DESIGN AND DEVELOPMENT OF RICE HUSK COMBUSTOR FOR INDUSTRIAL APPLICATIONS

Thesis

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DOCTOR OF PHILOSOPHY

By

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CERTIFICATE

This is to certify that the thesis entitled "Design and Development of Rice Husk Combustor for Industrial Applications", submitted by Arjun Badlani for the award of the Ph.D. degree of the Institute embodies original work done by him under my supervision.

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Dated : July 19, 1988

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ABSTRACT

Energy is the most important factor for economic progress. Industrialization and modernization has increased the consumption of traditional commercial sources of energy, namely the fossil fuels, coal, oil and natural gas. With the limited resources of oil, and exhorbitant costs of oil exploration, the critical energy challenge of improving productivity with lower energy costs needs to be met with innovative energy measures.

Agro residues form a large untapped renewable energy source in India, with a potential of more energy availability than the indigeneous production of coal. Rice husk is one such agro residue that until recently posed a problem for disposal. Attention has been focussed on rice husk as an alternative fuel for process heat requirements in industry.

A study of the rice husk burners for industrial applications has shown that the main system hitherto used commercially has been the grate furnace. This has been found wanting in the important aspects of poor flame temperature, inadequate combustion efficiency of husk, and inability to separate fly ash from flues.

A two stage swirl flow combustor incorporating a cyclone separator has been designed for use with an oil

fired boiler. A prototype of the designed combustor has been manufactured and installed with an oil fired boiler of rating 1200 Kg. steam per hour at 100 psi.

In a field trial of the husk combustor the steam generation ratio of fuel for the system was found to be 4.0 as compared to about 2.77 for existing inclined grate furances, 4.8 for coal and 13.0 for oil. The new design has successfully overcome the three disadvantages of the inclined step grate furnace, namely, low flame temperature, inadequate combustion efficiency and poor separation of fly ash from flues.The flame temperature attained in the swirl flow combustor is of the order of 1050° C compared to 700° C in the inclined step grate Furance. The combustion efficiency and fly ash separation achieved in swirl flow system is near hundred percent. Other design features of the swirl flow combustor include a provision to easily change back to original type of oil firing within a matter of 30 minutes. This is not possible in the grate system which takes over 72 hrs for a changeover. The swirl flow combustor being a closed and insulated system, the temperature drop overnight is small and it can be shut off and self started over a short period of time. This is not possible with the existing grate furnaces which are open to atmosphere and cool down fast making it necessary for prolonged starting time.

The main limitation of the swirl flow combustor is that the feed blower impellar for feeding the air-husk mixture gets worn out very fast - as often as once a month - and needs frequent replacement.

The cost of steam generation with the swirl flow combustor using rice husk comes to only Rs 75/- per tonne compared to Rs 260/- per tonne with oil as fuel and an estimated Rs 156/- per tonne with coal as fuel.A financial analysis of the designed system for replacing oil firing with husk firing on the boiler reveals a savings of Rs. 185/-per tonne of steam generation at a capital cost of Rs. 78,740. This capital cost is recovered in just about one month on the boiler.

The system has also been run on saw dust satisfactorily and can be suitably built to burn a number of specific bulk fuels available including dried leaves, maize waste, peanut shells, etc. However these fuels need to be reduced to appropriate size for optimizing their fluidizing properties. Studies in connection with their combustion properties in air suspension need to be carried out.

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SYMBOLS AND ABBREVIATIONS

A	Area
a, b	Length, width
C	degree centigrade
D, d	Diameter
E	Efficiency
F	Fuel Consumption Rate Kgs./hr.
G_x	Axial Flux of Linear Momentum
G_ϕ	Axial Flux of Swirl Momentum
G	Ratio of maximum swirl velocity to maximum axial velocity
H	Heat of Combustion
K	degree Kelvin
L	Length
m	Mass fraction
M_O	Original Mass flow rate
M_R	Recirculated mass flow rate
n	Number
δP	Pressure drop
Q	Volumetric flow rate
r	Radius, radial distance, cylindrical coordinate
Re	Reynolds number
S	Swirl number

t	Time
U, u	Time-mean axial velocity
v	Time-mean radial velocity
W	Time mean swirl velocity
w	angular velocity
V	Volume
$x, y, \emptyset$	Axial, radial, polar coordinates
X	Axial distance
ρ	Specific Weight
$\emptyset$	Vane angle of swirler
μ	Dynamic viscosity; turbulent viscosity
σ	ratio of blade pitch to length of flat blade swirlers
m	Maximum
o	Reference Value; inlet value; ambient conditions; main section of Cyclone Combustor
MT	Metric Tonnes
MTCE	Metric Tonnes Coal Equivalent
TwH	10^9 Watt hours
PJ	10^{12} Joules

1. INTRODUCTION

1.1 IMPORTANCE OF ENERGY

Energy is the most important factor for a country's progress. Increasing population, rapid industrialization and expanding urbanization have increased the energy needs globally. The dwindling fossil fuel reserves, coupled with their increasing rate of consumption and prices are forcing technologists to look for alternative and renewable energy sources.

An unprecedented energy consciousness has developed throughout the world in the last decade. It started with a threefold increase in petroleum prices in 1976. A crisis of energy has been gradually developing during this period because of increasing demands for conventional energy sources, particularly petroleum; while the restraints that have become operative in petroleum resources project a downward trend in production within the next years to come. The commercial energy consumption for the years 1982 to 1985 for some countries is given in Table 1.1.

TABLE 1.1 COMMERCIAL ENERGY CONSUMPTION FOR SOME SELECTED COUNTRIES[79] * (Kgs. OF COAL EQUIVALENT PER CAPITA)

S.NO.	COUNTRY	1982	1983	1984	1985
1.	QATAR	26685	21692	21610	20854
2.	BAHARAIN	12855	12912	13043	12796
3.	LUXEMBOURG	10973	10407	11187	11532
4.	CANADA	9638	9488	9630	9910
5.	W.GERMANY	7312	7193	7424	7717
6.	AMERICA	6811	6658	6808	6768
7.	AUSTRALIA	6272	5985	6136	6538
8.	RUSSIA	5762	5843	5982	6131
9.	ENGLAND	4753	4785	4706	4714
10.	FRANCE	3997	3914	3888	40134
11.	JAPAN	3460	3487	3748	3715
12.	CHINA	578	613	659	693
13.	INDIA	220	233	237	254
14.	PAKISTAN	217	233	238	251
15.	KENYA	102	102	91	83
16.	BANGLADESH	49	46	52	57
17.	TANZANIA	45	43	42	40
18.	NEPAL	15	16	17	17

The industrialized nations like USA,USSR, Australia and Germany that consume large quantitites of commercial energy are They are faced with the situation that future supplies of conventional energy, derived from petroleum and natural gas have become uncertain. Without the supply of adequate quantitites of commercial energy, these countries cannot maintain

* References are listed alphetabically at the end of the thesis

high level of productivities and high standard of living. The developing countries like India, Pakistan, Kenya, Tanzania and Bangladesh which consume relatively small quantitites of commercial energy are worried because the targets of higher levels of productivity and reasonable standard of living for their people will not be achievable especially if petroleum becomes more expensive or restrictive. It is now commonly realized that global cuts on energy supply will affect developing countries with inadequate fossil fuel resources most seriously.These countries will be ill-equipped to compete with the richer countries in the world market for fossil fuels particularly petroleum as the fuel supplies are restricted by the oil producing countries.

In the face of the critical challange of improving productivity with lower energy, costs and consumption, it is necessary that technologies should now be directed towards incorporating non conventonial energy sources to meet energy demands.

1.2 SCOPE OF UTILIZATION OF NONCOVNENTIONAL AND RENEWABLE ENERGY SOURCES

The four major non-conventional and renewable energy sources that can be considered for commercial exploitation are solar, geothermal, wind and biomasses.

SOLAR ENERGY appears to be the most attractive alternative energy source because of its availability and inexhaustive nature of supply. In fact solar energy is the source of all life and the sole cause of other sources of energy,like wind, tidal geothermal, fossil fuels, bio chemical etc. Even the small proportion of the total input which is used in photosynthesis ultimately reappears as heat through biological degradation. Planned biomass energy production is also indirect solar energy. The overall input of heat to the earth from the sun is balanced by heat lost by radiation of the earth to space.The thermodynamical potential of the solar radiation is high,though the energy density is very low at around only 0.1 Watt/cm^2.

The techniques used for harnessing direct solar energy fall into two categories (i)Thermal Collection and (ii) Photovoltaic Conversion.

Technologies using thermal collection have been developed for space heating devices, solar pumps and solar furnaces. The efficiency of heat collection achieved can be up to 85%. The Photovoltaic technique is used to collect and store solar energy in semiconductor cells. The upper efficiency achieved in this process is 15%. Semiconductor cells developed have a maximum open circuit voltage of 0.3 to 0.6 volts, Short circuit current of 40 mA/cm² and a maximum power output of 150 W.m². The cells are therefore connected in series and parallel circuits to provide the required current and Voltage for the load.

The main advantages of Solar energy are

1. It is a clean. sustainable energy source of considerable magnitude which can be considered preenial in the human life time frame.

2. A large number of people living in tropics, can benifit from solar energy as the sun shines brightly round the year in these parts of the world.

Some applications of solar energy like solar water heating and space heating have now become economically competetive with other forms of energy.

The main limitations of solar energy are

1. The intensity is low, so that very large devices are required to collect significant amounts of energy.

2. Solar radiation is intermittant and effective

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methods of storing energy for sunless periods are yet to be developed.

3. For many industrial applications, investment costs are still unattractive,while operational and maintenance costs are uncertain.

WIND ENERGY, as mentioned earlier is primarily due to the sun and results from the unequal heating of the earths rotating surface. Sufficient energy is continually being transferred from the sun to the winds of the earth and can be tapped for power generation and other uses where conventional fuels are now used. The total availability of wind energy is estimated at $3.6X10^{15}$ Watts.Wind energy has been tapped by wind machines from as early as 200 B.C. for grinding grain and its use has been continuously increasing in many countroes. In Denmark there were more than 2500 windmills in operation in 1900, supplying a total of 40,000 hp. which was more than 25% of the total power available to Danish industry at that time. In recent times, more than six million small bladed windmills providing power output of less than 1hp each in an average wind, have been built and used in U.S.A. to pump water.

The advantages of wind energy are :

1. It is a clean replenishable source of energy.

2. Windmills are simple in design.

3. Many types of windmill technologies have been proven reliable over a long period of time.

4. Windmills can be built rapidly and mass produced.

The limitations of wind energy utilization are :

1. The uncertain availability of wind energy at specific potential installation sites.

2. The need to provide a standby energy source sometimes due to intermittent nature of wind flow.

3. Limitation of power generation capability of a single windmill.

4. High capital costs.

Substantial R & D effort is now divertied to improve windmill technologies in terms of beter blade dynamics and engine control, with some emphasis on devices with capacities of at least 1 MW . New concepts are focussing on the use of wind concentrators, diffusers and vortex generators which increase ambient wind velocity and decrease the size of turbine blades which are the most expensive elements in the system.

GEOTHERMAL ENERGY can be produced by utilizing the terrestial heat of hot dry rocks. Natural steam is often found escaping from the surface of the earth in many places. This has suggested the possibility of using the heat of the earth for steam generation and using this steam to develop power. Deep exploratory drillings have often tapped sources of underground steam.

It has been seen that the temperature of the earth increases by about 2.75° C for every 100 meters depth. Deep drilling up to 15000 meters has made terrestrial heat naturally available at around 415 °C. Geothermal electrical generating plants employ this heat to raise steam from water. Water is fed into an entry pipe and an escape pipe is provided for the steam which runs a turbine. A 600 mm dia pipe drilled to 15,000 m. depth for feeding water for steam conversion produces 20,000 KW at peak load cyclicly for 3 hours per day. It would also furnish 75 million. kcal per day of process heat between 200 C and 40 C. In U.S.A. a geothermal plant of 600 MW is installed at the Geysers in California.*

Geothermal energy is economically competitive but the resource base is limited since it requires the relatvely rare geological combination of hot rocks and underground water system and an impermeable caprock for trapping the steam and providing pressure.The total installed global geothermal electrical generating capacity is only about 1400 Mw. Energy from hot dry rocks could greatly increase geothermal resoucres but technology is still in early stages of development.

The advantages of geothermal energy are:

1. The source of energy is abundant being the heat of the earth itself.

2. The process is pollution free.

The main limitations of geothermal energy use are :

1. The location where steam producing sub strata are close to the earth's surface are far removed from centers of civilization where the power could be usefully employed.

2. A high capital cost is required irrespective of the scale of energy production.

BIOMASS ENERGY is got from forest wood, plant and agro residues, sewage, and municipal wastes, cattle dung etc.Dry biomass like wood and residues may be combusted to produce heat and electricity for industry and domestic uses. They may also be gassified to produce gaseous fuels-methanol, hydrogen, ammonia etc.

and these may find uses in industry, transport, and chemicals. By the process of pyrolysis, oil, char and gas may also be got from dry biomass.

Wet biomasses like sewage, cattle dung etc. can be subjected to the process of anerobic digestion to produce methane that finds use in domestic and industrial appplications.

Biomass energy technology utilization has developed greatly in the form of Bio-gas generation plants from cattle dung. This has found applications for cooking and lighting purposes. Incineration of municipal wastes also affords considerable scope to generate energy for heating purposes and also for small power plants. However agricultural residues and wastes still form a very large and yet least explored source of energy for industrial applications.

The advantages of biomass for energy schemes are:

1. Energy is stored for use at will
2. It has versatile conversion capabilities for various processes to produce high energy content gaseous fuels.
3. It is dependent on existing technologies though these can be improved.

4. It can be developed easily at low cost and with waste materials.

The limitations of bio energy resources are :

1. Being bulky they pose problems for transport and storage.

2. They are subject to climatic variability.

3. Their supply is uncertain.

1.3 COMMERCIAL ENERGY SOURCES IN INDIA

The traditional commercial energy sources in India are coal, oil, gas and electricity. Electricity in turn is generated from thermal, hydro and nuclear sources. The status of production of these commerical energy sources for the years 1982-1985 converted to Million Tonnes Coal Equivalent is shown in Fig. 1.1 and given in Table 1.2. For electricity, only hydroelectric and nuclear energy are mentioned as balance electricity is got from either coal or oil or gas as primary fuel.

The commercial energy status of India presents a mixed picture. The coal and hydro electric resources of the country are substantial but their commercial exploitation is slow. The growth rate of production of coal in the period 1982-85 was around 4% per annum

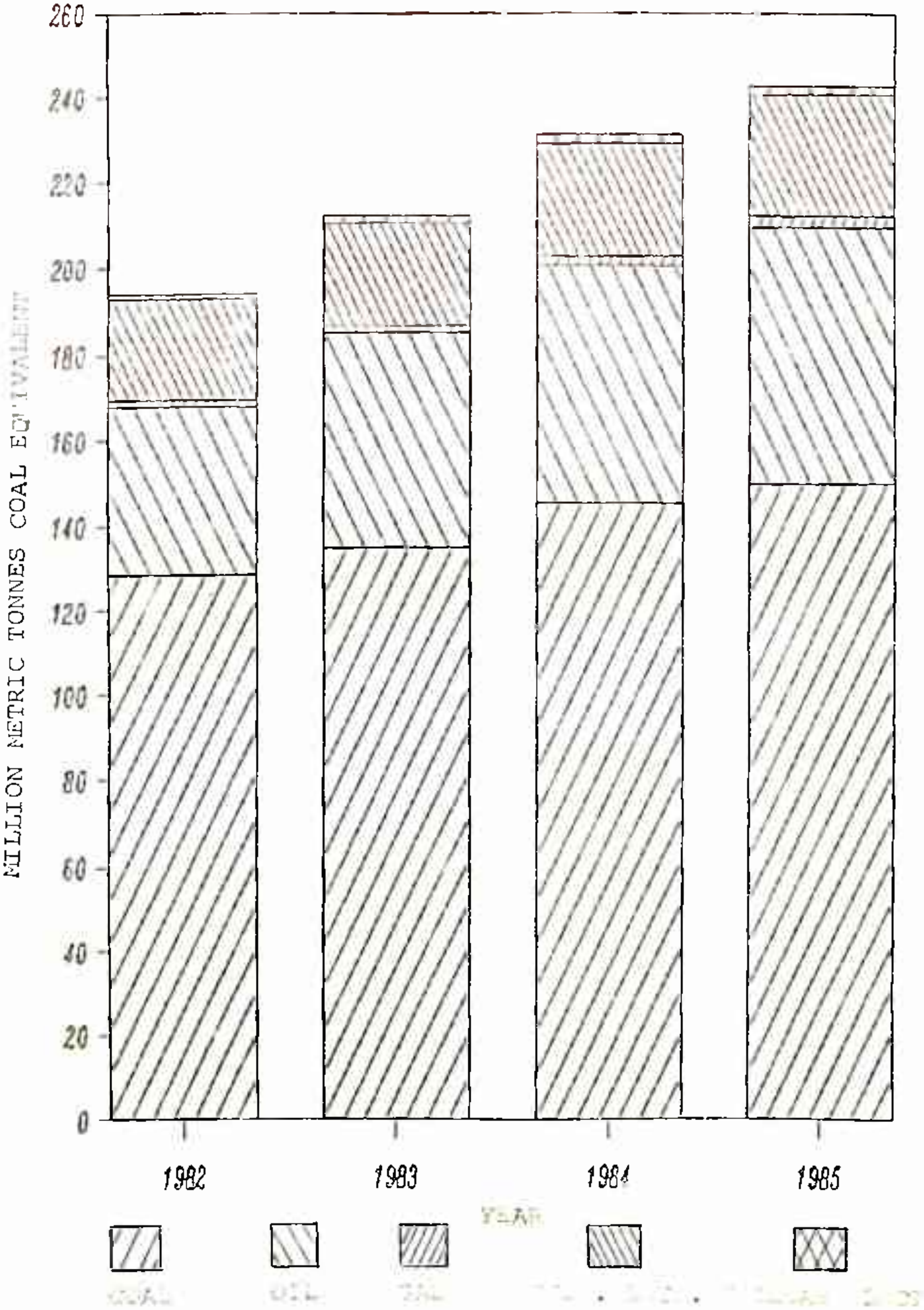


FIG 1.1 PRIMARY COMMERCIAL ENERGY PRODUCTION IN INDIA

whereas that of hydroelectricity was 5% per annum. The proven oil resources estimated at over 300 million tonnes are sufficient to meet the needs of only a few years to come. At the present rate of oil consumption which exceeds the production by about 15 million tonnes/annum, oil is to be imported which causes a heavy strain is put on the foreign exchange resources of the country. The shortage of traditional commercial energy is likely to continue for many years. It is therefore imperative that technologies be developed and utilized to harness non conventional energy sources for various applications.

TABLE 1.2 PRIMARY COMMERCIAL ENERGY PRODUCTION IN INDIA[70]
(MILLION METRIC TONNES COAL EQUIVALENT)

Energy type	Calorific value	1982	1983	1984	1985
Coal	5015 Kcal/Kg	128.5	134.8	144.9	149.7
Oil	10102 Kcal/Kg	39.5	50.3	55.9	59.7
Gas	12000 kcal/Kg	1.25	1.65	2.0	2.7
Hydr. Elect.	2450 Kcal/Kwh	23.70	24.48	26.38	28.42
Nuclear Elect.	2450 Kcal/Kwh	0.99	1.74	1.99	2.29
TOTAL PRODUCTION		193.94	212.97	231.18	242.81

1.4 ENERGY AVAILABILITY FROM AGRICULTURAL RESIDUES IN INDIA

Of the potential alternative fuels available in India, though biomasses like wood forestry and bio-gas plants have caught the attention of the planners, agricultural resources have been neglected and have only recently found their place in the energy budgets of the country.

For every tonne of foodgrain produced, one and a half tonne of crop residues are harvested. While all crop residues are cellulosic in nature their individual charaterstics vary over a wide range. Studies about their physical and chemical properties reveal that they can all be used as alternative fuel sources. Traditionally they have been pressed into use for the purpose of thatching in huts, cattle feed,baking bricks in rural areas, and sometimes as kitchen fuel.Not withstanding the fact that the the fuel potential of agro - residues is known and the residues are used as fuels in households and sometimes for process heat,this is done so with sub optimal utilization of their heat content.

The residue to crop ratio, calorific value, coal equivalent ratio and availability of coal equivalent energy from the residue per crop for six major crops in India is given in Table 1.3.

TABLE 1.3 COAL EQUIVALENT ENERGY FROM CROP RESIDUES

Crop	Residue	Residue ratio Kcal/Kg.	Calorific value	Coal Eq. ratio	Coal Eq. per crop kg./kg.
Rice	Straw	1.5	3589	0.71	1.065
Wheat	Straw	1.0	4095	0.82	0.820
Sugarcane	Bagasse	0.155	4776	0.82	0.820
Cotton	Sticks	3.0	4155	0.83	2.50
Maize	Stalks	2.0	3980	0.77	1.53
Maize	Cobs	0.5	4150	0.83	0.42
Groundnut	Shells	0.33	4776	0.75	0.[illegible]1

Source: Punjab Agricultural University, Ludhiana.

For every kg of rice produced, 1.5 kg of rice straw is produced which is used extensively for thatching and animal food. Rice husk, the hard and protective shell covering the rice kernel is also separated during the milling of paddy and about 300 gms of husk is obtained for every kg of rice. A kg of wheat straw is got for every kg of wheat produced but is conventionally used as cattle feed. Sugarcane crop yields about 160 gms of bagasse for every kg of sugarcane. The bagasse is used in the sugar industry itself as a fuel for boilers and also finds use as raw material in the paper and board industry. Cotton sticks produced weigh three times the yield of seed cotton and are preferred as kitchen fuel. The maize crop yields 2 kg of stalks and 500 gms of cobs for every kg of maize produced. Like cotton sticks, maize stalks and cobs are sometimes used as household fuel, though much attention is not paid to them. Groundnut shells, produced at 330 gms/kg of groundnut are also commonly used as a boiler fuel. The production figures for major crops of India for the years 1982-1985 are given in table 1.4 and table 1.5 gives the overall energy availability from crop residues for the same years.

TABLE 1.4 PRODUCTION OF MAJOR CROPS IN INDIA
(IN MILLION TONNES)

	1982	1983	1984	1985
Rice	47.12	60.10	58.34	64.15
Wheat	42.79	45.48	44.07	46.89
Sugarcane	189.50	174.08	170.31	171.68
Cotton	7.87	7.72	7.38	7.58
Maize	6.55	7.92	8.44	6.89
Groundnut	5.28	7.08	6.43	5.55
Total	229.11	302.38	294.97	302.74

Source : Planning Commission report 1986

TABLE 1.5 ENERGY AVAILABILITY FROM CROP RESIDUES IN INDIA (MILLION METRIC TONNES COAL EQUIVALENT)

	1982	1983	1984	1985
Rice straw	50.18	64.02	62.15	68.34
Rice husk	10.46	13.34	12.95	14.24
Wheat straw	35.08	37.29	36.14	38.45
Bagasse	28.42	26.11	25.55	25.75
Cotton sticks	19.67	19.3	18.45	18.95
Maize stalks	10.35	12.51	13.34	10.99
Maize cobs	2.75	3.33	3.55	2.89
Groundnut Shells	1.64	2.19	1.99	1.72
All residues	158.55	178.09	174.12	181.22

As can be seen from these tables the overall energy availability from crop residues is more than the energy contained in the total coal consumption of the country. The details of agro residue energy for the years 1982-1985 are graphically shown in Fig 1.2. As can be seen from this figure the difference between the available agro residue energy and the coal consumption for the year 1985 is equal to the energy availability from total oil imports for the year.

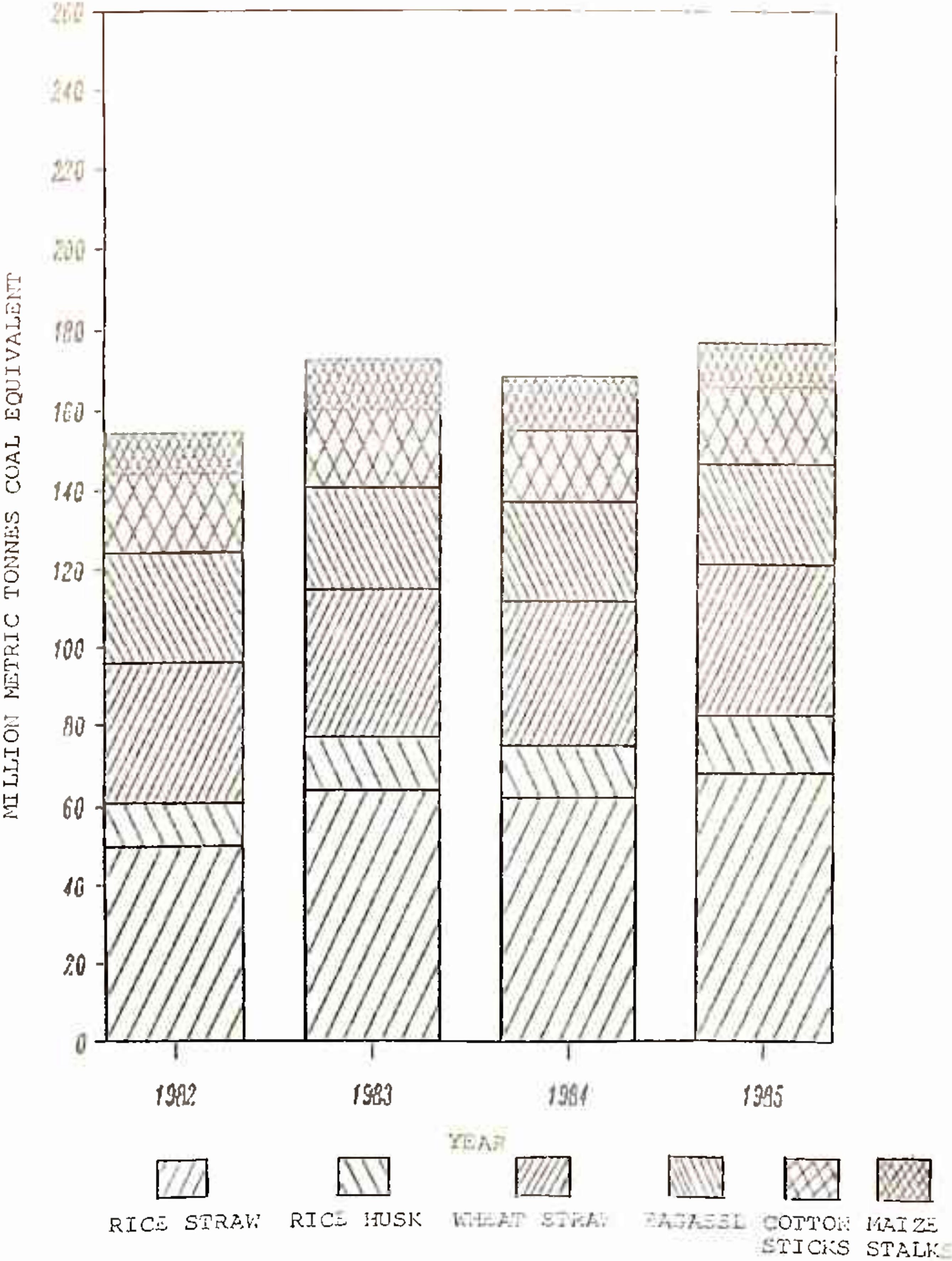


FIG 1.2 ENERGY AVAILABILITY FROM CROP RESIDUES IN INDIA (1982 1985)

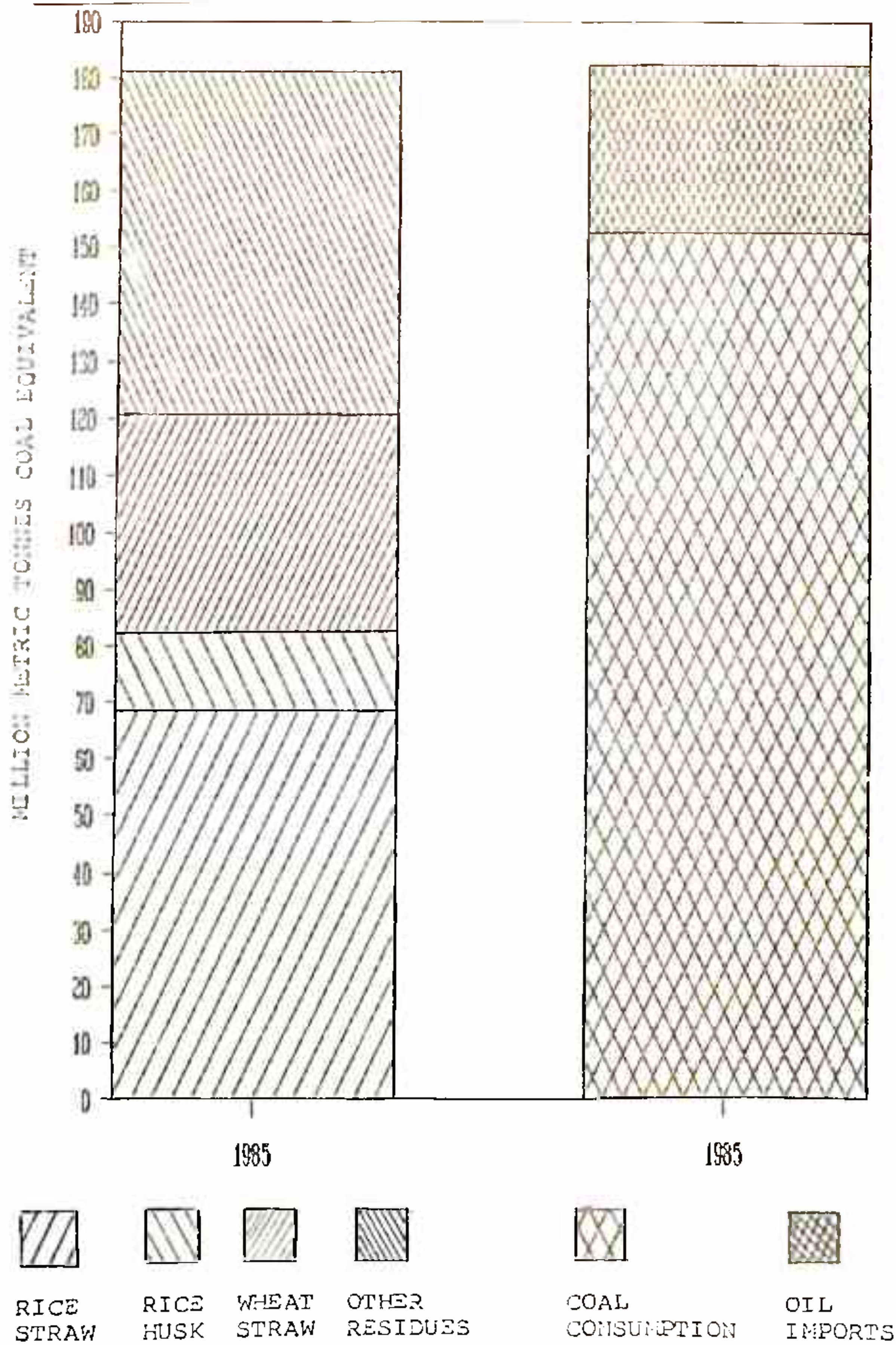


FIG 1.3 ENERGY AVAILABILITY FROM CROP RESIDUES, COAL CONSUMPTION AND IN OIL IMPORTS, 1985.

Of all the crops, rice crop residues are most surplus to their traditional uses of bedding, thatching and cattle feed. Rice husk was until recently a problem for disposal, and two national seminars have been held in 1981 and 1982 to discuss effective utilization of rice husk. These residues can form a significant source of alternative energy and constitute an equivalent of about 50% of coal consumption in India. Although much more rice straw is produced per kg than husk, the straw is generally widely dispersed in fields and poses problems of colection and transportation. The Department of Non - Conventional Energy has recently planned to put up a 20 MW power plant in Punjab based on rice straw as fuel, and the matter of collecting and transporting rice straw from the fields to the site has to be tackled in a planned manner.

Rice husk, on the other hand, is got as a bye product of the rice milling operation and is available in bulk at the rice shellers, and therefore does not pose a problem for collection. The statewise potential availability of rice husk in India is given in Appendix- A, and the statewise number of rice mills are given in Appendix- B.

1.5 RICE HUSK AS ENERGY SOURCE FOR PROCESS HEAT

In the industrial sector in India, there is a large demand of energy for process heat requirement,especially in the agro industries sector, at temperature ranges below 1000 C. such as in boilers, driers, calciners etc. There are over 18000 industrial boilers in the country, many of which are old, low capacity and inefficiently continue to use coal and oil. With increasing transportation and distribution costs and scarce avalability of coal and oil, the price of commerical energy to the users of rural based process energy equipment is exhorbitant. The current cost of coal to a few rural based boiler owners was found to be Rs. 900 per tonne.

The results of a study of all the rice shellers and industrial boilers for 9 districts in the state of Haryana are shown in Tables 1.6 and 1.7 respectively. There are 446 rice shellers in these districts which produce 391,250 tonnes of rice husk equivalent to 289525 tonnes of coal energy. The total number of boilers in Haryana is 631 of which 423 (67.05%) have a rating below 30 m^2. Another 145 (22.97%) have a rating between 30 m^2 and 100 m^2 and the balance 63 (9.98%)

have rating above 100 m^2.

The overall average rating of the boilers is 52.53 m2. Considering an energy requirement of one MTCE/day per 12.5 m2 rating boilers, it is estimated that the fuel requirement for all the 423 small boilers can be met by the rice husk generation in these districts collectively.

TABLE 1.6 ESTIMATED DISTRICT-WISE AVAILABLABILITY OF RICE HUSK IN HARYANA

Sl.No.	DISTRICT	NO.OF RICE SHELLERS	RICE HUSK AVAILABLE (TONNES)
1.	Ambala	46	40,338
2.	Faridabad	1	900
3.	Hissar	20	17,528
4.	Jind	25	21.949
5.	Karnal	127	111,428
6.	Kurukshetra	173	151,766
7.	Rohtak	1	900
8.	Sirsa	40	35,056
9.	Sonepat	13	11,385
	TOTAL	446	391,250

Source : Directorate of Industries, Haryana, Chandigarh.

TABLE 1.7 STUDY OF BOILERS OF HARYANA STATE

Sl. No.	District	Total No. of Boilers	Boilers with Rating < 30m²	Boilers with Rating 30-100m²	Boilers with Rating > 100 m²	Average heating surface m²
1.	Ambala	58	45	9	4	92.1
2.	Faridabad	97	46	33	18	51.6
3.	Hissar	40	32	5	3	31.2
4.	Jind	17	10	6	1	36.9
5.	Karnal	188	139	38	11	40.4
6.	Kurukshetra	109	83	20	6	28.0
7.	Rohtak	28	15	8	8	12.15
8.	Sirsa	40	25	8	7	46.6
9.	Sonepat	54	28	18	8	65.0
	TOTAL	631 (100%)	423 (67.05%)	145 (22.98%)	63 (9.98%)	
Av.heating surface		54.8m²	22.4m²	62.7m²	227.6 m²	

Source : Unitex Projects International Pvt Ltd. Delhi

It is for this sector of process heat; especially industrial small boilers that rice husk is especially suitable to replace coal and oil and be a source of easily available and cheap energy.

1.6 SCOPE OF WORK AND SCHEME OF PRESENTATION

The aim of the present work was to study the state of art of rice husk combustor design and develop a suitable design for efficienctly using rice husk as an energy source for direct end use applications like raising steam in boilers, driers, and heat exhcangers.The combustor was manufactured and tested in situ to establish its tecnical and economic viability.

The steps that have been taken are:

1. Collection of data and information available on the burning characteristics and other relevant properties of rice husk.
2. Design of a rice husk combustor using appropriate efficient technology with a particular view to convert existing small oil and coal fired boilers.
3. Development and field tests of the system.
4. Performance analysis of the designed unit in terms of overall economy, efficiency and effect of hot mass flow through the unit.

A review of the state of art of rice husk combustors has been made in Chapter 2 bringing out the main features, uses, drawbacks, and limitations of various designs.

The scope of rice husk as a fuel and its burning characterstics have been studied in Chapter 3. The effect of air feed rate, fuel feed rate, design features of the combustor, type of flow etc on the combustion efficiency and temperatures have been discussed in detail in this chapter.

Chapter 4 deals with solid gas flow systems and a detailed study is made on Swirl Flow Systems with and without combustion reactions, thereby laying the basis for designing a Swirl Flow Combustor System using bulk fuels.

The actual design, construction particulars, field testing, performance analysis, overall economy, efficiency, and effect of hot mass flow through the unit is given in Chapter 5.

Chapter 6 gives the conclusions and recommendations for further work.

STATE OF ART OF RICE HUSK COMBUSTORS

2.1 INTRODUCTION

Until recently, ,conversion and utilisation of rice husk attracted little attention from scientists and technologists. This was due to the fact that with cheap supplies of fossil fuels there was not much incentive to explore renewable sources of energy. The unprecedented hike in prices of fuels, uncertainity of availability , transportation difficulties,and finite nature of resources have changed the situation considerably making it imperative for energy planners to look for energy augmentation from non-conventional energy sources such as agro-residues.

As mentioned earlier, among the agricultural crops , paddy constitutes one of the most extensively cultivated crops covering an area of about 40 m.ha. During the milling of rice , husk and bran are obtained as bye products. Conventionally , rice husk is sometimes used as fuel for domestic purposes in villages . as a bedding material for animals , especially for poultry litter . It also is used as a packing material to protect commodities during handling and transportation. Rice husk is sometimes used as fuel in rice mills where parboiling of rice is practiced for raising steam or drying paddy.

Considerable amount of research effort is currently on to develop a suitable combustor that could effectively use rice husk as fuel. One of the primary challanges in this development process has been the poor combustion of rice husk. Some of the agencies working towards meeting this challenge are the rice Processing Engineering Centre ,IIT, Kharagpur, Dept. of Agricultural Engineering , PAU Ludhiana, College of Agricultural Engineering, Pantnagar Central Mechanical Engineering Research Institute, Dhanbad.

Attempts are being made to burn more husk more effectively so as to reduce dependence on conventional energy resources. Efforts are also on to trap the fly ash in flue gases escaping into the atmosphere.

The combustors used for burning rice husk may be classified into three broad categories:

1. Grate type furnaces: Here the rice husk is burnt in a bed on a grate specially designed for the burning of husk.

2. Husk Carbonizers: Here, the husk is merely roasted and the volatiles are either collected as combustible gas, or are burnt and hot air at relatively low

temperatures is obtained for drying purposes . The remaining charred husk and ash is discarded The charred husk may further be used to make fuel briquettes.

3.Suspension Burning Combustors: In these combustors necessary requirments for efficient combustion of husk are sought to be met by having the fuel burnt in a suspended state either by way of a fluidized bed or by suspension in an air flow. In this manner larger surface area per unit mass of fuel, long time of contact or large residence time and sufficient turbulence is brought about in the process of combustion thereby greatly enhancing the combustion efficiency.

A description of the various models of furances using husk as fuel is given in the following sections:

2.2 GRATE TYPE FURANCES:

The grate type furnaces may further be classified as conventional step grate type furances, a movable inclined box type grate furance and horizontal grate vertical pressurized furance. These furances can be used for steam generation as well as for drying paddy and other crops.

2.2.1 CONVENTIONAL INCLINED STEP GRATE FURANCE

The step grate firing method has been the most conventional technique for husk firing in the rice processing industry, perhaps all over the world, since its first application by Cowie[13] in Burma in1880. The basic features of a conventional inclined step grate furance are shown in Fig 2.1. Feeding of husk is done manually into the hopper and the rice husk passes on from the bottom onto the inclined step grate. The burning is initially commenced by starting a fire at the bottom of the grate with the help of firewood. The rice husk catches fire when a temperature of around 450 C. is attained. A natural draft is produced when the exhaust gasses by virtue of their high temperature and lower density flow through the doorway to the boiler to which the furance is attached, and get exhausted through the boiler chimney. The grate area to be provided is decided from the required heat liberation rate . The rate of combustion depends to a large extent on the fuel bed thickness. It decreases with increasing bed thickness. However , too small a thickness is also not desirable as it results in heavy entrainment of flue gas with ash. It is recommeded[43]

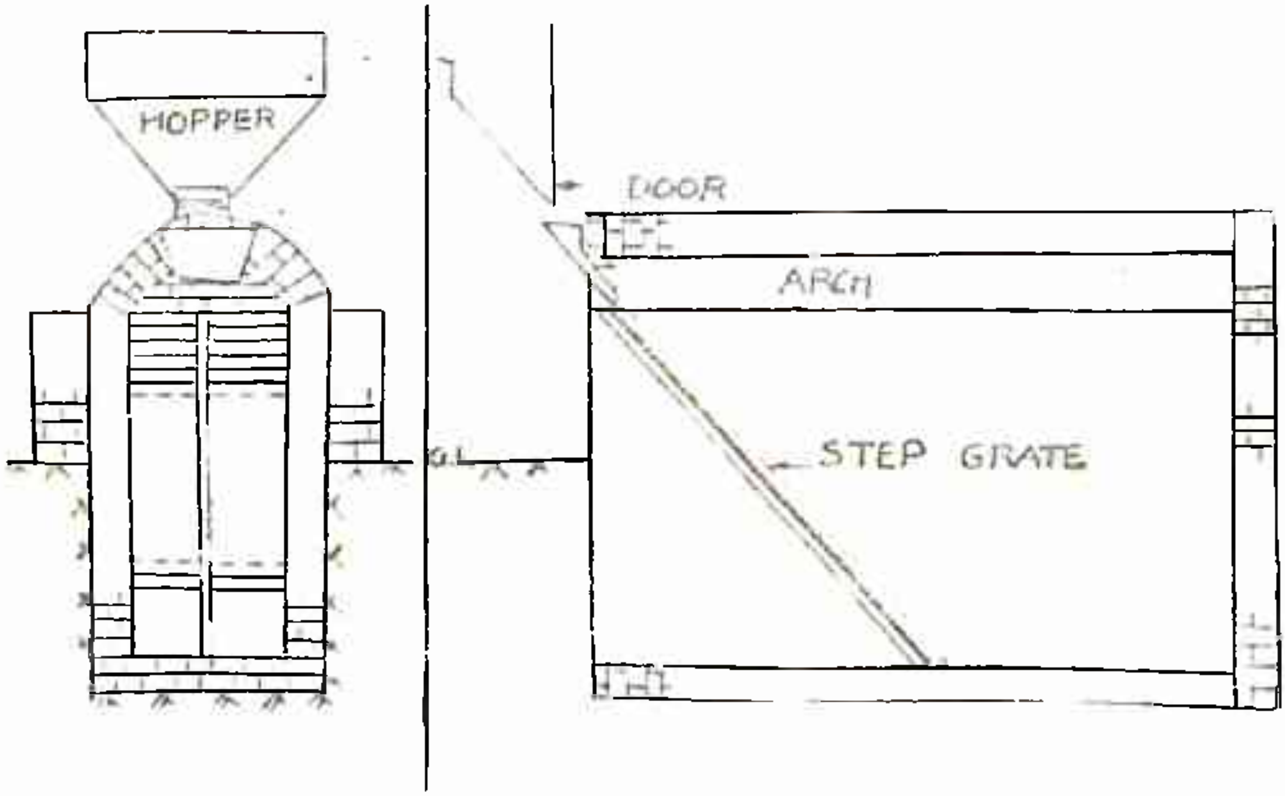


FIG. 2.1 A CONVENTIONAL INCLINED STEP GRATE FURNACE[8]

that a bed thicknes of 3-4 cms. should be maintained . The area of the grate can be calculated from the total quantity of husk to be fired which in turn would be dependent upon the load and the grate loading factor.The recommended grate loading factor is 70-80 kg/sq.m./hr.The volume of husk feed may be determined accordingly from the density of the husk which is 120-130 kg/m.^{3}.

The efficiency of this type of furnace is around 55-60%.It has the following main drawbacks for use on a boiler:

1. As the feeding is manual and the burning erratic, fluctuations in boiler temperature and pressure often occur.

2. The combustion rate of husk is low on a grate so that the response of the furnace to boiler load is poor.

3. The exhaust gasses contain a lot of fly ash which gets deposited on the tubes of the boiler. This results in decreases of heat transfer and hence efficiency of the boiler.The breakdown maintenance and downtime of the boiler also increases.

4. The construction of the furnace is rigid and it is not easily disconnected from the boiler. Interchanging of husk firing with coal fireing is time consuming, leading to considerable boiler downtime.

5. It requries constant poking to ensure proper combustion and an extra person is required for this purpose.

6. It has been found that adequate attention has not been paid to the slope of the grate which is usually 45°-50°. The angle of repose of rice husk varies from 35° to 45° depending upon the moisture content and size of particles. Thus, an inclination of 45° - 50° does not favour a smooth flow of the husk. Too high an angle of inclination is also harmful since in this case the particles move very fast and the retention time of particles in the combustion zone is not adequate enough to ensure complete combustion. Thus combustion efficiencuy is further adversely affected. It is therefore recommended that the slope of the grate should be between 50° - 55°.

7. The maximum flame temperature finally achived in grate type of furnaces at continuous combustion conditions is of the order 700° C only.

It may be mentioned that the main complaint of boiler operators that husk fired boilers converted from coal or oil do not give the same level of steam generation arises primarily from the use of undersized grate and the lower flue temperature. The maximum flue temperature attainable with the step grate furnace is about 700°C as against about 1100°C. in case of coal fired furnaces and 1400–1700°C. in case of furnaces using oil. A typical grate furnace used on a coal fired boiler of 1200 kg/hr saturated steam capacity consumed 360 kgs/hr of husk and raised 1000 kgs of steam at 50 psi giving a thermal efficency of about 51.1% and a water evaporation factor of 2.77 kg/kg of husk. Assuming the boiler efficiency to be 80% the combustion efficiency is calculated to be 63.75%.

2.2.2 MOVABLE INCLINED BOX TYPE GRATE FURNACE

Figure 2.2 shows a Movable Inclined Box Type Grate Furnace[22] developed at Rice Processing Engineering Center. I.I.T.Kanpur in 1976. The furnace is made of refractory bricks and is equipped with an inclined grate, consisting of cast iron bars in a staircase fashion at the bottom of which is provided a horizontal grate .

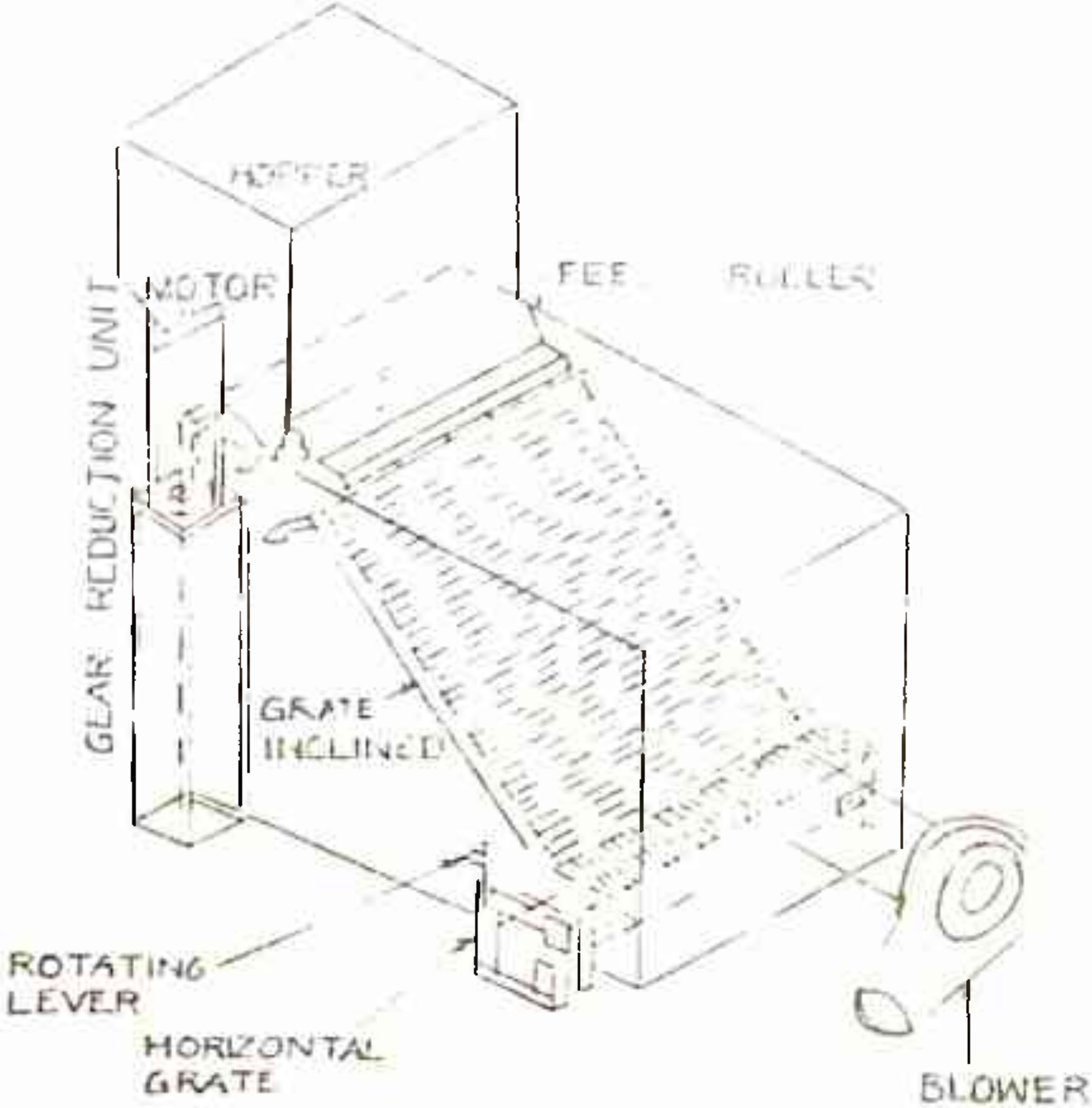


FIG. 2.2 MOVABLE INCLINED BOX TYPE GRATE FURANCE[44]

The husk is fed at the top of inclined grate with the help of feeding roller mounted in the hopper and powered by an electric motor. The burnt husk or ash is disposed off intermittently by rotating the horizontal grate manually . The inclined grate is also movable and is made in three sections. The angle of inclination of the steps in each part can be regulated making it possible to control introduction zone , the combustion zone and the residual zone separated from each other by having different angles of inclinations in each section.

This furnace also incorporates the provision of an air supply by providing an induced draft fan at the stack or a feed blower.

The advantages of this furnace over the step grate inclined furnace are as under :

1. The slope of the grate , which is in three sections, can be regulated, thus affording better control on flow, fuel bed thickness and combustion of husk on the grate.

2. There is a provision of mechanical air supply through the blower or induced draft fan where-as in step grate the draft was totally dependent on the

stack. Thus more complete combustion is possible.

3. The feeding of husk is uniform on the grate width due to mechanical feding of husk. The furnace described above performed with a combustion efficiency[44] of 67.32% at a husk feed rate of 20 kg/hr and an air flow rate of 2.83 m^3/hr. The maximum flue temperature was found to be only 380°C. This is due to the possibility of very high air fuel ratio conditions in combustion.

The main problems with this type of furnace are the high carry over of fly ash , large space requirement and low attainable flue temperature.

2.2.3 HORIZONTAL GRATE VERTICAL PRESSURIED FURNACE

Figure 2.3 shows a horizontal grate vertical pressuried furnace[32] developed by Annalmalai University in 1976. In this furnace the grate is horizontal and the husk if fired on to it by means of two chutes at the bottom of feeding hoppers. Paddles are provided for regulating the husk feed. Air required for burning the husk is injected through air nozzles under the conical shaped CI Grate which holds the heap of rice husk fed in the furnace. The furnace has a square section of 160 cm x 160 cm x 350 cms.

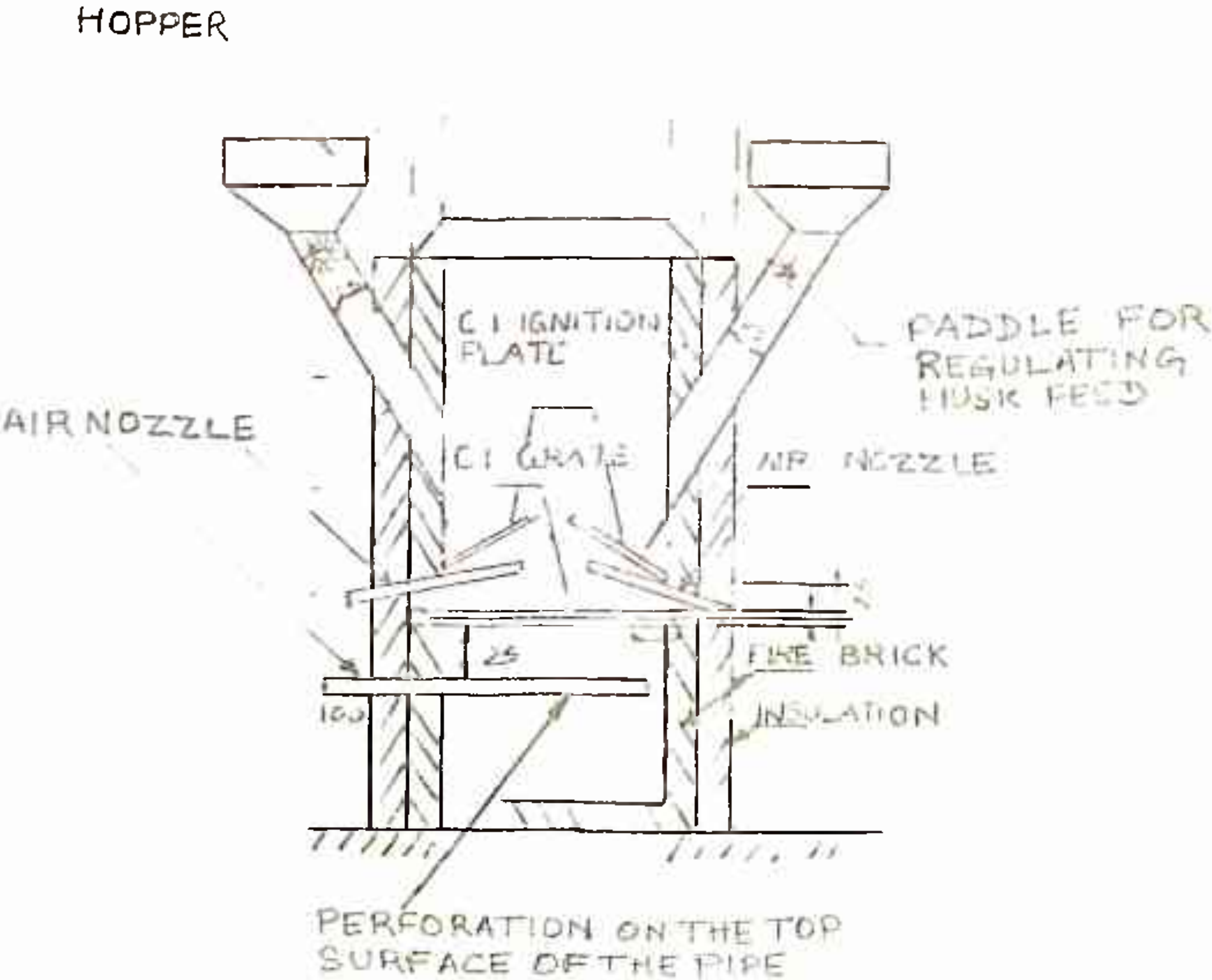


FIG. 2.3 HORIZONTAL GRATE VERTICAL PRESSURIZED FURNACE[8]

The furnace performed at a combustion efficiency of 73.31% at a husk feed rate of 40 kg/hr and and air feed rate of 2.83 m³/min.The maximum flame temperature was of the order of 700 °C.

The main drawback of this type of furnace also is the ash carry- over with flues and low maximum temperature of 700 C. Besides ,there is a high power consumption for the blower for feeding husk

2.3 RICE HUSK CARBONIZERS

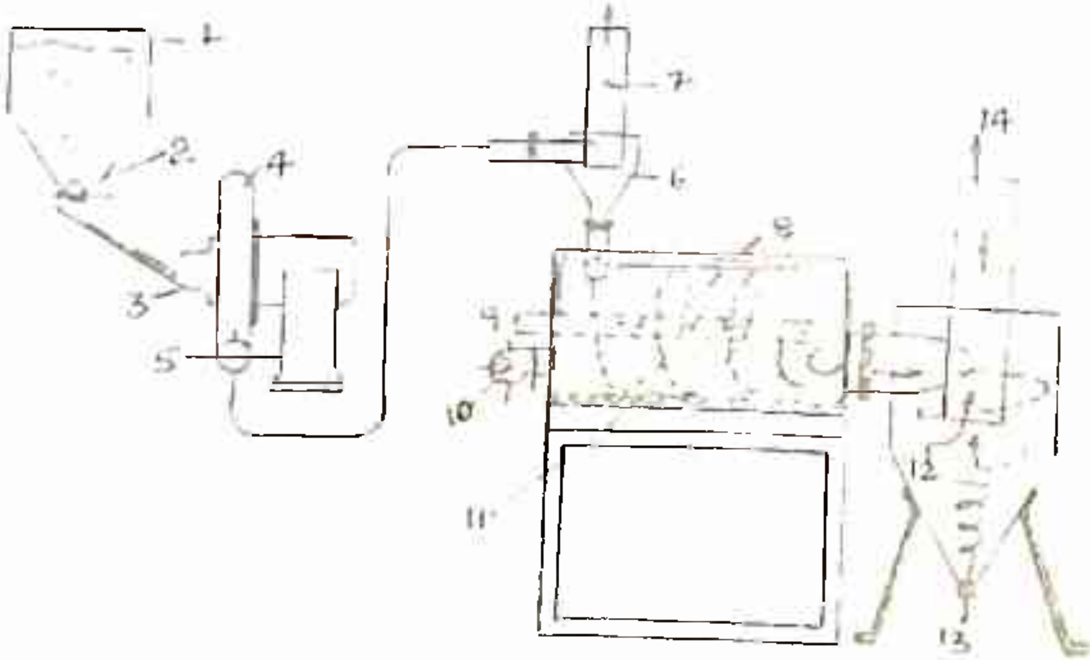
In this type of rice husk furnaces the energy extracted from the rice husk is only the sensible heat contained in the volatiles and part combustion of the fixed carbon . Carbonizers are also sometimes called gassifiers as they separate the volatile gasses and leave back the charred carbon and ash. They have the distinct advantage of having little or no fly ash but also the disadvantage of a high capital cost. A heat recovery of 45 to 50 % of the rice husk calorific value in the volatiles is achieved in the process of carbonizing the husk. The carbonated husk is subsequently briqutted into solid fuel pellets. However, they have a very high capital cost.

Some of the rice husk carbonizers are described below :

2.3.1 HORIZONTAL DRUM TYPE CARBONIZER

A schematic diagram of the horizontal drum type carbonizer[8] is given in Fig 2.4. Husk is manually filled in the husk tank (1) and fed by means of a feed roller (2) onto an inclined open short chute leading to the air inlet (3)of a blower (4).From the blower it is blown through a conveyor gate (5), cyclone (6) and a damper arrangement (7) into the burning chamber (8). The burning chamber has a secondary air inlet (9) and is equipped with an oil burner (10) to start the combustion process. The burning chamber is provided with insulation (11) to prevent excessive heat loses. The products of incomplete combustion are led to the carbonated-husk separating-cyclone (12) that separates the rice husk gas (13) from the carbonized husk (14) The air fuel ratio can be adjusted with the feed roll mechanism and damper to control the combustion reaction in the burner chamber.

The main advantage of the carbonizer is that there is no problem of fly ash. It however requires a regular provision of secondary oil firing system to sustain the combustion process



1. Husk Tank
2. Feeding Roll
3. First Air Inlet
4. Air Blower
5. Conveyor Gate
6. Cyclone
7. Damper
8. Burning Chamber
9. Secondary air inlet
10. Oil Burner
11. Insulation
12. Carbonated Husk Separating Cyclone
13. Carbonated Husk
14. Gas

FIG. 2.4 HORIZONTAL DRUM TYPE CARBONISER,

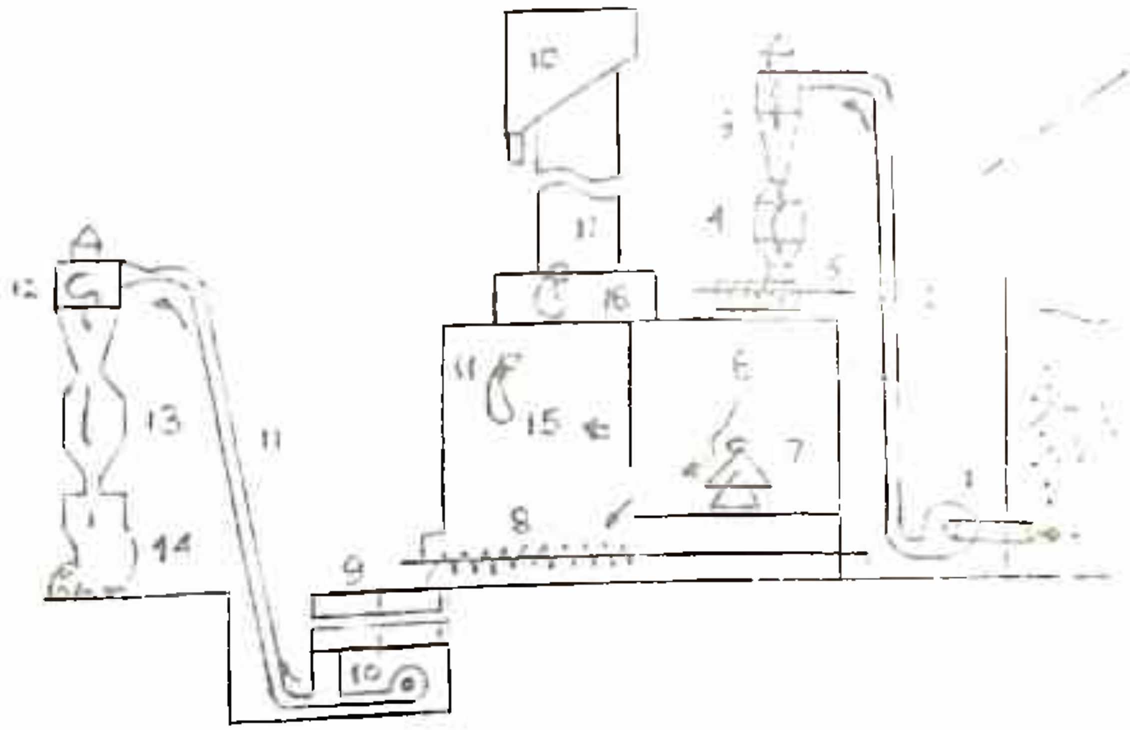
2.3.2 ROTATING SPREADER TYPE CARBONIZER

This type of furnace[a] is schematically shown in Fig. 2.5 . A husk conveyor blower (1) blows husk from an open heap through a conveyor tube (2) to an inlet cyclone (3) From the cyclone the husk is fed into an inlet hopper (4). A feed screw (5) at the base of the hopper feeds the husk on to a rotating spreader (6) in the first burning chamber (7).Here partial combustion takes place and the carbonated husk drops to the bottom from where it is fed by a screw conveyor (8) to an intermediate husk extinguishing chamber (9). It is then blown with-the-husk of another blower (10) through and husk conveyor pipe (11), cyclone, (12) and hopper (13), to the carbonated husk container (14) .

The gases, on the other hand pass from the first burning chamber (7) into second chamber (15), third chamber (16), and chimney (17), to showering tower (18), where they are washed for dust pollution control.

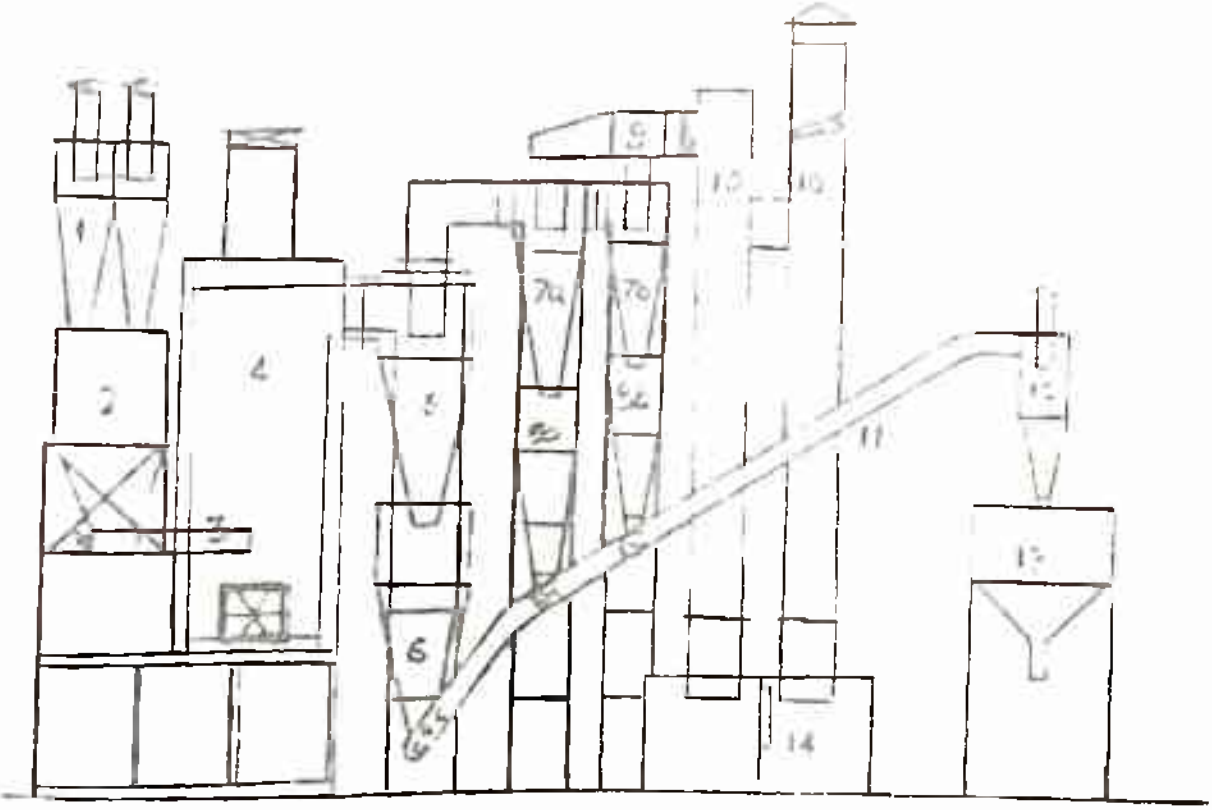
2.3.3 VERTICAL DRUM TYPE CARBONIZER

A schematic diagram of the vertical drum type carbonizer[a] is given in Fig 2.6 Husk from open heaps is blown through feeding cyclones (1), hopper (2) and feeding gate (3)into the first burning chamber (4).



1. Husk Conveyor Blower
2. Husk Conveyor Tube
3. Cyclone
4. Hopper
5. Feeding Screw
6. First Burning Chamber
7. Rotating Spreader
8. Screw Conveyor
9. Carbonated Husk Extinguisher
10. Carbonated Husk Conveyor Blower
11. Carbonated Husk Conveyor Pipe
12. Cyclone
13. Carbonated Husk Hopper
14. Carbonated Husk Container
15. Secondary Burning Chamber
16. Third Burning Chamber
17. Chimney
18. Showering Tower

FIG. 2.5 ROTATING SPREADER TYPE CARBONIZER[48]



1. Feeding Cyclone
2. Hopper
3. Burner Feeding Gate
4. First Burning Chamber
5. Secondary Burning Chamber
6. Carbonated Husk Collector
7. Dust Collection Cyclones
8. Dust Collectors
9. Smoke Path
10. Chimney
11. Carbonated Husk Conveyor Pipe
12. Carbonated Husk Cyclone
13. Carbonated Husk Hopper
14. Precipitation Chamber

FIG 2.6 VERTICAL DRUM TYPE CARBONIZER

The secondary burning chamber (5) is designed as a cyclone which separates the carbonized husk and drops it into the carbonated husk collector (6) from where it is conveyed through a pipe (11) and cyclone (12) to the carbonated husk hopper (13) . The smoke from the secondary burning chamber is passed through dust collection cyclones (7a) & (7b) to seperate the unbrunt which are collected in dust collectors (8a) and (8b). the husk drops into the conveyor pipe (11). While the husk free smoke is led through the smoke pipe (9) to the chimney (10) through the precipition chamber (14).

The above three furnaces are used for the the production of large scale carbonated husk for briquetting. The capital cost is high. Considerable sensible heat contained in the volatiles of husk however is often utilized for low temperature process heat requirements.

2.4 SUSPENSION BURNNING FURNACES

Traditional furnaces of the grate type suffer from high unburnts and poor load response . Efforts to improve the efficiency of such furnaces have been made by private manufacturers as well as technical and research institutes . These have led to the development of air suspension type furnaces. In these furnaces husk and air are blown togather in the burner chamber and husk is burnt in suspension, on providing a much larger surface area-to-volume ratio of fuel for combustion. The system ensures more complete combustion of rice husk leading to increased burning efficiency and higher flame temperatures.

2.4.1 HORIZONTAL CYCLONE FURNACE

Fig 2.7 shows a horizontal cyclone furnace[43] developed by Rice Processing Engineering Center, I.I.T.Khargpur. Primary air and husk are blown tangentially into the furnace There is also a provision for secondary air input into the furnace. The flues are led to the heat transfer tubes of the boiler and subsequently to the stack. They flues are subjected to cleaning by washing before going to the stack. The cyclone furnace is 1.10 m in diameter and 2.39m long. The maximum combustion efficency of the husk in this furnace was 70.14% at a feed rate of 110 kgs.husk /hr and an air flow rate of 12.74m^3 /min. The maximum temperature attained by the flues gases is of the order of 1100°C. This furance is well suited for vertical Lancashire type boilers with flame inlets at the bottom.

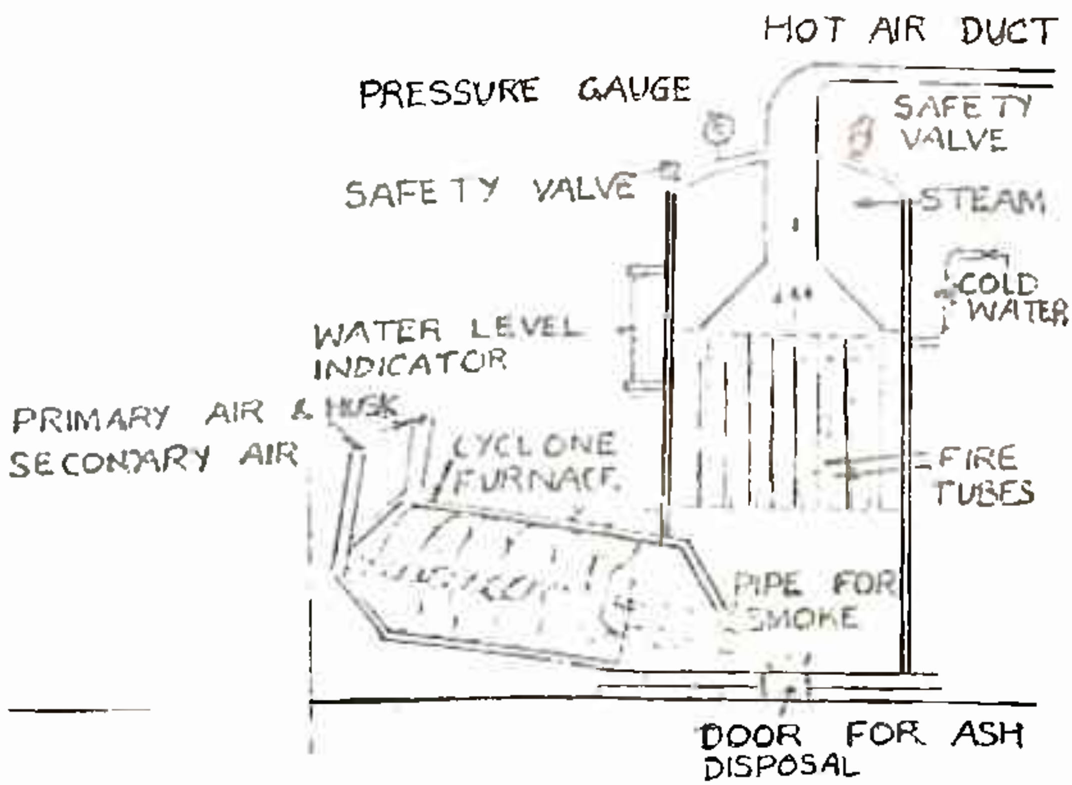


FIG 2.7 HORIZONTAL CYCLONE FURNACE

The disadvantages of this furnace include problems of vibration caused by the horizontal cylonic flow within the furnace. The foundations therefore need careful construction.

The fly ash is not separated before the flues reach the fire tubes and hence the hazard of excessive ash deposition on boiler tubes, low thermal efficiency and high maintenence remain for this type of furnace also.

2.4.2 FLUIDIZED BED FURNACE

Fig. 2.8 shows a fluidized bed husk fired furnace[36] developed at F C I , Thanjavur.

The furnace is a cylindrical hollow chamber with a concentric cylinder constructed within. The outlet of the inner cylinder leads to the heat exchange equipment. On a cement concrete foundation the base is made of standard quality red bricks, and the inner and outer cylinders are made of fire bricks of IS-8 quality. An M.S. jacket with necessary expansion joints are provided on the outer cylinder for structural strength. A pressure of (-) 12 mm WG. is created at the out let of the inner cylinder by means of an induced draft fan. The outer cylinder is provided with an

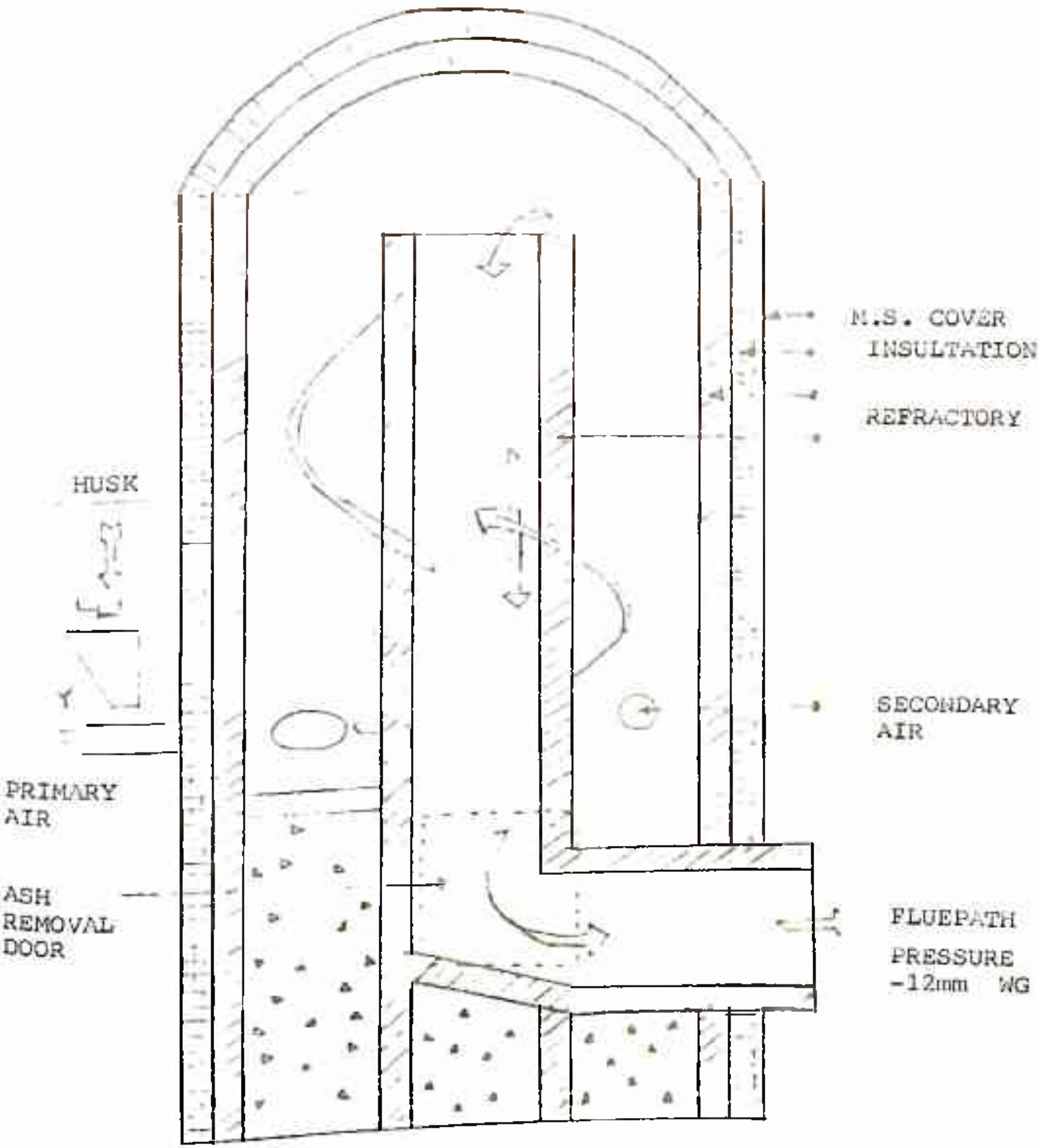


FIG 2.8 FLUIDIZED BED FURNACE

[illegible] for the husk [illegible] at a height of 0.5 meters above the floor [illegible] the mixture enters the outer chamber [illegible] to the annular space. The mixture [illegible] path in the outer chamber and rises upto the dome and moves down to ultimately pass out of the [illegible] through the flue path at the bottom.The central cylinder is 4.5 meters high and the fuel mixture travels atleast 20 meters from the point of entry to the outlet. The special feature of the vertical cylinder design is that the heat from the flue gas passing through the central cylinder is utilized for pre-heating the fresh fuel air mixture entering into the outer chamber . The temperature of this zone is always above 600° C.The temperature of the mixture (husk and air) rises in this preheating zone of pre-heating zone and the husk burns with the help of the oxygen available in the mixture. The ignition continues un-interrupted in this zone as long as the air husk mixture is fed in. The combustion is complete as thorough turbulence is maintained in this zone. Because of the agitation , the particles break up and complete incineration of husk takes place . The requisite amount of excess air keeps the particles provided with sufficient oxygen for combustion. The air husk mixture can also be admitted into the furnace from multiple points .This will help maintain the turbulence and improve combustion efficiency.

The aim of the cylindrical design is to trap the ashes produced in the process from escaping into the equipments with flues . This is achieved as the flue gases and mixture whirl around in the anular space between the cylinders .Due to the centrifugal action the particles are thrown and accumulate in the ash space at the bottom, while the gases rise upwards and are sucked into the inner cylinder.

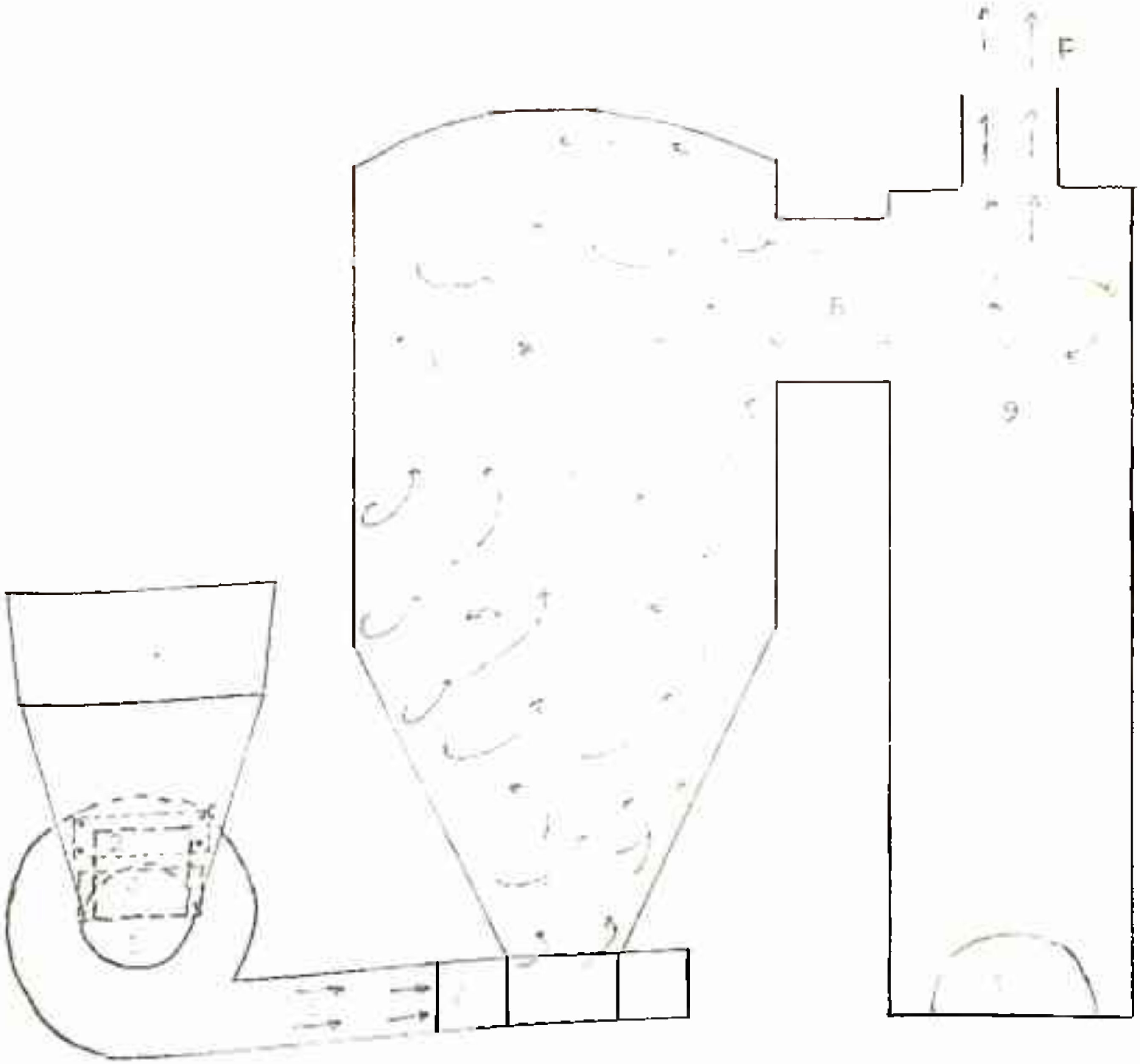
A model of this furnace installed at 'The Modern Rice Mills, Thanjavur' gave heat output is approximately 7.500 kcal/min. The internal temperature of the furnace reached upto 1200° C. The actual efficiency of combustion was worked out to be around 80 % and the ash produced was reported to be almost completely white with black specks upto 5% or so.

The main drawback of this system is that the upward cyclonic flow of feed is in the same annular space as the downward flow of ash from the combustion gases, so the separation achived is not of a high order. The cost of construction of this type of furnace with a capacity of burning husk at 240Kg./hr was about Rs. 75,000/= in 1982.

2.4.3 VERTICAL CYCLONE FURANCE

A schematic drawing of a vertical cyclone furance[10] is shown in Fig. 2.9. Husk is fed manually into a hopper(1) with an adjustable outlet opening (2) leading to the inlet of a blower (3). The inlet opening of the blower is also adjustable by means of a sliding damper plate (4) The air and fuel feed rates are controlled by these simple devices.

The husk and air are blown together into the burner chamber (7) through a connecting duct (5) and gas distributor (6) which gives the feed (fluidized husk air mixture) an upward spiral motion from the inlet at the bottom into the burner chamber.The combustion process is initially started by lighting a fire of wood placed in this chamber .Combustion of the fluidized husk takes place spontaneously and the combustion mechanism becomes very intense.The products of combustion are led from the burner chamber tangentially through a connecting duct (8) to the ash



1. Hopper
2. Blower Inlet
5. Connecting Duct
7. Burner Chamber
9. Ash Separation Chamber

2. Adjustable Outlet
4. Sliding Damper
6. Distributor
8. Connecting Duct
10. Ash Outlet

FIG. 2.9 VERTICAL CYCLONE FURNACE

separation chamber(9) burner chamber. The ash separates out to very large extent and the flues are then led to the heat transfer equipment carrying only very fine ash.

The design was first used for the calcination of lime in a kiln. The system burnt 50 kg.of husk/hr. and a flame temperature of around 700 °C .was easily achieved with remarkable stability. The residue ash was found to be greyish white with negligble traces of black spots.

The burner system was used next on a vertical coal fired boiler of capacity 250 kg./hr. of saturated steam at 50 psi. The temperature attained was about 1250° C. as estimated from the flame colour. The system burnt about 75 kg. husk per hour and gave the rated steam output thus giving a thermal efficiency of about 62%. Assuming boiler efficiency to be 75%. the combustion efficiency was estimated as 82.7%

There were however some problems of the system choking up due to softened ash cogglamorating on the inside walls of the combustion chamber and carry over of some fly ash, though much less than in conventional grate furance.

2.5 OVERVIEW

There have been many types or designs of grate furances for burning rice husk as fuel, however, most of them suffer from one or more of the following drawbacks:

1. The combustion efficiency is low, in the range of 67% to 73% and there is a high percentage of unburnt in the ash.

2. The flame temperature achieved is of the order of only $700\,^{\circ}C$ putting a limitation on the steam generation capacity of a boiler.

3. The burning of fuel on the grate is erratic leading to fluctuation in the boiler. An extra person is required to stoke the fuel on the grate to ensure proper combustion. The rate of combustion also is low so that these furnaces have a poor load response.

4. There is a high carryover of ash particles to the boiler tubes which get deposited there. This decreases boiler efficiency, higher maintenance costs, increased boiler downtime , and shorter life of boiler tubes.

The above facts have led to search for alternative techniques of utilizing rice husk energy leading to the development of husk carbonizers and supension burning furnaces.

Husk carbonizers are used to burn away the volatiles in rice husk and the remaining carbon is briquetted and used as fuel. They do not pose any fly ash problem. The heat of the volatile combustibles can be used for process heat, but the temperatures attained are very low and unsuitable for boilers. They may be used for low intensity heat operation like drying etc.

Air suspension burners offer maximum heat recovery from rice husk combustion. Three types of furnaces namely the horizontal cyclone furnace, the fluidized bed furnace and the vertical cyclone furnace have been developed. All of these burn husk in spiralling husk-air flows. The combustion efficiencies of these furnaces range from 70% to 82.7%, and the temperatures that have been attained are in the range of 1200° C, the highest ever for rice husk burning. The horizontal cyclone furnace does not incorporate a system to seperate fly ash from the flues, wheras attempts to do so in the fluidized bed furnace have met with been partial success. There is scope for increasing ash seperation efficiencies. The vertical cyclone furnace has a relatively good ash separation efficiency. The advantage of high temperature attained of an order of 1200° C has a consequent disadvantage of causing fly ash to soften and cogglamorate on the walls of the furnace. This leads to choking in the vertical cyclone furnace.

The suspension furnances need to be improved to attain complete combustion and better ash separation.

3. CHARACTERISTICS OF RICE HUSK AS ALTERNATIVE FUEL SOURCE

Efficient utilization of rice husk as fuel depends on proper understanding of its physical and chemical properties, its combustion characterstics and the requirements for assuring a proper flow of husk through the feeding system etc.

The characteristics of rice husk produced in India vary considerably because of a very large variety of rice grown in the country. Common varieties of rice grown include Padma, Dulai, IR-8, Patnai and Basmati. The yield of husk from paddy ranges from 14% to 27% depending on the variety. The average yield for these varieties may be assumed to be about 20%. Although all rice husk contains about 40% crude fibre, 25% nitrogen free extracts and 20% mineral matter with small quantities of crude protein and soluble extracts. The chemical composition differs according to variety of rice, location and efficiency of milling process.

3.1 PHYSICAL PROPERTIES OF RICE HUSK

Rice husk surface is a free flowing material with an angle of repose of about 35°. It can be bulk handled easily but because of it's low inertia and high air resistance mechanical throwing of the husk is difficult. Becuase of its free flowing characteristics rice husk can be easily drifted by wind when stored outdoors.The surface of husk is rough and abrasive. Hence it causes very fast wear of husk handling machinery. The coefficient of friction of rice husk on MS PLate is about 0.63.

The size of rice husk depends on the variety. Its length ranges from [illegible] mm to 10 mm and the width from 0.3 to 0.5 times its length. The husk, when separated from the kernel is boat shaped. As it is concave in shape, reduced husk particles, though maintaining their concavity, affect its bulk density.

Rice husk has a low apparent bulk density varying from 102 kg/m^3 to 135 kg/m^3. The apparent density increases substantially after size reduction. For example for husk of -50 + 100 mesh (i.e. 0.149 mm to 0.297 mm dia.) apparent density has bee reported to be between 270 kg/m^3 to 420 kg/m^3.

3.2 HEAT CONTENT OF RICE HUSK

The heat content of rice husk is found to vary substantially, depending on its variety. The calorific value of husk ranges from 3200 kcal/kg to 3800 kcal/kg on dry basis.Heat content of about 3400 kcal/kg might be considered a fair average for rice husk.

The heat content for the five varieties of rice husk commonly grown in India is given in Table 3.1

TABLE 3.1 CALORIFIC VALUE OF HUSK OBTAINED FOR DIFFERENT VARIETIES OF PADDY[a]

VARIETY	CALORIFIC VALUE(kcal/kg) WET BASIS	MOISTURE CONTENT (%) WET BASIS	CALORIFIC VALUE (kcal/kg.) DRY BASIS
IR 8	2937.29	8.67	3216.13
PATNAI	3355.43	10.38	3744.06
PADMA	3105.99	6.62	3326.18
DULAR	3461.31	10.50	3867.38
BASMATI	2994.20	6.16	3190.75

The heat content on wet basis varies with the amount of moisture retained in equilibrium with atmospheric relative humidity conditions.

3.2.1 EQUILIBRIUM MOISTURE CONTENT

The equilibrium moisture content of rice husk varies with the relative humidity as shown in Table 3.2 for four levels of relative humidity. The level of moisture retained becomes significant above 60% relative humidity.

TABLE 3.2 EQUILIBRIUM MOISTURE CONTENT

Relative humidity	20%	40%	60%	80%
Equilibrium moisture content	0.56%	[illegible].73%	21.60%	29.46%

3.3 COMPOSITION OF RICE HUSK

The proximate analysis of common varities of rice husk is given in Table 3.3. As shown in this Table rice husk contains 12 to 15% fixed carbon 60 to 68% volatile matter and 15 to 17% ash.

Table 3.4 gives the elemental analysis of rice As seen from the table rice husk contains about 39%. carbon, 5% hydrogen, 2% nitrogen and upto 0.12% sulphur.

TABLE 3.3 PROXIMATE ANALYSIS OF RICE HUSK

Variety of Husk	Volatile Matter %	Fixed Carbon %	Ash %	Moisture %
IR 8	67.0	13.0	17.4	3.5
Patnai	68.0	14.0	15.0	3.0
Padma	67.0	12.0	18.0	3.0
Dular	66.0	15.0	16.0	3.0
Basmati	66.5	15.0	16.0	2.5

TABLE 3.4 ULTIMATE ANALYSIS OF RICE HUSK

Variety of Husk	C	H	N	S
IR 8	39.26	4.99	1.99	0.10
Palnai	33.9	5.1	[illegible]	0.12
Padma	38.1	1.7	1.5	0.11
Dular	38.5	4.9	1.8	0.10
Basmati	38.6	5.1	2.1	0.10

3.4 AIR REQUIREMENT FOR CUMBUSTION OF RICE HUSK

The theoretical amount of air required for complete combustion of rice husk may be computed from the ultimate analysis of rice husk, using the basic equations of combustion of carbon, hydrogen, sulphur, etc. On application of these equations to rice husk of IR-8 variety, it was found that 4.807 kg. of air or 3.7333 m3 of air at NTP are required for complete combustion of one kg. of rice husk, The specific weight of products of combustion at NTP is found to be about 1.31 kg/m^3. The details are given in Appendix C.

These figures are used later on for designing suitable system for combustion of rice husk keeping in mind the heat flow, mass flow velocity and pressure drop factors in the design plan.

3.5 COMBUSTION OF RICE HUSK IN FIXED BED

The combustion of solid fuels in fixed beds has for long been regarded as a mass transfer problem. The diffusional mass transfer through the gas film surrounding the burning solid fuel piece controls the overall rate of reaction in fuel beds, except during the later stage of burning when the ash layer has grown sufficiently in thickness to become the rate controlling factor.

At ordinary temperatures rice husk acts as a flame retarding material. The peculiar silica-cellulose structural arrangement of rice husk restricts burning of husk and release of heat unlike other organic materials. If the husk pile is very thin and is adequate air blanket turbulence is present true burning of husk may occur in an atmospheric pile.

While investigating the combustion of rice husk on fixed beds of thicknesses varying from 2cm to 4.5 cm with air flow rates of 23 $kg/m^2/hr$. to 614 $kg/m^2/hr$. Maheshwari[47] found that the instantaneous rate of combustion attained its peak value between the 11th and 12th minute after ignition in all cases. Thereafter the rate decreased. This may be due to the growing ash layer thickness which gradually comes to control the overal reaction rate. The complete combustion of the husk in bed was observed to take about 16 minutes or so.

The average combustion rate was found to increase with the increase in air flow rate till a maximum was reached. Further increase in the air supply resulted in loss of fine husk particles from the bed. The combustion rate was decreased with decreasing bed height. The maximum combustion rate achieved in bed was 81.26 kg/m^2/hr at an air flow rate of 532.42 kg/m^2/hr.

As the air flow was increased the average fuel bed temperature also increased and attained a peak value much earlier than the maximum rate of combustion. Thereafter the average bed temperature gradually decreased. This was possibly due to the formation of a large volume of products of combustion which carried away an increasing amount of heat from the fuel bed thereby lowering the average fuel bed temperature. However in case of low bed heights the bed temperature attained its peak early in combustion as the ignition plane moves upward faster with the liberation of volatile matter.

easily carried by the normal quantity of air necessary for the combustion process. It has been established that the critical velocity for fluidizing the husk[44] is 6mt./sec and for fluidizing husk ash above 10 micron size 1.5 mts/sec.

In suspension burning of rice husk too, the ratio of husk feed rate to the air flow rate plays a crucial role in the combustion process, composition of combustion gases, heat loss in combustion, combustion efficiency and the temperature of combustion gases. It is also observed that a minimum temperature of 450°C must be maintained in the combustion chamber to continue the process of heat evolution. Accordingly for a given air flow rate and use of the conbustion chamber a minimum husk flow rate and size must be assured to generate sufficient heat for the required temperature.

3.7 EFFECT OF OPERATING PARAMETERS ON SUSPENSION BURNING OF HUSK

Considerable experimental evidence has been collected regarding the effect of operating parameters in suspension burning of husk. Appendix -D lists the results of a series of tests conducted by Arora [5] under varying conditions of husk feed rate and air flow rate. Some of the important conclusion arising out of these investigations are discussed below.

3.7.1 EFFECT OF HUSK FEED RATE ON COMPOSITION OF COMBUSTION GASES

Figure 3.1 shows the effect of variation of husk rate on percentage of CO, O and CO2 in combustion gases at different air flow rates. As can be seen from this figure, the percentage of CO and CO_2 on gases increases with an increase in the husk flow rate for a given air flow rate, while the percentage of O_2 decreases. This is due to the fact that with the increase in fuel rate, more fuel is burnt leading to an increase percentage to an increased percentage of CO and CO_2 and lower percentage of O_2.

3.7.2. TEMPERATURE OF COMBUSTION GASES

An increased supply of husk per hour results in an increased heat production inside the combustion chamber. This results in increased temperature of combustion gases at higher feed rates and vice versa. It may, however, be observed that this phenomena holds as long as the air flow rate is in excess of the air required for complete combustion of the husk feed flow rate.

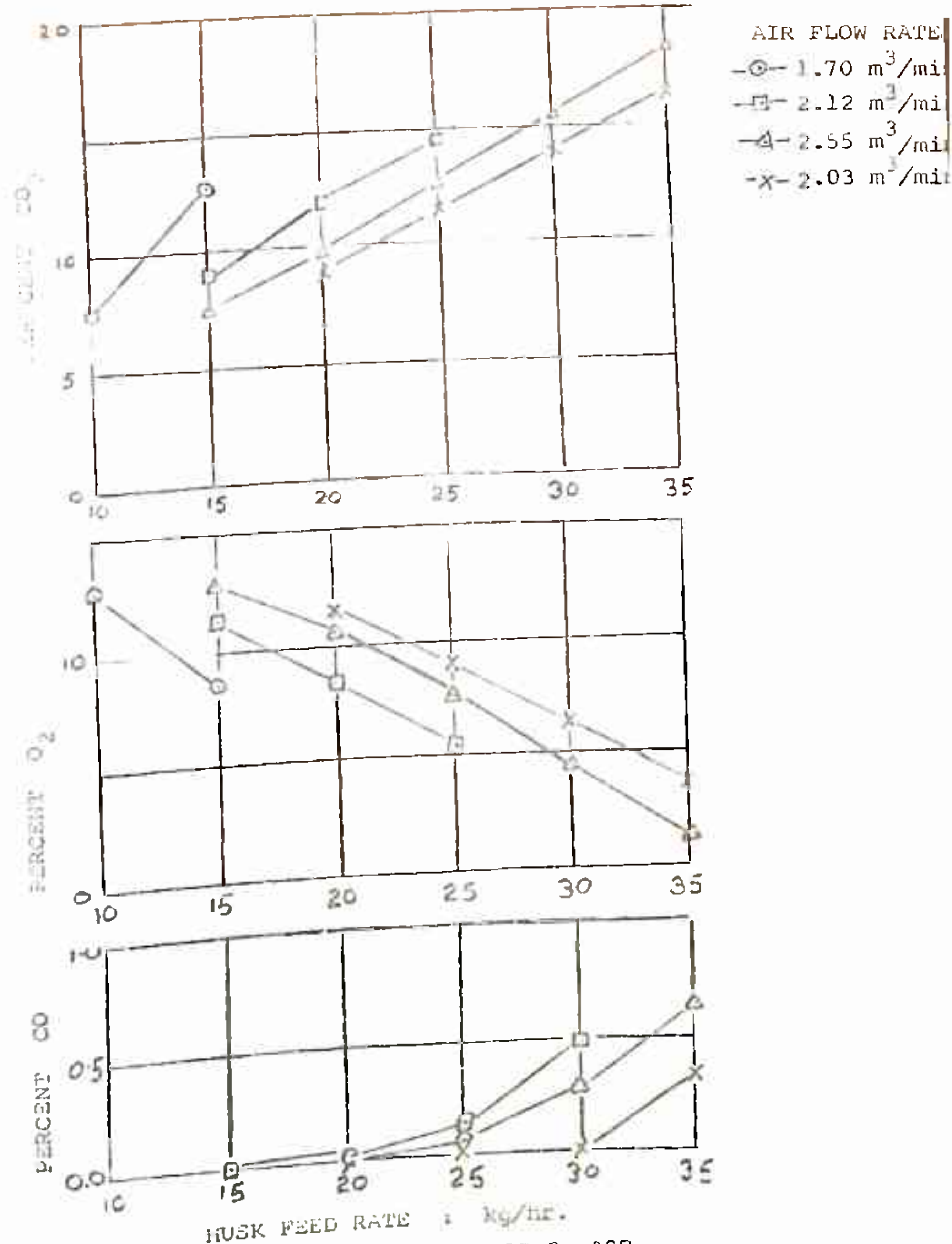


FIG 3.1 EFFECT OF HUSK FEED RATE ON CO, O_2, & CO_2 IN COMBUSTION GASES

3.7.3 PERCENT HEAT LOSSES IN COMBUSTION AND COMBUSTION EFFICIENCY

Fig 3.2 shows the percentage variation of heat loss due to C in the ash, CO in the combustion gasses and total heat losss with increase of husk feed rate. It can be seen that heat losses due to unburnt carbon in refuse go on decreasing first upto a minimum and then start increasing as feed rate of fuel is depending upon the air flow rate. The same is true for losses due to CO in combustion gases as well as total losses for the combustion process. This illustrates that proper combustion takes place at only a particular fuel air ratio. The optimum combinations are listed in Table 3.5 below.

TABLE 3.5 AIR FUEL COMBINATIONS FOR OPTIMUM OPERATION OF BURNER

Husk Feed kg/hr	Air flow rate m3/min	Excess Air %	Losses in unburnt carbon %	Losses in CO	Total Losses %	Combustion efficiency %
15	1.7	67.1	7.7		7.7	92.3
20	2.12	65.2	8.4	0.2	8.6	91.4
25	2.55	57.4	6.1	0.7	6.7	93.2
30	2.83	41.6	6.1	–	6.1	93.9

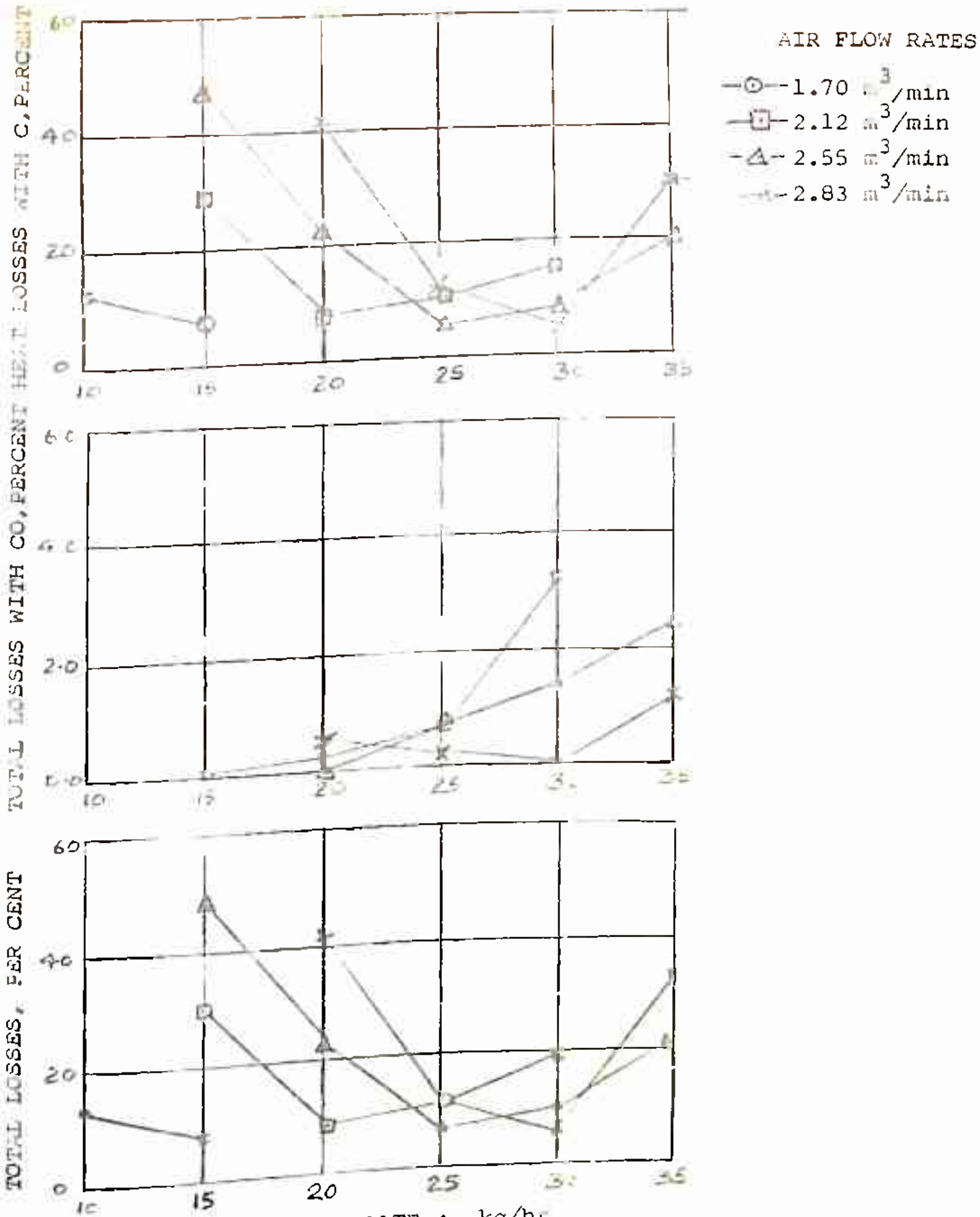


FIG 3.2 EFFECT OF HUSK FEED RATE ON COMBUSTION LOSSES FROM CARBON IN ASH, CO IN COMBUSTION GASES AND TOTAL LOSSES

This table also shows the combustion efficiency which can be directly found from combustion losses. Lower combustion losses mean a higher combustion efficiency and vice versa.

3.7.4 EFFECT OF PERCENT EXCESS AIR

The percentage of air supplied above the theoretical requirements of fuel has direct bearing upon the various parameters. Excess air has to be supplied to complete the combustion reactions in the required time and in the given space. Although a higher amount of excess air should not cause any harm to the combustion process as the additional air will go unreacted through the combustion chamber, it may lower the temperatures below the ignition temperature of fuel thereby stopping the process of heat generation.

An increase in the amount of excess air results in increased proportions of O_2 and decreased proportions of CO_2 and CO in combustion gases. Excess air also has a role in reducing the temperature of the combustion gases but this effect is compensated to some extent by higher heat evolution upto 50% excess air. Thus the temperature decreases slowly in this range.

Beyond 50% excess air, the temperature falls rapidly due to the added effect of increasing heat losses caused by unburnt carbon going in the refuse and the heat spread over a larger mass of combustion gases.

The effect of excess air on percent heat losses is given in [illegible]. The figure clearly shows that the losses due to unburnt carbon are the most predominant losses and go up to 48% of total potential heat of the fuel. The maximum losses due to CO formation are observed as [illegible]. The total losses are minimum in the excess air range of 40% to 60%. Heat losses due to carbon monoxide are negligible beyond 60% excess air. The unburnt carbon losses increase continuously as the excess air supply is increased beyond 60%. This is because additional air introduced into the system causes higher husk particle velocities, thus allowing them less time in the combustion space. This results in more and more unburnt carbon going with the refuse and hence higher losses. The effect of excess air on combustion efficiency is shown in Fig.3.4. The efficiency of combustion for the burner was found to be maximum in

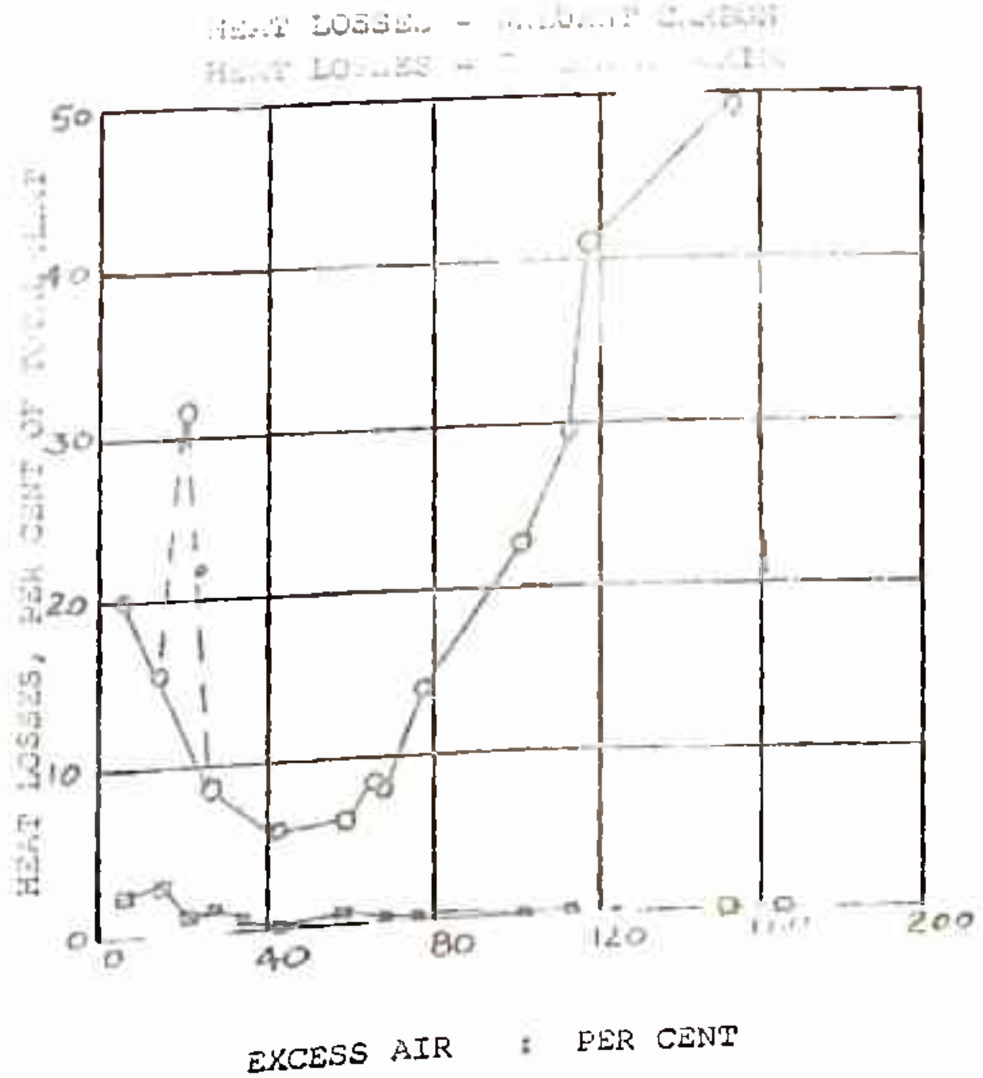


FIG 3.3 EFFECT OF EXCESS AIR ON HEAT LOSSES IN UNBURNT CARBON AND CARBON MONOXIDE*

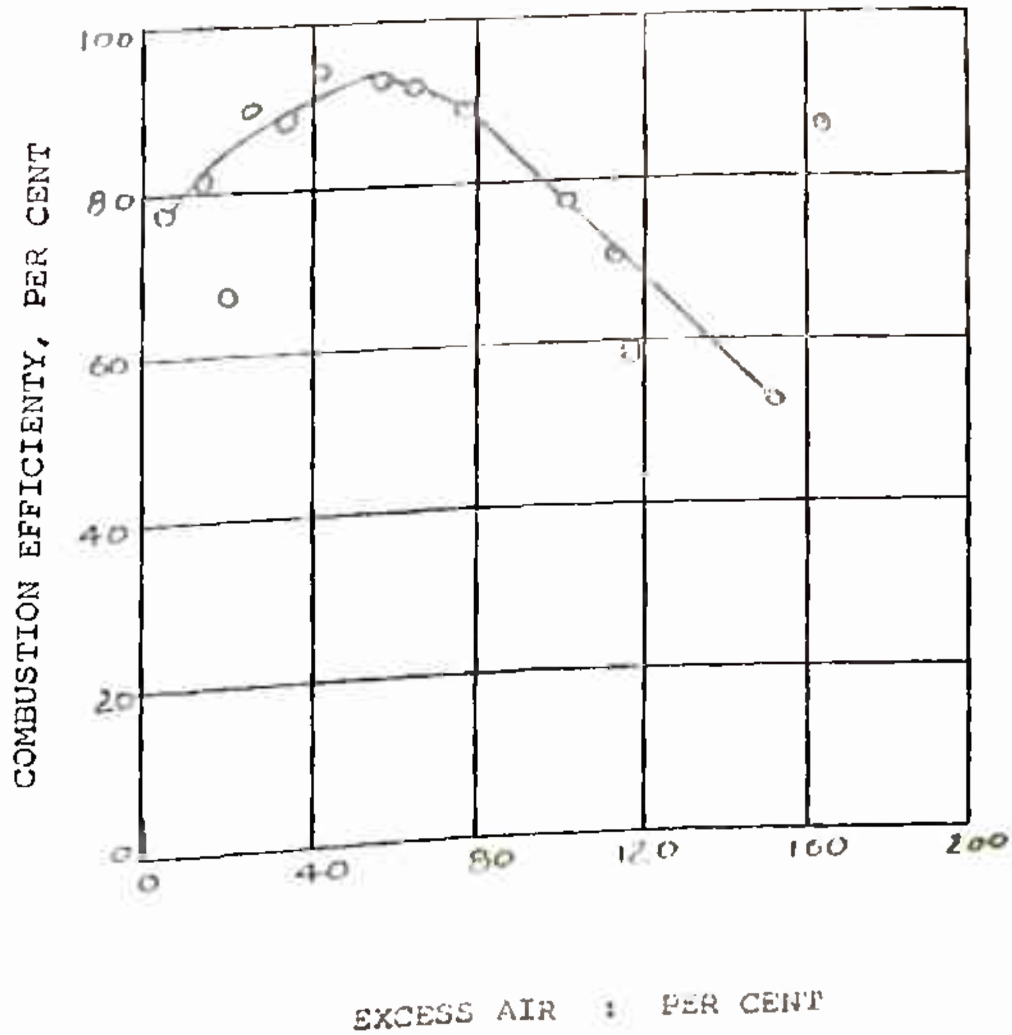


FIG 3.4 EFFECT OF EXCESS AIR ON COMBUSTION EFFICIENCY

the excess air range of 40% to 60%. Very poor combustionwas observed at excess air above 100% At higher excess air percentages, the temperature of combustion gases goes down resulting in low temperature exposure to husk particles resulting in loss of combustion.

It may be pointed out that if retaining time of husk particles is increased by making suitable modifications in the design of the combustion chamber, or controling the air flow patterns, still higher combustion efficiencies are possible.

4. DESIGN CONSIDERATIONS FOR SUSPENSION BURNING SYSTEMS

It has been established in the previous chapters that the suspension burning of husk in air is the most efficient method of heat recovery, though some other design aspects like control of excess air and handling of ash etc. need proper care. A proper understanding of the characteristics of solid-suspended flow systems is of prime importance for the design of a combustor burning bulk fuels like rice husk. The characteristic features of three types of suspended solid-air flow systems are discussed below:

4.1 FLUIDIZED BED SYSTEM

Consider a bed of granular particles through which a stream of gas is slowly flowing upward, as shown in Fig 4.1. As the gas flows upward friction produces a pressure drop which increases with velocity. If the bed is made of materials that are not free flowing, they can form an arch from wall to wall and the entire bed is lifted by the gas stream and rises like a piston. In the majority of cases, however the arch will break and the underside will fall down in clumps or aggregates. If the clumps fall so as to form an open, stable channel of sufficient size, most of

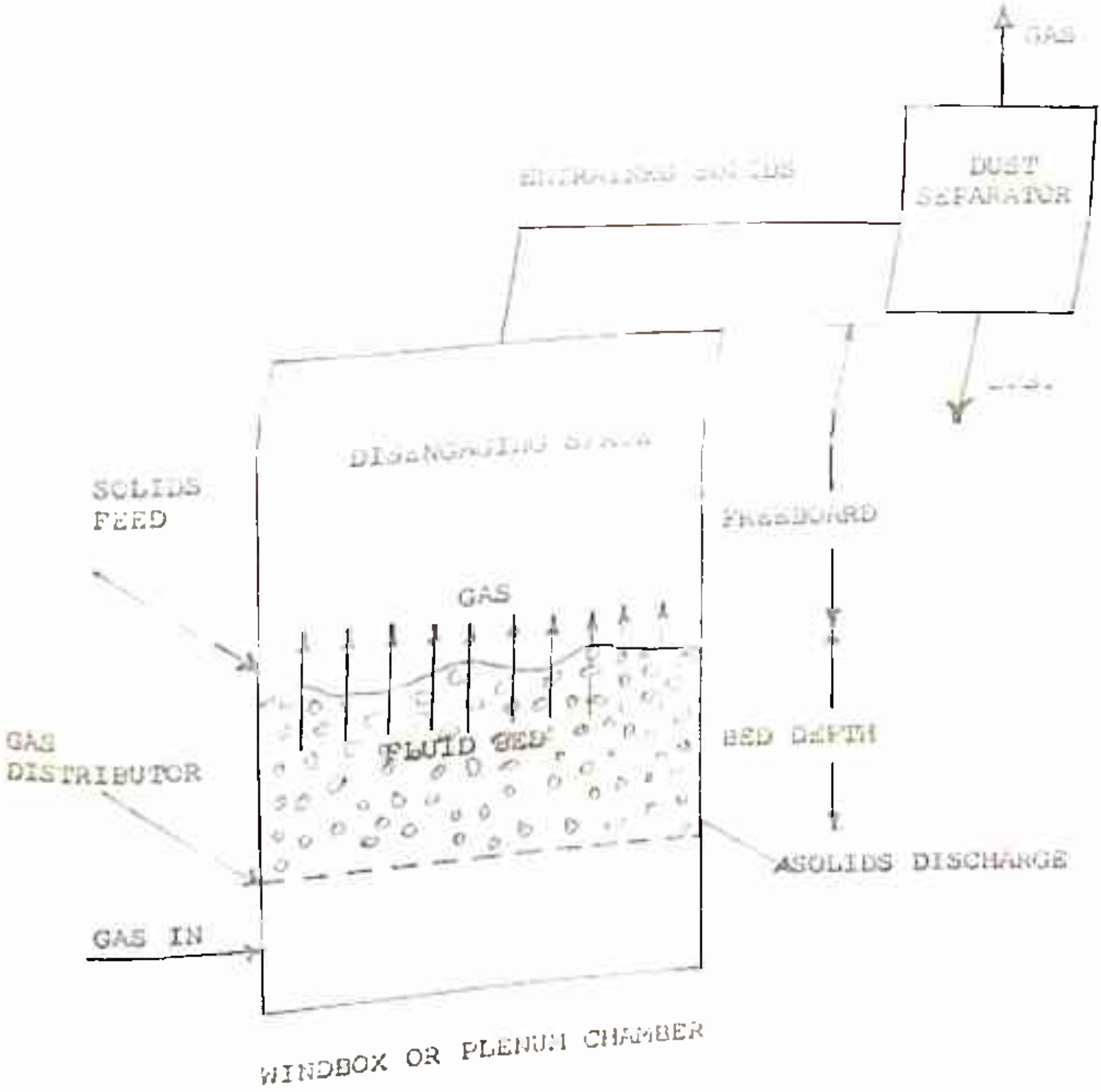


FIG 4.1 SCHEMATIC DIAGRAM OF FLUIDIZED BED SYSTEMS

the gas will flow through this channel. The expansion of the bed, in such cases is far from uniform. With an inrease in gas velocity, the pores and channels enlarge and the particles become more widely separated.

For free flowing materials, the pore spaces eventually become so large that no stable arrangement can exist, and the particles vibrate or circulate locally in a semi stable arrangement. An increase in velocity with such materials results in overall circulation of the bed, often with transient gas streams flowing upwards in channels. These streams contain relatively few particles, with clumps of particles flowing downward. In this type of gas fluidization, the net solids flow is almost zero.

The size of solid particles which can be fluidized varies over a wide range from about 1 micron to 60 mm. Particles in the size range of 10 microns to 0.2 mm. however are best for smooth fluidization with least formation of large bubbles. Large particles cause instability and result in spouting or slugging. Small particles less than 10 microns in size frequently form agglomerates in the bed. Adding finer sized particles to a coarse bed or coarser sized particles to a bed of fines usually results in better fluidization.

The proce of fluidizing therefore converts a bed of solid particles into an expanded suspended mass of zero angle of repose, that seeks its own level. It resembles a boiling liquid with bubbles. This mass As a bubble reaches the upper surface of a fluidized bed the gas breaks through the thin upper envelope composed of solid particles entraining some of these particles. The crater shaped void formed is rapidly filled by flowing solids. When these solids meet at the center of the void, they are geysered upwards. The particles are simoultaneously subjected to the downward pull of gravity and the upward pull of the drag force of the gas flowing upward. The larger and denser particles return to the top of the bed and the finer and lighter particles are carried farther upward until at some height known as the transport disengaging height (TDH), a constant loading and size distribution are reached. Just as in a vessel designed for boiling a liquid, for a fluidized bed also, space must be provided for vertical expansion of the solids and for disengagement of splashed and entrained material. The distance between the top of the fluid bed and the gas exit nozzle is termed as the freeboard or disengaging height.

The usual shape of the vessel for and fluidized beds is a vertical cylinder. The total cross sectional area of the vessel is determined by the volumetric flow of gas and the allowable or fluidizing velocity of the gas at operating conditions. The fluidizing velocity is usually between 0.15 to 3.5 metres/sec. This velocity is based upon the flow through the empty vessel and is frequently referred to as the superficial velocity.

4.2 SPOUTED BED SYSTEMS

Full benefits of fluidization cannot be realized with beds of coarse and uniform sized particles because of growth of large bubbles which causes a tendency towards slugging and surging.

In this type of system as shown in Fig 4.2, the gas enters the bed through a small opening at the center of a conical base instead of a uniform distributor. The high velocity gas causes a stream of solids to rise rapidly in a hollowed central core or 'spout' within the bed. After reaching somewhat above

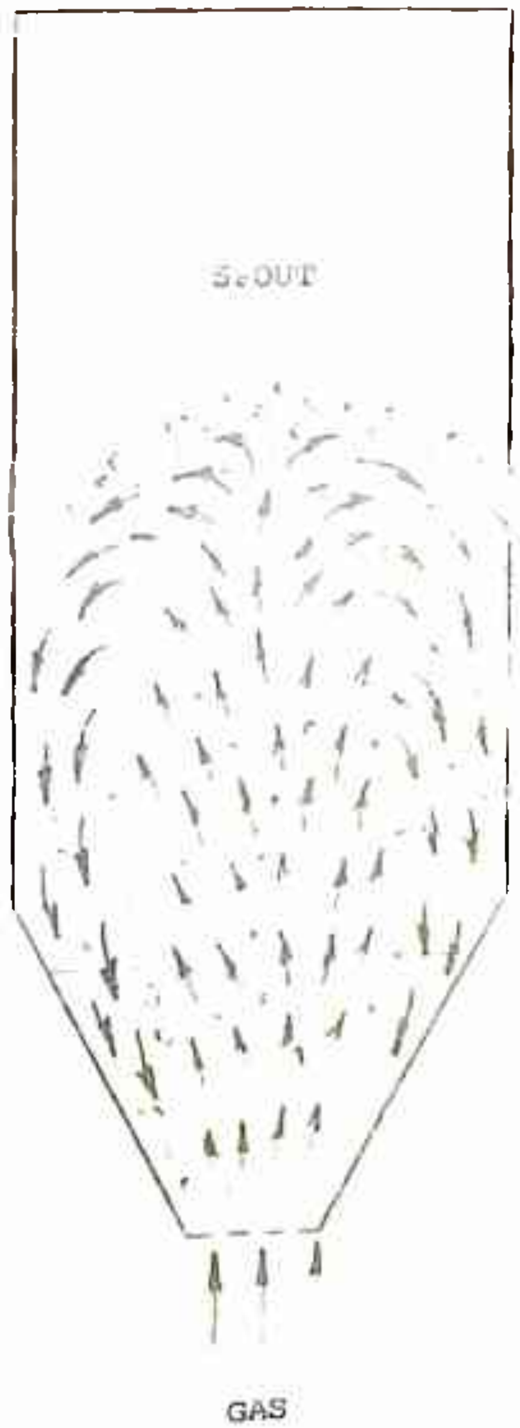


FIG 4.2 SPOUTED BED

the bed level,the solids fall back into the annular space between the spout and the container wall and travel downwards to form a packed bed, only to rise again with the incoming gas .The vertical cyclic motion of the solid particles up and down in the bed permits sufficient residence time of solids in suspension. This leads to more complete combustion of solids and a higher combustion efficiency.

The minimum particle diameter for which spouting is practical appears to be 1-2 mm. Finer materials tend to fluidize.For a given solid aggregate material column diameter and fluid inlet diameter there exists a maximum spoutable bed depth beyond which the spouting action degenerates into poor quality fluidiziation.[47]

At depths lesser than the maximum for spouting there exists an upper limit of gas flow rate for stable spouting, above which the systematic movement of solids tends to become disorganised and eventually gives way to slugging.

The spouting vessel is commonly either conical or cylindrical in shape. With the latter it is preferable to have a short conical base tapering down to the inlet orifice so that the solids can easily slide down into the gas jet region without forming a dead zone.

One of the major disadvantages of spouted bed systems for burning of rice husk is that such systems do not effectively form with free flowing solids like rice husk which tend to float away with the air. After rising above the bed level through the spout these solids do not fall back, making it impossible for the vertical cyclic motion to be established and thereby increase the residence time of husk in the vessel..

4.3 SWIRL FLOW SYSTEMS

Swirl flow systems use a spiralling motion to increase the residence time of solids in suspension. The spiralling motion results from the application of a swirl or tangential component to the flow. The degree or strength of Swirl is usually characterized by the Swirl Number 'S', which is a non-dimensional number representing the ratio of the axial flux of swirl momentum to the axial flux of axial momentum of the flow.

The tangential component of velocity for generating the swirl can be provided by any one of the following methods:

1. Use of guide vanes.

2. Combined axial plus tangential entry at gas feed inlet.

3. Tangential entry at gas feed inlet.

In the guided vane system,usually flat vanes or movable blocks are used to deflect the flow direction. The vanes are fixed at an angle to the mainstream direction and direct the flow accordingly.A recent trend in the design of vane swirlers is the use of curved shaped vanes which are more efficient than flat blade swirlers in producing swirl. Flat blade swirlers however are very easy to incorporate in situ, as no special manufacturing process is required.

In movable block swirlers,the vanes are usually mounted on a central hub on the axis of the pipe conveying the flow, and they occupy the annular region between the hub and the pipe wall..This is really akin to the axial plus tangential entry method. This system does not require a very high pressure drop for producing a certain swirl level and high swirl strengths are obtainable.

In the swirl generator using axial plus

tangential [illegible] swirl, the quantity of air can be controlled and metered seperately in the two respective ducts (Axial and tangential). The degree of swirl can be varied from zero to a strongly swirling [illegible] by adjusting the air flow [illegible] in the two directions.

In the tangential [illegible] the air is made to [illegible] tangentially [illegible] multiple entry points in the chamber [illegible] swirl flow is desired.

The Swirl Number S is given by

$$S = \frac{G_{\theta}}{G_x \cdot d/2} \qquad (4.1)$$

Where G_{θ} = axial flux of swirl momentum

G_x = axial flux of axial momentum

$d/2$ = nozzle radius

If swirl velocity 'W' is assumed to increase uniformly from 0 at r = 0; to W_{max} at r = d/2;

$$W = W_{max} \frac{r}{d/2} \qquad (4.2)$$

If the axial velocity U is a constant equal to U_{max} and turbulent stresses are neglected Eq. 4.1 for swirl number S reduces to :

$$S = \frac{G/2}{1 - (G/2)^2} \qquad (4.3)$$

Where $G = W_{max}/U_{max}$

to non combustive flows. For combustive processes also flow patterns have been found to be fairly similar. The main reason for this seems to be that the combustion process occupies most of the chamber volume and therefore does not produce strong density and pressure gradients. Experimental evidence substantiates the fact that results may be extrapolated for combustive conditions from established results of non-combustive conditions.

Under combustive conditions, the inlet angular momentum to the chamber remains approximately constant. Nevertheless, the axial momentum of the outlet fluid stream is considerably increased due the exothermic reactions. The swirl number** therefore is accordingly modified to

$$S = S_i \cdot \frac{T_i}{T_o} \qquad (4.6)$$

where T_i and T_o are the average inlet and outlet temperature of gases in degrees Kelvin respectively, and Si the swirl number calculated at the inlet.

Premixed swirled flames in furnaces with expansion ratios D/d between 2.5 and 5 have been studied at Glasgow from the aerodynamic and modelling points of view[3]. It has been seen that the same swirler can give different velocity patterns as the relative size of furnace diameter D_f is changed. Defining the new swirl number as:

$$S = \frac{S_{a}\, d}{D} \qquad (4.8)$$

It has been found that S gives a good correlation between measured data for annular and vane swirlers both in the combustive and isothermal states for the range of expansion area ratios mentioned above. This S definition based on furnace diameter rather than nozzle radius characterizes the ensuing flow in the main volume of the furnacemore satisfactorily, that is, the ensuing flow in different d/D systems depends more on D than on d.

The primary use of swirl is to increase the angle of spread and the rate of decay of axial velocity. One is not so much concerned with the swirl velocity field as with the effect of the initial degree of swirl on the subsequent flow.

4.3.1 EFFECT OF SWIRL:

For practical purposes it is necessary in engineering applications to know the effects of swirl on the flow pattern. Experimental studies[31] show that swirl has large scale efects on flow fields, jet growth, entrainment and decay (for inert flows) and on flame size, shape, stability and combustion intensity for swirling flows. The general effect of swirl is to increase the width of the flow field and the entrainment of solids with the increase in swirl intensity. For example, it has been shown that a jet with swirl number [illegible] is almost twice as wide as its non-swirling counterpart. However, the decay of swirl caused by shear and the mixing with surrounding fluid sets up adverse axial pressure gradients.

Figures 4.3 to 4.5 show the variation of axial velocity, swirl velocity and static pressure along the axis of flow at various swirl numbers. The decay of axial velocity U, swirl velocity W and axis static pressure ($P_o - P_a$) are found to be inversely proportional to the first, second and fourth powers respectively of normalized downstream distance. This in a free jet is due to sudden expansion and mixing and entrainment of ambient nonswirling surroundings.

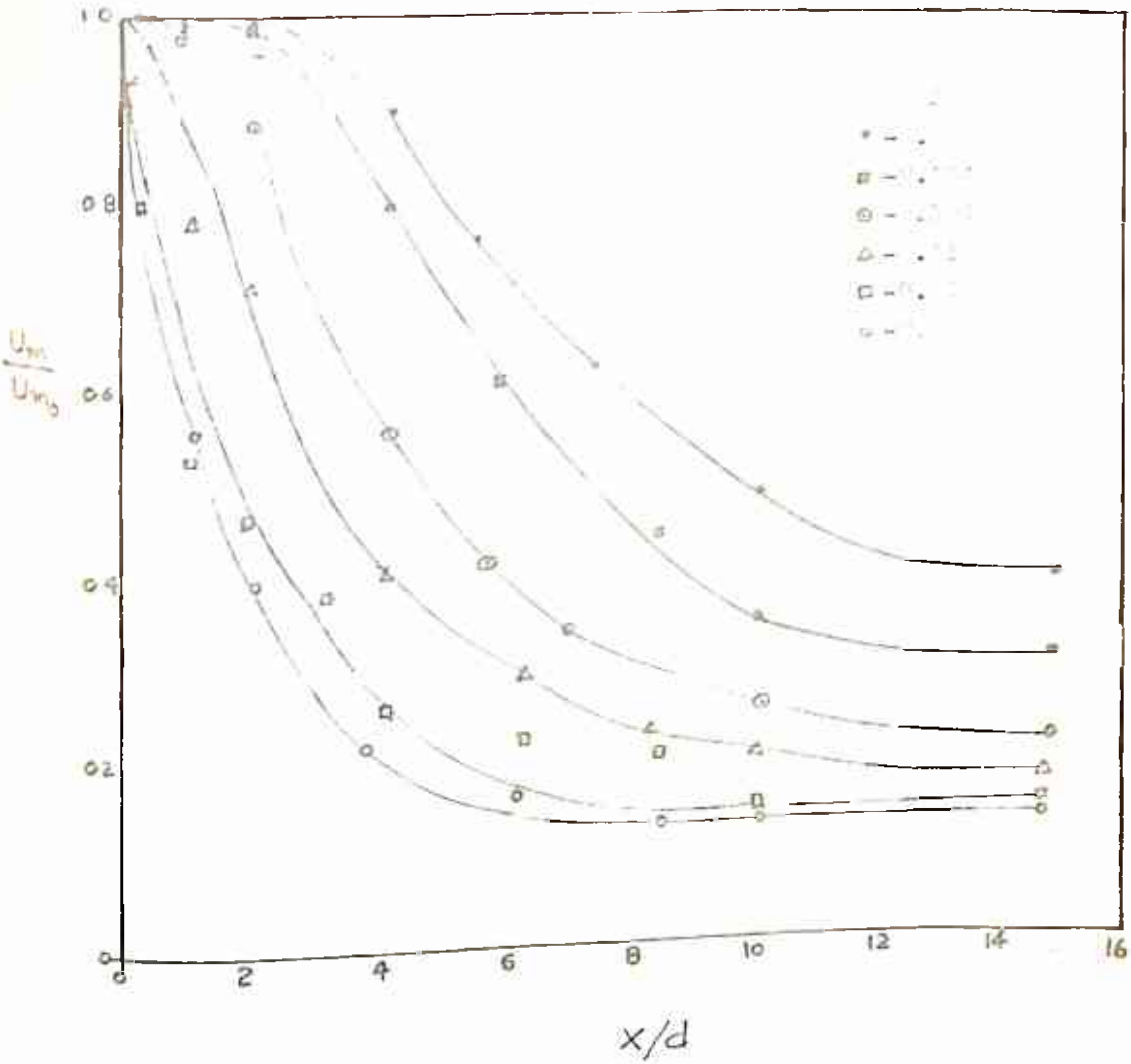


FIG 4.3 VARIATION OF MAXIMUM AXIAL VELOCITY ALONG AXIS OF FLOW

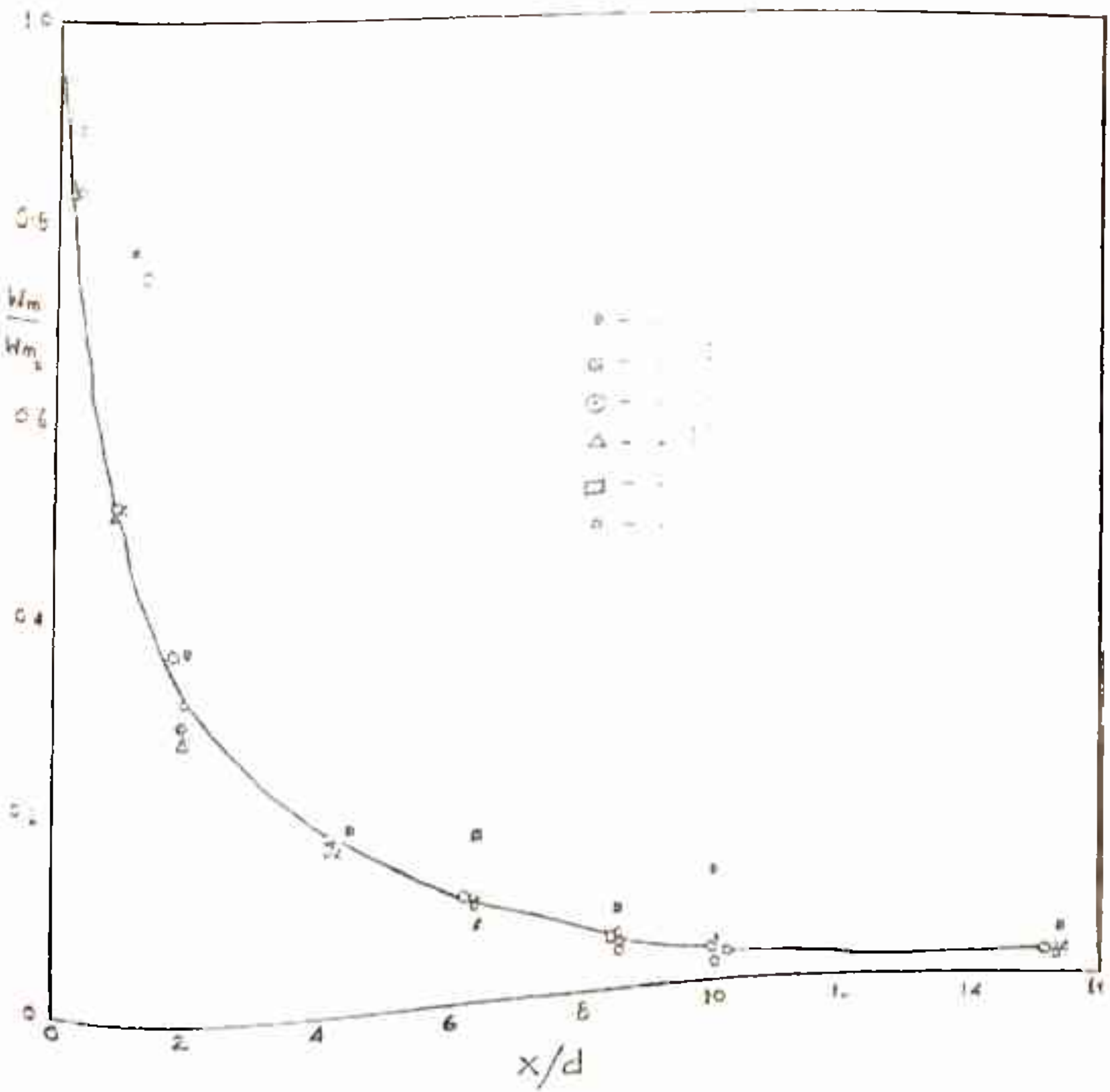


FIG 4.4 VARIATION OF MAXIMUM SWIRL VELOCITY ALONG AXIS OF FLOW

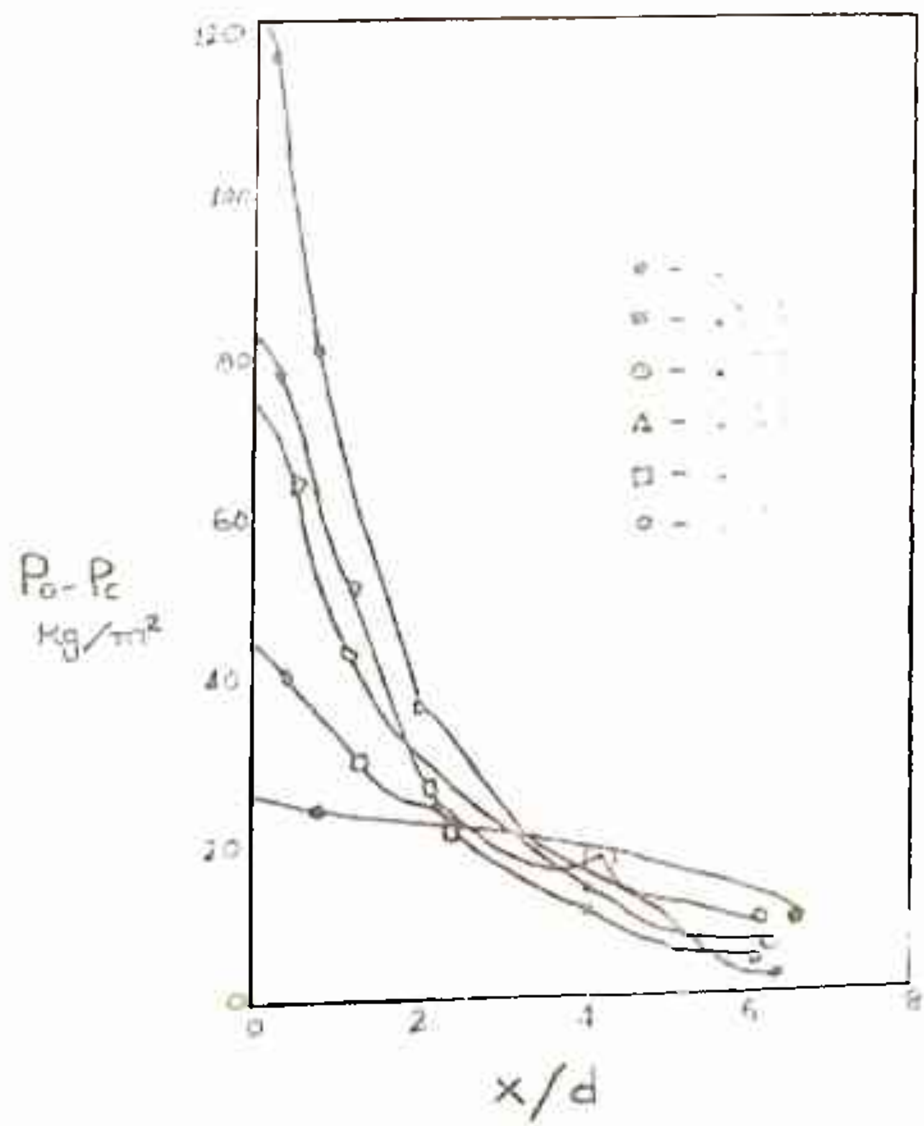


FIG 4.5 VARIATION OF STATIC PRESSURE ALONG AXIS OF FLOW

4.3.2 RECIRCULATION ZONE

As seen earlier as the swirl number is increased the radial spread of the jet increases and for flows with swirl number greater than a certain critical swirl number (approximately [illegible]) the forces due to axial [illegible] pressure [illegible] exceed the forward kinetic forces. The flow then reverses its direction in the central region near the inlet. This zone consists of largely recirculated mass with considerable mixing and is known as the recirculation zone. At high swirl numbers, there is considerable turbulence and this leads to the formation of [illegible] Torrodial Recirculation Zone(CRTZ).

The factors that affect the size and shape of the Central Torrodial-Recirculation Zone are :

1. Swirl strength - swirl number S or vane angle Ø
2. Vortex type - free, forced or flat swirl velocity
3. Reynolds Number
4. Presence of central hub
5. Ratio of the expansion to main chamber diameter
6. Geometry of the chamber.

The basic features of the flow in turbulent reacting flows are not known quantitatively with certainty. The prediction of time mean aerodynamic patterns in turbulent reacting flows are :

1. Isotropic conditions are assumed in the gross flowfield situation, but evidence shows that the turbulence is strongly non-isotropic. Errors are especially crucial in the regions of flame ignition and stablization.

2. Proper account of the Reynolds Number cannot be easily taken, as at a high temperature the kinematic viscocity hanges, and the prediction of recirculation is difficult.

3. Large [illegible] [illegible] and high levels of turbulence are generated with sufficiently high swirl number, [illegible] 0.61 and the Reynold Number [illegible] 18,000. The Reynolds number is calculated on the basis of nozzle diameter, average axial exit velocity and the kinematic viscosity of the gas at nozzle exit conditions.

In the prediction of time-mean aero-dynamic and combustion patterns produced in [illegible] swirl flows, many idealizations and simplifications are introduced according to known experimental results of non reacting flows. For combustion applications, one of the most significant and useful phenomena of swirl flows is the recirculation bubble generated centrally for super critical swirl numbers. Streamlines calculated from measured time-mean velocity distribution for annualar free jet with a swirl number of [illegible] are shown in Fig. 4.6. These streamlines carry with them a considerable amount of mass flow that is recirculated. For a free swirling jet of the type shown in Fig 4.6 a good correlation exists between the swirl number S and recirculation mass flow fraction M_R/M_o ,where, M_R is the recirculated mass flow, and M_o is the original mass flow. Fig 4.7 shows the ariation of recirculated mass flow with swirl number. It is seen that nozzles with a more divergent exit have a larger M_R/M_o for the same swirl number than for a less divergent exit.

The variation of centerline axial velocity with different S is shown in Fig. 4.8. For low degrees of swirl S <0.1 the centerline axial velocity remains constant for some distance along the jet axis and then decreases. As the swirl number increases the axial velocity drops considerably. Beyond S [illegible]

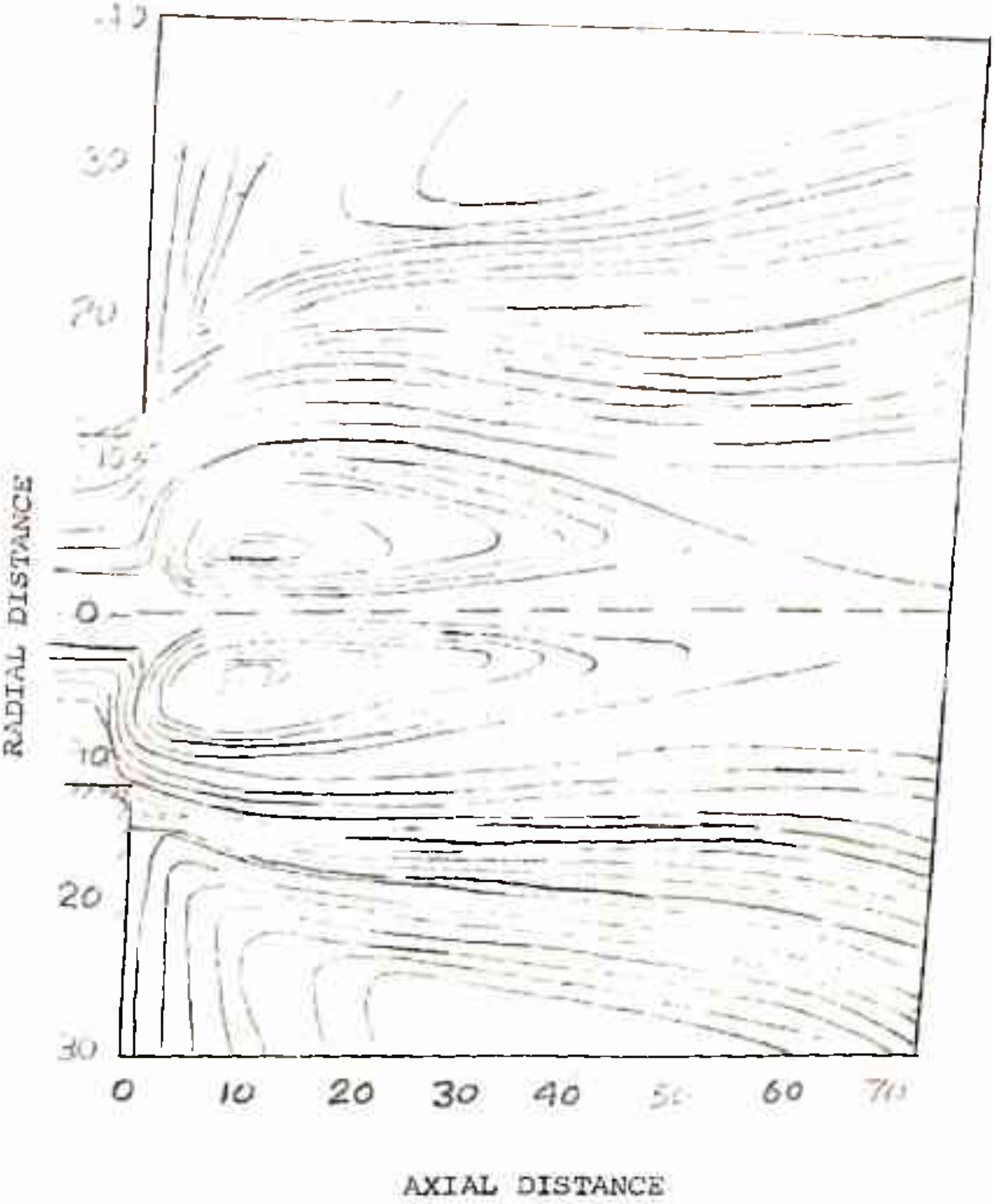


FIG 4.6 STREAMLINES IN SWIRLING ANNULAR FREE JET

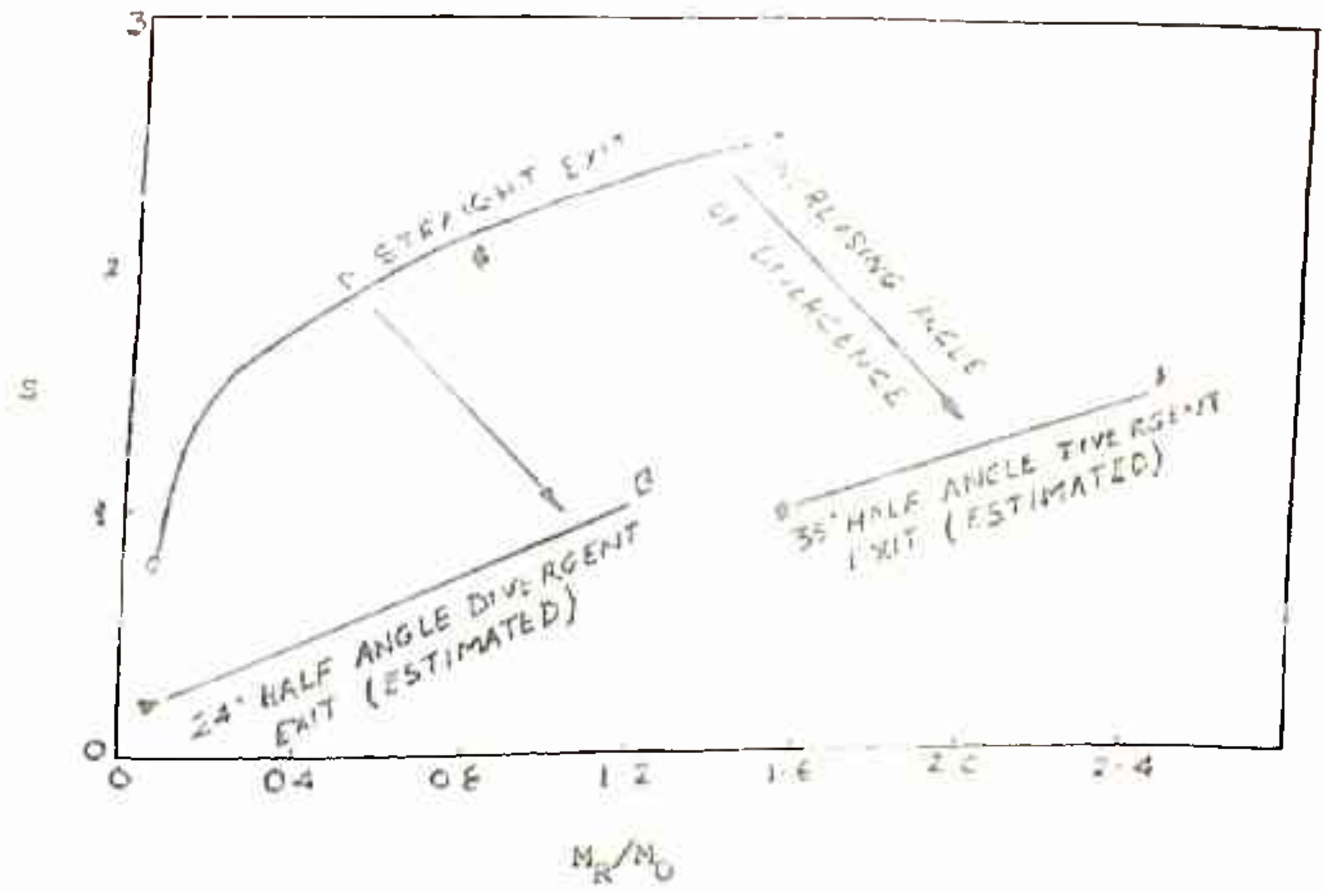
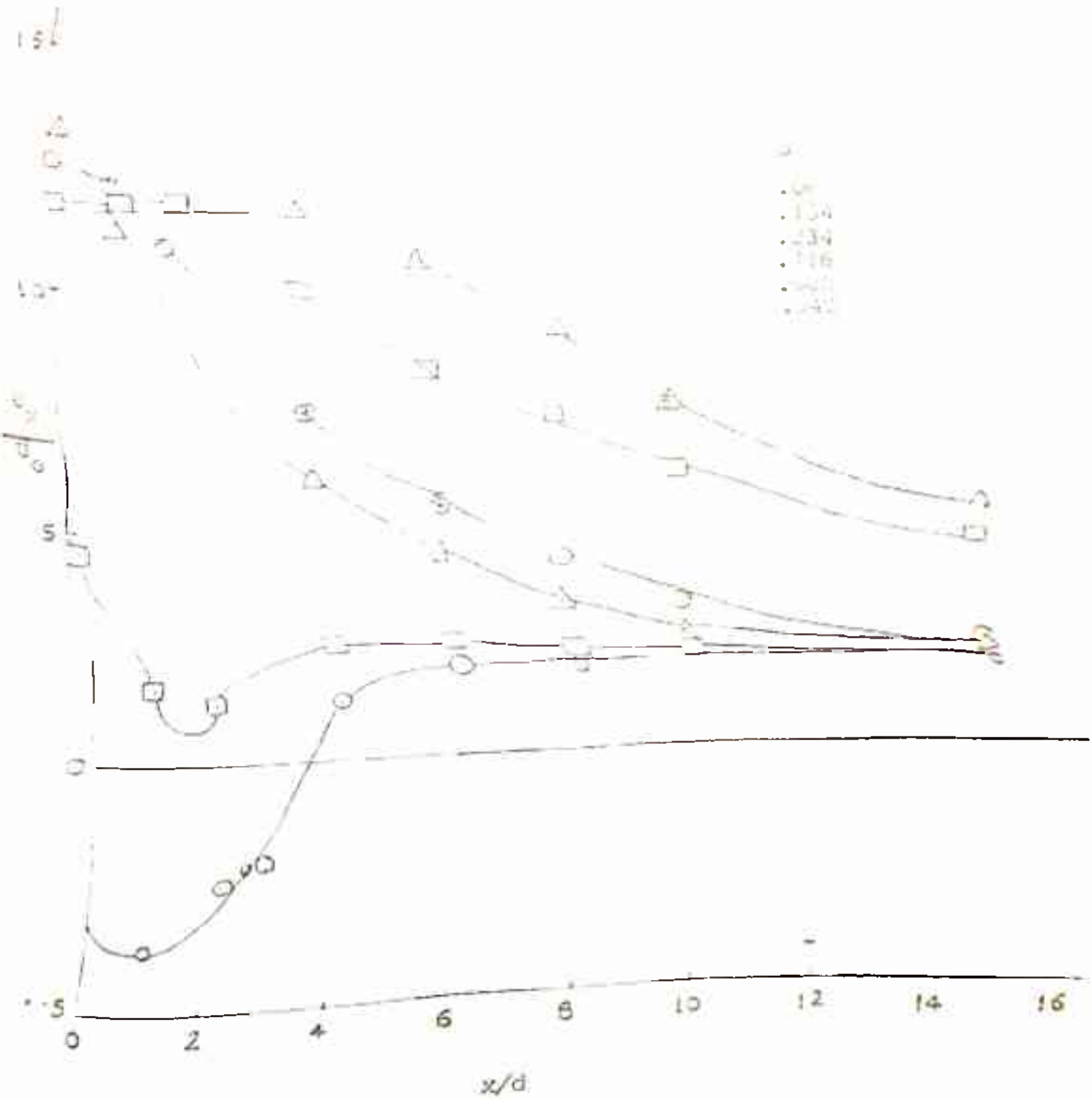
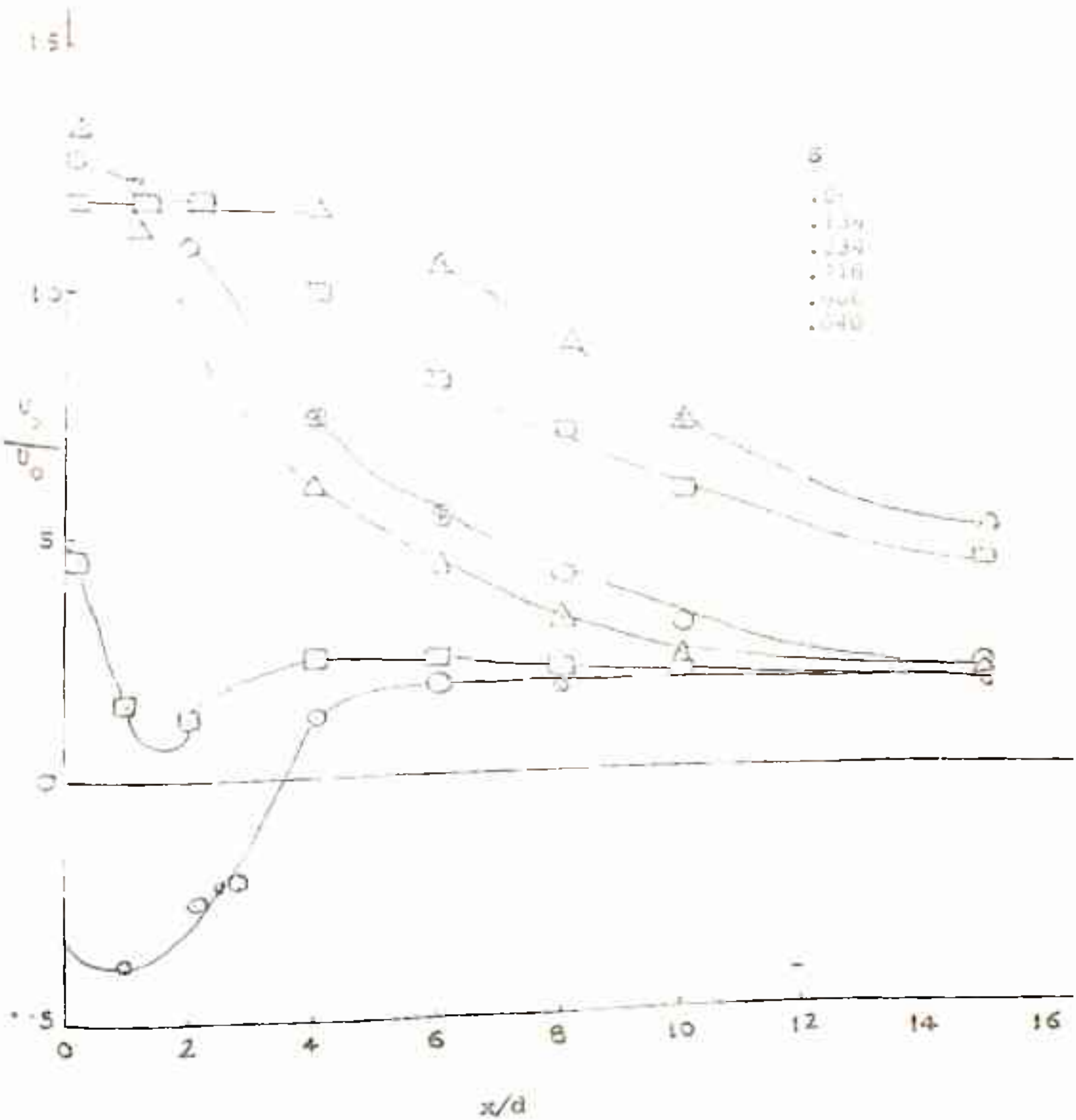


FIG 4.7 VARIATION OF RECIRCULATED MASS FLOW WITH SWIRL NUMBER



FFIG 4.8 VARIATION OF CENTERLINE AXIAL VELOCITY



FFIG 4.8 VARIATION OF CENTERLINE AXIAL VELOCITY

reverse flow is shown on the axis. This reverse axial flow often lead to vortex instability and breakdown.

It has been assumed often that the mean flow in vortex chambers is axisymmetric. Studies have shown this to be true only for low swirl and Reynold numbers[29]. For a given high Swirl Number (S > 0.6), when the flow reaches a certain critical Reynolds number, Vortex instability develops. The initial manifestation usually comprises a nearly symmetric swelling of the vortex core, enclosing a recirculating bubble of fluid. In the wake of this disturbance, another spiral instability often occurs in which the central forced vortex region starts to precess about the axis of symmetry. This so called precessing vortex core, (PVC) lies near the boundary of the mean reverse flow zone, and is responsible for very high levels of turbulence and mixing. There is now a three-dimensional time-dependent turbulent flow which has dramatic effects on the stability, rate of mixing, and combustion intensity.

Swirl flow principles can be used in many industrial processes.In separating units. The capabilities of cyclones employing high swirl flows for separating solid - gas- mixtures are well known and widely exploited in industry In combustors,swirl flows can be used for burning low calorific value fuels or fuels requiring long residence time for complete combustion.They are particularly usefuel for solids like rice husk which do not easily form fluidized or spouted beds for reasons explained earlier.

4.4 SWIRL BURNERS

Swirl burners have been developed in many forms and are usually used for the combustion and processing of materials that are normally considered difficult to burn or process efficienctly such as vegetable refuse, high ash content coals, anthracite, high sulphur oils, low calorific value waste gases etc.

The main advantages of the swirl burners are :

1. Long residence time, which depends upon swirl number and chamber length.

2. A recirculation zone formed internally close to the walls, that enhances flame stabilization ;

3. Considerably higher flame speeds particularly at higher swirl levels.

4. High particle combustion efficiencies.

5. Adaptability for two stage combustor arrangement

so that the first stage may partly act as a gasifier at relatively low temperatures, and the gas is then burnt out completely in the second stage. Provision for slag removal may be made in either, or both stages.

The special advantages of swirl burners are :

a) Excellent fuel air mixing.

b) Heat release concentrated over a reduced volume (high thermal load).

c) High flame temperatures.

d) Low excess air requirement..

e) Ability to burn large particle diameters in comparison to fluidized bed / spouted bed systems.

The development of flames for burners in industrial applications is still very much an art in which the practical experience of the designer plays the most significant role. Burner size and shape needs to be so designed that it provide an adequate residence time within the burner so as to achieve almost complete combustion of the fuel. The temperature of the gases at the burner exit must be low enough to avoid leaving high temperature deposits but at the same time have sufficient heat content to enable a suitable heat transfer requirement.

For the development of flames in burners it may be noted that most of the chemical reactions in flames are very fast at elevated temperatures so that the time taken to complete the reaction after the reactants have mixed is negligible. Hence the overall rate of progress of combustion can be determined with good approximation.from the rate of mixing.

Phenomena similar to those observed and measured in non-reacting swirling flows have been observed and measured in swirling flames.Because of instability problems, flames with a low degree of swirl have only limited practical interest, but they provide a useful proving ground for modelling concepts. Under special conditions, weak swirl can contribute to the lengthening of flame that may be desirable in a particular application. In high swirl conditions, S > 0.6, as mentioned earlier, reverse axial flows are observed. This causes the reduction of combustion lengths in burners because of higher rates of entrainment of ambient fluid, and fast mixing close to the inlet and near recirculation zone boundries.This also causes improved flame stability in combustion because of the presence of the Central Toridial

Recirculation Zone (CRTZ) which recirculates bubbles of hot combustion products.

The recirculation bubble plays an important role in flame stabilization by providing a heat source of recirculated combustion products and a reduced velocity region where flame speed and flow velocity can be matched. Direct comparisons of turbulent flow fields in non-reacting media with those in flames show that the thermal, molecular and atomic energy changes in the flames induce comparable or small changes in the gas dynamic flow fields of recirculating swirling [illegible] with combustion.
rates are reduced and, [illegible]

In the region close to the burner nozzle, the momentum flux affects the turbulent mixing. Further away, however, this is dissipated against the viscous forces in the fluid and this has little, if no effect upon the flow pattern downstream. The picture of mixing process is consistent with the assumption of a 'well stirred' region and 'plug flow region'. Ideally, properties of fluid in a well stirred region volume with continuous flow are uniform and identical with those of the outgoing stream. In plug flow', elements of fluid move through the reaction volume with properties uniform in any cross section perpendicular to the direction of flow but they may vary along the flow. For plug flow all particles of the combustible fluid have the same residence time in a [illegible] there is no back mixing.

In contrast to plug flow, back mixing is [illegible] the well stirred reactor so that the element of fluid entering the vessel are uniformly dispersed through its volume in a time much less than mean residence time $t = V_r/Q$, where V_r is the volume of reactor and Q is the flow rate of the fluid.

Under well stirred conditions, concentrations and temperatures are uniform over the entire volume, and therefore the volumetric combustion rate is uniform. In the plug flow reactor, the rate of combustion increases slowly at first because the temperature rises only as a result of the heat liberated as the combustion proceeds.

The fraction of unburned fuel for plug flow, and well stirred conditions plotted as a function of mean residence time is shown in Fig [illegible]. An optimization of

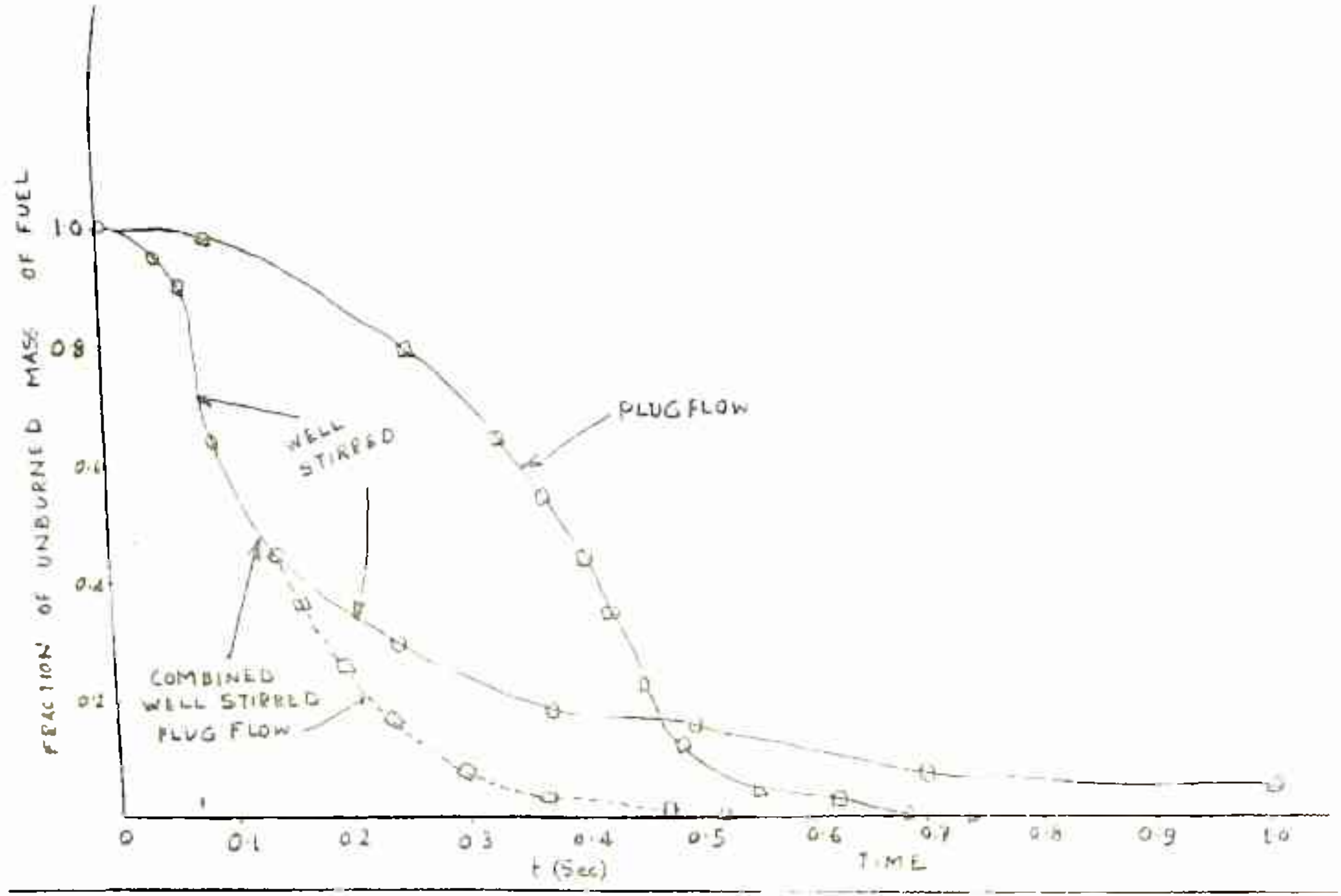


FIG 4.9 VARIATION OF FRACTION OF UNBURNED FUEL WITH MEAN RESIDENCE TIME

combustion performance within a reactor volume may be got by a combination of these two flows.

The concept of well stirred reactor coupled to a plug flow reactor has proved to be a powerful model for the performance and efficiency of swirl burners. Fig. 4.10 shows the proportion of residence time in stirred section (ts) to total residence time t as a function of Swirl number for S 0.8 [illegible] 0.5

Efficiency [illegible] pratical consideration in determining which type of swirler to use in swirl burner. Only [illegible] of [illegible] pressure drop across the swirler reappears [illegible]s kinetic energy of the subsequent swirling jet flow. the remainder being lost.Fig 4.11 shows the variation of efficiency with swirl numbers for different types of [illegible]wirlers.

The axial plus tangential entry swirler is very efficient at low swirl strength upto S=0.3. At higher swirl intensities the efficiency of such a swirl falls considerably. At S [illegible] 1 its efficiency is only 40%.

The movable block swirler is relatively inefficient at low and medium swirl strength (58 per cent) at S = 0.4 but efficiency [illegible] maintained and even increases at higher swirl strengths.

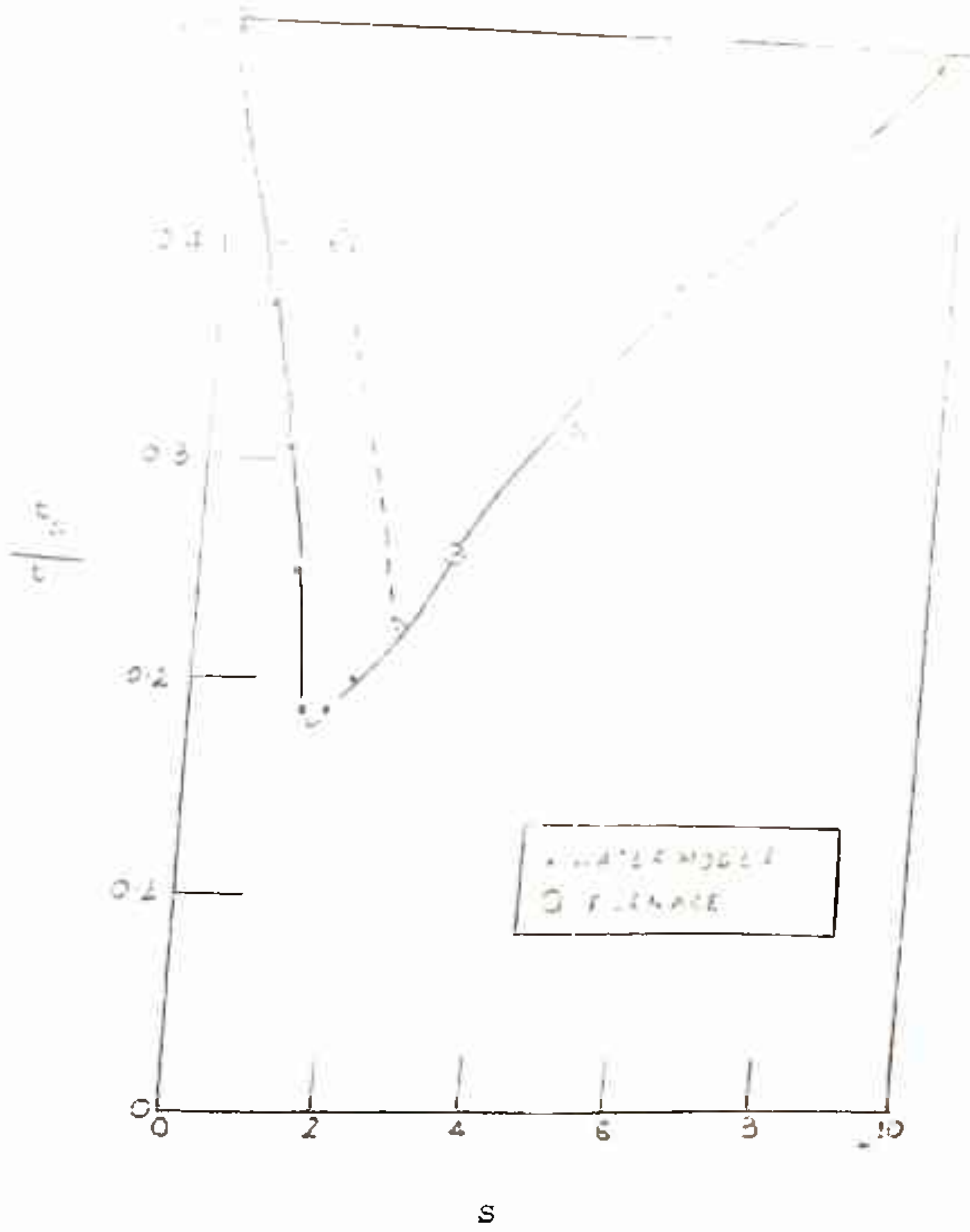


FIG 4.10 RESIDENCE TIME IN STIRRED SECTION AS FRACTION OF TOTAL RESIDENCE TIME AND SWIRL NUMBAR

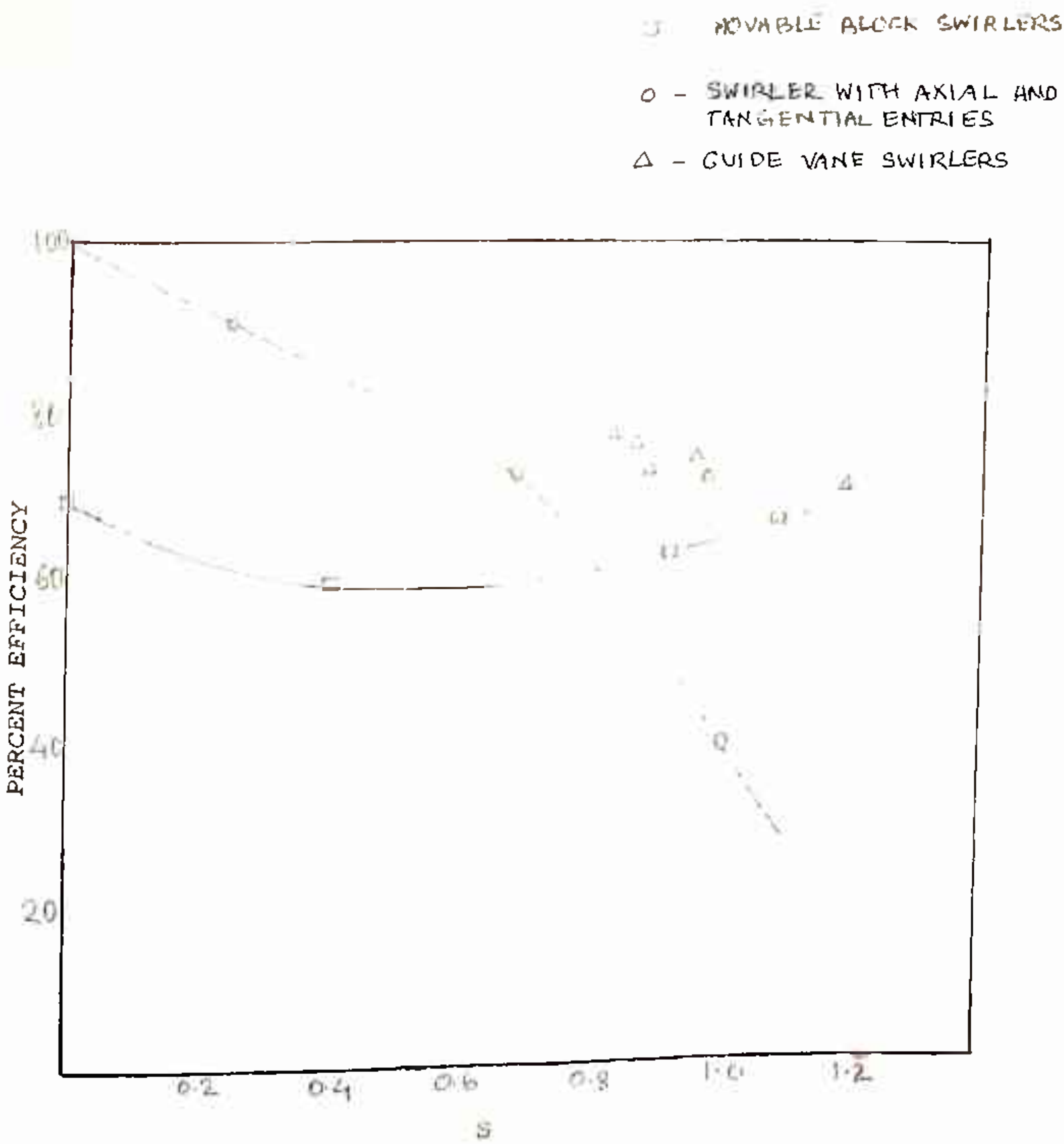


FIG 4.11 VARIATION OF EFFICIENCY WITH SWIRL NUMBERS FOR DIFFERENT TYPES OF SWIRLERS

The guide vanes swirler has a relatively constant efficiency of around 70% for swirls ranging from 0.6-1.2.

4.4.1 PRESSURE DROP IN SWIRL BURNERS.

The pressure drop through swirl burner is the sum of the pressure drops through the swirlers at inlet, the main chamber friction and outlet losses.

Fig 4.12 shows the inlet and outlet loss coefficients for various swirl burner configurations. It has been found that pressure drop at inlet and outlet depends upon the type of geometry and can be given by

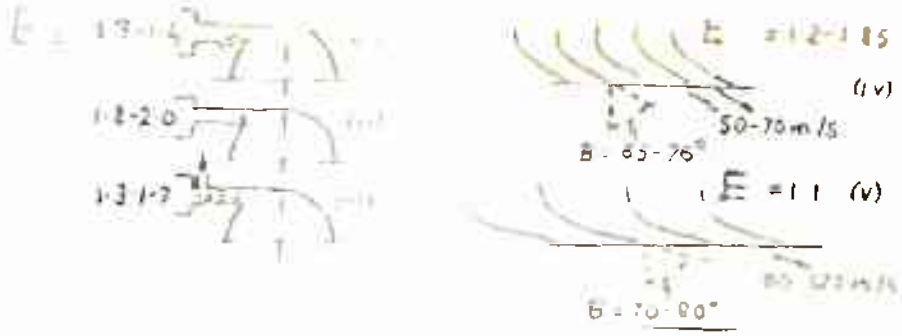
$$\delta P = E \frac{U^2}{2g} \qquad (\text{eq } 4.10)$$

where δP is the pressure drop at inlet or outlet, U is the average axial velocity and E is the pressure loss coeffcient across the inlet or outlet. E ranges from 1.2 to 2.0 for various inlet and outlet types where U is the axial average velocity.

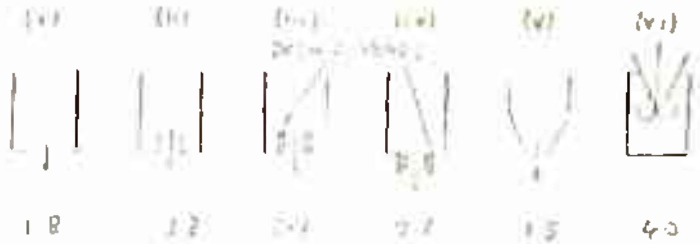
he pressure drop in the burner chamber is also a function of the outlet geometry. It can be represented by the relationship

$$\delta P_{cc} = E_{cc} \frac{U^2}{2g} \qquad (4.11)$$

(A)



(B)



INLET, OUTLET, AND CHAMBER LOSSES FOR VARIOUS GEOMETRIES

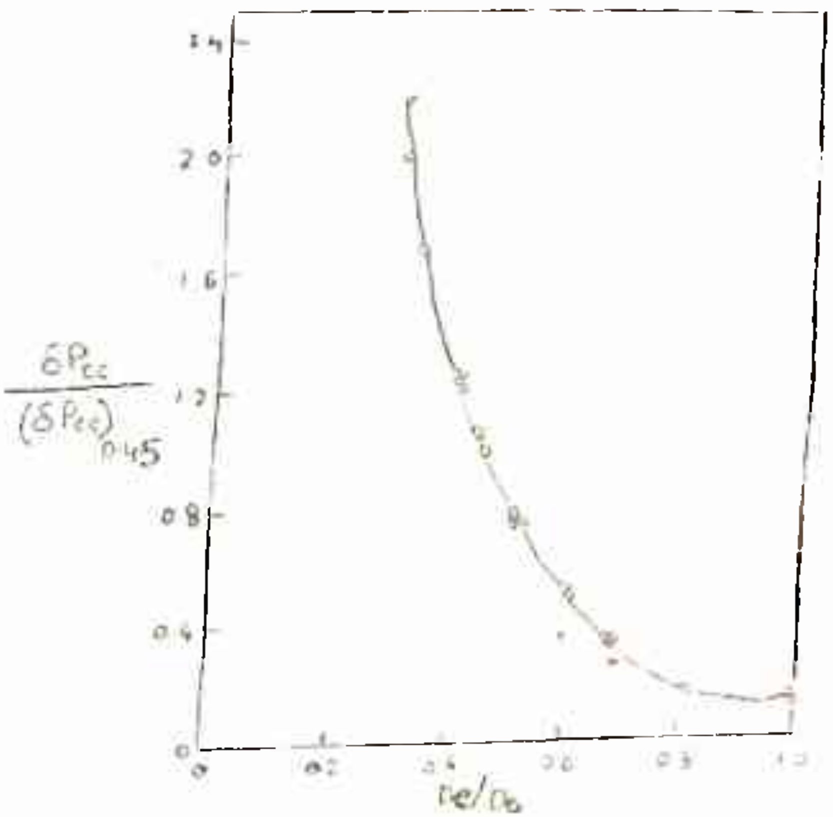


FIG 4.12 INLET AND OUTLET LOSSES FOR VARIOUS CYCLONE COMBUSTOR CONFIGURATIONS

The values of Ecc for the burner chamber are also

[illegible] for various outlet gepmetries

These [illegible] coeficients [illegible] where De/Do 0.45

$$\delta P_{c}$$

[illegible]gure 4.12 also shows [illegible] variation of δP (0.45)

[illegible] a function of [illegible]

$$\frac{\delta P_{e}}{\delta P} \quad [illegible]$$

This fits almost all experimental data pertaining to combustive and non-combustive swirl operations

4.5 UNITS OF SUSPENSION BURNING SYSTEM

An air suspended combustion system compreses of the following units.

1. Burner chamber
2. Gas Distributor
3. Air Supply unit
4. Solids feeder control unit.
5. Cyclone separator

4.5.1 BURNER CHAMBER

The burner chamberIt is usually a vertical cylinderical vessel but there is no real limitation on shape. The specific design features vary with operating conditions available space and use. The absence of moving parts facilitates a simple clean design. As the units operate at elevated temperatures refractory lined steel is the most economical design. The refractory serves two main purposes:

i) It insulates the metal shell from the elevated temperatures;

ii) it protects the metal shell from abrasion by the bed and particularly the splashing solids at the top of the bed resulting from bursting bubbles.

When heavier refractories are required because of operating conditions, insulating brick are installed next to the shell and a layer of firebricks is added to protect the insulating brick. Industrial experience in many fields of applications has shown that such a lining successfully withstands the abrasive conditions for many years without replacement.

Care should be taken during design and installation to eliminate the possibilities of gas leakage. A small flow of gas and solids can quickly erode large passages in the insulating bricks. In many cases, cold spots on the burner shell can result in condensation and high corrosion rates. The violent motion inside the burner requires an ample foundation and a sturdy supporting structure. Even a relatively small differential movement of the refractories from the shell can materially shorten refractory life. The lining and shell must be designed as a composite unit. The burner chamber has to be sealed from outside atmosphere. Hence the type of discharge mechanism for any solids to be introduced or removed from the vessel continuously or periodically, has to be designed accordingly.

4.5.2 GAS DISTRIBUTOR

The gas distributor has a considerable effect on proper operation of the combustor. and is of paramount importance to downstream flow pattern. The distributor is basically put to use in two types of situations i.e. when the inlet gas is clean or when it contains solids. The distributor must be designed to prevent backflow of solids during operation. In order to provide distribution, it is necessary to restrict the flow of gas or gas and solids so that the pressure drops across the restriction amount to only a few mm of WG. As a general rule, pressure drops in excess of 10 mm WG are not used. Structurally, distributors must withstand the differential pressure across the restriction during normal and abnormal flow.

4.5.3 AIR SUPPLY UNIT

Air is usually supplied to the combustor with the help of fans or blowers. Fans may be classsified as centrifugal type or of the axial flow type. Both types are used for ventilating work, supplying draft to boilers and furnaces, moving large volumes of air or gas through ducts, supplying air for drying, conveying material by suspending in the gas stream, removing fumes etc.

The draft inside the burner may be classified as forced or induced. The forced draft fan draws in air from the atmosphere and delivers it at a slight pressure to the combustion, whereas the induced draft fan sucks out gases from the chamber by creating a slight vaccum and usually delivers them to the atmosphere.

Forced draft (plenum) alone is undesirable though used successfully in package oil-burning boilers etc. as combustion gases escape through joints and flame. There is also more "soaking up" of heat by the combustion system.

Induced draft alone causes dilution of products of combustion if the system is not fully air tight which is often the case. Moreover, it alone cannot be used effectively where conveyance of material is required by suspension in the gas stream.

The logical arrangement is to employ both plenum and vacuum in such proportions that the combustion system is nearly atmospheric. In such a balanced draft system, the controls are usually set to maintain about 2 to 3 mm WG vaccum at exit of burner chamber.

4.5.4 SOLIDS FEEDER CONTROL UNIT

The main solids-flow-control problem is to maintain a balanced flow of solids with the optimal air required for combustion, keeping in mind the limitations of heat discharge and temperature constraints. Husk, having the property of being easily blown with air is best fed along with the air by the help of a blower. Its flow would be continuous and controlled and thus would maintain constant conditions in the combustor. The control of husk flow feed may be achieved with the help of a variable opening at the hopper mouth where the rice husk is stored as well as with a damper plate at the feed blower opening.

4.5.5 CYCLONE SEPERATOR

Even after complete combustion of rice husk the gas leaving the burner chamber is not free from solids. It contains ash which is to the extent of 15-17% of husk. It is therefore necessary to recover this ash before leading the gas to the process heat equipment in order to meet the following objectives:

1. To reduce maintenance cost, particularly of heat transfer surfaces which get covered with ash and have to be periodically cleaned
2. To limit air pollution

Cyclone separators are the most widely used type of dust collection equipment. In these separators the dust laden gas enters a cylindrical or conical chamber tangentially at one or more points and leaves throuth a central opening.. The immediate entrance to a cyclone is usually rectangular. In a cyclone the gas path involves a double vortex with the gas spiralling downward at the outside and upward at the inside. When the gas enters a cyclone, its velocity undergoes a redistribution so that the tangential component of velocity increases with decreasing radius. The spiral velocity in a cyclone may reach a value several times the average inlet velocity. A schematic diagram of a cyclone chamber is shown in Fig. 4.13 It shows a typical configuration and the general concepts of the composite flow patterns and the resulting particle separation encountered in a cyclone . It consists of a cylindrical section mounted on a truncated cone with an inlet nozzle that directs flow into the inner cylindrical section tangentially. The dust particles, by virtue of their inertia, will tend to move towards the outside separator wall and slide down along it through the exit. The cyclone is essentially a settling chamber in which gravitational acceleration is replaced by centrifugal acceleration.

Cyclone Separators offer one of the least expensive means of dust collection from both an operating as well as investment viewpoint. Cyclones have been employed to remove solids from gases at temperatures as high as 1000°C and pressures of 500atm.

Cyclones for removing solids from gases are generally applicable when particles of over 5 micron (0.0002 in) diameter are involved, although smaller sized ones upto 3 micron are separated at over 80

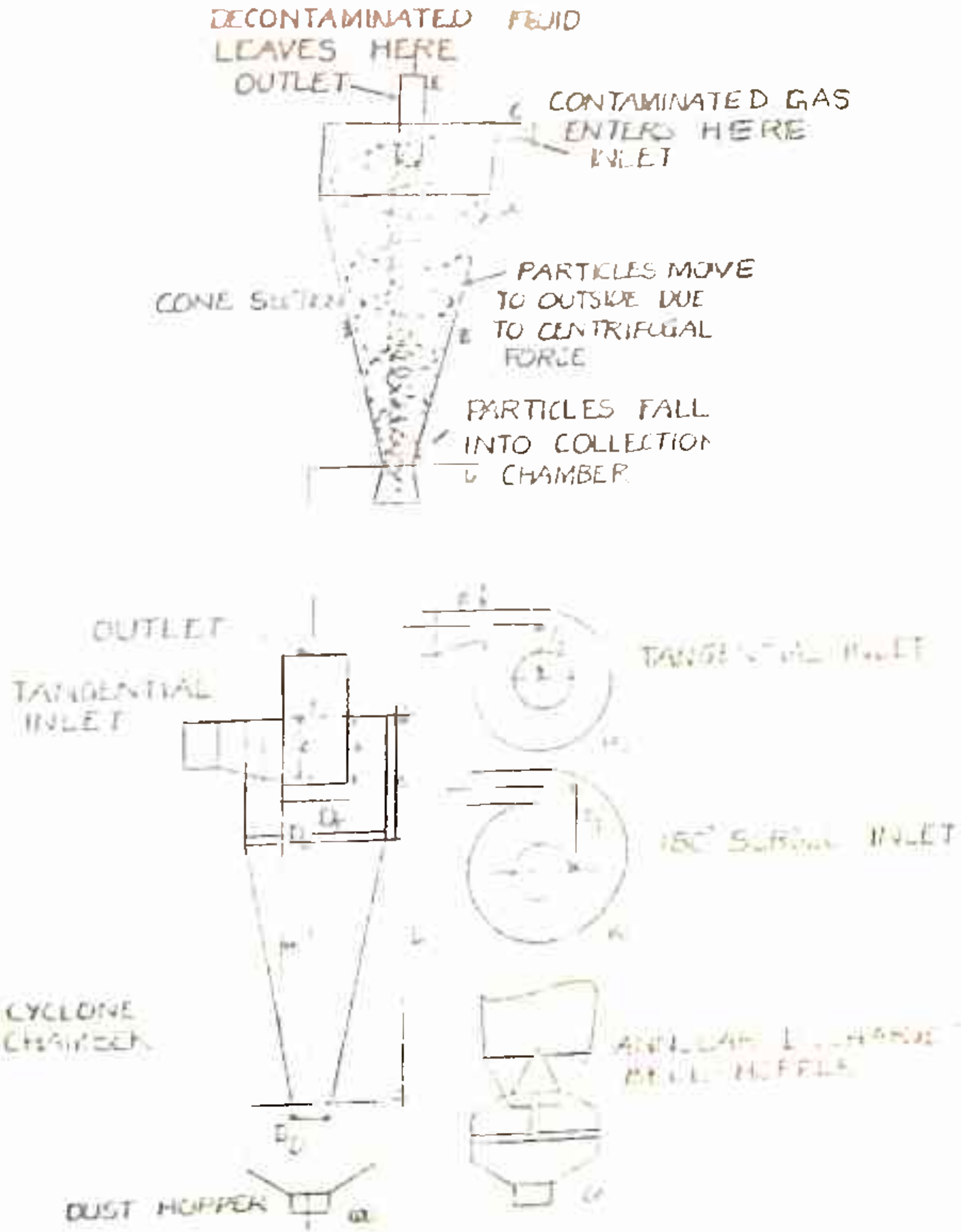


FIG 4.13 SCHEMATIC DIAGRAM OF CYCLONE CHAMBER

percent efficiency sometimes in certain cyclones. In collecting particles over 200 microns diameter, cyclones may be used but gravity settling chambers are usually satisfactory and less subject to abrasion. In special cases where the dust shows a high degree of agglomeration or where high dust concentrations over say 4 grams per litre are involved, cyclones will remove dusts having a much smaller particle size. In certain cases efficiencies as high as 98 percent have been realized on dusts having an ultimate particle size of 0.1 to 2.0 micron because of the predominant effect of agglomeration.

Cyclone separators were first conceived and utilized in plant a very long time ago. However, despite much scientific advancement in this period, the basic design has not changed much. The dimensions of conventional designs of cyclones (See Fig. 4.13 for parameter definitions) are given in Table 4.1. Type II cyclones are the most commonly used variety of cyclones, while the average dimension ratios of different types of cyclones are given in the table under Type III.

TABLE 4.1 DIMENSIONS OF CONVE[illegible] DESIGN OF CYCLONES

Parameter	[illegible]	[illegible]	[illegible]
Do	I	[illegible]	I
De	0.[illegible]	[illegible]	[illegible]
Dp	0.375	N.A.	N.A.
a	0.2	[illegible]	0.2
b	0.5	[illegible]	0.45
c	1.5	2.0	0.75
h	0.5	0.625	0.625
L	4	4	2
H	[illegible]		

DESIGN AND DEVELOPMENT OF RICE HUSK COMBUSTOR

5.1 DESIGN OBJECTIVES

The rice [illegible] combustor to be [illegible] [illegible] fuel oil burner in a horizontal four [illegible] boiler. The boiler [illegible] bran oil [illegible] in an agro [illegible] adjoining [illegible]

[illegible] of the boiler ar[illegible] below.

[illegible] boiler = 1200 kg [illegible]

Rated pressure [illegible]

Rated Evapor[illegible] = 13 kg steam / kg. fuel oil.

Boiler tube length [illegible]

The other boiler [illegible] Table 5.1 below.

TABLE 5.1 BOILER T[illegible] SPEC[illegible]TIONS

Pass No.	Nominal dia. (m)	Outer dia. (m)	No. of tubes	L/d factor	Heating surface (m^2)
1	0.4064	0.52	1	8	5.06
2	0.0445	0.0575	46	2720	25.75
3	0.0445	0.0575	32	189[illegible]	17.91
4	0.0381	0.0490	24	804	11.45

Total heating surface = 60.17 m^2

Actual steam evaporation = 700 kg per hr. x 24 hrs.

Actual fuel consumption 1200 kg/day

Actual Evaporation factor = 12.92 kg steam/kg. fuel oil

The main objective for this replacement was to effect savings by way of fuel replacement.However,the [illegible] changeover from the original oil burner [illegible] the newly designed rice [illegible] combustor [illegible] was required to be maintained. This was [illegible] continuous operation of the boiler even when rice husk [illegible] considering the fact that [illegible] usually available only for about six months [illegible] a year.

5.2 BASIC DESIGN DECISIONS

The basic design was based on the "Swirl Flame" firing technique. The design incorporated the folowing features:

i Combination of two tangentially coupled cylindrical cyclonic chambers; the first for injection of husk with primary air to burn it and the second to complete the combustion process of gaseous combustibles formed in the first chamber, and to separate the ash.

ii) Non-ash slagging combustion.

iii) Helical loci of the particulate matter and the gaseous combustibles rendering the flame a shape more or less like a ring adjacent to and in contact with the walls of the chamber.

iv) Relatively prolonged period of residence of the combustible matter in the chambers.

v) Peripheral discharge of the ash at the bottom of the second cyclone chamber.

A schematic diagram of the basic design is shown in Fig 5.1. Husk is fed manually into a hopper provided with an adjustable outlet opening to control the husk feed rate. From the hopper the husk falls on to a short open chute leading to the inlet of the air feed blower. The inlet opening of the blower is also made adjustable with the help of a sliding damper plate to control the rate of air flow.

Husk and air are blown together by the air feed blower through a connecting duct to an inlet distributor at the bottom of the burner chamber. The inlet distributor shown schematically in Fig 5.2 is of the guided fixed vane type. It gives the fluidized husk air mixture a swirl flow at the inlet. The opening ports at the inlet are slightly tapered downwards ensuring swirling over the complete cross section of the bottom of the chamber.

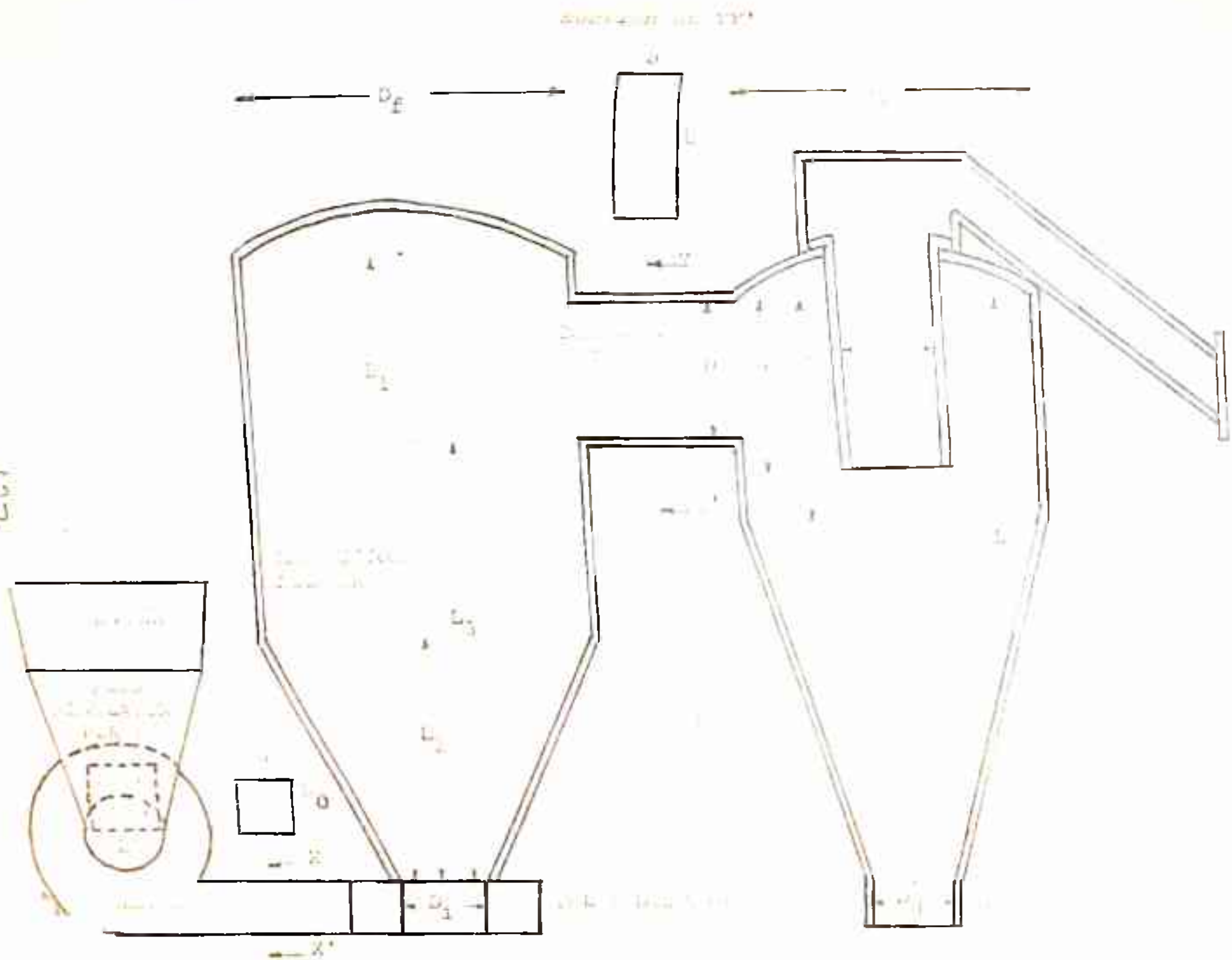


FIG 5.1 SKETCH OF SWIRL FLOW COMBUSTOR SHOWING DESIGN PARAMETERS

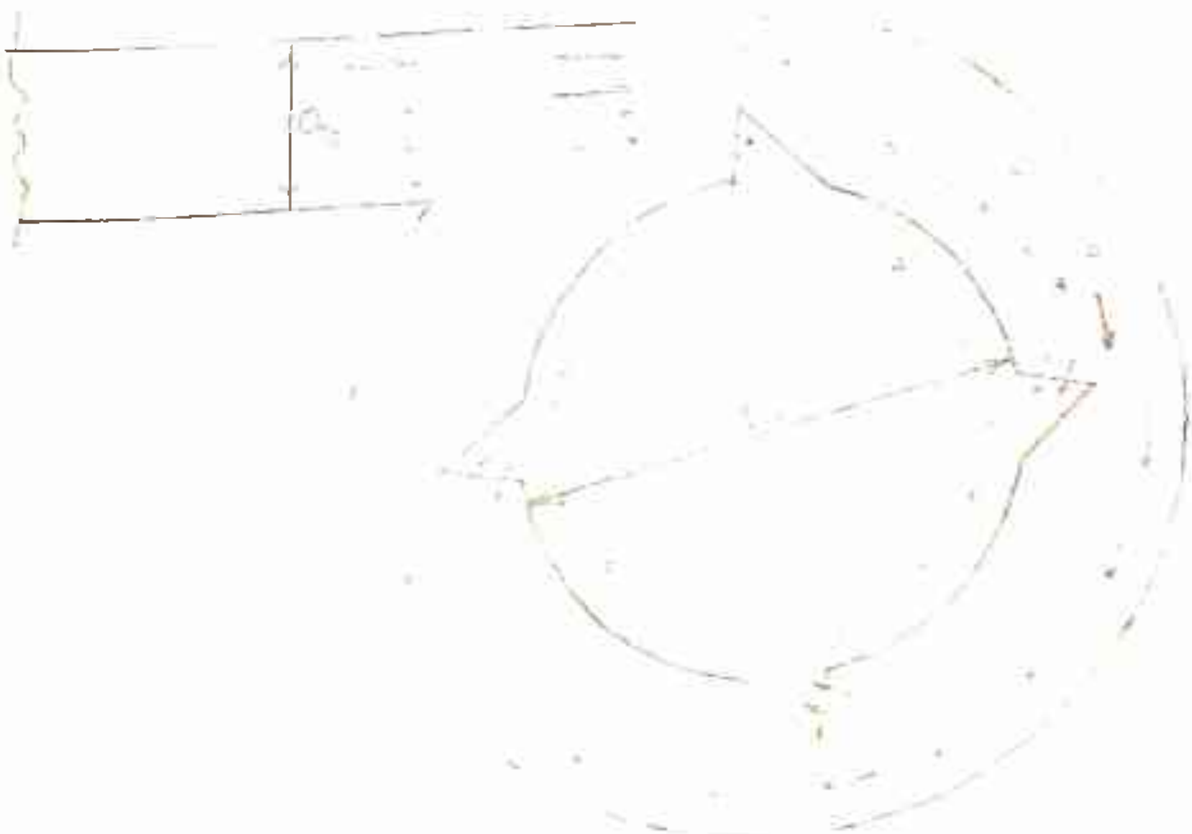


FIG 5.2 SKETCH SHOWING DETAILS OF INLET GAS DISTRIBUTOR

The combustion process is initially started by lighting a fire to some kerosene soaked wood placed in the burner chamber through a solid fuel feed inlet port as may be seen in Fig 5.3. Combustion of the fluidized husk takes place spontaneously and the combustion mechanism become [illegible] the products of combustion [illegible] cyclone through the [illegible] duct [illegible]. In the cyclone the [illegible] and the combustion is completed. The flame is thereafter led to the boiler inlet through a removable connecting duct.

5.3 DESIGN PARAMETERS

The parameters of the combustor that need to be decided are shown in Figs 5.1 and 5.2. These are as listed below for reference.

1. Width of inlet duct to combustion chamber from blower [illegible]
2. Height of inlet duct to combustion chamber from blower [illegible]
3. Number of inlet ports of the gas distributor [illegible]
4. Width of each inlet port [illegible]
5. Height of each inlet port [illegible]

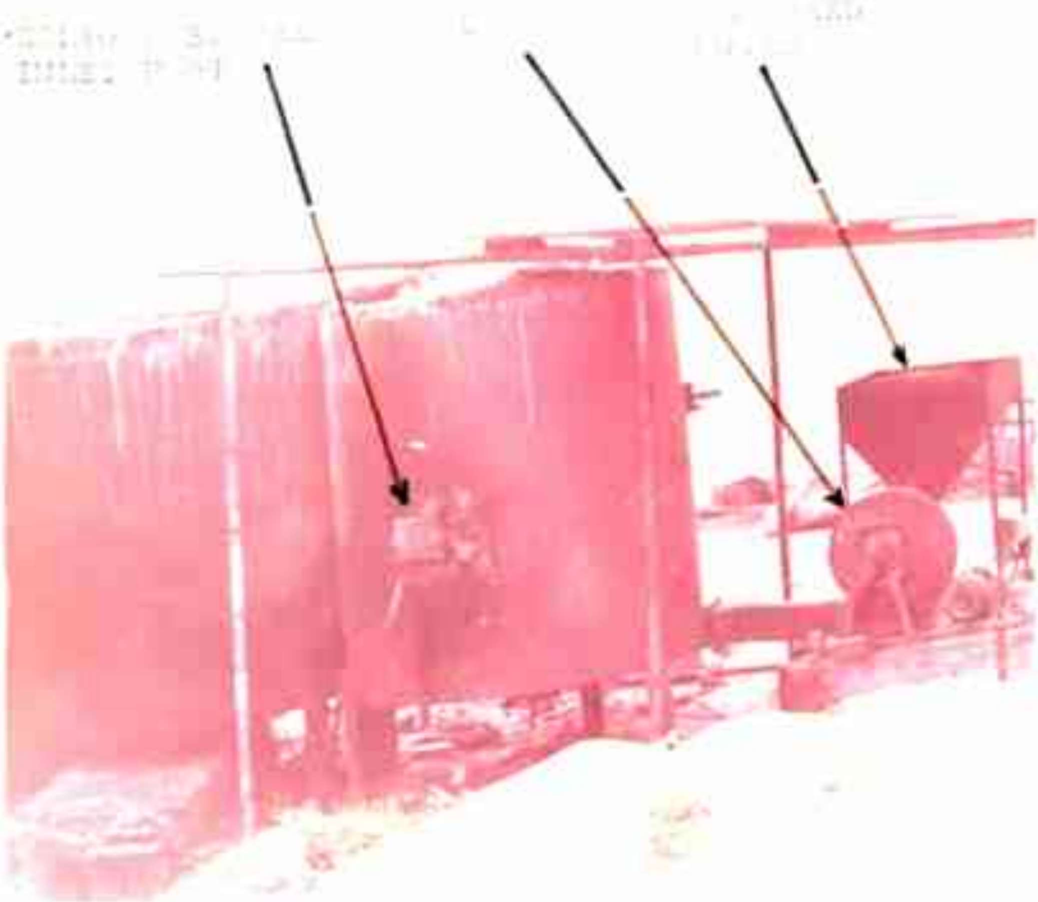


FIG 5.3 PICTURE OF SWIRL FLOW COMBUSTOR SHOWING SOLID FUEL FEED INLET PORT

6.	Diameter of bottom of combustion chamber	[illegible]
7.	Diameter of main section of combustion chamber	D_r
8.	Height of combustion chamber	L_1
9.	Height upto main diameter of combustion	[illegible]
10.	Height upto bottom of connecting duct between the chambers	L_3
11.	Width of conencting duct	[illegible]
12.	Height of connecting duct	[illegible]
13.	Diameter of Main section of cyclone	D_o
14.	Diameter of sleeve of cyclone	D_e
15.	Diameter of bottom of cyclone	D_d
16.	Depth of section dia D_o of cyclone separator from top of inlet duct up to start of conical section	C
17.	Length of sleeve in cyclone chamber	H
18.	Height of cyclone chamber upto top of inlet duct	L

5.3.1 SWIRL NUMBER

As mentioned in chapter 4, swirl number plays a crucial role in the combustion process in swirl flow combustors. Typical values of swirl strengths for swirl flow combustors range between 0.8 to 2.5.

If Q be the volumetric flow rate at inlet of the combustion chamber, maximum axial velocity at inlet

$$U_c = \frac{4Q}{\pi D_1^2}$$

The maximum swirl velocity at the inlet ports

$$W_c = \frac{Q}{n \times a_1 \times b_1}$$

$$G = \frac{W_c}{U_c} = \frac{\pi D_1^2}{4 \times n \times a_1 \times b_1} \qquad (5.3)$$

Then swirl number at inlet

$$S_1 = \frac{G/2}{1-(G/2)} \qquad (\text{from } 4.4)$$

5.3.2 RESIDENCE TIME IN COMBUSTOR

The mean residence time in the combustor can be calculated as volume of combustion chamber divided by volumetric flow rate entering the combustor; that is,

$$t = V_r \; / \; Q \qquad (5.4)$$

Where V_r is combustion chamber volume and Q the volmetric flow rate.

For achieving combustion of more than 95% in a well stirred combustion situation, the burner must be so designed that the minimum residence time t>1.0 sec as seen from Fig 4.10.

CRITICAL FLUIDIZING VELOCITIES

The critical fluidizing velocity** of husk in air is 6 m /sec and of ash in combustion gases is 1.5 m/sec.

5.4 CALCULATION OF DESIGN PARAMETERS

Rating of boiler = 1200 Kg/hr at [illegible] Kg/cm²

Enthalphy rise required for steam =

1200 x 633 Kcal/ hr = 759600 Kcal/ hr

Actual Evaporation factor of Boiler =

12.92 Kg steam/Kg. fuel oil.

Calorific value of fuel oil = 10400 kcal/kg.

Boiler efficiency = 12.92 x 633/10400 = 0.786

Therefore Heat load on the combustor system

H = 759600/0.786 = 966412 kcal /hr.

Calorific value of husk = 3400 kcal/kg

Let combustion efficiency of husk = 98%

Rate of husk feed:

$$F = \frac{966412}{3400 \times 0.98} = 290 \text{ kg/hr.} = 0.8 \text{ kg/sec}$$

Air required for theoretical 100% combustion of husk = 3.733 X F m^3/hr at NTP.

At 50% excess air at ambient temp of 300K, and neglecting volume of husk, the volumetric flow at inlet

$Q = 1.5 \times 3.733 \times F \times 300/273 = 6.21\ F\ m^3/hr$

Volumetric flow at inlet conditions of 300° K

$Q = 6.21\ F\ m^3/hr = 1801\ m^3/hr = 0.50\ m^3/sec$

In the combustion chamber, the ratios L_2/D_1, D_4/D_1 and L_4/D_1 are to be first determined.

For dimensioning the combustion chamber we keep in mind the downstream development of centerline axial velocity (refer Fig. 4.8). It will be seen that U_x/U_o stabilises at an x/d value greater than '6' and reverse flow [illegible] value [illegible] for high swirl numbers S [illegible] 0.6.

We therfore choose L_2/D_1 [illegible] and [illegible] 4 for combustion chamber so as to [illegible] the [illegible] the recirculation zone and well stirred portin of the burner..

Choosing the slope of the half cone angle at the bottom of the burner to be 0.5 (half divergent angle =25.56 °)

For L_2 = $3D_1$, D_4 = 4 D_1

For combustion chambers, conventional L/D ratios[33] typically lie between 1.5 to 3.

Choosing L_4/D_4 = 1.875 we have L_4 = 7.5, which also satisfies the condition L_4/D_1 [illegible].

Then volume of combustion chamber is given by

$$V_c = \frac{\pi D_c^2 \times (L_1 - L_3)}{[illegible]} + \frac{L_2 (\pi D_c^2 + \pi D_1^2 + \pi D_c D_1)}{[illegible]}$$

Substituting $L_1 = 7.5 D_1$, $L_2 = 3D_1$ and $D_c = 4D_1$ in the above equation we have

$V_c = 73 D_1^3$

The dimension D_1 is determined by the designed residence time [illegible]

Keeping in mind [illegible] for the combustion chamber and assuming the average temperature of the fluidized flow in the combustion chamber to be 750°K, average volumetric flow rate in combustion chamber Q_{av} = 0.5 × 750 / 300 = 1.25 m^3/sec.

$V_c/Q_{av} = t = 1$ sec. chosen.

$73 D_1^3 / 1.25 = 1$, therfore $D_1 = 0.257$m.

Hence minimum value for D_1 should be 0.257m. for a mean residence time of 1 sec.

We therefore choose D_1 as 0.3 m.

The dimensions of the inlet duct from blower are kept such that the velocity within the duct of fluidized bush lies between 2 to 3 times the critical velocity of fluidization of husk in air, and subject to physical conveniences at [illegible]. For inlet duct from blower, choosing square section, for mean velocity of 12 m/sec in duct, and a_o = b_o = $\sqrt{(Q/12)} = \sqrt{(0.5/12)} = .2041$. Hence a_o = b_o = 0.20m.

The dimensions a_1, [illegible] of the inlet gas distributor are got for chosen 'G' value, ensuring designed swirl number S_o using equations 5.3 and [illegible].4

For dimensioning the ports of the inlet gas distributor

Choosing G = 1.[illegible]

From eq. [illegible] $\frac{\pi \times 0.[illegible]}{4}$ = $4 \times a_1 \times b_1 = 1.3$

Hence $a_1 \times b_1$ = .0135 m^2.

Leaving 1.5 cm. on both top & bottom and keeping b_1 as 3 cm. less than b_o, i.e. $b_1 = 0.17$m., a_1 = 0.135/0.17 = 0.08m

From eqn. 4.4 since $S = \frac{G/2}{1-(G/2)}$

For chosen value G = 1.3 we have S = 1.85

The Swirl Number at inlet therefore also falls in the range commonly used for the industrial boilers[31] that is, between S_o = 0.8 and S_o = 2.[illegible]

Volumetric flow at exit of combustion chamber

$Q_e = Q \times T_{ce}/T_{ci}$

Assuming a rise in temperature of 900 K in the combustion chamber T_{ce} = 1200 K and T_{ci} = 300 K

Q_e = 4 Q (5.6)

We have Q_e = 4Q [illegible]

The dimensioning [illegible] connecting duct from the combustion chamber to the cyclone will be based upon having an exit velocity (same as entering velocity in cyclone) designed for a value between 15 to [illegible] m/sec.[illegible]

For dimensioning [illegible]ting duct between the two chambers [illegible] geometry should conform to the standard geometry [illegible] cribed for cyclone separators.

From table 4.1, b_2 = 2.[illegible] for inlet of cyclone of "Consensus" type, hence for cross sectional area of connecting duct A2 we have:

For U_d = 20m/sec. and Q_e = 2.0 m^3/sec A_2 = 0.1 m^2

Hence 2.25 a_2^2 = 0.1, or a_2 = 0.21m. and b_2 = 0.475m.

We therefore choose b = 0.5m

After dimensioning the connecting duct, the dimensioning of the cyclone may be done as per standard conventions given in table 4.1, on the basis of the dimensions of 'a' and b

All the required dimensions of the parameters as calculated are given below for the complete system including burner chamber, cyclone separator and ducts in meters.

1.	a	=	0.20
2.	b	=	0.20
3.	n	=	4
4.	a	=	0.08
5.	b	=	0.17
6.	D	=	0.30
7.	D	=	1.20
8.	L	=	2.25
9.	L	=	0.90
10	L	=	1.60
11.	a	=	0.21
12.	b	=	0.50
13.	D	=	1.05
14.	D	=	0.55
15.	D	=	0.30
16.	C	=	0.80
17.	n	=	0.65
18.	L	=	2.10

5.4.1 PRESSURE DROP ESTIMATION THROUGH THE BOILER.

Air required for theoretical complete combustion of husk= 4.870 kg (see Appendix C)

Mass flow of Air = 0.08 × 4.807 × [illegible] 0.576 kg./sec.

Density of inlet husk air mixture at 300 deg. K.
= 0.08 + 0.576/0.[illegible] = 1.33 kg/m³.

Volume of Combustion product[illegible] calculated at inlet flow and the last 90° long radius change in flow direction in to the stack.

The presure drop through the boiler has been calculated by assuming the losses in the tubes as obtained from the velocity estimations from Table 5.2 and shown in Table 5.3 below.

TABLE 5.3 PRESSURE DROP ESTIMATION THROUGH BOILER

Pass No.	Velocity m./sec.	Density kg m.$^{-3}$	Velocity head	L/d	Velocity head drop	Press. drop in kg/m.^{2}
1.	19.04	0.2670	4.88	7.6	1.638	7.99
2.	26.6	0.3471	12.51	71.9	2.81	35.15
3.	28.9	0.4628	19.70	71.9	2.81	55.35
4.	49.5	0.5785	72.24	89.0	2.06	148.81
					Total presure drop	247.30

5.5 CONSTRUCTIONAL PARTICULARS OF SYSTEM

The burner chamber, cyclone and connecting ducts of the system are made of 5 mm thick mild steel sheets. The side walls of the burner chamber and cyclone separator are lined with standard refractory bricks IS-8. The tops are lined with Siliminite bricks. An additional layer of insulation bricks is provided both to the walls of these chambers and their top. These linings are 22.8 cms. each of refractory and insulation bricks on the sides and top. The overhang duct in the cyclone is 11.4 cms. thick. The connecting duct between the two chambers is also lined with layers of 7.6 cms thickness each of refractory bricks and insulation bricks.

The hopper for feed of fuel to blower and the connecting duct to combustion chamber is made of 3mm thick M.S. sheet.

When used with furnaces and burners the blower is the basic part of the combustion system. It should have sufficient pressure and capacity to mix the fuel and air properly after overcoming the resistance offered by pipes and fittings. It is essential to select a blower for the type, size and number of furnaces to be handled. for best fuel economy. The design parameters for the blower selection are the air flow rate required and the pressure drop through the complete system.

The centrifugal blower for feeding air is selected as per air requirement from standard availability . The requisite motor too is bought out from standard manufacturers.

Keeping in view the maximum estimated pressure of 247.30 kg/m² and maximum air flow rate requirment of 30m³/min.. a blower of 40 m³/min. 405 mm water gauge pressure and 5.5 kW. motor rating at 2880 rpm. was selected from a list of available standard blowers given in Appendix- E

5.6 PERFORMANCE TESTING OF THE COMBUSTOR SYSTEM

The details of the first trial run of the rice husk combustor designed are given in Appendix-F.

As mentioned earlier this combustor was used to replace the fuel oil fired burner of a boiler supplying steam for a solvent extraction plant.Since the air flow rate required was only 3/4th of the blower capacity rated at 2880 RPM, the blower was run at 3/4th speed with a cone pulley reduction from the motor. It took almost 110 minutes to adjust the proper husk- air combination with the help of the damper arrangements at the hopper and feed blower openings. Till then the pressure developed in the hopper was 4[illegible] psi. The pressure of steam rose to 65 psi at 150 minutes. The pressure remained between 85 and 105 psi from 230 minutes to 275 minutes. The temperature in the duct rose to above 1000 °C at [illegible] minutes and to 1282 °C at 225 minutes. Considerable amount of flames were found to escape from the bottom of the cyclone chamber meant to separate the ash.

After 305 minutes, the steam pressure in the boiler started falling and the blower motor started getting overloaded. At 390 minutes the motor stopped due to overloading. When the system was opened it was found to be choked. The burner chamber, duct and cyclone were found to have large deposits of soft whitish ash stuck all along the inner surface of the walls.

5.6.1 ANALYSIS OF FIRST TRIAL

During the first trial of [illegible] minutes a total of 81 bags of rice husk was fed to the combustor. Each bag weighed at an average of 16.25 kg. Water was fed to the boiler by the feed water pump of capacity 86 lt/min for a cumulative time period of [illegible] minutes.

Total husk burned = 16.25 x 81 = [illegible] kg

Total water fed to boiler = 59 × [illegible] 3074 litre.

Water evaporation to fuel ratio = 3074/1316.25 = 3.89

The choking of the combustor system that occoured at 390 minutes was apparently due to the fact that the blower head was not enough to overcome the resistance of the burner chamber, cyclone and the boiler. The retention time of the fuel within the system increased leading to higher temperature. This lead to softening of the ash which stuck to the walls of the system aggravating the pressure build up till the feed blower stopped due to overloading.

To overcome the difficulties encountered in first trial run the following changes were made in the system.

5.6.2 MODIFICATIONS MADE IN THE ABOVE SYSTEM

1. The 5.5 kW motor was replaced by 7.[illegible] kW.

2. An induced draft fan of 80 m^3/ min. and 305 mmWg was installed at the stack.

3. The size of the connecting duct between the burner chamber and the cyclone separator was increased from 0.5m x 0.21m to 0.55m x 0.25 m.

4. A provision to supply excess air was made in both the chambers through anether air pipe, so that the

temperature in the chambers could be controlled.This pipe can be seen in photograph shown in Fig 5.4

5. A water seal was provided at ash outlet of cyclone chamber as the flame escaped from this point.

6. An air port was provided to the passage from the cyclone exit duct and the boiler mouth to check the draft there and help maintain it at a slight vacuum in order that flames do not escape.This is seen in photograph of the combustor shown in Fig 5.5

Details of the trial run for the modified system are given in Appendix G The system ran satisfactority over the entire trial run period of 920 minutes .

The steam pressure stabilized between 95 and 102 psi after 140 minutes w ith a duct temperature of 1025°C .The feedwater pump was run for 174 minutes over this period.

5.6.3 ANALYSIS OF SECOND TRIAL AFTER MODIFICATION

Total husk burned = 16.25 x 230 = 3737.5 kg.

Total water fed = 174 x 86 = 14964 litres.

Water evaporation to fuel ratio = 14964/3737.5 = 4.00[illegible]

Evaporation capacity of boiler on husk firing 1.

14964/920 = 16.266kg/min = 976 kg/hr.

FIG 5.4 PICTURE OF SWIRL FLOW COMBUSTOR SHOWING PIPE FOR SECONDARY AIR

FIG 5.5 PICTURE OF SWIRL FLOW COMBUSTOR SHOWING AIR PORT TO HELP MAINTAIN PROPER DRAFT

Rate of husk burning = 3737.5/920 = 4.0625kg/min
=0.068kg./sec.

Air utilised for combustion
= 40 x .75/60 m^3/sec. = 0.50 m^3 /sec.

Specific weight of air = 1.18 kg./m^3

Mass flow rate of air = 0.59 kg./ sec

Neglecting volume of husk density of inlet fuel air mixture
= 1.317 kg/m^3

Assuming ratio of volume of combustion products at NTP to volume of 100% theoretical air as 1.15

Volume of combustion products air to vol. of at 50% excess air at NTP = 1.65/1.5 = 1.1

Hence the volume of combustion products = 0.5 x 1.1
=0.55 m^3/sec.

Volume of combustion products at 1300K

= 0.55x1300/273 = 2.615m^3/sec.

Velocity in feeding duct to distributor at 300 K

$$= U_o/a_o b_o = \frac{0.55 \times 300}{0.2 \times 0.2 \times 273} = 15.1 \text{ m/sec.}$$

Velocity head in feeding duct at 300°K

$$= \frac{(15.1)^2 \times 1.317 \times 273}{2 \times 9.81 \times 300} = 13.92 \text{ Kg./m}^2$$

From Fig 4.12 A(iv), for inlet losses for various types of swirlers, we have E=1.85

Hence $\delta P_{sw} = 1.85 \times 13.92 = 25.76\ Kg/m^2$

From Fig 4.12 B(vi), for chamber friction swirl and outlet losses reading E = 4, and $U_1 = 8.55$ m/sec.

$$\delta P_c = \frac{4 \times (8.55)^2 \times 1.317 \times 273}{2 \times 9.81 \times 800} = 6.69\ Kg./m^2$$

for average temperature of gases in combustion chamber equal to 800K assumed.

At inlet to connecting duct, where temperature is measured as 1029°C, the volume of combustion products = $2.64 m^3$

Therefore velocity $U_d = 2.64/a_2 b_2$

$= 2.64/.25 \times .55 = 20.96 m/sec$

From Fig 4.15 A (ii) E=2.0, also $\rho = .2877\ Kg/m^3$ at 1302K

$$\text{Hence } \delta P \text{ for duct entry} = \frac{2 \times (20.96)^2 \times 0.2877}{2 \times 9.81}$$

$= 12.36\ kg/m^2$

At entrance to cyclone from the duct, δP equals $12.36\ Kg/m^2$ as E = 2 from Fig 4.15 (A-ii).

From Fig 4.15 E(iv), for outlet from cyclone,

E = 4.0

$$\text{Velocity at exit of cyclone} = \frac{4 \times 2.62}{\pi (.5)^2} = 13.34 m/sec$$

Pressure loss in cyclone δP is calculated to be $= 10.58\ Kg/m^2$

Total estimated pressure drop in the complete system = (25.76 + 6.69 + 12.36 + 12.36 + 10.58)

= 67.75 kg/m²

Earlier the pressure drop through the boiler was estimated at 247 Kg/m² for a volumetric flow rate of [illegible] m³/hr. For the total estimated flow rate of [illegible] the calculated pressure drop in the boiler is calculated to be 284.81 Kg/m².

Total estimated pressure drop in the combined combustor system coupled to the boiler therefore = 284.81 + 67.75 = 352.56 kg/m²

Pressure developed by feed blower = 227.81 kg/m²

Pressure developed due to I.D.Fan = 305 × 273/600 = 138.77 kg/m²

Total pressure developed = 366.58 kg/m², which is just slightly above the calculated pressure drop through the system.

5.7 SAVING OF FUEL COSTS BY CONVERSION TO HUSK FIRING SYSTEM

The savings in fuel cost per tonne of steam due to conversion of the oil fired boiler to the husk firing system can be calculated as follows-

Rate of steam consumption	: 700 kg/hr
No. of hours worked /day	: 24
Steam output/kg oil	: 12.92 kg.
Oil consumption / day	: 1300 Kg
Price of Oil	: Rs 3.35/kg
Oil cost per day	: Rs 4355
Oil cost per tonne of steam	: Rs 260
Steam output per kg of husk	: 4 kg
Husk consumption per day	: 4.2 tonnes
Price of husk	: Rs 300/tonne
Husk cost per day	: Rs 1260
Husk cost per tonne of steam	: Rs 75
Savings per day by fuel conversion	: Rs 3095
Savings per tonne of steam	: Rs 185

If coal is used as fuel, the steam output obtained is 4.8 kg per kg of coal. Cost of coal being Rs 750 per tonne, the fuel cost per tonne of steam using coal works out to Rs 156.25. The savings for conversion from coal to husk would be Rs 81.25 per tonne of steam.

5.8 FINANCIAL ANALYSIS OF THE COMBUSTOR SYSTEM

The cost of the combustor system as designed, fabricated and installed at the site of an agro solvent extraction plant worked out to Rs. 78,740. The details of the materials, quantities used, prices and charges for labour utilized in the system are given below:

TABLE 5.4 COST OF THE COMBUSTOR SYSTEM

S.No.	Particulars	Qty	Rate Rs.	Amount Rs.
1.	Refractory bricks IS-8	1200	6.25	7,500
2.	Side Arch bricks IS-8	1000	6.75	6,750
3.	Std.Siliminite bricks	200	26	5,200
4.	Side Arch Siliminite bricks	200	27	5,400
5.	ACC Superfine Castable cement	16 bags	195	3,120
6.	Fireclay for IS-8 bricks	30 bags	20	600
7.	Fireclay for Siliminite	6 bags	50	300
8.	Material for foundations	bulk	1200	1,200
9.	Steel (Flats & Channels)	2.7tonne	6300	17,010
10.	Blower	1	4200	4,200
11.	I.D.Fan	1	6800	6,800
12.	A.C.Motor,3Ph,7.5kw	1	4800	4,800
13	Pulleys,belts,etc for motor drive	2 sets	175	350
14.	Digit Temp.meter 0-1300°C	1	4500	4,500
15.	Labour charges for steel fabrication	2.7tonne	1300	3,510
16.	Labour charges for construction of system	1	2700	2,700
	Total			78,740

The running and maintenance cost of the system have been estimated at around Rs 2800 per month, after a trial of about seven months of the system. Thus however does not include the boiler downtime losses due to breakdown of the husk of the husk combustor.

Thus a capital [illegible] incurred of Rs 78,740 for [illegible] of Rs.185 per tonne of steam [illegible]. The capital [illegible] of the system is [illegible] merely [illegible] tonnes of steam [illegible]. At a [illegible] consumption of 700 Kg of steam per hour round the clock the initial capital cost is recoverable in just about a month.

5.9 OTHER SYSTEM ADVANTAGES

1. In the swirl combustor, regular and continuous feed of husk is made so that temperature stability of the flame and pressure stability of the steam in the boiler is maintained.

2. The constructional details of the combustor are such that there is very little fall in internal temperature of the system when shut over night due to it being a closed unit with double brick lining. The system thus acts like a thermal flywheel and may be shut off and self started over short period of time.

3. Only one person is required to feed the husk in the feed hopper and the activity of stoking necessary on grate fired furnaces that required are additional

manpower is done away with.

4. The system can burn poor quaity husk with some moisture content without any loss in combustion efficiency.

5. The higher flame temperatures in the range of 1000°C increases the heat transfer rate in the boiler tubes and hence the steam generating capacity of the boiler.

5.10 SYSTEM LIMITATIONS

1. Continued running of the system has shown that the feed blower impellar gets worn out and needs to be replaced as often as once a month. This is due to the hard abrasive nature of rice husk.

2. Sufficient care has to be taken while operating the system to ensure that the temperature doesn't rise much above 1050°C. High temperature can lead to softening of the ash husk that sticks to the walls of the chambers. Thus causes choking of the system and leads to an imminent breakdown.

3. Rice husk, is available for only about five months or so in a year and hence the system can use it as fuel for only about six or seven months in a year without facilities for stocking large quantities of husk.

[illegible].11 USE OF SAWDUST AS FUEL FOR THE DESIGNED COMBUSTOR SYSTEM

A combustor system similar to the one discussed in the preceding sections was tried on sawdust as fuel instead of rice husk. It was found that the system performed fairly satisfactorily with saw dust also. The following observations were recorded during the trial firing of the combustor with saw dust.

Moisture Content of the saw dust	20%
Average temperature attained	1030°
Time to attain average temp.	30 minutes
Maximum temperature attained.	1056°
Fuel consumption	[illegible] kg [illegible]
Ash colour	grey with 10-15% black spots.

It is thus establlished that there is a distinct possibility of using the Swirl flow system in principle, for any bulk fuel, having good fluidizing and combustion properties in air .For best results, however it will be necessary to design each system according to the flow characteristics and burning properties of each fuel

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The increasing costs of conventional sources of energy and the likely reduction in their availability have made it imperative for the industry to search for alternative sources of energy which are easily available and renewable. This search for cheaper and easily available alternative fuels is all the more important for developing countries like India which do not have the resources to compete with rich developed countries of the world for continuously dwindling available supplies of conventional fuels.

Agroproducts form a large untapped renewable energy source in India. In the year 1985, for example, the energy availability from agro residues from six major crops was equal to the sum of the totalenergy available from the indigeneous production of coal plus that available from the oil imports for the year.

Rice husk, which until recently posed a problem for disposal and was sometimes used as a bedding material or packing material and household fuel, has considerable potential as a source of renewable energy

The main properties of rice husk that make it suitable as a fuel are its high calorific value and its free flowing properties that enable it to be easily fluidized with an air stream. It can thus easily be burnt in suspension in its natural state and no extra size reduction process is required to prepare it for suspension burning. Its principal disadvantage is its abrasive nature which leads to considerable wear of husk handling machinery.

The combustion systems burning rice husk used commercially so far have mostly been using inclined step grates for this purpose. Such systems provide temperatures in the range of 700°C and have a poor thermal efficiency. They also suffer from the inability to separate fly ash from the flames. When attached to boilers the chimney exhaust carries considerable ash. Fly ash is also deposited on the fire tubes along with tar. This results in a fall of heat transfer capacity making it necessary for repeated shutdowns for tube cleaning.

Other shortcomings of the grate system are as follows:

1. In the grate system firing is manual. As such

efficiency of combustion depends entirely on the skill of the operator. Normally, firing is erratic resulting in very large fluctuations in boiler temperature and pressure.

2. Restarting of the boiler after stoppage takes considerable time as the system is open and cools down fast.

3. Proper and full utilisation of boiler capacity can never be obtained

4. The Grate System requires constant poking and stoking. One extra person is equired for this purpose in handling the system.

5. Only dry and good quality rice husk can be used effectively in the Grate System.

6. The Inclined Step Grate Furance has a very rigid construction and therefore a minimum of 72 hours is required to convert back to coal or oil.

Swirl burning of rice husk eliminates most of the disadvantages of the inclined grate system leading to a very satisfactory combustion characteristics.

The design of the swirl flow combustor depends on the heat output required, thermal efficiency of the boiler, calorific value of the husk and elemental composition of the husk which depends on the particular variety of husk and its quality. With this information the necessary air fuel ratio is determined. Based upon the volumetric flow of the fluidized husk-air mixture to be handled by the system, the volume of the burner chamber of the system is calculated for required residence time necessary for combusting the husk.

In the swirl flow combustor, flame temperatures possible are in the range of 1200°C. The higher temperatures are attained by the flue gases lead to increased heat transfer rate in the boiler, and hence more steam generating capacity. The combustion efficiency of rice in swirl burning is nearly 100%.

In the swirl flow combustor the firing is controlled by a hopper feeder and blower, and is regular and continuous. This ensures temperature and pressure stability of the boiler over long periods. The system acts as a thermal flywheel as it is closed and insulated. There is little drop in temperature overnight. The system may be shut off and self started over short period of time. Only one person is required for feeding the husk to the feeder hopper, and the need for another person for poking and stoking the husk as is done for the grate system is eliminated.

The swirl flow system combustor designed for this project was connected to a horizontal four pass boiler providing steam at 100 psi for use in an agro solvent extraction plant. The design incorporates the provision that the combustor could be easily disconnected from the boiler and rerun alternatively on its original oil firing system.

In a field trial of the combustor, a temperature of around 1000°C was obtained with a combustion efficiency close to 100% . The ratio of water evaporation rate to fuel feed rate was 4, compared to 2.77 of husk in the inclined grate furnace, 4.8 for coal and 13.0 for oil.

Other important features of the design are that almost all the fly ash can be removed with the help of a cyclone separator before the flames enter the boiler mouth thus reducing the possibility of pollution hazard. Only minimal deposits of fine ash on the boiler tubes could be expected.

By removing the connecting duct from the system to the furance, it takes only about 30 minutes to convert the combustor back to original oil fired system.

The cost of steam generation with the rice husk combustor comes to only Rs [illegible] per tonne compared to Rs 260/- per tonne with oil as fuel and an estimated Rs 156/- per tonne with coal as fuel.

The initial cost of the material and labour charges for the fabrication and installation of the unit are Rs 78,740/-. At a plant consumption of 700 kg of steam per hour round the clock, this initial cost can be recovered in less than a month.

A trial on the husk fired combustor designed, with sawdust as a fuel established that the swirl flow firing can effectively be used to burn other bulk fuels. However it was felt that it will be necessary to design the system acording to flow characteristics and burning properties of each fuel.

The main limitations of the system are that the feed blower impellar for feeding the air-husk mixture gets worn out as often as once a month. This is due to the abrasive nature of husk.

The combustor temperature, if permitted to rise above the ash softening point of rice husk which is around 1200°C, can also cause damage to the linings of the chambers, choking of the system, and associated downtime of the boiler causing loss of production in the plant.

It is of course realised that adequate rice husk storage facilities will have to be created to use such systems round the year.

6.2 RECOMMENDATIONS FOR FURTHER WORK

Further work should be carried out to explore the utility of the swirl flow combustor for multifuel burning using agrowastes and residues as per their availability. Field trials have shown a good performance of the designed unit when run on saw dust. Other fuels that can be used are peanut shells, gin waste, maize waste, dried leaves, bagasse, coir etc. However, size reduction to about 0.5 mm would be necessary for these other bulk fuels.

The necessary information of calorific value, and elemental analysis of other agro residues, burning properties, fluidizing velocities etc. need to be known for these residues to arrive at accurate designs of swirl flow combustors incorporating them as fuels.

It is necessary to study the abrasive wear characteristics of rice husk with different blower blade materials to arrive at the optimum design to reduce frequent blade replacements.

BIBLIOGRAPHY

1. Ahmed, F.U. and S Prakash 'Use of Rice Husk as Fuel in Brick Kiln', paper presented at the National Workshop on" Rice Husk for Energy" held at New Delhi from 25-27 August 1982.

2. Alam, A. 'Experience of China and Philippines on producer g s technology using Rice Husk' paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

3. Amar Singh and B.S. Pathak, 'Use of Rice Husk as Fuel', paper presented at the National Seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September. 1981.

4. Arora, B.K.. 'By-products Utilisation fron Rice Milling Industry, Problems and Suggestions', paper presented at the National Seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

5. '__________' 'Suspended Burning of Paddy Husk', paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982.

6. '__________' 'Energy Management for a Rice Mill', paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

7. Arjunan M.R., L.Gothandapani, V. Subramaniyan,and K.R.Swaminathan, 'Rice Husk Energy for Drying Paddy', paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

8. Arumugam,R. S.P.Chandak,and P.K Srivasan, 'Efficiency Improvement of Rice Husk Fired Furnaces," paper presented at the National Seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

9. Aurora, A.K.,'Husk Fired Boilers', paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

10. Badlani, A., 'Development of Burner System for Suspension Burning of Rice Husk' paper presnted at the all India Seminar on" Energy Conservation for Process Heat Industries",held at Roorkee,from 1-2 July, 1985

11. Bedekar, V.G. and R.N.Joshi,'Rice Husk is not Waste'.Farmer, 8(12), 1957,pp 31-32.

12. Beer, J.M. and N.A. Chigier , Combustion Aerodynamics Halsted- Wiley, New York, 1972

13. ____________ and K.B.Lee (1965) in 'Modelling of Swirl Burners', Swirl Flows Abacus Press,Kent,U.K.,1984 p 232.

14. Beltaugi,S.A. and N.R.L Maccalum,(1976) in 'Generation of Swirl Flows'Swirl Flows,Abacus Press Kent,1984,p 7.

15. Bockhop, C.W.,L.D. Halos, and Jeon, 'Design of Center- Tube Type, Furance for Efficient Rice Hull Burning,paper presented at the National Workshop on "Rice Husk for Energy" he d at New Delhi from 25-27 August,1982

16. Buckley,P.L.,et.al.(1980)in'Swirl Flow Characterization' Swirl Flows,Abacus Press,Kent,1984, p 5.

17. Chigier, N.A. and A.J. Chervinski,Journal of Applied Machanics,, 34(6) 1967 ,p. 443.

18. ____________ (1967)in 'Swirling Flames SwirlFlows, Abacus Press, Kent,U.K., 1984, p129

19. ____________ and J.M.Beer, Journal of Basic Engineering 86(4), 1964,p. 788.

20. ____________ (1972) in 'High Swirl Phenomena' Swirl

Flows ,Abacus Press,Kent, U.K.1984,p.168.

21. ________ and J.L.Gilbert(1968) in'Recirculation Zone Structure' Swirl Flows Abacus Press,Kent,U.K.1984 p 179.

22. ________ J.M. Beer and N. Syred (1971)in 'Recirculation Zone Structure' Swirl Flows Abacus Press,Kent,U.K. 1984 p 179.

23. De,S.K., 'Conservation of Energy Resources achievable by Application of [illegible] Rice Husk Firing Technique' Chemical Age of India 35(12),1984,pp929-934

24. Devan, M.,- "Utilisation of By-products from Rice Mill Industry- Rice Husk for Producing Thermal Energy', paper presented at the National Seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

25. ________ "New Design of Paddy Husk Furnaces and Production of White Ash", paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

26. Gopalachari, N.C.,- "Briquettes from Rice Husk and Saw Dust As Fuel for Curing Virgina Tobacco", paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

27. Greenland, A.,'Rice Hulls Pulverised for Use', Rice Journal, 79 (8), 1976.pp 8-9.

28. Grover, P.D., 'Energy from Agricultural and Forestry Wastes PARU Fuels", paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

29. ________ ' Briquetted Fuel PARU from Agricultural and Forest Residues',paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

30. Gujaral, R.S. et.al.,'Biomass Energy Alternatives', Changing Villages 6(5) 1984,pp. 373-378

31. Gupta, A.K., D.G. Lilev and N. Syred (eds) Swirl Flows, Abacus Press, Kent, U.K., 1984

32 Gupta,C.P. "Existing Rice Husk Furances and their Problems", paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August, 1982

33. Halos,L.S Y.W.Jeon and C.W. Bockop. 'Design of Centre Tube Type Furance for Efficient Rice Hull Buring', paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August, 1982

34. Huxley,E.G., 'Rice Husk as a Fuel for Village Level Dryers' paper presented at the National Seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

35. Iyengar, N.G.C., 'Improving Efficiencies of Rice Husk fired Furances' paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August, 1982

36. Kapur, [illegible] 'Tube in Basket Burner for Rice Husk' paper presented at the national seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

37. Kelly, W.R., D.E. Mudin, and J.M.Rourkee, 'Industrial Application of Fluidized Bed Cogeneration Systems' Chemical Engineering Progress, 80(1) 1984, pp 35-40.

38. Khalil, E.E., Modelling of Furance and Combuster Flows. Abacus Press, Kent, U.K., 1984.

39. Krishnamurthy, M. and P.N.Srinivasa Rao, 'Rice Husk as a Source of Energy for Dehydration Industry' paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August, 1982

40. Kumar, K. et.al., 'Heat Loss due to Incomplete Combustion of Agricultural Residues', Energy

Management, 8(3) 1984,pp. 205--207

41. Maheshwari, R.C. and P.K.Srivastava, 'Review of Utilisation of Rice Husk as a Source of Fuel'paper presented at the National Seminar on "Utilization of Bye Products from Rice Milling industry" held at New Delhi from 24-25 September, 1981.

42. '____________' 'Design and Testing of Box and Cyclone Type Furances'paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982.

43. '____________' 'Combustion Properties of Rice Husk'paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

44. '____________' et.al.,'Energy Demand and Biomass Energy Potential',Changing Villages, 6(5) 1984,pp.351-361

45. Manivannau, K.,'Utilisation of Residues and by-products related to Paddy and Paddy based Industries'paper presented at the National Seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

46. '____________' 'Utilisation of Rice Husk as Fuel',paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

47. Mathur, K.B. and N. Epstein,'Dynamics of Spouted Beds', Advances in Chemical Engineering Vol 9, Academic Press,New York, 1974.pp 111- 191.

48. Morse,F.T. Power Plant Engineering,East West Press, N.Y., 1981.

49. Mukherjee, N.D. 'Problems of by-products Utilization of Rice Mills in India',paper presented at the national seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September. 1981.

50. '__________' 'Utilizing Paddy Husk as Fuel for Mechanical Dryers and Steam Generation', Investment Intelligence, 14(4) 1976, pp 148-150.

51. Ojha, T.P.'Utilisation of Rice Ash', paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

52. '__________' ,R.C. Maheshwari and B.D.Shukla, 'Present Status of Rice Bye-Product Utilisation', Productivity 18 (2) 1977 pp 249-259.

53. Perry R.M. and C.H. Chilton,Chemical Engineers Handbook,5th Edition, Mc Graw Hill, New York, 1973.

54. Ravindran,S.M.,'Fluidised Bed Husk Fired Furance',paper presented at the National Workshop on "Rice Husk for Energy" held at New Delhi from 25-27 August,1982

55. Richmond, O.R.,'Gravity Hopper Design',Mechanical Engineering, 85(1), 1983,pp 46-49.

56. Robert. J. S.'Energy Recovery from Fluidized Bed Combustion, Chemical Engineering Progress, 80(1) 1984, pp. 48- 54

57. Salariya, K.S. and S. Ohri,'Rice Husk as Kitchen Fuel',paper presented at the national seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

58 Sarpkaya,T.,(1971) in 'Vortex Breakdown' Swirl Flows, Abacus Press, Kent, U.K.,1984, p 187

59. Shagalova,S.L. et.al.(1965) in 'Modelling of Swirl Burners', Swirl Flows, Abacus Press, Kent, U.K.,1984, p 229.

60.. Sheshan, C.S., and S.Bhat,'Biomass Energy Resources and Technology for India', Changing Villages 6(5) 1984.

61. Sidharatha B. and S. Reddy,'Energetics of Agricultural Systems- a Macro Energy Flow Model of Rice Cultivatiion', Energy Management 8(2) 1984, pp. 113-121

62. Stambolis C.(Ed) Solar Energy in the _80's_, Pergamon Press, Oxford, 1981.

63. Stambuleanu,A. _Flame Combustion Processres in Industry_, Abacus Press, Turnbridge Wells, U.K,1976

64. Syred,N., and K.R.Dahmen _Energy_ 2(1) 1978 p 8.

65. Tager S.A._Thermal_ Engineering 18(7)1971 p.120

66. ______________', (1971) in Pressure Drop', Swirl Flows, Abacus Press, Kent, U.K., 1984, p 330.

67. '______________' et.al. (1976) in 'Cyclone Combustors and Flame Structure' _Swirl Flows_ Abacus Press, Kent, U.K., 1984, p 332.

68. Troyankin Y.V.and E.D.Baluev (1969) in 'Pressure Drop' Abacus Press, Kent, U.K., 1984, p 328.

69. Tyagi, P. D. and O.P. Vimal,'Utlisation of By Products of Rice Milling Industry-role of Information and Documentation agencies',paper presented at the national seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

70. United Nations, Department of International Business and Social affairs, _Energy Statistics Year Book 1985_. New York, 1987.

71. Venkatesham, Y,'Utilisation of By Products from Rice MIlling Industry-Role of NRDC of India', paper presented at the national seminar on "Utilization of Bye Products from Rice Milling Industry" held at New Delhi from 24-25 September, 1981.

72. Vimal O.P. and G.C.Chugh,'Paddy Husk', _Yojna_, 19(16) 1976, pp 25-31.

APPENDIX -A

STATEWISE POTENTIAL AVAILABILITY OF RICE HUSK

Sl. No.	State	Husk (000 tonnes)
1.	West Bengal	2502.9
2.	Tamil Nadu	1967.0
3.	Bihar	1839.5
4.	Andhra Pradesh	1766.4
5.	Utter Pradesh	1713.9
6.	Madhya Pradesh	1465.0
7.	Orissa	1439.7
8.	Punjab	931.3
9.	Maharashtra	781.4
10.	Assam	761.3
11.	Karnataka	760.2
12.	Kerala	423.1
13.	Haryana	321.3
14.	Gujrat	223.1
15.	Other states	662.5
	TOTAL ALL INDIA	17,558.6

APPENDIX - B

STATE-WISE NUMBER OF RICE MILLS

State/Union Territory	Hullers	Shellers	Hullers cum Shellers	Other Modern machines	Total
1. Tamil Nadu	14,910	220	211	600	15,941
2. Kerala	13,063	5	3	11	13,083
3. Andhra Pradesh	5,587	1,090	3,626	1,585	11,888
4. Karnataka	6,778	3,567	728	141	8,214
5. Maharashtra	5,123	303	488	17	5,931
6. Uttar Pradesh	5,140	433	141	221	5,975
7. Bihar	4,749	63	9	51	4,872
8. Madhya Pradesh	3,114	239	227	94	3,674
9. Orissa	3,050	334	220	674	3,978
10. Gujrat	3,026	360	163	121	3,670
11. Punjab	2,777	54	1	639	3,471
12. Assam	466		2,163	103	2,732
13. Haryana	1,067	325		326	1,718
14. West Bengal	205	3	2	430	640
15. Other States/ Union Territories	1,544	32	23	12	1,819
TOTAL	70,579	7,028	8,006	5,025	87,606

APPENDIX - C

DETERMINATION OF THEORETICAL AIR REQUIREMENT AND PRODUCTS OF COMBUSTION FOR RICE HUSK OF IR-8 VARIETY

Assuming 100 kg of rice husk of IR-8 variety with an ultimate analysis as shown in table 3.2 and 3.3 the amount of air required for complete combustion and the weight of the products of combustion can be obtained from the folowing chemical relationships.

$$C + O_2 \longrightarrow CO_2$$

$$2H_2 + O_2 \longrightarrow 2H_2O$$

$$S + O_2 \longrightarrow SO_2$$

The calculations are set in table C-1. It is assumed that air contains 21% oxygen and 79% nitrogen by weight.

TABLE C - I COMBUSTION CALCULATIONS FOR 100 kg OF IR-8 HUSK

Composition of 100 kg.Rice Husk (IR-8)				Mole Requirment air		Mole Produced			
Component	Molecular Wt.	Wt. in kgs.	Mole	O2	N2	CO2	H2O	SO2	N2
C	12	39.26	3.271	3.271	12.3095	3.271	.	.	12.3095
H2	2	4.99	2.495	1.248	4.6949	.	2.495	.	4.6949
O2	32	32.70	1.002	1.022	-3.8447	.	.	.	-3.8447
N2	28	1.99	0.071	.		.	.	.	0.071
S	32	0.10	0.0031	0.003	0.0113	.	.	.0031	0.0113
H2O	18	3.56	0.198	.	.	.	0.198	.	
Ash	-	17.40		.	.	.	.	.	.
Total		100 Kg.		3.5	13.159	3.271	2.693	.0031	13.230

Air required

= 3.5 x 32 + 13,167 x 28 = 480.7 kg

Assuming a density of air as 12.87 kg/m³, the volume of air required = 473.1 m³

Total quantity of products of combustion

= 3.271 + 2.693 + 13.238 = 19.2051 mole

Multiplying by their molecular weight, the total weight of these gases

= 143.924 + 48.470 + 370.664 + 0.1984 = 563.256 kg.

The total volume of products of combustion

= 19.2051 x 22.4 = 430.18 m^3

Thus, the specific weight of flue gases

= 563.2564/430.18 = 1.31 kg/m^3

Volume of products of combustion / kg of husk = 4.30 m^3

The material balance for the above combustion process is given in Table C-2.

TABLE C-2 MATERIAL BALANCE FOR COMPLETE COMBUSTION OF 100 kg. RICE HUSK

Input kg		Output kg	
Husk :	Air:		
containing			
C = 39.260	O_2 = 112.000	CO_2 =	143.93
H_2 = 4.990	N_2 = 368.45	N_2 =	370.45
O_2 = 32.700		H_2O =	48.48
N_2 = 1.99		SO_2 =	0.20
S = 0.100		Ash =	17.40
H_2O = 3.560			
Ash = 17.400			
Total (Husk + Air)	= 580.45		580.45

APPENDIX - D

EXPERIMENTAL RESULT OF SUSPENSION BURNING OF RICE HUSKS

Fuel Rate kg/min	Air Flow rate m³/min	Excess Air Observed %	Excess Air Calculated %	Temp. of Combustion Gases °C	Heat in Unburnt Carbon in Refuse kcal/kg	Heat in Unburnt Carbon in Refuse %	Heat in Carbon Monoxide kcal/kg	Heat in Carbon Monoxide %	Total Heat Lost kcal/kg	Total Heat Lost %	Heat Recovered kcal	Combustion Efficiency %
10	1.70	164.2	159.29	454	455.7	13.1			455.7	13.1	3021.5	86.9
15	1.70	67.1	72.86	588	268.5	7.7			268.5	7.7	3211.7	92.3
15	2.12	112.7	116.08	531	1025.3	29.5			1025.3	29.5	3451.9	70.5
15	2.55	152.8	159.29	467	1673.3	48.2			1673.3	48.2	1803.9	51.8
20	2.12	65.2	6.06	620	292.9	8.4	6.9	0.2	299.8	8.6	3177.4	91.4
20	2.55	100.9	94.47	598	781.2	22.5	-	-	781.2	22.5	2696.0	77.5
20	2.83	117.1	116.08	503	1432.2	41.2	13.4	0.4	1445.2	41.6	2031.6	58.4
25	2.12	34.1	29.68	685	374.3	10.8	24.8	0.7	399.1	11.5	3078.1	88.5
25	2.55	57.4	55.61	641	211.6	6.1	23.3	0.7	234.9	6.8	3242.3	93.2
25	2.83	77.1	72.89	618	374.3	10.8	7.0	0.2	381.3	11.0	3095.9	89.0
30	2.12	13.6	8.04	715	537.1	15.4	108.7	3.2	645.8	18.6	2831.4	87.4
30	2.55	26.4	29.65	699	292.9	8.4	49.6	1.4	342.5	9.8	3134.7	90.2
30	2.83	41.6	44.05	673	211.6	6.1	-	-	211.6	6.1	3265.6	93.9
35	2.55	4.9	11.12	717	699.8	20.1	83.1	2.4	782.9	22.5	2694.3	77.5
35	2.83	20.2	23.47	702	1090.4	31.4	41.9	1.2	1132.3	32.6	2344.9	67.4

APPENDIX- E

AVAILABILITY OF STANDARD MS PLATE SINGLE STAGE CENTRIFUGAL BLOWERS

Pressure in water gauge mm.	Capacity per Minute m^3	Motor power at 2880 RPM	Size of the air outlet mm
305	8	0.75	[illegible]
305	13	1.5	102
305	24	[illegible]	127
305	40	3.7	152
305	57	5.5	152
305**	80**	[illegible]	203**
305	122	11.0	203
305	156	15.0	254
305	204	18.5	254
305	240	22.0	305
305	300	30.0	305
305	340	37.0	355
405	4	0.75	52
405	11	1.5	76
405	17	2.2	102
405	26	3.7	102
405*	40*	5.5*	152*
405	57	7.5	177
405	88	11.0	177
405	120	15.0	227
405	160	18.5	254
405	160	18.5	254
405	180	22.0	305
405	220	30.0	305
405	270	37.0	305

DETAILS OF FIRST TRIAL RUN OF RICE HUSK COMBUSTOR

Time	Run time min	Combustor temp. in duct °C	Cumulative water pump run time min	Cumulative bags of husk fed in Hopper	Steam Pressure psi	Remarks
1100	0	-	-	6		Solid fuel wood 40 kgs. soaked in 5 lt. kerosene loaded and lighted.
1138	38	270		-		Blower and husk feed started.
1200	60	275	-	8		Blackish ash from cyclone and . black smoke in stack observed .
1210	70	358	-	9	-	.Husk feed reduced
1220	80	562	-	11	24	
1235	95	738	4	13	35	
1250	110	845	7	15	42	Husk feed adjusted until
1310	130	950	11	18	55	greyish smoke in stack
1330	150	975	15	24	65	
1350	170	990	18	31	60	
1420	200	1008	24	40	70	Steam flashed off.
1430	210	1008	26	42	78	
1450	230	1140	30	47	85	
1515	255	1209	36	55	105	Flames escaping from the bottom of the cyclone chamber .
1535	275	1282	40	60	105	
1550	290	1282	43	67	101	
1605	305	1282	45	70	95	
1625	325	1275	49	73	85	
1650	350	1270	53	76	75	
1710	370	1255	56	79	62	
1730	390	1249	59	81	50	Combustor stopped due to build up of pressure in the system.

APPENDIX - G

DETAILS OF THE TRIAL RUN OF MODIFIED RICE HUSK COMBUSTOR

Time	Run Time min	Combustor Temp. in Duct °C	Cumulative water pump run time min	Cumulative bags of husk fed in hopper	Steam Pressure psi	Remarks
0710	0	-	-	7	-	Start up of Combustor with solid fuel.
0715	5	200	-	-	-	Start up of blower husk feed.
0730	20	450	-	9		Setting of air fuel feed.
0740	30	750	-	12		
0800	50	860	-	16	80	
0815	65	932	-	20	91	
0830	80	994	8	24	102	
0845	95	1020	-	27	96	
0900	110	1022	12	31	102	
0915	125	1023	15	35	97	
0930	140	1025	18	39	Stablized between 95 and 102 psi	
0945	155	1026	21	42	-	Flame temperature stablised at around 1026° C.
1000	170	1026.5	24	46	-	
1015	185	1027	27	50	-	-
1030	200	1027.5	30	54	-	-
1100	230	1028	36	62	-	-
1130	260	1029	42	69	-	-
1200	290	1029	48	79	-	-
1230	320	1028.5	54	82	-	-
1330	380	1028	66	97	-	-
1430	440	1028.5	78	113	-	-
1530	500	1026	90	127	-	-
1630	560	1026	102	142	-	-
1730	620	1027	114	158	-	-
1830	680	1028	126	174	-	-
1930	740	1028.5	138	187		
2030	800	1027	150	203		

APPENDIX-H

PERFORMANCE AND MAINTENANCE OF COMBUSTOR SYSTEM

Day No.	Particulars	Remarks
0	Commissioning of system	
17	Exhaust blower impeller damaged	Repaired and working
29	Top of husk combustor chamber fell down.	Stopped.Repairs complet on day 35
35	Water feed check valve not working properly. Water was leaking in pipe to boiler.	Repaired
	Feed blower impellar damaged	Impellar replaced
39	Exhaust fan vibrating too much	Bearing cha-nged
60	Boiler exhaust fan vibrating too much.	Bearings cha-nged and shaft and bearings dipped in water trough to avoid overheating.
102	The bricks of husk furance fell down as well as the dust receiving cyclone damaged badly.	Brick work of Furnance and cyclone was redone .
123	Steam Pressure below 35 psi	Cleared sur-faces of cha-mbers
129	Blower scroll damaged	New scroll fitted
145	Bottom water seal pipe of cycl-one chamber	pipe replaced

contd...

157	Cyclone chamber bricks fell down from bottom dust outlet.	New brick lining installed.
168	Boiler was stoped for inspection of tubes.	Tubes cleaned
170	Blower impeller damaged	Impeller changed.
194	Blower Impellar damaged	Impeller changed.