximum 30 minutes intensity

Erosivity indices = EI_{30}

= 3.99 x 116

= 462.84Jm^2

Soil loss = 0.00094 x 3.99 x 116

$= 0.435 Kg / m^2$

4.3 Discussion of the Result

The rainfall intensity of 116 / hr recorded indicated that the intensity is high and as a result, substantial amount of soil were lost, because the higher the rainfall intensity, the higher the amount of soil lose, this is evident in the soil loss of $0.4253 Kg / m^2 s$.

The high erosivity indices of $452.4 Jm^2$ demonstrated the aggressiveness of the climate (rainfall) to cause erosion.

However, the aggressiveness of those rainfall parameters not withstanding, soil loss rate can be minimize with proper cover management practices. The over all performance of the simulator indicated that it is reliable since the storm events clearly indicated repeatability. A uniform rainfall across the test plots was also established, this was made possible by uniform drop holes in the spray head. All these results recorded were insulated by the simulator characteristics of ease of assemble and disassemble, hight weight, resistance to being blown away by wind and incorporation of the roller wheel for maneuverability across the test plot.

4.4 Cost Analysis

Table 4.1 Cost of production of the Simulator

No.	Items	Quantity	Unit cost(₦)	Total cost (₦)
1.	Pressure pump	1	13,500	13,500
2.	Oscillating mechanism	1	4,000	4,000
3.	Steel angle section	3	120	460
4.	hose (1 /	'	5m	200
1,000				
	Hose (1 ½ '')	5m	400	4,000
5.	Galvanized pipe (1/ 2'')	1 length	1,200	1,200
6.	Square steel pipe (1 x 20)	4	1, 500	6,000
7.	Bolt and nut	2 dozens	30	720
8.	Paint and brush	1	500	500
9.	Welding electrodes	1 packet	750	750
10.	Fittings	Nos	1,160	1160
11.	Union connector (3 / 4)	2	100	200

12. Socket (1 / 2)	1	150	150
13. Copper rods for drop formers	2	350	700
14. Saw blades	2	150	300
15. Sealant for drop formers	1	400	400
16. Yarn	1	100	100
17. Switch board	1	750	750
18. Simulator head	1	6,000	6,000
19. Wind shield	5 yards	200	1000
20. Transportation			3, 000

3,000

Total N45,930

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

It was established that provided there is continuous heavy downpour soil lost will always be recorded and this losses depends on raindrop size and its kinetic energy. Hence any observed variations in soil lost will be due to soil factors, this factor can be varied under laboratory conditions with much more confidence and precision than available in the field. The test result and subsequent calculations show that rainfall simulated meet all the requirement of the conventional standard drop and can be used to evaluate the effects of different phases of erosion process. The rainfall simulator cost about 55,000 naira and readily availability of its component materials put it in good state for acceptance by researchers and experts with interest in soil erosion studies. The rainfall simulator is therefore presented to the Department of Agricultural and Bioresources Engineering, Federal University of Technology Minna, for soil erosion studies.

5.2 RECOMMENDATIONS

1. I recommend that either a wind shield is constructed or simulator be used in the laboratory or in the morning hours (before 9am) when wind velocity is low.

2. The spray head should be constructed facing upward and slightly inclined at an angle, so that the initial terminal velocity will be attained and the drops fall under gravity as in natural rainfall.

3. Reliance on public power supply to power the pump limits the

Simulator use. Future designs should incorporate water pump operating independent of the main power supply.

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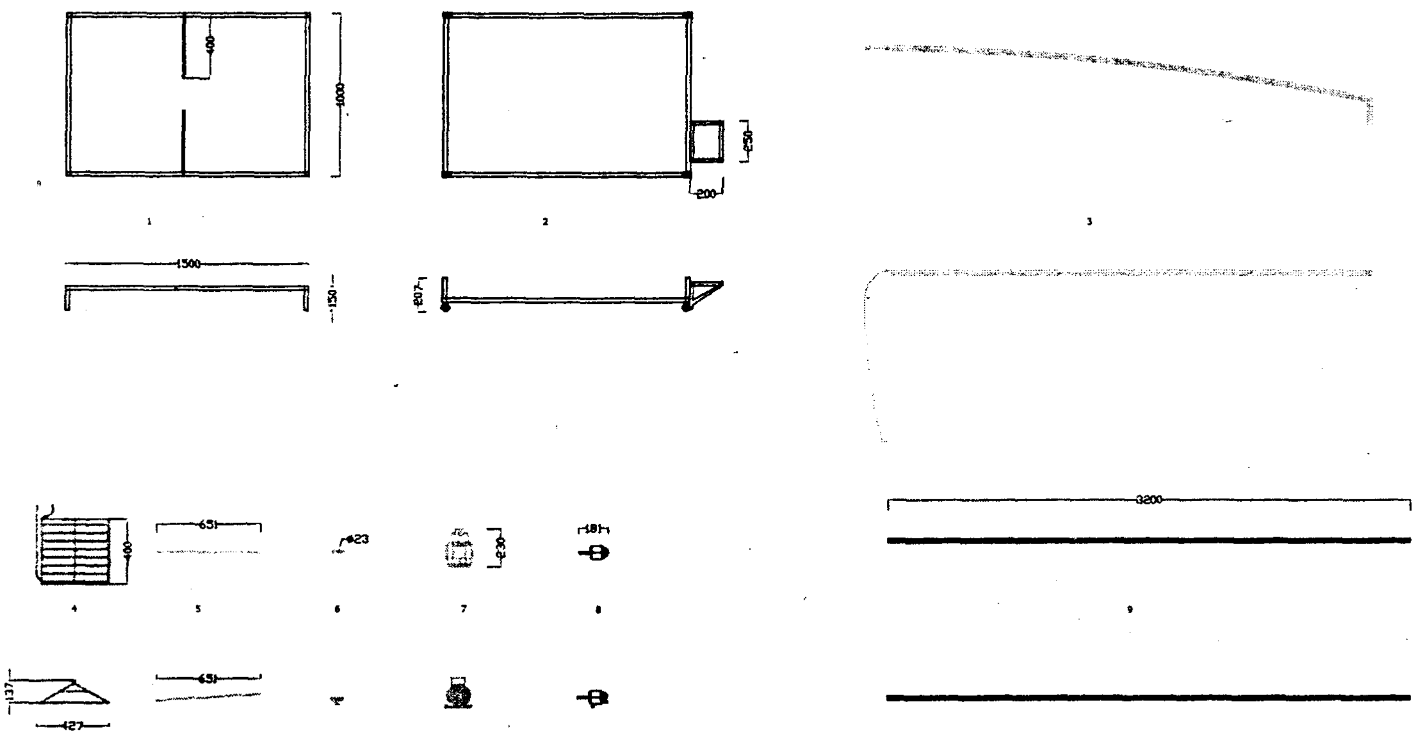

S/NO	PART	MATERIAL
9	SUPPORT PIPE	MILD STEEL
8	ELECTRIC MOTOR	ALUMINUM
7	WATER PUMP	MILD STEEL
6	PIPE TEE JUNCTION	PVC PIPE
5	CONNECTING ROD	STAINLESS STEEL
4	SPRAY HEAD	GALVANISED SHEET
3	HOSE PIPE	RUBBER
2	BASE FRAME	MILD STEEL
1	UPPER FRAME	MILD STEEL

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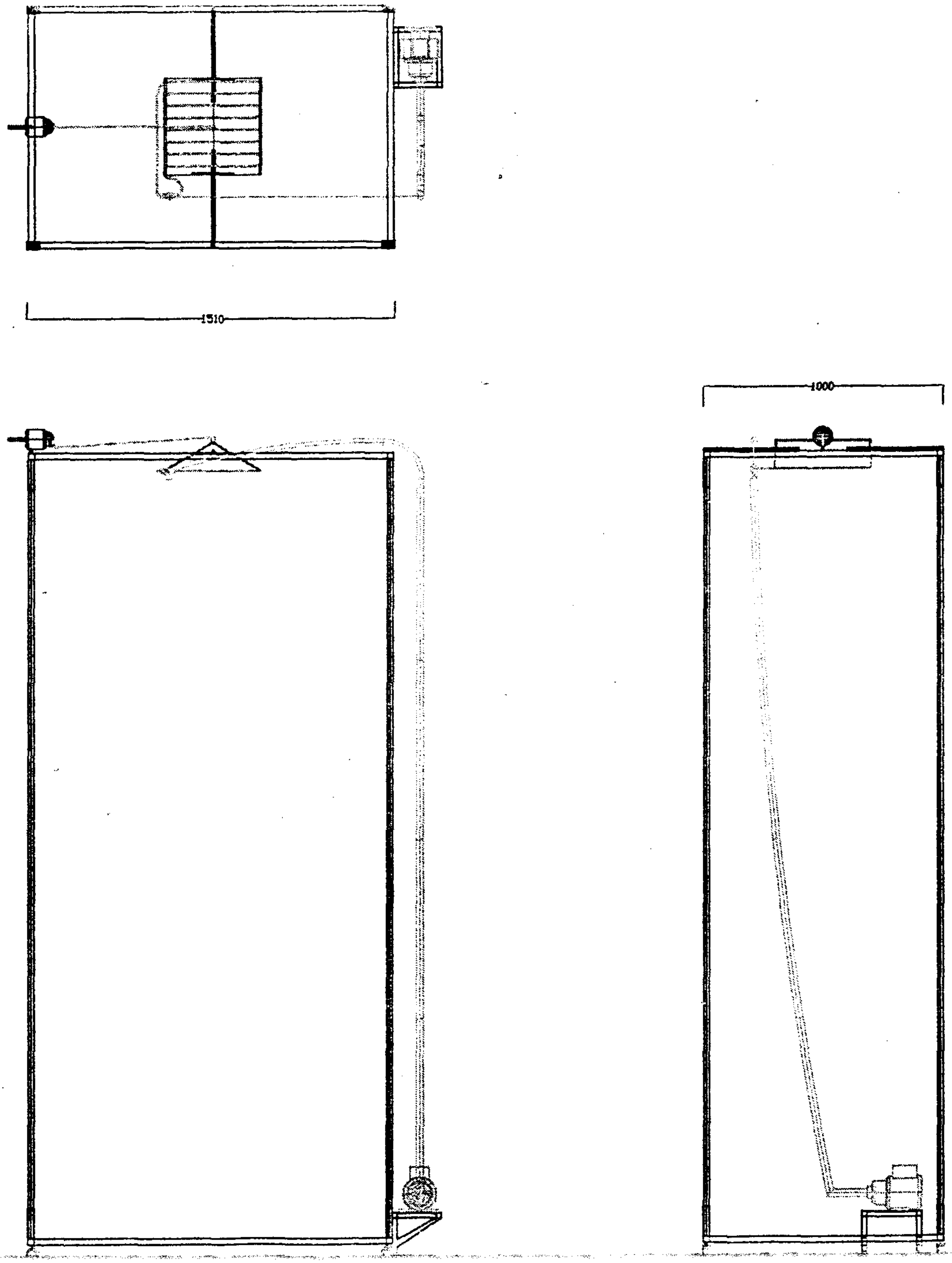

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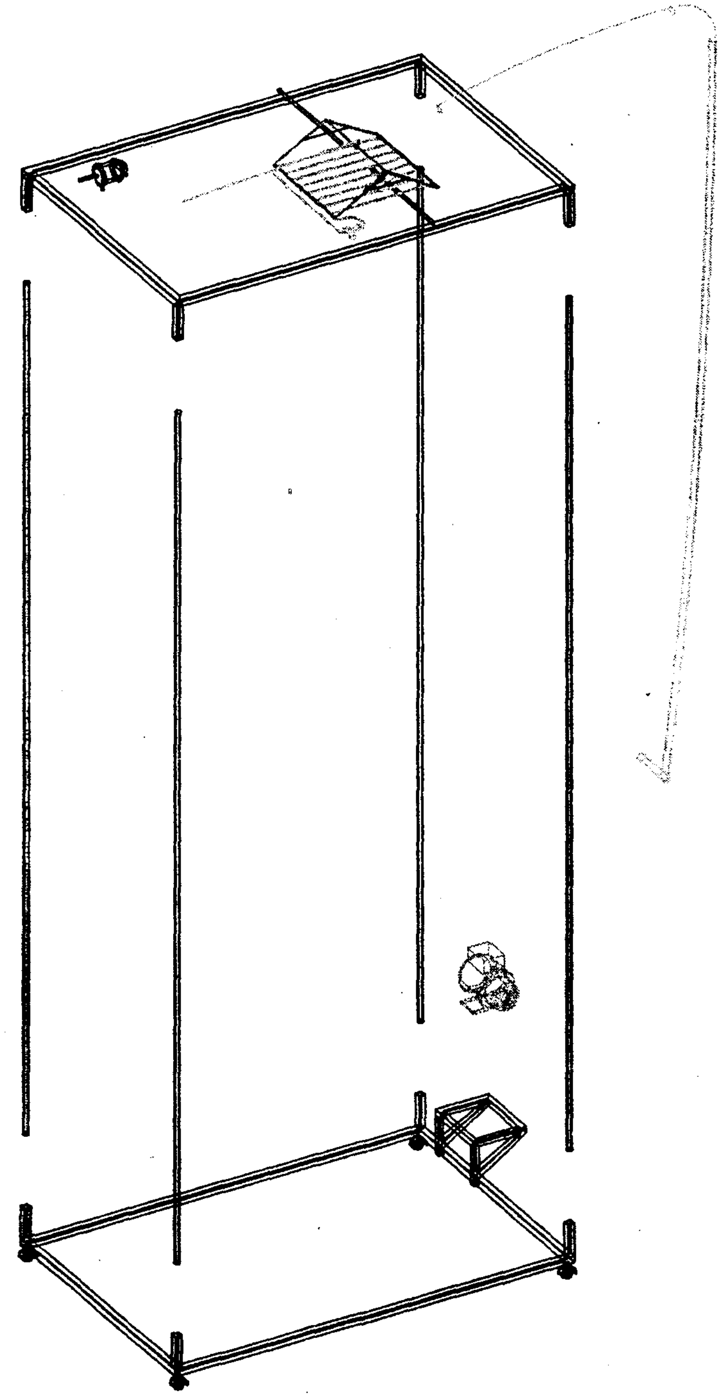

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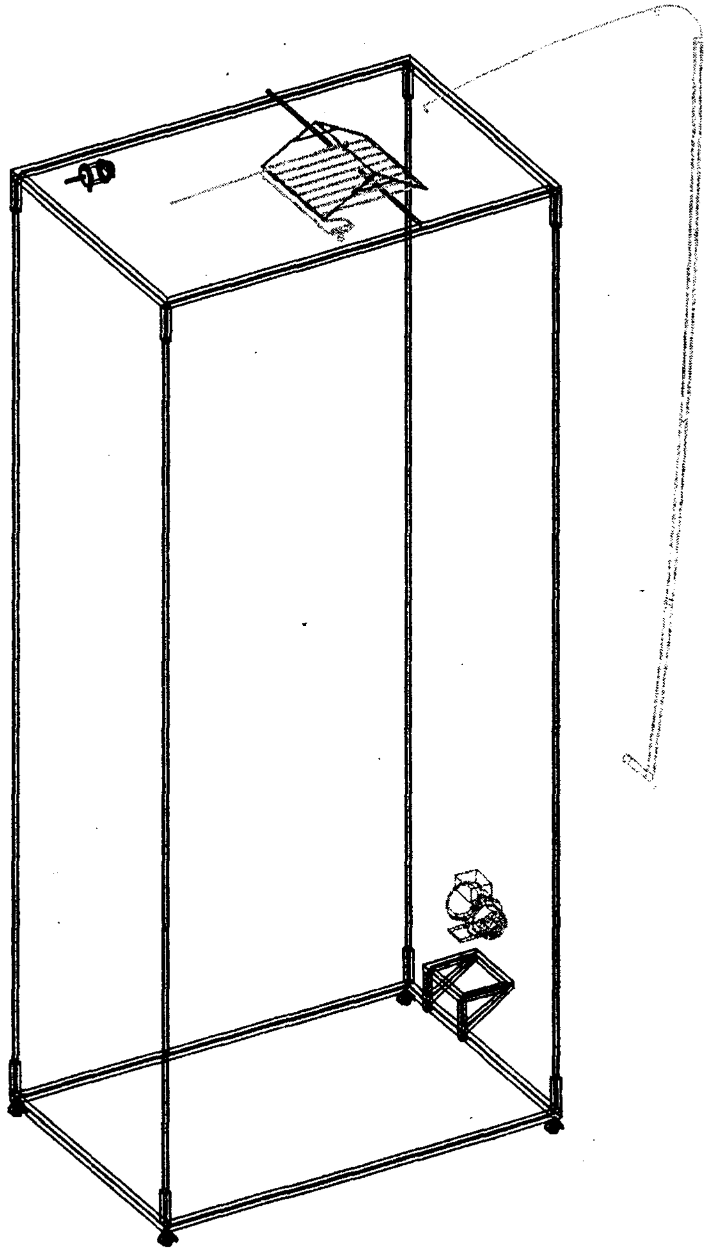

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