DESIGN AND DEVELOPMENT OF A HIGH CAPACITY SALVINIA HARVESTER

By

HAJILAL. M. S.

THESIS

submitted in partial fulfilment of
the requirement for the degree

Master of Science in Agricultural Engineering

Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Irrigation and Drainage Engineering
Kelappaji College of Agricultural Engineering and Technology
Tavanur - Malappuram

1987

DECLARATION

I hereby declare that this thesis entitled "Design and development of high capacity Salvinia Harvester" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara,
1st November 1987.

HAJILAL, M.S.

CERTIFICATE

Certified that this thesis, entitled "Design and development of a high capacity Salvinia Harvester" is a record of research work done independently by Shri. HAJILAL, M.S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

Vellanikkara,
3rd November, 1987.

K. JOHN THOMAS,
Chairman,
Advisory Committee,
Professor and Head,
Dept. of Irrigation
and Drainage Engg.

CERTIFICATE

We, the undersigned members of the Advisory Committee of Shri. HAJILAL, M.S. a candidate for the degree of Master of Science in Agricultural Engineering agree that the thesis entitled "Design and development of a high capacity Salvinia Harvester" may be submitted by Shri. HAJILAL, M.S. in partial fulfilment of the requirement for the degree.

K.John Thomas,
(Chairman)
Professor and Head (IDE),
KCAET, Tavanur.

T.P.George,
Dean-in-charge,
KCAET, Tavanur.

C.P. Muhammad,
Professor and Head (FPME),
KCAET, Tavanur.

Dr. P.J.Joy,
Associate Professor,
RARS, Kumarakom.

External Examiner.

ACKNOWLEDGEMENT

I consider it a pleasure and privilege to express my profound gratitude to Shri. K.John Thomas, Professor and Head, Department of Irrigation and Drainage Engineering, Chairman of the Advisory Committee for his valuable guidance, critical suggestions and help throughout the course of this investigation and in the preparation of this thesis.

My sincere thanks are also due to Shri.T.P.George, Dean-in-charge, Shri. C.P. Muhammad, Professor and Head (FPME) and Dr. P.J. Joy, Associate Professor, members of the Advisory Committee for their constant encouragement, constructive suggestions and keen interest at every stages of investigation and preparation of the thesis.

I am greatly indebted to Sri. M.R.Sankaranarayanan Assistant Professor for his valuable suggestions and immense help during the field investigations. I sincerely acknowledge the help and co-operation rendered by the technicians, Engineering Research Workshop, Mannuthy, during the course of research work.

I express my heartfelt thanks to all the staff members in the Department of Agricultural Engineering, College of Horticulture and KCAET, Tavanur and to my beloved friends for their tireless co-operation and enthusiastic help from time to time for the completion of this thesis.

Thanks are also due to the financial assistance and the permission granted for taking this problem as a part of the ICAR project on "Mechanical control of floating type aquatic weeds". My posting in the above ICAR Ad-hoc scheme as research associate is duly acknowledged.

HAJILAL, M.S.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS USED

An	-	Area of nozzle
At	-	Area of throat
Cd	-	Coefficient of discharge
cm	-	Centimetre(s)
°C	-	Degree celsius
D_n	-	Diameter of nozzle
D_t	-	Diameter of throat
Fig.	-	Figure
g	-	gram(s)
G.I.	-	Galvinised iron
ha	-	Hectare
D_d	-	Delivery head
H_p	-	Head at nozzle
H_s	-	Suction head
H_g	-	Mercury
hp	-	Horse power
kg	-	Kilogram(s)
kg/cm^2	-	Kilogram(s) per square centimetre
kg/m^2	-	Kilogram(s) per square metre
kg/m^3	-	Kilogram(s) per cubic metre
km	-	Kilometre(s)
km^2	-	Square kilometre(s)
l	-	Litre(s)
lpm	-	Litre(s) per minute
lps	-	Litre(s) per second
m	-	metre(s)

m^2	-	Square metre(s)
mm	-	Millimetre(s)
M	-	Flow ratio
M*	-	Capacity ratio
M.S.	-	Mild Steel
N	-	Pressure ratio
N*	-	Head ratio
P_1	-	Pressure at nozzle
P_2	-	Suction pressure
P_5	-	Delivery pressure
Q	-	Discharge
R	-	Area ratio
Rs.	-	Rupee(s)
Rs/ha	-	Rupee(s) per hectare
rpm	-	Revolutions per minute
s	-	Second(s)
t/ha	-	Tonne(s) per hectare
t/hr	-	Tonne(s) per hour
°	—	Degree
/	-	Per
η	-	Efficiency
%	-	Per cent
π	-	Pi (22/7)
$<$	-	Less than
$>$	-	Greater than

Introduction

INTRODUCTION

Aquatic weeds have become a menace to agriculture, pisciculture and inland navigation in many parts of humid tropics. This is particularly true of the state of Kerala where the weeds have spread to such an alarming extent.

<u>*Salvinia molesta*</u> Mitchell locally known as 'African Payal' is found all over Kerala. It is estimated that nearly 50,000 ha of water surface is infested with this molesting weed. Alleppey, Ernakulam, Kottayam and Trichur are the most affected districts. Salvinia is a non-flowering weed of South American origin and is capable of prolific growth and rapid multiplication. They spread themselves like a blanket over the water surface. They compete with crops for available space and nutrients and interfere with paddy cultivation. The additional expenditure incurred for clearing the weeds from paddy fields has enhanced the cost of cultivation. It is reported that the additional expenditure needed for clearing the weeds from paddy fields, varies from Rs. 900/- to Rs. 2,700/- per hectare depending upon the degree of infestation.

Salvinia often damages the engines of small motor boats by blocking cooling water intake apertures. In thickly infested canals, the forward movement of boats is hindered by the resistance offered by the weeds. A thick layer of salvinia restricts the passage of sunlight and consequently fish production is adversely affected. Decayed salvinia pollutes water, making it unfit for human use. It provides optimum breeding conditions for certain types of mosquitoes. There are also reports of extensive clogging of irrigation and drainage channels by the weeds. In short, these weeds adversely affect the quality of human as well as aquatic life. It is therefore of utmost importance that these weeds which have already become so widespread in Kerala are controlled.

Although mechanical control of aquatic weeds is a sound management approach, the present day equipment available is too expensive in relation to the benefits derived. However mechanical measures of weed control have the great attraction that the control obtained is very quick and also causes minimum pollution hazards. Another advantage is that the collected weeds can be put to use for agricultural or industrial purposes.

The Kerala Agricultural University in 1981 developed a cheap mechanical device for harvesting *Salvinia molesta*. But in this machine clogging was a serious problem. Further the efficiency under all conditions of weed growth was not studied.

The objectives of the present study are to evaluate the performance characteristics of the machine developed earlier under various conditions and to develop a clog free high capacity ejector system.

Review of Literature

REVIEW OF LITERATURE

The informations relating to the origin, growth and control of salvinia are reviewed in this chapter. The review is presented in the following headings:

1. Origin of salvinia
2. Salvinia in Kerala
3. Properties of salvinia and
4. Control of salvinia

2.1 Origin of salvinia

Salvinia molesta which is locally known as African Payal is actually a native of South America. Records gave evidence that specimens of Salvinia molesta, Salvinia biloba and Salvinia auriculata were present in the Botanical Garden at Rio de Janeiro, South America in 1941. This raises the possibility that Salvinia molesta is a hybrid of horticultural origin (Mitchell, 1973). Upto 1973, Salvinia molesta Mitchell was misidentified as Salvinia auriculata Aubl. Mitchell studied the biology, morphology, taxonomy and ecology of this and revealed that the weed which was of common occurence in Africa and Ceylon was not the same as Salvinia auriculata but a distinct taxon, named Salvinia molesta. This weed may be distinguished from other species of salvinia, initially by the confirmation of the presence of hairs on the apices of the pepillae on the upper surface of the leaves. In Africa, salvinia was reported for the first time in 1948 at Zambezi river system, but was not considered as a weed until it invaded Kariba reservoir in 1969. Hence to call it 'African Payal' is perhaps a little erroneous.

2.2 Salvinia in Kerala

Cook and Gut (1971) reported that salvinia must have reached Kerala in about 1950-'60 from Ceylon and was first noticed as a menacing weed around 1964. George (1976) pointed out that the plant, unknown in Kerala before 1953, was believed to have been brought to Trivandrum from Bangalore for botanical studies. According to Thomas (1979), salvinia was introduced as a rarity in the Botanical Gardens, and the presence of this floating fern was first noticed as a noxious weed in 1956 at Veli near Trivandrum.

Over the last 30 years the weed has spread to all districts of the state extending from the fresh water surface of Kuttanadu region which lies below sea level, to the Kakki dam which has an altitude of 984.5 m. A study conducted jointly by the Kerala Agricultural University and the Calicut University identified that nearly 7150 km^2 (18.4% of the total area of the State) was affected by the weed. The districtwise infestation of salvinia according to this report is given in Table 1.

The table shows that the more heavily infested districts are Alleppey, Ernakulam, Kottayam and Trichur. The weed is causing extensive damages to paddy cultivation and disruption of inland navigation for several months in an year.

The low lying coastal areas of the state have provided a highly favourable condition for the growth and spread of this weed. Consequently there was an explosive development of the weed from the Trivandrum district, where it originated, into the Kuttanadu region and the Kole lands of Trichur district. The spread of the weed however, has been less drastic to higher elevation areas of the northern and eastern regions of the State.

The State Department of Agriculture estimated that the total area of water-surface actually covered by the weed was about 2,00,000 ha. This information indicates the magnitude of the problem and the enormity of the task involved in effecting any control in the spread of this weed.

Estimates made by Samuel (1980) revealed that the area requiring removal of the weed was of the order of 1,00,000 ha.

Table 1. African Payal infestation in Kerala State 1977-'78

Sl. No.	Districts	Area (km²)	Approx.area under salvinia infestation, (km²)	Per cent area infested
1.	Cannanore	5706	100	1.75
2.	Calicut	3726	300	8.04
3.	Malappuram	3638	450	12.37
4.	Palghat	4400	150	3.40
5.	Trichur	3032	1300	42.87
6.	Ernakulam	2377	1200	50.49
7.	Alleppy	1884	1100	58.38
8.	Kottayam	2196	700	31.88
9.	Idukki	5087	200	3.93
10.	Quilon	4623	800	17.31
11.	Trivandrum	2192	850	38.78
	Total	38864	7150	18.40

(Joy, 1978)

2.3 Properties of salvinia

2.3.1 Biological properties

The important biological properties concerning the morphology, growth phases and reproduction are briefly described below.

2.3.1.1 Morphological characters

Salvinia has small fragile horizontally floating stems which bears paired floating leaves. A long finely dissected submerged leaf hangs from each node and this absorbs water and ions, under the influence of transpiration pull exerted from the floating leaves and thus performs the function of the roots which are absent. One of the three buds present at each node produces a dissected leaf, another a pair of floating leaves while the third normally remains dormant. Any part of the stem bearing one or more buds is capable of growing into an independent plant. The floating leaves as well as the submerged leaves are shown in Fig.1.

2.3.1.2 Growth phases and factors affecting growth

Cook and Gut (1971) identified four distinct phases during the growth of salvinia (Fig. 2). In the first phase salvinia was in the primary invading form

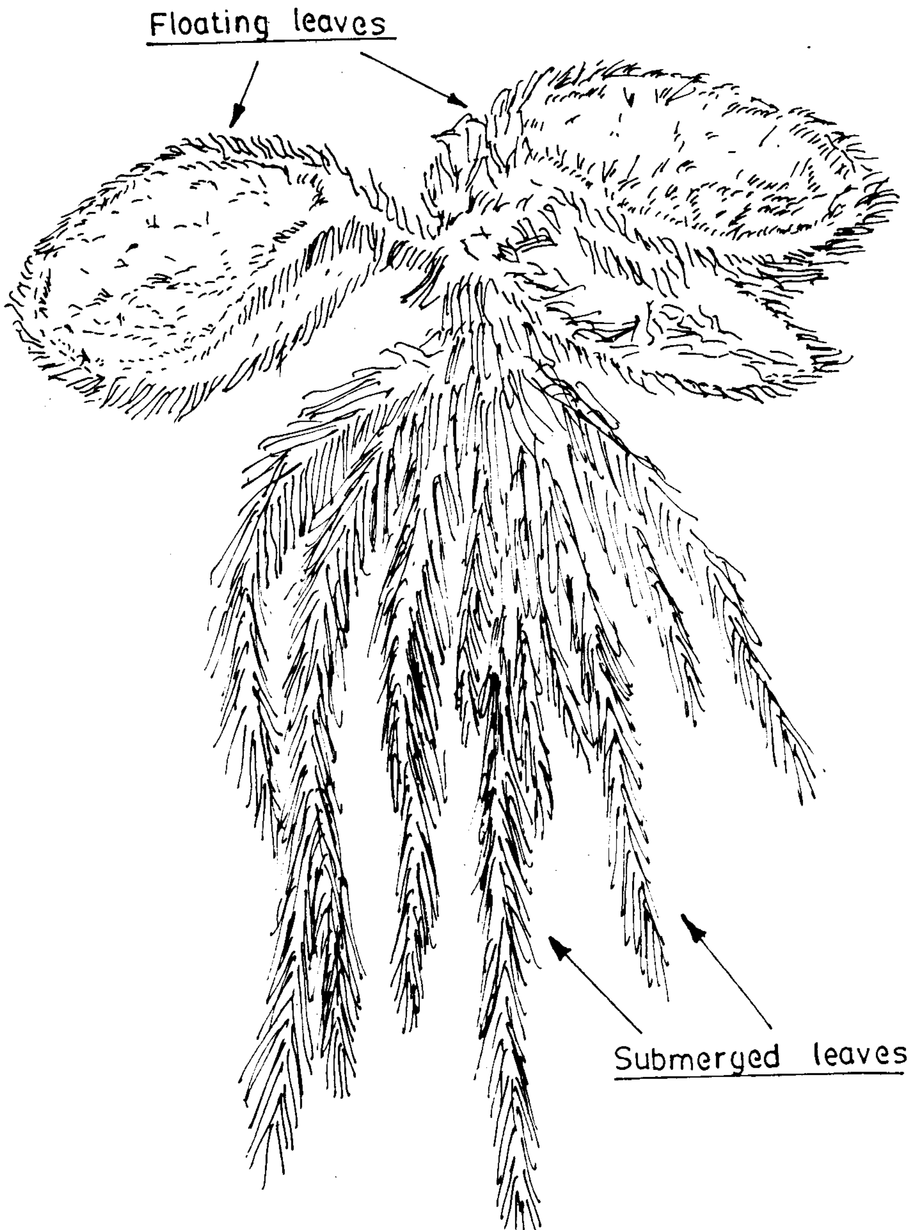


FIG.1. FLOATING & SUBMERGED LEAVES OF A SALVINIA PLANT

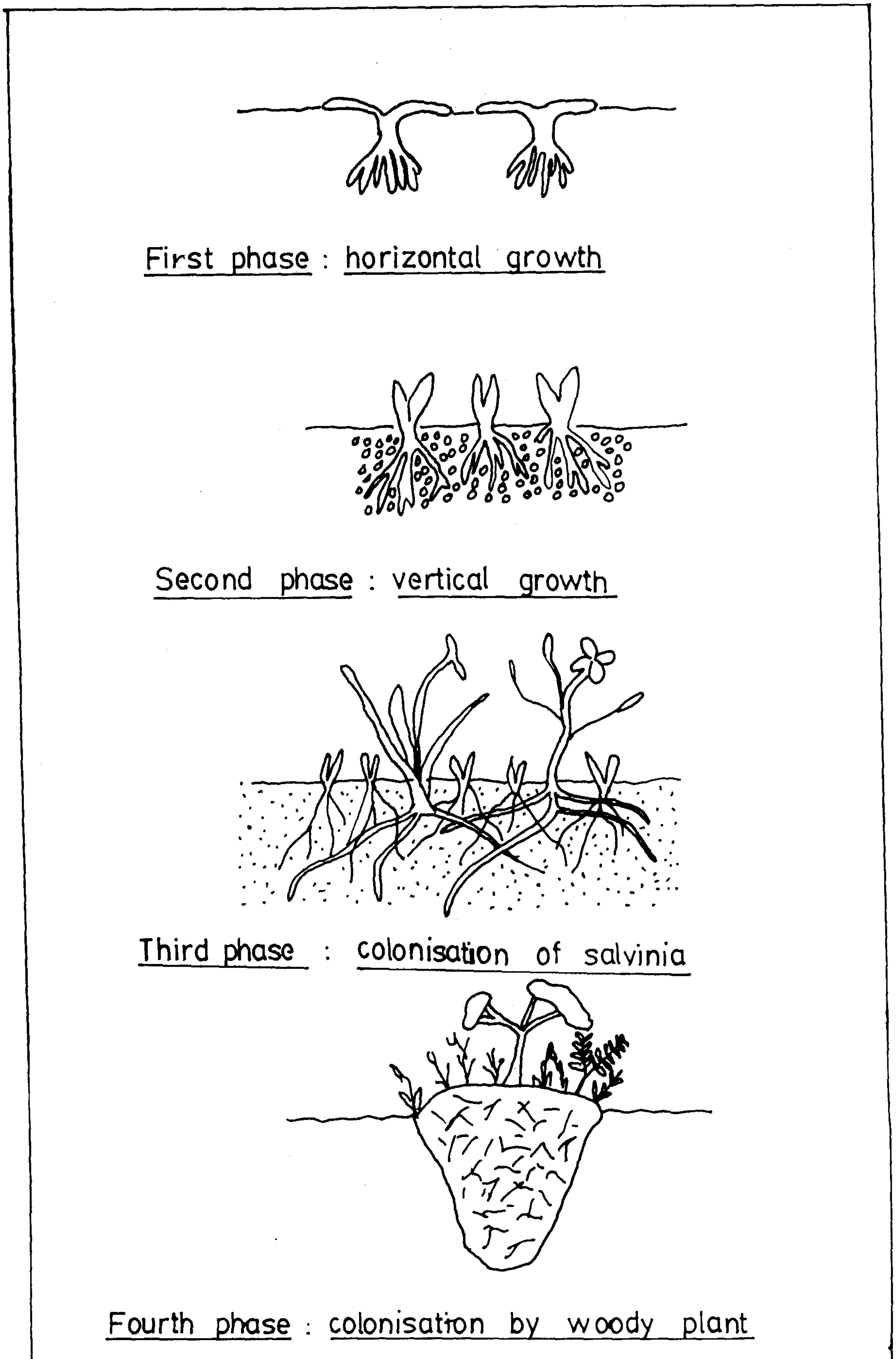


FIG.2. FOUR GROWTH PHASES OF SALVINIA

(Cook & Gut, 1971)

and only lateral growth occured. But when there was no space for lateral growth, the leaf grew in the vertical position and built up on its own dead material. In this second growth phase plant became very large. This growth stage went on until the weed was not able to obtain the large quantity of water needed for its growth due to the massive deposit of dead litter. The habitat was thus changed and was ready to be colonised by other plant species. The initial colonisers were mostly herbaceous plants which crept over the mats of salvinia and bound them together, giving rise to the third phase. The herbaceous plants also contributed litter which was deposited on the island, providing a comfortable habitat for woody shrubs which would, in turn, be eventually replaced by trees (fourth phase).

Light, temperature and nutrients are the fundamental factors that influence the growth of salvinia. Mitchell and Tur (1975) noted that as the light intensity increased the growth of salvinia also increased. Growth rates shot up with increasing temperatures from 22°C to 30°C, but decreased rapidly with further rise to 35°C. Salvinia grows four times as fast in direct sunlight as in the shade, (George, 1976). Shade, movement and salinity of water and drought conditions inhibit the growth of salvinia. The submerged third leaflet of salvinia is essential for absorption of nutrients and its removal affects growth and development of the plant.

It was found that the transition from the first growth phase of salvinia to the second phase takes place in as little as one and a half months time in a suitable habitat like Kumarakam area (Sankaranarayanan, 1981). Most habitats in Kerala are either in the first or in the second phase of growth. But in isolated ponds the third growth phase is also seen. There have been little information of the weed having grown into the fourth phase anywhere in Kerala.

2.3.1.3 Reproduction

In all the salvinia species, fragmentation and regeneration were more prevalent than development of sexual propogules (Loyal and Greval, 1966). Mitchell (1970) showed that salvinia was incapable of forming viable spores and as such did not reproduce separately.

According to Joy (1978), Salvinia molesta was a sterile plant and its reproduction was solely vegetative, the broken pieces of mother plants developing into new ones. It has a surprising ability to regenerate from relatively very small pieces of the plant tissue. Winds and waves, birds and beasts and though quite inadvertently, man himself play the part of a propagating agent and transport and disperse the weed. There is abundant evidence that man, through his equipment or activities, is the main agent for spreading the plant into new situations.

2.3.2 Chemical properties

A series of chemical analysis of salvinia by Williams (1956) yielded the following results shown in Table 2.

Little and Henson (1967) analysed the Salvinia and found that protein content in it was 0.63 per cent. Studies conducted by Thomas _et al_. (1976) on salvinia, based on the samples collected from Kerala State gave the following composition on dry matter basis (Table 3).

2.3.3 Physical properties

Important physical properties of aquatic weeds relevant to mechanical harvesting include water content, density characteristics and pressure density relationships.

2.3.3.1 Water content

The analysis made by Williams (1956) on salvinia showed that the water content was 89.30 per cent. According to Little (1968), the water content of all aquatic plants was about 92 per cent by weight, resulting in only eight per cent of solid matter. Analysis by

Table 2. Chemical contents of *Salvinia molesta*

Sl. No.	Contents	Fresh matter %	Dry matter %
1.	Moisture	89.30	-
2.	Organic matter	6.07	56.72
3.	Ash and Sand	4.63	43.28
4.	Nitrogen	0.09	0.84
5.	Potash (K_2O)	1.156	1.46
6.	Phosphoric acid	0.022	0.207
7.	Lime (CaO)	0.042	0.386

(Williams, 1956)

Table 3. Composition of salvinia on dry matter basis

Sl. No.	Contents	Dry matter (%)
1.	Dry matter (oven dried)	10.1 ± 0.21
2.	Crude protein	13.2 ± 0.92
3.	Ether extract (fat, carotene, etc.)	3.7 ± 0.18
4.	Crude fibre (Cellulose)	23.5 ± 1.1
5.	Nitrogen free extract (soluble carbohydrates)	46.9 ± 1.3
6.	Total ash	12.7 ± 0.41
7.	Acid insoluble ash (Silica)	2.1 ± 0.31
8.	Calcium	1.35 ± 0.15
9.	Phosphorus	0.35 ± 0.03

(Thomas *et al*., 1976)

Thomas *et al*. (1976) on salvinia yielded a value of 10.1 ± 0.2 per cent of dry matter content. Studies made by the Department of Life Sciences of Calicut University (Ignatious, 1979) and Department of Agricultural Engineering of Kerala Agricultural University (Samuel *et al*., 1980) indicated that salvinia weed contained only less than five per cent solid matter. This showed that the moisture content of fresh salvinia would be around 95 per cent.

2.3.3.2 Bulk density

Bulk density means the weight of weed (in moist stage) per unit volume. Field experiments conducted by Sankaranarayanan (1981) in Kuttanadu region and in Kole lands of Trichur district showed that the bulk density of salvinia at the beginning of the second phase of growth was between 370 and 400 kg/m^3.

2.3.3.3 Spread density

The term spread density was introduced by Samuel (1972) which was defined as the weight of immediately harvested drip dry salvinia per unit area. Preliminary experiments done by Samuel and Jacob (1977) showed that for salvinia weed which had completed horizontal expansion just to cover the water surface, the spread density was of the order of 3 kg/m^2. In the second phase of growth the value was about 7.5 kg/m^2 and with secondary growth of creepers over the salvinia canopy, the spread density was found to be upto 12.5 kg/m^2.

Sankaranarayanan (1981) observed the values of spread density under different habitats and degree of packing as given in Table 4.

2.3.3.4 Pressure - Density relationship

Livermore *et al.* (1971) reported that in the case of water milfoil, it was possible to reduce about 50 per cent the original weight by the application of a pressure of 2 kg/cm^2. However, similar studies on salvinia has not been yet reported.

2.4 Control of salvinia (Weed Management)

Since aquatic weed management aims at drawing the maximum benefits from these weeds, it does not often call for total eradication. Biological, chemical and mechanical methods are the usual techniques for controlling aquatic weed growth in water bodies. But, so far, no single method alone has found suitable for the complete control of salvinia.

2.4.1 Biological control

Biological methods are the most desirable because it will not cause environmental pollution and the control once achieved will be relatively permanent.

Table 4. Spread density of salvinia under different habitats and degree of packing

Sl. No.	Degree of packing	Approximate spread density (t/ha)
1.	Light infestation (no artificial packing, does not completely occupy the water surface - I stage	80
2.	Severe infestation (completely occupies the water surface - II stage	160
3.	Severe infestation and packing under wind pressure - II stage + wind action	240
4.	Severe infestation and packing by manual pushing	320

(Sankaranarayanan, 1981)

But this is a slow process and will take its own time to accomplish. This method involves the use of competitive organisms to suppress the growth of the weed species. This pauses the problem of uncontrolled growth of organisms and then attack on alternate feed stocks.

A common tropical snail, Pila globosa has been found to eat voraciously on Salvinia molesta, without any appetite for paddy plants (Thomas, 1975). The overgrowth in population of the snail could be used as human food. According to Phillipose (1976), most submerged weeds in confined water areas could be controlled by rearing of weed eating Chinese grass carp of proper size with the weed. In Kenya and Rhodesia, Paulinia acuminata was considered as a promising biocontrol agent of salvinia (Sankaran, 1976). He also reported Paulinia acuminata, Samea multiplicalis and Cyrtobagous salviniae as promising biocontrol agents for salvinia. The Department of Agricultural Entomology, Kerala Agricultural University, Vellanikkara has initiated a scheme for the biological control of Salvinia and has found that in Kerala, Cyrtobagous salviniae is the most suitable bioagent.

Various types of bioagents may prove useful in different places. In some places, the existing stand of the weed may be too dense and hard for the biological agent to be very effective. In such places, the weeds have to be eliminated by chemical or mechanical means and the use of a biological agent should come as a secondary step to keep down the palatable re-growth. All these bioagents reported need be subjected to further research for achieving complete control of salvinia.

2.4.2 Chemical control

Control of aquatic plants with herbicides is usually easier, faster and frequently cheaper than by any other method. Ecologically, chemical methods are disadvantageous because they cause environmental pollution.

Reports of Stephens et al. (1963) showed that Diquat at 2 kg/ha was recommended against Salvinia species in U.S.A. In the non-fishery waters of Ceylon methyl-chlorophenoxy acetic acid (MCPA) plus mineral oil emulsion, sold as "Shell Salvinia", has proved effective in destroying the Salvinia (Philipose, 1968). Dassanayaka (1976) reported that Paraquat gave temporary control of salvinia in Ceylon.

George (1976) found that Diquat and 2, 4-D were effective against Salvinia in India. Diquat at 2 kg/ha was found to destroy salvinia plants in five days, 2, 4-D was effective at a high dose of 25-40 kg/ha. Both herbicides were effective at the first growth phase of salvinia. Mineral oils, kerosene, diesel and powerene, particularly along with urea or some surfactant, destroy salvinia leaf hairs, which are the main loci of bouyancy control of this plant. The treated plants then sink and decompose thereafter.

Salvinia was found to be sensitive to bases, among which ammonia was the most effective in killing the weed selectively, (Ariyaratna, 1977). Salvinia was found susceptible to thiram, a well known fungicide, at the rate of 7-12 kg/ha when applied with a wetting agent like Agral-90. Thiram is highly selective to rice plants, therefore, it is a very promissing compound for salvinia control in paddy fields (WRO, 1977).

In Kerala, chemicals like Paraquat have proved effective in paddy fields where the weed mat is not very thick (Joy and Abraham, 1977). The use of chemicals on an extensive scale might cause water pollution problems, particularly in water logged areas of the State, like Kuttanadu. Studies on the pollution hazards due to frequent use of chemicals are to be carried out prior to the extensive use of toxic chemicals.

2.4.3 Mechanical control

Mechanical control of aquatic weeds is defined as the physical removal of aquatic weeds mannually or by power operated devices (generally called as harvesters). Mechanical control might be more advantageous, if utilisation of the harvested material can be further developed, for the manufacture of hard board and packing materials, for biogas production, for making compost and for mulching in coconut gardens (Thomas, 1980).

2.4.3.1 Manual methods

Floating booms made of bamboo, rope or nets are used for removing free floating weeds by encircling a small portion of the weed infested area and pulling the weeds ashore. This method can be effectively used for small areas from the shore and for larger areas if a boat is employed. The most widely practiced method in Kerala for the removal of salvinia from paddy fields is hand picking. Dragging was often recommended for use in lakes, canals and narrow rivers (Sculthrope, 1967). A heavy chain or rake bearing downward projecting teeth is dragged by means of a power winch or two persons on either bank. Cook (1976) reported that mannual chaining was used for the removal of salvinia from Kakki reservoir in 1973, and the estimated

2.4.3 Mechanical control

Mechanical control of aquatic weeds is defined as the physical removal of aquatic weeds mannually or by power operated devices (generally called as harvesters). Mechanical control might be more advantageous, if utilisation of the harvested material can be further developed, for the manufacture of hard board and packing materials, for biogas production, for making compost and for mulching in coconut gardens (Thomas, 1980).

2.4.3.1 Manual methods

Floating booms made of bamboo, rope or nets are used for removing free floating weeds by encircling a small portion of the weed infested area and pulling the weeds ashore. This method can be effectively used for small areas from the shore and for larger areas if a boat is employed. The most widely practiced method in Kerala for the removal of salvinia from paddy fields is hand picking. Dragging was often recommended for use in lakes, canals and narrow rivers (Sculthrope, 1967). A heavy chain or rake bearing downward projecting teeth is dragged by means of a power winch or two persons on either bank. Cook (1976) reported that mannual chaining was used for the removal of salvinia from Kakki reservoir in 1973, and the estimated expenditure was Rs. 2,700/ha. In Ceylon drag-netting of salvinia was adopted on thousands of hectares of water during a "Salvinia Week", but the area was infested with salvinia in a few months (Robson, 1978). These methods are very slow, time consuming and also not suitable for very large areas.

The method now practised in Kuttanadu area consists of draining the paddy field, collection of salvinia into heaps and then dragging them on coconut leaves to the border bunds (Sankaranaarayan, 1981). He also pointed out that the minimum cost for manual removal just by pushing the material during the low tide to the adjoining canal, which provides only partial control, was about Rs. 500/ha. The costs for collection and disposal of salvinia at a reasonable lead distance varies from Rs. 900 to Rs. 2,700/ha.

2.4.3.2 Mechanical harvesters

Machines that either cut the submerged weeds or pick up floating weeds and transport them simultaneously to the shore are called aquatic weed harvesters. A harvester may be either mobile or shore based. The mobile harvesters are launched on sturdy boats or floating platform. They move in water and pick up weeds and throw them on to the shore.

Weed cutting machines manufactured abroad have been tried in Kerala, but without much success. These machines are generally made for submerged weeds and they only cut the upper portion of the weeds leaving behind 40-50% which regenerate very fast.

Under the initiative of the Government of Kerala, Cook and Gut (1971) Professors at the University of Zurich made a study of the weed problem, in Kerala. They have reported that chemical control is not advisable owing to possible pollution of water and consequent danger to human life. The report while endorsing the proposal made earlier by Simmonds of Commonwealth Institute of Biological Control, Trinidad says that trials of biological control of weeds may be attempted. It was further suggested that "it is perhaps worth considering the development of a suitable salvinia removing machine" as an approach to aquatic weed control.

Samuel (1972) formulated some concepts for mechanical devices which could utilize manual and mechanical power to suit different habitats of weeds. The Central Institute of Fisheries Technology, Cochin has developed one machine for the removal of aquatic weeds (Velu, 1976). This machine is claimed capable of clearing weed infested area at the rate of 1.5 to 2.0 ha/day of eight hours at a rate of Rs. 150 to Rs.200/ha. The estimated cost of the machine including the engine was Rs. 84,000/- (Kaimal, 1976). But the equipment has not yet been brought into public use for want of further modification to handle specifically the salvinia weed. A local innovator, near Kottayam, developed a machine in 1977, which consisted of an engine operated conveyor system mounted on a platform supported by two country boats. Due to the very low speed attainable by the harvester when pushing a large conveyor through the water, the tendency of the weed materials is to flow away from the pick up point and this development programme is also now suspended.

Samuel and Jacob (1977) proposed a novel fluidisation technique for harvesting the salvinia weed, based on the principle of a high capacity water jet device originally developed by Samuel in 1972 to improve the discharge capacity of the conventional irrigation pumpsets. They suggested that a portable pumpset can be used as a primemover to produce the primary flow which will induce the weed to move through an ejector system into the collection tank. Based on the above design concept, the Department of Agricultural Engineering, Kerala Agricultural University, Vellanikkara successfully developed one prototype Salvinia Harvesting Machine (Sankaranarayanan, 1981).

Later Chandramohan (1984) developed a small scale dredging unit for the collection of sand using the above fluidisation technique. It has got a collection capacity of four tonnes of dry sand per hour.

2.4.4 The KAU Salvinia Harvester

The four major components of this machine are,

a) A twin pontooned floating platform on which the harvester is mounted

b) An engine driven high head pumpset which serves as the primemover for the ejector system

c) A high capacity jet device which multiplies the pump discharge by about four times. The secondary flow generated by the jet device suck the salvinia from water.

d) A floating container placed at the delivery side of the ejector system collects the weed.

Figure 3. Shows the schematic representation of Salvinia Harvester developed in KAU. In this machine, the delivery of the pumpset is connected to a jet, positioned near the venturi shaped throat of the ejector system. High velocity of the water discharged through the jet creates a partial vacuum inside the throat.

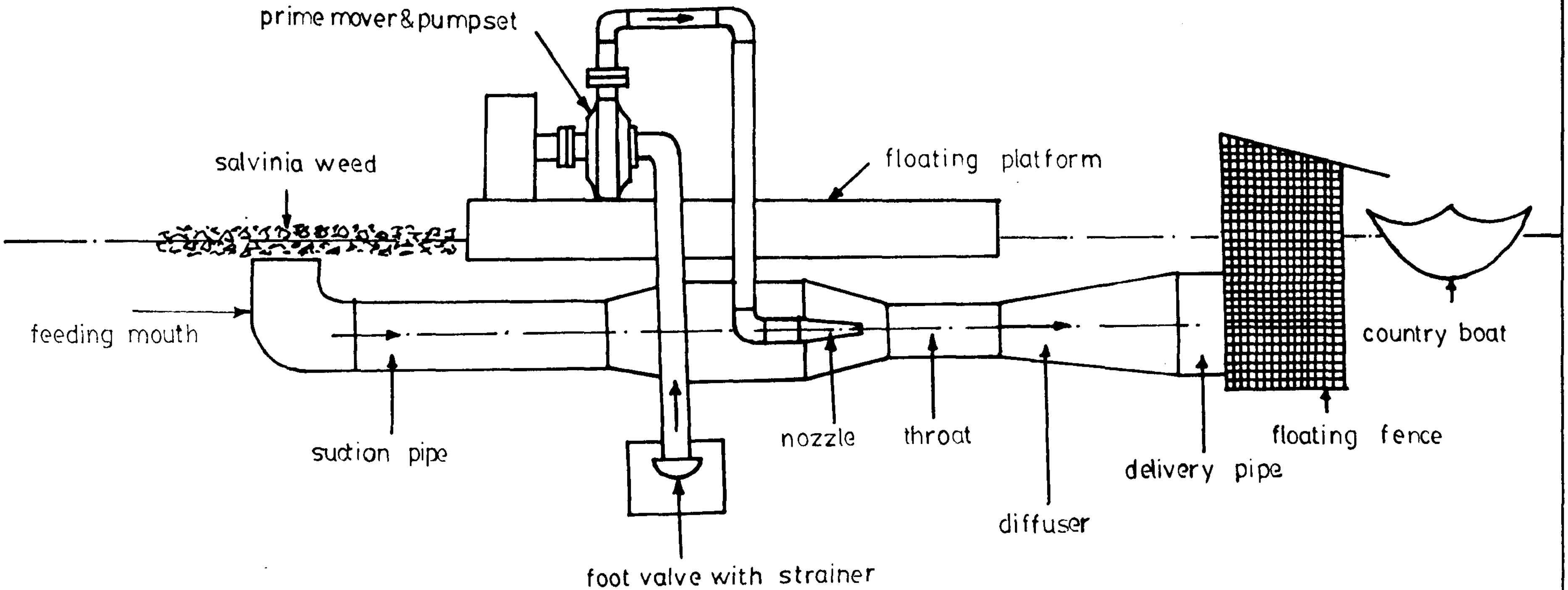


FIG.3 SCHEMATIC REPRESENTATION OF THE PROTOTYPE SALVINIA HARVESTER

This causes water to be sucked in through the inlet of the ejector system, located just below the water surface. Along with the water, salvinia passes around the jet to the delivery side of the ejector system. During this process weed does not pass through any moving part. The delivery is connected to a floating container. Water from this container is drained off by gravity and the weeds are collected in it. The capacity of this machine was found to be about 16 tonnes per hour and the estimated cost of operation amounted to Rs. 280/ ha (Sankaranarayanan, 1981).

2.4.4.1 Ejector System:

Ejector system, which is the main part of the Salvinia Harvester, consists of a jet device, having a jet inlet fitted into a suction chamber, a throat portion and a diffuser. Figure 4. shows the ejector system used by Samuel (1972) to improve the discharge capacity of conventional irrigation pumpsets. He has studied the influences of area ratios, throat entry profile, nozzle spacing, throat length and diffuser angle, on the performance of the ejector system. Some of his findings are listed below:-

i) The maximum efficiency was obtained with a throat entry profile of 90° at almost zero nozzle spacing.

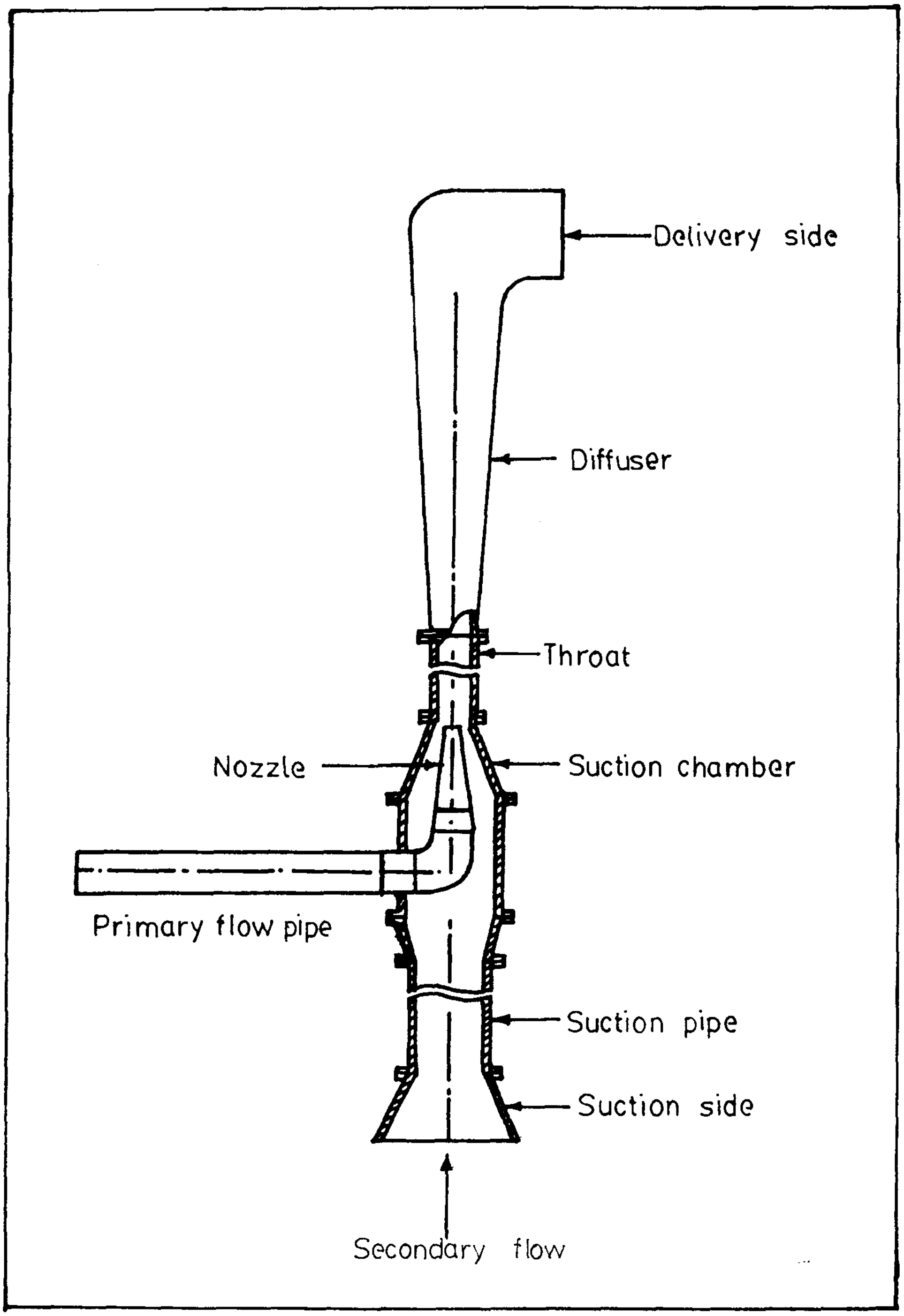


FIG.4. DETAILS OF EJECTOR SYSTEM (Samuel, 1972)

ii) For any given area ratio (area of the nozzle to the area of the throat), the throat entry profile difference affected only to a lesser degree than the location of the nozzle required to achieve maximum efficiency.

iii) Reduction of the throat length from 7 to 5 times diameter had caused the best efficiency point to remain relatively constant when the nozzle spacing varied from zero to one throat diameter.

iv) A 5° diffuser angle gave maximum efficiency than 7.5° diffuser.

v) The maximum efficiencies for each area ratio (0.125, 0.063, 0.043, 0.035, and 0.028) were obtained in a configuration having a throat length of 7 times diameters, a diffuser angle of 5° and at zero nozzle spacing for a throat entry included angle of 90°.

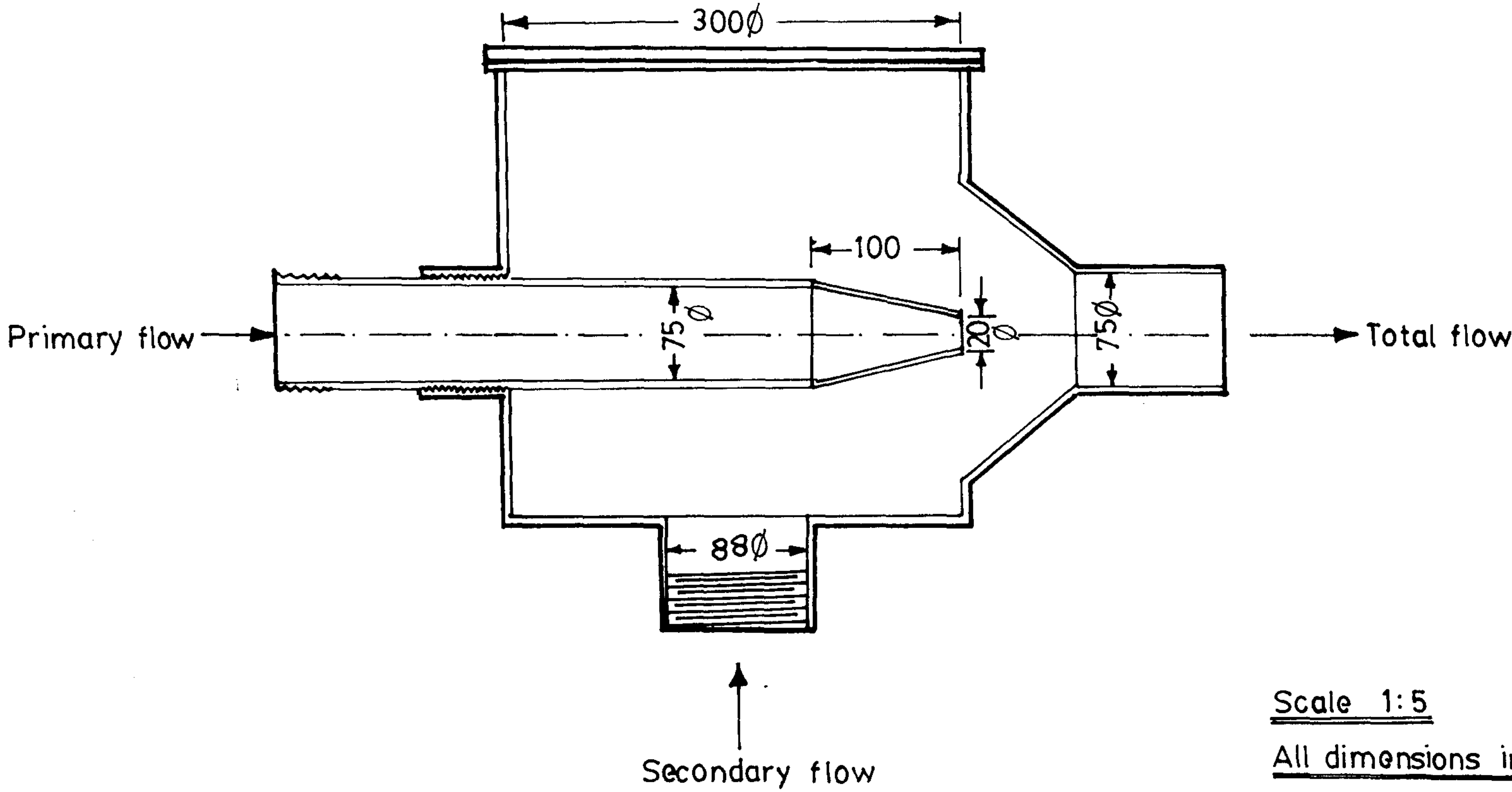
vi) For the lowest area ratio of 0.028, the maximum efficiency of 24.96 per cent was achieved at a capacity ratio (total flow to primary flow) of 7.02. This pump had a throat length of 7 times diameters, a 5° diffuser and a throat entry angle of 90° at zero nozzle spacing.

vii) In the highest area ratio of 0.125, the maximum efficiency was 40 per cent. This difference in performance was attributed to the low throat entry angle and the high diffuser included angle used in the particular configuration.

Considering all the above points and keeping the primary flow straight, an ejector system was developed in KAU (Sankaranarayanan, 1981). The details of this ejector are given in Fig.5.

For the prototype Salvinia Harvesting Machine, the ejector system was designed to suit the two 5 hp pumpsets which were connected in series. The dimensions of this prototype ejector system are as shown in Fig.6.

In the initial ejector system, a straight line direction was given to the primary flow and in the prototype a 90° flow pattern was given. In the prototype Salvinia Harvesting Machine a circular mouth (an elbow) was used as the feeding mouth. It was suggested that the effect of the change of direction of the primary flow as well as the secondary flow and the effect of making the mouth other than the circular one, on the collection capacity has to be studied in detail.

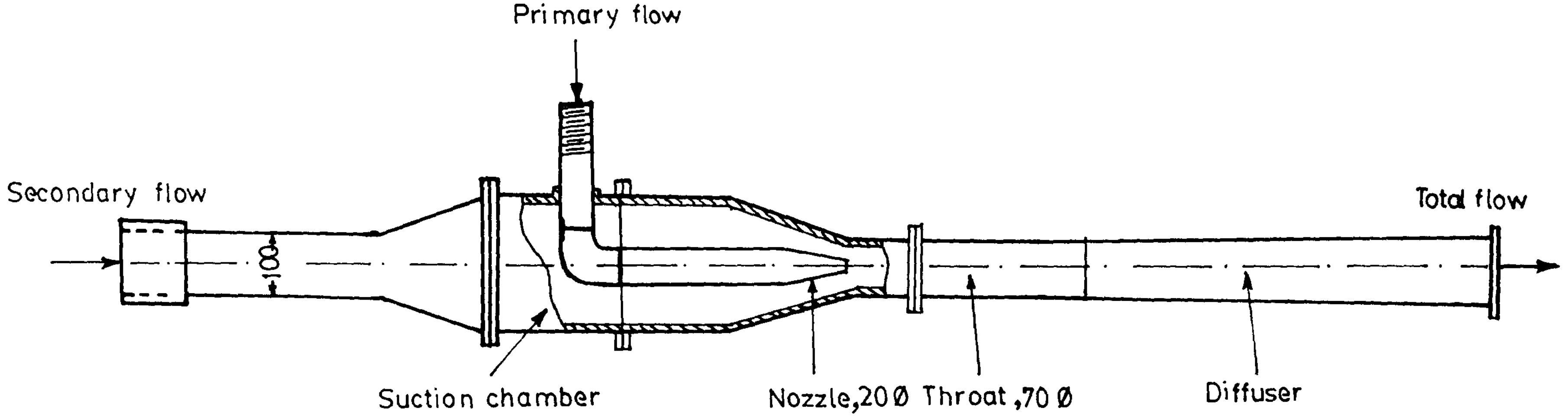


Scale 1:5

All dimensions in mm

FIG. 5. INITIAL EJECTOR SYSTEM

Materials and Methods



Scale 1:10
All dimensions in mm

FIG.6. PROTOTYPE EJECTOR (E_1)

MATERIALS AND METHODS

This chapter deals with the methods and materials employed for the investigations. These are arranged in the following sub-headings:

1. Objectives
2. Preliminaries
3. Ejector system
4. Fabrication works and
5. Experimental programme

3.1 Objectives

The main objective of this study was to design and develop a high capacity ejector system and matching feeding mouth for the already developed Salvinia Harvester by the Kerala Agricultural University. The specific objectives were

1) to design a high capacity ejector system for the Salvinia Harvester developed by KAU
2) to modify the feeding mouth and feeding mechanism for the collection of *Salvinia molesta*
3) to conduct preliminary investigations on additional approaches to improve mechanical control of the floating type aquatic weed, *Salvinia molesta*

3.2 Preliminaries

The main parts of the Salvinia Harvester are

i) Prime mover and pumpset

ii) Ejector system

iii) Feeding mouth

iv) Floating platform

v) Floating fence

The prime mover, pumps and the floating platform used for the sand dredging equipment were in good condition and those were used for the present study also. The details of prime mover, pumps and floating platform are given in Appendix-I.

3.3 Ejector system

3.3.1 Theoretical consideration

The ejector system operates on the principle of transfer of energy and momentum from primary to secondary fluid through a process of turbulent mixing. A schematic representation of an ejector system is shown in Fig. 7. The primary fluid, which has a high pressure, is accelerated to a high velocity fluid by means of the nozzle. The secondary fluid is entrained by and mixed with the primary fluid in the constant diameter throat section. The mixed fluids then pass through a diffuser in which a portion of the velocity head is converted to pressure head. Figure 8. shows the mixing velocity profile in the ejector system.

According to Gosline and O'Brien (1934) the characteristics of an ejector system can be represented by three ratios. The ratios are the nozzle-throat area ratio, $R = \frac{A_n}{A_t}$, secondary to primary flow ratio, $M = \frac{Q_s}{Q_n}$, and pressure ratio, $N = \frac{P_5-P_2}{P_1-P_5}$,

where

A_n - Area of the nozzle
A_t - Area of the throat
Q_s - Secondary flow discharge
Q_n - Primary flow discharge
P_1 - Pressure at the nozzle
P_2 - Suction pressure
P_5 - Delivery pressure at exit

The conventional form expression for efficiency based on the concept of useful work done as Q_s (H_d-H_s) and input energy expended as Q_n (H_p-H_d), is

$$\eta = \frac{Q_s\ (H_d-H_s)}{Q_n\ (H_p-H_d)} ,$$

where

H_d - Delivery head
H_s - Suction head
H_p - Head at nozzle

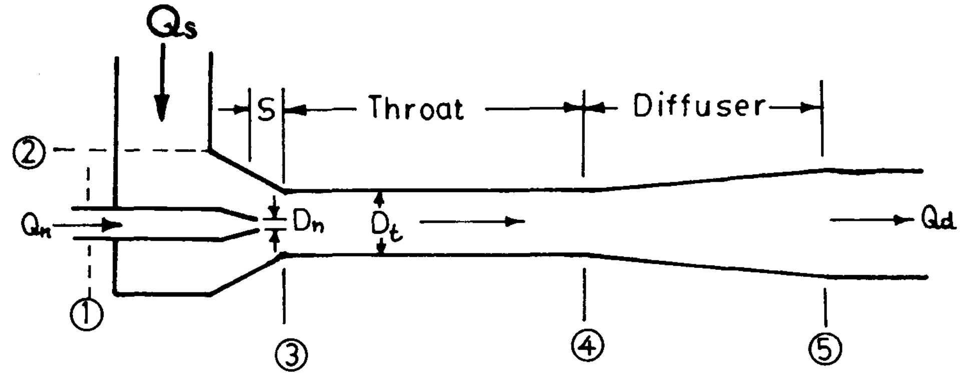


FIG. 7. Schematic representation of ejector system

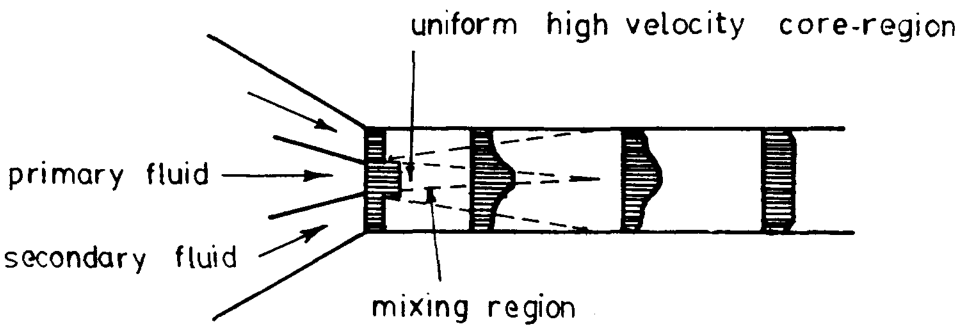


FIG. 8. Mixing velocity profile in an ejector system

The efficiency can also be represented as

$$\eta = \frac{Q_s \; (P_5 - P_2)}{Q_n \; (P_1 - P_5)}$$

$$\eta = M \times N \qquad (1)$$

Silvester (1960) pointed out that when the primary and secondary liquids are drawn from the same source, the useful work consists of both Q_n and Q_s being elevated through a head of $(H_p - H_s)$. The centrifugal pump then has only to supply a head of $(H_p - H_s)$ to Q_n, which results in the efficiency ratio

$$\eta^* = \frac{Q_s + Q_n}{Q_n} \times \frac{H_d - H_s}{H_p - H_s}$$

$$\eta^* = \frac{Q_d}{Q_n} \times \frac{P_5 - P_2}{P_1 - P_2}$$

$$\eta^* = (1+M) \times \frac{N}{N+1}$$

$$\eta^* = M^* \times N^* \qquad (2)$$

M^* and N^* are termed as capacity ratio and head ratio in order to distinguish from M and N.

In designing an ejector system for a particular application, the most critical feature is to consider the area ratio. It also serves as a type of criterion in the same manner as specific speed does for a centrifugal pump. An accepted procedure for the design of an ejector system for any application was described by Stepanoff (1964). In this method, the flow phenomenon is related to physical parameters of the ejector by equating the momentum of the driving fluid to the discharge fluid, which consists of both the driving and driven fluids. Assuming no pressure change within the throat the relation is

$$\rho \, Q_n V_n = \rho \, (Q_n + Q_s) \; V_t \qquad (3)$$

where

ρ - the density

V_n - the velocity through the nozzle and

V_t - the velocity at the throat exit

Since $R = \frac{A_n}{A_t}$, by applying continuity equation it can be shown that

$$M = \frac{1}{\sqrt{R}} - 1 \qquad (4)$$

Thus for a required flow ratio Eqn.4 defines the particular area ratio to be used.

Since analytical methods have not been sufficiently developed to predict head ratio, Stepanoff (1964) developed an equation considering the efficiency values obtained by general research workers and it showed that

$$N = 1.5 \, R \qquad (5)$$

would meet the desired criteria satisfactorily. Since $\eta = M \times N$ this in turn provided the emperical equation for efficiency as

$$\eta = 1.5\,R\left(\frac{1}{\sqrt{R}} - 1\right) \tag{6}$$

Thus for conventional application of the ejector system the set of equations 4, 5 and 6 could be used as design equations, all of which are realated only to R, the independent parameter, as shown in Fig.9.

These equations can be rearranged in terms of the flow ratio to give

$$R = (1 + M)^{-2} \tag{7}$$

$$N = 1.5\,(1 + M)^{-2} \tag{8}$$

$$\eta = 1.5\,M\,(1 + M)^{-2} \tag{9}$$

which are shown graphically in Fig.10.

For use in low lift pumping application these equations were modified in accordance with Eqn.2. This led to the following set of equations

$$M^* = \frac{1}{\sqrt{R}} \tag{10}$$

$$N^* = 1.5\,R\,(1 + 1.5\,R)^{-1} \tag{11}$$

$$\eta^* = 1.5\,\sqrt{R}\,(1 + 1.5\,R)^{-1} \tag{12}$$

$$R = M^{*\,-2} \tag{13}$$

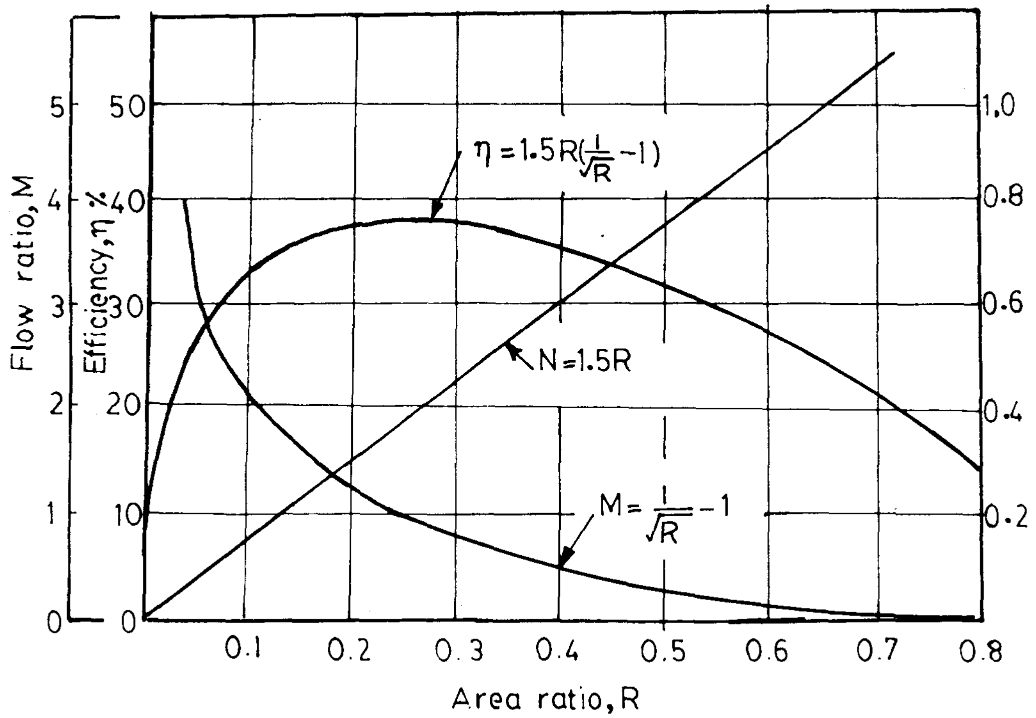


FIG.9. Design relationships for conventional ejector applications (Samuel, 1975)

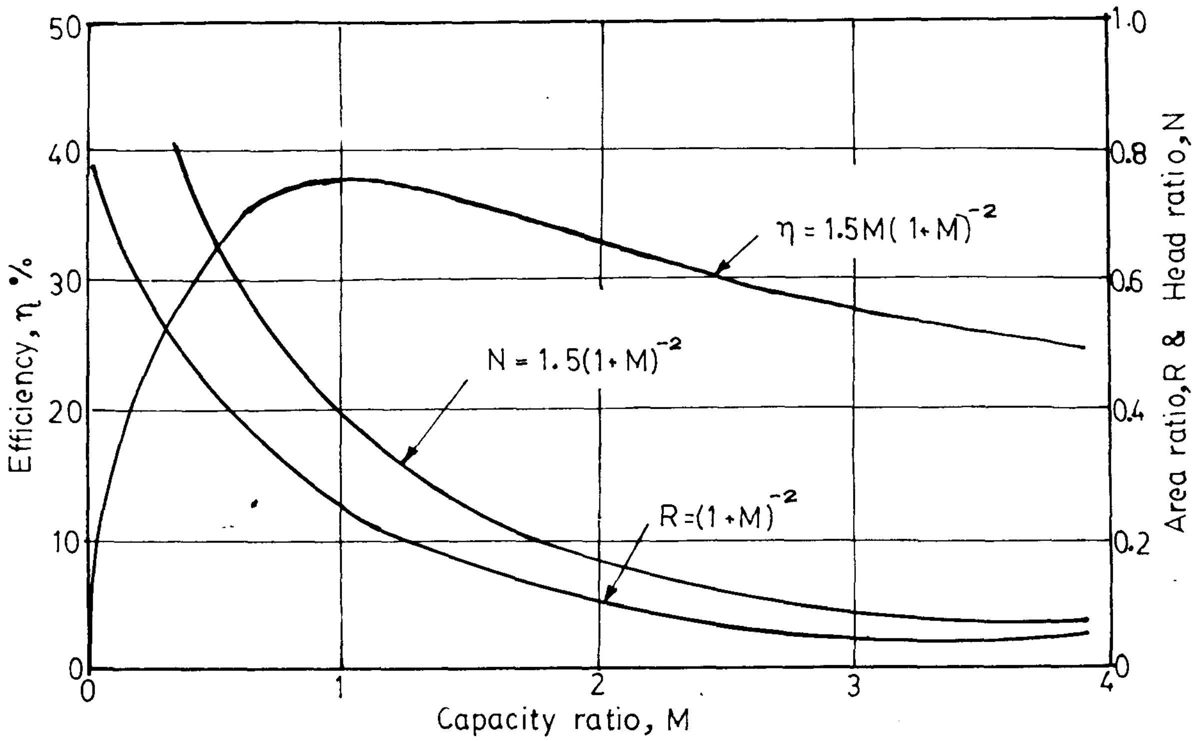


FIG.10. Design relationships of ejector system for various flow ratios (Samuel, 1975)

$$N^* = 1.5\ M^{*-2}(1 + 1.5\ M^{*-2})^{-1} \quad (14)$$

$$\eta^* = 1.5\ M^{*-1}(1 + 1.5\ M^{*-2})^{-1} \quad (15)$$

These relations are shown graphically in Fig.11 and Fig. 12.

It may be seen from the graphs that when we use a centrifugal ejector system combination, the efficiency will be higher in low lift applications than the conventional applications.

3.3.2 Design procedure

The prototype ejector system developed by Sankaranarayanan (1981) was designed to match two 5 hp pumpsets which were connected in series. He designed the ejector system of the following specifications.

Suction head (H_s)	= 1.5 m
Delivery head (H_d)	= 2.5 m
Head at nozzle (H_n)	= 40 m
Discharge Q	= 500 lpm at 40 m head
Diameter of the nozzle (D_n)	= 20 mm
Head ratio (N)	= 0.107
Nozzle throat area ratio (R)	= 0.0713
Flow ratio (M)	= 2.85
Diameter of throat (D_t)	= 75 mm

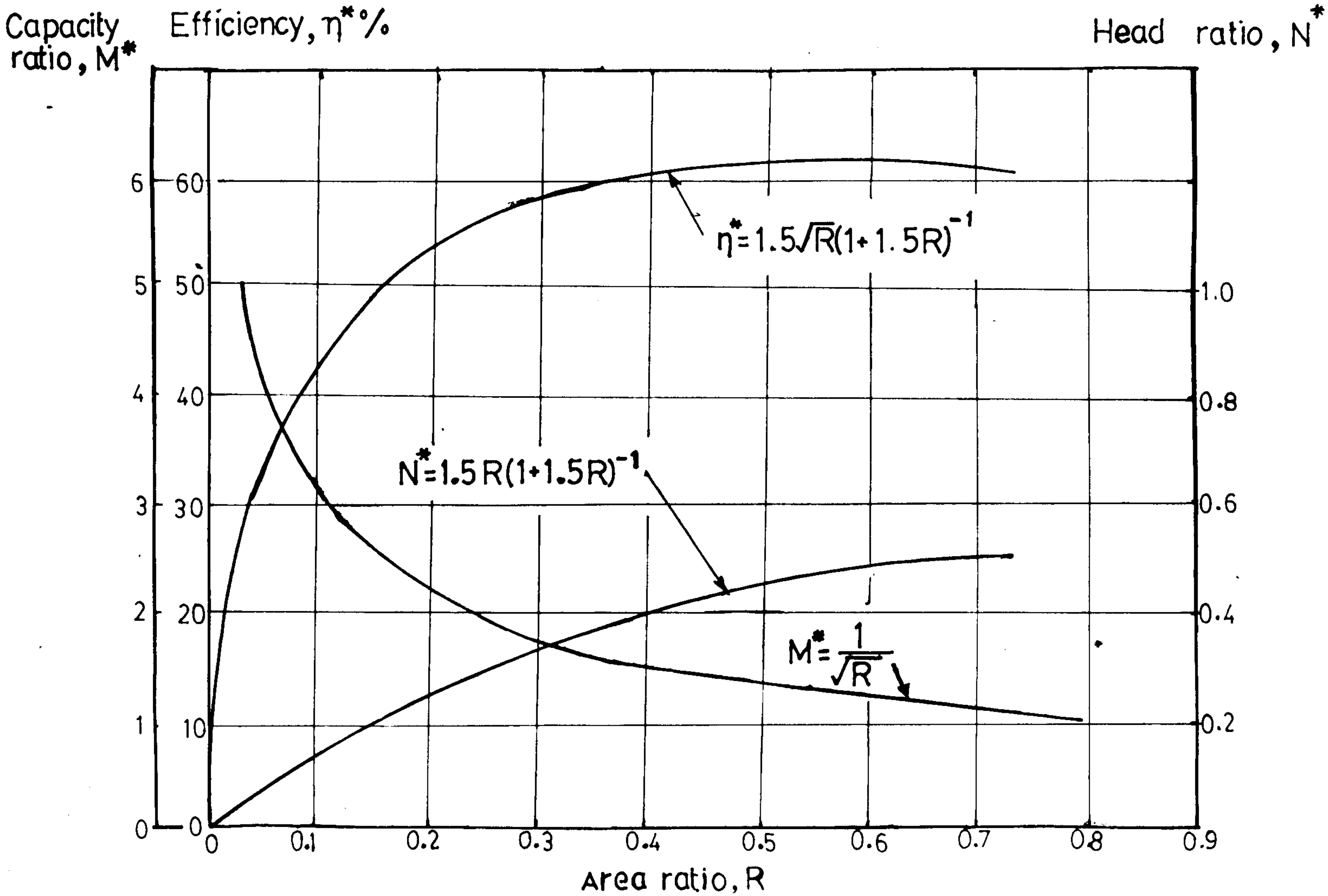


FIG.11. Design relationships for low lift applications in terms of area ratio (Samuel 1975)

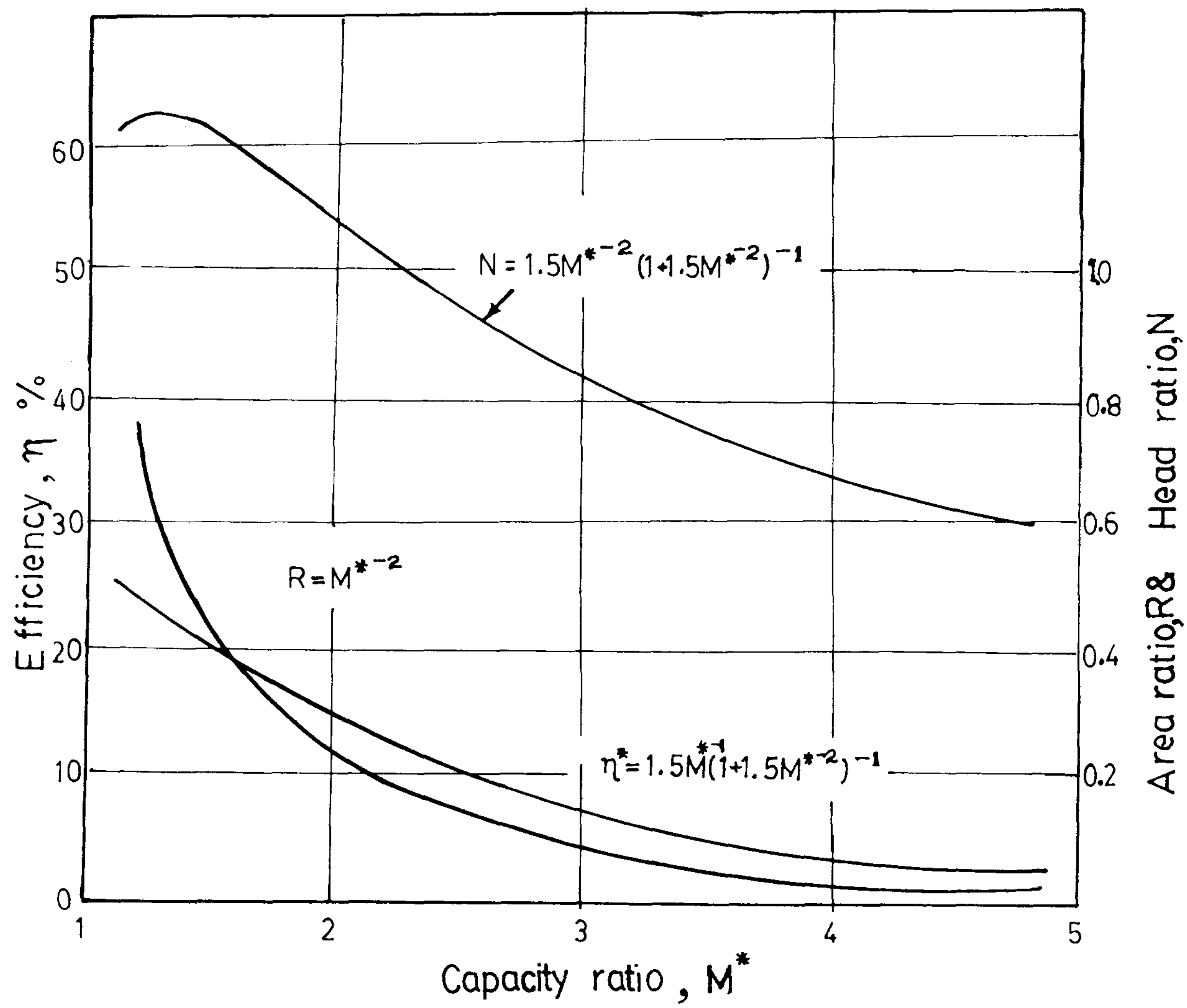


FIG.12. Design relationships for low lift applications in terms of capacity ratio (Samuel, 1975)

Even though the preliminary investigations were carried out by the pumpsets used by Sankaranarayanan, main observations were carried out on a high pressure single stage centrifugal pump operated with an 8 hp diesel engine. From the laboratory experiments conducted, the design discharge was chosen to be 400 lpm at 40 m head. From this the nozzle diameter (D_n) is calculated as follows

$$Q_n = C_d \times A_n \times V_n$$

where

Q_n - discharge through the nozzle

C_d - the coefficient of discharge

A_n - the area of the nozzle, and

V_n - the velocity of flow through the nozzle

$$V_n = \sqrt{2gH_n}$$

$$A_n = \frac{Q_n}{C_d \sqrt{2gH_n}}$$

substituting the values for Q_n, g, H_n and assuming

$$C_d = 0.95$$

$$A_n = \frac{400 \times 100 \times 100}{0.95 \times 1000 \times 100 \times \sqrt{2 \times 9.81 \times 40}}$$

$$= 2.505 \text{ cm}^2$$

$$A_n = \frac{\pi}{4} D_n^2$$

$$D_n = \sqrt{\frac{A_n \times 4}{\pi}} = \frac{2.505 \times 4}{\pi}$$

$$= 1.786 \text{ cm (selected a diameter of 18 mm)}$$

The main characteristics of the ejector system can now be determined as follows:

Assuming suction head (H_s) equal to 1.5 m to include entrance, sudden expansion and friction losses and delivery head (H_d) equal to 2.5 m to include velocity and friction head losses,

$$N^* = \frac{H_d - H_s}{H_p - H_s}$$

$$= \frac{2.5 - (-1.5)}{40 - (-1.5)}$$

$$= 0.096$$

$$N^* = \frac{1.5\ R}{1+1.5R}$$

$$0.096\ (1 + 1.5\ R) = 1.5\ R$$

$$0.096 + 0.144\ R = 1.5\ R$$

$$0.096 = 1.356\ R$$

$$R = 0.0709$$

$$M^* = \frac{1}{\sqrt{R}} = \frac{1}{\sqrt{0.0708}}$$

$$= 3.76$$

since

$$R = \frac{A_n}{A_t} = \frac{\frac{\pi D_n^2}{4}}{\frac{\pi D_t^2}{4}}$$

$$= \frac{D_n^2}{D_t^2}$$

$$D_t = D_n \sqrt{R}$$

$$= 18 \times \sqrt{0.0708}$$

$$= 67.6 \text{ mm (selected a diameter of 70 mm)}$$

The remaining dimensions of the ejector system were found out by the relations developed by Samuel (1975).

Throat length = 5 D_t = 5 x 70 = 350 mm

Nozzle spacing = 0.75 D_t = 0.75 x 70 = 52.5 mm

Throat entry profile = 90°

Diffuser angle = 7°

The expected efficiency of the ejector was found from the eqn.2

$$\eta^* = M^* \times N^*$$

$$= 37.6 \times 0.96 \times 100$$

$$= 36\%$$

3.4 Fabrication works

3.4.1 Ejector system

The nozzle was fabricated with 10 gauge sheet metal. The cone angle was taken as 16° and the nozzle length was calculated as 11.4 cm inorder to weld it to a piece of standard 50 mm GI pipe. A 50 mm GI coupling was provided on the suction chamber to which the nozzle was fitted. The pipe of the nozzle assembly was externally threaded to a length of 50 mm which enabled the adjustment of the nozzle throat spacing. While conducting preliminary investigations with the prototype ejector, it was noticed that clogging of the weeds inside the ejector, was a serious problem. In order to avoid clogging inside the ejector system and to study the effects of direction changes in primary and secondary flows, three different ejectors were fabricated with the above designed values (Plate I). The directions of the primary flow as well as secondary flows were changed in these ejectors as shown in Fig. 13, Fig. 14 and Fig. 15.

In the ejector (E_2), the primary flow was made straight and a direction change of about 40° was given to the secondary flow by using a portion of a 10 cm diameter 90° elbow as the suction chamber. Suitable attachments were welded so that it could be fixed to the throat and diffuser used for the earlier experiments.

Ejector (E_3) was also fabricated with the primary flow straight and a change of direction of about 20° was given to the secondary flow with the help of a portion of 10 cm diameter 90° bend.

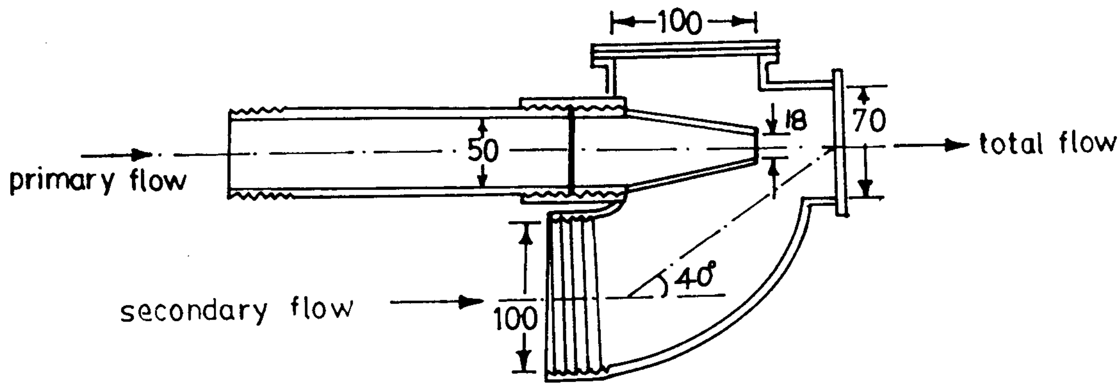


FIG. 13. 40° EJECTOR SYSTEM (E2)

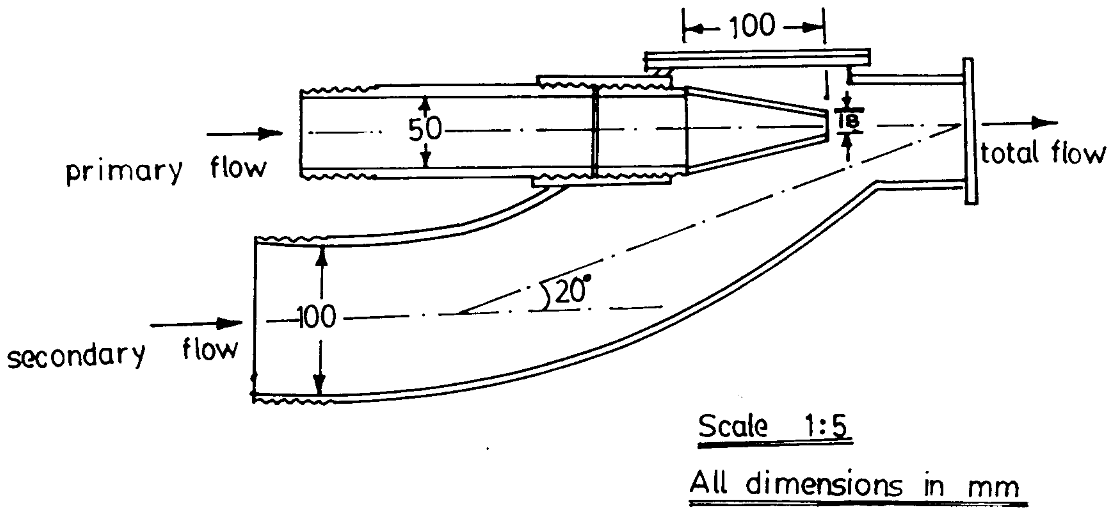


FIG. 14. 20° EJECTOR SYSTEM (E3)

The ejector (E_4) was fabricated with 16 gauge M.S.sheet with the secondary flow straight and a 30° change of direction to the primary flow. The ejector suction and discharge pipe size were chosen as 10 cm for convenience in handling and fitting of pipe connections. The suction line was extended by means of flexible pipe to the front portion where the mouth was to be fitted.

3.4.2 Feeding mouth

In the previous experiments of prototype Salvinia Harvester, a 10 cm diameter GI elbow was used as the feeding mouth. In order to get control over the feeding mouth, a new rectangular shaped mouth with two adjustable flaps was fabricated. The provision of adjustable flaps enabled the adjustments in mouth opening. The test results with the rectangular feeding mouth showed that the optimum size would be 30 cm x 7.5 cm. Hence an elliptical feeding mouth having major axis 30 cm and minor axis 7.5 cm was also fabricated. The details of these feeding mouths are shown in Fig. 16 and also in Plate II.

3.4.3 Floating fence

For the collection of the harvested weeds, a floating fence of size 150 x 150 x 120 cm was fabricated and its floatation was given by six air tight

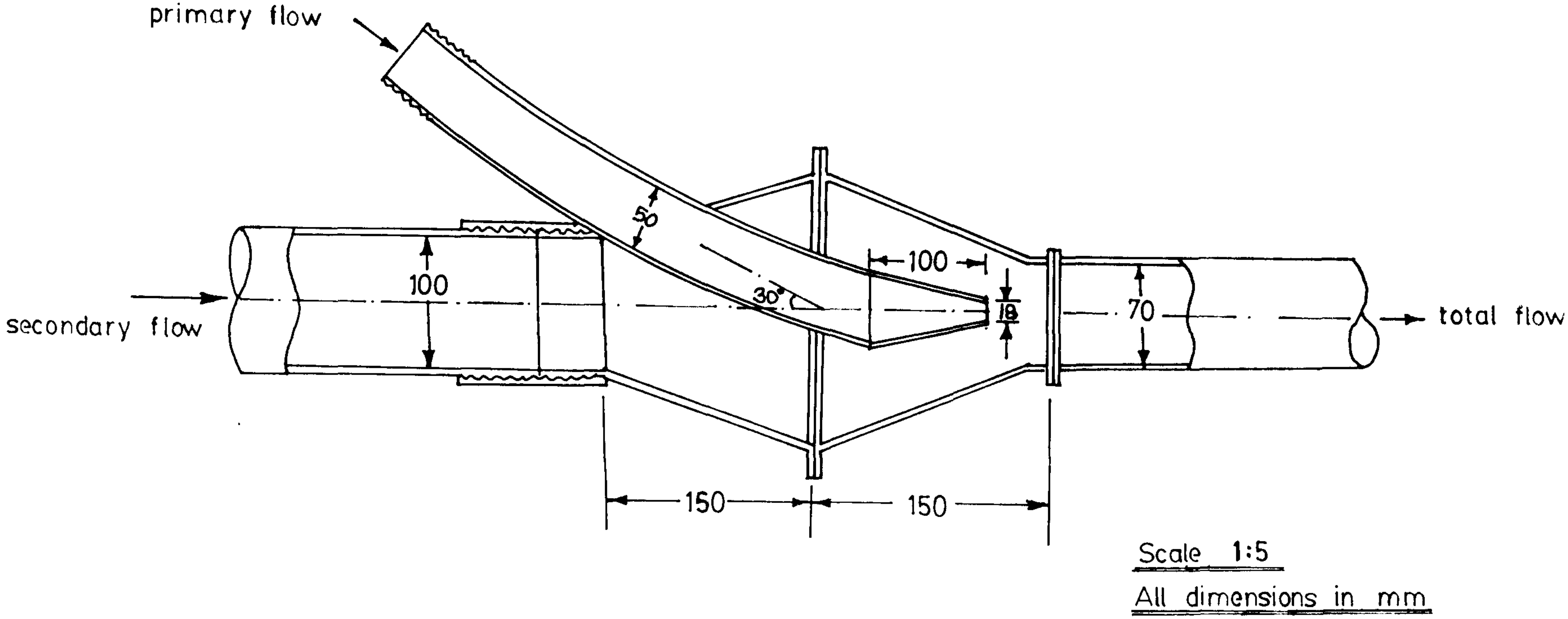


FIG.15. 30° EJECTOR SYSTEM (E4)

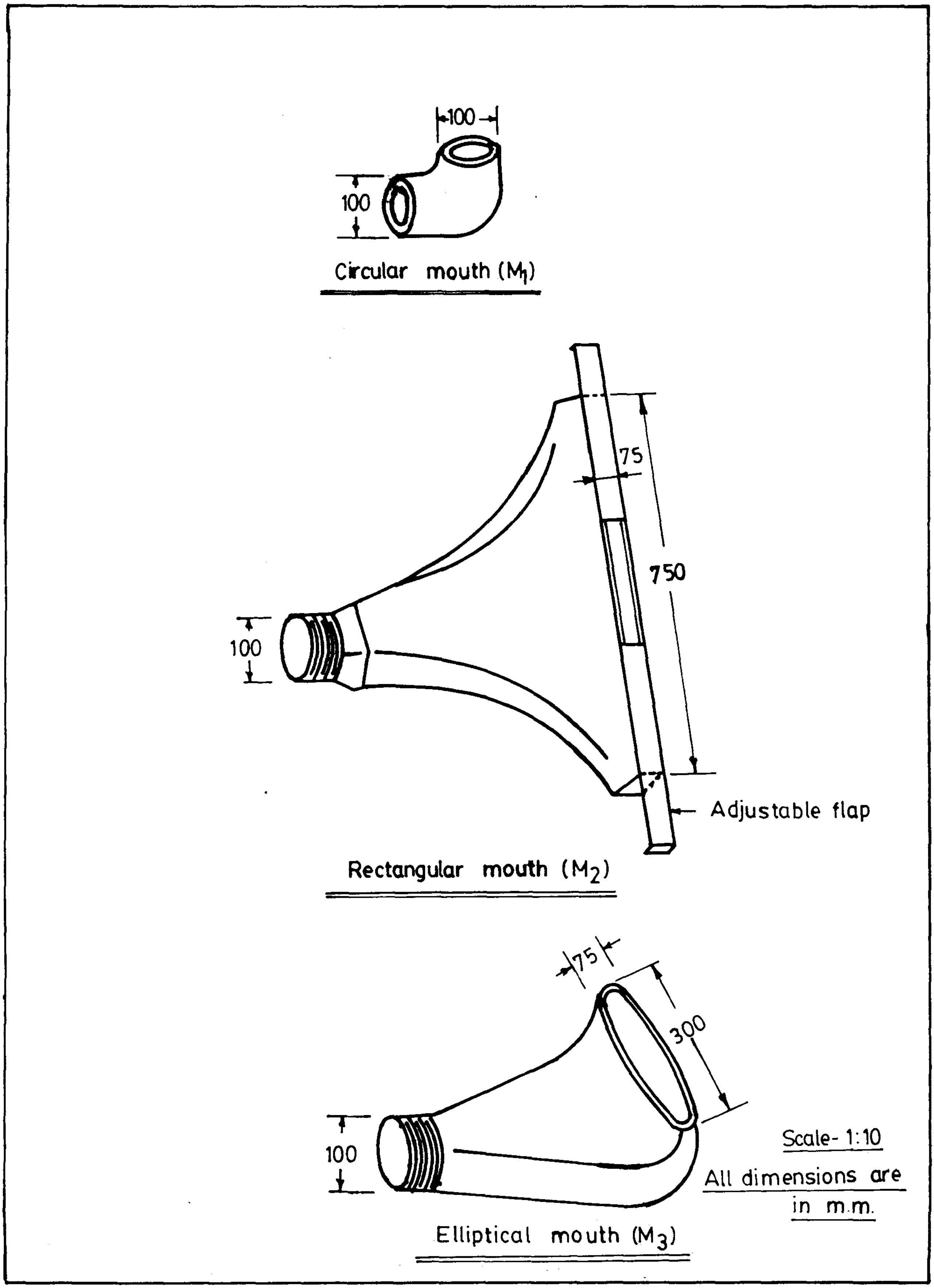


FIG.16. DIFFERENT FEEDING MOUTHS.

Plate I. Ejectors E_1, E_2, E_3 and E_4

Plate II. Feeding mouths M_1, M_2 and M_3


E1

polyethylene drums of 50 l capacity. The total weight of the floating fence was 80 kg, (Fig.17). Welded mesh (20 mm x 20 mm) was used to cover the sides and provision was also made to open one side for the easy removal of harvested salvinia from the floating fence. This floating fence was found essential for collecting the harvested salvinia, when the unit was operated as a self propelled one.

3.5 Experimental programme

3.5.1 Laboratory testing

Laboratory testing of the pumpsets were conducted to determine the capacity ratios with water alone. The performance of the two 5 hp pumpsets connected in series and the single 8 hp pumpset were tested at the Agricultural Engineering Research Workshop, Mannuthy (Plate III). The pumpsets were fitted on the available platform and operated to pump water from the tank into a 200 l capacity M.S. barrel and time for filling was noted. All the ejector systems (E_1, E_2, E_3 and E_4) were tested for the primary flow rate as well as the secondary flow rate, inorder to find out the capacity ratios.

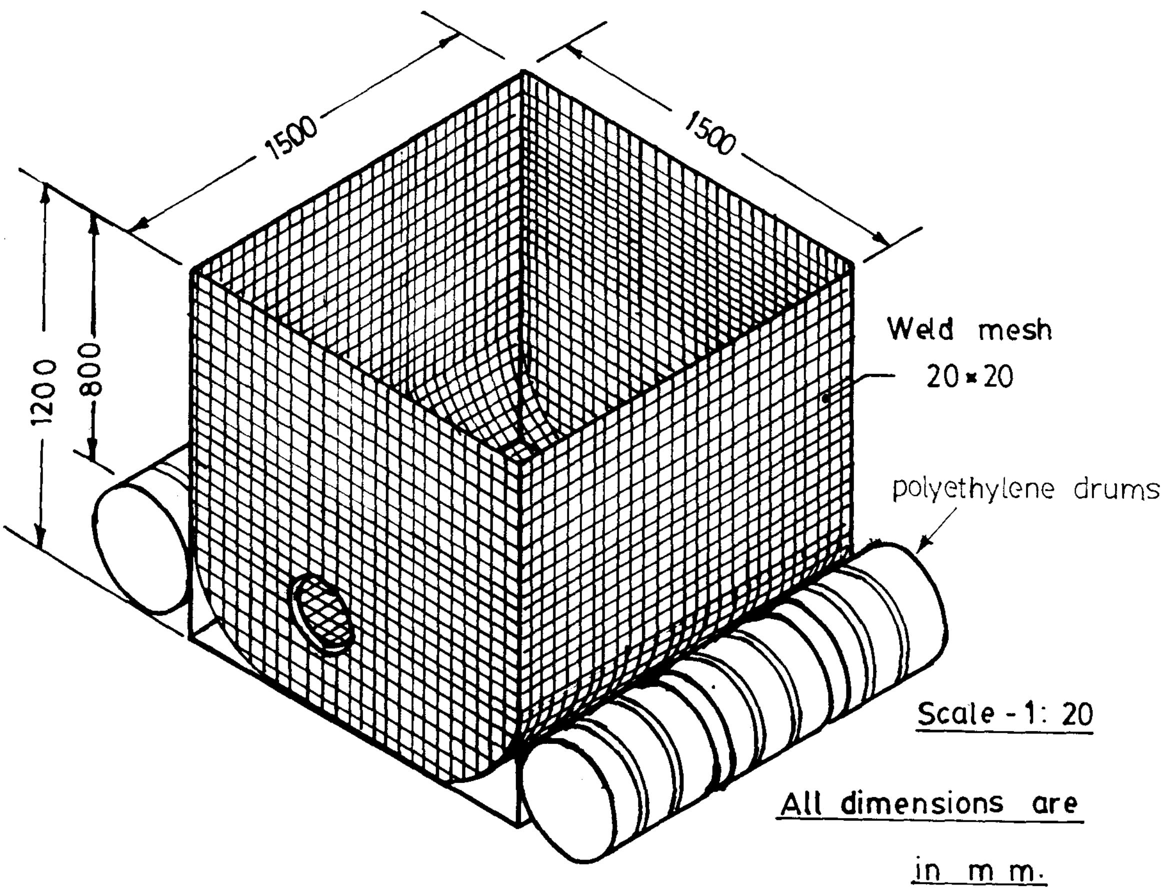


FIG. 17. FLOATING FENCE (an isometric view)

3.5.2 Field testing

3.5.2.1 Preliminary experiments

Preliminary investigations of the Salvinia Harvester were made with the prototype ejector (E_1). The floating platform available at the Engineering Research Workshop, Mannuthy was used for giving adequate flotation and as a base for fixing the ejector system as well as the pumpsets. Its floatation was tested at a local pond near Ollukkara Panchayat Office, Mannuthy.

3.5.2.2 Main experimental programme

The main experimental programme of the field testing of the Salvinia Harvester were conducted in the Kole lands of Trichur District. The field testing were conducted in two stages at two different locations of Kole lands, namely Nanthikkara and Pudukkadu. Plate IV shows the test field at Nanthikkara, heavily infested with salvinia.

The series of experiments conducted at Nanthikkara (32 km from Vellanikkara) during the first stage of testing included the investigations on

Plate III. Laboratory testing of ejector system

Plate IV. Salvinia infested test field at Nanthikkara

1. Spread density
2. Bulk density
3. Root ratio
4. Harvesting of salvinia into a 200 l capacity barrel
5. Harvesting of salvinia into a wire net fixed on the shore and
6. Harvesting of salvinia into the floating fence.

First stage of testing:

Test No.1 : Spread density

Spread density as defined in Chapter-II refers to the weight of immediately harvested drip dry salvinia per unit area. The weed within one sq. m. was encircled by means a coir tied around poles fixed at one metre apart and it was collected manually in a perforated trough. The weeds were collected from five different locations and weighed to give the spread density values.

Test No.2 : Bulk density

Two sets of bulk density measurements were made in this test; 1. bulk density before harvesting and 2. bulk density after harvesting with the machine. To do this, a cage of size 0.5 m x 0.5 m x 1 m was fabricated using angle irons for frame and the sides and bottom were closed with welded mesh. The salvinia was filled in it and its weight was noted after the water drained off. This experiment was also repeated for five different locations in order to get the average value.

Test No.3 : Root ratio

Root ratio is defined as the ratio of the weight of submerged leaves (roots) to the total weight of weed, after water drained off by gravity. According to different growth phases, the root length as well as the root ratio will be varying and hence for different root lengths the root ratios were determined. The root ratios were expressed in percentage. Plate V and VI show the difference in root lengths in different growth phases.

Test No.4 : Harvesting of salvinia into a 200 l capacity M.S. barrel

The harvested weed along with water was collected in the barrel to get an idea of the harvesting capacity of the different ejector systems fabricated (E_1, E_2 and E_3) and the affect of feeding months M_1 and M_2. The harvesting capacity of the following combinations of ejector systems and mouths were tested.

Plave V. Salvinia in the initial stages of first growth phase (root length $<$ 20 cm)

Plate VI. Salvinia in the initial stages of third growth phase (root length $>$ 60 cm)

1. $E_1 - M_1$

2. $E_1 - M_2$

3. $E_2 - M_1$

4. $E_2 - M_2$

5. $E_3 - M_1$ and

6. $E_3 - M_2$

These combinations were also tested under different depths of feeding mouth below the water surface. Each experiment was repeated five times to get the average harvesting capacity.

Test No.5 : Harvesting of salvinia into a wire net fixed on the shore

In order to ascertain the continuous operation of the harvester, salvinia was pumped into a wire net fixed on the shore, with all the combinations tried in the previous test.

Test No. 6 : Harvesting of salvinia into the floating fence

The delivery of the ejector system was placed inside the floating fence through a hole made at the front side of the floating fence and this enabled the pumping of salvinia directly into the floating fence.

Observations were also carried out to find the capacity of floating fence and the weight of weeds was noted when the floating fence was about to sink. All the different combinations were again tested to find out the harvesting capacity at a static head of about 40 cm. Field operation of Salvinia Harvester is shown in Plates VII and VIII.

Second stage of testing:

The second stage of testing was conducted at Pudukkadu (28 km from Vellanikkara) in an isolated pond. The properties of salvinia like spread density, bulk density and root ratio were also found for this area. The ejector E_4 and the feeding mouth M_3, fabricated after the first stage testing were subjected to test during this stage. The combinations E_4 & M_1, E_4 & M_2, E_4 & M_3, E_1 & M_3, E_2 & M_3 and E_3 & M_3 were tested as in the test No. 4, 5 and 6 of the first stage.

The results obtained are tabulated and discussed in detail, in the next chapter.

Plate VII. Salvinia Harvester in the field

Plate VIII. Salvinia being pumped into the floating fence

Results and Discussion

RESULTS AND DISCUSSION

The results of laboratory studies as well as the field tests of the Salvinia Harvester in two stages are discussed separately in this chapter.

4.1 Laboratory tests

4.1.1 Head-discharge relationship of pumpset

The results of the laboratory tests conducted with the 8 hp high pressure pumpset are given in Table 5 and it is graphically presented in Fig. 18. From the test results the design discharge was chosen as 400 lpm at the required nozzle head of 40 m.

4.1.2 Testing of ejector systems

The results of laboratory tests to findout the capacity ratios of various ejector systems (E_1, E_2, E_3 & E_4), are given in Tables 6 to 9. The ejector E_1 was designed and tested for two 5 hp pumpsets connected in series whereas the other ejectors were designed and tested for the 8 hp high pressure pumpset.

It may be seen from the tables that the capacity ratio for ejector E_1 is 3.76 where the primary flow was given a change in direction of 90°, and for the other ejectors namely E_2, E_3 and E_4 the values are 3.62, 4.03 and 3.75 respectively. Among the two

Table 5. Performance of 8 hp high pressure pumpset

Sl. No.	Suction head		Delivery head		Quantity of water collected (l)	Average time taken (s)	Discharge	
	cm of Hg	m of water	kg/cm^2	m of water			lps	lpm
1.	4.0	0.544	1.0	10.0	200	25.30	7.9	474
2.	4.0	0.544	2.0	20.0	200	25.63	7.8	468
3.	3.5	0.476	3.0	30.0	200	26.90	7.4	446
4.	4.0	0.544	4.0	40.0	200	29.00	6.9	416
5.	5.0	0.680	5.0	50.0	200	44.90	4.8	267

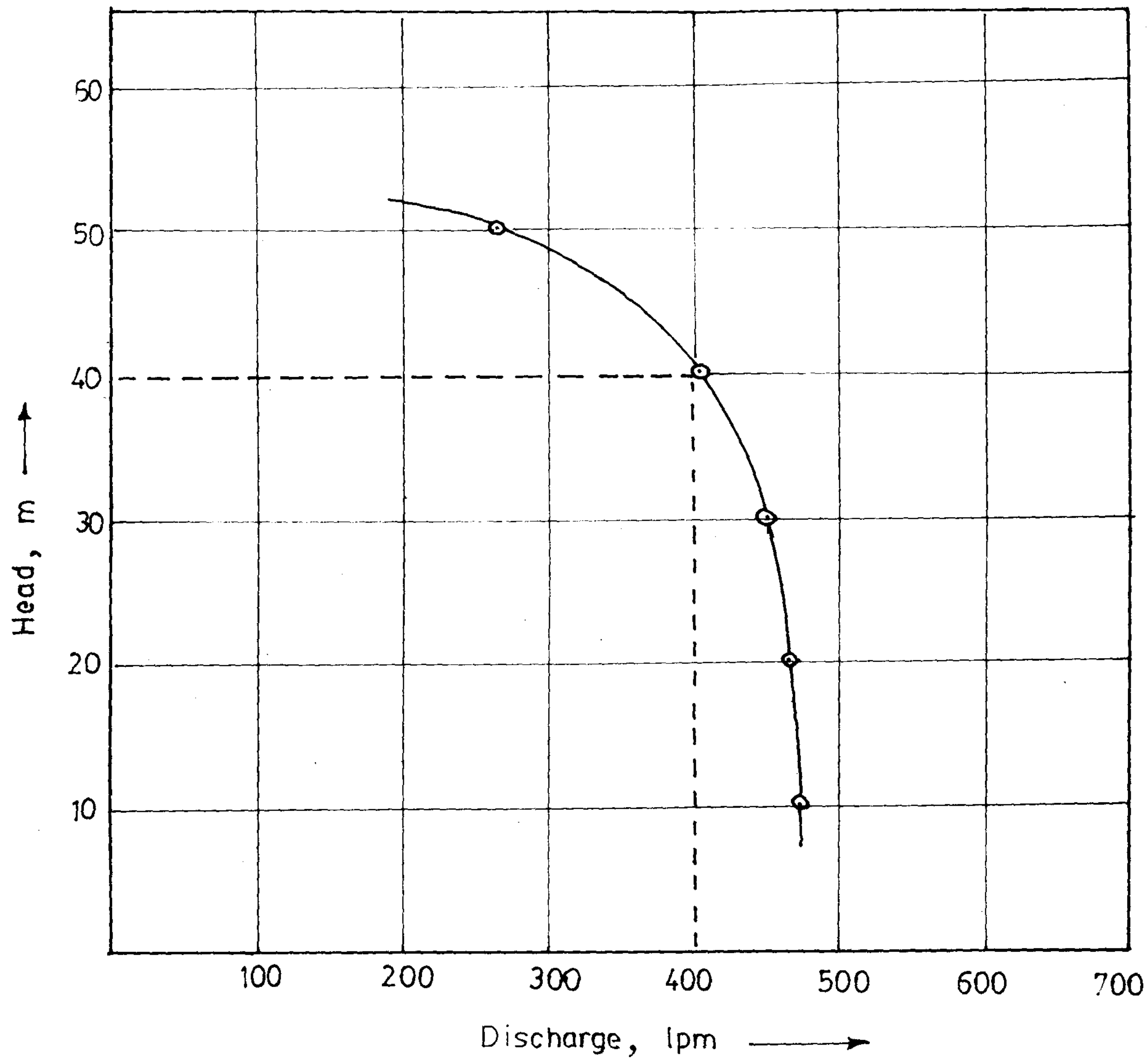


FIG.18. HEAD DISCHARGE RELATIONSHIP OF 8hp HIGH PRESSURE PUMPSET

Table 6. Capacity ratio of $E_1 - M_1$ combination, static lift of one metre

Sl. No.	Pressure developed (kg/cm^2)	Primary flow			Total flow (primary flow+secondary flow)			Capacity ratio
		Quantity of water collected (l)	Time taken (s)	Discharge (lps)	Quantity of water collected (l)	Time taken (s)	Discharge (lps)	
1.	5.0	200	25.5	7.84	200	6.6	30.30	3.86
2.	5.0	200	25.1	7.97	200	6.8	29.41	3.69
3.	5.0	200	25.2	7.94	200	6.7	29.85	3.76
4.	5.0	200	25.3	7.91	200	6.8	29.41	3.72
5.	5.0	200	25.2	7.94	200	6.7	29.85	3.76
			Average	7.92			29.76	3.76

Table 7. Capacity ratio of $E_2 - M_1$ combination, static lift of one metre

Sl. No.	Pressure developed (kg/cm^2)	Quantity of water collected (l)	Primary flow		Total flow (Primary + Secondary)		Capacity ratio
			Time taken (s)	Discharge (l)	Time taken (s)	Discharge (l)	
1	4.1	200	26.5	7.55	7.5	26.67	3.53
2	4.0	200	26.8	7.46	7.2	27.78	3.72
3	4.0	200	27.6	7.25	7.6	26.32	3.63
4	4.1	200	26.7	7.49	7.5	26.67	3.56
5	4.0	200	27.1	7.38	7.4	27.03	3.66
			Average	7.43		26.89	3.62

Table 8. Capacity ratio of $E_3 - M_1$ combination, static lift of one metre

Sl. No.	Pressure developed kg/cm^2	Quantity of water collected (l)	Primary flow		Total flow (Primary + Secondary)		Capacity ratio
			Time taken (s)	Discharge (l)	Time taken (s)	Discharge (l)	
1	4.0	200	26.5	7.55	6.4	31.25	4.14
2	4.0	200	28.6	7.52	7.0	28.57	3.80
3	4.0	200	26.5	7.55	6.6	30.30	4.01
4	4.1	200	26.9	7.43	6.5	30.77	4.14
5	4.0	200	26.7	7.49	6.6	30.30	4.05
			Average	7.51		30.24	4.03

Table 9. Capacity ratio of E_4 - M_1 combination, static lift of one metre

Sl. No.	Pressure developed kg/cm^2	Quantity of water collected (l)	Primary flow Time taken (s)	Primary flow Discharge (l)	Total flow Time taken (s)	Total flow Discharge (l)	Capacity ratio
1	4.0	200	30.5	6.56	7.8	25.64	3.91
2	4.1	200	31.0	6.45	8.0	25.00	3.88
3	4.1	200	29.8	6.71	8.3	24.10	3.59
4	4.0	200	30.2	6.62	8.3	24.10	3.64
5	4.0	200	30.4	6.58	8.1	24.69	3.75
			Average	6.58		24.71	3.75

ejectors E_2 and E_3 with primary flow straight and secondary flow inclined the ejector E_3 which was given less change of direction to the secondary flow yielded a better capacity ratio of 4.03 than the other ejector E_2 with a value of 3.62. These results showed that the change of direction of the primary as well as the secondary flow has got direct influence in the capacity ratio. When the change of direction of the primary flow increases, the capacity ratio decreases. Similar is the case with the change of direction of the secondary flow also.

4.2 First stage field tests

4.2.1 Properties of salvinia

4.2.1.1 Spread density

The spread density values obtained at Nanthikkara during the first stage field experiments are given in Table 10.

Table 10. Spread density of salvinia in an isolated pond at Nanthikkara

Trial No.	Area covered (m^2)	Weight of salvinia (kg)	Spread density (kg/m^2)
1.	1.0	59.0	59.0
2.	1.0	62.5	62.5
3.	1.0	56.5	56.5
4.	1.0	60.5	60.5
5.	1.0	63.0	63.0
		Average	60.3

This shows that the average spread density values were around 60 kg/m^2, which was higher than the value of 16 kg/m^2 (160 t/ha) reported by Sankaranarayanan (1981). The higher values are due to the change in the growth phase as well as the increased root length. The isolated pond at Nanthikkara was heavily infested with salvinia in the third growth phase which had root length even up to 80 cm.

4.2.1.2 Bulk density

The bulk density values of the floating salvinia and harvested salvinia were found. The bulk density values after harvesting would be important for calculating the cost of transport of the harvested salvinia. The values obtained are listed in Table 11 and Table 12.

Average bulk density value of the floating weed was 370 kg/m^3 and this was in agreement with the values obtained previously by Sankaranarayanan (1981). This indicated that the changes in the growth phase would not have much effect on bulk density. The bulk density of harvested salvinia was found to be about 330 kg/m^3. The reduction in weight could be attributed to the removel of some amount of water from salvinia while it passes through the suction chamber.

Table 11. Bulk density of the floating salvinia (volume of the cage is 0.125 m^3 and weight of the cage is 10.5 kg)

Sl. No.	Weight of Cage + Salvinia (kg)	Weight of salvinia (kg)	Bulk density (kg/m^3)
1.	58.0	47.5	380
2.	54.5	44.0	352
3.	56.5	46.0	368
4.	58.5	48.0	384
5.	56.0	45.5	364
		Average	370

Table 12. Bulk density of harvested salvinia (volume of the cage is 0.25 m^3 and weight of the cage is 10.5 kg)

Sl. No.	Weight of Cage + Salvinia (kg)	Weight of salvinia (kg)	Bulk density (kg/m^3)
1.	96.0	85.5	342
2.	91.0	80.5	322
3.	92.5	82.0	328
4.	93.5	83.0	332
5.	88.0	77.5	310
		Average	330

4.2.1.3 Root ratio

The data relating to the measurements of root length as well as root ratio, under different growth phases, are presented in Table 13. The values showed that the weight of the salvinia weed in second and third growth phase is mostly the weight of roots (actually the submerged leaves). The weight of roots in most cases contributed more than three-fourth of the total weight of the weed in the third phase of growth. The relation between root length and root ratio is presented graphically in Fig. 19 and it gives that as the root length increases the root ratio also increases. The significance of root ratio and root length in the harvesting capacity is discussed in the subsequent sections of this chapter.

4.2.2 Harvesting of salvinia into a 200 l capacity barrel

4.2.2.1 E_1 - M_1 combination

The results obtained when E_1 - M_1 combination was tested under different depths of feeding mouth below the water surface are given in Table 14. From the visual observations itself, it was found that no weed was sucked in, when the feeding mouth was kept at less than or equal to 4 cm below the water surface.

Table 13. Ratio ratio of salvinia under different growth phases

Growth phase with root length	Sl. No.	Weight of sample (g)	Weight of leaves (g)	Weight of root (g)	Root ratio (%)	Average root ratio (%)
	1	370	220	150	40.5	
First growth phase	2	420	220	200	47.6	46.0
(< 20 cm)	3	480	240	240	50.0	
Initial stage of	1	480	125	355	74.0	
Second growth phase	2	335	115	220	65.7	69.0
(20-40 cm)	3	425	135	290	68.2	
Later stage of	1	470	130	340	72.3	
Second growth phase	2	550	130	420	76.4	76.0
(40-60 cm)	3	380	80	300	78.9	
Initial stage of	1	580	100	480	82.7	
Third growth phase	2	510	60	450	88.2	83.0
(> 60 cm)	3	350	80	270	77.1	

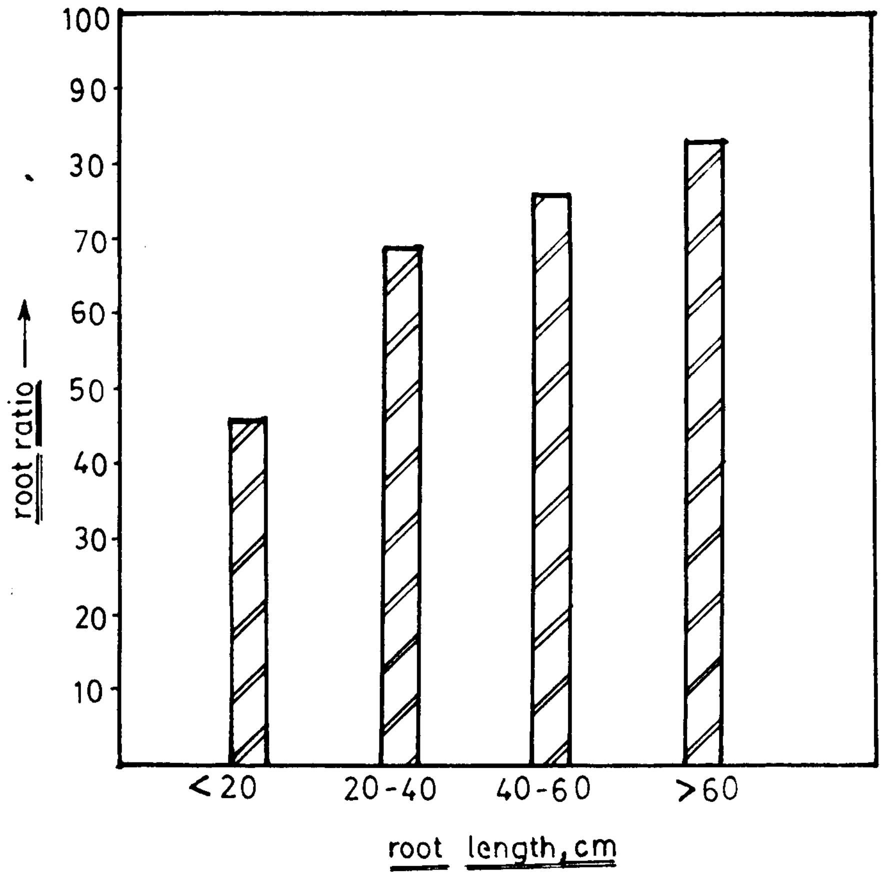


FIG.19. Root ratio variation with root length

Table 14. Harvesting capacity of $E_1 - M_1$ combination under different depths of feeding mouth

Depth of mouth below water surface (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	10.2	22.0	7.76	
	2	9.8	19.0	6.98	
6	3	10.4	21.0	7.27	7.26
	4	10.8	22.0	7.33	
	5	9.6	18.5	6.94	
	1	9.6	28.0	10.50	
	2	9.9	30.0	10.91	
8	3	9.8	26.5	9.73	10.40
	4	9.4	29.0	11.11	
	5	9.6	26.0	9.75	
	1	9.1	25.0	9.89	
	2	7.1	22.5	11.41	
10	3	9.3	26.5	10.26	10.82
	4	8.0	24.0	10.80	
	5	7.2	23.5	11.75	
	1	9.2	21.5	8.41	
	2	8.5	19.5	8.26	
12	3	8.8	22.5	9.20	8.64
	4	7.9	18.0	8.20	
	5	8.1	20.5	9.11	
	1	7.8	13.0	6.00	
	2	8.3	15.5	6.72	
14	3	8.1	17.5	7.78	6.61
	4	8.5	14.5	6.61	
	5	7.9	13.0	5.92	

This is due to the low suction created at the mouth and the prevention of free movement of weeds by the mouth edges. Hence observations were made only from 6 cm depth onwards. When the mouth was kept at depths of 8 cm and 10 cm collection was maximum and was in the order of 10.40 t/hr and 10.82 t/hr. When the depth of mouth below water surface was further increased, the harvesting capacity was again found to decrease. This is due to the reduction in the area influenced by the suction as the depth of mouth increases. The trends in the harvesting capacity due to different depths of feeding mouth below water surface is presented in the graph given as Fig. 20.

Eventhough the earlier test results by Sankaranarayanan (1981) showed that the machine achieved a maximum harvesting capacity of 16 t/hr at Kuttanadu region, the present test with the same ejector and mouth gave only 10.82 t/hr at a static lift of 1 m. The reduction in harvesting capacity is due to the change in growth phases of the salvinia along with the presence of long roots. The spread density values reported by Sankaranarayanan (1981) at his test locality (Kuttanadu) was only 16 kg/m^2. Whereas at the present locality (Nanthikkara, Trichur Kole lands) the value was 60 kg/m^2. This itself shows the variation of weed concentration in the two

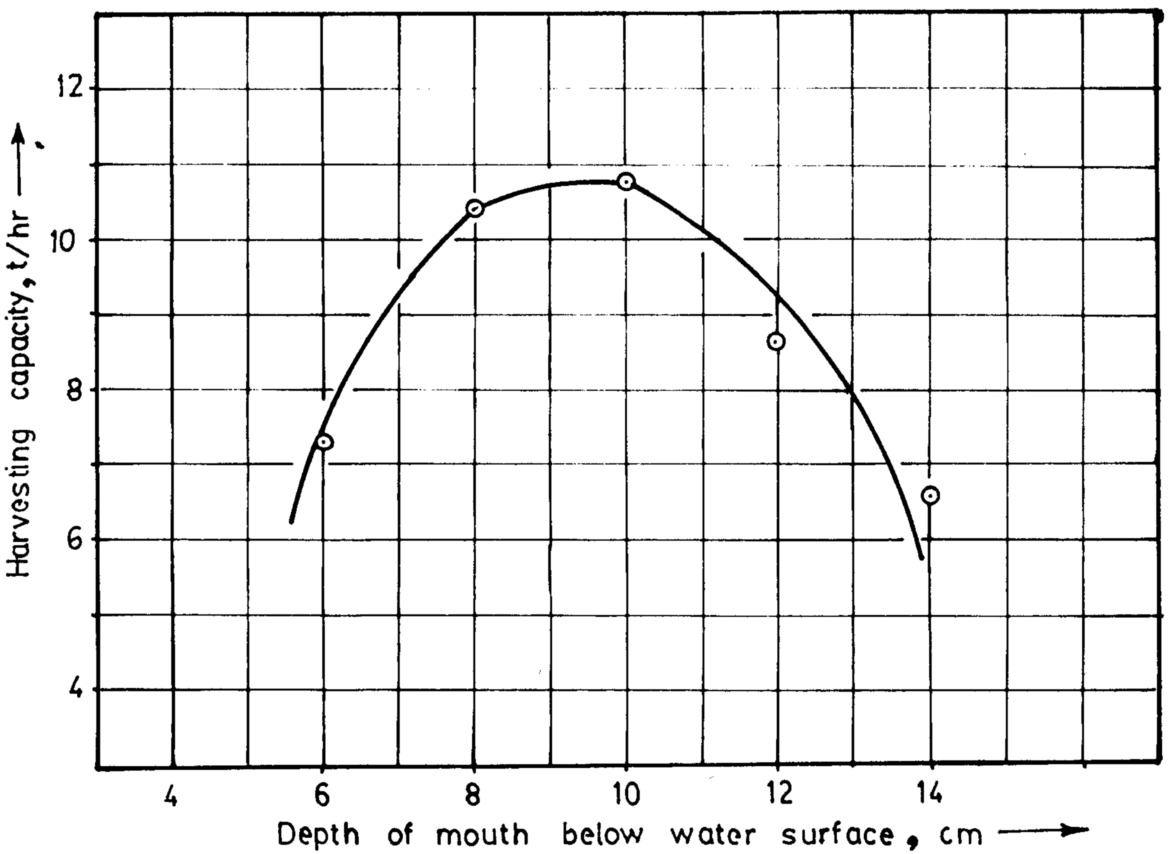


FIG.20. HARVESTING CAPACITY OF E_1-M_1

test localities. Regarding the static lift condition 16 t/hr was achieved at almost zero lift condition, while 10.82 t/hr was obtained at a static lift of about one metre. Another important factor noticed during the testing of $E_1 - M_1$ combination was intermittent clogging of the weeds inside the ejector system. The clogging was observed due to the presence of longer submerged leaves (roots). The chance of clogging with such long roots is high in the present combination. In the above test, the maximum time operated without clogging or any other problem was only 20 minutes. Hence it is evident that the prototype Salvinia Harvester with $E_1 - M_1$ combination cannot be used for effective harvesting of Salvinia under all field conditions.

4.2.2.2. $E_1 - M_2$ combination

Tables 15 to 20 give harvesting capacity values of $E_1 - M_2$ combination under different mouth openings and for various depths of feeding mouth below water surface. The average capacities obtained with $E_1 - M_2$ combination is represented in Fig. 21. The graph shows that the peak values are always attained at 10 cm depth of feeding mouth below the water surface.

The width of the rectangular mouth was kept at 7.5 cm and the length of mouth was adjusted from

Table 15. Harvesting capacity of $E_1 - M_2$ combination for a mouth opening 15 cm x 7.5 cm, under different depths

Depth of mouth (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	8.4	8.0	3.43	
	2	9.2	14.5	5.67	
6	3	8.1	10.0	4.44	4.24
	4	8.1	8.5	3.83	
	5	8.5	9.0	3.81	
	1	9.5	17.5	6.63	
	2	9.6	19.0	7.60	
8	3	8.8	14.5	5.93	6.89
	4	9.1	17.5	6.92	
	5	9.3	19.0	7.35	
	1	8.9	19.0	7.68	
	2	10.3	22.5	7.86	
10	3	10.3	20.5	7.17	7.78
	4	9.3	22.0	8.52	
	5	9.6	20.5	7.69	
	1	9.2	17.5	6.85	
	2	8.9	19.0	7.69	
12	3	8.7	17.5	7.24	7.38
	4	9.2	20.0	7.83	
	5	8.9	18.0	7.28	
	1	8.5	11.5	4.87	
	2	8.1	9.0	4.00	
14	3	9.2	11.5	4.50	4.56
	4	8.8	10.5	4.30	
	5	9.8	14.0	5.14	

Table 16. Harvesting capacity of $E_1 - H_2$ combination for a mouth opening 20 cm x 7.5 cm, under different depths of mouth

Depth of mouth (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	9.1	13.0	5.14	
	2	8.8	11.5	4.70	
6	3	9.6	16.0	6.00	5.28
	4	8.4	11.0	4.71	
	5	9.2	15.0	5.87	
	1	8.9	19.5	7.89	
	2	9.6	23.5	8.81	
8	3	9.5	24.5	9.28	8.38
	4	8.3	15.5	6.72	
	5	9.8	25.0	9.18	
	1	9.8	21.5	7.90	
	2	10.5	25.0	8.57	
10	3	9.8	23.5	8.63	8.23
	4	9.2	31.5	8.41	
	5	9.1	21.5	7.66	
	1	9.4	21.5	8.23	
	2	8.2	15.5	6.80	
12	3	8.7	18.0	7.45	7.45
	4	8.3	17.5	7.59	
	5	9.0	18.0	7.20	
	1	8.2	11.0	4.83	
	2	8.8	13.5	5.52	
14	3	8.5	13.0	5.51	5.21
	4	9.0	15.5	6.20	
	5	8.1	9.0	4.00	

Table 17. Harvesting capacity of $E_1 - M_2$ combination for a mouth opening 25 cm x 7.5 cm under different depths of mouth

Depth of mouth (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	9.8	17.0	6.24	
	2	9.2	13.5	5.40	
6	3	8.9	14.5	5.87	5.84
	4	9.4	17.5	6.70	
	5	7.9	11.0	5.01	
	1	9.4	19.5	7.47	
	2	9.8	23.0	8.45	
8	3	8.8	20.0	8.18	8.33
	4	10.0	25.0	9.00	
	5	9.7	23.0	8.54	
	1	10.2	25.0	8.82	
	2	9.8	25.5	9.37	
10	3	9.4	23.0	8.81	8.91
	4	10.0	24.5	8.82	
	5	9.5	23.0	8.72	
	1	8.8	19.0	7.77	
	2	9.2	21.5	8.41	
12	3	8.9	19.0	7.69	7.98
	4	9.4	21.5	8.23	
	5	9.0	19.5	7.80	
	1	8.8	16.5	6.75	
	2	8.1	14.5	6.44	
14	3	8.6	16.5	6.91	6.61
	4	8.2	16.0	7.02	
	5	7.9	13.0	5.92	

Table 18. Harvesting capacity of E_1 - M_2 combination for a mouth opening 30 cm x 7.5 cm under different depths of mouth

Depth of mouth (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	9.1	17.5	6.92	
	2	9.4	21.5	8.23	
6	3	9.2	19.0	7.43	7.20
	4	10.1	19.5	6.95	
	5	8.9	16.0	6.47	
	1	9.7	22.5	8.35	
	2	10.4	26.5	9.17	
8	3	10.6	27.5	9.34	8.97
	4	9.9	24.0	8.72	
	5	9.5	24.5	9.28	
	1	10.2	27.0	9.53	
	2	10.4	26.0	9.00	
10	3	9.9	25.0	9.09	9.25
	4	10.1	26.0	9.27	
	5	10.2	26.5	9.35	
	1	9.5	23.5	8.91	
	2	9.5	24.5	9.28	
12	3	8.9	22.5	9.10	8.80
	4	9.2	21.5	8.41	
	5	9.3	21.5	8.32	
	1	8.1	14.5	6.44	
	2	8.5	15.0	6.35	
14	3	8.9	18.0	7.28	6.60
	4	8.5	16.5	6.99	
	5	8.8	14.5	5.93	

Table 19. Harvesting capacity of E_1 - M_2 combination for a mouth opening 35 cm x 7.5 cm under different depths of mouth

Depth of mouth (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	10.0	20.5	7.38	
	2	10.4	18.0	6.23	
6	3	9.8	18.0	6.61	6.82
	4	10.3	19.5	6.82	
	5	10.7	21.0	7.07	
	1	9.9	21.5	7.82	
	2	10.8	25.5	8.50	
8	3	10.1	23.0	8.20	8.18
	4	10.5	23.0	7.89	
	5	11.0	26.0	8.51	
	1	10.5	24.0	8.23	
	2	10.3	23.5	8.21	
10	3	10.8	27.0	9.0	8.50
	4	10.3	24.5	8.56	
	5	10.4	24.5	8.48	
	1	9.9	22.0	8.00	
	2	10.7	25.0	8.41	
12	3	9.8	21.5	7.90	8.13
	4	10.0	22.5	8.10	
	5	10.5	24.0	8.23	
	1	8.2	12.5	5.49	
	2	9.1	15.0	5.93	
14	3	8.7	14.5	6.00	5.84
	4	8.3	12.0	5.20	
	5	9.3	17.0	6.58	

Table 20. Harvesting capacity of E_1 - M_2 combination for a mouth opening 40 cm x 7.5 cm under different depths of mouth

Depth of mouth (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	10.8	18.5	6.17	
	2	10.2	15.0	5.29	
6	3	9.8	13.0	4.78	5.38
	4	11.2	18.5	5.95	
	5	10.3	13.5	4.72	
	1	10.7	17.0	5.72	
	2	11.2	16.0	5.14	
8	3	10.8	14.5	4.83	5.40
	4	10.8	17.5	5.83	
	5	11.8	18.0	5.49	
	1	11.3	22.0	7.01	
	2	10.8	23.5	7.83	
10	3	10.3	21.0	7.34	7.16
	4	10.7	20.0	6.73	
	5	11.0	21.0	6.87	
	1	10.4	21.0	7.27	
	2	10.1	18.0	6.42	
12	3	10.3	21.5	7.51	7.00
	4	9.7	18.5	6.87	
	5	9.8	18.5	6.94	
	1	9.9	13.0	4.73	
	2	9.1	10.5	4.15	
14	3	8.9	9.5	3.84	4.32
	4	9.2	11.0	4.30	
	5	9.8	12.5	4.59	

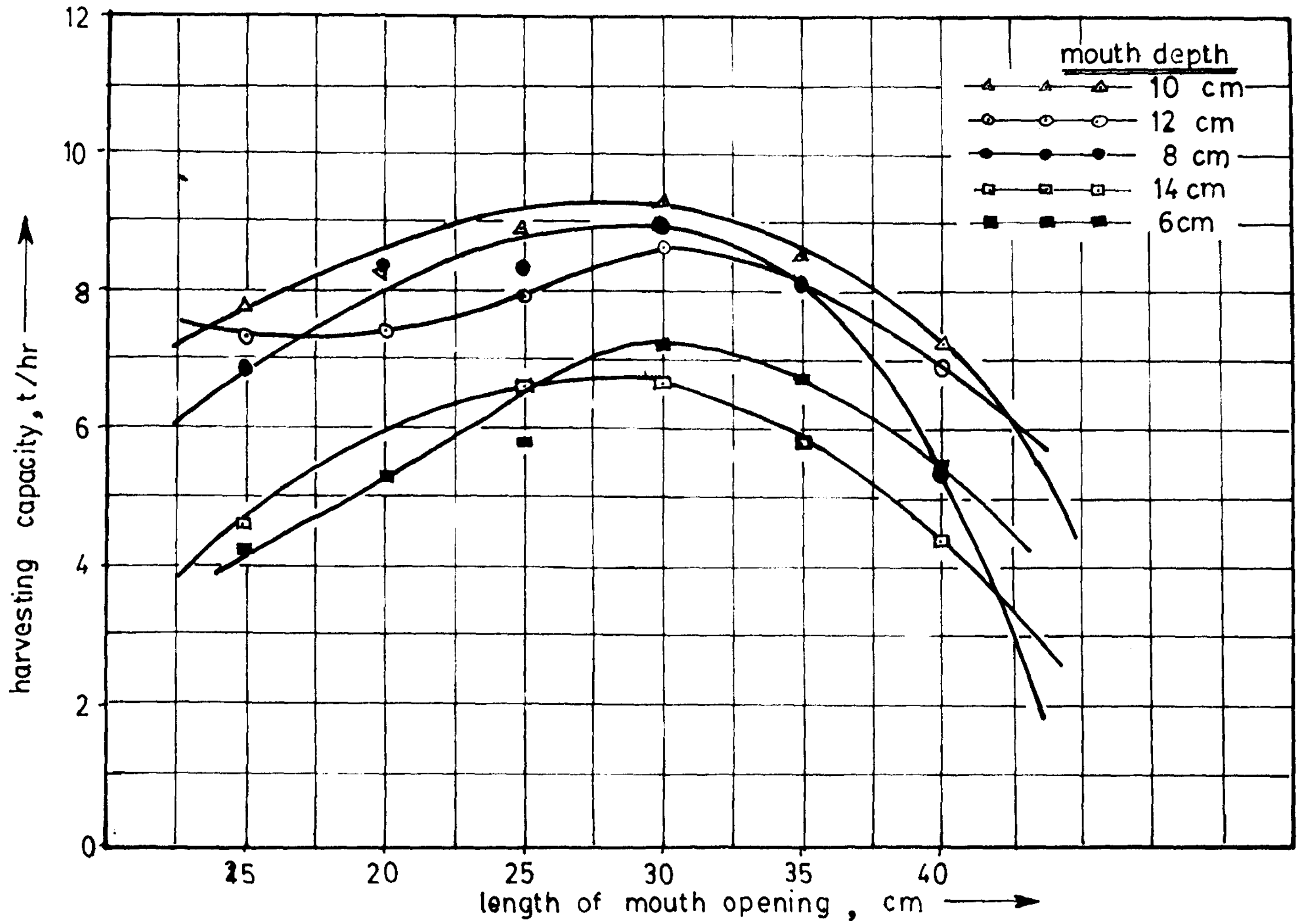


FIG.21. HARVESTING CAPACITY OF E_1-M_2 UNDER DIFFERENT MOUTH DEPTHS

15 to 40 cm with an incremental variation of 5 cm. When the length of opening increased from 15 cm onwards, an increase in collection of weed was noticed and the maximum was obtained at a mouth opening of 30 cm. Thereafter the value gradually decreased. This happened for all the depths tried and could be due to the decrease in suction force per unit area as the mouth opening area increased.

The data was subjected to analysis of variance (Table 21). The main effects of the depths of feeding mouth and the length of mouth opening as well as their interaction were significant at 5% level. Considering the over all performance, the mouth length of 30 cm was found superior to all other lengths tested. Similarly 10 cm depth for feeding mouth was superior to all the other depths considered. Though the interaction was significant, 30 cm mouth length was either most superior or one among the superior lengths for every depths. Similarly 10 cm depth for feeding mouth was either most superior or one among the superior depths for every lengths of mouth opening.

It was thus found for a rectangular feeding mouth of 7.5 cm width of opening, optimum length of mouth was 30 cm. At this optimum value of 30 cm x 7.5 cm mouth area, a maximum harvesting capacity of 9.25 t/hr

Table 21. Analysis of varience

Source	D.F.	Sum of squares	Mean sum of squares	F
Length	5	97.300	19.460	66.154*
Depth	4	193.830	48.458	164.729*
Length x depth	20	24.424	1.221	4.510*
Error	120	34.300	0.294	
Total	149	350.854		

* Significant at 1% level C.V. = 7.721

Mean of two-way table

Lengths (cm)	Depths (cm)					
	6	8	10	12	14	Mean
15	4.24	6.89	7.78	7.38	4.56	6.17
20	5.28	8.38	8.23	7.45	5.21	6.93
25	5.84	8.33	8.91	7.98	6.61	7.53
30	7.20	8.97	9.25	8.80	6.60	8.16
35	6.82	8.18	8.50	8.13	5.84	7.49
40	5.38	5.14	7.16	7.00	4.32	5.85
Mean	5.79	7.69	8.30	7.81	5.52	7.02

Critical difference at 5% level, for length - 0.304, for depth - 0.277 and for combination - 0.879

was achieved. When the area was decreased or increased by adjusting the length of mouth opening, the harvesting capacity was reduced. For the smaller mouth areas, eventhough the suction force per unit area was more, the mouth opening was incapable of permitting the entry of sufficient quantity of salvinia water mixture because the high velocity of the mixture increased the frictional resistance at the mouth. When the length of opening was increased from 30 cm, there was a decreasing trend in harvesting capacity. This was because the suction force per unit area was inadequate for sucking more weeds into the harvester.

In this combination also, intermittent clogging inside the ejector was observed. This is because the long rooted weeds partially encircled the primary flow pipe which is projecting into the suction chamber.

4.2.2.3 $E_2 - M_1$ and $E_2 - M_2$ combinations

The ejector E_2 along with the circular as well as the rectangular mouth was tested but there was frequent clogging inside the ejecter with the weeds. In this ejecter a change of direction approximately 40° was given for the secondary flow. Thus the momentum of the flowing fluid with the weeds was lost due to the sudden change in direction. The slowed down weeds thus easily got stuck around the annular space between the nozzle and the suction chamber. Visual observation itself showed that this ejecter could not be used for the efficient collection of salvinia because of this frequent clogging and hence no further experiments with this combination was continued.

4.2.2.4 $E_3 - M_1$ combination

In this case, the 10 cm diameter elbow was used as the mouth and the test results are given in Table 22. The mouth was kept at the optimum depth of 10 cm below the water surface. Average harvesting capacity obtained was 11.28 t/hr, which was greater than the previous observations. The higher harvesting capacity was due to the smooth change in direction given to the secondary flow. This in turn reduced the loss of momentum for the flowing fluid in the secondary flow. Moreover the present design enabled almost free movement for the weeds within the suction chamber. But this combination showed intermittent clogging of weeds. The higher suction force per unit area created at the mouth permitted the entry of more weeds than that could pass through the annular space in the suction chamber.

4.2.2.5 $E_3 - M_2$ combination

In this combination the circular mouth was replaced by the rectangular mouth and the results

Table 22. Harvesting capacity of E_3 - M_1 combination

Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
1	8.4	28.0	12.00	
2	9.8	30.5	11.22	
3	9.4	27.5	10.56	11.28
4	8.8	29.0	11.88	
5	8.9	26.5	10.74	

obtained are given in Table 23. Readings were taken at the optimum depth of 10 cm below water surface, and for varying mouth lengths from 15 cm to 40 cm. The results revealed that the optimum length of mouth opening was 30 cm with a harvesting capacity of 9.92 t/hr. Even though the harvesting capacity obtained was slightly less than that obtained in the case of $E_3 - M_1$ combination, there was no clogging in this combination. The harvester could be worked continuously for hours together without any problem. Among all the combinations described earlier this combination was found to be the best. The higher harvesting capacity shown by $E_3 - M_1$ combination in comparison with $E_3 - M_2$ was not useful for practical purposes as in the former case intermittent clogging occured.

4.2.3 Harvesting of salvinia to the shore

All the combinations were used to pump salvinia to the shore for finding out its ability for continuous operation, at a static lift of one metre. Results obtained are presented in Table 24. It is concluded that $E_2 - M_1$ and $E_2 - M_2$ combinations were not found suitable for harvesting due to the frequent clogging. $E_1 - M_1$, $E_1 - M_2$ and $E_3 - M_1$ showed the tendency of clogging intermittently. Among these three

Table 23. Harvesting capacity of $E_3 - M_2$ combination for different mouth opening for the optimum mouth depth of 10 cm

Mouth opening (cm)	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)
	1	8.8	19.0	7.80	
	2	9.2	22.0	8.58	
15	3	9.3	21.0	8.10	8.44
	4	8.9	23.0	9.30	
	5	8.8	20.5	8.40	
	1	9.6	24.0	9.00	
	2	9.4	22.5	8.64	
20	3	9.0	21.0	8.40	8.63
	4	8.6	20.5	8.52	
	5	8.9	21.0	8.58	
	1	8.9	22.0	8.88	
	2	9.0	22.5	9.00	
25	3	9.2	24.0	9.42	9.18
	4	8.9	23.5	9.48	
	5	8.7	22.0	9.12	
	1	9.8	25.0	9.18	
	2	9.5	27.5	10.44	
30	3	9.1	25.0	9.90	9.92
	4	9.4	26.0	9.96	
	5	9.6	27.0	10.14	
	1	10.5	24.5	8.40	
	2	10.2	23.0	8.10	
35	3	9.9	22.5	8.16	8.34
	4	10.3	24.0	8.40	
	5	10.4	25.0	8.64	
	1	10.9	23.0	7.62	
	2	10.5	22.5	7.74	
40	3	10.8	23.0	7.68	7.57
	4	10.6	21.5	7.32	
	5	10.8	22.5	7.50	

Table 24. Pumping of salvinia to the shore for a duration of 2 minutes, at a static lift of one metre

Combination tested	Sl. No.	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)	Remarks
$E_1 - M_1$	1	345.0	10.32		
	2	320.5	9.62		
	3	339.0	10.17	10.05	Intermittent clogging
	4	355.0	10.65		
	5	315.5	9.47		
$E_1 - M_2$	1	304.5	9.14		
	2	291.0	8.73		
	3	310.5	9.30	8.71	Intermittent clogging
	4	260.0	7.80		
	5	285.5	8.57		
$E_2 - M_1$		No reading because of frequent clogging			
$E_2 - M_2$		No reading because of frequent clogging			
$E_3 - M_1$	1	364.5	10.94		
	2	382.5	11.48		
	3	352.0	10.56	10.93	Intermittent clogging
	4	367.5	11.03		
	5	354.0	10.62		
$E_3 - M_2$	1	334.0	10.02		
	2	280.0	8.40		
	3	339.5	10.19	9.49	No clogging
	4	331.0	9.93		
	5	296.5	8.90		

combinations $E_3 - M_1$ was found to have the maximum harvesting capacity of 10.93 t/hr. The $E_3 - M_2$ combination was found to work satisfactorily without any clogging at an average harvesting capacity of 9.49 t/hr. This combination was found more practicable than the other combinations.

The harvesting capacity in this case was slightly less than that obtained when salvinia was pumped into the barrel for a short duration. This could due to the non-uniformity in the density of weeds in a larger area.

4.2.4 Harvesting of salvinia into the floating fence

Salvinia water mixture was pumped into the floating fence described in chapter III. The sise of the floating fence was 150 cm x 150 cm x 120 cm and its maximum capacity was 400 kg. The combination $E_3 - M_2$ was used to pump the weed into the floating fence. The advantage of the floating fence was that it needed only a static lift of 40 cm. The results obtained are given in Table 25. The higher harvesting capacity in this case was due to the reduction in the static lift which in this case was only 40 cm while in the previous case it was one metre.

Table 25. Harvesting capacity of $E_3 - M_2$ at a static lift of 40 cm

Sl.No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)
1.		92.5	11.00
2.		89.5	10.74
3.	30	91.0	10.92
4.		86.5	10.38
5.		93.0	11.16
		Average	10.86

4.3 Second stage field tests

The properties of salvinia observed in the second stage of field experiments conducted at Pudukkadu are given in Tables 26, 27 and 28.

From these tables, it was found that the spread density, bulk density and root ratio values were in accordance with the previous values given in section 4.2.1.

The ejector E_4 with its secondary flow in the horizontal direction and the primary flow entering the suction chamber at an angle of 30° to the horizontal was tested with various mouths. In addition to the mouths M_1 and M_2, a third mouth M_3 elliptical in shape

Table 26. Spread density of salvinia in the test pond at Pudukkadu

Sl. No.	Area covered (m^2)	Weight of Salvinia (kg)	Spread density (kg/m^2)
1	1.0	61.5	61.5
2	1.0	54.0	54.0
3	1.0	59.0	59.0
4	1.0	61.0	61.0
5	1.0	56.5	56.5
		Average	57.8

Table 27. Bulk density of salvinia in the test pond at Pudukkadu, volume collected 0.125 m^3, weight of cage = 10.5 kg

Sl. No.	Weight of cage + salvinia (kg)	Weight of salvinia (kg)	Bulk density (kg/m^3)
1	52.0	41.5	332
2	59.0	48.5	388
3	53.5	43.0	344
4	55.0	44.5	356
5	59.0	48.5	388
		Average	362

Table 28. Root ratio values of salvinia in the test pond at Pudukkadu

Trial No.	Weight of sample (g)	Weight of leaves (g)	Weight of roots (g)	Root ratio
1.	485	105	380	78.4
2	510	75	435	85.3
3	425	85	340	80.0
4	380	100	280	73.7
5	460	70	390	84.8
			Average	80.44

was also used in this test. The results obtained for these different combinations in this second stage of experiments are given in Table 29.

It was found that the performance of M_2 and M_3 were almost identical in all the experiments. Hence it is evident that there is no particular advantage in using one over the other. Though $E_4 - M_1$ combination gave comparitively higher values of harvesting capacity compared to $E_4 - M_2$ and $E_4 - M_3$, however, this is not recommended for practical use because of intermittent clogging. From these experiments, it is clear that $E_4 - M_2$ and $E_4 - M_3$ combination yield maximum harvesting capacity without clogging and hence can be used for continuous operation.

The ejector E_4 with M_1, M_2 and M_3 were tested for its continuous operation by pumping salvinia to the shore at a static lift of one metre. The same combinations were again tested by pumping salvinia to the floating fence at a static lift of 40 cm. The results are given in Tables 30 and 31 respectively.

It was seen that the $E_4 - M_1$ combination had the same problem of intermittent clogging even though it attained a maximum harvesting capacity of 13.16 t/hr at a static lift of 40 cm. The $E_4 - M_2$ and $E_4 - M_3$ combinations attained a maximum capacity of about 12 t/hr at 40 cm static lift without any clogging.

Table 29. Harvesting capacity of different combinations tested in second stage of experiments

Combination tested	Sl. No.	Time taken (s)	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)	Remarks
$E_1 - M_3$	1	9.8	25.5	9.37		
	2	9.6	24.0	9.00		
	3	9.9	26.0	9.45	9.11	Intermittent clogging
	4	10.1	25.0	8.91		
	5	9.8	24.0	8.88		
$E_2 - M_3$	No readings because of frequent clogging					
$E_3 - M_3$	1	9.8	26.5	9.73		
	2	9.5	26.0	9.85		
	3	9.7	28.0	10.39	9.82	No clogging
	4	9.3	25.0	9.68		
	5	9.7	25.5	9.46		
$E_4 - M_1$	1	8.3	26.5	11.50		
	2	9.0	28.5	11.40		
	3	8.4	27.5	11.79	11.55	Intermittent clogging
	4	8.1	25.5	11.33		
	5	8.6	28.0	11.72		
$E_4 - M_2$	1	8.8	26.5	10.84		
	2	9.1	28.0	11.08		
	3	8.8	27.5	11.25	11.2	No clogging
	4	9.2	29.0	11.34		
	5	9.4	30.0	11.49		
$E_4 - M_3$	1	9.0	27.0	10.80		
	2	8.8	26.0	10.64		
	3	9.3	28.5	10.03	10.94	No clogging
	4	9.0	27.5	11.00		
	5	9.3	29.0	11.22		

Table 30. Pumping of salvinia to the shore for a duration of two minutes, at a static lift of 40 cm

Combination tested	Sl. No.	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)	Remarks
$E_4 - M_1$	1	381.5	11.45		
	2	372.5	11.18		
	3	390.0	11.70	11.28	Intermittent clogging
	4	370.5	11.30		
	5	358.5	11.76		
$E_4 - M_2$	1	347.5	10.43		
	2	342.5	10.26		
	3	353.5	10.61	10.46	No clogging
	4	349.5	10.47		
	5	350.5	10.52		
$E_4 - M_3$	1	341.5	10.25		
	2	333.0	9.99		
	3	338.5	10.16	10.15	No clogging
	4	346.5	10.38		
	5	333.5	9.95		

Table 31. Pumping of salvinia to a floating fence for 30 seconds at a static lift of 40 cm

Combination tested	Sl. No.	Salvinia collected (kg)	Harvesting capacity (t/hr)	Average harvesting capacity (t/hr)	Remarks
$E_4 - M_1$	1	108.5	13.02		
	2	115.0	13.80		
	3	104.5	12.54	13.16	Intermittent clogging
	4	111.5	13.38		
	5	109.0	13.08		
$E_4 - M_2$	1	100.5	12.06		
	2	108.0	12.96		
	3	104.0	12.48	12.38	No clogging
	4	102.5	12.30		
	5	101.0	12.12		
$E_4 - M_3$	1	97.5	11.70		
	2	104.0	12.48		
	3	102.5	12.30	12.12	No clogging
	4	99.0	11.88		
	5	102.0	12.24		

From the two stages of testings it was found that $E_4 - M_2$ and $E_4 - M_3$ were giving better performance. Hence it is recommended. These two combinations are suitable for the harvesting of salvinia under all conditions of weed growth in Kerala.

4.4 Economic analysis

The operating cost of Salvinia Harvester was worked out on the basis of the assumption and calculations given in Appendix III. It was worked out on the assumption that the salvinia problem was prevelant for about 8 months during the year. Hence a very conservative figure of 1000 hours of annual use of the equipment was taken for the cost analysis. The life of the equipment is taken as 10 years with 10 per cent salvage value and the operating cost was obtained as Rs.35.30/hr. The spread density value of salvinia in Kuttanadu region, where the weed was in the first growth phase, was 16 kg/m^2. The harvesting capacity obtained for the prototype Salvinia Harvester was 16 t/hr. Hence the clearance time using this equipment is 10 hrs/ha. Therefore the expected cost for clearing one hectare of weed infested field is Rs.353/-.

Summary

SUMMARY

An investigation on "Design and development of a high capacity Salvinia Harvester" was carried out to improve the performance of the Salvinia Harvester developed by the Kerala Agricultural University. The main emphasis of the study was on the design of a high capacity ejector system that would work without clogging under all conditions of weed growth. In order to achieve this objective different directions of primary and secondary flows were tested and various sizes and shapes of feeding mouth were tried. The optimum position of the mouth below the water surface was also determined. The details of the complete machine are shown in Fig. 22. The results obtained are summarised below:-

1. Among the two ejectors E_2 and E_3 with primary flow straight and secondary flow inclined, the ejector E_3 yielded a better capacity ratio (total flow $\div$ primary flow) of 4.03.

2. The two ejectors E_1 and E_4 with secondary flow straight and primary flow inclined gave identical capacity ratio of 3.75.

3. The average spread density value for the salvinia in the initial stage of third growth phase was 60 kg/m^2.

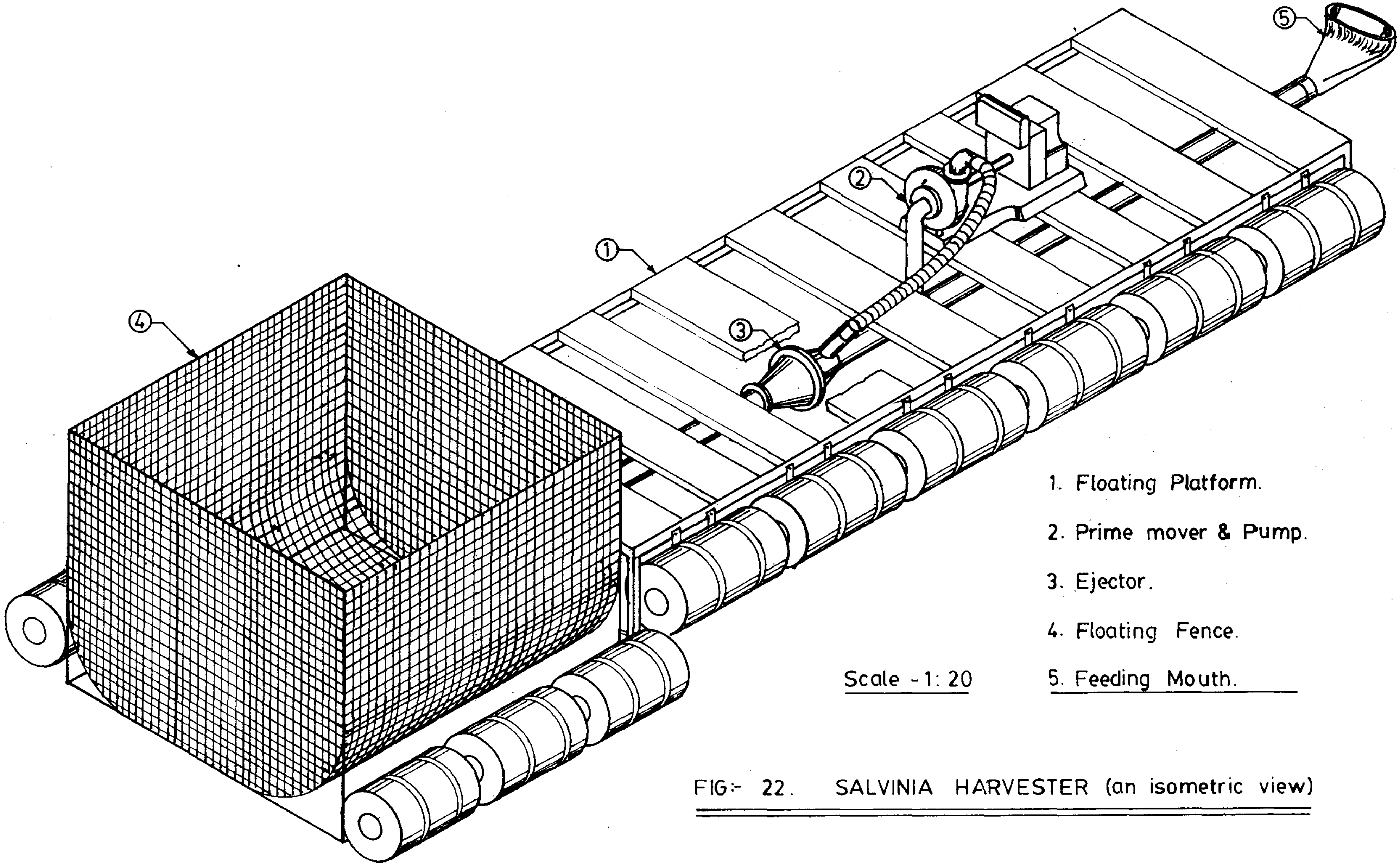


FIG:- 22. SALVINIA HARVESTER (an isometric view)

4. The bulk density value before harvesting at the two test localities where the weed was in the initial stages of third growth phase was of the order of 370 kg/m^3.

5. The bulk density of salvinia harvested with the machine was around 330 kg/m^3.

6. The average root ratio values obtained for different growth phases and root length were 46 per cent in the first growth phase (root length less than 20 cm), 69 per cent in the initial stages of second growth phase (root length 20 - 40 cm), 76 per cent in the later stages of second growth phase (root length 40 - 60 cm) and 83 per cent in the initial stages of third growth phase (root length greater than 60 cm).

7. The $E_1 - M_1$ combination yielded the maximum harvesting capacity of 10.82 t/hr at a static lift of one metre with the feeding mouth 10 cm below the water level.

8. Experiments with $E_1 - M_1$ combination with mouth at different depths showed that the optimum depth was 10 cm.

9. The $E_1 - M_2$ combination was tested with varying mouth depths from 6 cm to 14 cm and length of opening from 15 cm to 40 cm, keeping a constant width of 7.5 cm. It was found that for a rectangular feeding mouth of 7.5 cm width, the optimum length of opening was 30 cm.

In this combination also the depth of feeding mouth below water surface was found to be 10 cm for maximum collection.

10. The test results with ejector E_1 and mouths M_1 and M_2 showed intermittent clogging in the ejector system with the weeds.

11. The ejector E_2 did not function satisfactorily due to frequent clogging.

12. The observations made with $E_3 - M_1$ and $E_3 - M_2$ showed that $E_3 - M_2$ was the best combination. The harvesting capacity obtained with $E_3 - M_2$ was 9.92 t/hr without any clogging problem at a static lift of one metre.

13. All the above combinations when tested for continuous operation by pumping salvinia directly to the shore, $E_3 - M_2$ yielded a maximum harvesting capacity of 9.49 t/hr, at a static lift of one metre.

14. The $E_3 - M_2$ combination when used to harvest the weed into a floating fence at a static lift of 40 cm, achieved a higher harvesting capacity of 10.86 t/hr.

15. Clogging was a very serious problem for $E_4 - M_1$ combination, eventhrough it attained a harvesting capacity of 11.55 t/hr at a static lift of one metre and 13.16 t/hr at a static lift of about 40 cm.

16. $E_4 - M_2$ and $E_4 - M_3$ yielded almost the same harvesting capacity of 11 t/hr at one metre static lift whereas at 40 cm static lift a value of 12 t/hr, without any problem due to clogging.

17. All these experiments conducted revealed that the ejector E_3 and E_4 can be used under all conditions of weed growth without clogging along with the mouths M_2 and M_3.

18. The capacity of floating fence of size 150 cm x 150 cm x 120 cm with six polyethylene drums was 400 kg.

19. Economic analysis showed that the operating cost of the machine was Rs. 35.3/hr. The expected cost for clearing the weed infested areas where spead density values were around 16 kg/m^2 (like Kuttanadu area) is Rs.353/ha.

The following are some of the works suggested for further investigations:

1. Study of drag characteristics of the salvinia weed and its influence on the geometry of the ejector system.

2. Development of an automatic feeding mechanism for guiding the weeds easily into the mouth.

3. Assessment of mechanical properties of the salvinia weed including possible methods and machine components for its processing and disposal.

4. Modification of the mouth as well as the ejector system to suit it for the collection of other common floating type aquatic weeds like water hyacinth.

References

REFERENCES

Ariyaratna, J.K.P. 1977. Some preliminary observations on the selective toxicity of ammonia towards Salvinia molesta D.S. Mitchell. (In) Proc. Sixth Asian Pac. Weed Sci. Soc. Conf., Indonesia pp. 283-87.

Chandramohan, V. 1984. Development of small scale dredging unit. M.Sc. thesis, Kerala Agric. Univ., Vellanikkara 80 pp.

Cook, C.D.K. 1976. Salvinia in Kerala, South India and it's contro. (In) Varshney, C.K. and Rzoska, J. (Ed.). Aquatic weeds in S.E. Asia. Dr. W. Junk b.v., The Hague pp. 241-44.

Cook, C.D.K. and Gut, B. 1971. Salvinia in the state of Kerala, India. Pestic. Abstr. 17 : 438-47.

Dassanayake, M.D. 1976. Noxious aquatic vegetation control in Sri Lanka. (In) Varshney, C.K. and Rzoska, J. (Ed.). Aquatic weeds in S.E.Asia. Dr. W. Junk b.v., The Hague pp. 59-66.

George, K. 1976. Studies on the chemical control of some important aquatic weeds of Kerala, Salvinia, Ludwigia and Cyperus. (In) Varshney, C.K. and Rzoska J. (Ed.). Aquatic weeds in S.E. Asia. Dr. W. Junk b.v., The Hague pp. 255-62.

Gosline, J.A. and O'Brien, M.P. 1934. The water jet pump. Univ. of California publications in Engg. Vol.2 (In) Samuel, J. 1975. Water jet pumps for low lift applications. Ph.D. thesis, Indian Agric. Res. Inst., New Delhi.

Ignatious, D.K. 1979. Preliminary work reports of Ph.D. Studies. Botany Dept., Calicut Univ. (Unpublished).

Joy, P.J. 1978. Ecology and Control of Salvinia (African Payal), the Molesting weed of Kerala. Kerala Agric. Univ., Trichur, 40 pp.

Joy, P.J. and Abraham, C.C. 1979. An integrated programme for weed management against Salvinia molesta Mitchell in Kerala. (In) Abstr. Weed Sci. Conf., Parbhani. pp.44-48.

Kaimal, P.N.R. 1976. Aquatic Weed Harvester. Central Institute of Fisheries Technolocy, Cochin. 56 pp.

Little, E.C.S. 1968. The control of water weeds. Weed Res., 8 : 79-105.

Little, E.C.S. and Henson, I.E. 1967. The water content of some important tropical water weeds. Pestic. Abstr. 13 : 223-27.

Livermore, D.F., Bruhn, H.D. and Pollock, B.W. 1971. Processing characteristics of sub surface macrophytes of Madison, Wisconsin Lakes. Hydrobiologica, 12(1) : 48-60.

Loyal, D.S. and Grewal, R.K. 1966. Cytological study on sterility in Salvinia auriculata Aubl. Curr. Sci. 33 : 344-46.

*Mitchell, D.S. 1970. The autoecology of Salvinia auriculata Aubl. Ph.D. thesis, University of London, London.

Mitchell, D.S. 1973. The Kariba Weed Salvinia molesta Br. Fern. Gaz. 10 : 251-52.

Mitchell, D.S. and Tur, N.M. 1975. The rate of growth of Salvinia molesta in laboratory and natural conditions. J. Appl. Ecol. 12 : 213-25.

Philipose, M.T. 1968. Present trends in the control of weeds in fish cultural waters of Asia and the far East. FAO Fish. Rep. 44(5) : 26-52.

Philipose, M.T. 1976. Fifty years of aquatic weed control in India (In) Varshney, C.K. and Rzoska, J. (Ed.). Aquatic Weeds in S.E.Asia. Dr. W. Junk. b.v., The Hague pp. 112-16.

Robson, 1978. A review of the distribution of aquatic weeds in the tropics and sub tropics. (In) Varshney, C.K. and Rzoska, J. (Ed.). Aquatic Weeds in S.E. Asia. Dr. W. Junk. b.v., The Hague pp. 281-83.

Sankaran, T. 1976. Possibilities of biological control of aquatic weeds Eichhornia crassipes and Salvinia molesta in India. (In) Varshney, C.K. and Rzoska, J. (Ed.). Aquatic Weeds in S.E. Asia. Dr. W. Junk. b.v., The Hague pp.323-30.

Sankaranarayanan, M.R. 1981. Mechanical control of floating type aquatic weed, Salvinia molesta (African Payal). M.Sc. thesis, Kerala Agric. Univ., Vellanikkara pp-145.

Samuel, J. 1972. Control of floating type aquatic weeds. Paper presented in the division of Agric. Engg., IARI, New Delhi (Unpublished).

Samuel, J. 1975. Water jet pumps for low lift applications. Ph.D. thesis, Indian Agric. Res. Inst., New Delhi.

Samuel, J. 1980. Development of Salvinia Harvesting Machine. Paper presented at the seminar held at the college or Agriculture, Vellayani (Unpublished).

Samuel, J and Jacob, J. 1977. Prospects for mechanical control of salvinia in Kerala. Paper resented in the symposium on rice research at the Rice Res. Stn., Pattambi (Unpublished).

Samuel, J., Sukumaran, R. and Rawther, K. 1980. Note on biogas production from African Payal. Dept. of Agrl. Engg. Kerala Agric. Univ., Vellanikkara (Unpublished).

Sculthrope, C.D. 1967. The biology of aquatic vascular plants. Edward arnold, London, 610 pp.

*Silvester, R. 1960. Characteristics and applications of the water jet pump. La Houlle Balance, Aug. Sept. (In) Samuel, J. 1975. Water jet pumps for low lift applications. Ph.D. thesis, Indian Agric. Res. Inst., New Delhi.

*Stepanoff, A.J. 1964. Centrifugal and axial flow pumps. John Wiley & Sons Inc. (In) Samuel, J., 1975. Water jet pumps for low lift applications, Ph.D. thesis, Indian Agric. Res. Inst., New Delhi.

*Stephens, J.C., Lamech, R. and Henson, H.C. 1963. Retardance effects and control of water weeds in drainage and irrigation channels in the South East. Rept. Crops Res. Div., ARS, USDA, Washington 16-17.

Thomas, K.J. 1975. Biological control of Salvinia by the Snail Pilaglobosa. Biol. J. Linn. Soc. 7 : 243-47.

Thomas, K.J. 1979. The extent of salvinia infestation in Kerala (S. India), it's impact of suggested methods of control. Environ. Consv. 6 : 12-42.

Thomas, K.J. 1980. Salvinia in India. Tropic Pest. Manag. 26 : 318.

Thomas, C.T., Devassia, P.A., Kunjikutty, N. and Nandakumar, N. 1976. A preliminary study on the composition of African Payal (Salvinia molesta Mitchell) (Unpublished).

Velu, M. 1976. Development of equipment for eradication of submerged weeds, (In) Varshney, C.K. and Rzoska, J. (Ed.). Aquatic weeds in S.E.Asia. Dr. W. Junk b.v., The Hague pp. 233-40.

Weed Research Organisation. 1977. Aquatic weeds. Pestic. Abstr. 23 : 333-34.

Williams, R.H. 1956. Salvinia auriculata Aubl., the chemical eradication of a serious aquatic weed in Ceylon. Tropic. Agric. 33 : 145-47.

* Originals not seen

Appendices

Appendix - I

Specifications of prototype Salvinia Harvester

Engines, 2 Nos.	: Greaves lombardini
Speed	: 3000-3600 rpm
Bore	: 78 mm
Stroke	: 68 mm
Displacement	: 325 cm^2
Compression ratio	: 18:1
Maximum torque	: 1.48 kg.m
Specific fuel consumption	: 0.253 g/bhp.hr
Fuel tank capacity	: 4.5 l
Oil consumption	: 0.013 kg/hr
Dry weight	: 38 kg
Pumps, 2 Nos	: Texmo
Head	: 10-35 m
Suction line	: 6.25 cm
Delivery line	: 5 cm
Length of floating platform	: 425 cm
Width of floating platform	: 120 cm
Floatation	: 12 Nos. polyethylene drums of 50 l capacity

Appendix - II

Specifications of 8 hp High Pressure Pumpset

Engine type	: LDA-510
Bore	: 85 mm
Stroke	: 90 mm
Displacement	: 510 cm^3
Compression ratio	: 17.5 : 1
Speed	: 2600 - 3000 rpm
Maximum torque	: 3 kg.m.
Mean piston speed	: 7.8 - 9.0 m/s
Specific fuel consumption	: 184-196 g/bhp/hr
Fuel tank capacity	: 5.5 l.
Liquid oil consumption	: 0.022 kg/hr
Sump capacity	: 1.75 l
Dry weight	: 59 kg
Pump type	: KH7
Suction line	: 5 cm
Delivery line	: 5 cm

Appendix - III

Calculation of operating cost of Salvinia Harvester

1. Assumptions

1.	Life of the harvester(L)	: 10 years
2.	Salvage value	: 10% of initial cost
3.	Rate of interest(i)	: 10% of average investment
4.	Repair and maintenance cost	: 6% of initial cost
5.	Insurance and taxes	: 2% of initial cost
6.	Housing charges	: Rs.300/year (assumed)
7.	Number of working hours/year	: 1000
8.	Fuel cost/litre (diesel)	: Rs.4.02
9.	Lubricants cost	: 30% of fuel cost
10.	Wages for skilled man labourer	: Rs.40/day
11.	Wages for unskilled man labour	: Rs.30/day
12.	Wages for unskilled woman labour	: Rs.25/day
13.	Number of working hours/day	: 8
14.	Minimum number of skilled man labourers to operate the machine	: One
15.	Minimum number of unskilled men labourers to guide the weeds into the mouth	: One

16.	Minimum number of unskilled women labourers for removing the weeds from the floating fence	: Two
17.	Fuel consumption	: 2 l/hr
18.	Spreed density of salvinia in the first of growth	: 16 kg/m^2

2. Investments

1.	Cost of 8 hp high pressure pumpset and its starting accessories	: Rs. 17,000.00
2.	Cost of fabrication of ejector system including cost of materials	: Rs. 1,000.00
3.	Cost of floating platform	: Rs. 1,500.00
4.	Cost of floating fence	: Rs. 500.00
5.	Cost of other accessories and pipe fittings	: Rs. 1,400.00
6.	Overhead charges for fabrication work	: Rs. 600.00
	Total	Rs. 22,000.00

3. Calculations

1. Depreciation $= \frac{0.9\ C}{LH} = \frac{0.9 \times 22,000}{10 \times 1000}$ = Rs.1.98/hr

2. Interest on capital investment $= \frac{0.55\ C}{H} \times$

$= \frac{0.55 \times 22,000}{1000} \times \frac{10}{100}$

= Rs. 1.21/hr

4. Insurance and taxes $= \frac{C}{H} \times \frac{2}{100} = \frac{22,000}{100} \times \frac{2}{1000}$

$= \underline{\text{Rs. } 0.44/\text{hr}}$

5. Housing charges = Rs. 300/year

$= \frac{300}{1000} = \underline{\text{Rs. } 0.30/\text{hr}}$

6. Fuel cost (diesel, @ 2 l/hr) $= 2 \times 4.02 = \underline{\text{Rs. } 8.04/\text{hr}}$

7. Lubricants cost (@ 30% of fuel cost) $= \frac{30}{100} \times 8.04 = \underline{\text{Rs. } 2.41/\text{hr}}$

8. Labour charges

i) Skilled man labourer $= \frac{40}{8} = \underline{\text{Rs. } 5/\text{hr}}$

ii) Unskilled man labourer $= \frac{30}{8} = \text{Rs. } 3.75/\text{hr}$

iii) Unskilled women labourers $= \frac{2 \times 25}{8} = \text{Rs. } 6.25/\text{hr}$

Operating cost (sum of items 1 to 8) $= \underline{\text{Rs.} 30.70/\text{hr}}$

9. Establishment charges (@ 15% of operating cost)

$= 30.7 \times \frac{15}{100} = \underline{\text{Rs. } 4.60/\text{hr}}$

Total operating cost of Salvinia Harvester

$= \underline{\text{Rs.} 35.30/\text{hr}}$

DESIGN AND DEVELOPMENT OF A HIGH CAPACITY SALVINIA HARVESTER

By

HAJILAL, M. S.

ABSTRACT OF A THESIS

submitted in partial fulfilment of the requirement for the degree

Master of Science in Agricultural Engineering

Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Irrigation and Drainage Engineering
Kelappaji College of Agricultural Engineering and Technology
Tavanur - Malappuram

1987

ABSTRACT

Salvinia molesta locally known as 'African Payal' is a noxious floating type aquatic weed in many parts of the humid tropics. Kerala Agricultural University developed a mechanical device to harvest this menacing weed.

An investigation on the performance of the prototype Salvinia Harvester was carried out under various conditions. Prototype ejector E_1 with secondary flow straight and primary flow inclined at 90°, ejectors E_2 and E_3 with primary flow straight and secondary flow inclined at 40° and 20° respectively and ejector E_4 with secondary flow straight and primary flow inclined at 30° were tested along with circular mouth (M_1), adjustable rectangular mouth (M_2) and elliptical mouth (M_3). Experiments were also conducted to find out the optimum depth of mouth below the water level.

The study revealed that clogging was a serious problem for the prototype Salvinia Harvester, where the weed was in the initial stages of third growth phase. Ejectors E_1 and E_2 showed clogging when tested with all the different feeding mouths. The E_4-M_2 & E_4-M_3 combinations yielded almost identical harvesting capacity of 11 t/hr at one metre static lift and 12 t/hr at 40 cm static lift without any problem due to clogging. All these

experimmnts conducted revealed that the ejectors E_3 and E_4 can be used under all conditions of weed growth without clogging along with mouths M_2 and M_3.

The machine is capable of removing weeds at the rate of 16 t/hr where the spread density value was around 16 kg/m^2 (160 t/ha) like Kuttanadu area. Hence the machine would be capable of removing the weeds in one hectare in 10 hours. The estimated cost of operation amounted to Rs. 353/- per hectare which compared favourably with the reported costs of Rs.900/- to Rs. 2,700/- per hectare for manual collection and disposal.