DEVELOPMENT AND TESTS OF A DOMESTIC COOKER FOR METHANOL BASED FUELS

GOKUL KRISHNA GHOSH

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by

GUKUL KRISHNA GHOSH

Approved as to style and content by:

Afroza

Dr. Dil Afroza Begum
Associate Professor
Dept. of Chemical Engineering
BUET, Dhaka.

Afroza
Chairman

Dr. K. Ikhtyar Omar
Professor
Dept. of Chemical Engineering
BUET, Dhaka.

Co-Chairman

Nooruddin ahmed
Dr. Nooruddin Ahmed
Professor
Dept. of Chemical Engineering
BUET, Dhaka.

Member

Dr. A.K.M.A. Quader
Professor & Head
Dept. of Chemical Engineering
BUET, Dhaka.

Member

Khaliqur Rahman
Dr. Khaliqur Rahman
Professor
Dept. of Chemical Engineering
BUET, Dhaka.

Member

Majid Rahimi
Mr. A.H.M.A Majid Rahimi
Deputy General Manager
Eastern Refinery Limited
North Potenga
Chittagong.

External Member

ABSTRACT

The present work was concerned with the investigation of the possibility of using methanol as a domestic cooking fuel. The work consisted of two parts. In the first part work was concentrated on the development of methanol fuel blends. This was done to decrease the volatility and associated toxicity of methanol. Different petroleum fractions, aliphatic alcohols and a few aromatic compounds were used as blending agents and as co-solvents. It was found that the co-solvency power of the compounds tested may be shown in the following order: Butyl alcohol>Benzene>Ethyl Methyl Ketone >Isopropanol>Xylene>Ethanol> 100-Octane (Reformate).

The second part of the work was devoted to the development of a vaporizing type cooker for domestic use. Initial studies revealed that existing domestic cookers using kerosene as fuel are not suitable for use with neat methanol or its blends due to problems of leakage and vapour locking. A self vaporizing type cooker for domestic use was designed, fabricated and tested in the laboratory. Evaporation of methanol is obtained by using a part of the heat of combustion of the fuel. Methanol fuel blends and ethanol can also be used as fuels in this cooker. Performance tests carried out with the developed cooker indicated that the present design may be used satisfactorily for domestic cooking.

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CHAPTER - 1 INTRODUCTION

1. INTRODUCTION

The energy resources of Bangladesh are limited compared with the existing and potential demands. To date, a small reserve of crude oil has been discovered in Haripur. Hydropower potential, despite the abundance of water, is limited. Coal exists at Jamalgonj to the extent of perhaps 1 billion tons, but the depth of the reserves (over 1,000 metres) limits the recoverable quantity to possibly less than 50 million tons and makes exploitation expensive and problematic. Coal has recently been found at Dinajpur at a much shallower depth, but its production has to be started. Reserves of peat, estimated at 600 million tons located in the South West (including 8 million tons in Khulna and 125 million tons in Faridpur), are also available but, again, a number of technical and economic problems must be resolved before these can be exploited to any significant extent. Natural gas, on the otherhand, exists in relatively larger amounts. It has been estimated that the remaining reserves in existing fields amount to about 10 TCF.

The position with respect to the availability of traditional energy resources is even less certain. According to the Bangladesh Bureau of Statistics, the amount of energy supplied by traditional fuels grew at a rate of less than 1% per year between 1976 and 1982. This relative stagnation compared with commercial energy consumption growth of about

8% per year has particularly severe consequences because of the large proportion of traditional energy in total energy demand. For example, a 10% increase in total energy demand results in about a 30% increase in commercial energy demand if traditional energy supply remains constant (1). Particularly significant in this area is the role of tree biomass where over extraction is having serious consequences for the environment in the form of deforestation.

During 1985-86 kerosene use in Bangladesh exceeded 3,84,000 tons. Of the total consumption 69% came from Eastern Refinery Limited and 31% was imported. Kerosene accounts for 23.1% of the total petroleum products consumption. Nearly 94% of the kerosene is used as domestic cooking fuel and illuminant. The growth in domestic use appears to be in the range of 10-11% per annum and total consumption is likely to exceed 4,28,000 tons during 1987-88(2).

The net cost of importing commercial fuels (including import of lubricants and allowing for petroleum product exports) constitutes a large proportion of the country's total export earnings as the following figures indicates(1):

	1980-81	1981-82	1982-83	1983-84
Net import cost of commercial fuels (million taka)	7,457	10,722	9,182	8,145
Percent of export earnings	65	87	51	45

Present figures indicate that approximate 40% of the export earning is being used for fuel oil.

Deforestation may be prevented by maximising use of natural gas in the domestic sector. Natural gas fields of Bangladesh are in the Eastern Zone. As Bangladesh is a riverine country, the transmission and distribution of natural gas all over the country would be a very expensive affair.

In order to relieve Bangladesh from this strain the energy planners of the country are trying to find alternate energy sources. In this connection, it may be helpful to convert natural gas into liquid fuel. Transportation and distribution will be easier. There are two possibilities in this respect. One is to convert natural gas into LNG. However, widespread use of LNG requires cryogenic technology and in the context of Bangladesh this will be a problem. The other method is to convert natural gas into Methanol which is a liquid at ambient conditions and which can be manufactured easily. Utilization of Methanol as domestic fuel will save the country from deforestation and drainage of foreign exchange.

A review of available literature reveals that very limited research works on domestic uses of methanol was carried out about 80 years ago. Three types of methanol based cookers were invented in France at the beginning of 20th Century. But these cookers had some inherent problems.

Some preliminary studies were carried out locally in 1979 on the use of methanol as a domestic fuel using locally available appliances (25). Attempts were made to develop methanol base blend fuel and determination of heat utilization efficiency using locally available cookers.

During the last eighty years, there is no information on the use of methanol as domestic fuel. The lack of global interest in using methanol as a domestic fuel is due to its toxicity and low heat content. The easy availability of other conventional petroleum fuels is also another reason for decreased interest in methanol. There is a possibility that the toxicity of methanol due to its high volatility may be decreased blending with less volatile liquid fuels.

It is felt that exhaustive research work should be carried out in order to assess the suitability of methanol as domestic fuel in Bangladesh.

The present work consists of two parts: (A) Development of Methanol fuel Blends (B) Design, fabrication and testing of vaporizing type cooker for using neat methanol and its fuel blends.

CHAPTER - 2 LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 Introduction

Methanol production and use at present is concentrated mainly in the industrial countries. In those countries it is mostly being used as a feedstock or intermediate in chemical industry. It has grown to become the 21st largest commodity chemical with over 14 million metric tons annually produced in the world. Methanol, for many years, has been used as a feedstock for the production of formaldehyde. Nearly half of the methanol produced has been used for this purpose. However, in recent years newer uses have been found for this alcohol.

As a feedstock and intermediate chemical it is being increasingly used for the production of various chemicals, viz.

- acetic acid
- plastics
- pharmaceuticals
- methyl tert-butyl ether(a gasoline booster)

It is also finding use as,

- solvent
- antifreeze
- extractant
- denaturant in ethanol
- dehydrator for natural gas

Direct use of methanol as fuel is still not significant around the world. Its use as a gasoline blend for increasing the octane number has however gain ground in some highly industrialized countries.

2.2 Methanol as a fuel

By the middle of Ninteenth Century, Methanol was well established in Europe, more particularly in France as a fuel for cooking and heating. It was also used for lighting until replaced by the more luminescent kerosene about 1880(3). In the literature of that time domestic uses of methanol are only mentioned without much details, except some patent literature (4,5,6). Since that time, no serious work was carried out on the domestic uses of methanol. At present gasoline Methanol blends are used in some West-European Countries and in the United States. In the Federal Republic of Germany a blend of 3 percent methanol, 3 percent co-solvent and 94 percent gasoline is currently used to meet 70 percent of West Germany's gasoline requirements(7). In USA, the 1:1 Methanol/GTRA (gasoline grade tortiary-butyl alcohol) blend have been marketed, currently trade-marketed and sold as oxinol by ARCO chemical company. In the early 1985, Du Pont won a Waiver for a Methanol-gasoline blend. The EPA approved to add 5% Methanol and at least 2.5% of co-solvent alcohols to gasoline. In Canada, Mohawk Oil Co. sells a blend of unleaded gasoline (92%) Methanol (5%) and Ethanol 3% named "EM" unleaded, in Alberta(8). EEC Countries allow 3% Methanol in gasoline.

Early in the seventies use of methanol in boilers and gas turbines was tried on an experimental basis mainly in USA and Japan. Power companies took this initiative in consideration of the low pollution problems experienced while burning methanol. Methanol contains no sulphur compounds and so emission of NO_x are low compared to hydrocarbon products.

During these tests no inherent difficulties were encountered in burning methanol in conventional boiler or furnace. However, it was realized that a specially designed burner would be required to achieve proper atomization of the fuel if it is fed in liquid form. The fuel circuit has to be redesigned to take into account the specific characteristics of methanol as fuel (viscosity, heating value, flame velocity, etc.). Because of the solvent nature of methanol, independent storage, piping, pumps, etc. would have to be provided to segregate methyl fuel from any conventional fuel oil system. Low viscosity and high volatility of the fuel would require improved valve packing and installation of floating roof tanks.

However, there is yet no methanol-fuelled boiler or gas turbine in continuous active service. But the potential lower NO_x emision will have considerable bearing on the future utilization of methanol as an industrial fuel in view of tightening emission control standards throughout the world.

2.3 COMBUSTION CHARACTERISTICS OF METHANOL

The fuel properties of methanol are presented in Table 2.4.

The combustion of methanol may be presented by the reaction $CH_3OH + 1.5\ O_2 = CO_2 + 2H_2O$ ..... (2.3.1) the heat of combustion is partially absorbed by vaporization of the liquid fuel. Also, with the increase of temperature, methanol dissociates into carbon monoxide and hydrogen. The combustion process may be considered to take place in three steps.

(a) Vaporization of liquid methanol

(b) Dissociation of methanol vapour into carbon monoxide and hydrogen ($CH_3OH = CO + 2H_2$)

(c) Combustion of the carbon monoxide and hydrogen ($CO + 2H_2$) mixture.

The vaporization and dissociation steps absorb as amount of heat equal to approximately 4 MJ/Kg of methanol which is equivalent to 20 percent of the low heating value of liquid methanol (19,900 KJ/Kg. This is shown is details in the following sections.

2.3.1 Methanol Vaporization

The boiling temperature of methanol at atmospheric pressure is 64.7°C. This is rather a low figure compared to conventional petroleum fuel oils. The latent heat of vaporization at 25°C is about 1185 KJ/Kg. The latent heat decreases at high temperature and at 65°C it is only 1076 KJ/Kg. Thus we see that vaporization consumes about 6 percent of the lower heating value of the liquid methanol.

2.3.2 Methanol Dissociation

The equilibrium of methanol dessociation was studied by T.B. Reed (9). The dissociation reaction is opposite that of synthesis:

$$CH_3OH = CO + 2H_2 \quad .... \quad (2.3.2)$$

The reaction is endothermic and the heat absorbed by dissociation of gaseous methanol at 25°C is 2825 KJ/Kg which is approximately 14 percent of the lower heating value of the liquid methanol.

At atmospheric pressures, the dissociation should be complete for temperatures over 250°C. At 10 atmosphere pressure the temperature level should be around 350°C.

Thus we see that vaporization and dissociation steps together absorb about 20 percent of the lower heating value (19,000 KJ/Kg) of the liquid methanol. It would be interesting to perform these two steps before the combustion process by waste heat recovery of the flue gases coming out of a combustion system.

2.3.3 Combustion of CO + $2H_2$ Mixture

The heat released by the combustion of the carbon monoxide and hydrogen as represented by the reaction

$$CO + 2H_2 + 1.5\ O_2 = CO_2 + 2H_2O \ \ldots. \qquad (2.3.3)$$

is approximately equal to 26700 KJ/Kg of the mixture.

The latent heat of water formed in the combustion reaction is about 2750 KJ/Kg of the mixture.

The heat necessary to vaporize and dissociate methanol, when introduced in a liquid state is taken from the heat of combustion of the CO_2 and H_2 mixture. The remaining part of the energy produced is devided into Sensible heat in the dry flue gases (about 88 percent) and latent heat of condensation of the water vapour produced (12 percent).

The heat recovered after combustion is dependent upon the process used. The most common case is when the water formed during the combustion reaction or initially contained in the fuel leaves the system in a vapour state. In this condition the maximum recoverable energy corresponds to the lower heating value of the fuel i.e. 19,900 KJ/Kg of pure methanol injected in the liquid state.

2.3.4 Methanol Flames and Emissions

Methanol is similar to natural gas in its flame characteristics. Due to its moleculer composition, pure methanol can burn without producing soot particles which cause flames to be luminous. The Methanol flame is bluish, without opacity, nearly invisible in the daylight. These flames present advantages in cycles transforming heat directly into mechanical energy and where radiant heat is lost i.e. in the case of gas turbines and internal combustion engines. On the other hand, the non-luminous flame excludes the use of neat methanol for lighting directly.

The lack of opacity and brightness entails the use of appropriate flame detection means.

Regarding combustion emissions of methanol the following points may be mentioned:

(a) There is no sulphur in synthetic methanol and as such flue gases are free of sulphur oxides.

(b) Flame temperatures of liquid methanol are lower than those of petroleum oil fuels and as a consequence nitrogen oxide emissions will be lower for methanol.

(c) The molecular composition of methanol does not allow carbon to stay in an unoxidized state and thus prevents formation of soot particles.

2.4 BIOLOGICAL AND ENVIRONMENTAL CONSIDERATION

Methanol is a well-known poison. Serious consequences to an individual can result if adequate means for prevention and protection from the potential dangers are not taken. The effects of methanol exposure can be immediate as well as of a long-range accumulative nature. Exposure time as well as the individual's personal tolerance influence the severity of the symptoms(10).

Methanol damages the central nervous system and has the most obvious effect on the optic nerve. This can cause a strong sensitivity to light and temporary or permanent blindness. Muscular effects can result in addition to progressive damage to the heart, liver, kidneys and other organs. Methanol is released very slowly from the body and many of the effects are thought to result from the formaldehyde or formic acid which are considerably more toxic than the methanol.

It is interesting to note here that methanol is more toxic to human than animals(11). The lethal oral doze of methanol in man, on a body-weight basis is one-third that for monkeys and one-ninth that for rats.

Exposure to methanol can result from inhalation, ingestion, dermal contact or exposure to the eyes.

2.4.1 Inhalation Exposures

Inhalation of methanol vapour causes irritation to the mucous membrane. It may also cause headache (at concentration as low as 22 mg/m^3) vertigo, nausea, gastric disturbances, convulsions, and even less of vision. In severe cases of exposure, tracheitis, bronchitis and blepharospasm (uncontrollable winking) may occur. When at high concentration, the vapour causes violent inflammation of conjunction and epithelial defects on the cornea of the eye.

The value of 260 mg/m^3 or 200 ppm is generally estimated as the upper limit to exposure of eight hours per day for a single 40-hour week.

The threshold of odour indentification may be as high as 7800 mg/m^3 but it is around 100 mg/m^3 on the average although some studies indicate that 4.3 mg/m^3. This discrepancy may be due to the purity of methanol used in testing(12).

2.4.2 Ingestion Absorption

If methanol is ingested orally, it takes 12 to 18 hours for the symptoms of toxicity to appear. The toxic symptoms include headache, weakness, leg cramps, nausea and vomitting, sometimes with violent abdominal pain, vision defects, mania and convulsions. Death, if it occurs, takes place due to respiratory failures.

The lethal dose of methanol on human according to different researchersare shown in Table 2.1.

TABLE 2.1:LETHAL DOSE OF METHANOL

Researcher	Grams
Puka	15-250
Moeschlin	30-100
Paul	40-80
Gleason	55-255

2.4.3 Skin Absorption

The initial effects of methanol on the skin are the removal of grease and drying of the skin, typical of other solvents. However absorption through the skin can also cause the toxic and lethal effects.

The threshold of danger following skin absorption of methanol is approximately 0.5 cc/Kg of body weight(13).

2.4.4 Exposure to the Eyes

If the eyes come into contact with methanol, it should be washed out promptly. Whether by direct contact or inhaled or ingested methanol will cause blurring of vision and inflamation (conjinctivitis). Severe exposure can destroy the optic nerve, leading to blindness.

Methanol is eliminated very slowly from the body.

Table 2.2 gives comparative toxicity ratings of me methanol gasoline, benzene and ethanol(14).

TABLE 2.2: COMPARATIVE TOXICITY RATINGS

	Eye contact	Inhalation	Skin Penetration	Ingestion
Gasoline	(2)	(3)	(3)	(2)
Methanol	2	2	2	1
Benzene	2	4	2	2
Ethanol	2	1	1	1

1 = mild, 5 ektreme toxicity, ( ) estimated

2.4.5 Poisoning Symptoms and First Aid

As mentioned earlier the symptoms of acute methanol poisoning usually occur 12 to 48 hours after it has been absorbed. The usual symptoms are visual disturbances, severe acidosis, abdominal pain, nausea and vomitting, weakness, shortness of breath and dizziness. The areas of the body affected by the poisoning are the eyes, skin, and central nervous system.

First Aid

Speed is essential in administering first aid for acute methanol poisoning. However, a physician should be called as soon as possible.

There are three steps which should be taken:

(i) To correct the acidosis

(ii) To block the metabolism of methanol

(iii) To wash and clean the affected parts thoroughly

The person should be removed from the area at once and contaminated clothing removed and the exposed skin areas should be washed with soap and water. The eyes should be irrigated liberally with water. Methanol taken orally is a serious threat to life and requires intensive medical care. Vomitting should be induced and repeated until vomitted fluids are clear. Ordinary sodium bicarbonate in small amounts (5-10 gms) every 15 minutes can be used to resist acidosis. Ethanol can be partially effective in the treatment of methanol poisoning. However, this therapy must be monitored closely because of the potential combined central nervous system depression which can result. In severe cases hemodyalysis can be highly effective.

2.5 STORAGE, HANDLING AND DISTRIBUTION OF METHANOL

2.5.1 Storage in Tanks

The higher flammability and lower heating value of methanol are the main factors of the storage system design differences compared to hydrocarbon fuel oil facilities. The lower heating value dictates that the storage capacity be at best double that for petroleum fuels.

Venting requirements are different for methanol storage tanks because of the flammability and vapour pressure characteristics. The higher vapour pressure of methanol will require alternate vent designs that may be sealed, such as vapour recovery or nitrogen blankets. Dry inert gas blanketing is one method of preventing moisture accumulation and avoiding the formation of a flammable fuel/air mixture in the vapour space above the liquid. Tanks of floating roof design with proper seals have been utilised for bulk methanol storage(15). Emergency venting requirements are a consideration in the design of methanol tanks. Any relief vents should be equipped with flame arrestors.

2.5.2 Transportation and Handling

As already mentioned, methanol is a highly flammable liquid. When shipped by rail, water or road it must be packaged in authorized and tested containers and shipper must follow all regulations regarding loading, handling and levelling.

All precaution must be taken to guard against health and fire hazard in handling methanol. Personnel engaged in routine handling of bulk methanol should wear rubber gloves and rubber aprons for protection against skin contact.

Methanol flames are non-luminous and this adds difficulty to extinguishing a methanol fire. Fire fighting equipment can be equipped with alcohol resistant foam generating and spraying systems and are best for large fires.

Air pressures should not be used for emptying drums and tankers. Drums may be emptied by hand pumps.

Tankers and tank trucks are to emptied by using a pump. The car should be vented during unloading

When methanol is to be handled in small quantities safety cans with pouring outlets should be used. The containers should be equipped with tight fitting caps or valves normally closed by springs. The storage and handling of methanol in glass containers is not recommended except in small amounts (maximum of 1 litre) (16).

2.6 METHANOL AS A DOMESTIC FUEL.

Presently methanol is not used in cooking or lighting. However, by the middle of the nineteeth century, methanol was well established in Europe, more particularly in France as a fuel for cooking and heating. In addition, it was reported as a fuel for lighting until replaced by kerosene. A few development works were undertaken on these subjects about eighty years ago. There are some information of patents during that time(4,5,6).

After reading these old patents it appears that some problems have to be solved:

(i) The self-vaporization of methanol. Proposed solution were to pass methanol through a pipe warmed by the flame of the main or auxiliary burner.

(ii) The risk of backfire. Generally, air and fuel are mixed ahead of the burner; the risk of backfire is serious if the speed of the air-fuel mixture becomes slower than that of flame propagation.

(iii) The initial warming up of the apparatus.

Before using a stove at steady state, the apparatus must be warmed-up; hence methanol is poured into a cupel and ignited to warm up the system. This quantity must not be prohibitive compared to fuel burnt in steady state.

2.7 Liquid fuel cookers used in Bangladesh

In Bangladesh liquid fuel used for cooking purpose, is kerosene. Three types of kerosene based domestic cookers are locally produced. These are:

i) Wick control cooker
ii) Flow control cooker
iii) Pressurized kerosene stove

Short descriptions on cookers are written in the following sections.

2.7.1 Wick Control Domestic Cooker (WCDC)

In this type of cooker the fuel consumption is controlled by operating the Wick Control Knob, which varies the exposed length of the wick thereby the consumption of fuel.

The fuel oil is stored in the cylindrical oil storage tank, which also acts as the base of the cooker. The top of the storage tank is covered with a movable cover. The wick tubes, wick holes, wick control knob and fuel filling port are fitted with the cover of the storage tank.

The flow of combustion air to the wick flame are controlled by three air diffusers set in concentric position. The outermost diffuser has twelve air holes at the bottom around the periphery, this diffuser also acts as the support for the cooking pan. The top of ten wick holes is set between half an inch annular space of the inner most diffuser and the middle diffuser. Both the inner most diffuser and the middle diffuser have smaller holes around the periphery for better diffusion of air during combustion. The inner-most diffuser has also got an half inch dia hole at the roof top, which enable it to create a draft for the suction of air.

Cylindrical cotton wicks soaked in fuel in the storage tank are fixed through the individual wick tubes. The upward and downward movement of the wick tubes through wick holes are controlled by the wick control knob. For 5 cm upward and downward movement of wick control knob, wicks move 2.5 cm.

Seat ring placed on the top of the outer most diffuser acts as the seat for cooking pan.

This type of cookers are of single burner type, which means that one cooking utensil can be used at a time. The cookers have been shown in Fig. 2.1A - 2.1C and Plate. 2.1.A.

2.7.2 Flow Control Domestic Cooker (FCDC)

In this type of cooker single wick (tape type made of asbestos fibre) remain fixed on the wick seat and the fuel consumption is controlled by the flow control needle valve.

Fuel flows from the storage tank by gravity via fuel pipe. The diffusers which control the air flow to the wick are fixed by cross bars. The whole mechanism is placed on a separate frame to support hthe load. Seat ring is fixed on the top of the frame to support the pan.

This type of cookers are available with single burner and double burner. Fig. 22A-2.2C and Plate 2.1B. Show the diagram and photograph of the flow control cooker.

2.7.3 Pressurised Kerosene Stove

In a presurized kerosene stove air is pumped into the top empty space of the fuel tank. This pressure carries the oil through a small tube to the upper part of the stove where it comes out as a jet and hits a hot circular surface. The atomised oil is evaporated and the vapours burn with a short but intense flame. Plate 2.1C shows the photograph of this type of cooker.

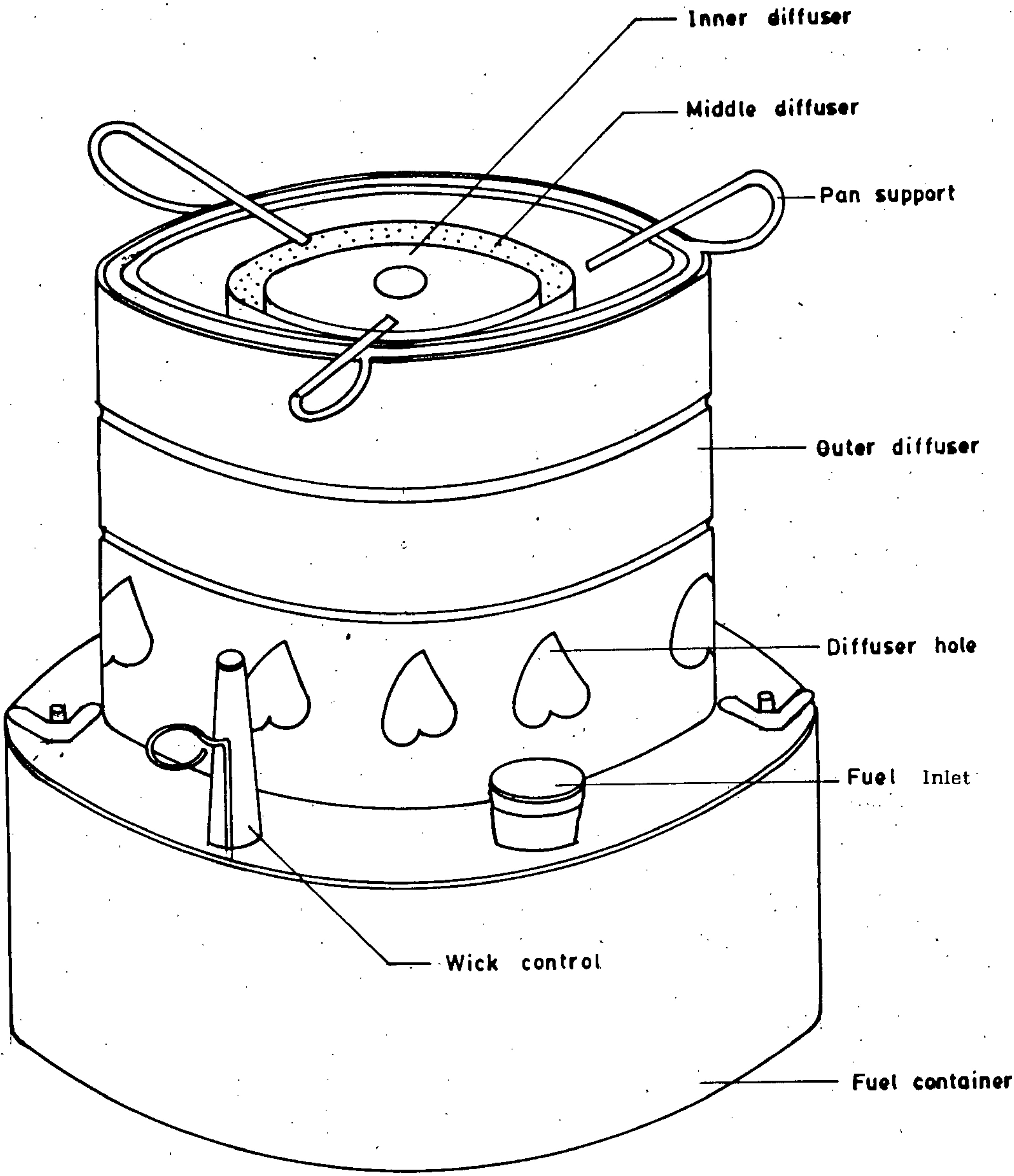


FIG. 2.1A: ISOMETRIC VIEW OF A WICK CONTROL COOKER

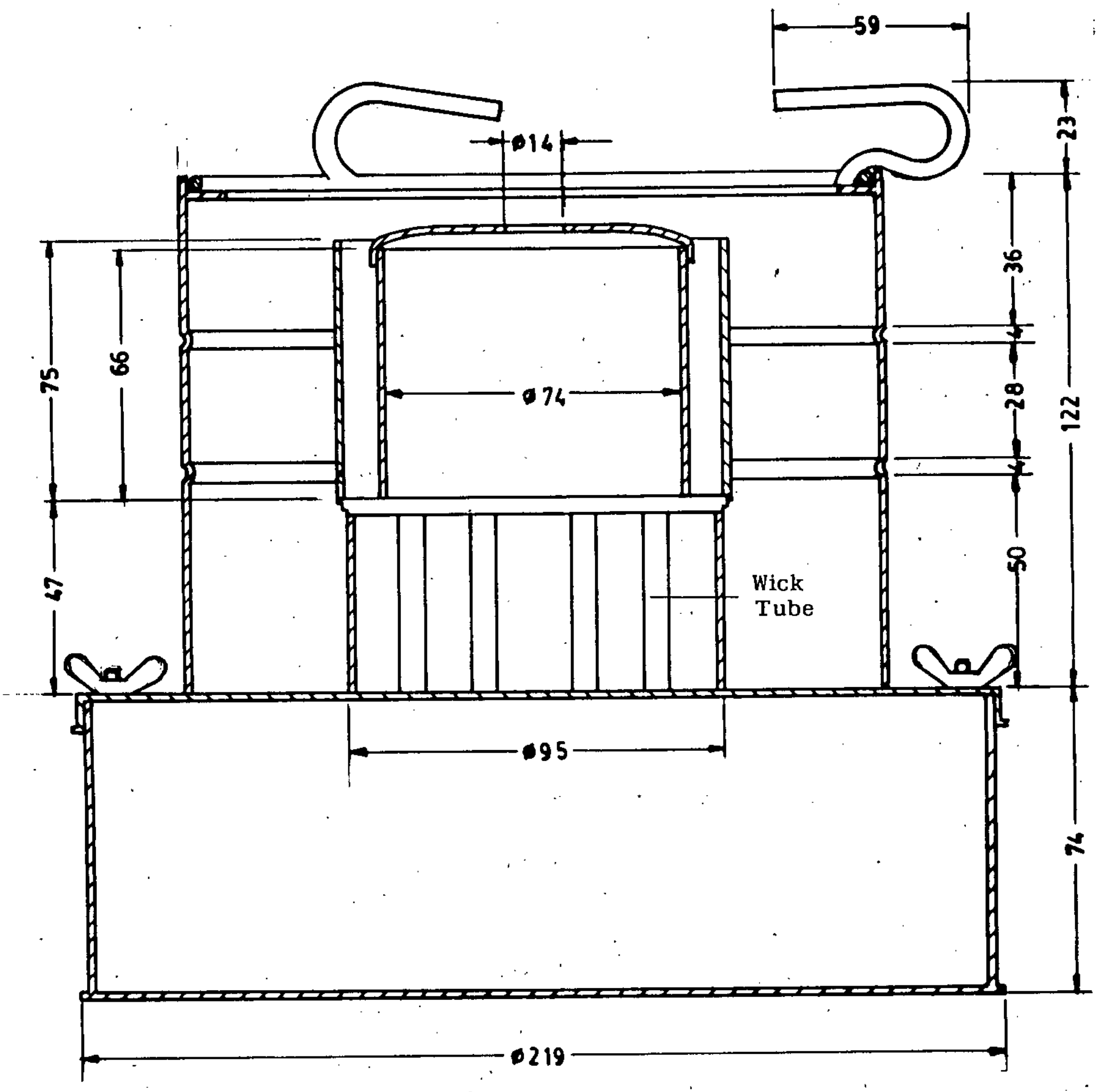


FIG 2.1B: FULL SECTION OF THE WICK CONTROL COOKER

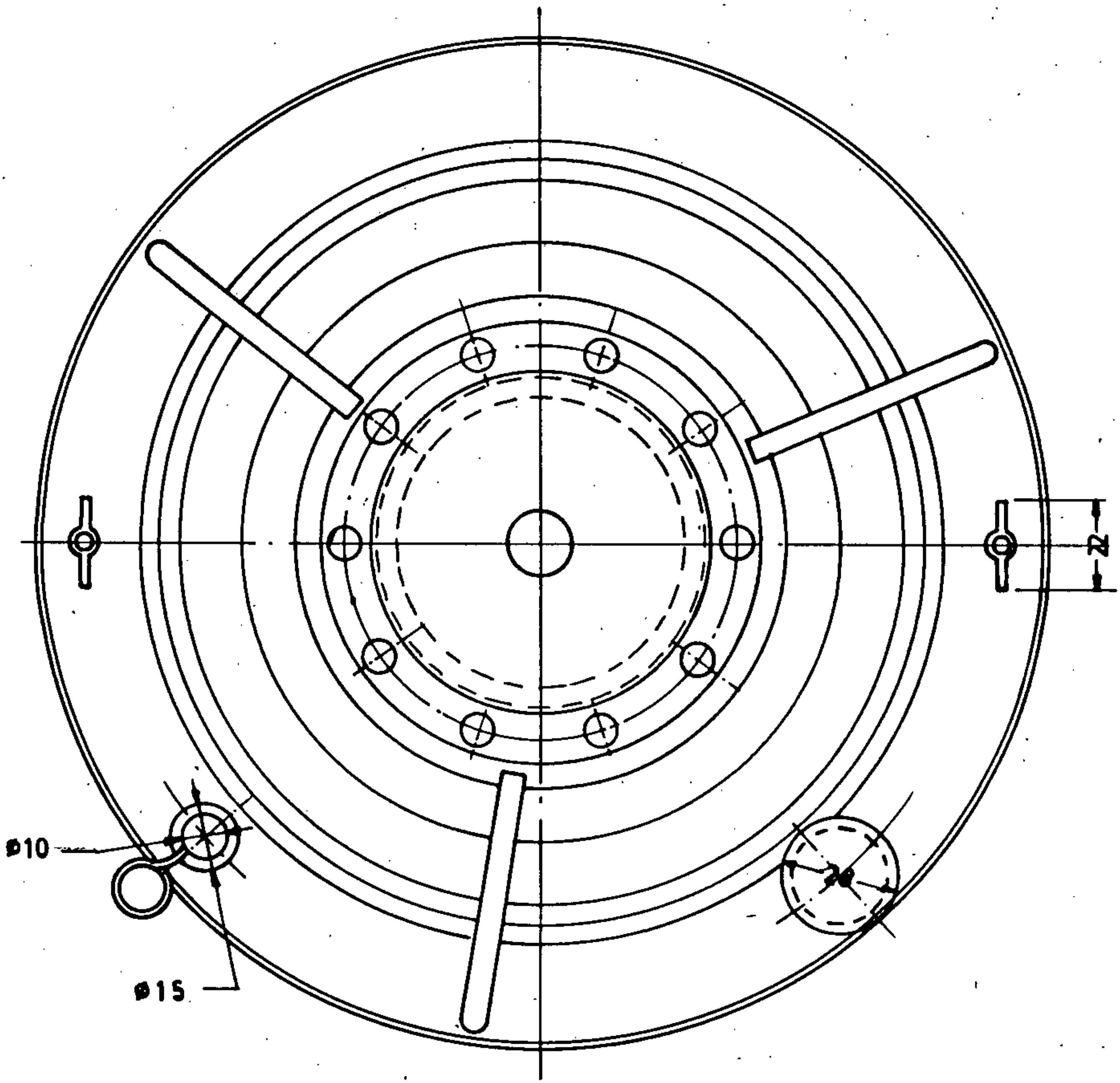


FIG 2.1C: TOP VIEW OF THE WICK CONTROL COOKER

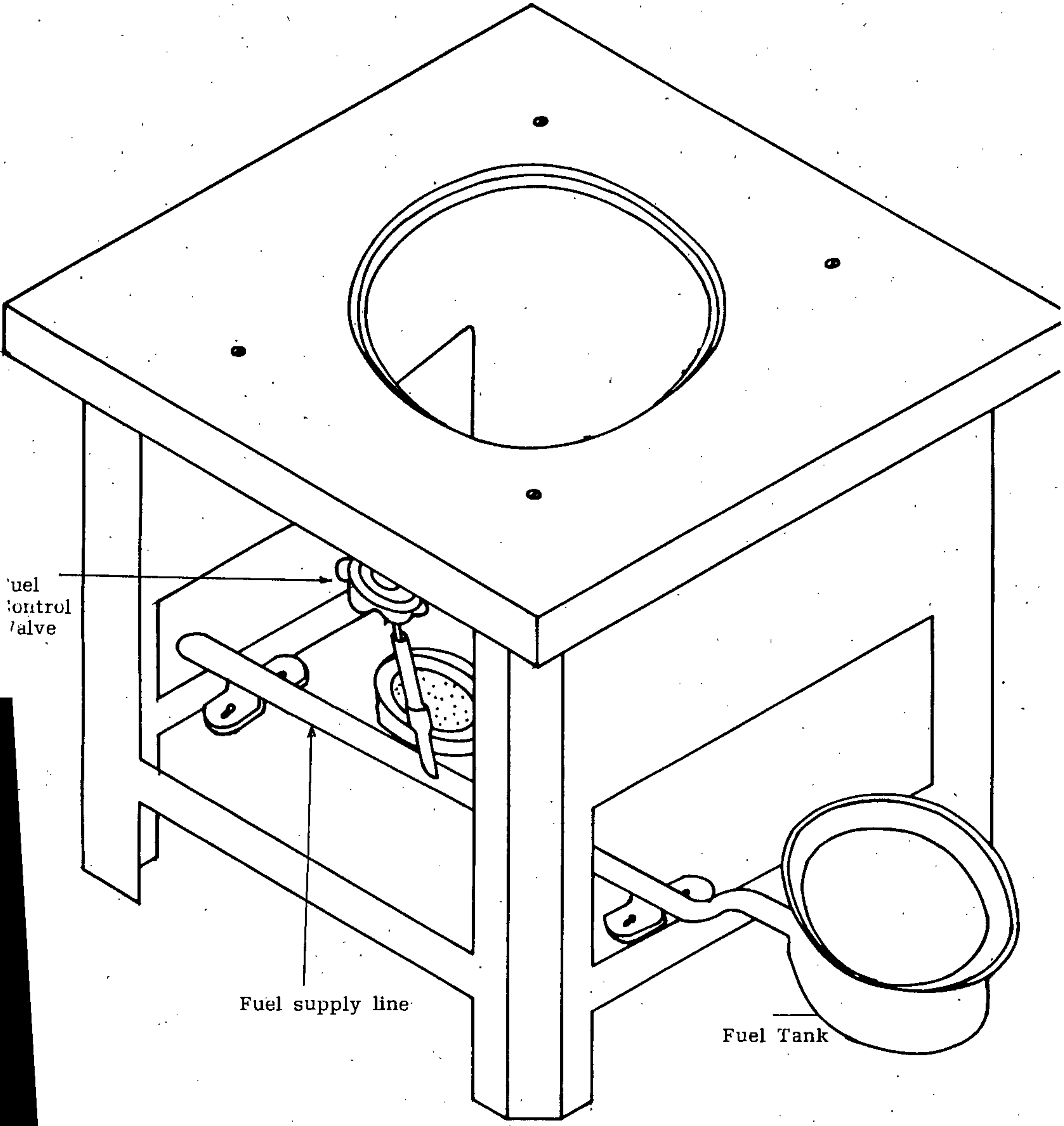
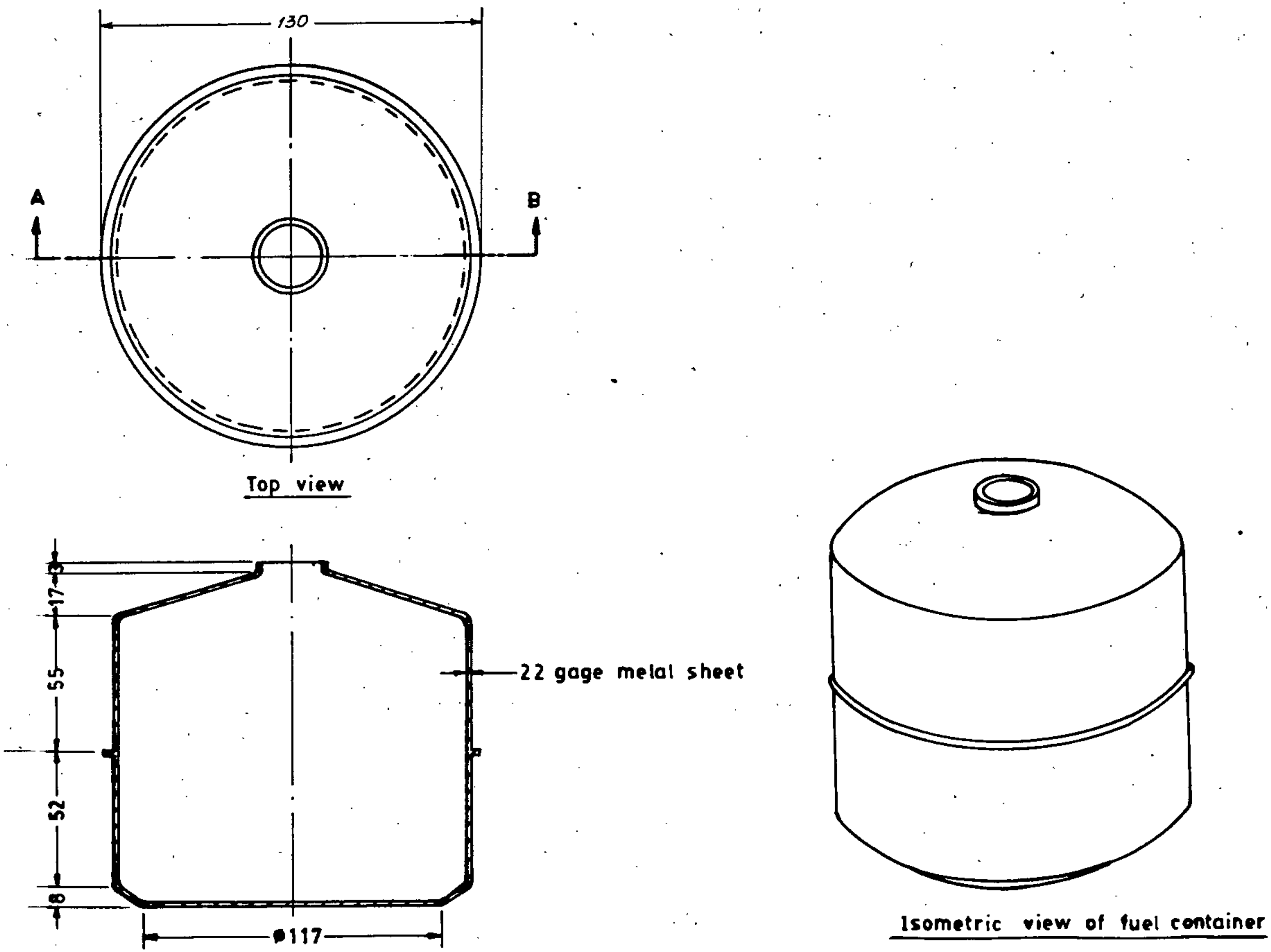


FIG. 2.2A: ISOMETRIC VIEW OF A FLOW CONTROL COOKER



Top view

Section- AB

Isometric view of fuel container

Fig. 2.2B: Fuel container of the flow control

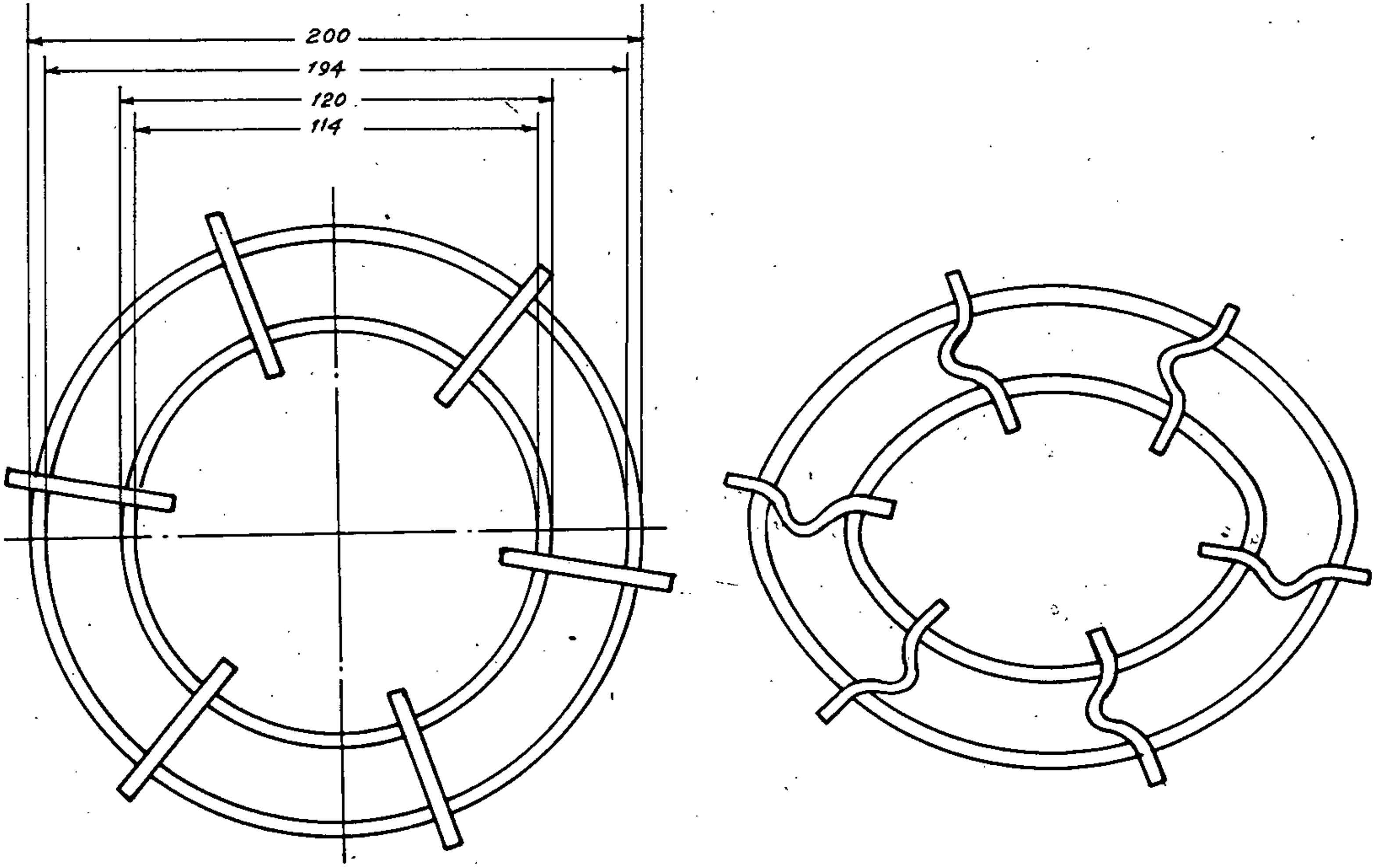


Fig. 2.2C: Pan Support of the flow control cooker.

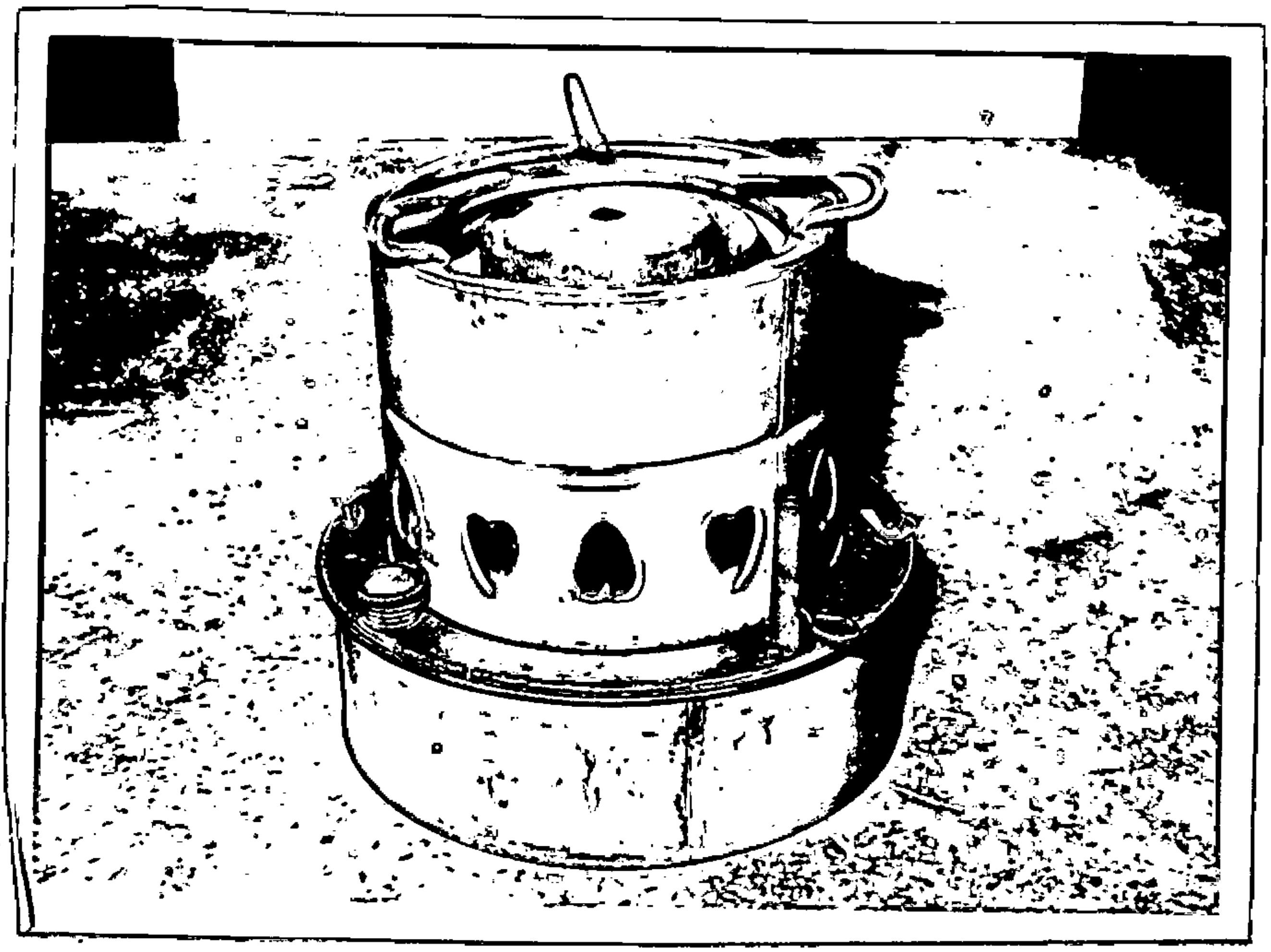


Plate 2.1.A: Wick Control Cooker.

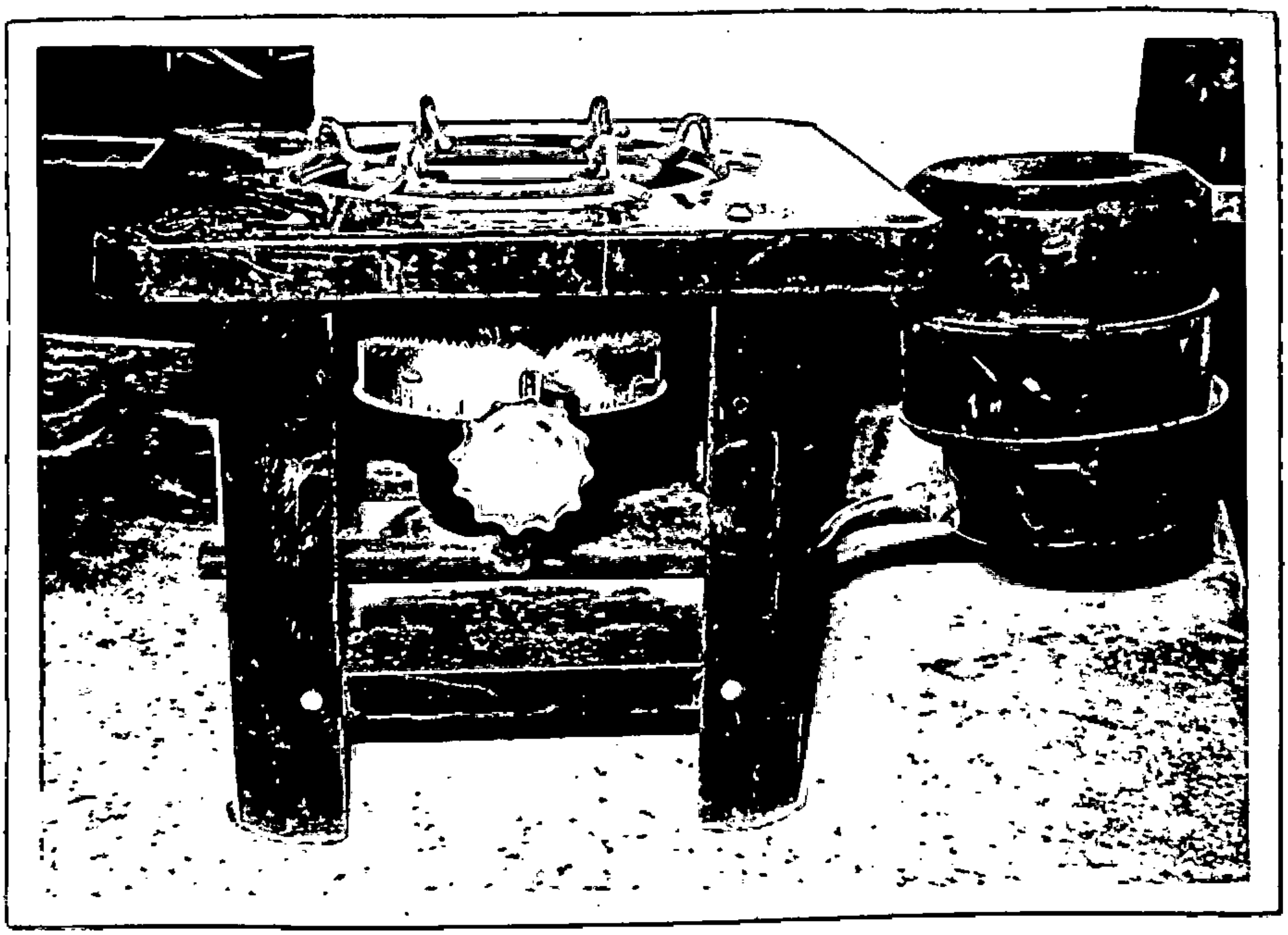


Plate 2.1.B: Flow control cooker (without diffuser).

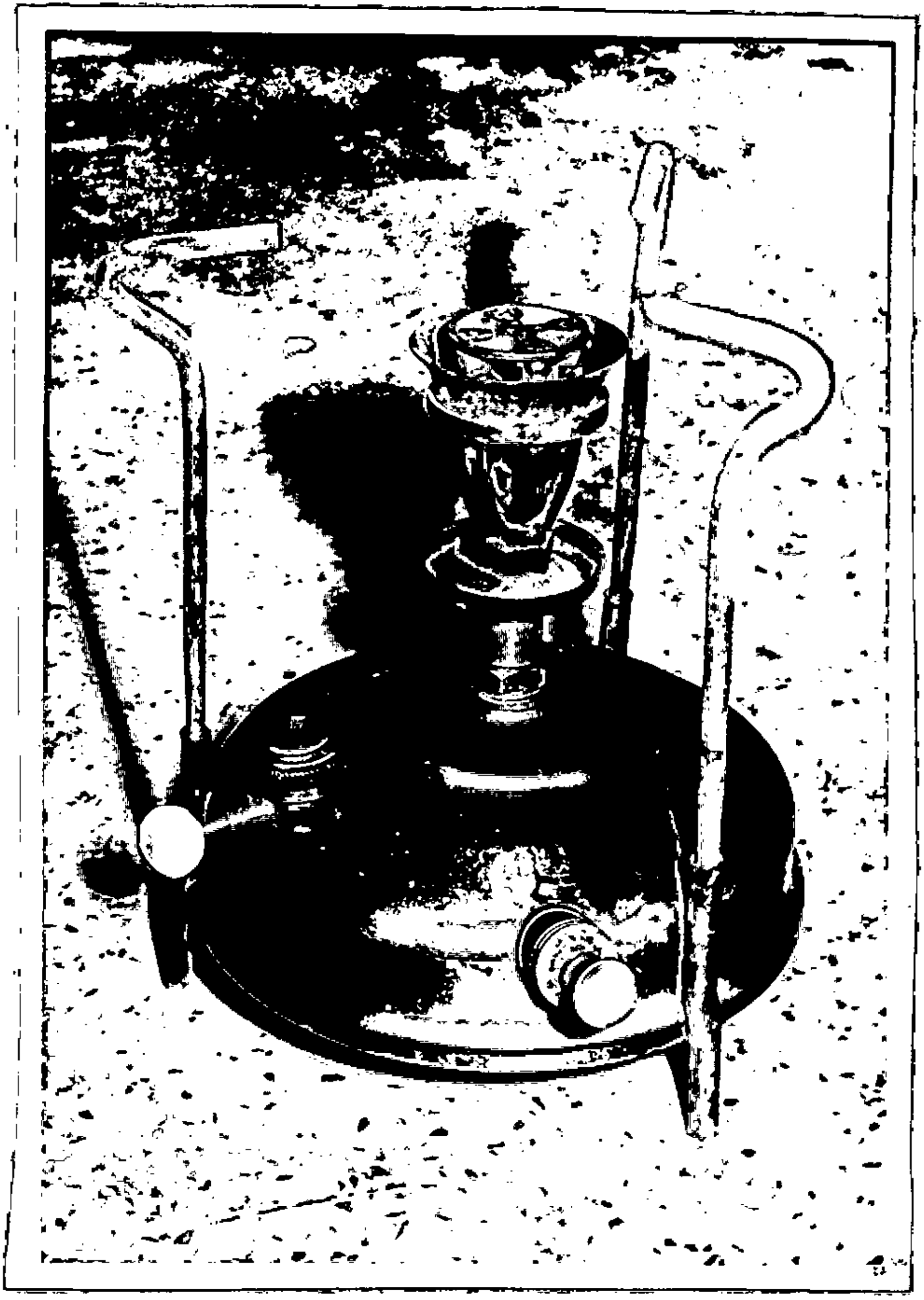


Plate 2.1C: Pressurized kerosene stove.

CHAPTER - 3 PROGRAMME OF RESEARCH

3. PROGRAMME OF RESEARCH

3.1 Background to the present study

The main energy resources at present in Bangladesh are biomass fuels and natural gas. Some deposits of coal, peat and crude oil have been established in the country; but the detailed feasibility of their mining has yet to be studied. On the other hand a major share of the export earnings is being spent every year for the import of liquid fuels (kerosene, diesel and crude oil).

At present biomass fuels are being consumed at a much higher rate than their regenerative supply rate. This is causing environmental degradation in the form of deforestation and loss of soil organic matter. As Bangladesh is a riverine country; the transmission and distribution of natural gas all over the country would be a very expensive affair and alternatives have to be looked into.

During 1985-86 kerosene use in Bangladesh exceeded 3,84,000 tons. Of the total consumption, 69% came from ERL and 31% was imported. Kerosene accounts for 23.1% of the total petroleum products consumption. Nearly 94% of the Kerosene is used domestic cooking fuel and illuminant. The growth in domestic use appears to be in the range of 10-11% per annum and total consumption is likely to exceed 4,28,000 tons during 1987-88(2).

Methanol, which is a liquid fuel at ambient temperature and which can be made relatively easily from natural gas, offers the possibility of the partial substitution of kerosene as a domestic fuel.

As indicated in the literature review, the industrialized countries are carrying out some research directed towards probable use of methanol only as an industrial and automobile fuel because of its low pollutant emissions.

On the other hand, the lack of interest in using methanol as domestic fuel is due to its toxicity, high volatility, wider flammability limits, low heating value, invisibility of flame and corrosiveness. These limitations methanol may be eliminated by research work.

Worldwide interest in investigating the possible use of methanol as a domestic fuel decreased as a result of easy availability of other conventional fuels. As mentioned earlier, available informations on methanol cookers indicate that they are some inherent disadvantages with these designs. The problems encountered in those cookers were:

1) vapour locking; 2) back firing; 3) initial start-up.

It is felt that exhaustive research work should be carried out before drawing conclusions on utilization of methanol as a domestic fuel. The above mentioned points and the unique requirements of the energy situation in Bangladesh are the backgrounds to the present study. The present work consists of two parts:

(A) Study of Methanol Fuel Blends.

(B) Design, fabrication and testing of a vaporizing type cooker for using neat methanol and its fuel-blends.

Detail research programme of those parts are given in Section 3.2 and 3.3.

3.2 Development and Study of Fuel Blends

Since the objective of the present work is to study the possibility of the partial substitution of kerosene with Methanol, tests will be carried out for preparing blends of Methanol and kerosene. However, Methanol is completely immiscible in kerosene. Hence various co-solvents will have to be used to prepare stable kerosene/Methanol fuel blends. After the preparation of the stable blended fuels, their combustion and other properties will be studied using locally available domestic cookers.

3.3 Development of self vaporizing type cooker.

New domestic cooker will be designed and fabricated for burning Methanol and other alcohol fuels and their blends. The design parameters would be obtained from studies carried out in section 2.2. Heat utilization efficiency, turn drown ratios and other aspects of the cooker will be studied in details. Flue gas analysis will be carried out to determine combustion efficiencies. These studies will help to come up with an optimum design.

CHAPTER - 4 METHANOL FUEL BLENDS

4. METHANOL FUEL BLENDS

4.1 Introduction

The high volatility and the toxicity of methanol vapours is a major hindrance to its use as a domestic cooking and lighting fuel. However, as indicated in Section 2.2.1. methanol offers the possibility of the partial substitution of kerosene as a domestic fuel.

The volatility and the toxicity of methanol may be decreased by admixing (blending) it with other hydrocarbon fuels. There is also the possibility that some of these blends would have better combustion properties than neat methanol and have improved flame properties. It is with these ideas that the study of methanol blends was planned.

4.2 Preparation of Methanol Fuel Blends

Methanol is a highly polar substance and is immiscible with kerosene which is non polar in nature. Thus, it is necessary to add a third component (co-solvent) which is miscible in both methanol (M) and kerosene (K).

Review of the literation revealed that aliphatic alcohols (ethanol, propanol, butanol etc), benzene and its homologues and ketones are soluble in methanol (17,18,19).

In preliminary investigations of the present work, it was observed that a few aliphatic alcohols, low boiling petroleum fractions (Boiling point below 200°C), methyl ethyl ketone, and a few available proprietary surfactants are soluble in both methanol and kerosene. Thus these substances were used as co-solvents for making the different fuel blends.

The co-solvents used in this study were ethanol (E). propanol (P), butanol (B), benzene (Ben), toluene (T), xylene (X), 100-octane (O), ethyl-methyl-ketone (EMK) and some proprietary surfactants. The solubility and stability of the fuel blends were examined at 30°C under atmospheric pressure and ternary diagrams were plotted for the different blends. Solubility studies were also carried out with gasoline and natural gas condensates (from different gas fields of Bangladesh).

In making the blends it was ensured that methanol and other alcohols (ethanol, propanol and butanol used as co-solvents) were moisture-free by treating these with indicating type silica gel. Each blend was tested for complete miscibility by examining the clarity of the solution.

The relevant properties of different co-solvents used and their concentration ranges have been given in Tables 5.1 and 5.2. The high octane blending component (sold locally in filling stations as 100-Octane) was separated into three fractions by ASTM distillation:

Fraction I - Boiling range 50 - 80°C
Fraction II - Boiling range 85 - 100°C
Fraction III - Boiling range 100-145°C

The results obtained during the blending tests have been presented in the ternary diagrams. The ternary diagrams identify the single phase region above the experimental curve (indicating complete miscibility) and the two phase region below the experimental curve indicating immiscibility. Besides three component systems (methanol-kerosene-co-solvent), the properties of several two component systems have also been studied and the results of investigations are also discussed in the following sections. All the ratios and percentage of theblended fuel given in this section are volumetric. Natural gas condensate obtained from different gas fields, has been termed as condensate in the section on methanol blends.

4.2.1 Observed Blending Behaviour

The results of investigations of the development of methanol fuel blends are presented in Table 4.3. - 4.5 and Figures 4.1 - 4.3. The results reveal that large amounts of individual co-solvents are necessary for solubilizing methanol into kerosene. The amounts of the different co-solvents necessary for solubilizing equal volumes of methanol and kerosene depend on their chemical nature (Table 4.4). The composition of the blends presented in Figures 4.1 - 4.3 are given in Appendix A1.

In the aliphatic alcohol series, it has been observed that the amounts necessary to make a stable blend decreases as the molecular weight of the co-solvent increases. The curves 1,2,3 in Figure 4.1 reveals that the amount of Butanol required to make a stable blend of methanol and kerosene of any composition, is less than that required by ethanol with propanol taking the intermediate position. Similar phenomena has been observed during the study of stability of gasoline - methanol - water system in presence of higher alcohols(20,21,22).

In the case of aromatics, benzene, and its homologues were found to be quite effective and the effectiveness as cosolvent decreases with the increase in boiling point. This is clear from the ternary diagram of the kerosene-methanol-aromatics system (Fig. 4.2). On the other hand, naphtalene and its homologues showed poor effectiveness as co-solvents.

Ethyl-methyl ketone was found to have a behaviour similar to that of toluene. Octane - 100 (High Octane Blending Compound) exhibited a lower activity as a co-solvent (Table 4.4). Gas condensates showed poor effectiveness as co-solvents although condensates from two gas fields (Titas and Bakhrabad) were found to be soluble in methanol.

An interesting phenomena was observed during the preparation of blends. It was found that any amount of kerosene could be added to a methanol - cosolvent systems below a certain critical ratio of methanol to cosolvent. For example the critical ratio for methanol and ethanol is equal to 0.30:1 (Table 4.5). Similarly, it was found that any amount of methanol could be added to a kerosene/co-solvent system below a certain critical ratio of kerosene to co-solvent. Table 4.5 reveals that in the case of kerosene-ethanol system this ratio is equal to 0.43:1.

Literature review on production of methanol reveals that a modified catalyst formulation coupled with optimum operating conditions may produce methanol containing controllable quantities of higher alcohols, mainly ethanol, n-propanol and iso-butanol(23,24). The comparison of co-production of methanol containing higher alcohols and production of methanol alone indicates that the cost of co-production of methanol containing higher alcohols is higher on an energy basis, than producing methanol alone. But this difference in energy requirement is partly offset by the lower transportation cost for the methanol containing higher alcohols due to its higher energy content per unit volume(24).

During this research work it has been noticed that higher alcohols act as good co-solvent for kerosene-methanol system. So, an experiment was performed using a typical mixture, (methanol - 79.58% wt.; Ethanol = 6.8% wt.; n-propanol = 4.10% wt. Iso-butanol = 9.5% wt.) mentioned in the paper(24). It has been found that two phase does not appear on addition of kerosene to this mixture upto 16% wt. This fact indicates that kerosene can be added to the mixtures of methanol with higher alcohols, manufactured by modified catalytic system.

4.3 Theoretical Consideration on Blends

The theory of solubility states that component A makes a solution with component B only when intermolecular force between A and B exceeds A-A and B-B forces. On the basis of this theory and experimental results obtained during the present work the following points emerge about the mechanism of solubility:

(i) It was observed that the solubility of methanol in n-paraffins decreases with the increase in boiling point of the paraffin. Again, between the n-paraffins and naphthenes, having the same number of carbon atoms; the solubility of n paraffins in methanol is more. The solubility of n-hexane and cyclohexane presented in Table 4.3.

It was also observed that n-heptanes solubilizes in methanol upto 36 percent (volume) but the solubility of n-decane in methanol was found to be less. As such, the maximum solubility of Octane should be in between 29 percent and 36 percent. However, the maximum solubility of iso-octane was found to be 42 percent (Table 4.3). On the basis of these findings, it may be concluded that the iso-paraffins are more soluble in methanol than n-paraffins.

Among the aromatic hydrocarbons, benzene and its homologues solubilize into methanol at any proportion. (Table 4.3). Thus the intermolecular attraction between benzene and its homologues and methanol is greater than that of paraffinic and naphthenic hydrocarbons.

(ii) On addition of aliphatic alcohols to the methanol-kerosene mixture, alcohol interact with methanol and forms a new associated species (Fig. 4.4). The resultant of forces of interaction between these species and the hydrocarbons of kerosene exceeds the resultant of intermolecular forces of the hydrocarbons of kerosene. So, methanol solubilizes in kerosene in presence of aliphatic alcohols. The co-solvency power of aliphatic alcohols is related to the structure of radical attached to OH group.

(iii) The p-electrons of aromatic rings may be responsible for solubility of aromatics in methanol. It is assumed that the p-electrons help to form an association with methanol (Fig. 4.4). The resultant of the intermolecular forces between the above mentioned association and paraffinic-napthenic hydrocarbons exceeds the intermolecular forces of the hydrocarbons of kerosene. As a result, methanol solubilizes into kerosene.

(iv) The presence of carbonyl functional group may be responsible for ketone's co-solvency power. On addition of ethyl-methyl-ketone to the methanol-kerosene system, ketone forms associated species with methanol (Fig. 4.4). These species help in solubilizing methanol into kerosene. As the polarity of ketone is greater than that of aliphatic alcohols, the co-solvency power of ketone was found greater (Table 4.4).

e) Kerosene, Habiganj and Kamta condensates boil in the range of 142-350°C and contain a large amount of high boiling paraffinic-napthenic compounds and higher aromatics similar to that of kerosene (Fig. 4.5).

The above discussion has pointed out that Benzene homologues, aliphatic alcohols and ketone act as a cosolvent for kerosene-methanol system. These compounds are absent in these gas condensates. That is why these condensates are insoluble in methanol. On the other hand gasoline, 100-octane, Titas and Bakhrabad condensates boil in the range of 50-200°C. Table 4.3 shows that all the paraffinic and napthenic hydrocarbons which boil below 200°C. are partially soluble in methanol. Aromatics present in those products are mainly benzene homologues, so they act as a co-solvent during the solubilizing process of paraffinic and naphthenic compounds in methanol. 100-octane, Titas and Bakhrabad condensate and gasoline are, therefore, soluble in methanol at any proportion by themselves. Regarding the co-solvency power of the low-boiling fraction it may be mentioned that only the aromatics in 100-octane are mainly responsible for co-solvent power (Fig. 4.5). The amount of 100-octane required was greater in comparison to individual aromatics.

f) Experimental data have proved that the power of co-solvency depends on the structure of the components. This may be related to the ease of formation of association with methanol and the magnitude of attractive force between the associated species and paraffinic-naphthenic hydrocarbons of kerosene. It has been observed that for each composition of kerosene-methanol system, a minimum amount of co-solvent is required to make a clear solution of kerosene-methanol-co-solvent system. This fact may be related to the following reasons:

i) The magnitude of the resultant of intermolecular forces between methanol-co-solvent associated species and hydrocarbons present in kerosene depends on the number of associated species formed.

ii) The number of species formed depends on the amount of co-solvent added to the methanol-kerosene system.

In the following two sections (Sections 4.4 & 4.5) evaporation loss and combustion studies with existing cookers were carried out with a limited number of blends.

4.4 EVAPORATION LOSSES OF METHANOL AND ITS BLENDS

This section is concerned with the study of evaporation losses of methanol and some of its blends with other hydrocarbon fuels during storage in containers, from hurricane lanterns and kupi lamps and in two types of domestic cookers which normally uses kerosene as fuel. Evaporation losses of methanol and its blends were compared to those obtained with kerosene. Estimates were also made of evaporation losses during transfer of methanol and blends from one container to another.

The blends used in this part of the study were:

(i) Blends of methanol kerosene and a fraction of 100-Octane (Boiling range 100-145°C)

(ii) Blends of methanol, kerosene and 100-Octane.

(iii) Blends of methanol, kerosene and gas condensates.

Results of the experiments carried out to determine evaporation losses of methanol and its blends are shown in Table 4.6 - 4.13. All experiments were performed in locally available appliances.

The reasons for selecting these particular blends is that the blending components are locally available.

4.4.1 Discussion on Evaporation Losses

Table 4.6 shows the evaporation losses of kerosene, methanol and their blends with Octane fuel (boiling range 100-145°C) from an open container (exposed surface area = 5.07 cm^2) in still air at ambient temperatures. It can be seen that the evaporation of neat methanol is 11.6 times that of kerosene. The evaporation of fuel blends depend on the concentration of methanol in that blend and the rate of evaporation is less than that of methanol.

Evaporation losses from the domestic hurricane lanterns (in the non-operating condition) are shown in Table 4 .7. From the table it is obvious that the evaporation losses of methanol and its blends with kerosene are not much higher as compared to values obtained with neat methanol. The same observation can be made with results obtained with kupi lamps as presented in Table 4.8.

Table 4.9 shows results of evaporation losses from a wick control domestic cooker (in the non-operating condition). Results show that evaporation losses are higher than that from hurricane lantern and kupi lamps. The evaporation of methanol from the wick control cooker is about 6 times compared to kerosene and the value goes down to 4 times for dilute blends of methanol. The evaporation losses in these cookers take place from the wicks which remain soaked with fuel at all times and also from the sides of the fuel container because these are not completely gas tight.

Some studies were carried out with flow control domestic cookers. Evaporation losses are lower for this type of cookers because after use the fuel supply to the wick at the burner base is cut off. However, this type of cooker is not practical for using three component fuel blends because there is preferential burning of the low-boiling components in the fuel blends and combustion is very unsteady.

Experimental results on evaporation rate of Methanol-condensate blends from open container are tabulated in Table 4.10. This table shows that the rate of evaporation of fuel increases with the increases of condensates concentration in the blend. Similar phenomena has also been observed in hurricane lantern, kupi and domestic cooker study (Tables 4.11-4.13). Results of investigations on Hurricane lantern, kupi and wick control cooker have been presented in Tables 4.11, Table 4.12 and Table 4.13 respectively Data presented in those tables reveals that the rate of evaporation of blend from different burning appliances in non-operating condition (i.e. after burning) is greater to that from open container.

On the basis of the data presented in Tables 4.6 - 4.11 it can be concluded that the rate of evaporation of two component system (methanol-condensate) is much higher than that of three component systems. However, the rate of evaporation of two component system can be decreased using fractions of gas condensates boiling in the range 100-185°C and modifying the design of existing appliances.

Some experiments were carried out with the help of a methanol detector tubes to determine the concentration of methanol in the environment under different conditions. The results of the investigations have been presented in Table 4.14. This table shows that blending and design modifications will be helpful in decreasing concentration of methanol in the environment to negligible amounts.

4.5 Use of Methanol Blends in Locally Available Domestic Cookers

This part of the study is concerned with experimental trials of the use of methanol fuel blends in locally available domestic cookers which normally use kerosene as fuel. Two types of cookers - the Flow Control Domestic Cooker and the Wick Control Domestic Cooker were used in the tests. The fuel blends used were two component blends:

(i) Blends of Methanol - Bakhrabad condensate
(ii) Blends of Methanol - Titas condensate
(iii) Blends of Methanol - 100-Octane.

Combustion of the fuel blends were carried out in the two types of cooker to examine the possibility of using methanol fuel blends and also to identify necessary design changes.

ASTM distillation of the different fuel blends before and after use in the cookers were carried out to see if there is preferential combustion of the blend components.

Flue gases were analysed with the help of Orsat analyser. The carbon monoxide indicator (Backhare type) and methanol indicator tubes were used for measuring small concentrations of Carbonmonoxide and methanol vapours respectively.

Results of the investigations are presented in Table 4.15.

Preliminary investigations indicated that the flow control cooker needed modifications to burn blended fuels. This was because the liquid fuel line from the tank to the burner was experiencing vapour lock problems. Thus uniform flow of fuel to the burner was not possible. The fuel line in the existing cooker is nearly 20 mm in diameter. This was decreased to 5 mm. Also the fuel tank height was increased from 5 cm to 40 cm. This created a pressure head greater than that of existing system. The flow of fuel was controlled by a needle valve. The wick - well was also decreased in width such that the wick just fitted into the space.

4.5.1 Results of Cooker Study with Blends

Table 4.15 shows that the locally available wick control cooker and the modified flow control domestic cooker can be burned with the two component blends mentioned earlier. The combustion gas analysis show (Table 5.15) show that emission of carbon monoxide is low and unburnt methanol vapour concentrations are with threshold limit values (TLV). No sooting was observed during combustion.

However, methanol evaporated from the wicks when the cookers are not in operation. Also there was leakage from the fuel tanks and other parts of the cookers. Measurements taken of methanol vapour concentrations in the vicinity of the cookers, when not in use showed that the concentrations exceeded the threshold limit value of 200 p.p.m.

Thus it can be concluded that the use of blends in existing cookers would not be advisable.

4.6 General Discussions on Methanol Blends

Chapter three was concerned with the preparation of various blended fuels and the study of their properties. The main findings of this part are as follows:

1) Kerosene is completely immiscible in methanol. However, its solubility in methanol may be improved by adding aliphatic alcohols, Benzene homologues, ketones and aromated petroleum fractions(boiling points less than 200°C). In order to get a completely miscible and stable solution of methanol and kerosene, a large amount of third component (co-solvent) has to be added and the amount of third component required depends on its chemical nature. Methanol fuel blends are very sensitive to moisture which cause phase separation (tolerance to water is less than 1% by volume depending on the composition of methanol blends). During the studies with kerosene - Methanol-co-solvent system, it was found that any amount of kerosene can be added to methanol - co-solvent system below a certain critical ratio of methanol to co-solvent. Similarly, it was observed that any amount of methanol can be added to kerosene - co-solvent system below a certain critical ratio of kerosene to co-solvent. Methanol blends are not hygroscopic and are stable in air.

2) Among all the blends studied, the three component kerosene-methanol-100-octane and the two component methanol-

condensates may be considered more practical because these are locally produced unlike the others. Further, considering technico-economic feasibility, the two component system (Methanol-condensate) is better than three component system (kerosene-methanol-100-octane) because of the local availability of the gas condensate.

3) Literature review on production of methanol reveals that methanol containing upto 30% (by weight) higher alcohols may be manufactured using modified catalyst at optimum conditions. In accordance with the experimental results of this research work, nearly 30% (by weight) kerosene can be added to this mixture. So, the amount of kerosene and higher alcohols in kerosene-methanol-higher alcohols blend will be about 60% (by weight). On the basis of experimental results obtained during this study, this type of methanol blend will be good in all respect. So, co-production of methanol containing higher alcohols may be recommended instead of production of methanol alone if large scale of methanol is planned.

4) During the study on evaporation of methanol blends, it has been observed that the concentration of methanol vapour in air can be decreased to low levels by blending and changing the design of the existing cooking and illumination appliances.

5) Methanol and its blends cannot be burned in locally available flow control cooker due to vapour looking and severe leakage from the fuel tanker. These problems have been eliminated by modifying the design of the cooker. In modified cooker, two component system burns very well but three component systems can not be used due to unsteady burning. Wick control cooker may be used for both type of fuels (two component and three component systems). However, during combustion study using blends, leakage of fuel was detected from the wicks and wick rider of the wick control cooker. As a result, the concentration of methanol in air exceeds threshold limit. Thus the use of blends in existing cooker is not practical. Most of the fuel blends burn without smoking and flue gas temperatures lie in the region of 740-850°C.

6) During the trials of burning kerosene-methanol-alcohol system in the conventional hurricane lanterns, it was observed that the illumination levels of the flame from the blends having methanol concentration upto 15% (by volume) are similar to that obtained with kerosene. At higher concentrations of methanol in those systems, the luminous (yellow) part of the flame is reduced leading to a lowering of the illumination level. The illumination intensity is increased with the use of higher alcohols as co-solvents. Burning rate and evaporation losses (for non-operating conditions) increases with the increase of methanol concentrations in the above mentioned blends. There is no change in the fuel composition with time.

TABLE 4.1: PHYSICAL CONSTANTS OF THE COMPONENTS USED IN BLENDING

Name of component	Specific gravity	Refractive index, n_D^{20}	Boiling point °C
Kerosene	0.785	1.438	I.B.P*=142,95%=265
Titas Gas condensate	0.770	1.366	I.B.P.=59,95%=165
Kamta Gas condensate	0.865	1.4825	I.B.P.=136,95%=340
Bakhrabad Gas condensate	0.765	1.433	I.B.P.=38,95%=182
Habiganj Gas condensate	0.8653	1.4715	-
100-octane	0.745	1.435	I'B.P.=52,95%=185
Octane (50-85°C)	0.685	1.393	50 - 85
Octane (85°-100°C)	0.725	1.414	85 - 100
Octane (100-145°C)	0.78	1.445	100 - 145
Petrol	0.700	1.402	I.B.P.=60,95%=172
Benzene	0.879	1.5011	80.1
Toluene	0.867	1.4961	110.1
Xylene	0.880	1.5055	144.4
Ethyl methyl ketone	0.805	1.3788	79.6
Methanol	0.780	1.336	64
Ethanol	0.785	1.3611	78.3
Propanol	0.804	1.3850	79.4
Butanol	0.81	1.3993	117
n-hexane	0.660	1.3751	69
n-heptane	0.684	1.3878	98.4
n-decane	0.73	1.4102	174
Iso-Octane	0.692	1.3915	99.2
Cyclohexane	0.778	1.4266	80.7

*I.B.P. : Initial Boiling Point

95% : Point of Distillation of 95 percent of Sample (ASTM).

TABLE 4.2: LIMITS OF CO-SOLVENT USED IN METHANOL KEROSENE BLENDS

Name of co-solvent	Range of Kerosene (Percent)	Range of Methanol (Percent)	Range of co-solvent (Percent)
Ethanol	0-100	0-100	0-46
Propanol	0-100	0-100	0-34
Butanol	0-100	0-100	0-25
Benzene	0-100	0-100	0-26
Toluene	0-100	0-100	0-30
Xylene	0-100	0-100	0-38
Ethyl-Methyl Ketone	0-100	0-100	0-30
*100-Octane	0-100	0-100	0-58
+(50-85°C)	0-100	0-100	0-66
**0(100-145°C)	0-100	0-100	0-56

* High Octane Blending Component, sold as 100-Octane in Petrol Pumps.

\+ Fraction of 100-Octane boiling between 50 and 85°C

** Fraction of 100-Octane boiling between 100 and 145.

TABLE 4.3: SOLUBILITY RANGE OF BLENDING COMPONENTS IN METHANOL AND KEROSENE

Name of the component	Solubility range in Methanol	Solubility range in Kerosene
1. Titas condensate	Any proportion	Any proportion
2. Bakhrabad condensate	Any proportion	Any proportion
3. Kamta condensate	Insoluble	Any proportion
4. Habiganj condensate	Insoluble	Any proportion
5. 100-octane	Any proportion	Any proportion
6. Petrol	Any proportion	Any proportion
7. n-hexane	0-50%(by volume)	Any proportion
8. Cyclo hexane	0-45%(by volume)	Any proportion
9. n-heptane	0-36%(by volume)	Any proportion
10. Iso-octane	0-42%(by volume)	Any proportion
11. n-decane	0-29%(by volume)	Any proportion
12. Benzene	Any proportion	Any proportion
13. Toluene	Any proportion	Any proportion
14. Xylene	Any proportion	Any proportion
15. Naphthalene	0-12.6%(by weight)	Any proportion
16. 142-172°C fraction of kerosene	0-16%(by volume)	Any proportion
17. 172-185°C fraction of kerosene	0-14%(by volume)	Any proportion

TABLE 4.4: AMOUNT OF ADDITIVES REQUIRED FOR SOLUBILIZING EQUAL VOLUMETRIC AMOUNTS OF METHANOL AND KEROSENE

Name of additives	Volumetric ratio of Methanol : Kerosene : Additive
1. Benzene	1 : 1 : 0.7
2. Toluene	1 : 1 : 0.86
3. Xylene	1 : 1 : 1.13
4. Ethyl methyl ketone	1 : 1 : 0.86
5. Butyl alcohol	1 : 1 : 0.63
6. Isopropanol	1 : 1 : 0.94
7. Ethanol	1 : 1 : 1.7
8. Octane - 100	1 : 1 : 2.76
9. 0(50-85°C)*	1 : 1 : 3.55
10. 0(100-145°C)**	1 : 1 : 2.54

* Octane-100, fraction between 50-85°C

** Octane-100, fraction between 100-145°C.

TABLE 4.5: CRITICAL RATIO OF DIFFERENT BLENDS

Name of the component	Critical ratio (volumetric)
1. Methanol : Ethanol	0.33 : 1
2. Methanol : Propanol	1.03 : 1
3. Methanol : Butanol	1 : 1
4. Methanol : Ethyl methyl ketone	1.16 : 1
5. Methanol : 0(50-85°C)	0.07 : 1
6. Methanol : 0(100-145°C)	0.11 : 1
7. Methanol : Benzene	1 : 1
8. Methanol : Toluene.	0.34 : 1
9. Methanol : Xylene	0.22 : 1
1. Kerosene : Ethanol	0.43 : 1
2. Kerosene : Propanol	0.52 : 1
3. Kerosene : Butanol	0.88 : 1
4. Kerosene : Ethyl methyl ketone	0.67 : 1
5. Kerosene : 0(50-85°C)	0.14 : 1
6. Kerosene : 0(100-145°C)	0.2 : 1
7. Kerosene : Benzene	1 : 1
8. Kerosene : Toluene	0.78: 1
9. Kerosene : Xylene	0.47 : 1

TABLE 4.6: EVAPORATION RATE OF DIFFERENT FUELS FROM OPEN CONTAINER (5.067 cm^2 SURFACE AREA) IN STILL AIR AT (29-30°C), (65-70)% HUMIDITY.

Fuel K : M : O(100-145)*	Evaporation rate gm/cm^2-hour	Evaporation rate with respect to kerosene
100: O : 0	0.005	1.0
71: 2 :26.7	0.0104	2.08
58: 4.837.2	0.0153	3.06
36: 9 : 55	0.0185	3.7
27.9:13.9:58.2	0.021	4.2
24:24 : 52	0.022	4.4
10: 50 : 40	0.0314	6.28
3: 75: 22	0.0449	8.98
0:100: 0	0.058	11.6
0:0 : 100	0.01	2.0
100-Octane	0.11	22.0

* (100-145)°C Fraction of High Octane Blending Component (100-Octane) with a boiling range of 100-145°C.

TABLE 4.7: EVAPORATION LOSS IN HURRICANE LANTERN (IN THE NON-OPERATING CONDITION).

	Fuel		Evaporation loss gm/hr.	Evaporation Rate with Respect to Kerosene
K	M	0(100-145)		
100	0	0	0.02	1.0
71	2.3	26.7	0.04	2.0
58	4.8	37.2	0.04	2.0
27.9	13.9	58.2	0.04	2.0
24	24	52	0.04	2.0
10	50	40	0.06	3.0
3	75	22	0.06	3.0
0	100	0	0.06	2.0
0	0	100	0.04	2.0
100-Octane			0.10	5.0

TABLE 4.8: EVAPORATION LOSS IN KUPI LAMP (IN THE NON-OPERATING CONDITION)

Fuel			Evaporation loss, gm/hr	Evaporation rate with respect to kerosene
K	M	0(100-145)		
100	0	0	0.02	1.0
71	2.3	26.7	0.02	1.0
58	4.8	37.2	0.02	1.0
27.9	13.9	58.2	0.04	2.0
24	24	52	0.04	2.0
10	50	40	0.06	3.0
3	75	22	0.06	3.0
0	100	0	0.06	3.0
0	0	100	0.04	2.0
100-Octane			0.16	8.0

TABLE 4.9: EVAPORATION LOSS IN WICK CONTROL DOMESTIC COOKER (IN THE NON-OPERATING CONDITION)

Fuel			Evaporation loss gm/hr	Evaporation rate with respect to kerosene
K	M	0(100-145)		
100	0	0	0.27	1.0
71	2.3	26.7	0.98	3.6
58	4.8	37.2	1.00	3.7
27.9	13.9	58.2	1.08	4.0
24	24	52	1.08	4.0
10	50	40	1.38	5.1
3	75	22	1.46	5.4
0	100	0	1.60	5.9
0	0	100	1.25	4.6
100-Octane			3.67	13.6

TABLE 4.10: EVAPORATION RATE OF METHANOL-CONDENSATE BLENDS FROM OPEN CONTAINER (5.067 cm^2 surface area) IN STILL AIR AT (23-24°C), (60-63)% HUMIDITY.

Volume % of blends Methanol : Bakhrabad condensate	Evaporation rate gm/cm^2-hr	Evaporation rate with respect to kerosene
75 : 25	0.065	13·0
50 : 50	0.073	14.5
25 : 75	0.080	16·0
Volume % of blends Methanol : Titas condensate		
75 : 25	0.600	12
50 : 50	0.065	13
25 : 75	0.700	14

TABLE 4.11: EVAPORATION RATE IN HURRICANE LANTERN (In non-operating condition)

Volume % of blends Methanol : Bakhrabad condensate	Evaporation rate gm/hr	Evaporation rate with respect to kerosene
75 U 25	0.10	55
50 : 50	0.12	6·0
25 : 75	0.14	7·0
Volume % of blends Methanol : Titas condensate		
75 : 25	0.08	4·0
50 : 50	0.09	4.5
25 : 75	0.12	6·0

TABLE 4.12: EVAPORATION RATE OF METHANOL-CONDENSATE BLENDS IN KUPI LAMP (in non-operating condition)

Volume % of blends Methanol : Bakhrabad condensate	Evaporation rate gm/hr	Evaporation rate with respect to kerosene
75 : 25	0.09	4.5
50 : 50	0.10	5.0
25 : 75	0.13	6.5
Volume % of blends Methanol : Titas condensate		
75 : 25	0.08	4.0
50 : 50	0.10	5.0
25 : 75	0.11	5.5

TABLE 4.13: EVAPORATION RATE OF METHANOL-CONDENSATE BLENDS IN WICK CONTROL DOMESTIC COOKER (in non-operating condition)

Volume % of blends Methanol : Bakhrabad condensate	Evaporation rate gm/hr	Evaporation rate with respect to kerosene
75 : 25	2.03	7.5
50 : 50	2.30	8.5
25 : 75	2.70	10.0
Volume % of blends Methanol : Titas condensate		
75 : 25	1.84	6.8
50 : 50	2.16	8.0
25 : 75	2.57	9.5

TABLE 4.14: CONCENTRATION (ppm) OF METHANOL IN AIR AT DIFFERENT CONDITIONS. FUEL : METHANOL-CONDENSATE BLEND*
RATIO : 1 : 1.

Condition of use	Kupi	Lantern	Wick control cooker	Flow control cooker	Modified flow control cooker
1. During filling of the appliances	75	100	100	200	90
2. During refilling	90	110	150	200	100
3. In the combustion Gases	25	30	20	25	20

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* Bakhrabad condensate.

TABLE 4.15: FLUE GAS ANALYSES OF DIFFERENT FUELS

Name of the cooker	Name of the fuel	Flue gas analyses			
		O_2, % by Vol.	CO_2, % by vol.	CO, % by vol.	Methanol ppm
1. Wick control cooker	Kerosene	7.0	10	0.02	-
2. Wick control cooker	Methanol:BK.Cond.* 1:1	7.0	8.8	0.025	32
3. Wick control cooker	Methanol:Tital Cond.** 1:1	7.8	8.0	0.027	30
4. Wick control cooker	Methanol:100-octane = 1:1	9.0	8.0	0.03	20
5. Modified flow control cooker	Methanol	11.5	8.0	0.15	50
6. Modified flow control cooker	Kerosene	12.2	7.0	.018	-
7. Modified flow control cooker	Methanol:BK. Cond. 1:1	13.1	6.5	0.023	25
8. Modified flow control cooker	Methanol:Titas Cond. 1:1	13.8	6.0	0.025	23

* BK Cond. is Gas condensate from Bakhrabad Gas Field.

**Titas Cond. is Gas condensate from Titas Gas Field.

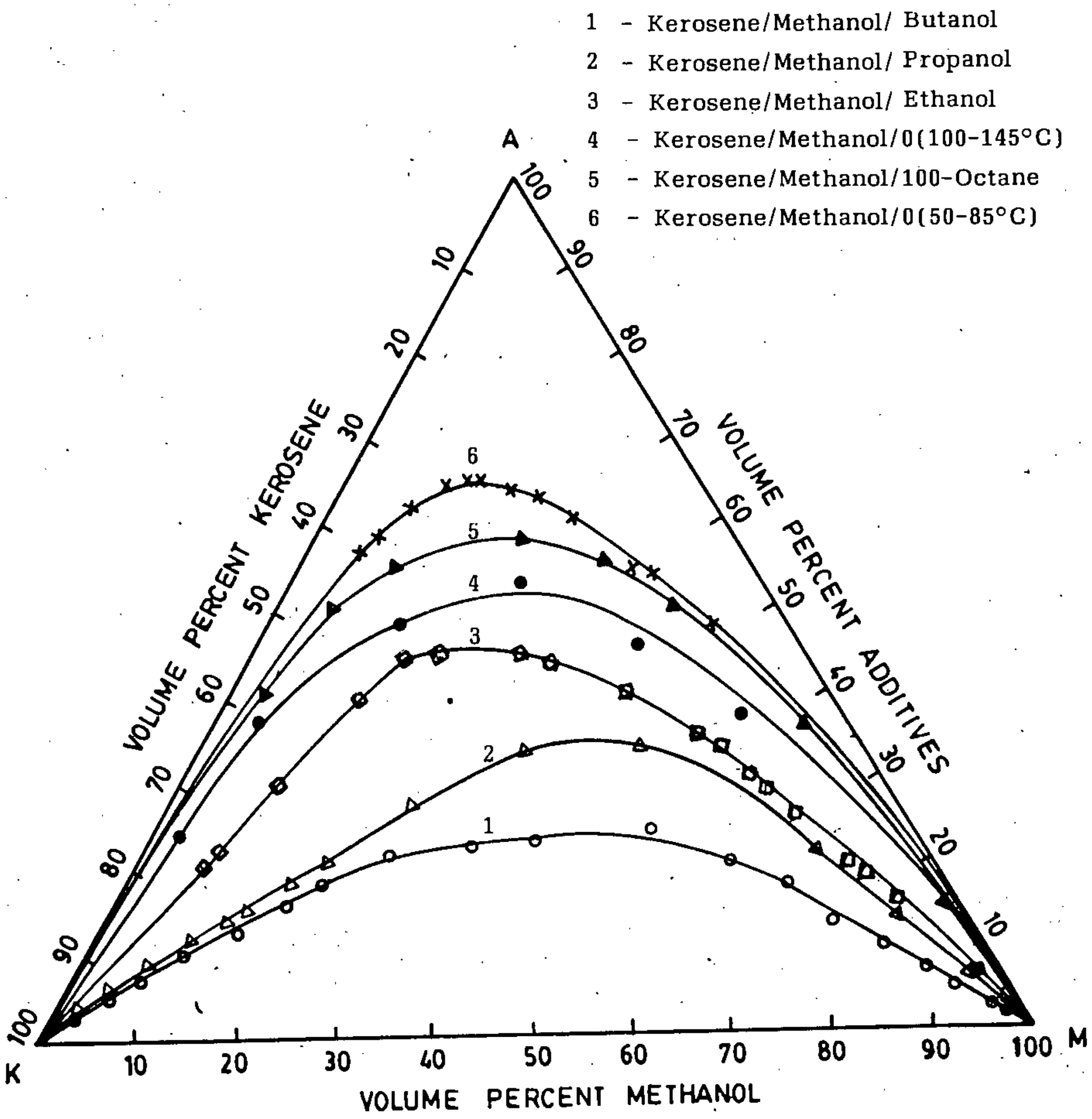


Fig. 4.1: Mutual solubility of kerosene Methanol-Additives system.

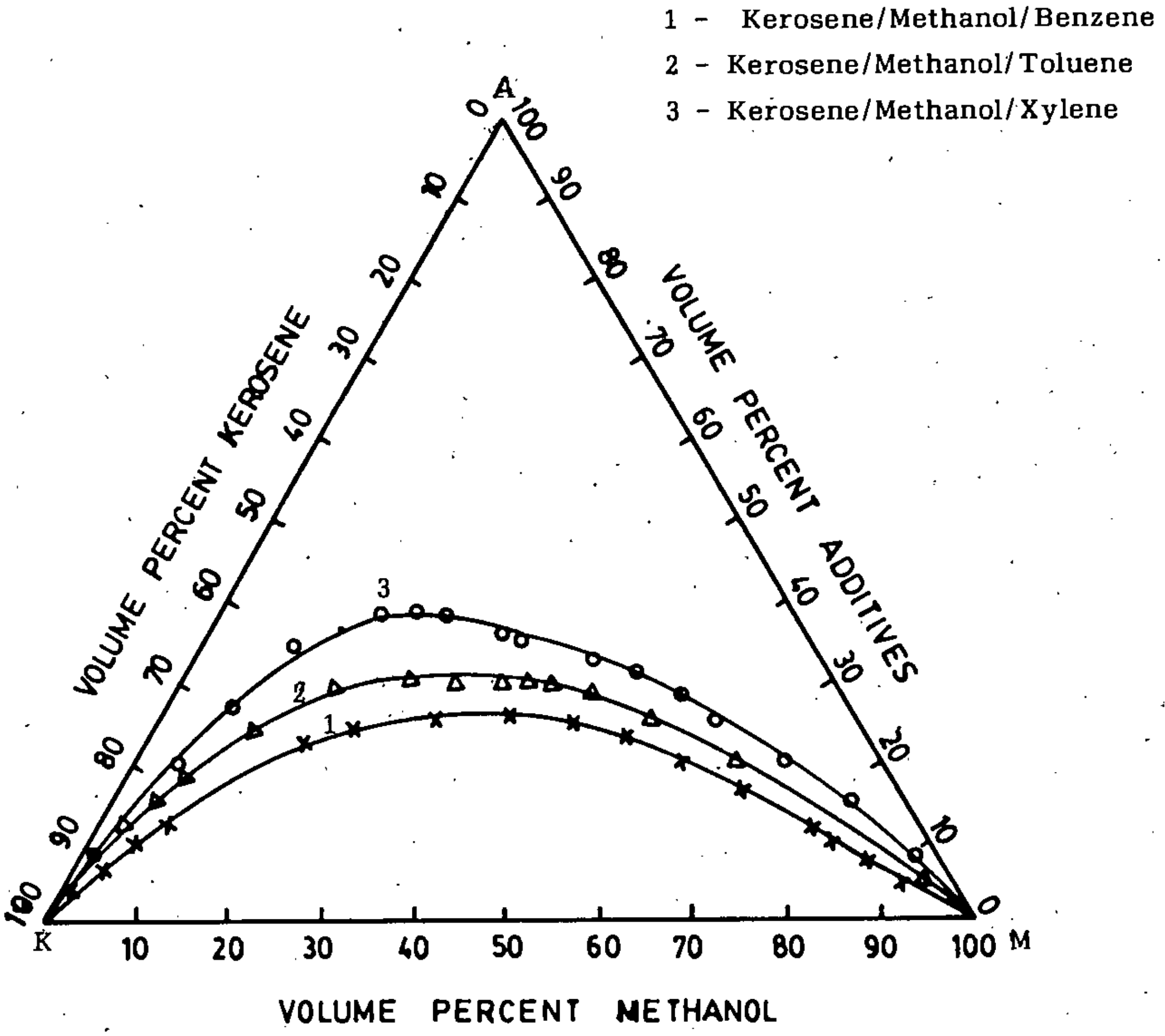


Fig. 4.2: Mutual solubility of kerosene Methanol-Aromatics.

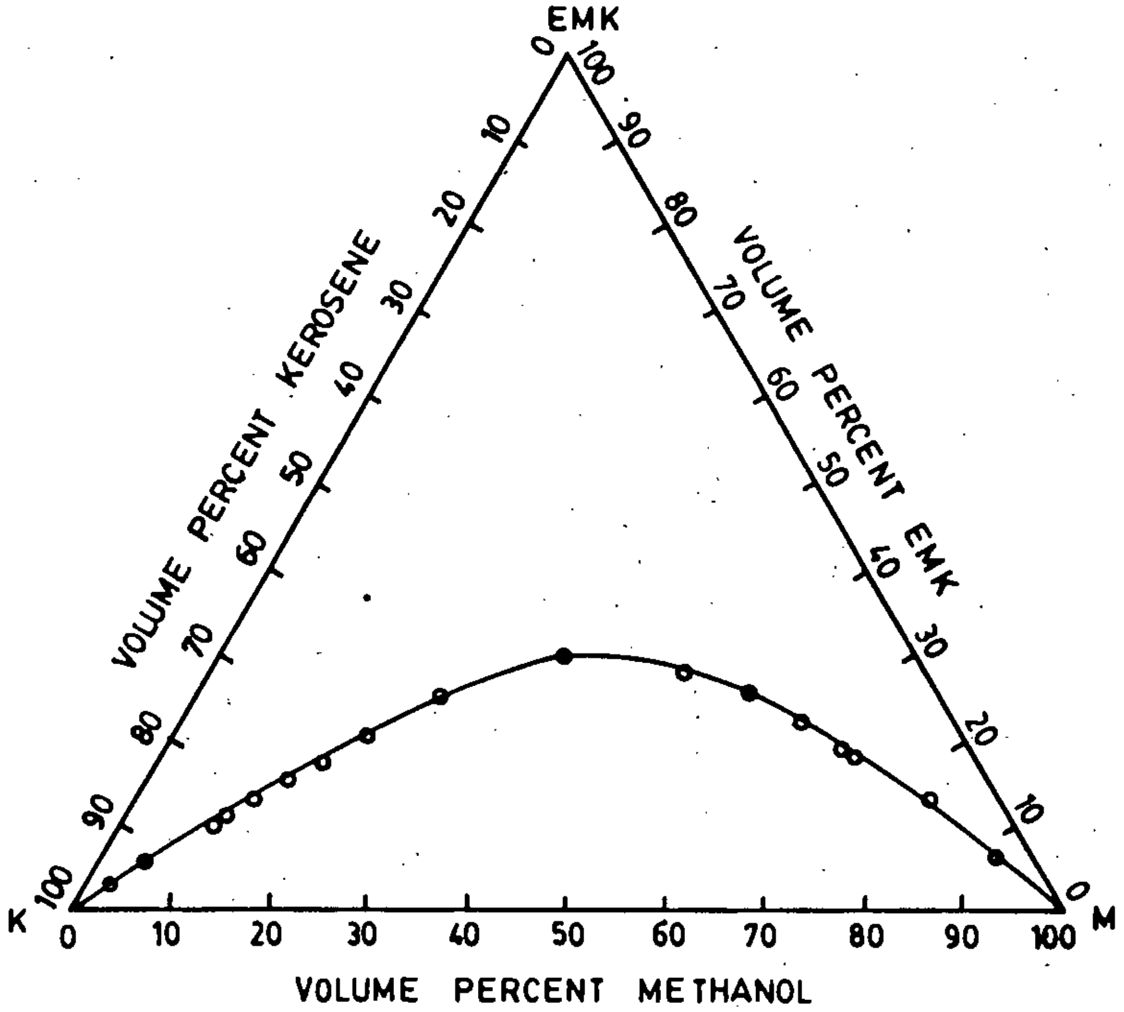


Fig. 4.3: Mutual solubility of kerosene/Methanol/EMK system.

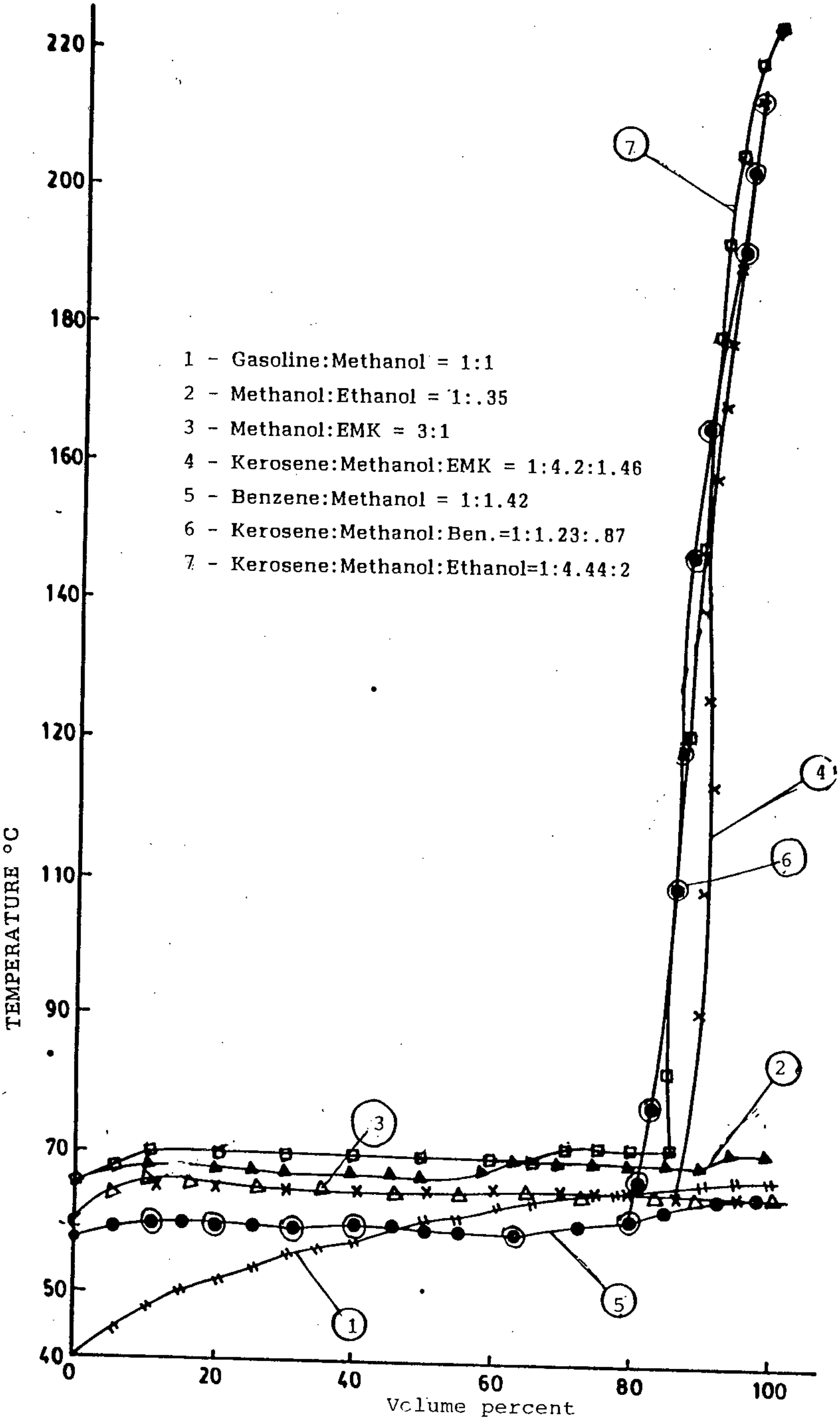


Fig. 4.4: ASTM Distillation curves of different blends.

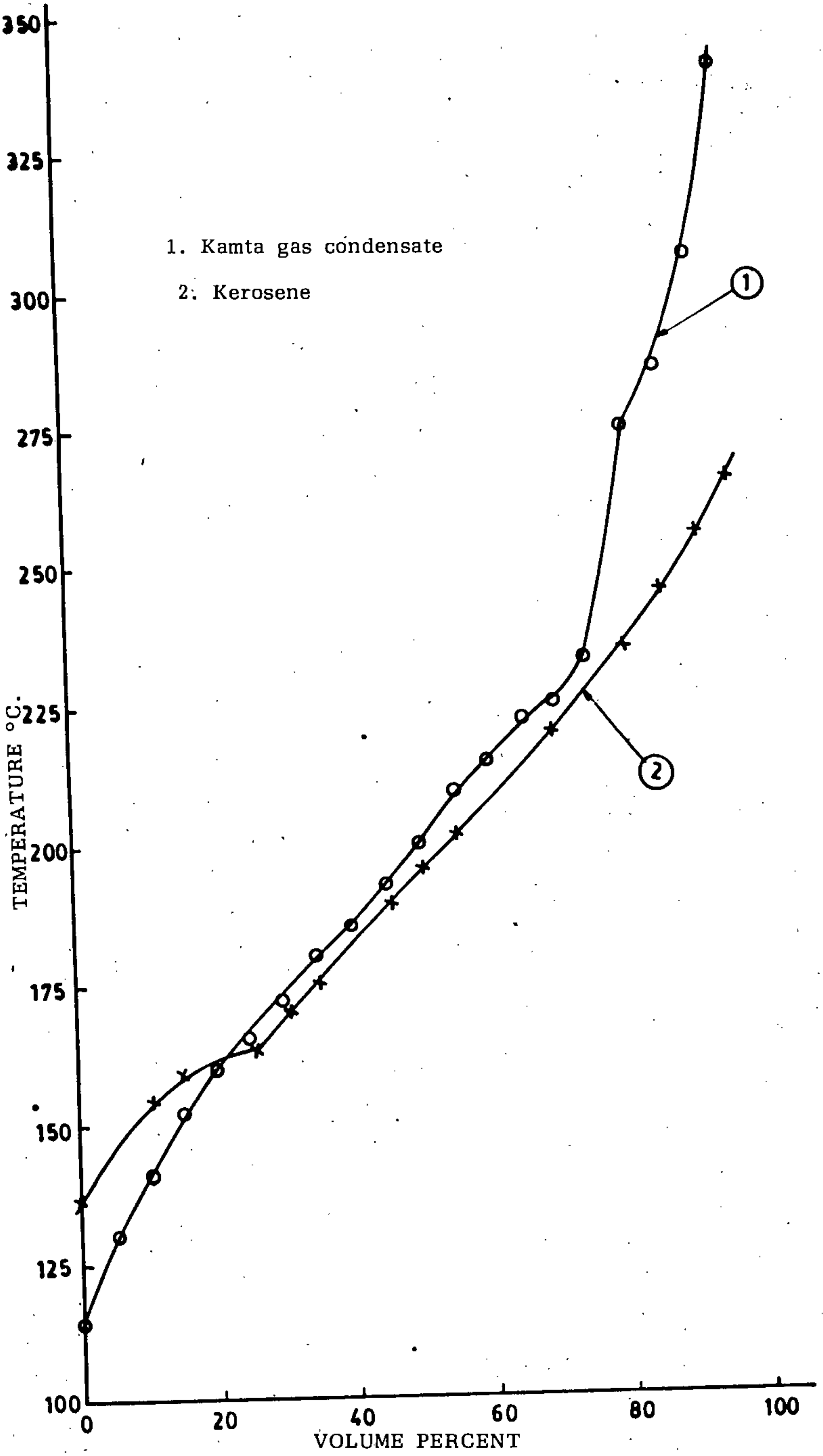


Fig. 4.5: ASTM Distillation curves of Kamta gas condensate and Kerosene.

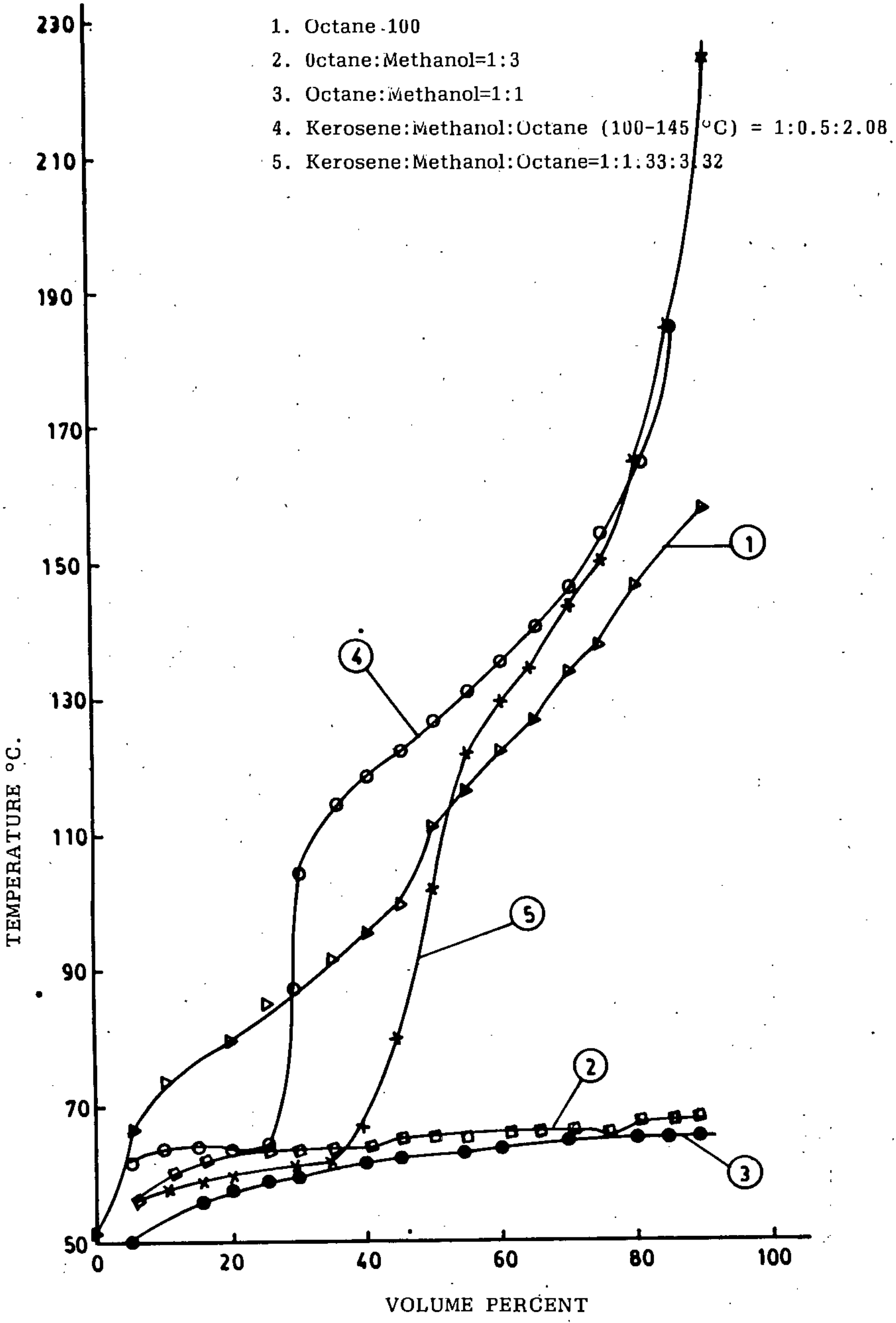


Fig. 4.6: ASTM Distillation curves of 100-Octane and its blends.

CHAPTER - 5 DESIGN AND DEVELOPMENT OF A VAPORIZING TYPE COOKER

5. DESIGN AND DEVELOPMENT OF A VAPORIZING TYPE COOKER

5.1 Introduction

In Bangladesh two kinds of kerosene burning cookers namely wick control cooker and flow control cooker are generally used for cooking purposes. Besides these there is another kind of pressurized kerosene stove which is also used in limited numbers for domestic cooking. Initial investigations on these cookers and available information from the literature brought forward the following points:

i) Methanol cannot be used in the existing wick control and flow control domestic cookers because the evaporation rate of Methanol from these cookers is high (6 times of kerosene in the case of wick control cooker as shown in Section 3.3.1).

ii) Also, for the wick control domestic cooker the temperature of the top surface of the fuel container rises to 70°C within 30 minutes of operation. This is dangerous because the Methanol vapour which accumulate above the liquid surface in the tank can cause explosions.

iii) In the case of flow control domestic cooker, methanol vaporizes in the fuel supply line and retard the flow of liquid Methanol (vapour lock) from the container to the wick. Due to the above disadvantages the existing wick control and flow control cookers are not considered appropriate for Methanol.

iv) Pressurised type cooker is not suitable for Methanol due to safety consideration.

However, it is possible to envisage a self evaporating type cooker where a fraction of heat of combustion is returned to the liquid to sustain the evaporation. Further work was thus directed to the development of a self vaporizing type cooker based on neat Methanol.

5.2 PRELIMINARY INVESTIGATIONS

Work was undertaken on the development of a vaporizing type cooker based on the idea that the liquid Methanol is vaporized while passing through a closed heating zone and then burned as a gaseous fuel. The heat required to vaporized this liquid Methanol is approximately 6 percent of it heat of combustion (as shown in Section 2.4.1). This idea was tested initially by trying to burn methanol in a bunsen burner as a gaseous fuel as shown in Fig. 5.1.

Methanol flows to the burner from the container through a 0.635 cm diameter copper tube. The middle portion of the copper tube is ring shaped and placed surrounding the top of the bunsen burner. Liquid methanol vaporizes while passing through the ring shaped copper tube. But the methanol vapour condenses inside the bunsen burner. To avoid the condensation it was necessary to heat the bunsen burner diffuser tube by an external heat source and to maintain its temperature above the boiling point of methanol (64°C). It was observed that although methanol vapour burned well initially in the bunsen burner there was a problem of back pressure and vapour lock after some time. Which prevented uniform flow of liquid methanol from the container to the burner.

A second attempt was made with two copper rings placed one upon the other as shown in Fig. (5.2). The upper ring was made of copper tube of 0.952 cm in diameter and acted as the vaporizer and the lower ring tube was 0.635 cm in diameter with drilled holes which served as flame ports. The two rings were connected after a 'U' bend which prevented the flow of liquid methanol to the burner ports. In this modification the problem of external heat supply was solved but the problem of back pressure remained.

Further experiments were carried out based on the idea of the diffusion of Methanol through cotton wicks. In this design the problem of back pressure and the evaporation loss from the top hole of the fuel container was avoided. This design is shown in Fig. 5.3 and 5.4. A copper pipe section was welded on top of a mild steel pipe which served as the container. A number of cotton wicks (eight) were suspended from the copper pipe section into the liquid container. liquid methanol diffuse through the cotton wicks and pass to the upper portion of the copper tube where it is vaporized. Methanol vapour flow through the valve to the burner ring where it is ignited.

A series of experiments were carried out with this cooker using methanol to determine the burning rate of methanol. It was observed that the burning rate of methanol in this cooker was about 1 gm. per minute. The rate of heat produced in this cooker is half of that produced in the existing wick control domestic cooker using kerosene. This would cause difficulty in cooking. Attention was thus given to increase the burning rate. Burning rate can be increased by increasing the number of wicks. A series of experiments were carried out with different number of wicks. The amount of methanol burned in the experiments were found out by measurements before and after each test. Data obtain in this experiments are shown in Table 5.1

In this type of cooker liquid methanol is carried upwards by the wick and vaporises in the top (hot) part and collects in the vapour chamber. From the data it was observed that increasing the number of wicks increases the rate of diffusion of liquid-Methanol and greater amounts of methanol is vapourized and burned.

The amount of liquid methanol in the tank also influences the diffusion rate. More diffusion and vaporization was observed when the liquid Methanol level is higher.

During tests carried out, it was observed that flame height decreases with time. Flame height varied from 7.62 cm to 2.54 cm.

The main disadvantage of this design, was that the wicks burn off after a few operations. The idea of using wicks for vaporizing methanol was thus abandoned.

5.3 VAPORIZATION OF METHANOL FROM HEATED COPPER SURFACES

The next phase of the work on cooker development was devoted to the evaporation of methanol from hot surfaces. This idea resulted from the original theory of utilizing a part of the combustion heat for vaporization of the liquid methanol. After a few preliminary tests a design was made of a cooker where vaporization took place from heated copper surfaces immersed in methanol and this design is shown in Fig. 5.5

and 5.6). The bottom parts of two concentric copper pipe sections were put inside a mild steel pipe (serving as the fuel container) and these pipe sections were heated at the upper part when methanol vapour burned in a ring burner. The heat is conducted downwards and methanol in the annular area, between the copper pipe evaporates and collects in the vapour space at the top of the vaporizer assembly. The vaporization rate was determined by measuring the weight before and after the experiments.

A series of experiments were carried out with different liquid levels of Methanol in the container. It may seen from Table (5.2) that the vaporization rate decreases with decrease of liquid level of Methanol. This is evident due to the fact that the immersion level of the heated copper surface is decreased with the dicrease of liquid level.

In the above design the vaporization rate of Methanol was found to be quite low.

To increase the vaporization rate, three copper tubes of 1.27 cm in diameter were put inside the inner copper pipe section shown in Fig. 5.7 and 5.8. The upper portion of these three copper tubes were extended to the heating zone above the burning ports. To minimise the heat transfer from the outer surface of the outer copper pipe section, a brass pipe section was added as shown in the figure. As a result heat transfer rate to the Methanol in the annular spaces and inside the tubes increased.

A series of experiments were carried out to determine the vaporization rate of Methanol in this design. It may seen from the Table 5.3 8 to 9 gm Methanol vaporized and burned per minute which was a big improvement over the previous design. Further work was concentrated in this design.

5.4 DESIGN, FABRICATION AND STUDY OF A VAPORIZING TYPE COOKER

After priliminary investigations and study of vaporization of methanol from hot surfaces it was decided to make a vaporizing type of Methanol cooker where vaporization would take place from conductive surfaces immersed in the liquid Methanol. In the final design the cooker has the following parts:

a) Liquid container
b) Vaporizer
c) Burner ring and air mixing tube
d) Diffusers

Figs. 5.9 show the diagram of the vaporizer type cooker with further details in Figs. 5.10 - 5.17 .The cooker was fabricated out of copper and mild steel material. The liquid Methanol container (a) was made of mild steel. A thick mild steel circular plate (b) was welded at the bottom of cooker which act as the base of the cooker. The container was wrapped with asbestos wool and then covered with a tin sheet to avoid heat loss from the outer surface of the container. On the top of the liquid container there is a shallow trough (c) where ethanol or kerosene is burned to preheat the cooker and initiate the vaporization. The liquid container also has an opening for filling and this is fitted with a threaded cap. (d). The vaporizer assembly (Fig. 5.11) was made out of two concentric copper pipe section of 4.2 cm and 4 cm in diameters respectively (e,f). Three other small diameter (1.27 cm) copper tubes (g) were put inside the inner copper pipe section. The upper portion of these copper tubes were extended to the heating zone above the burner ports. This extended portions collect convective and radiactive heat from the flames. The outer copper pipe section (e) also collects convective and radiactive heat from the flame and carries the heat downwards. The other copper pipe section (f) which is joined to the outer one at the top also helps to increase the surface area of heat transfer. A large part of the heat is carried downwards into the fuel tank by the three small copper tubes (g) (heat conduction tubes). To minimize the heat transfer from the outer surface of the vaporizer system a concentric brass tube (h) was added to the system immersed in the tank. Holes 1.58 mm. diameter) were drilled in the vaporizer tubes to maintain a stable pressure in the system. The methanol vapour collecting in the vapour space of the vaporizer system flows to the burner ring (i) via a needle valve (j) The vapour flows out in a jet through a small hole (k) into the air mixing tube (l) just before the burner ring (i). The burner ring (i) was made with copper tube of 9.5 mm diameter. Burner ports were drilled on this ring. The bruner ring was continuous with a air mixing tube (l) with four radial holes (Fig. 5.13). The discharge of Methanol vapour through a tiny orifice at the end of the nozzle tuble causes a suction of primary air through the radial holes of the air mixing tube. The air and Methanol vapour mixed in this tube and passes to the burner ports where it is ignited. The burner ring rests on a support (m) (Fig. 5.14).

Three concentric secondary air diffusers (n,o,p) were added to the burner part of the cooker (Fig. 5.16-5.17). These diffusers were made out of thin mild steel sheets and were similar to the diffusers used in locally available kerosene cookers. The optimisation of the air diffusers is given in section 5.4.3.

A few experiments were carried out to find out if other alcohol fuels (ethanol) and methanol fuel blends can be burned in the developed cooker. This is discussed in the next chapter (Section 6.4).

5.4.1 Operation of the Cooker

The container was filled with liquid methanol by siphoning the fuel into the fuel tank. Then the filling cap was closed tightly and the diffusers placed in the proper positions. To initiate vaporization, 20 ml ethanol or 10 ml kerosene is burned on the shallow trough. During the burning of the 20 or 10 ml fuel the vapour valve was opened; vapour followed to the burner ports through the valve and was ignited at the burner ports. Once vaporization started it was sustained from the heat of the flame. The burning rate is controlled by the vapour valve. To stop the operation it is necessary to just close this valve. It was observed that combustion is quite intense with short flames. The number of ports on the burner ring (Fig. 5.13) and the distance between the ports were optimised by carrying out a series of burning test on flame stability. It was found that 34 ports of 1.58 mm diameter in a burner ring of diameter 9.5 cm was optimum to burn methanol vapour in this cooker without lift off or flash back.

5.4.2 Pressure Measurement

Pressure exerted by the Methanol vapour inside the vaporizer system was determined by a manometer. One end of the manometer was open to the atmosphere and the other end was connected with the copper vaporizer through a 6.35 mm diameter copper tube. Mercury was used as the manometer fluid to determine the pressure.

It may be seen from the Fig. 5.18 that the pressure increases during the initial period and then it attains a steady level depending on the amount of Methanol in the container and then finally starts falling off and ultimately drops down and the cooker is no longer operable. It is interesting to note that with increasing amount of Methanol in the cooker, the period of steady state pressure decreases. The falling off period of pressure starts early when the liquid level in the container is high.

5.4.3 Optimization of the Number of Diffusers

The performance of the cooker depend on the heat utilization efficiency and combustion performance. Incomplete combustion not only decrease the heat utilization efficiency but also lead to environmental pollution as Methanol vapour is very toxic. Optimum amount of primary and secondary air supply is essential for complete combustion. Primary air is supplied through the radial holes of the mixing tube placed near the vapour injector. The flow of the secondary air is controlled by the three diffusers set in concentric position around the ring burner.

A series of experiments were carried out using different number of diffusers to examine the combustion performance of the cooker. Flue gas analyses were carried out for this purpose. The equipments used to analyse the flue gases included the Orsat and Fyrite analysers and on-line gas analysers. A few samples were also collected for chromatographic analyses. It may seen from the Table 5.4 that the percentage of carbon dioxide (CO_2) increase, oxygen (O_2) and carbon monoxide (CO) decrease with increase of the number of diffusers. Based on the above experiments three concentric diffusers were considered appropriate for this cooker. The outer most diffuser has eight air holes of 1.3 diameter at the bottom around the periphery. This diffuser also prevents heating up of the flow control valve. The inner and the middle diffusers have smaller radial holes of 1.5 mm in diameter around the periphery for better diffusion of air for combustion. As already mentioned, locally available domestic cookers also have three diffusers.

5.4.4 Flue Gas Temperature Measurement

Flue gas temperatures of a vaporizer type Methanol cooker were determined by a Chromel Alumel Thermocouple and a Temperature indicator of Model No. 660 (Measuring range - 245°C to 1999°C). The results were compared with the flue gas temperatures of wick-control domestic cooker (kerosene) and Natural gas cooker. The results were shown in the Fig. (5.19).

It may seen from the Fig. 5.19 that the flue gas temperature increases from a low value to a maximum at a particular height from the burner ring and then continuously decrease as the distance from the ring increases. For the vaporizing type Methanol cooker the maximum flue gas temperature 955°C has been observed at a height of 5.5 cm from the burner ring. A temperature of 920°C for Natural gas cooker at a height of 5 cm from the burner ring and a temperature of 895°C (at a height of 10 cm from the wicks) was observed.

It may be mentioned that heat utilization efficiencies were measured setting the pan at different distances from the burner ring to find the optimum height for cooking pots. The results were shown in Fig. 5.20. Maximum heat utilization efficiency was observed at a distance 5 cm from the burner ring which is nearly the same height as the height of maximum temperature. So, for this cooker optimum height for the cooking pot is 5 cm from the burner ring.

TABLE 5.1: BURNING RATE OF METHANOL WITH WICKS

Length of wick (cm)	No. of wicks	Diameter of each wick (cm)	Amount of Methanol taken in the cooker (gm)	Amount of Methanol burned (gm)	Time required for burning (mins)	Burning rate of Methanol (gm/min)
17.78	10	0.254	200	50	40	1.25
17.78	10	0.254	200	55	44.7	1.23
17.78	8	0.254	200	60	54.5	1.10
17.78	8	0.254	200	45	38.5	1.17
17.78	10	0.254	300	48	34.3	1.40
17.78	10	0.254	300	47	31.3	1.50

TABLE 5.2: BURNING RATE OF METHANOL WITHOUT HEAT CONDUCTING TUBES INSIDE VAPORIZER

Amount of Methanol taken in the cooker (gm)	Fuel in Tank	Amount of Methanol burned (gm)	Time required for burning (min)	Burning rate of Methanol gm/min.
110	50%	40.5	27	1.5
132	60%	43.6	28	1.56
154	70%	52.8	33	1.6
176	80%	57.7	35	1.65
220	100%	68.0	40	1.7

TABLE 5.3: BURNING RATE OF METHANOL WITH THREE HEAT CONDUCTING TUBES INSIDE VAPORIZER.

Amount of Methanol burned	Fuel in Tank	Time required for burning	Burning rate of Methanol
160	50%	18.6	8.57
192	60%	22.3	8.62
224	70%	25.89	8.65
256	80%	29.4	8.7
320	100%	35.5	9

TABLE 5.4: COMBUSTION DATA

Name of the Cooker	Fuel	Analyses of Flue Gas			
		CO_2 Vol %	O_2 Vol %	CO Vol %	CH_3OH p.p.m.
Vaporizer type cooker (without diffuser)	Methanol	11.0	6.5	.009	35
Vaporizer type cooker (with inner one diffuser)	Methanol	13.0	2.0	.007	30
Vaporizer type cooker (with inner two diffusers)	Methanol	13.5	1.0	.008	27
Vaporizer type cooker (with three diffusers)	Methanol	14.25	.50	.005	20
Vaporizer type cooker (without diffuser)	Ethanol	10	6.0	.012	
Vaporizer type cooker (with inner one diffuser)	Ethanol	12	5.0	.010	
Vaporizer type cooker (with inner two diffusers)	Ethanol	12.5	4.5	.009	
Vaporizer type cooker (with three diffusers)	Ethanol	12.5	4.0	.007	
Vaporizer type cooker (without diffuser)	Methanol:BK. Cond.* 1:1	7.8	9.5	.013	30
Vaporizer type cooker (diffuser inner one)	Methanol:BK. Cond. 1:1	9.5	8.5	.01	28
Vaporizer type cooker (Diffuser inner two)	Methanol:BK.Cond. 1:1	11	6.0	.009	26
Vaporizer type cooker (with three diffuser)	Methanol:BK.Cond. 1:1	12.5	3.0	.009	25

* BK Cond. is Gas condensate from Bakhrabad Gas field.

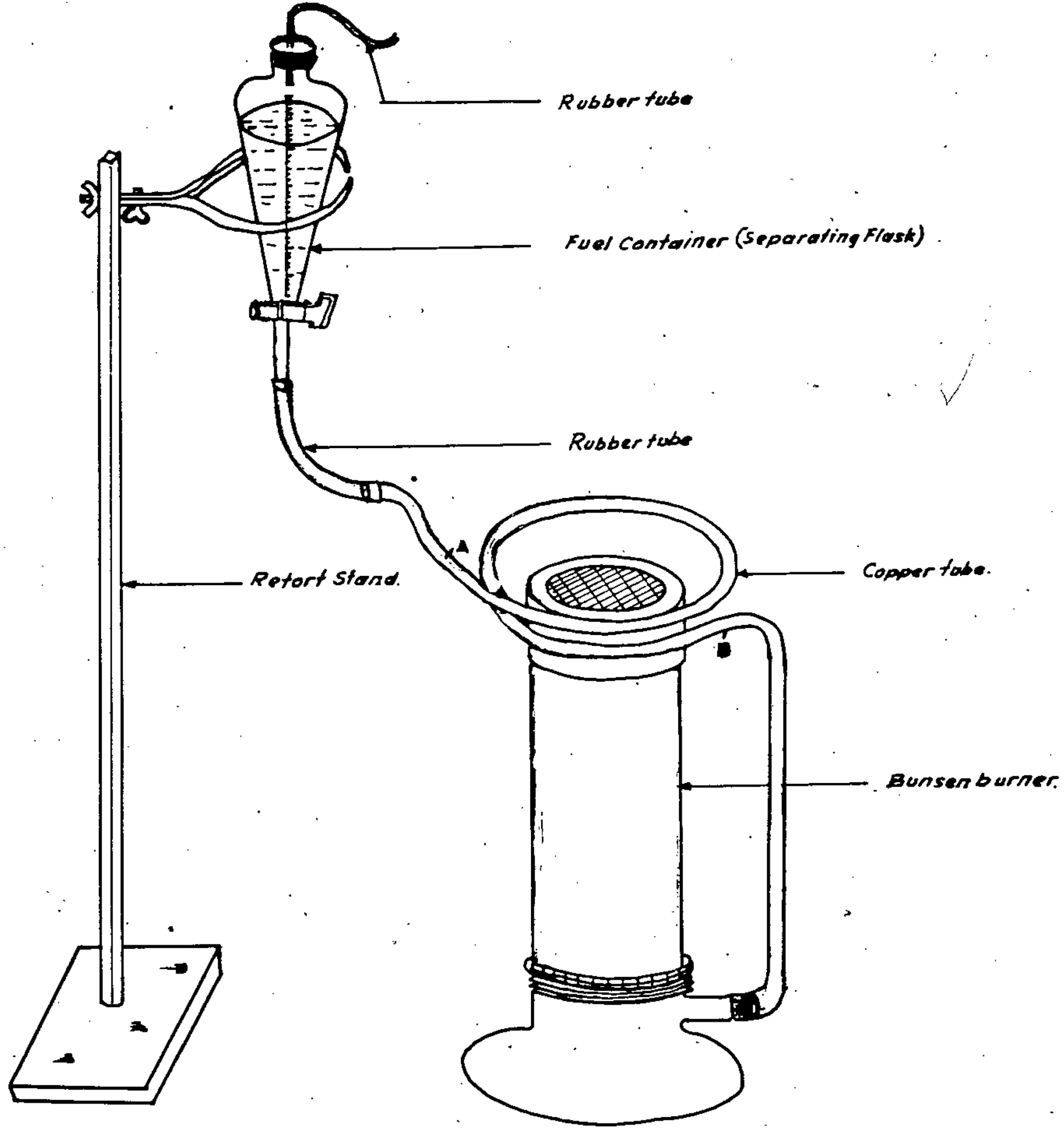


Fig. 5.1 Burning of Methanol Vapour in the Bunsen Burner.

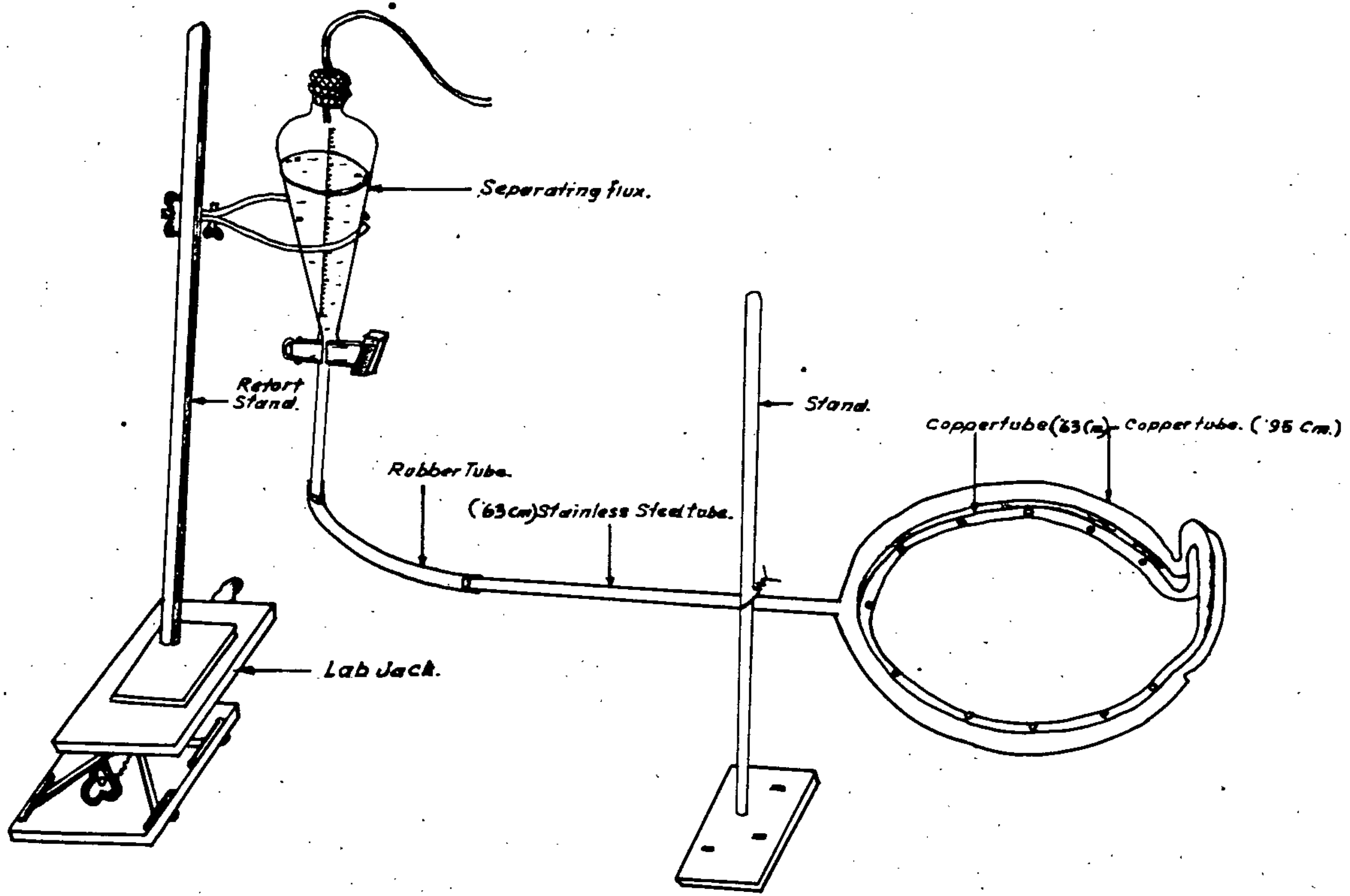


Fig. 5.2 Tubular Vaporizer Burner for Methanol .

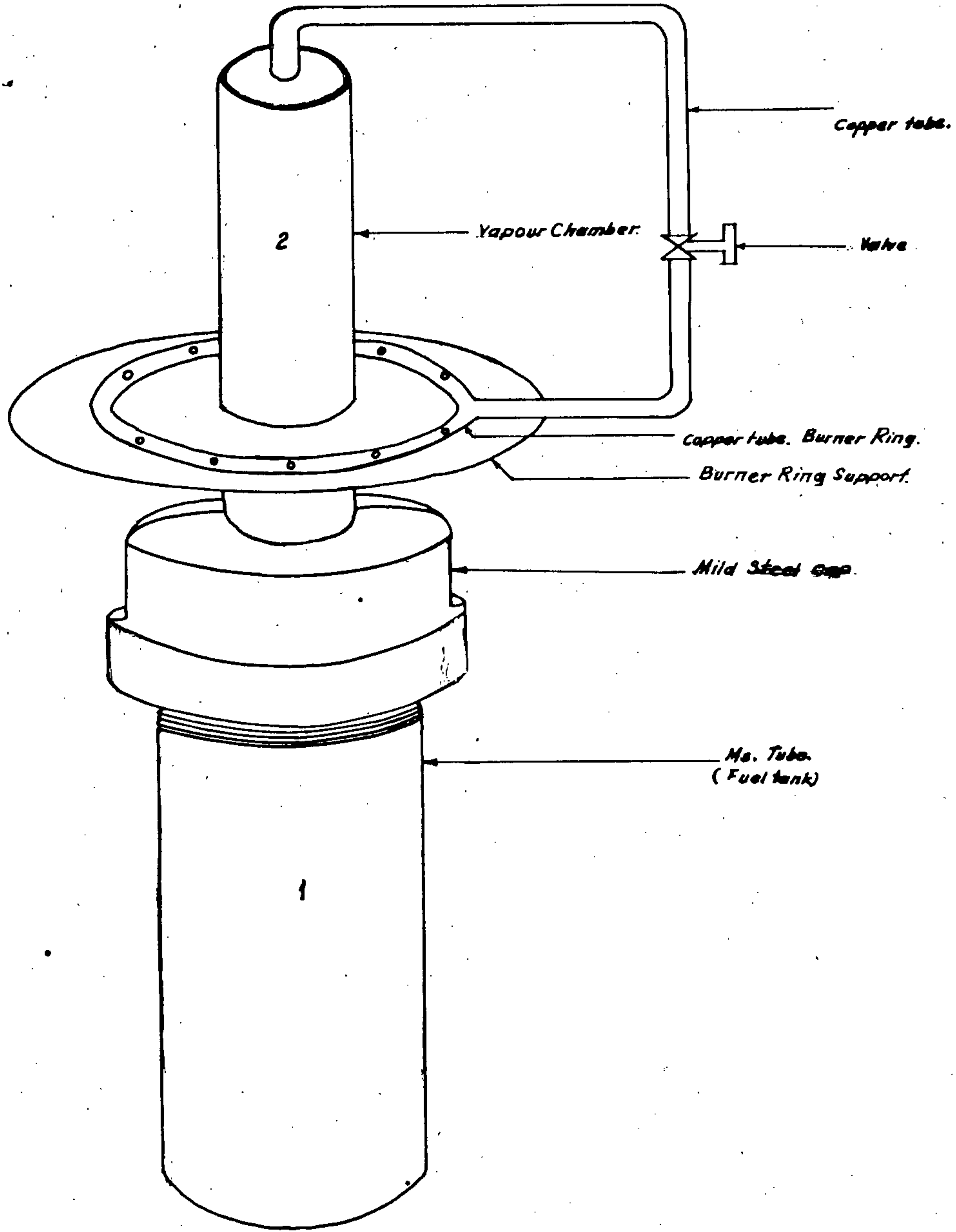


Fig. 5.3 Wick - Type Methanol Cooker .

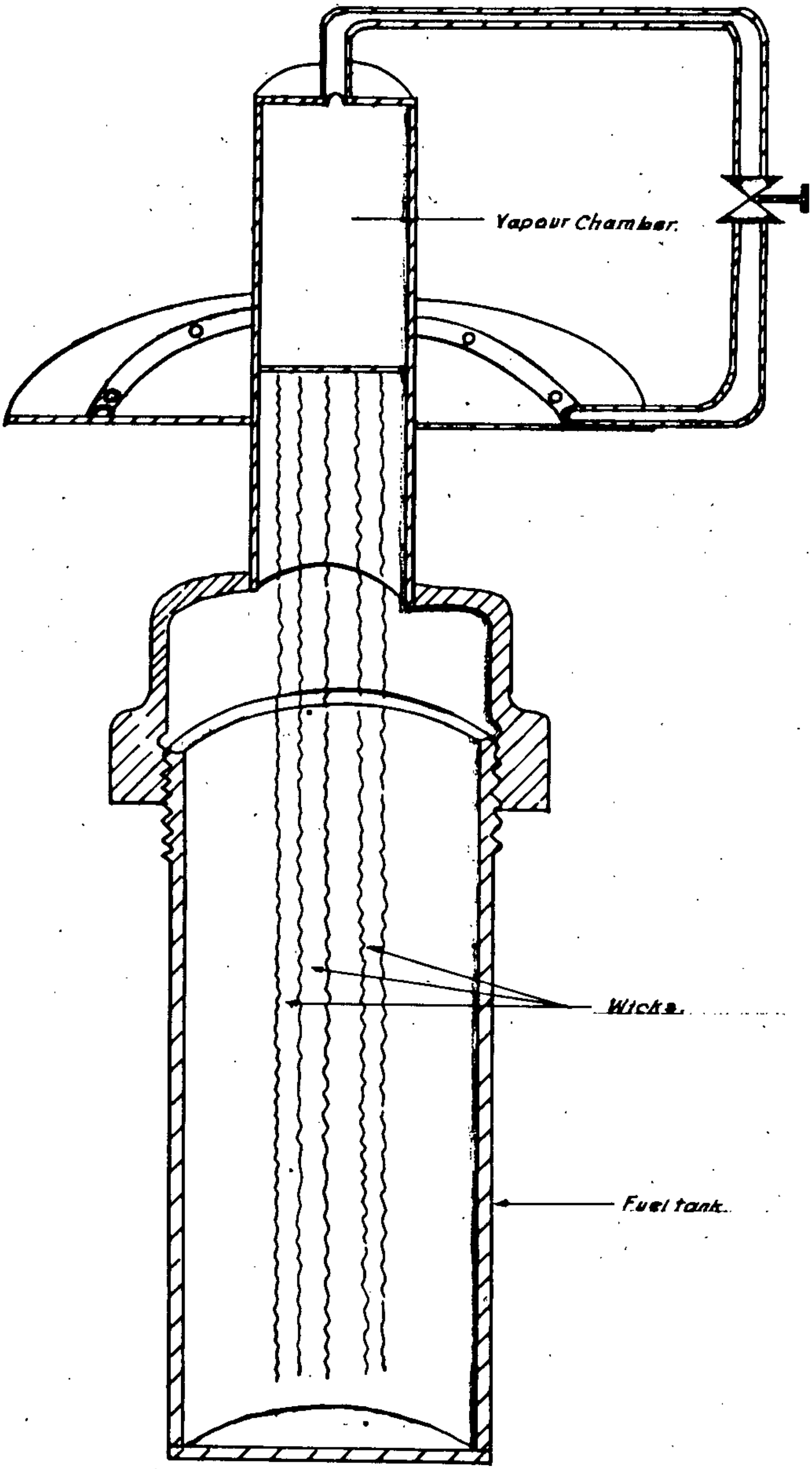


Fig. 5.4 Sectional View of Wick Type Methanol Cooker .

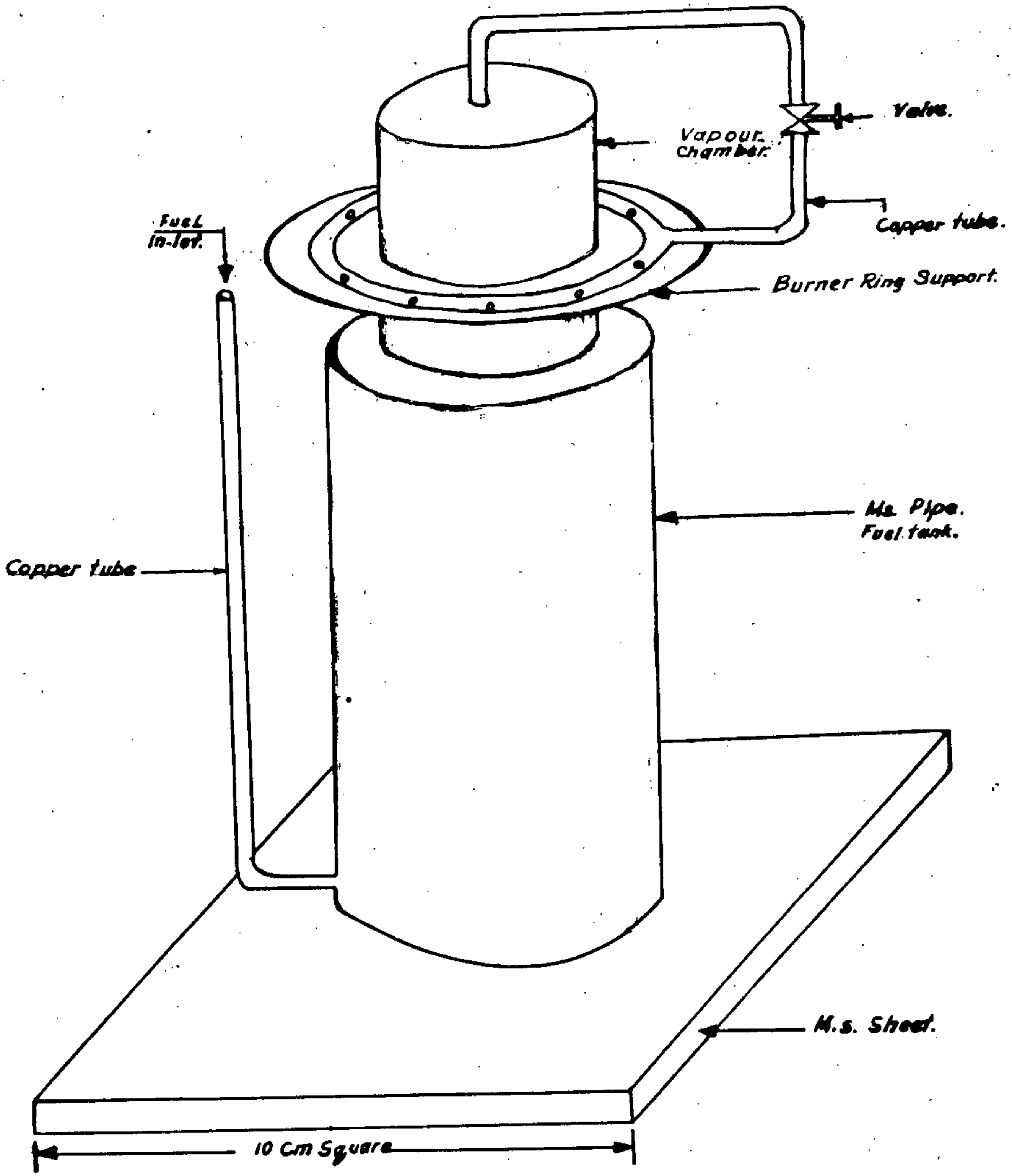


Fig. 5.5 Methanol Vaporization From Heated Copper Surfaces.

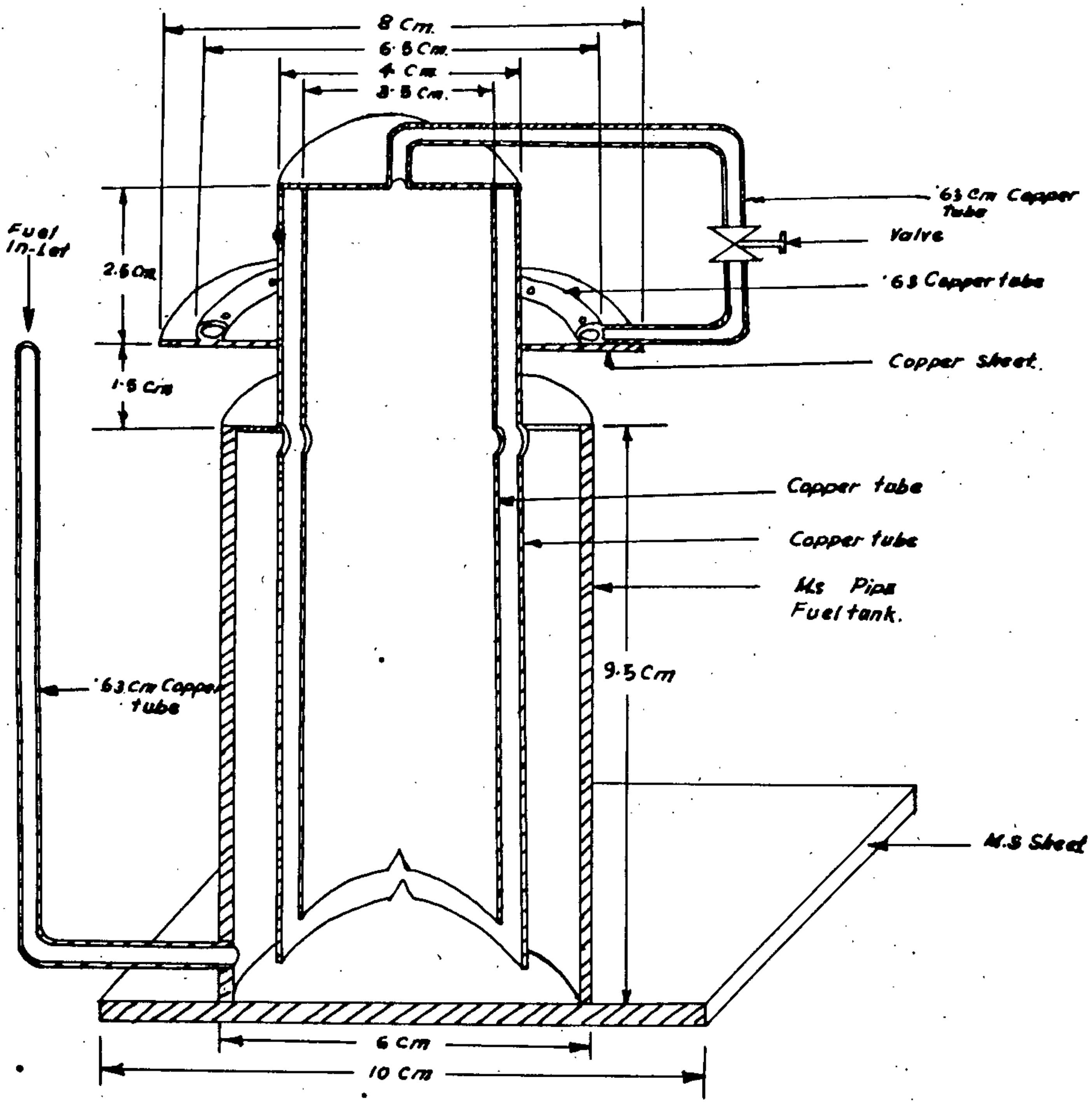


Fig. 5.6 Sectional View of Fig. 5.5

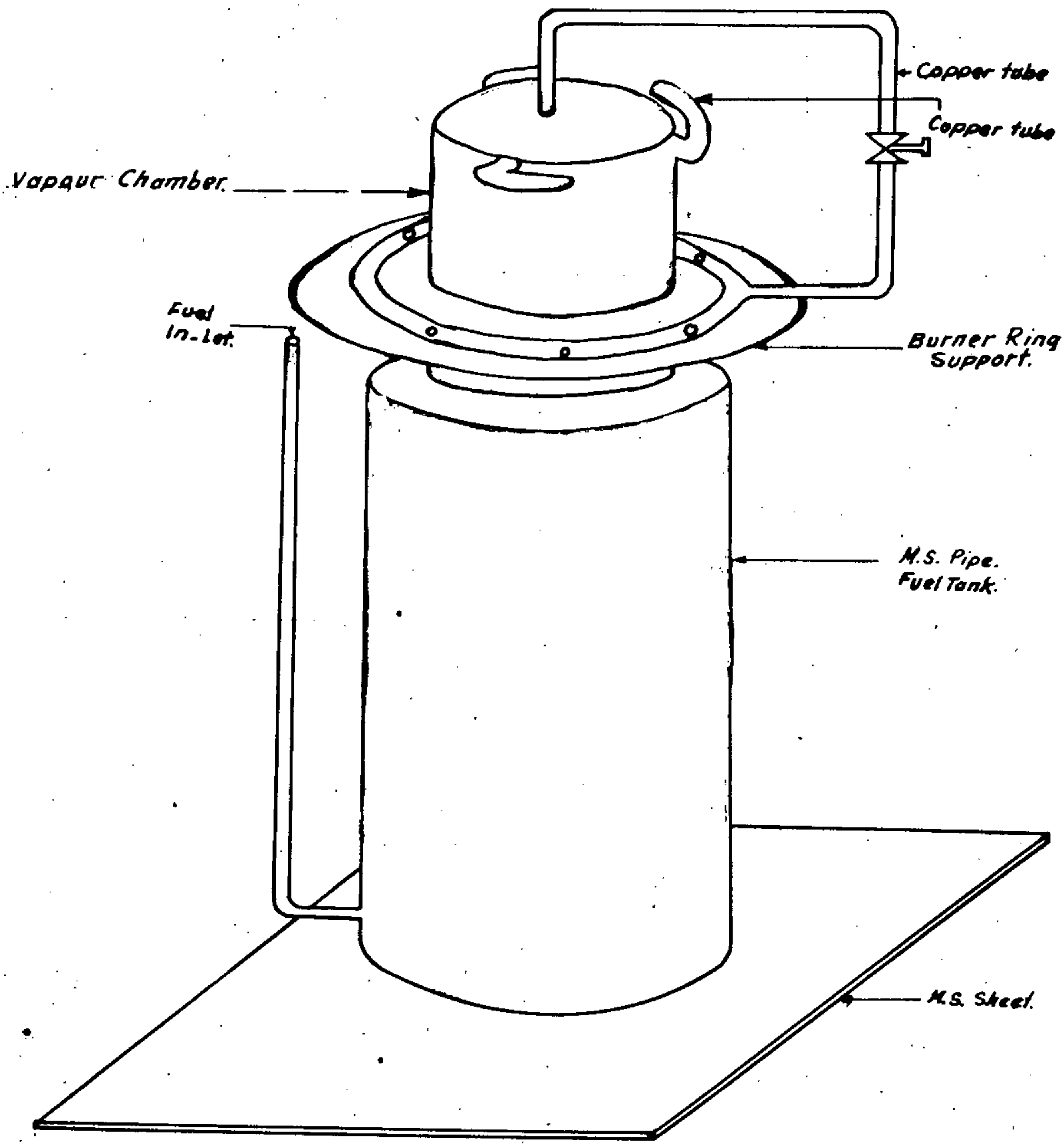


Fig. 5.7: Self Vaporizing Cooker with Heat Conducting Tubes .

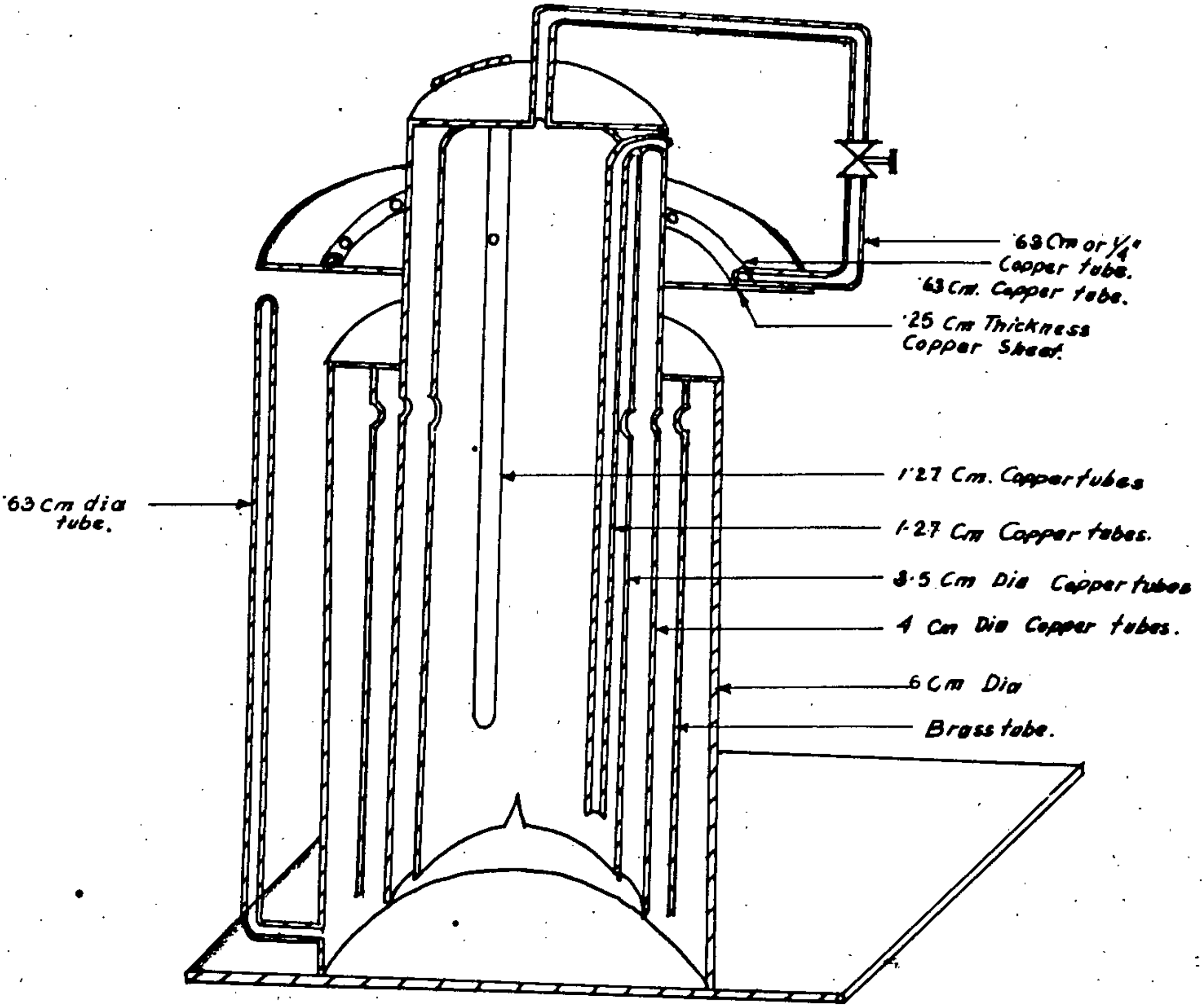


Fig. 5.8 Sectional View of Fig. 5.7

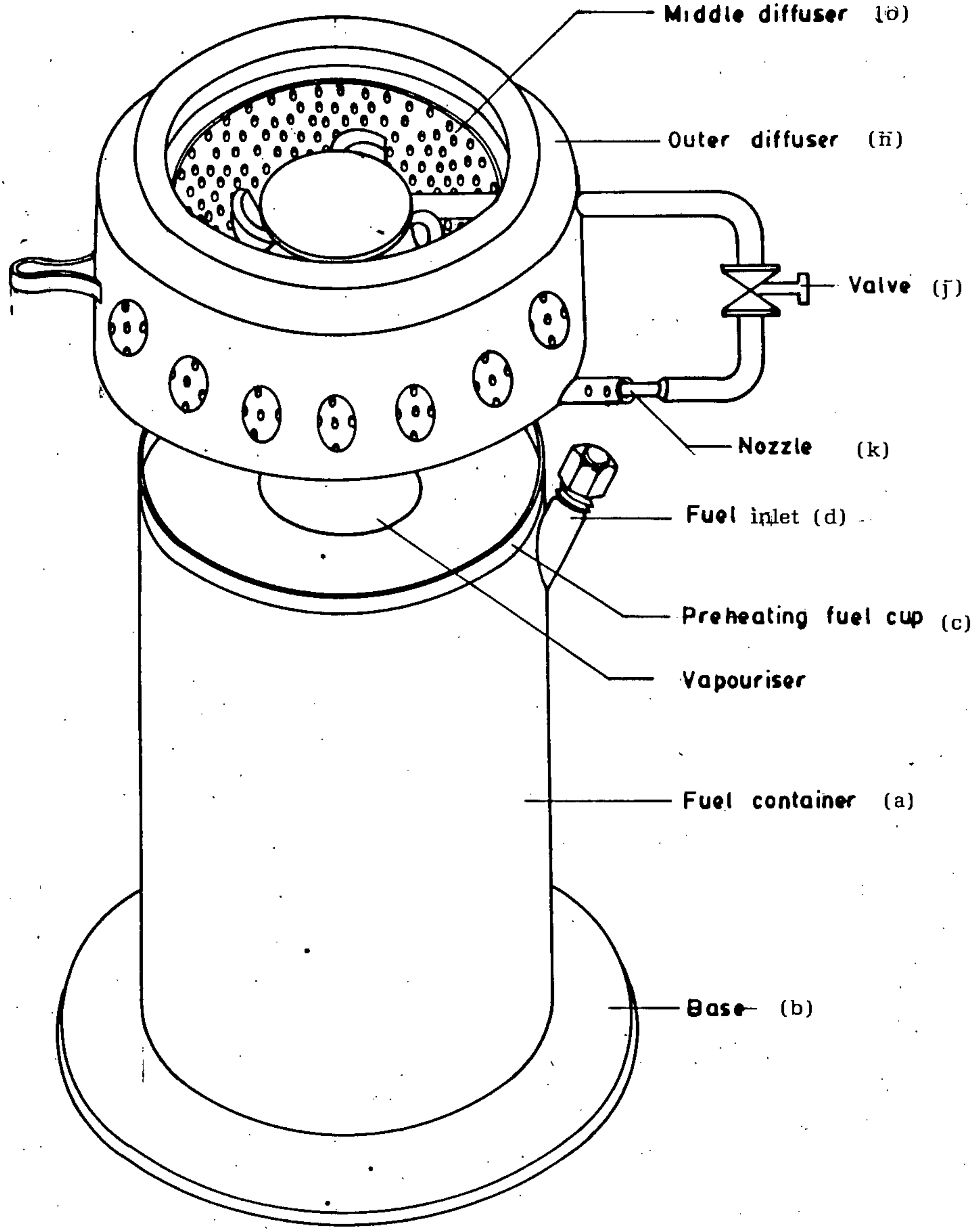


FIG. 5.9: ISOMETRIC VIEW OF A VAPOURISER TYPE COOKER

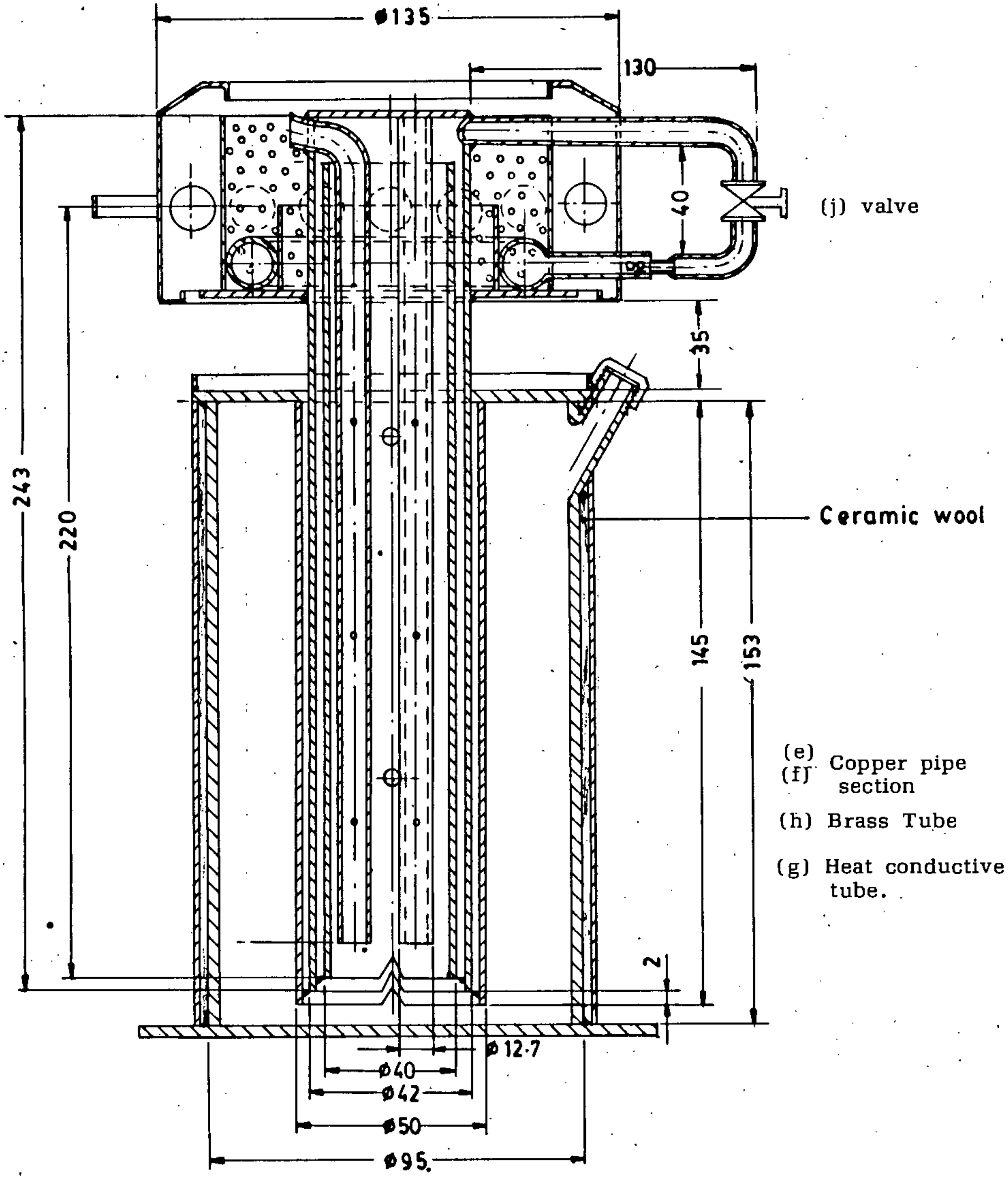


FIG. 5.10: FULL SECTION OF THE COOKER

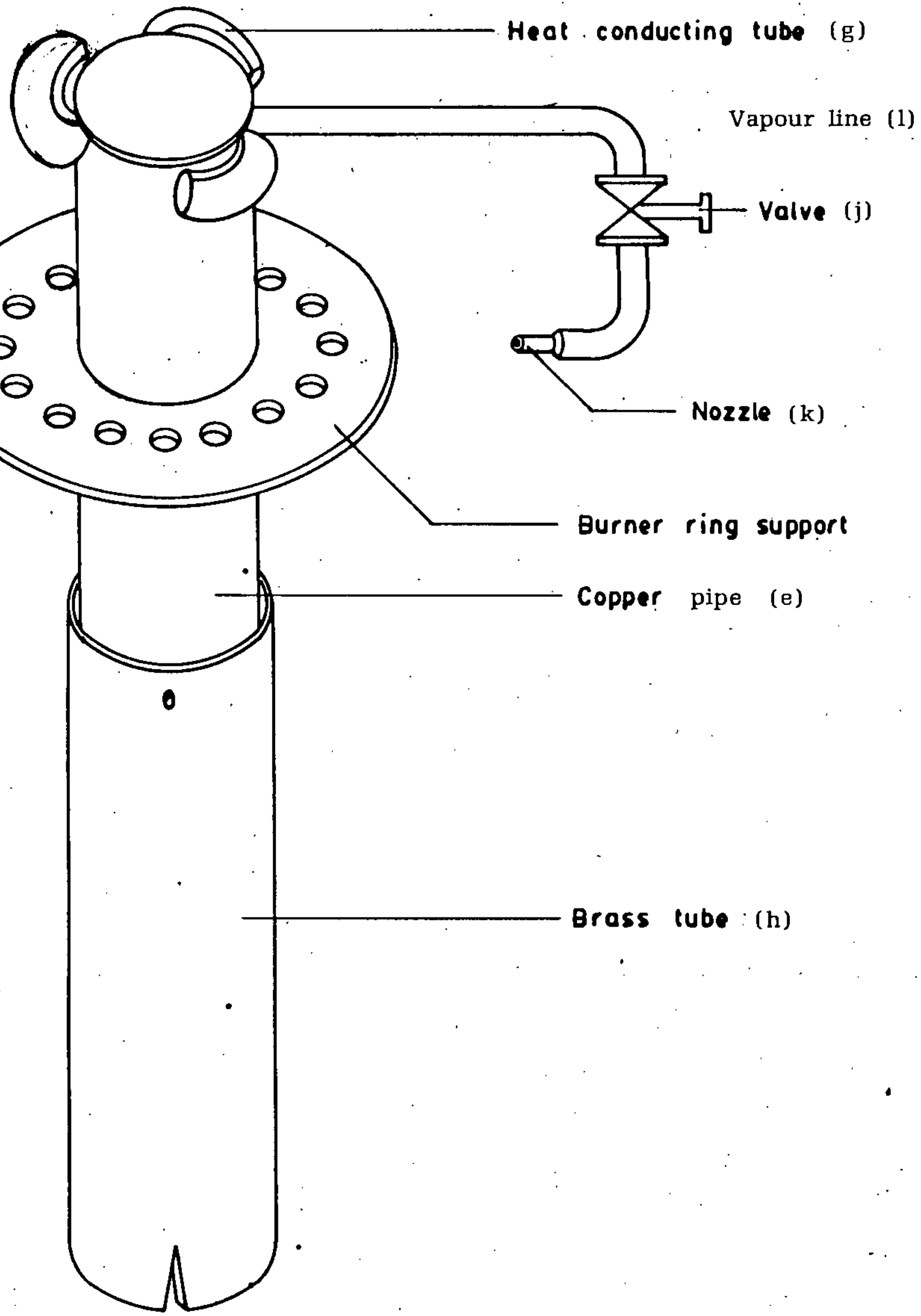


FIG 5.11: ISOMETRIC VIEW OF THE VAPORIZER ASSEMBLY

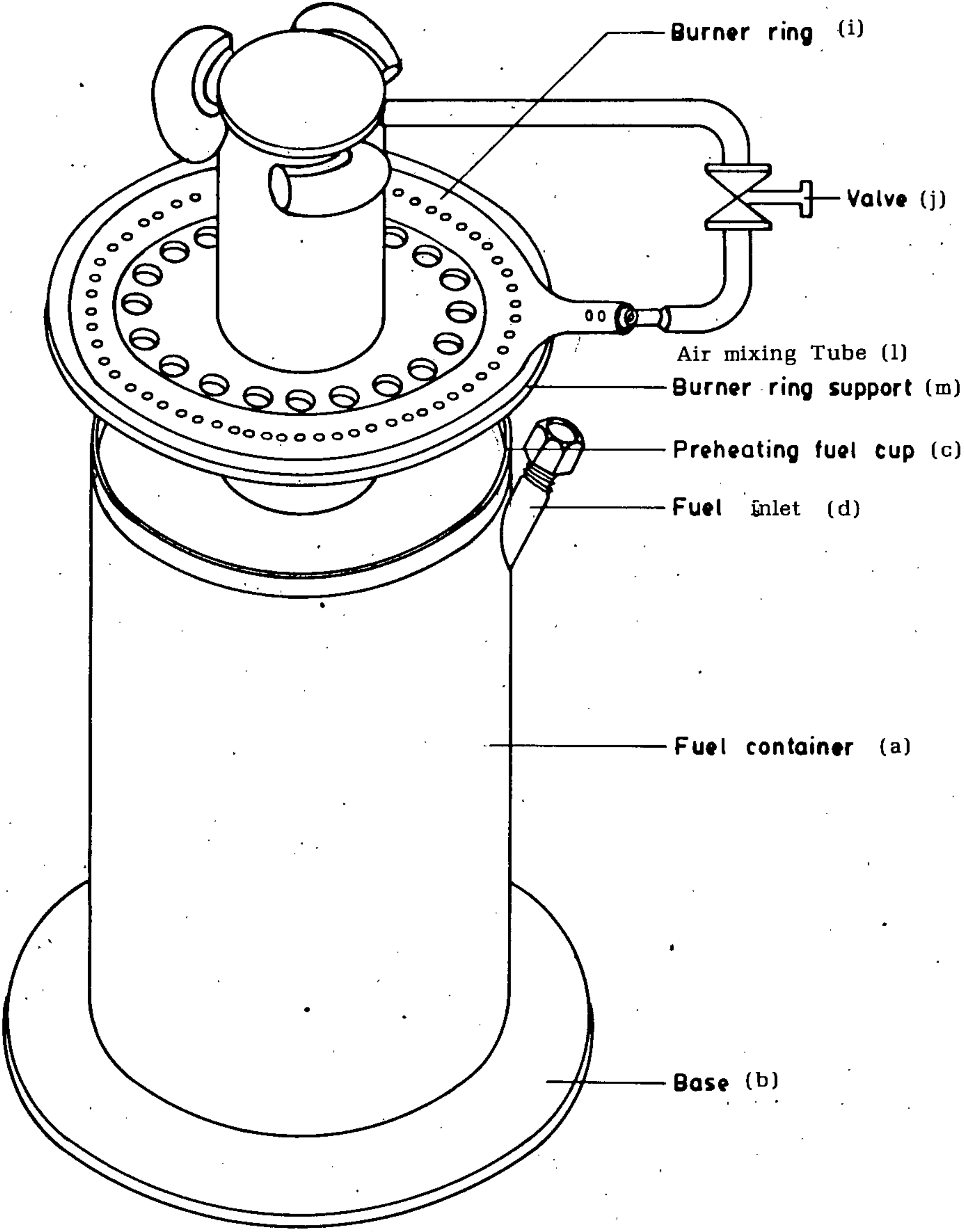
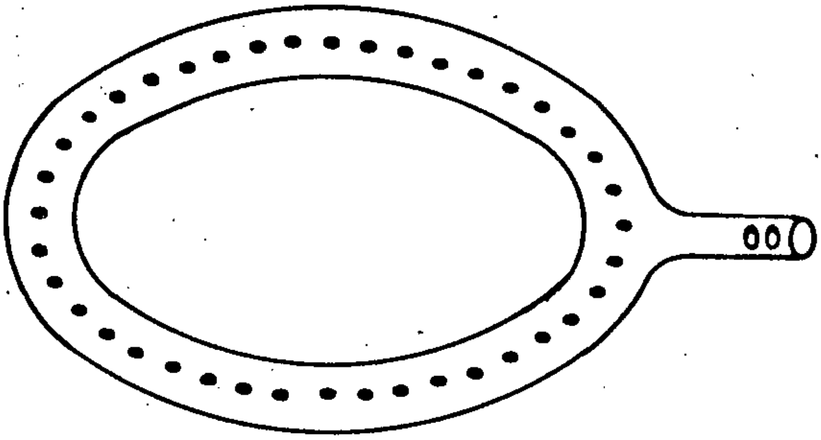
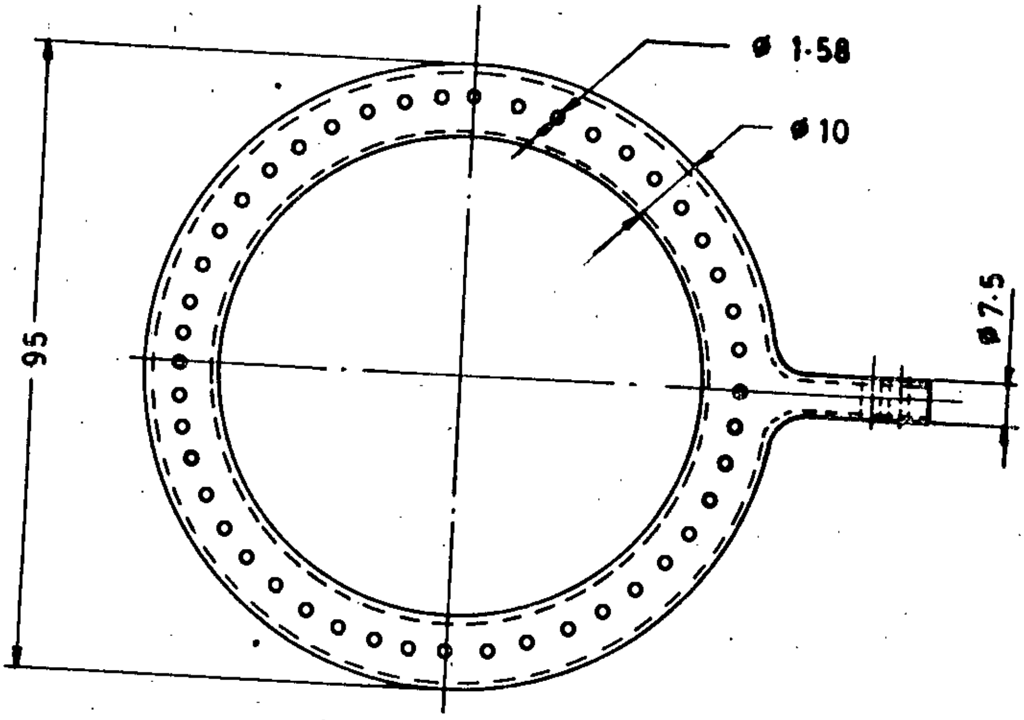


FIG. 5.12: ISOMETRIC VIEW OF A COOKER WITHOUT DIFFUSERS.

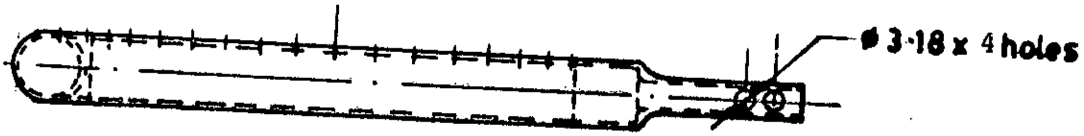
Material:- Copper



Isometric view



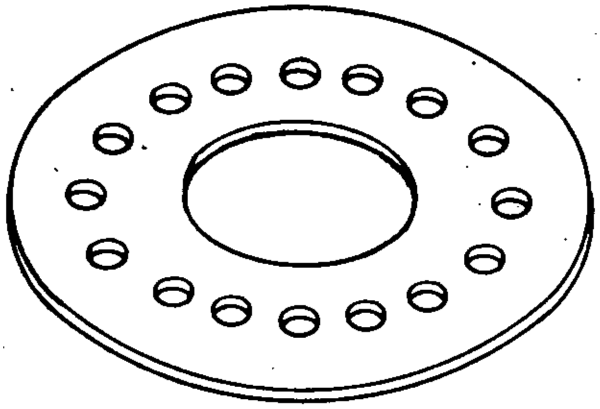
Top view



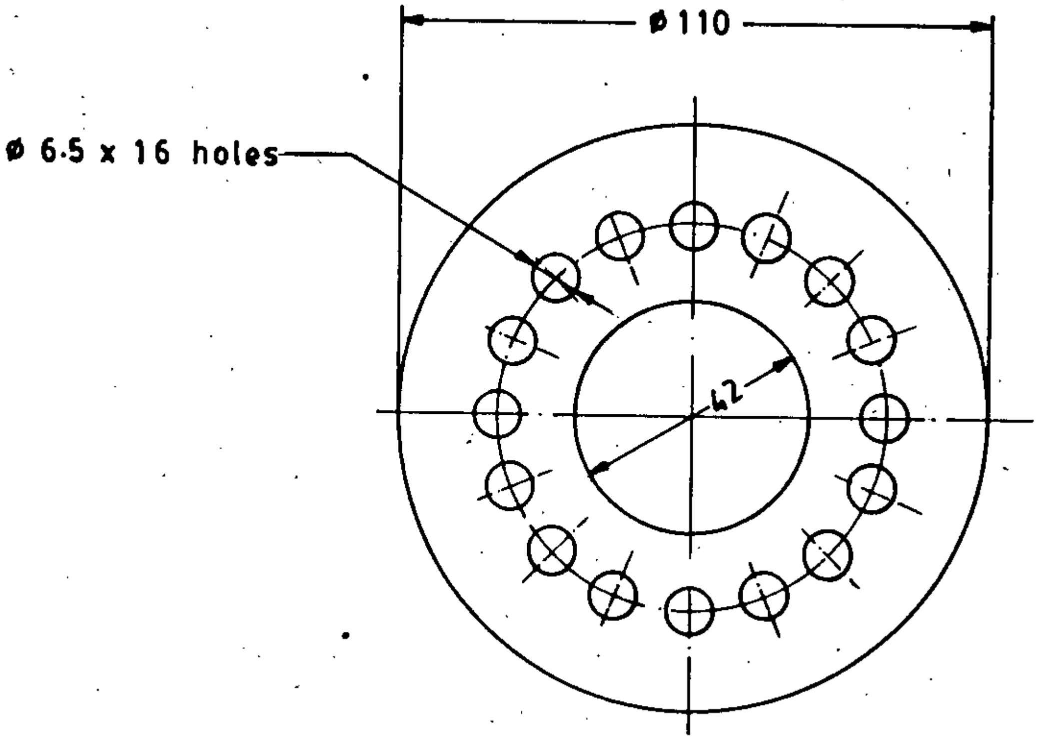
Front view

FIG 5.13: THE BURNER RING (I)

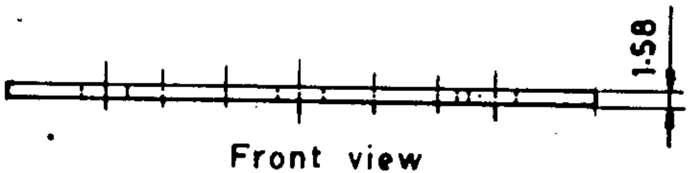
Material:- Mild steel



Isometric view



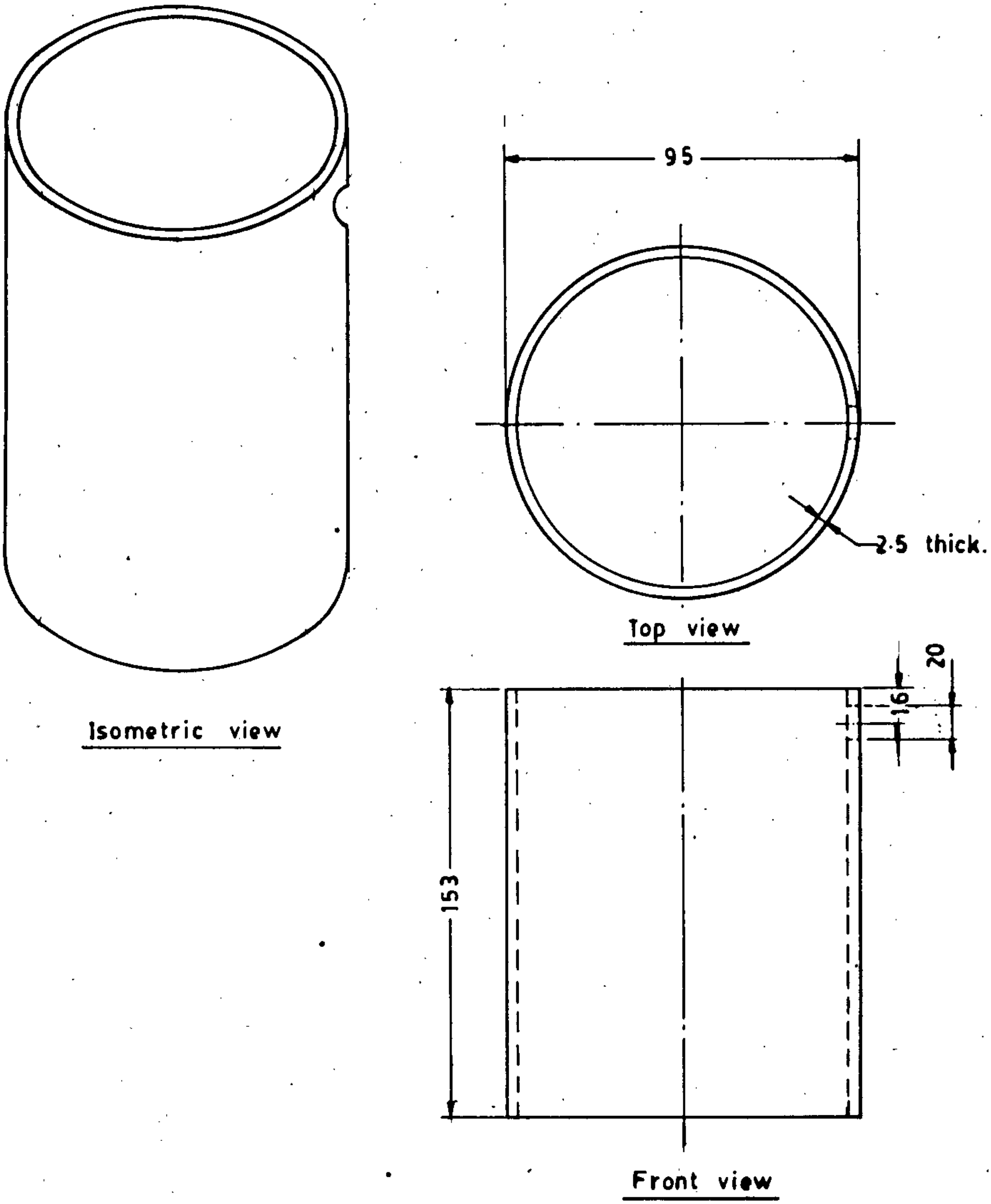
Top view



Front view

FIG. 5.14: THE BURNER - RING SUPPORT (m)

Material:- Mild steel



Isometric view

Top view

Front view

FIG. 5.15 PARTS OF THE FUEL CONTAINER (a)

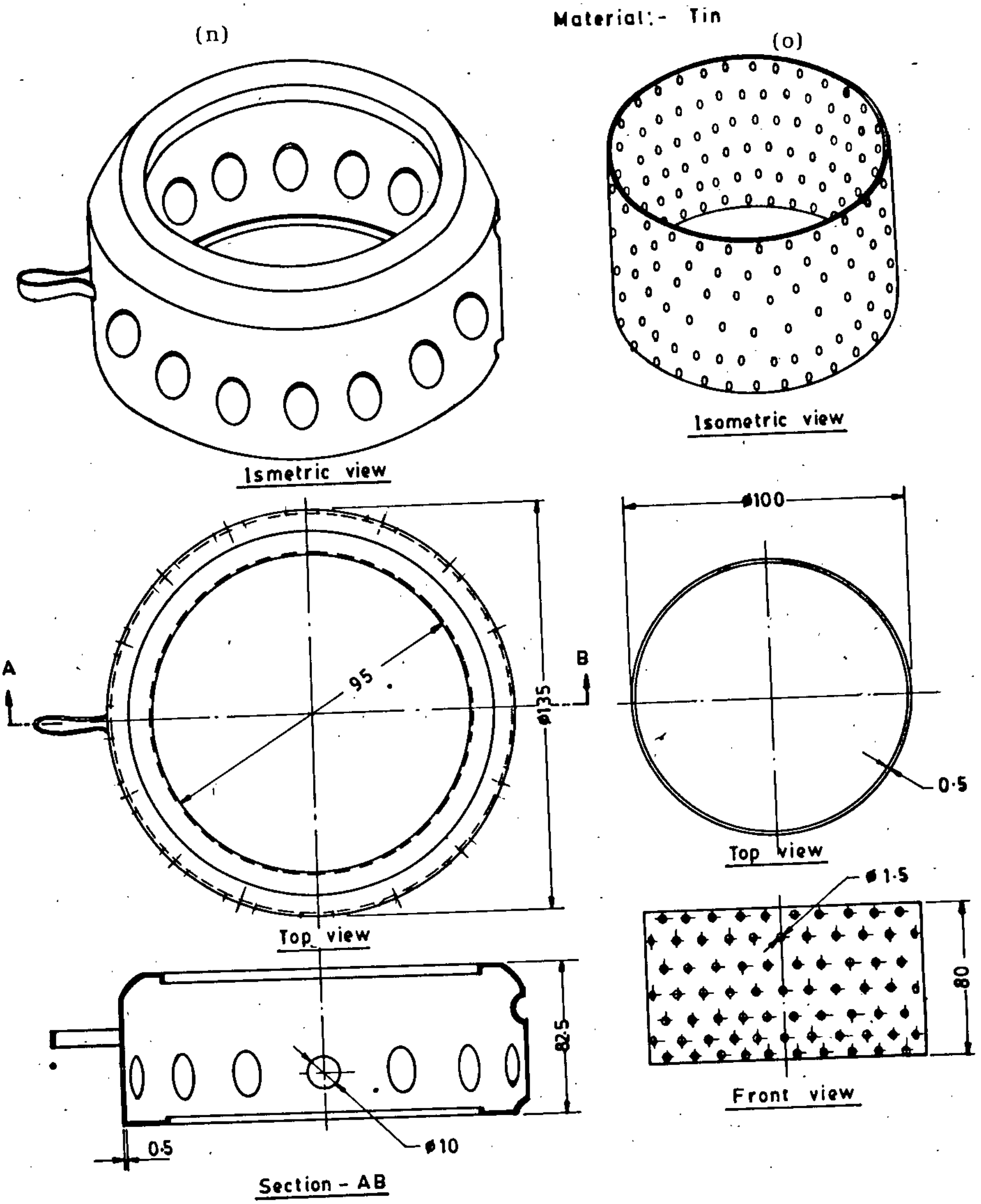
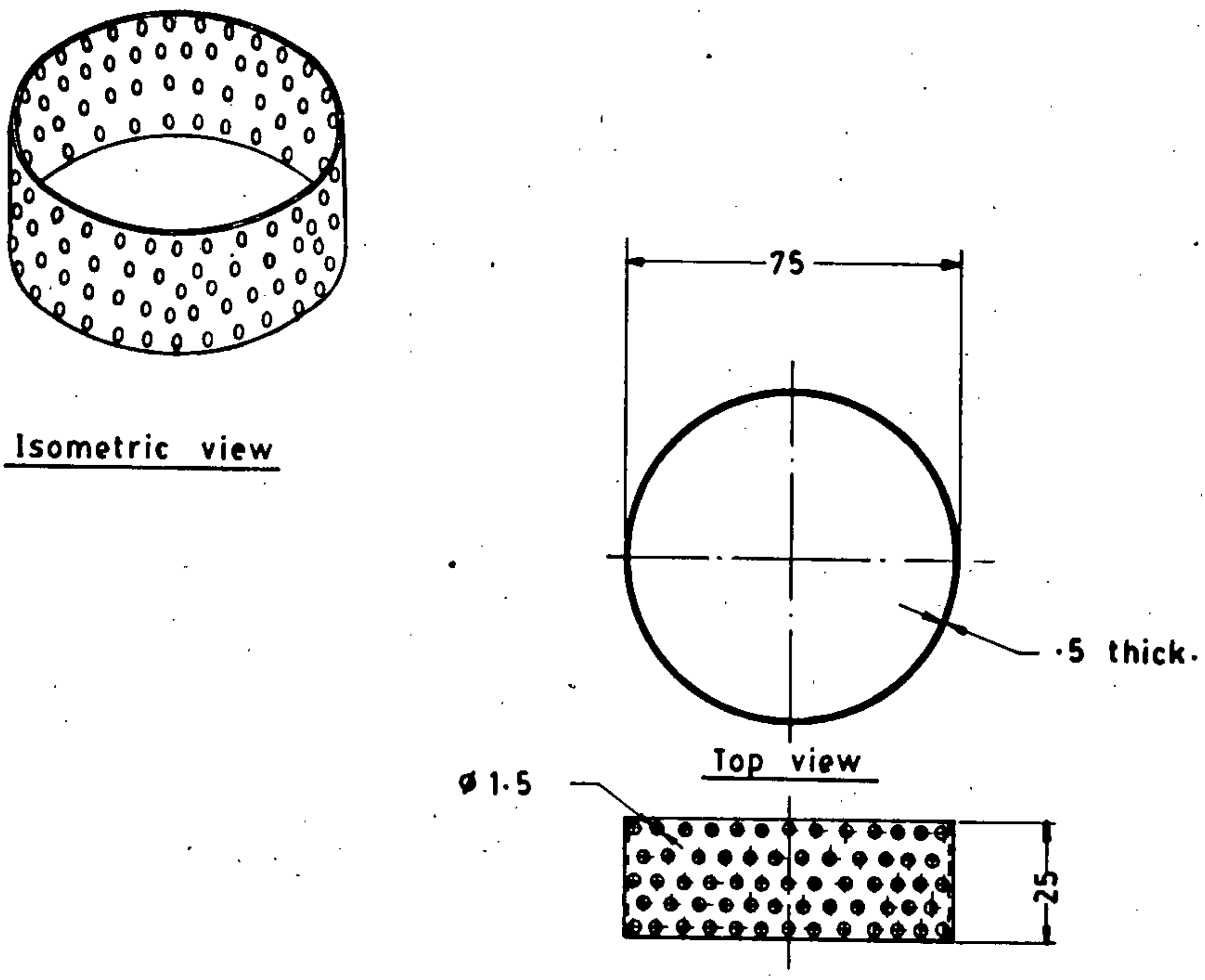


FIG 5.16: THE OUTER (n) AND THE MIDDLE DIFFUSERS (o)

Material:- Tin



Isometric view

Top view

Front view

FIG. 5.17: THE INNER DIFFUSER (p)

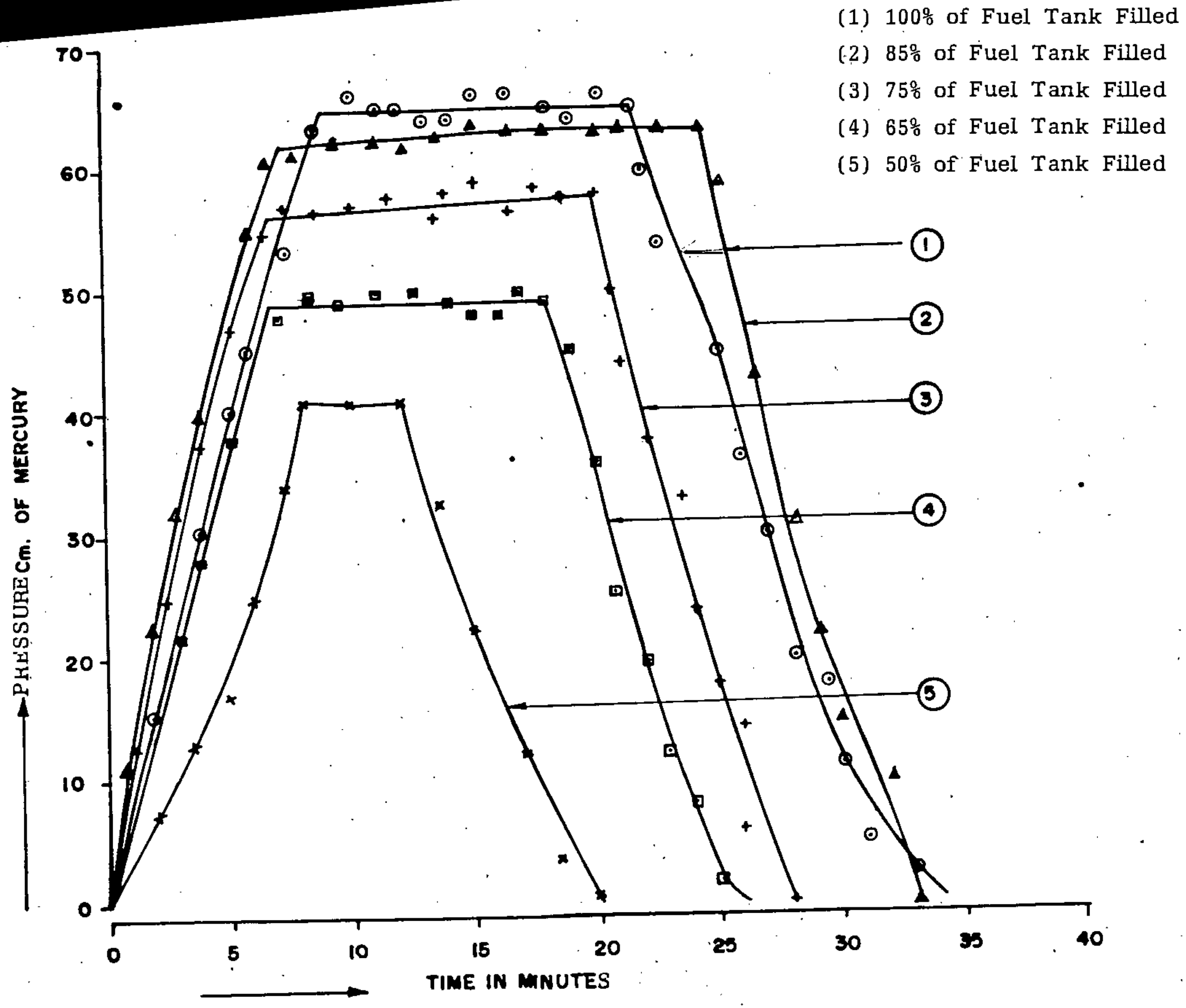


Fig. 5.18: Pressure developed inside the vaporizer with time

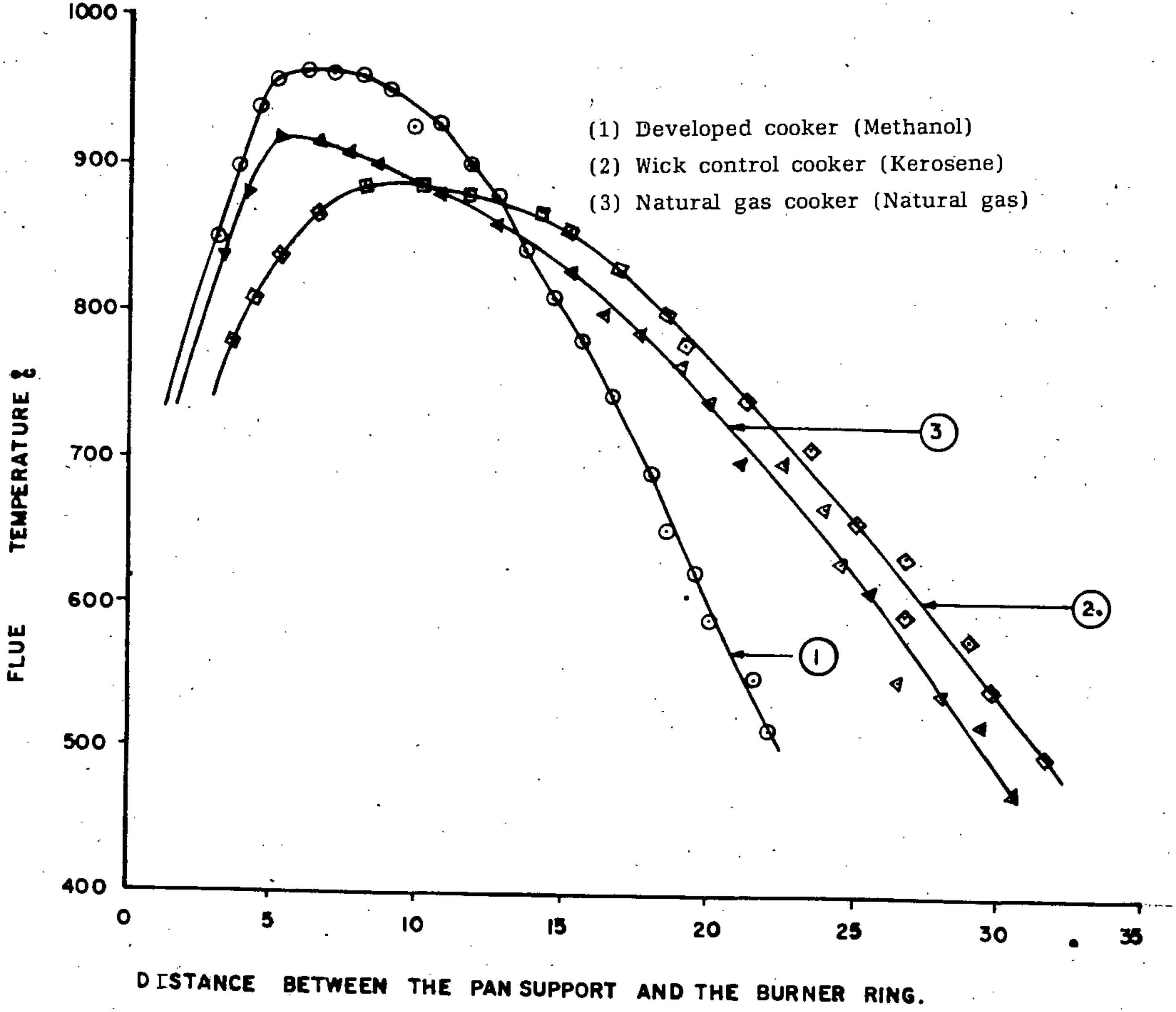


Fig. 5.19: Flue gas temperature as a function of distance from the burner ring

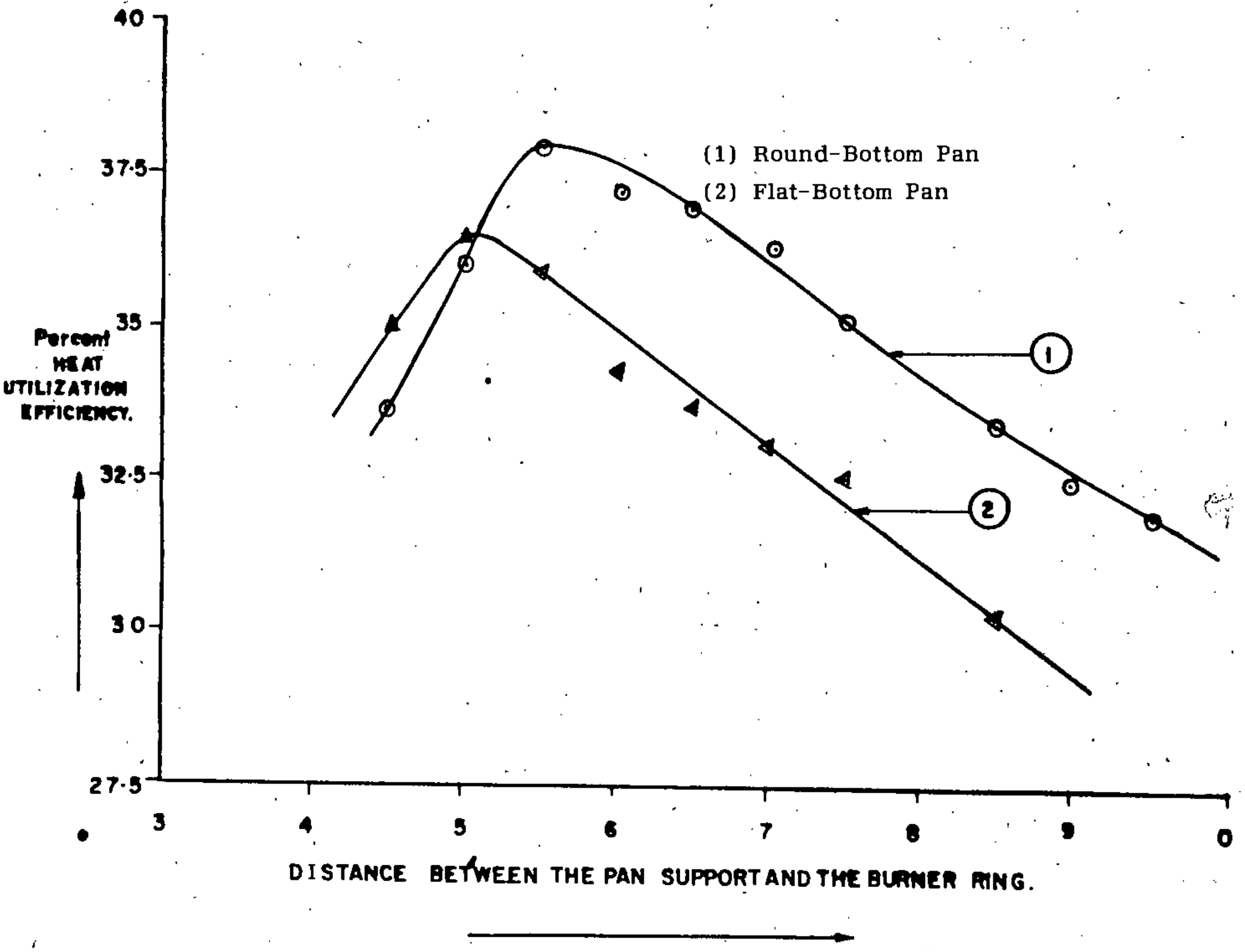


Fig. 20:Heat Utilization Efficiencies of the Developed Cooker.

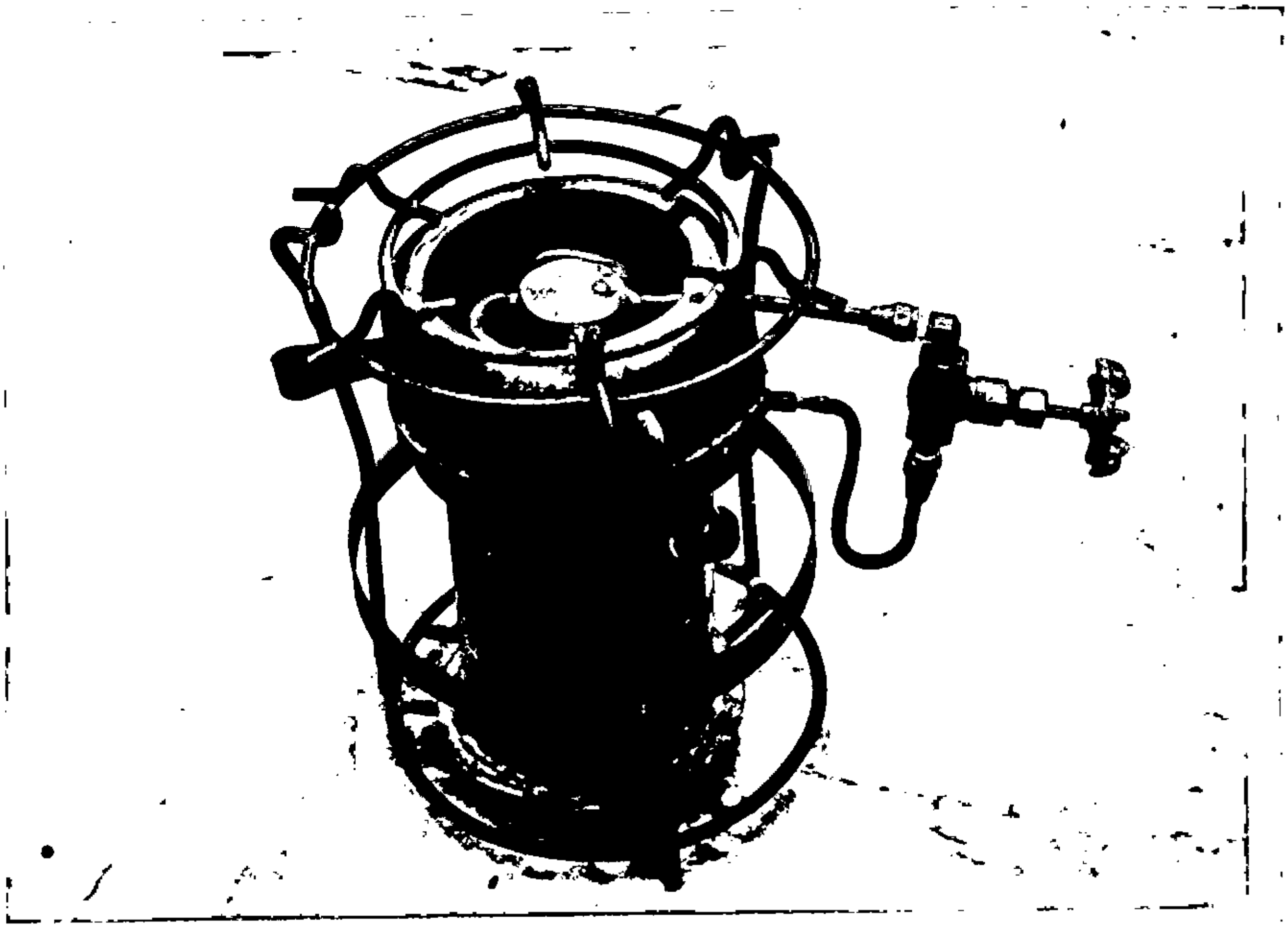


Plate: 5.1A: The developed vaporizer type cooker.

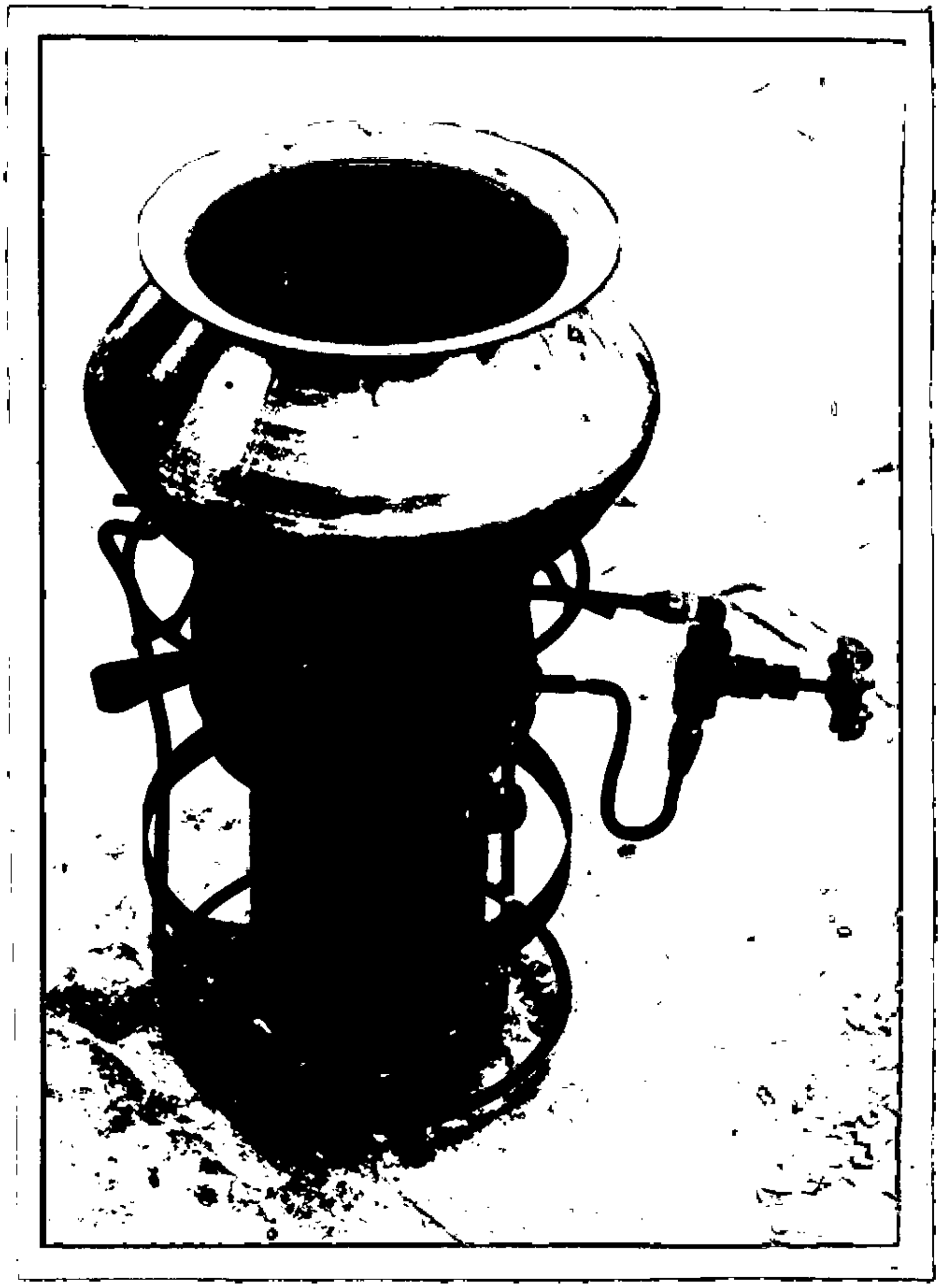


Plate 5.1B: The developed vaporizer type cooker with round bottom cooking pan.

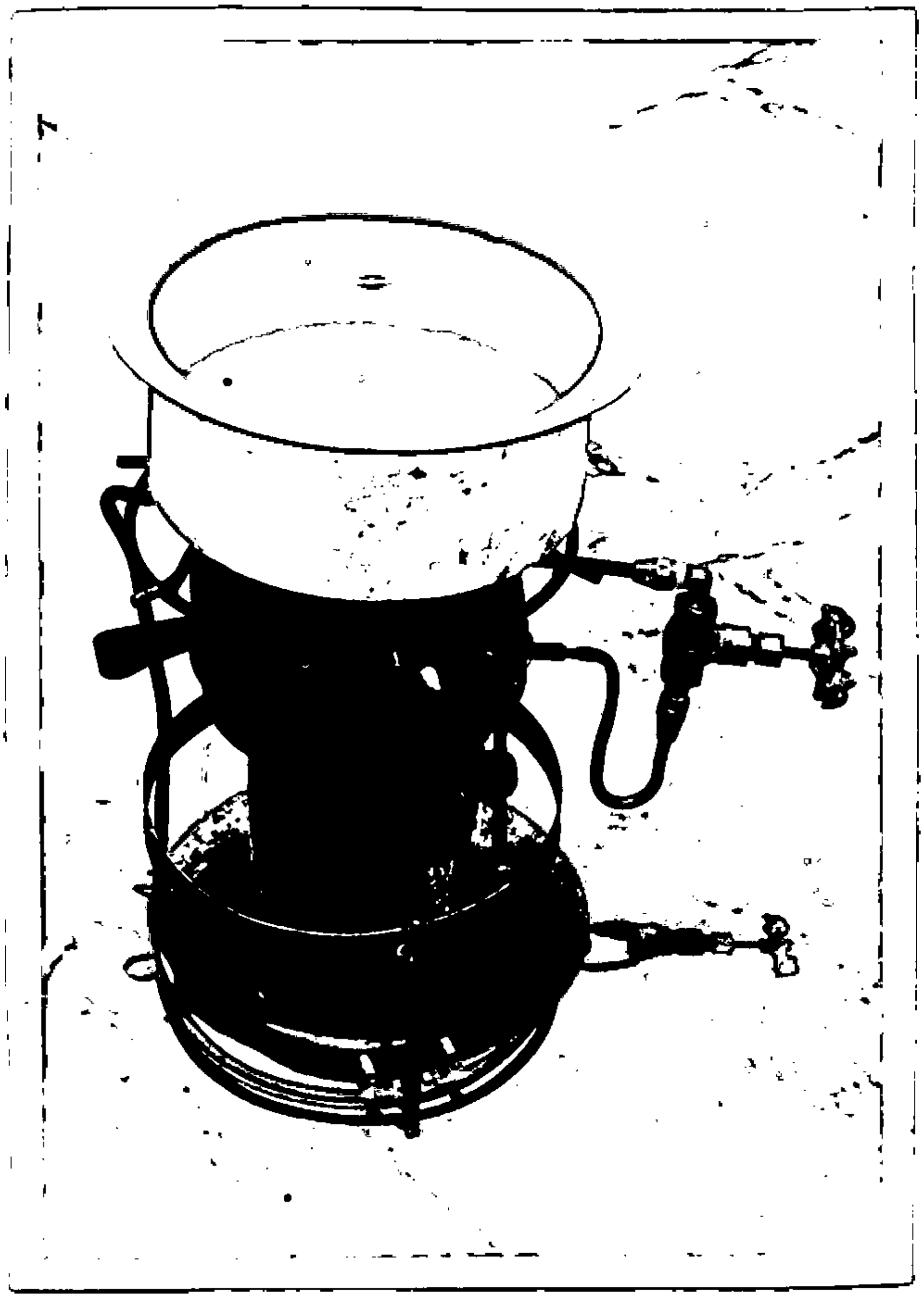


Plate 5.1C: The developed vaporizer type cooker with flat bottom cooking pan.

CHAPTER - 6 STUDY OF PERFORMANCE OF THE DEVELOPED COOKER

6. STUDY OF PERFORMANCE OF THE DEVELOPED COOKER

6.1 Introduction

The performance of the developed cooker was determined by carrying out a series of different experiments.

i) Flue gas analyses were carried out to find out the combustion efficiency of the burner assembly.

ii) The turn down ratio was found out to see the maximum and minimum burning rates.

iii) The overall performance of the cooker was found out by determining the heat utilization efficiency.

The different experiments and the results obtained are presented in the following sections. For all the sets of experiments carried out with the developed cooker, comparative tests were also made on locally available domestic kerosene cookers and cookers using natural gas as the fuel. Ethanol and methanol fuel blends with natural gas condensates were also used in the developed cooker in these experiments to study cooker performance with other similar fuels.

6.2 Flue Gas Analyses

The combustion efficiency of any fuel burning device can be found by carrying out an analysis of the combustion gases. The method used for carrying out the flue gas analyses were similar to those given in British Standards (BS 5386 part 3: 1980).

The analysing equipments included the Orsat and Fyrite analysers and on-line gas analysers (Shimadzu Oxygen, Carbon dioxide and Carbon monoxide testers). For measuring very small concentration of carbon monoxide and unburnt methanol vapour, the appropriate indicating tubes (Bacharach Type) in conjunction with sampling pumps were used.

The results obtained of the flue gas analyses are presented in Table 6.1. Table 6.2 also shows flue gas analyses of other available domestic cookers. As can be seen from the table, combustion is quite satisfactory with the developed cooker. As compared to other cookers combustion takes place with low levels of excess air. The emission of carbon monoxide are low and unburnt methanol vapour concentration are well within the threshold limit value (200 ppm).

Table 6.1 also shows that ethanol and methanol fuel blends can also be burned in the developed cooker without any problems.

6.3 Turn Down Ratios

The turn down ratio of a fuel burning device is also an indication of its performance. This parameter is defined as the ratio of the maximum fuel burning rate to the minimum fuel burning rate, both with satisfactory combustion.

$$\text{Turn Down Ratio} = \frac{\text{Fuel combustion at Maximum Burning Rate}}{\text{Fuel combustion at Minimum Burning Rate.}}$$

A series of experiments were carried out to determine the turn down ratio of the developed cooker with methanol, ethanol and fuel blends. Comparative studies were also made with other cookers as mentioned earlier. Results are shown in Table 6.2.

As seen from Table 6.2 Turn down ratios for the developed cooker is superior to other cookers when burning methanol and ethanol.

6.4 Heat Utilization Efficiency

The heat utilization efficiency of a cooker is a very import parameter indicating the overall performance of the device. It indicates the percentage of the fuel burned in the cooker which is used usefully, Experiments to determine the heat utilization efficiencies of the developed cooker were carried out according to British Standards mentioned earlier. Comparative studies were also carried out with other available cookers.

Two types of cooking pans (round - bottom and flat-bottom) were used in these studies.

Results are shown in Tables 6.3, and 6.4. A sample calculation to find out heat utilization efficiency of a particular run is shown below:

Sample Calculation (Heat Utilization Efficiency)

$$\text{Fuel consumption rate} = \frac{\text{Amount of fuel burned}}{\text{Time required for burning}}$$

$$= \frac{F_f - F_i}{\theta_f - \theta_i} \text{ (gm/min)}$$

$$\text{Heat utilization efficiency (HUE)} = \frac{W_w C_w (T_2 - T_1)}{(F_f - F_i) C_v} \times 100$$

C_w = Heat capacity of water, $\frac{(\text{Cal}\quad)}{\text{gm} - {}^{o}\text{C}}$

C_v = Heating value of methanol, (Cal/gm)

F_i = Initial weight of the cooker (gm)

F_f = Final weight of the cooker (gm).

θ_i = Initial time of experiment ($\theta_i = 0$) min.

W_w = Amount of water taken in the pan (gm)

θ_f = Final time, min.

T_i = Initial temperature of water ^{o}C(Room temperature)

T_f = Final temperature of water ^{o}C(90 ± 1 ^{o}C according to British standard).

(F_f-F_i) = Weight of methanol burned in a particular run.

$(\theta_f-\theta_i)$ = Time of experiment(min)

For vaporized type Cooker with a Round bottom Pan: (Table 6.3)

$$\text{H.U.E.} = \frac{3000(90 - 30.5)}{92 \times 4800} \times 100 = 40.42\%$$

Table 6.3 and 6.4 shows the heat utilization efficiencies of the developed cooker and other available domestic cookers. Values obtained of the heat utilization efficiencies for the developed cooker are quite satisfactory as can be seen from the Tables.

6.5 Discussion on the Developed Methanol Cooker

A methanol cooker for domestic use was designed, fabricated and tested in the laboratory. The design is based on the principle of self-evaporation of liquid methanol. Evaporation is obtained by collecting a portion of the heat of combustion and then conducting this heat into the liquid methanol in the fuel tank. The results obtained on the design and operation of the methanol cooker are significant in the present context. Available information on this subject which are over eighty years old (The French Patents, ref..4, 5, 6...) is very sketchy and tentative and it was not at all clear whether a methanol cooker was at all operable. This present study shows that a methanol cooker can be made and operated satisfactorily. The difficulties of methanol evaporation and back-fire were overcome.

Tests on combustion efficiencies, (indicated by flue gas analyses) turn down ratios and heat utilization efficiencies indicated that these were satisfactory. Measurements of methanol vapour showed that these are low. The unburnt methanol concentrations in the flue gases were well within the threshold limit values (TLV). This result of the low CO emission is encouraging from an environmental point of view.

However, one aspect of the cooker that would require serious study is the technique for handling methanol and filling methanol into small containers, for domestic use. Although the concentration of methanol vapour in the combustion gases is small, the level would be high during filling of methanol in the container and when there is a spill. It is felt that a continuous monitoring of the environment is needed using sophisticated analytical techniques for this purpose and future work has to be taken in this direction. Also a study of material compatibility with methanol is needed to identify materials that can be safely used with methanol. This is perticularly true of gasket materials.

It is felt that a significant progresses have been made in the design of a vapouring type of methanol cooker within the limited time of this work. However, as indicated above, solution of their associated problems would be required before methanol can be used as a domestic cooking fuel.

TABLE 6.1: FLUE GAS ANALYSES

Name of the Cooker	Fuel	Analyses of Flue Gases			
		CO_2 vol %	O_2 Vol %	CO Vol %	CH_3OH p.p.m.
The Developed Vaporizer - Type Cooker	Methanol	14.25	.50	.005	20
	Ethanol	12.5	3.0	.006	0
	Methanol:BK.Cond.*	14.0	1.5	.008	17
	Methanol:Titas Cond.**	14.0	2.0	.009	15
Wick Control Domestic Cooker	Kerosene	10.0	7.0	.020	0
	Methanol:BK.Cond. 1:1	8.8	7.0	.025	32
	Methanol:Titas Cond. 1:1	8.0	7.8	.027	30
Flow Control Domestic Cooker	Kerosene	12.2	7.0	.018	0
	Methanol:BK.Cond.	6.5	13.1	.023	25
	Methanol:Titas Cond.	6.0	13.8	.025	23
Natural Gas Cooker	Natural gas i) Flow rate $\frac{6\ dm^3}{min}$	5.5	12.5	.011	-
	ii) Flow rate $\frac{3\ dm^3}{min}$	3.0	17.0	.010	-

* BK Cond. is Gas condensate from Bakhrabad Gas Field.

** Titas Cond. is Gas condensate from Titas Gas Field.

TABLE 6.2: TURN DOWN RATIO

Name of the Cooker	Name of the Fuel	Maximum burning rate gm/min	Minimum burning rate gm/min	Turn down ratio
The developed Vapourizer type cooker	Methanol	10	2.5	4.0
	Ethanol	8.5	2.2	3.8
	Methanol:BK.Cond.* 1:1	5.0	2.0	2.5
	Methanol:Titas Cond.** 1:1	5.0	2.0	2.5
Wick Control Cooker	Kerosene	1.72	.455	3.7
	Methanol:BK.Cond. 1:1	2.1	1.2	1.7
	Methanol:Titas Cond. 1:1	2.5	1.3	1.9
Flow Control Cooker	Kerosene	2.1	.77	2.7
	Methanol:BK. Cond. 1:1	2.92	1.90	1.5
	Methanol:Titas Cond. 1:1	2.86	1.81	1.6
Natural gas Cooker	Methanol	6.1 $\frac{dm^3}{min}$	1.69 $\frac{dm^3}{min}$	3.6

* BK Cond. is Gas condensate from Bakhrabad Gas Field.

**Titas Cond. is Gas condensate from Titas Gas Field.

TABLE 6.3: HEAT UTILIZATION EFFICIENCY, PAN SHAPE: ROUND BOTTOM, PAN DIAMETER - 24 cm.

Name of the Cooker	Name of the Fuel used	Amount of water taken in the pan W_w(gm)	Initial Temperature of water T_i(°C)	Final temp. of water T_2(°C)	Amount of fuel burned (F_f-F_i) gm	Time required for burning $(\theta_f-\theta_i)$ mins	Burning rate gm/min	Heat Utilization Efficiency (Percent)
The developed Vaporizer type Cooker	Methanol	3000	30.5	90	92	12	7.67	40.42
The developed Vaporizer type Cooker	Ethanol	3000	31.	91	64.2	11	5.83	39.5
Wick Control Cooker	Kerosene	3000	29.5	90	65	43	1.51	27.07
Flow Control Cooker	Kerosene	3000	30.0	90.5	60	35	1.71	29.08
Natural Gas Cooker	Natural Gas	3000	29	90	56.5 $\frac{dm^3}{min}$	9.5	5.9 $\frac{dm^3}{min}$	36.20

TABLE 6.4: HEAT UTILIZATION EFFICIENCY, PAN SHAPE : FLAT BOTTOM, PAN DIAMETER - 24 cm

Name of the Cooker	Name of the Fuel used	Amount of water taken in the pan W_w (gm)	Initial Temperature of water T_1 (°C)	Final Temperature of water T_2 (°C)	Amount of fuel burned $(F_f - F_i)$ gm	Time required for burning $(\theta_f - \theta_i)$ min	Burning rate gm/min	Heat Utilization Efficiency (Percent)
The developed Vaporizer type Cooker	Methanol	3000	30	90	90.0	13	7.38	39.06
The developed Vaporizer type Cooker	Ethanol	3000	29.5	90.5	68.9	12.5	5.5	37.4
Wick Control Cooker	Kerosene	3000	29	90	76	50	1.52	23.15
Flow Control Cooker	Kerosene	3000	30	90	71	42	1.69	24.30
Natural Gas Cooker	Natural Gas	3000	30.5	90	62 dm^3	11.5	5.39	32.20

CHAPTER - 7 CONCLUSIONS & SUGGESTIONS

7. CONCLUSIONS & SUGGESTIONS

7.1 Conclusions

Based on the findings of the present research work the following general conclusions may be made:

i) Kerosene and methanol are immisicible in each other. If blends of kerosene and methanol are to be made, a third component (cosolvent) is to be used. The co-solvents used successfully in the present study included aliphatic alcohols, benzene and its homologues and ketone. A few proprietary surfactants also exhibited satisfactory performance as co-solvents. The blends are stable and do not show hygroscopic behaviour.

ii) Methanol may be co-produced with higher alcohols using modified catalytic systems. This will help to make stable blends with kerosene without having to import co-solvent alcohols. The toxicity problem associated with the use of neat methanol may thus be decreased to a large extent.

iii) Two component methanol fuel blends may also be made using low boiling fraction of locally produced natural gas condensates (end point less than 200°C).

iv) Two component methanol fuel blends may be prepared by mixing methanol with low boiling (end point less than 200°C) petroleum fractions. For example, low boiling fractions of natural gas condensates, gasoline and reformate (100-Octane).

v) Among all the blends studied in the present work, the three component kerosene - methanol - 100-Octane and the two component methanol/gas - condensates may be considered more practical in the present context because these are locally produced. However if methanol is co-produced with higher alcohols this mixture would help in making stable blends with kerosene, which will have superior properties compared to other blends.

vi) The concentration of methanol vapour in the surrounding air can be decreased by blending & changing the design of existing liquid fuel cookers.

vii) Locally available liquid fuel cookers are not suitable for burning with neat methanol and its blends. This is largely due to problems of leakage of methanol vapour to the surroundings and vapour locking.

viii) A self vaporizing cooker for domestic use was designed, fabricated and tested in the laboratory. Evaporation of methanol is obtained in this cooker by using a part of the heat of combustion of the fuel. Methanol fuel blends and Ethanol can also be used as fuels in this cooker.

ix) Tests carried out on the developed cooker of combustion efficiencies, turn down ratio and heat utilization efficiencies indicated that the present design may be used satisfactorily for domestic cooking.

7.2 Suggestion for further work

The results of the present work pointed out the need for continuing research endeavours in the following lines:

i) Study of Methanol fuel blends may be extended using different types of surfactants. A few proprietary surfactants were tried in this work with encouraging results. However, further work in these lines would help to identify useful surfactants. Also fuel emulsions of methanol-kerosene system using surfactants would be an interesting study.

ii) Development work on the re-filling system of the developed cooker would be essential for stable operation of the cooker.

iii) Studies should be carried out on techniques for handling methanol and filling methanol into small containers for domestic use. This is very important considering the toxicity of methanol.

iv) Corrosion studies with neat methanol and its blends should be carried out to find out materials that are compatible with these fuels. This is necessary to identify suitable materials of construction for use in systems using methanol and its fuel blends.

v) Experiments under different pressures should be carried out using the developed methanol cooker.

vi) Heat utilization efficiency measurement experiments should be carried out using blended fuel in the developed methanol cooker according to British standard. Further exhaustive study is essential on the blended fuel.

vii) In blending study plate point should be determined and the relationship between the plate point and critical point should also be established.

CHAPTER - 8 REFERENCES

8. REFERENCES

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APPENDICES

TABLE A.1.1: BLENDS OF KEROSENE - METHANOL - ETHANOL

No. of fuel	Volume % of blends (composition) K : M : E	Result(solubility)
1.	72:7:21	Clear
2.	70:8:22	Clear
3.	60:10:30	Clear
4.	47:13:40	Clear
5.	39:15:46	Clear
6.	36:18;46	Clear
7.	27:27:46	Clear
8.	25:30:45	Clear
9.	20:40:40	Clear
10.	16:50:33	Clear
11.	15:52:33	Clear
12.	13:57:30	Clear
13.	12:60:28	Clear
14.	11:63:26	Clear
15.	11:65:24	Clear
16.	11:67:22	Clear
17.	10:69:21	Clear
18.	9:72:19	Clear
19.	8:75:17	Clear
20.	6:79:15	Clear
21.	5:83:12	Clear
22.	2:95:3	Clear
23.	95:1:4	Clear

TABLE A.1.2: BLENDS OF METHANOL - KEROSENE - PROPANOL

No. of fuel	Volume % of blends (composition) K : M : P	Result(solubility)
1.	34:34:32	Clear
2.	22:44:34	Clear
3.	14:58:28	Clear
4.	11:68:21	Clear
5.	48:24:28	Clear
6.	59:19:22	Clear
7.	65:16:19	Clear
8.	70:14:16	Clear
9.	74:12:14	Clear
10.	77:10:13	Clear
11.	2:95:3	Clear
12.	3:90:7	Clear
13.	7:80:13	Clear
14.	95:2 :3	Clear
15.	90:4:6	Clear
16.	85:6:9	Clear

TABLE A.1.3: BLENDS OF KEROSENE - METHANOL - BUTANOL

No. of fuel	Volume % of blends (composition) K : M : B	Result (solubility)
1.	38:38:24	Clear
2.	45:32:23	Clear
3.	52:26:22	Clear
4.	62:20:18	Clear
5.	73:14:13	Clear
6.	25:50:25	Clear
7.	20:60:20	Clear
8.	16:66:18	Clear
9.	14:71:15	Clear
10.	68:17:15	Clear
11.	80:10:10	Clear
12.	90:5:5	Clear
13.	95:2.5:2.5	Clear
14.	10:80:10	Clear
15.	2.5:95:2.5	Clear
16.	5.90:5	Clear
17.	7.5:85:7.5	Clear
18.	85:7.5:7.5	Clear

TABLE A.1.4: BLENDS OF KEROSENE - METHANOL - ETHYL METHYL KETONE

No. of fuel	Volume % of blends (composition) K : M : EMK	Result (solubility)
1.	35:35:30	Clear
2.	24:48:28	Clear
3.	18:56:26	Clear
4.	15:63:22	Clear
5.	13:68:19	Clear
6.	12:70:18	Clear
7.	50:25:25	Clear
8.	60:20:20	Clear
9.	70:15:15	Clear
10.	75:12.5:12.5	Clear
11.	90:5:5	Clear
12.	95:2.5:2.5	Clear
13.	7:80:13	Clear
14.	4:90:6	Clear
15.	78:11:11	Clear
16.	80:10:10	Clear
17.	66:17:17	Clear

TABLE A.1.5: :BLENDS OF KEROSENE - METHANOL - 100-OCTANE

No. of fuel	Volume % of blends (composition) K : M : O	Result(solubility)
1.	21:21:58	Clear
2.	35:10:55	Clear
3.	15:30:55	Clear
4.	44:6:50	Clear
5.	57:3:40	Clear
6.	81:2:17	Clear
7.	10:40:50	Clear
8.	6:59:35	Clear
9.	83:2:15	Clear

TABLE A.1.6: BLENDS OF KEROSENE - METHANOL - 100-OCTANE(100-145°C)

No. of fuel	Volume % of blends (composition) K : M : O(100-145°C)	Result(solubility)
1.	22:22:56	Clear
2.	38:14:48	Clear
3.	59:4:37	Clear
4.	74:3:23	Clear
5.	16:39:45	Clear
6.	10:52:38	Clear
7.	6:62:32	Clear
8.	61:3:36	Clear

TABLE A.1.7: BLENDS OF KEROSENE - METHANOL - 100-OCTANE(50-85°C)

No. of fuel	Volume % of blends (composition) K : M : O(50-85°C)	Result(solubility)
1.	6:62:32	Clear
2.	9:45:46	Clear
3.	10:34:56	Clear
4.	12:30:58	Clear
5.	13:27:60	Clear
6.	15:25:60	Clear
7.	16:20:64	Clear
8.	18:18:64	Clear
9.	19:16:65	Clear
10.	21:14:65	Clear
11.	22:12:66	Clear
12.	24:11:65	Clear
13.	26:10:64	Clear
14.	29:9:62	Clear
15.	31:8:61	Clear
16.	29:6:65	Clear
17.	33:6:61	Clear
18.	36:6:58	Clear
19.	37:5:58	Clear
20.	61:3:36	Clear

TABLE A.1.8: BLENDS OF KEROSENE - METHANOL - BENZENE

No. of fuel	Volume % of blends (composition) K : M : Ben	Result (solubility)
1.	37:37:26	Clear
2.	44:30:26	Clear
3.	54:22:24	Clear
4.	61:17:22	Clear
5.	80:7:13	Clear
6.	85:5:10	Clear
7.	90:3:7	Clear
8.	95:1:4	Clear
9.	30:45:25	Clear
10.	25:52:23	Clear
11.	22:58:20	Clear
12.	17:66:17	Clear
13.	12:76:12	Clear
14.	10:80:10	Clear
15.	7.5:85:7.5	Clear
16.	5:90:5	Clear

TABLE A.1.9: BLENDS OF KEROSENE - METHANOL - TOLUENE

No. of fuel	Volume % of blends (composition) K : M : T	Result (solubility)
1.	95:1:4	Clear
2.	85:3:12	Clear
3.	90:2;8	Clear
4.	80:5:15	Clear
5.	75:7:18	Clear
6.	65:10:25	Clear
7.	54:17:29	Clear
8.	45:25:30	Clear
9.	40:30:30:	Clear
10.	35:35:30	Clear
11.	33:37:30	Clear
12.	31:39:30	Clear
13.	26:45:29	Clear
14.	22:53:25	Clear
15.	15:65:20	Clear
16.	3:92:5	Clear

TABLE A.1.10: BLENDS OF KEROSENE - METHANOL - XYLENE

No. of fuel	Volume % of blends (composition) K : M : X	Result (solubility)
1.	94:1:5	Clear
2.	85:2:13	Clear
3.	75:5:20	Clear
4.	66:7:27	Clear
5.	55:10:35	Clear
6.	44:18:38	Clear
7.	40:22:38:	Clear
8.	37:25:38	Clear
9.	32:32:36	Clear
10.	27:38:35	Clear
11.	24:43:33	Clear
12.	21:48:31	Clear
13.	17:55:28	Clear
14.	15:60:25	Clear
15.	10:70:20	Clear
16.	5:80:15	Clear
17.	3:90:7	Clear

Physical, chemical and thermodynamic properties of methanol

The physical and chemical properties have a large influence on its performance in combustion systems. Unlike the petroleum based fuels, methanol is a pure substance and therefore, its properties are well defined in chemical grade form.

Properties of methanol are summarized in the following tables

TABLE A 2.1: PHYSICAL PROPERTIES OF METHANOL

Physical state:		Liquid.
Specific gravity of pure liquid		
	20/4°C	0.7910
	20/20°C	0.7924

Density, gram per milliliter:

Temperature °C	Density	Temperature °C	Density
00	0.8100	100	0.7132
10	0.8007	120	0.6894
20	0.7913	150	0.6473
25	0.7866	200	0.539
50	0.7632	220	0.403
64	0.7500	239	0.272

Relative vapour density (air = 1): 1.11

Boiling point : 647°C

Melting point :-97.8°C

Critical points:

Temperature °C	Pressure	Volume	Compressibility factor
239.43°C	78.7 atm.	118 ml/mol.	0.224

Viscosity: 0.614 cps at 20°C.

0.541 cps at 25°C

Surface tension(mN/m = dyn/cm): 22,6 dyn/cm.

Refractive Index, n_D^{20} 22.6 dyn/cm.

Dielectric Constant at 25°C 0.202

Vapour Pressure:

Temperature °C	Vapour pressure (mm Hg)
0	29
5	40
10	52
20	92
21.2	100
30	159
40	258
50	410
60	630
64.5	760

Appearance:	Clear, colorless liquid(alcohol-like).
Solubility in water:	Infinite

TABLE A2.2: CHEMICAL AND HAZARD PROPERTIES

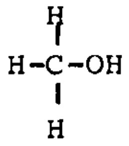
Empirical formula:	CH_3OH or  $H-\overset{H}{\underset{H}{C}}-OH$	
Molecular weight:	32.04	
Specific Sub-products:	Formaldehyde (HCHO) Formic Acid (HCOOH)	
Light Sensitivity	none.	
Auto-ignition temperature	464°C	867°F
Flash point : Tag Open Cup	16°C	61°F
Tag closed cup	12°C	54°F.
Lower and upper limits of inflammability: (volume % in air)	6.72(lower)	36.5(higher)
Threshold limit value(TLV)	260 mg/m^3 (200 ppm)	
Odour:	pure material has a slight alcoholic odor.	
Colour:	Colourless, Water-white	
Colour of flame	Blue flame, almost invisible.	
Hygroscopicity	Considered as none.	
Reactivity	Not dangerously reactive.	

TABLE A2.3: THERMODYNAMIC PROPERTIES OF METHANOL

Heat of formation (liquid) at 25°C		-239.03 Kj/mol
Free energy of formation (liquid) at 25°C		-166.81 "
Heat of fusion		3.29 "
Latent heat of evaporation:		
25°C	9.1 Kcal	
64.7°C	8.25 Kcal/mol.	
High heating value (25°C)		173.5 Kcal/mol.
Lower heating value (25°C)		152.5 Kcal/mol
Specific heat of vapour at 25°C		1.37 J/(g-k)
Entropy of liquid		30.4 cal/°C-mol.
Entropy of vapour		57.2 cal/°C-mol.

TABLE A2.4: COMBUSTION PROPERTIES OF METHANOL

Stoichiometric combustion in air (dry) :	
Air/fuel ratio $N_m^3/Kg\ CH_3OH$	5.01
CO_2 content in the flue gases (wet)% vol. :	11.55
H_2O content in the flue gases (wet)% vol. :	23.1
Dew point of flue gases:	64°C
Theoretical temperature of the adiabatic flame:	
Injection in liquid state :	1850°C
Injection in vapour state:	1950°C
Pollution emission, compared with hydrocarbons :	
Nitrogen oxides:	low
Carbon monoxide, hydrocarbons equivalent:	low
Soot and carbon particles	nil