

BIOMASS GASIFICATION AS AN ALTERNATE FARM FUEL

by

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A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
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Winnipeg, Manitoba

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ABSTRACT

Energy is one of the basic requirements of modern society and many alternate fuels are being examined because of escalating fuel prices or because of diminishing conventional sources. Canada is fortunate to possess rich natural resources including fossil fuels; however, there is a concern that shortages will be encountered in the immediate future. Canada produces about 151×10^6 tonnes of biomass per year which should not be overlooked as a potential energy source. This biomass has an energy of 2.77×10^{18} J.

Gasification of biomass has received renewed interest as an energy conversion process. Three prototype producer gas systems incorporating updraft and downdraft gasifiers were designed and fabricated to provide gaseous fuel to a 5.59 kW spark ignition engine. Tests were performed with different types of fuel, i.e. peat, wood and charcoal briquettes. Good combustible gas was obtained from an electric furnace and gasifier model number 3 when operated as an updraft gasifier. The engine ran at a speed of 1000 and 1800 RPM when fuelled with gas from peat and wood respectively.

An important requirement in the operation of the gasifiers is to maintain the temperature in the range of

800-1000°C within the reduction and combustion zone for continuous production of good quality gas. The gas needs to be cleaned well, removing tar and other impurities, before it is fed to the engine.

ACKNOWLEDGEMENTS

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Chapter I

INTRODUCTION

The major advances that have been achieved by man in the economic, technical and industrial areas during the last few centuries are awesome. These advances have created an unbounded faith in mankind's ability to achieve almost all goals that may be set before him. If there is any area that may be singled out as the most important in these recent endeavors it is the supplementing of muscle energy by various forms of mechanical energy. This idea has developed through ages and in fact the whole history of civilization is the history of continued increase in the use of energy by mankind. Not only our bodies but also our life support systems, agriculture and industry, require energy. In a paper presented at the Agricultural Engineering Conference Days, Lapp(1974) stated, that if energy is withdrawn from agriculture and industry, our life support systems would cease to function.

As a result of the concern for a continuous secure supply of energy, attention has been focused on the need not only to conserve conventional sources of energy as alternative energy, but also to explore the potential for non-conventional sources as alternatives. Though Canada is not in an

energy crisis (Energy Alternatives,1981), it must respond to the alternative energy challenge more quickly or be placed in the paradoxical position of having a wealth of energy potential but a shortage of energy options because of failure to capitalize upon that potential.

Biomass which refers to all matter of plant or animal origin excluding fossil fuels (Energy Alternatives,1981), has been suggested as an important alternative energy source (Klass,1982). Today the use of biomass for energy varies in different areas of the world and depends in part on the level of development of the various countries. In the United States for example, biomass conversion amounts to about one percent of the United States energy supply (Vergara and Pimentel,1978) while in the Sudan it accounts for as much as 65 percent. An estimated use of biomass for energy in Canada in 1980 was 3.5 percent of the total energy used. It is believed that biomass could contribute 10 percent of Canada's energy supply by the turn of the century (Energy Alternatives,1981).

Various studies have suggested that producer gas from biomass has potential as an alternative source of energy, particularly in developing countries. A comparison with other renewable energy options, on the common basis of energy efficiencies and economics, shows that gasification technology may have significant advantages and deserves serious at-

tention. Internal combustion engines are used extensively in developing countries for generation of electricity, water pumping, on field machines and in transportation. In areas where there is an excess of locally produced biomass, it is reasonable to consider the utilization of energy conversion processes to produce fuels which could have the potential to replace conventional fossil fuels. Since vast quantities of biomass, including large reserves of peat, are available in Canada as well as in many developing countries, this thesis project on biomass gasification was undertaken.

Objectives:

To evaluate the feasibility of applying the gasification process to biomass in order to assess its potential as an alternate fuel for internal combustion engines.

Specific objectives include:

1. to build and operate prototype models of updraft and downdraft gasifiers to gasify peat moss and wood, and
2. to utilize the producer gas to fuel a small, spark ignition internal combustion engine.

Chapter II

REVIEW OF LITERATURE

2.1 BIOMASS

Biomass refers to all matter of plant or animal origin excluding fossil fuels (Energy Alternatives,1981). Hall(1981) defines biomass as, "All forms of plant and animal materials, grown on land, in or on the water, and substances derived from biological growth, such as animal, plant and human wastes and residues, consisting primarily of carbon, hydrogen, and oxygen". Biomass is a general term which comprises agricultural crop residues, manures from confined livestock, wood and bark residues from primary wood product manufacturing mills, bark residues from the wood pulp industry, peat, logging residues from timber harvesting operations, non-commercial components of standing forests, and the organic fraction of municipal solid waste (Reed,1981). The high organic content of biomass makes it an exploitable energy resource, because the carbon contained in the large molecules of biological organisms can be made to undergo a variety of chemical reactions which either release energy directly, or convert the original substance into new forms which can be reacted later to release energy (Energy Alternatives,1981).

There are a number of advantages which apply to the exploitation of biomass as a source of energy:

1. ready availability,
2. renewability,
3. clean, nearly pollution-free combustion,
4. low energy and capital requirements for production,
and
5. no requirements for special storage facilities.

There are, however, a number of difficulties associated with using biomass for energy production on a large scale including:

1. relatively low heat value per unit volume,
2. variability of quality and heat value,
3. difficulty in controlling the rate of burning,
4. rapid burning, necessitating frequent refuelling,
5. economic problems in transportation and distribution,
and
6. the source is often in remote locations.

The ultimate applicability of all biomass conversion technologies, including biomass gasification, is restricted by the quantity of biomass that can be made available for conversion. A literature review of biomass availability in Canada detailing the quantity and energy available is discussed in section 2.1.1 following.

2.1.1 Quantity and Energy Available

Various forms of biomass currently account for approximately 3.5 percent of the total energy consumption in Canada per year. (Love and Overend, 1978) This biomass is primarily recovered from wood waste of spent pulping liquors at pulp mills. Table 1 summarizes the quantity for the various types of biomass available in Canada. From Table 1 it can be noted, even excluding the huge potential offered by dedicated forest or crop energy farms that, these sources have a gross energy content of $2.77 \times 10^{18} \text{ J}$, or almost 25 percent of Canada's total energy demand if a 70 percent energy conversion efficiency is assumed (Balatinecz, 1982).

In the less developed countries, 72 percent of the wood that is cut each year is used as a fuel for cooking and heating (FAO, 1978), while only 5 percent of that cut in North America is used for similar purposes. Much of the wood that is currently used in the less developed countries is burned inefficiently. A study done in 1977 by the Brookhaven National Laboratory in New York, presented some interesting numbers on biomass availability for Peru, Thailand, Indonesia, and India (Mubayi et al., 1980). Estimates of available biomass in these countries in various categories are shown in Table 2 which indicates that wood is the dominant potential supplier of energy although crop residues and manures are also very important.

TABLE 1

Estimates for the supply of biomass in Canada per year by
type and source

Type/Source of biomass	Quantity produced 10 ⁶ ODT(@)	Gross energy content 10 ¹⁸ J
Forest waste		
-Mill residues	7.5	0.14
-Residues from forest operations	31.0	0.58
Dedicated forest biomass		
-Unutilized trees in currently logged areas	20.0	0.37
-Wood available in area not currently logged	52.0	0.97
-Energy farms	(*)	(*)
Animal Waste	12.6	0.28
Crop waste	16.9	0.25
Dedicated crops	(*)	(*)
Aquatic biomass	(**)	(**)
Solid waste	10.6	0.17
Sewage sludge	0.4	0.01
Total	151.0	2.77

Source: Love and Overend, 1978

(*) No estimate of the potential contribution of agro-forestry crops designed for energy production could be made.

(**) No estimates available.

(@) Oven dried tonnes.

TABLE 2

Estimates of biomass availability per year in rural areas

Source	Peru		Thailand		Indonesia		India	
	10 ⁶ t	10 ¹⁶ J	10 ⁶ t	10 ¹⁶ J	10 ⁶ t	10 ¹⁶ J	10 ⁶ t	10 ¹⁶ J
Human waste(\$)	0.1	0.001	0.5	0.007	1.6	0.024	7.2	0.107
Animal Manure(#)	5.2	0.078	9.6	0.144	7.5	0.112	148.5	2.228
Crop Residues(\$)	2.7	0.037	16.7	0.234	23.4	0.328	24.0	0.560
Fuel Wood(*)	76.5	1.223	29.7	0.474	108.0	1.728	119.0	1.900
Total	84.5	1.339	56.5	0.859	140.5	2.192	298.7	4.795

\$ - Assuming 50% collectibility

- Assuming 75% collectibility

* - Assuming 15% use of the estimated annual increment of wood.

Source: Mubayi, V., et al., 1980.

The quantity of peat available for energy conversion has been separated from the overall potential biomass because in the literature cited peat is alternately referred to as biomass and fossil fuel. Peat is described as partially fossilized plant matter which occurs in wet areas and is formed by the decay of the vegetation under anaerobic conditions (Monenco,1981).

Peat is a worldwide resource. It is widely used commercially in Ireland, Finland and Russia as a source of energy. According to a recent United Nations(UN,1980) report the world peatlands are estimated to cover 420 million hectares. Table 3 contains estimates of peatland areas in various selected countries. Peat is commercially produced in almost every country. The current annual production of fuel peat (Punwani,1981) corresponds to about 0.45 percent of the world output of other fossil fuels.

According to the UN report, the energy contained in world peat resources is estimated to be equivalent to over 630 billion barrels of oil, which is equivalent to more than 50 percent of the world's known natural gas resources.

Although Canada has almost 40 percent of the world peat resources, it produces only 0.2 percent of the total of 220 million tonnes produced worldwide (Table 4). Even if only a fraction of the total peat resources is economically recoverable, there is a significant peat resource that should not be ignored for energy recovery.

TABLE 3

Present estimates of the total world peatlands

(Millions of hectares with more than 30 cm of peat)

Geographical Location	Area (10 ⁶ ha).
Canada	170.000
USA	40.000
USSR	210.000
Asia	32.040
Europe	28.240
S.America	0.495
Australia	0.165
Middle East	0.050
Total	480.990

Source: UN Report, 1980.

TABLE 4

Present production of fuel and horticultural peat

(Thousands of tonnes per year, 40 percent moisture content w.b.)

Location	Fuel peat(*) 10 ³ tonnes	Horticultural peat 10 ³ tonnes	Total 10 ³ tonnes
USSR	80,000	120,000	200,000
Europe	8971	4334	13305
Asia	800	1300	2100
Canada	-	488	488
USA	-	330	33
Others	100	2412	251
Total	89871	128864	216177

Source: UN Report, 1980.

(*) 1 tonne of fuel peat = 11,605 MJ

2.2 HISTORY OF GASIFICATION

The history of gasification reveals that gasifiers were first developed in the mid-nineteenth century in Germany. Towards the end of the century stationary gas producers were being used to gasify wood and coal (Habib and Stebar, 1981). The beginning of World War II and the scarcity of liquid fuels in Europe intensified the search for domestically available fuels and resulted in a great surge of activity in designing and installing gas generators. In Sweden, approximately 70,000 vehicles were converted to generator gas operation within two years (Johansson). These engines operated reliably although there was a derating of power output to approximately 75 percent of the gasoline rating. It requires 8 kg of wood to replace 4.5 litres of gasoline (SERI, 1979). The end of World War II brought renewed availability in supplies of liquid fossil fuels and a rapid reconversion of vehicles to the convenient diesel and gasoline fuels.

With the increase in oil prices and concern for the security of supplies following the formation of OPEC, there has been a renewed interest in all forms of gasification production and utilization technology.

2.2.1 Gasification Processes

A simple definition of gasification observed in the literature states that, "Gasification is the conversion of a solid to a gas by heating without leaving a combustible residue"

(Hall,1981). Another simple description from the literature states that, "Gasification is the controlled, partial combustion of the fuel" (Habib and Stebar,1981). The gasification process uses the intense heat of partial combustion to break molecular bonds in the fuel, thus transforming the solid fuel to a gaseous fuel. Pyrolysis, which is the destructive decomposition of biomass using heat to produce char, pyrolysis oil, and medium energy gas (Reed,1981), is often referred to as a gasification process by various researchers (Levelton et al,1980). The presence of air is not necessary for thermal decomposition of biomass which will decompose under vacuum or in an inert atmosphere. Gasification systems can, therefore, be directly fired with air or oxygen or indirectly heated by an external source.

Air Gasification: The production of a low energy gas containing primarily hydrogen and carbon monoxide can be achieved by burning biomass with a limited supply of air. The gas produced typically has an energy content of 3.7-9.3 MJ/m³ .

Oxygen Gasification: When biomass is burned with a limited supply of oxygen it will yield a medium energy gas (11-16 MJ/m³).

Hydrogasification: Describes the conversion of biomass to a high energy gas in the presence of pressurized hydrogen with an energy content of 37 MJ/m³ .

Pyrolysis Gasification: The biomass fuel is heated in an environment which is void of oxygen by an external heat source to produce a gas with a medium energy content of 11-16 MJ/m³ .

Biomass can be converted to a number of useful products through the processes shown in Figure 1. A schematic for an air gasifying system is shown in Figure 2 (Reed,1981). The biomass in the gasifier is supported by a grate and an additional fuel is stored in a vessel directly above the gasifier. Preheated air is introduced into the bed of solid fuel through air nozzles (cross-draft), or through the grate supporting the solid fuel (updraft). The bed pressure drop is initially overcome by a blower, until the engine starts, and then by the intake suction of the engine. Producer gas laden with ash, soot, tar and acids exits from the gas producer.

Producer gas first goes through an ash removal system, such as a single or multistage cyclone cleaner and filters. Ash and soot are collected in a container directly below the ash removal system. The gas then passes through a heat recovery system where heat is transferred to the incoming air. Tar and acids condense from the gas and are removed in this step. To remove fine particulates and other impurities, the gas goes through a final cleaning system which can be a combination of a fibre glass bag filter, a scrubber, and/or a

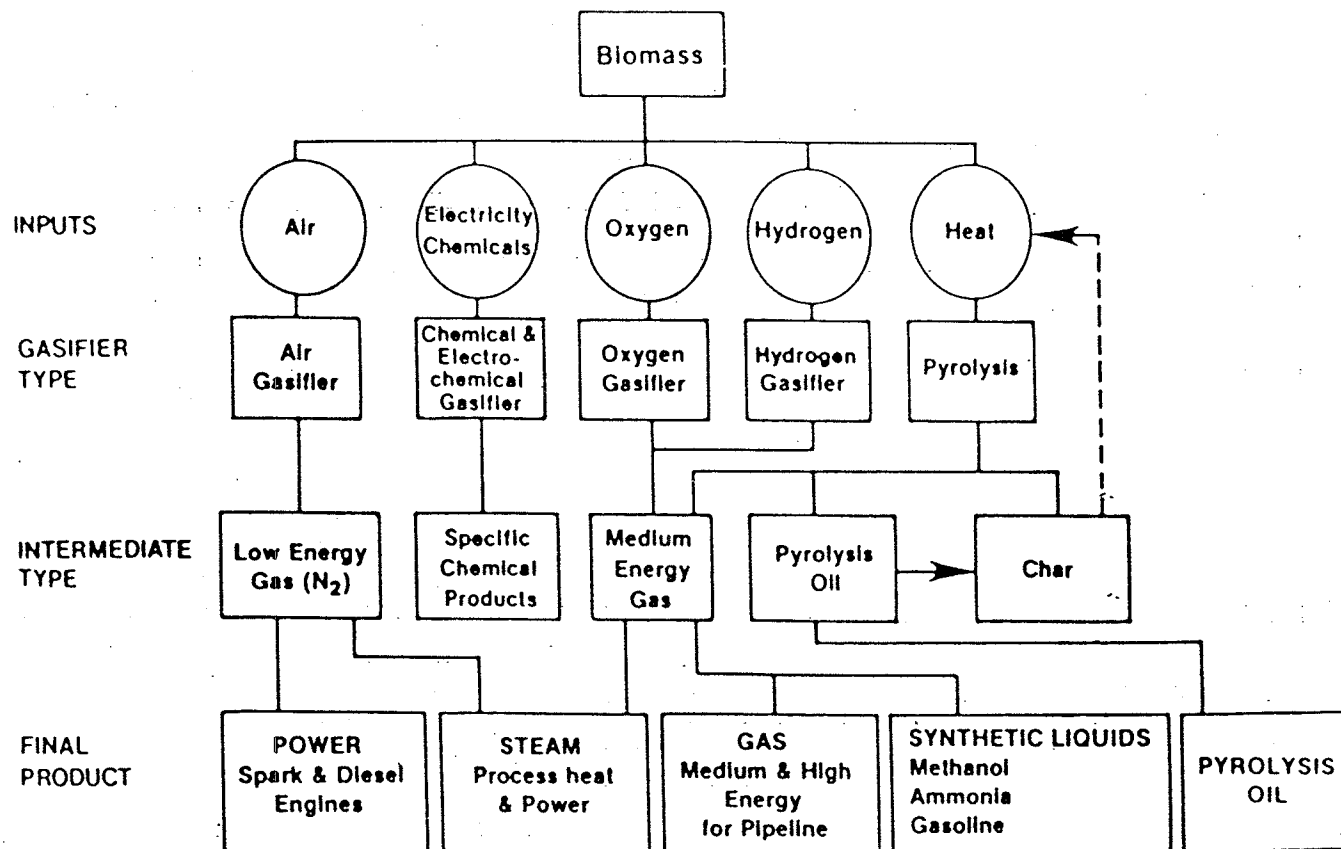


Figure 1: Gasification processes and their products
(Source: Reed, 1981)

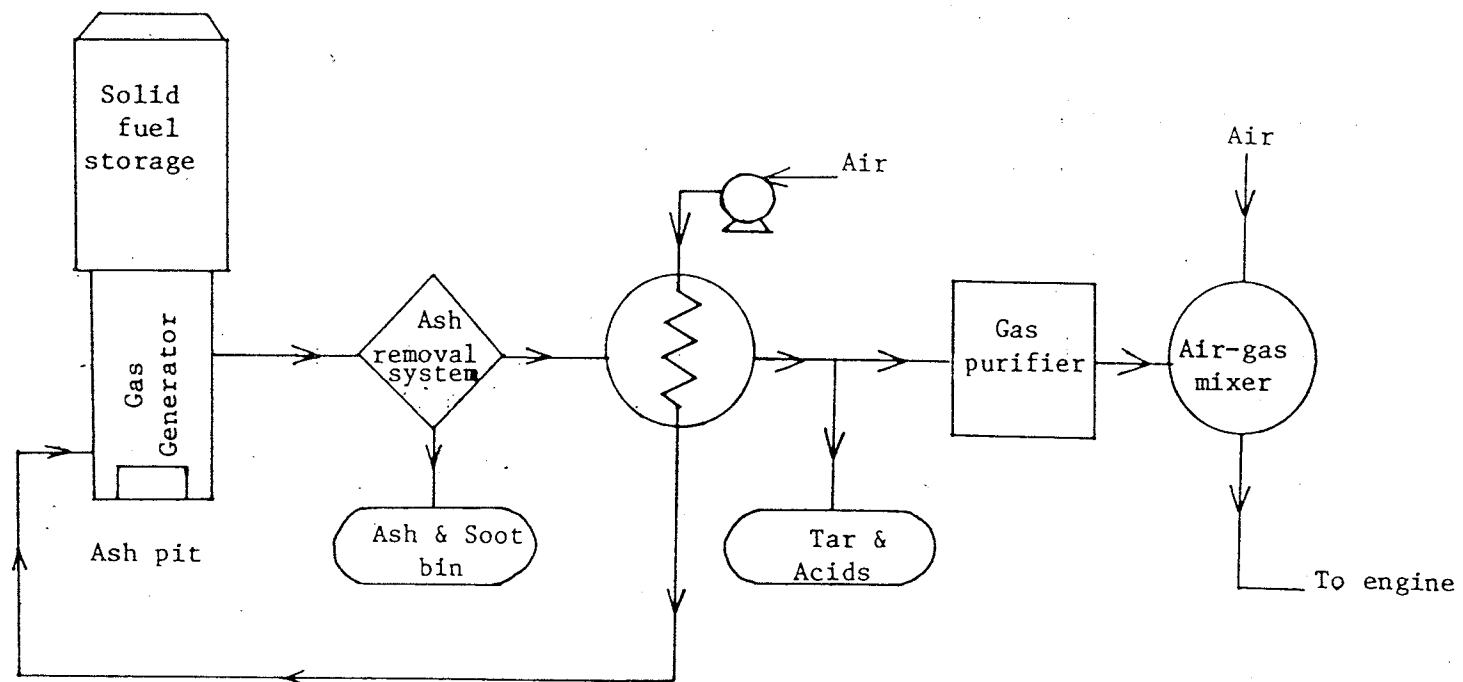


Figure 2: Schematic for gas producer system (Reed, 1981)

charcoal bed. After the gas is cleaned, it is fed to a gas mixer where sufficient air is added. The producer gas-air mixture is then inducted into the engine.

2.2.2 Types of Gasifiers

The object of gasification is to convert the solid biomass elements into gases containing the highest possible energy. Gasification at lower temperatures, 200-300°C, prevents the system from reaching chemical equilibrium and thus produces a high proportion of oils and tar. Conversion of these oils and tar to gases can be accomplished in either fixed or fluidized bed gasifiers. Fixed bed gasifiers are used for bulky fuels such as wood chips, pellets, or corncobs. Up-draft and downdraft are two classifications of the fixed bed gasifier according to the direction and method of air delivery for the process.

In the updraft type, solid fuel is fed into the top of the gasifier. Air or oxygen is introduced at the bottom and flows upward (Figure 3). As the fuel moves slowly downward through the gasifier it is dried, distilled, reduced and oxidized. The ash is finally discharged from the bottom.

A disadvantage of the updraft gasifier is that a variety of chemicals, tars and oils are produced in the pyrolysis zone which will condense in the cooler regions near the top of the gasifier.

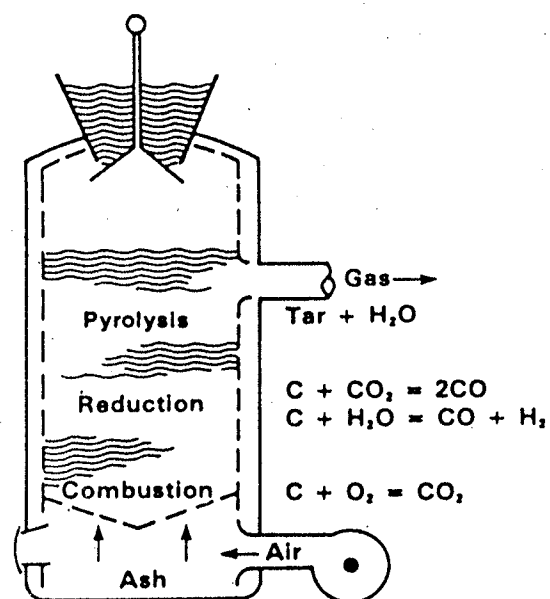


Figure 3: Schematic diagram of an updraft gasifier (Reed 1981)

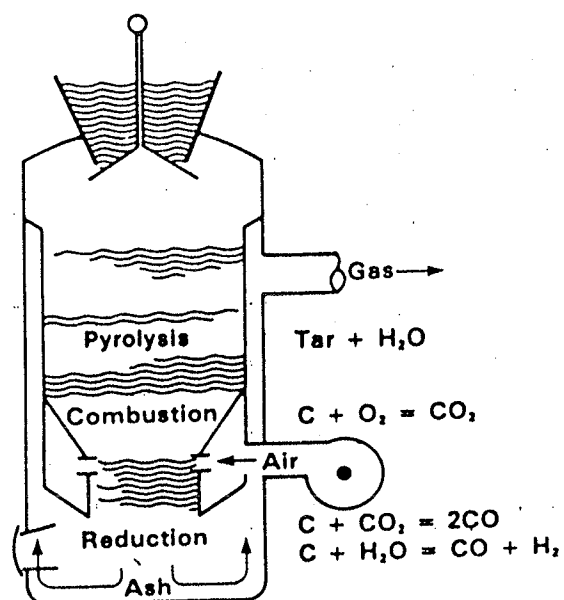


Figure 4: Schematic diagram of a downdraft gasifier (Reed 1981)

The downdraft fixed bed gasifier has the same configuration as the updraft gasifier (Figure 4) except that the air or oxygen flows cocurrently downward with the solid fuel. The fuel gases produced sweep past the oxidation zone of the bed and exit near the bottom of the gasifier. Due to the cocurrent flow and to the drawing off of the gases from the bottom, a vertical temperature profile as shown in Figure 5 will develop. In the downdraft gasifier the devolatilization products encounter high temperatures, in the range of 800-1000°C and break down into smaller molecules, thus reducing the tar content in the fuel gas.

Although, the idea of a tar free gas is usually associated with downdraft gas producers and many results of successful gasifiers have been reported, Kaupp (1982) report that no downdraft gasifier exists which can produce tar free gas.

The often claimed homogenous high temperature generated in the throat section of the downdraft gasifiers, which help cracking the tar vapors is usually unobtainable (Kaupp, 1982).

In a fluidized bed gasifier, as shown in Figure 6, a bed of fine particles of solid fuel is fluidized by an air stream passing upward through the fuel at controlled velocity. The bed is continuously subjected to rapid agitation and mixing, resulting in high heat and mass transfer rates. Since fluidized bed gasifiers are a newer development than

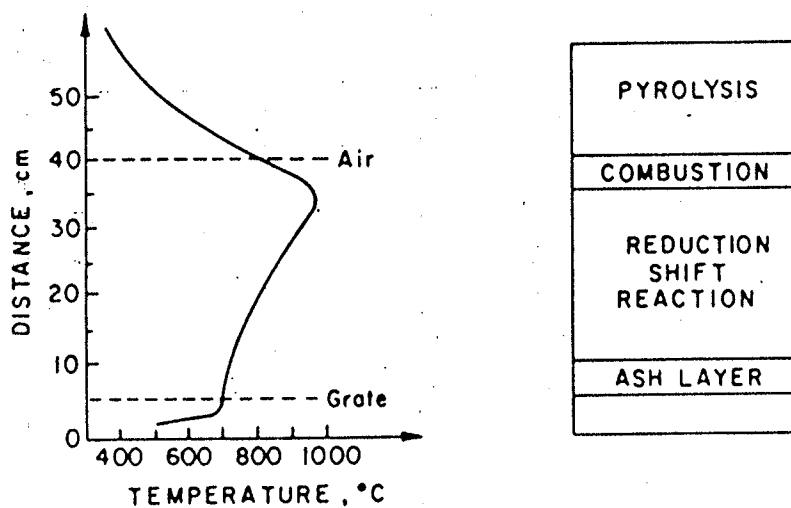


Figure 5: Temperature profile in a downdraft gasifier (Kaupp 1982)

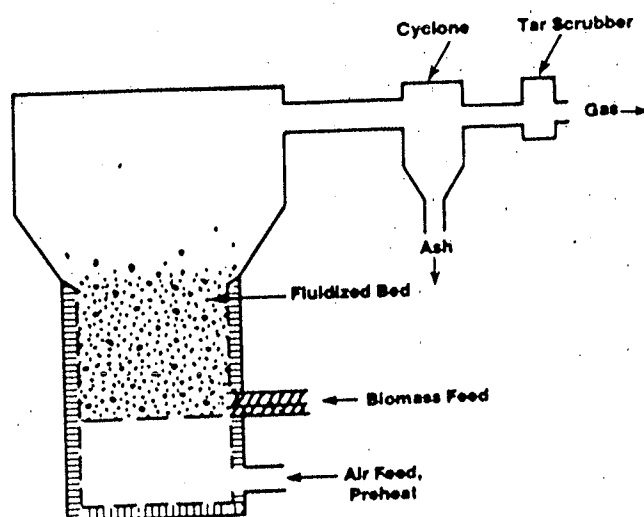


Figure 6: Schematic diagram of a fluidized bed gasifier (Reed 1981)

updraft and downdraft, their characteristics are not well known.

2.2.3 Major Reactions and Chemical Equilibrium

The production of producer gas, which is "gasification" or partial combustion of a solid fuel, is, like the total combustion of a solid fuel, a reaction at a high temperature between the oxygen of the air and the solid fuel. In total combustion there is usually a surplus of air or oxygen; in gasification there is a surplus of the solid fuel.

The processes occurring in any gasifier are oxidation, reduction, pyrolysis and drying. Figure 7 shows the reaction zones and a schematic temperature profile for an updraft gasifier. The reactions taking place in the gasifier are listed in Table 5.

In the lowest zone (Figure 7), oxidation of char¹ with oxygen(O_2) occurs. The heat produced by this exothermic reaction drives the subsequent processes. The gas stream issuing from the oxidation zone is hot and rich in carbon dioxide(CO_2). The high temperatures, 900-1000° C, in the oxidation zone favour the reduction reactions c and d (See Table 5) which are highly endothermic. As the gases rise beyond the reduction zone, they come in contact with cooler, solid fuel. The temperature falls below 600°C and the reduc-

¹ A dark-colored form of carbon made from vegetable or animal substances at 500-750°C

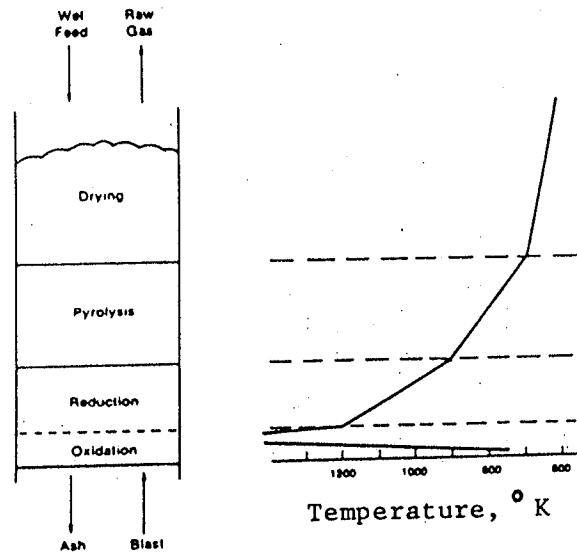


Figure 7: Major processes occurring in an updraft gasifier (Reed 1981)

TABLE 5

Important reactions in gasification

Reactions	H(kJ/mole)	
	25°C	727°C
a) $\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$	41.2	34.77
b) $\text{C} + 2\text{H}_2 = \text{CH}_4$	74.93	89.95
c) $\text{C} + \text{H}_2\text{O} = \text{CO} + \text{H}_2$	-131.40	-136.0
d) $\text{C} + \text{CO}_2 = 2\text{CO}$	-172.60	-170.7
e) $\text{C} + \text{O}_2 = \text{CO}_2$	393.80	394.9

tion and the water shift reactions are frozen. The partially dried feed above the char bed is pyrolyzed by the rising hot gas stream. The immediate products are low molecular mass hydrocarbons, alcohols, acids, oils, and tars, as well as CO , H_2 , CO_2 , H_2O and CH_4 . The hydrocarbons undergo cracking and reforming to H_2 , CO , and CO_2 . The temperature near the top of the bed is too low for this reforming to be completed and the raw gas stream leaving the reactor is laden with products which are not characteristic of the equilibrium established in the reduction zone. Desrosiers (1981) observed that, in a downdraft gasifier, a near-equilibrium product distribution is achieved because the final gas-solid contact involves hot char rather than volatile laden feed as is the case in an updraft gasifier.

The composition of the gas produced by a gasifier depends on the degree of equilibrium attained in the various reactions (SERI, 1979). The chemical equilibrium in turn depends on the temperatures, residence times, and gas-solid contacting methods (Desrosiers, 1979). Wark (1971) defines chemical equilibrium as the ratio of the reactants in a reaction. Thimsen and Morey (1981) used an equilibrium model to calculate equilibrium compositions of corn cob flames. They carried out a full series of composition calculations for moisture contents of 0, 5, 10, 15, 20, and 50 percent w.b., and equivalence ratios² of 1.19, 1, 0.8, 0.59, 0.4, 0.2 and 0.1

² A concept widely used in the study of fuel combustion.

and temperatures from 300 to 1600°C . They found that at equivalence ratios of 1.0 or more the equilibrium composition is almost nitrogen (N_2), water vapor (H_2O), and carbon dioxide (CO_2) (See Figure 8). They also observed that, as the equivalence ratio decreased, significant amounts of CO and H_2 were present in the final gas composition. A typical composition of gas obtained from corn cobs at a moisture content of 20 percent w.b. and equivalence ratio (ER) of 0.2 is shown in Figure 9. In a similar kind of experiment with air gasification of dry wood Desrosiers (1979) reported that the chemical energy stored in the gas is maximum at an equivalence ratio of 0.255 (See Figure 10). Thimsen and Morey (1981) and Desrosiers (1979) concluded that, for best results, the temperature inside the system, in the oxidation zone should be greater than 725°C and that the ER be adjusted to 0.255. In a fixed bed gasifier, however, the ER is not adjusted easily. The variation of the gas composition with temperature for a fixed ER was studied by Desrosiers (1979). He found that, in oxygen gasification of dry wood, maximum energy gas is obtained if the temperature is in the range of 900-1000°C.

Though the attainment of chemical equilibrium in a gasifier seems to be important, only two of the various references cited have studied chemical equilibrium on laboratory

Equivalence ratio (ER) is the oxidant to fuel weight ratio divided by the stoichiometric ratio (Reed, 1981).

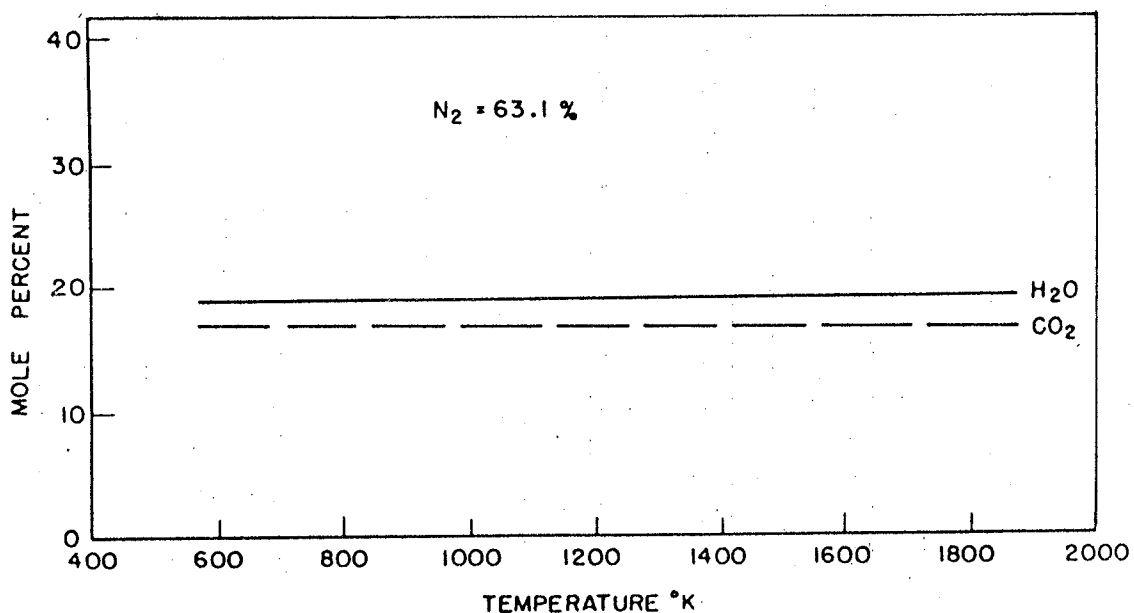


Figure 8: Gas composition of corncocks at 20% moisture content (w.b.) and E.R.=1.0 (Thimsen and Morey 1981)

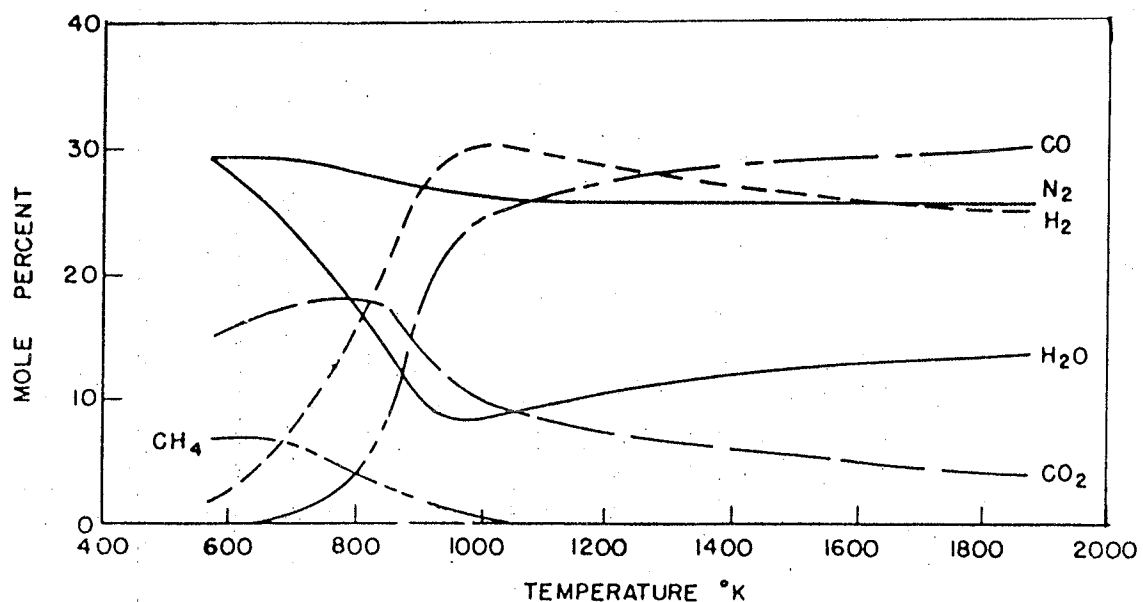


Figure 9: Gas composition of corncocks at 20% moisture content (w.b.) and E.R.=0.2 (Thimsen and Morey 1981)

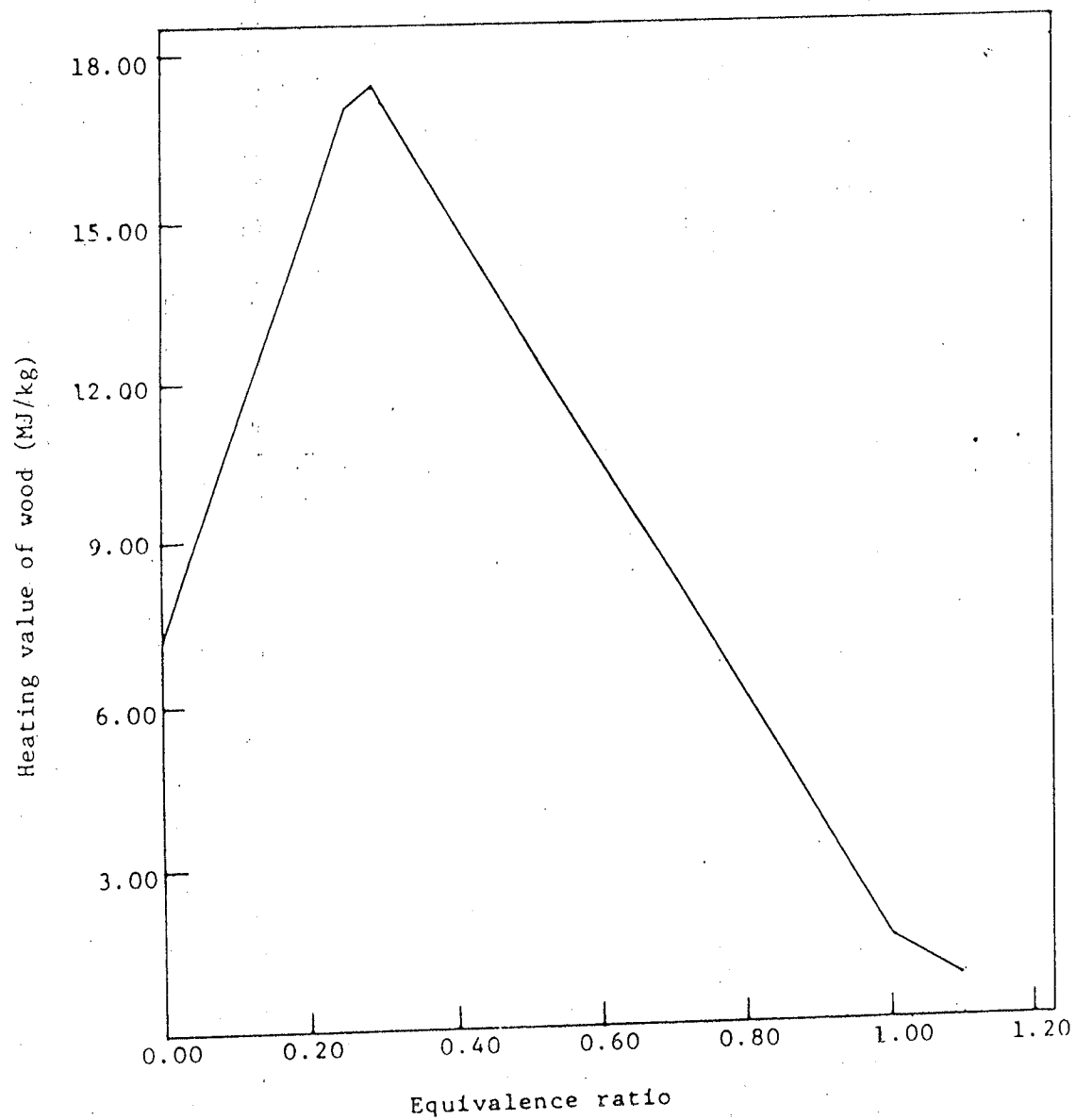


Figure 10: Energy in the producer gas from air-gasification of wood (Desrosiers 1981)

models under controlled conditions. While limited information was noted in the literature, it seems hardly possible to attain equilibrium without having control over the temperature, air to fuel ratio and other factors that affect chemical equilibrium.

2.3 HEATING VALUE OF BIOMASS

The energy released upon burning a unit mass of solid fuel is the heating value. The heat value obtained by burning a substance in a closed chamber, where the heat of vaporization of water and the heat of condensation of water vapor formed by the combination of hydrogen and oxygen are added to the heat of the combustion of solid material, is called higher heat value (Saxena and Buchanan, 1982). Lower heat value represents the heating value of a substance burnt in open air, where the heat of vaporization and the heat of condensation of water and the water vapor are lost.

The heating value of biomass is important in the process of gasification as it directly affects the heating value of the gas produced. It ultimately influences the efficiency of a gasifier which is the ratio of the heating value of the produced gas to that of the feedstock. Table 6 shows the higher heat values of various biomass and fossil fuels. The heating values and chemical properties of various gases are compiled in Table 7.

TABLE 6

Higher heat values of various biomass and fossil fuels

Fuel	MJ/kg	Moisture content % w.b.
Biomass		
Peat		
Sod peat	11-14	30-45
Peat pellets	13-16.5	14-30
Peat briquettes	17-18.5	10-15
Wood		
Birch	20.08	*
Elm	20.45	*
Oak	18.99	*
Pine	20.66	*
Poplar	20.70	*
Wood Residue		
Pine bark	21.02	*
Pine sawdust	20.36	*
Pine shavings	20.49	*
Agricultural residues		
Oat straw	7.60	27.68
Barley straw	8.25	30.79
Flax straw	9.00	17.13
Corn silage	10.80	25.79
Fossil fuels		
Bitumenous coal	31.30	-
Fuel oil	42.90	-
Gasoline	43.50	-
Natural gas	58.00	-
Propane	49.70	-

Source: Saxena and Buchanan, 1982 and Harker and Backhurst, 1981.
 (*) : Data not available.

TABLE 7

Heating values and chemical properties of common gases.

Gas	Chemical symbol	Molecular weight	Density kg/m ³	Heating value MJ/m ³	Stoichiometric Air ratio m ³ /m ³	Heating value of Stoichiometric mixture. MJ/m ³
Carbon monoxide	CO	28	1.25	11.97	2.38	3.54
Hydrogen	H ₂	2	0.089	12.10	2.38	3.57
Methane	CH ₄	16	0.717	37.70	9.52	3.58
Ethane	C ₂ H ₆	30	1.356	66.07	16.66	3.74
Acetylene	C ₂ H ₂	26	1.171	55.85	11.90	4.32
Carbon dioxide	CO ₂	44	1.977	-	-	-

Source: SERI: Generator Gas- The Swedish Experience from 1939-1945, Golden, Colorado.

2.3.1 Effect of Moisture Content

The moisture content of the feedstock has a direct influence on the heat content of the feedstock as well as on the quality of the gas produced. Saxena and Buchanan (1982) reported on heat recovery from burning of agricultural residues. They found that most crop residues had little or no available heat value when the moisture content was greater than 50 percent w.b. Table 8 shows the gas composition, at various moisture contents of hybrid poplar, found in a test series conducted by Forintek (1981). At increasing moisture contents the concentration of carbon-dioxide produced in the gas increases thus decreasing its calorific value. Salo Kari et al.(1980) reported that the moisture content of peat should not exceed 40 percent. If the moisture content is higher, peat is not dried. totally in the drying zone of the gasifier and water is carried over into the gasification zone. As a consequence, the temperature decreases and the process of gasification is adversely affected. The result of the experiment carried out by Salo Kari et al. (1980), (See Figure 11) showed that the chemical efficiency on a dry and raw gas basis decreased significantly as the moisture content of the peat, increased.

TABLE 8

Gas composition and calorific value of hybrid poplar tree
chips at various levels of moisture content

Gas composition (% by volume)	Moisture content(%w.b.)		
	13	24	34
H ₂	17.5	16.7	15.1
CO	19.7	16.0	11.9
CH ₄	3.5	3.2	2.1
C _x H _y *	2.1	1.9	1.4
CO ₂	12.7	15.8	17.7
O ₂	1.9	0.9	0.9
N ₂	42.6	45.5	50.9
Calorific value(MJ/m ³)	7.13	6.37	4.94

Source Forintek Corp., 1981.

* Other hydrocarbons, C₂H₂, C₂H₄, C₂H₆

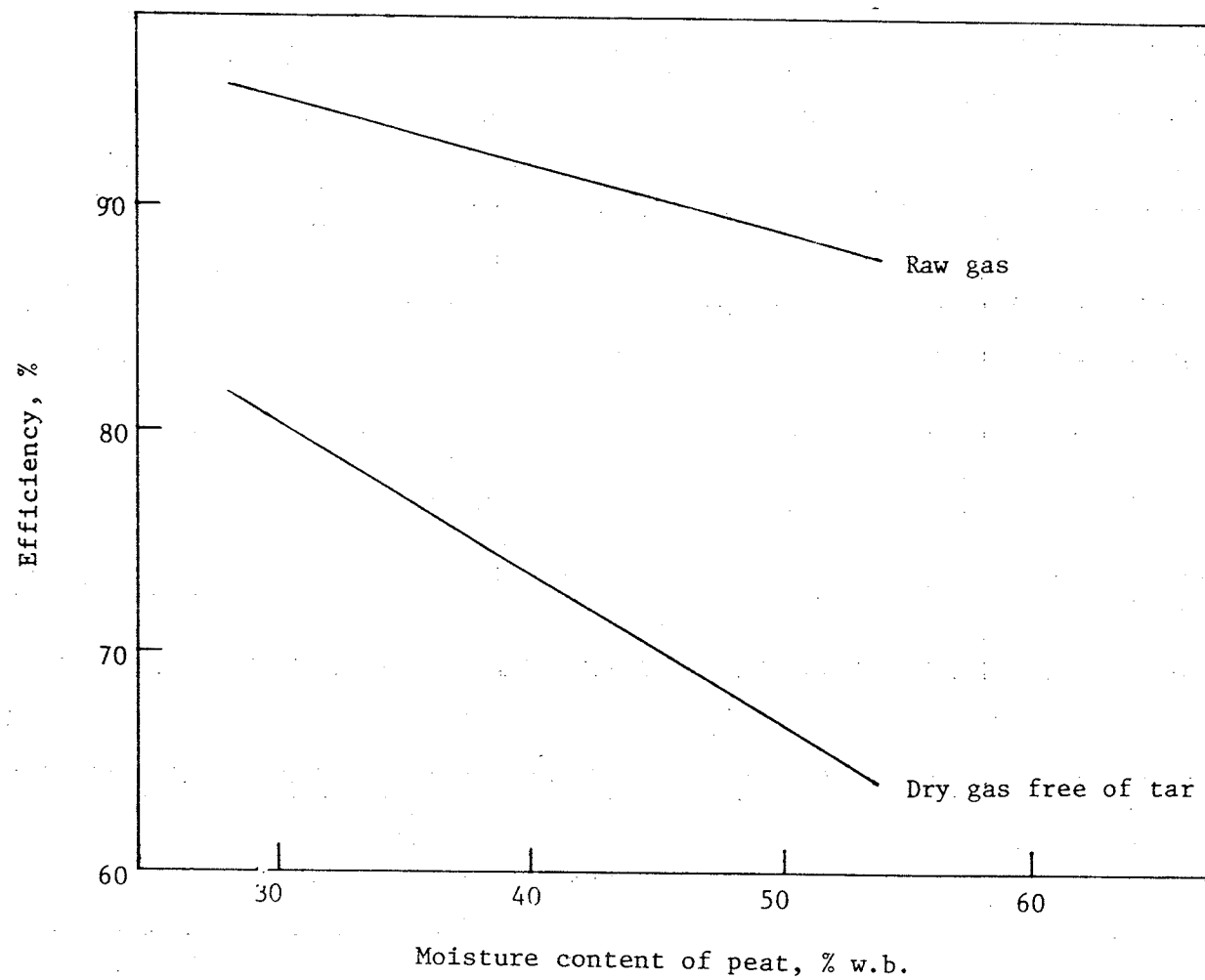


Figure 11: Efficiency of gasifier as a function of the moisture content of sod peat (Kari et al 1980)

2.4 ENERGY USE OF PRODUCER GAS

The gases produced through various gasification processes have a wide range of energy content and corresponding applications, as presented in Table 9. Several research projects in the past have shown that use of gases with low energy content results in some loss of performance in internal combustion engines. The engine performance using producer gas is discussed within this section.

2.4.1 Engine Power Output

Tatom et al. (1976) reported fueling a General Motors truck engine with a pyrolysis gas consisting of 12, 24, 7, and 57 percent hydrogen, carbon monoxide, methane and nitrogen respectively. Engine power output was 60-65 percent of that attained with gasoline. The decrease in power levels is due mainly to the relatively lower heating value of the air-producer gas mixture compared to an air-gasoline mixture (SERI, 1979); also the number of molecules present in the combustion chamber decreases for a producer gas-air mixture. Most researchers reported some power loss due to a drop in volumetric efficiency of the engine. Results presented by Parke et al. (1981) for spark ignition engine performance characteristics when fueled with biomass producer gas, showed that the maximum power output for an engine fueled with natural gas was 12.5 kW which occurred with a nearly correct, but slightly rich mixture. The maximum power de-

TABLE 9
Energy content of fuel gases and their uses.

Name	Source	Energy Range (MJ/m ³)	Uses
Low Energy Gas (LEG) (Producer gas)	Blast furnace	2.97-3.72	On-site industrial heat and power, process heat.
Low Energy Gas (Generator gas)	Air gasification	5.58-7.44	Close-coupled to gas/oil boilers operation of diesel and spark engines.
Medium Energy Gas (MEG) (Town gas, Syngas)	Oxygen gasification Pyrolysis gasification	11.16-18.6	Regional industrial pipelines synthesis of fuels & ammonia.
Biogas	Anaerobic digestion	22.32-26.04	Process heat, pipeline.
High Energy Gas (HEG)	Oil/Gas wells	37.2	Long distance pipelines for general heat, power.
Synthetic Natural gas (SNG)	Further processing of MEG & biogas	37.2	Long distance pipelines for general heat, power.

Source: Reed T.B., 1981.

veloped with producer gas was 8.2 kW which occurred with a lean mixture, about 93 percent of the stoichiometric mixture. The power loss was due to the decreased heating value of the air-fuel mixture entering the engine, which was 2.11 MJ/m³ for producer gas and 3.07 MJ/m³ for natural gas.

2.4.2 Air-Fuel Mixture and Flammability Limits

Spiers (1942) found that maximum engine power using producer gas occurred with a lean mixture about 93.5 percent of the stoichiometric mixture strength for engine speeds of 1000-3000 r/min. Woods (1942) reported that maximum power using producer gas occurred with a mixture 2-3 percent lean.

While the limits of flammability of simple mixtures of a single combustible gas and air have been documented with relative consistency by Harker and Backhurst (1981), (See Table 10), the flammability limits for mixtures of more than one combustible gas are less definite. Stassen concluded that because of the wide range of the flammability limits of the producer gas components, the risk of non-ignition due to incorrect air/gas mixture is less. The theoretical stoichiometric air-gas ratios for producer gas consisting of 1 percent CH₄, 15 percent H₂, and different percentages of CO, as reported by Stassen are presented in Figure 12.

TABLE 10

Approximate limits of flammability of gases in air at STP

Gas	Lower limit (v/v%)	Upper limit (v/v%)
Hydrogen	4.0	75
Carbon monoxide	12.5	74
Methane	5.3	15
Ethane	3.0	12.5
Propane	2.2	9.5
Natural gas	4.8	13.5

Source: Harker and Backhurst, 1981.

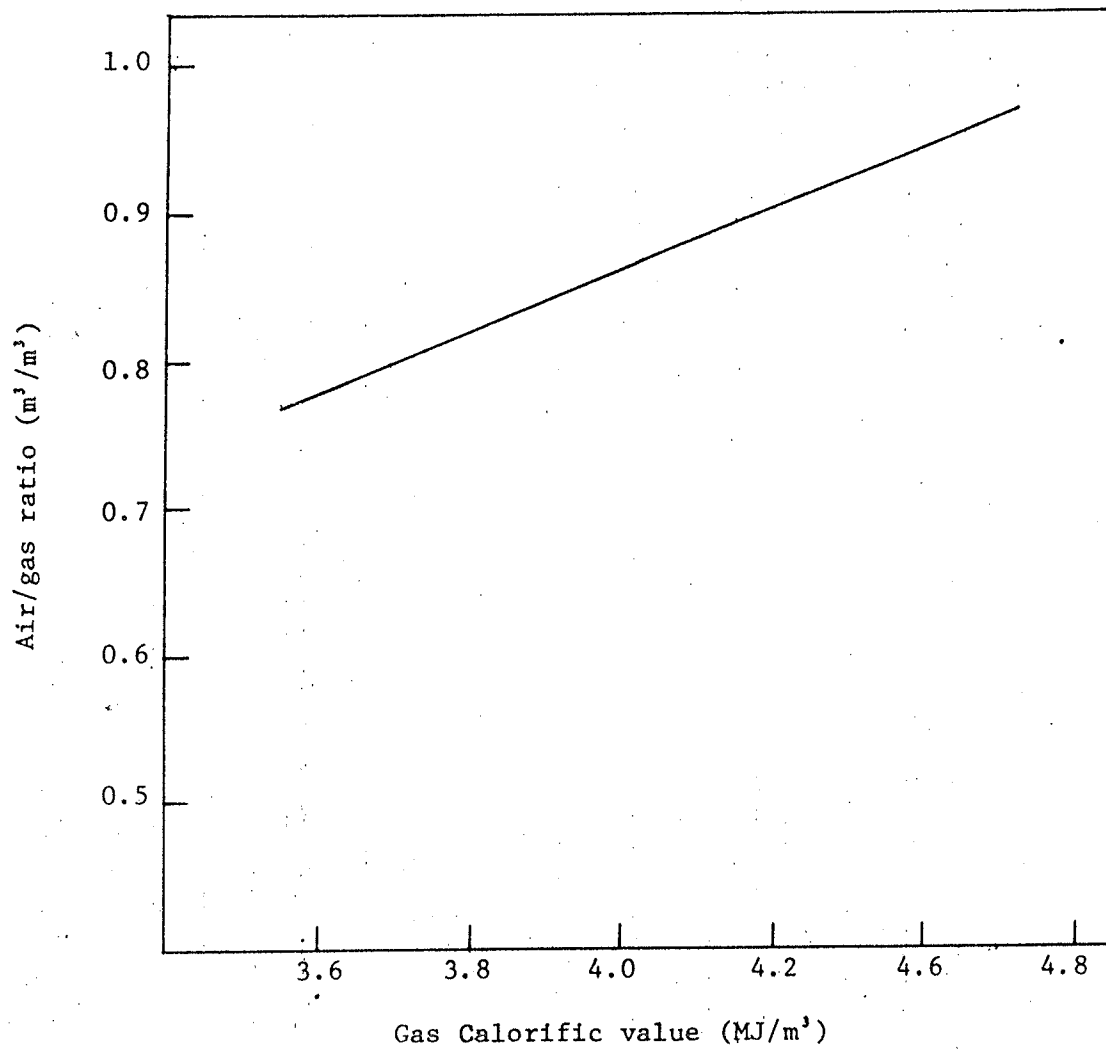


Figure 12: Theoretical variation of air/gas ratio with gas calorific value (Stassen H.E.M.)

Chapter III

PROCEDURES AND RESULTS

3.1 HEAT OF COMBUSTION OF BIOMASS FUELS

The gross heat of combustion of peat, wood and charcoal briquettes was determined by burning weighed samples in an oxygen bomb calorimeter. The net heat of combustion of the fuel samples was not determined because the elemental composition was not available.

3.1.1 Apparatus

Equipment required to determine the heating value of the selected biomass fuels included an oxygen bomb calorimeter, thermometer in the fraction of ° C graduation, standard alkali solution of 0.0725N, benzoic acid pellets, methyl indicator, an oxygen cylinder and timer in fractions of a second.

3.1.2 Standardization of Calorimeter

The Parr oxygen bomb calorimeter and accessories used in the experiment are shown in Figure 13. Two thousand millilitres of distilled water were placed in the oval bucket. A 100 mm length of nickel alloy fuse wire was used to connect the two electrodes for ignition purposes. A standard benzoic acid

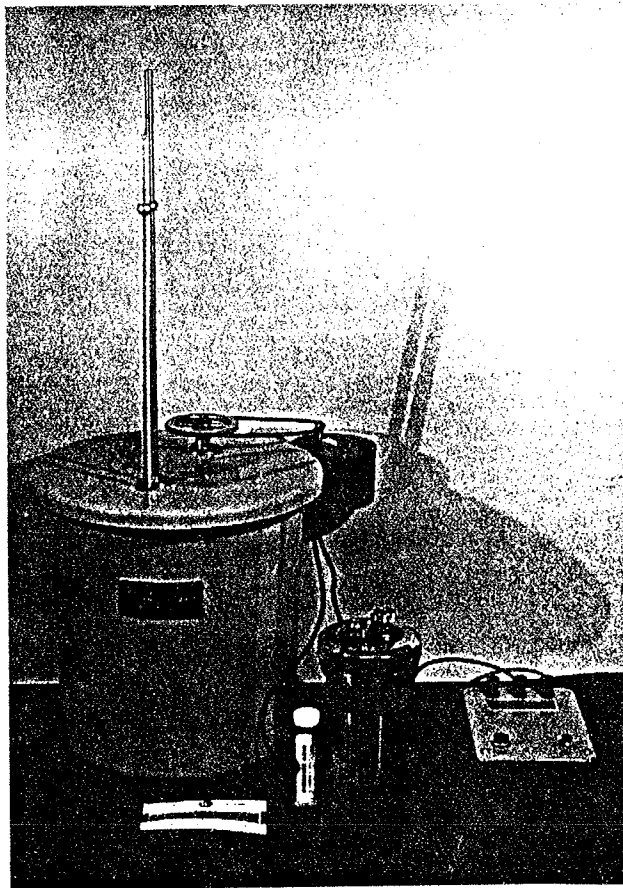


Figure 13: Oxygen bomb calorimeter to determine heat of combustion

pellet was used for standardization. Initially an empty steel capsule was weighed on the balance and reweighed with a benzoic acid pellet. This capsule was placed on a support formed by the electrodes and the fuse wire was adjusted so that it just touched the sample. One millilitre of distilled water was added to the bomb with a pipette. The bomb was then closed and tightened by hand.

The bomb was filled with oxygen until the bomb pressure rose to 2533 kPa (25 atm). After connecting the electric terminals to the electrodes the charged bomb was lowered into the bucket and the calorimeter was closed. After making all electrical connections the stirrer and timer were turned on simultaneously. Before starting, the water temperature was recorded and then readings were taken at one minute intervals. This process continued for about 5 minutes or until any temperature rise ceased. At the instant the temperature rise ceased the ignition unit button was pressed to ignite the nickel wire, which ignited the benzoic acid pellet.

The heat released was transferred by conduction to the bucket water which was indicated by a temperature rise. Again temperature readings were taken at one minute intervals, and were continued for 5 minutes after the temperature rise had ceased. At this stage the stirrer was stopped and the calorimeter cover removed.

The gases inside the oxygen bomb were released by opening the safety valve on the bomb head. When all gases had escaped, the bomb head was unscrewed and the electrodes and the interior of the bomb were washed with 10 ml of distilled water. The length of unburned wire was carefully measured and noted. About 2 to 3 drops of methyl orange indicator were added to the washings from the bomb. These washings were then titrated against a 0.0725N sodium carbonate solution, to find the volume of nitric acid formed.

A graph of time versus temperature, as shown in Appendix A, was drawn to get the time at 60 percent temperature rise. Time and temperature readings were then used to calculate the exact temperature rise by the following equation:

$$t = t_c - t_a - r_1 (b-a) - r_2 (c-b) \text{ ----(1)}$$

where:

t = corrected temperature rise, °C

a = time of firing, min

b = time when temperature reaches 60 percent
of total rise

c = time at beginning of period (after the temperature rise) at which the rate of temperature change had become zero, min

t_a = temperature at time of firing, °C

t_c = temperature at time c , °C

r_1 = rate of temperature rise during first five
minutes, °C/min

r_2 = rate of temperature change during last five

minutes, °C/min

The energy equivalent (W) of the calorimeter was then calculated as follows:

$$W = (Hm + e_1 + e_3) / t$$

where:

W = energy equivalent, J/° C

H = heat of combustion of standard benzoic acid
pellet, 26.454 kJ/g

m = mass of standard benzoic acid pellet, g

t = corrected temperature rise, ° C

e_1 = correction for heat of formation of HNO_3 , J

e_3 = correction for heat of combustion of fuse wire, J

3.1.3 Determination of Heat of Combustion of Biomass Fuel

The procedure for determining the gross heating value of biomass fuel is the same as discussed in section 3.1.2. The value of m in equation 2 is replaced by the mass of fuel sample. The following equation was used to calculate the gross calorific value:

$$H_g = (Wt - e_1 - e_2 - e_3) / m$$

where:

H_g = gross heat of combustion, MJ/kg

e_2 = correction for heat of formation of H_2SO_4 , J

For all the three fuel samples, e_2 was considered to be zero because peat, wood and briquettes have a negligible sulfur content.

The above procedure was followed three times for each fuel sample to have a representative value of the gross heat of combustion. A sample calculation for gross heating value of peat is shown in Appendix A. The results obtained are as follows:

TABLE 11
Gross heating values of fuels used

Solid fuel	Moisture content, % w.b.	Gross heating value, MJ/kg	Standard deviation
Peat	19%	16.54	0.749
Charcoal	8%	18.37	0.437
Wood	23%	18.82	0.268

3.2 GASIFIERS

The object of this thesis project was to build a gasifier and to utilize the produced gas to operate an internal combustion engine driving a 4 kW generator. A downdraft gasifier design was elected initially since this type has been reported to produce a tar-free gas that can be utilized in an engine without much cleaning.

A limited budget was available to cover the cost of building prototype models and it was necessary to keep material costs as low as possible. All designs considered were simple so that the costs for both material and fabrication could be maintained as economical as possible. Three models were built and tested during the course of the investigation. These models are described together with test procedures and results obtained in sections which follow.

3.2.1 Model Number 1

This first model was a very simple unit, which was made from two 0.46 m diameter oil barrels. The gasifier was a suction-type, downdraft reactor with two 12.5 mm diameter inlet holes located 300 mm above the grate, which were near the mid-section of the cylindrical body. A single producer gas outlet, 38 mm in diameter was installed through the perimeter wall into the ash collection zone at the base of the unit. The grate was the bottom of the upper barrel section containing a series of 30 mm diameter holes to allow the passage of ashes. A vertical 12.5 mm diameter shaft was installed in the centre of the gasifier and was attached to a section of grate material at its base. Rotation of this shaft and attached grate material caused ashes to drop into the ash collection zone. A locally available lid, 500 mm in diameter was used for the top of the gasifier. A condensation unit fabricated from 38 mm outer diameter copper tubing

was connected to the gas outlet. Four pipe sections, 600 mm long were set vertically and connected in series. Two condensate taps were installed in the base of the condenser to collect condensate from the producer gas.

Experiments: At start up, the gasifier was initially loaded with sphagnum peat moss, a type of horticultural peat which occurs in South Eastern Manitoba and which was obtained from the Plant Science Department, University of Manitoba. The gasifier was loaded from the grate up to the level of the air inlet holes. Loading was done by removing the top of the reactor.

A burning zone was started on the top of the peat bed by igniting small pieces of wood and when the peat was burning evenly over the entire area at the level of the air holes (this took about 20 minutes to occur from the time the fire was lit), the gasifier was loaded with more peat until it was full. The top of the gasifier was then replaced, and the suction inlet of a shop vacuum cleaner was connected to the producer gas outlet below the grate. The suction of the vacuum cleaner caused air to enter through the air inlet holes, and also from the top of the gasifier, since the lid was not air tight. Later the gasifier was wrapped with fibre glass insulation to reduce heat losses.

Results and Conclusions: No combustible gas was obtained from the gasifier after firing with peat having moisture

contents of 55, 43 and 38 percent w.b. The probable reasons of the failure of model number 1 are as follows:

1. The high temperature needed in the oxidation zone for the thermal cracking of the peat, was not achieved. The fibre glass insulation was also not sufficient to retain heat to reach the required temperature. Though the temperature was not measured, it was obvious that the temperature was too low, as could be sensed by touching the gasifier physically, by hand.
2. The quality of the peat burned may have affected the gas production, because the peat used was a horticultural type, which has different heat content than fuel peat. The analysis of the peat was not available, so it is not possible to comment on the organic content of the fuel.
3. The lid of the gasifier was not air-tight, therefore it is probable that, more air than was needed for the partial combustion was entering the gasifier when the pressure was reduced by the suction of the vacuum cleaner. As a result complete combustion of peat was taking place and the gas leaving the gasifier was non-combustible and probably contained large amounts of steam, carbon-dioxide, and unburned carbon. Though a gas analysis was not performed it can be assumed that the gas contained a high percentage of carbon dioxide, since during many attempts to ignite the gas

with a match the flame was extinguished. Equipment to perform analysis of the gas was not available and the cost to obtain an analysis from commercial sources was beyond the budget limits for the project.

3.2.2 Model Number 2

Because of the lack of success with model number 1, it was decided to design a second model incorporating a number of modifications. The pictorial view and the schematic diagram of model number 2 is shown in Figures 14 and 15 respectively. This unit was fabricated in the agricultural engineering workshop. The material used for fabricating the main body of the gasifier was sheet metal from the walls of a discarded oil burning furnace.

As shown in Figure 15, this unit was 220 mm square in cross-section and 900 mm high. In order to have intense combustion in the oxidation zone, the area in the oxidation zone was reduced by constructing a venturi having a cross-section of 120 mm square. To reduce the heat dissipation the space between the venturi and the inner surface of the outer walls was densely packed with refractory cement. A single air inlet tube 1.25 cm in diameter was installed through the side of the gas producer extending into the reduced area of the venturi, so that the combustion zone was concentrated in the vicinity of this single air inlet. The gas outlet was again placed in the ash zone.

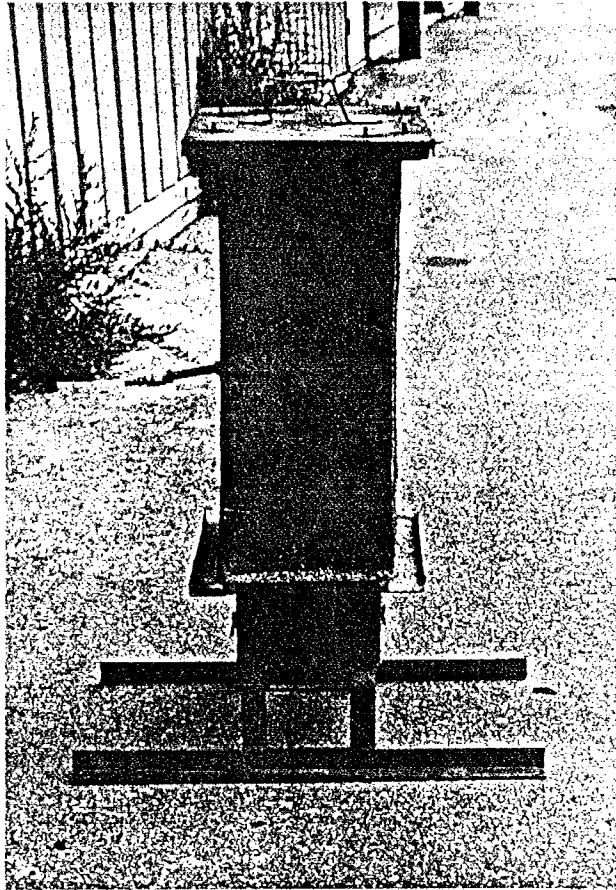


Figure 14: Pictorial view of model number 2

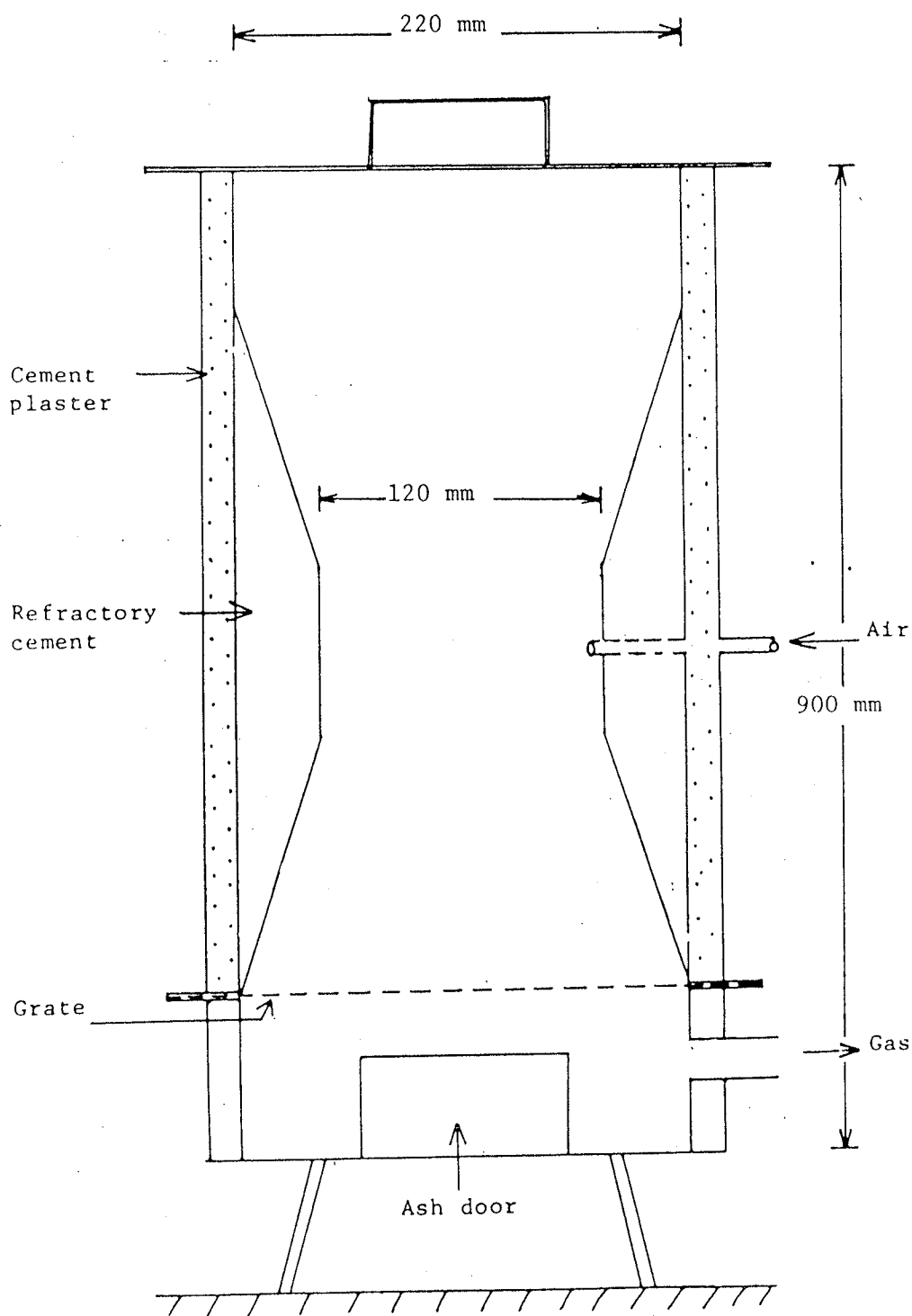


Figure 15: Schematic diagram of model number 2

The condenser which was the same unit that was used with model number 1 was installed on model number 2. After some test trials a cement plaster coating, 12.5 mm in thickness was placed on the outer walls of the gasifier to reduce heat losses and thus to contribute to the goal of achieving a high temperature inside the gasifier.

Experiments: The testing procedure adopted was the same as that used for model number 1, except that this time an air compressor was used to introduce air through the inlet tube during firing. Fuel for the initial trials was wood blocks cut into approximately 25.4 mm cubes, rather than peat. The wood was waste from a local sawmill and lumber yard. The blocks were prepared manually using a band saw and an axe. The wood cuttings used were a mixture of spruce, pine and poplar taken from Manitoba forests. The moisture content of the wood blocks was 23 percent w.b.

In testing, the gasifier was loaded with wood blocks up to the level of air inlet. Lighting fluid was sprinkled on the wood bed, ignited and a fire zone was established. The gasifier was loaded with more wood after the wood was burning evenly at the level of the air inlet, and the cover was put into place. A small aspirator fan was connected to the producer gas outlet leading from the ash zone to induce a downdraft through the gasifier.

A second loading procedure tested was to load the gasifier with charcoal briquettes to a depth of approximately 100 mm above the grate and with wood cubes up to the level of the air inlet followed by firing. A complete charge of charcoal briquettes was fired several times as a third trial procedure.

Results and Conclusions: On several occasions combustible gas was obtained from this second model when it was fired with wood cubes, a mixture of charcoal briquettes and wood cubes and with charcoal briquettes alone. It was observed that the production of combustible gas with each kind of fuel took about two and half to three hours from the start of firing.

The gas composition varied according to the length of time that burning had occurred. Soon after the gasifier was loaded and ignited a large quantity of water vapor was emitted from the wood and as a consequence gas with poor combustion characteristics was obtained during this interval. As fuel was consumed the combustion quality of the gas improved and the gas was observed to burn best when the charge was almost completely burned. The consumption of the fuel made it necessary to refill the gasifier with a fresh charge which lowered the temperature inside the gasifier.

Though temperature was not measured, it was evident from the deterioration of the gas quality that a temperature drop

had occurred. While operating the gasifier, although combustible gas was obtained, the supply of the combustible gas was intermittent and of variable energy content. Good quality gas was obtained only after the air input was increased and the discharge gases allowed to escape for several minutes.

On one occasion when a mixture of wood blocks and charcoal was fired, a continuous supply of readily combustible gas was obtained for a period of over 25 minutes. During this period the gas was delivered into a bottle and burning was sustained at its top as the gas was delivered. The gas was not analyzed as it was very costly to do so.

The gas produced from wood contained large quantities of tar, steam and other impurities which frequently clogged the small aspirator fan which had to be cleaned several times.

The metal used for the walls of the venturi was found to be too thin to withstand the heat generated inside the gasifier. It was observed that the inner wall in the venturi zone opposite to the air inlet was melted after six firings.

During the experiments with models 1 and 2, it was noted that the elevated temperatures that favor the gasification reactions were reached only when the air input to the gasifier was increased under pressure from the air compressor. Increasing the air input accelerated combustion in the burning zone and did increase the temperature, but the combusti-

ble quality of the produced gas deteriorated. Thus the supply of combustible gas was intermittent.

3.2.3 Laboratory Pyrolysis Test

A number of laboratory experiments were conducted to determine whether low temperatures were the barrier reducing gas production in the gasifier. A pyrolysis tube was used to heat the fuel samples for these laboratory tests. The pyrolysis tube was a black iron pipe, 76.2 mm in diameter and 457.2 mm long, threaded at both ends. One end cap had a 5 mm tube gas outlet installed.

The fuel sample was placed in the tube, and both ends of the tube closed. The pyrolysis tube was then heated evenly with a bunsen burner. Sphagnum peat moss and wood shavings were used as feedstock for these laboratory tests. It was observed that when the pyrolysis tube was heated, with wood shavings as a feed stock, combustible gas production was achieved. The outlet tube was inserted in a bottle and the evolved gas was ignited with a match. The gas continued to burn with a yellow flame for 15 minutes after the heating with the bunsen burner was stopped. When peat was heated in the tube combustible gas was obtained only after the tube was heated with two burners for 45 minutes. The flame size obtained by igniting the gas from peat was small in comparison to that obtained from wood shavings.

Though no quantitative measure of the temperature, gas production and gas quality was made, during the bench trials completed with the pyrolysis tube it can be concluded that: peat and wood shavings have a potential to produce combustible gas, provided high temperature favorable for the production of combustible gas is maintained in the system.

3.2.4 Model Number 3

The configuration of model number 3 was basically the same as that of model number 2. The main differences were: the material used in fabrication of the main body was a 250 mm diameter (7 mm thick) black iron pipe. The inner manifold was prepared by welding two cones to a cylindrical throat section 120 mm in diameter and 150 mm high. This inner section thus formed a venturi. There were four air inlets, 90 degrees apart, around the midsection of the cylindrical body. The four air inlets were connected by an outside perimeter plenum tube 25 mm in diameter and discharged into the venturi at mid height of its central section. Air was fed from the air compressor to a single inlet in the outside plenum tube and distributed to the four inlets leading to the cylindrical throat section of the venturi. The pictorial view and schematic of model number 3 is shown in Figures 16 and 17.

The gas outlet was provided in the annular space between the outer cylinder wall and the inner venturi, below the air

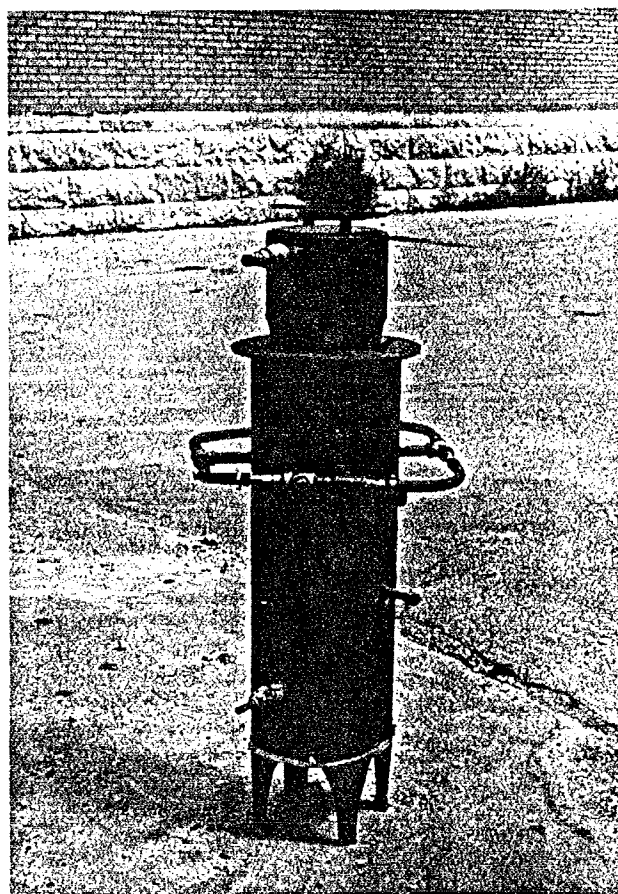


Figure 16: Pictorial view of model number 3

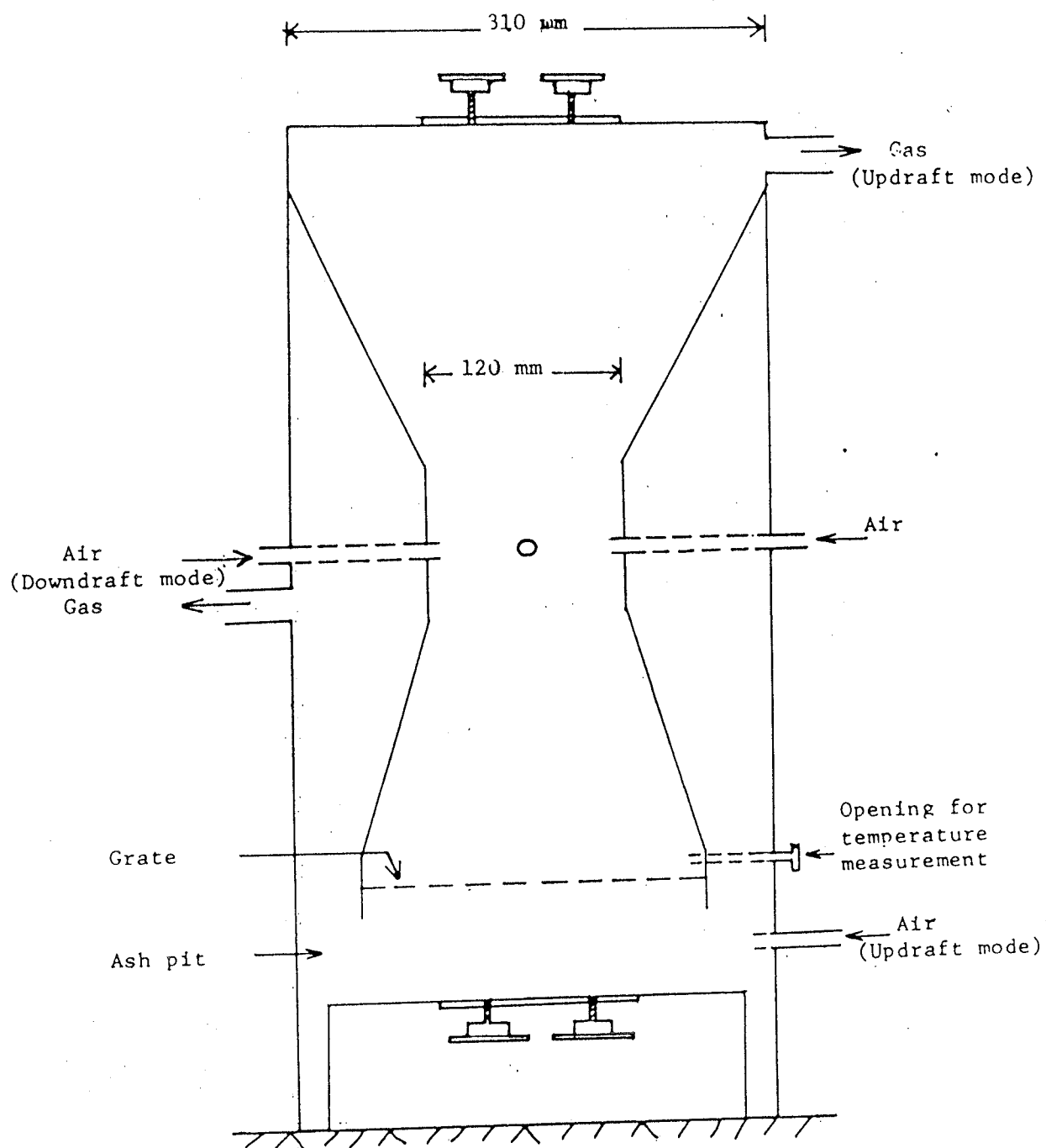


Figure 17: Schematic diagram of model number 3

inlet (See Figure 17). The produced gas was made to travel upwards after exiting from the grate to reach the 5 cm diameter gas outlet leaving the gasifier.

Later the gasifier was modified to operate in an updraft mode, by providing an air inlet in the ash zone and a producer gas outlet near the top of the gasifier. At the same time a hole was drilled through the side wall 5 cm above the grate through which a 1.25 cm diameter pipe was installed and welded into place. This tube extended from the outside into the burning zone and permitted a probe to be inserted so that temperature measurements could be taken. A type K thermometer probe and a meter for recording the temperature were borrowed from the Mechanical Engineering department.

Experiments: When operating as a downdraft gasifier, the unit was loaded with wood blocks, a mixture of wood blocks and charcoal, and charcoal alone for different firings. An aspirator fan was used to draw the produced gas from the gasifier outlet and through the condenser. For one trial the charcoal briquettes were soaked in water for few seconds before loading into the gasifier. The size of the briquettes was reduced by breaking.

When operating as an updraft gasifier, the gas was taken out through the outlet near the top of the gasifier. The temperature in the oxidation zone was measured with a thermocouple probe.

Results and Conclusions: The problem of not achieving sufficiently high temperature, as with the first two gasifiers, was again experienced in model number 3. The temperature recorded in the reduction zone when the gasifier was operated in downdraft mode was only 200° C. The temperature in the oxidation zone was measured by inserting the probe through the air inlet and was found to be 300° C. These low temperatures encountered in the oxidation and reduction zone prevented the occurrence of the reduction reactions which contribute to the formation of CO and H₂. It is reported in the literature (SERI,1979) that it requires 1100° C temperature for the complete reduction of CO₂ to CO. The recorded temperature obtained from operating model number 3 were far from even being close to this requirement. This was the main cause of not getting combustible gas.

When the gasifier was operated as an updraft unit, temperature measurements were again taken in the oxidation and reduction zone. The temperature in the oxidation zone on one occasion was measured at 760° C and that in the reduction zone up to 575° C. These temperature readings were taken after a quantity of air was fed to the gasifier from the compressor. At this stage the top lid of the gasifier was taken off and the gas lighted at the mouth of the gasifier with a match. A fairly good quality gas was obtained as indicated by the vigorous burning and flame production. This flame production continued for ten minutes.

Feeding of more air again caused combustible gas to be evolved and it was observed that the temperature rose in a range from 600-700° C. The temperature soon dropped to around 350-400° C (in 5-10 minutes) after the supply of air was shut off. As long as the temperature in the burning and reduction zone were in the range 600-700° C combustible gas was obtained. Whenever the temperature dropped below this range a non-combustible gas evolved from the gasifier. Since the supply of the combustible gas was intermittent no attempt was made to feed the gas to the engine.

3.2.5 Electric Furnace

An electric furnace was made available for use on the project by Dr. Gallop of the Food Science department. The furnace (See Figure 18) consisted of a 910 mm length of 150 mm diameter pipe heated with three electric heaters mounted along the length of the pipe. The pipe was inserted in an insulated casing. There was a temperature control for each individual heater mounted on the pipe. The range of the control switches was from 37-1093° C. One end of the furnace had a 38.1 mm diameter outlet pipe for the emission of gas. This outlet pipe was inserted through a flange, which served as a cap for closing the furnace. The other end had a similar type of flange cap with an air inlet pipe 6.3 mm in diameter inserted through it.

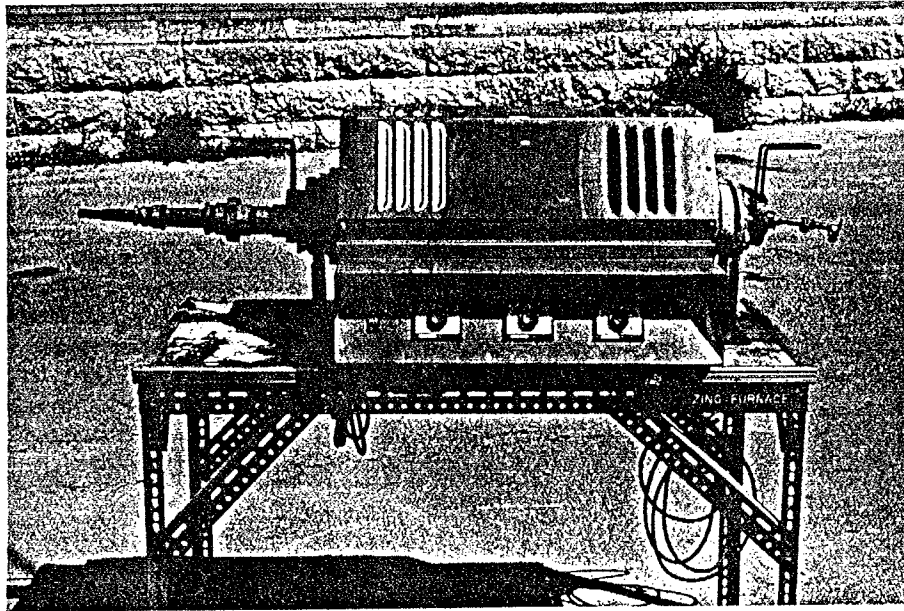


Figure 18: Pictorial view of the electric furnace

Experiments: Three tests were performed using wood blocks, peat and charcoal briquettes. In each test, the starting temperature was set at 37° C and was increased in steps of 37° C until good quality combustible gas was obtained. The gas was passed through a condensing unit to drain off the condensate and tar. After every 10-15 minutes a match was lighted near the outlet to determine if the production of combustible gas had started.

Results and Conclusions: It was observed that combustible gas production began at 537, 593 and 676° C for wood, charcoal briquettes and peat respectively. It took an average of one and a half hours for the gasing to start in this furnace with each kind of fuel. The gas production stopped two and a half hours after it started. The maximum height of flame was produced from wood fuel and measured 400 mm. The flame heights from charcoal and from Sphagnum peat were 155 mm and 140 mm respectively.

Gas Collecting Unit: The gas which evolved from the electric furnace was collected in an over water gas collecting unit employing two tanks as shown in Figure 19. The smaller tank which was 0.58 m in diameter and 0.89 m high was inverted into the larger tank. It was held in place by an angle iron bar welded to the the smaller tank and which rested on the top edges of the larger tank. The smaller tank had two openings in its top end, one for the inlet of gas

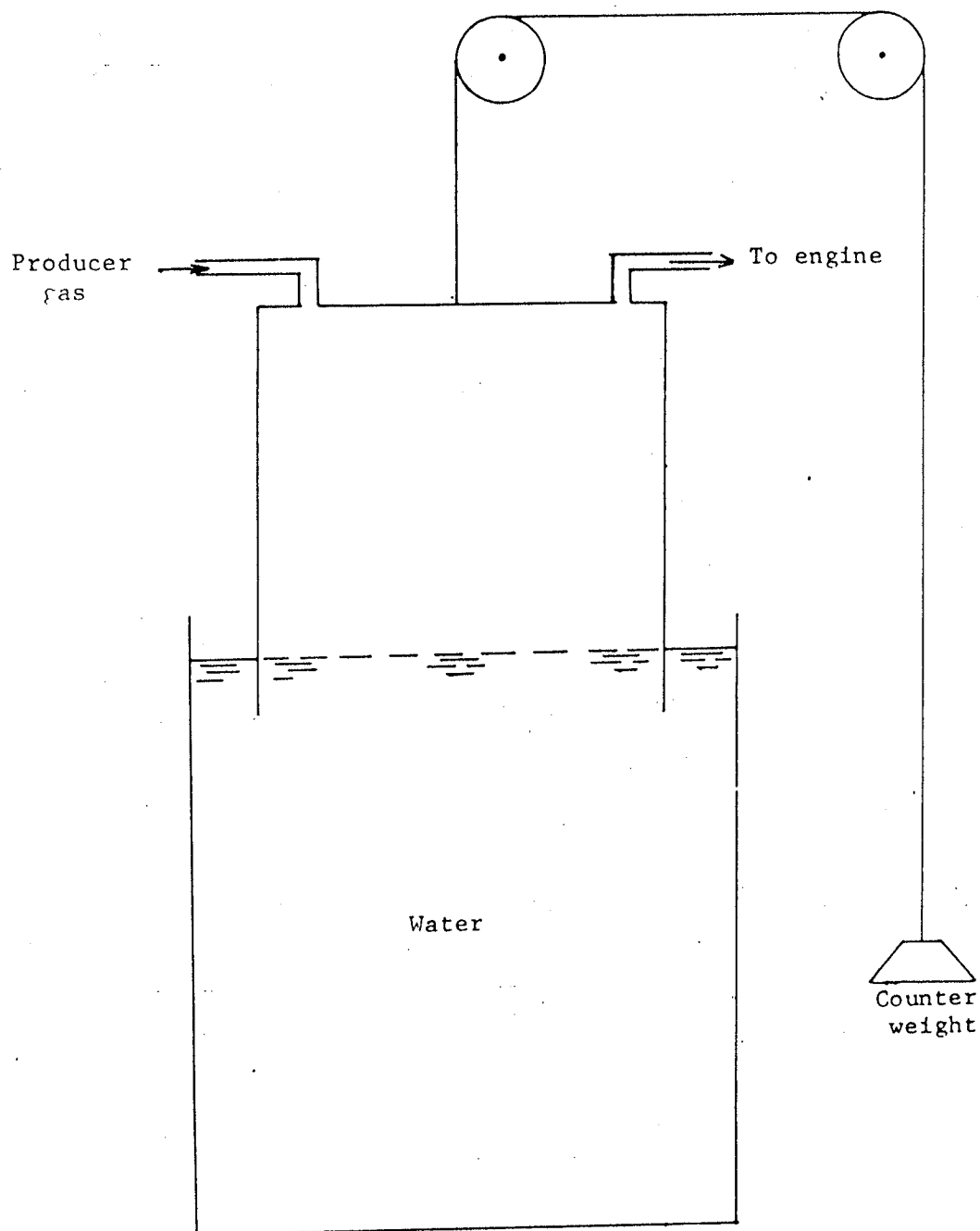


Figure 19: Schematic diagram of the gas collecting unit

from the furnace and the other for the outlet of the gas leading to the engine intake manifold. The larger tank was filled with water. An angle iron rectangular frame was erected over this larger tank upon which two pulleys were suspended. The smaller tank mass was counterbalanced by adding mass in the bucket which was attached to one end of the rope passing over the pulleys while the other end was attached to the top end of the smaller tank.

The electric furnace was loaded with fuel and set to heating mode. Sequential tests for the production of a combustible gas were made by striking matches at the end of the gas outlet tube leaving the furnace. When combustible gas production began the outlet of the furnace was connected to the inlet of the gas collection unit through a water heater hose. The outlet from the gas collecting chamber was plugged and additional mass was added in the bucket to create a vacuum. In this mode of operation combustible gas was drawn into the gas holder from the furnace. The gas holder tank slowly lifted as gas entered from the furnace and raised to accommodate 0.19 m^3 of gas. This stored gas was later used for fueling an internal combustion engine.

3.2.6 Internal Combustion Engine Operation

A used single cylinder, air cooled Wisconsin engine was made available for testing purposes. The engine was coupled to a 4 kW generator which would be used for load testing. A re-

sistance box, borrowed from the Electrical Engineering department was used for loading the generator and thus the engine. The specifications of the engine and the generator are given in Appendix B.

Modifications: It was decided to compare the engine performance operating on producer gas with its operation using propane as fuel. The major modification made for the engine to operate on gaseous fuel was the replacement of the existing gasoline carburetor with an air-gas mixer. A propane tank was purchased and an adjustable pressure regulator was attached to it. The adjustable regulator had the capacity of reducing 1.72 MPa pressure down to 0.013 MPa. A hose 1.5 m long and 6.35 mm in diameter supplied this gas of reduced pressure to a second regulator. This second regulator was a model 300E Algas unit. The outlet from this unit was connected to the air-gas mixer through a valve, which served for shutting off the propane supply to the engine. A tee-connection was installed in the propane line before it entered the air-gas mixer. A valve and a 6.35 mm black iron pipe was connected on the tee, for introducing the producer gas into the engine.

Producer gas has a low heat value ($3-4 \text{ MJ/m}^3$), and ignition timing should be advanced to obtain more complete combustion in an engine since the flame front velocity of the gas is slower than conventional fuels. Ignition timing on

the engine was advanced an additional 15° before top dead centre. The total advance was about 30° in an attempt to improve the engine operation.

Experiments: An attempt to start the engine directly on propane was unsuccessful. To start the engine on propane, 3-4 mL of gasoline was added in the air-gas mixer and the engine was then cranked manually. The propane valve on the tank was then opened and the lever on the second level regulator depressed manually, to allow the propane to flow into the intake manifold. The regulator valve operated automatically under the vacuum created when the engine was running. The speed of the engine was set to 3600 r/min by adjusting the air throttle and the gas flow. The generator output was connected to an adjustable resistance loading system which consisted of electrical resistance coils. The load on the engine was slowly increased by varying the resistances. The speed of the engine at various loads was recorded. A curve of engine speed against the load was then plotted and is presented in Figure 20.

In operating the engine on producer gas, it was first started on propane. When the engine had warmed up after 5-10 minutes, the propane valve was slowly closed and at the same time the producer gas valve was opened slowly. The air throttle was then adjusted until the engine ran satisfactorily on producer gas.

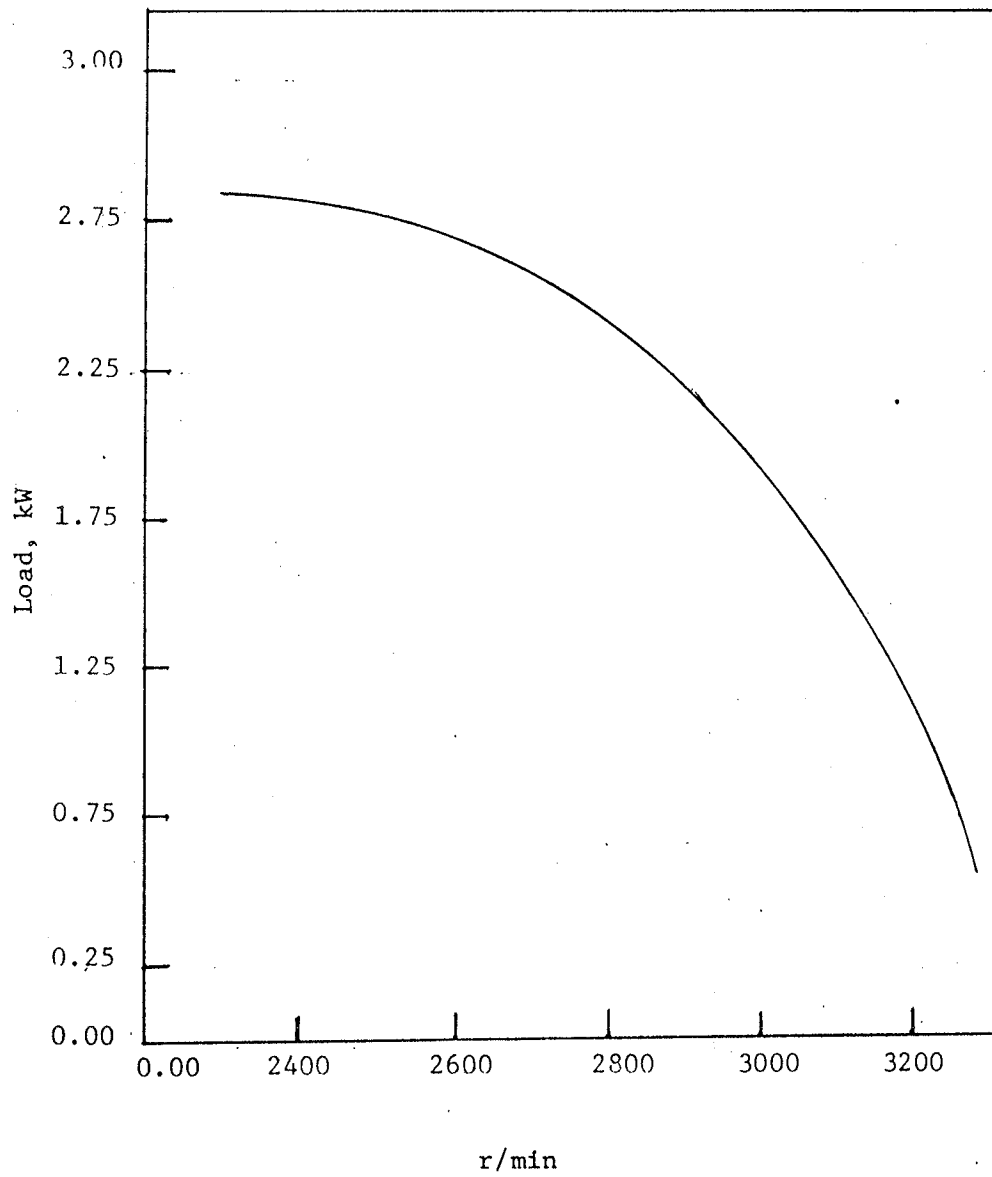


Figure 20: Load versus engine speed

During the concluding phase of experimentation, it was decided to try fuel peat from Elma peatland, located 150 km east of Winnipeg. The peat sample was excavated from the bank of a drainage ditch. The as received moisture content of the peat was 77.30 percent w.b. This peat was dried to 12.94 percent w.b. in an electric oven, before it was loaded into the electric furnace. The heat content of this peat at a moisture content of 12.94 percent w.b. was determined to be 13.70 MJ/kg.

Results and Conclusions: Though the engine ran well on propane as a fuel, several difficulties were encountered when producer gas from peat and wood was fed to the intake manifold of the engine. The air to fuel ratio for combustion of producer gas is about 0.91, while that for propane is around 14. These wide limits of air to fuel ratios for producer gas and propane made it difficult to adjust the air to fuel ratio when switching from propane to producer gas. By the time the correct air fuel mixture was obtained the engine frequently stalled. On a number of occasions the correct air to fuel mixture was obtained when operating on producer gas. The engine ran at 1000 r/min when gas from peat was used. It seemed from the firing of the engine that it would stall at any moment and it would not carry any load. The engine ran at 1800 r/min on two occasions on gas produced from wood but a speed greater than 1000 r/min was never obtained with gas produced from peat or charcoal. Opera-

tion at speeds above 1000 r/min could not be obtained with regularity even with gas from wood. Failure to obtain this consistency of engine performance was attributed to variations in the energy quality of the produced gas.

The ignition timing advance did not show any significant improvement on the engine performance while operating on producer gas. No concrete conclusion can be drawn on the effect of ignition advance, as the testing time was very short. As the gas demand of the engine exceeded the supply of gas from the furnace, it was necessary to build up the gas volume in the collection unit after each trial of running the engine. As the engine could not be run continuously for a longer time, it was not possible to perform load tests while operating on producer gas.

Chapter IV

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are drawn from the investigation:

1. Gasification is recognized as a proven technology, however, the experience gained from experiments in this project with three fabricated gasifier models and a high temperature electric furnace has demonstrated that technology transfer must be improved to make gasification technology available for acceptable widespread application.
2. Maintenance of a high temperature, ranging from 800-1000° C, in the reduction and burning zones of a gasifier is essential for the production of a satisfactory producer gas for use in an internal combustion engine.
3. The assumptions, as read in the literature, that combustion in the throat section of a downdraft gas producer generates a homogeneous high temperature, ranging from 900-1000° C and that tar vapors are cracked as they pass through this region were not verified. This description of the gasification process was found to be oversimplified.

4. Materials used to fabricate gasifiers must withstand high temperatures up to 1000° C. The metal from the walls of a used oil burning furnace rapidly burned out in regions close to the burning zone in the second model fabricated.
5. The lack of detailed technical specification data in the literature on gasifier construction and operation is a major constraint to future adaption of this old technology.
6. Promoters of producer-gas engine systems have stressed "successful gasification of carbonaceous fuels" without adequately describing problems such as slag production, bridging in the fuel feed system, desired moisture content of the supply fuel and operating time intervals.
7. The use of the gasification process to produce a combustible gas capable of providing a fuel to operate a spark ignited internal combustion engine was demonstrated by the project. A single cylinder, air-cooled, 5.59 kW Wisconsin engine was operated for short intervals. This operation was not completely satisfactory as it was not possible to obtain data on load carrying characteristics.
8. The gas produced from a gasifier is too polluted with tar, unburned carbon and steam to be fed directly into the intake manifold of an engine. A good scrubber

system including a condenser and a particulate remover must be used.

9. The calorific value of the gas produced was too low and of variable energy quality to obtain desirable performance. The engine operated satisfactorily on propane running at its rated speed at no load and was able to handle a 2.4 kW load. The speed dropped to about 1000 r/min for most trials on producer gas but it did run at 1800 r/min on two occasions using gas produced from wood.
10. The most successful gas producer operation was achieved with model number 3, modified to function in an updraft mode.

Finally it is recommended that:

1. A future research effort should concentrate on stabilizing the vertical temperature profile as well as exploring the mechanism of tar cracking in a down-draft gas producer.
2. A future project be adequately funded to allow for the purchase of instrumentation, procurement of gas analysis either by custom service or by local analysis and for the building of quality prototype models.
3. Efforts be made to concentrate biomass fuels into briquettes, pellets or other forms to facilitate the development of automatic feeding systems and a continuous flow process.

4. A future investigation include the performance evaluation of a commercially designed gasifier. Neither the author nor others involved in this project have observed an operating gasifier. Any future investigation should focus on operational procedures and problems encountered so that operation of a gasifier would become routine.

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Appendix A

SAMPLE CALCULATION OF GROSS CALORIFIC VALUE OF PEAT

mass of capsule = 11.95 g

mass of capsule + sample = 12.94 g

mass of sample = 0.99 g

After igniting the mass 'm' of the peat sample in the oxygen bomb the following times and temperatures were observed.

Time, min	Temperature, °C
0	22.22
1	22.24
2	22.32
3	22.32
4	22.32
5	22.32
6	23.24
7	23.62
8	23.84
9	23.90
10	23.92
11	23.92
12	23.92
13	23.91

14	23.91
15	23.90

Calculation for net temperature rise

$$t = t_c - t_a - r_1 (b-a) - r_2 (c-b) \quad \text{----(4)}$$

where:

a = time of firing, 5 min

b = time at 60 percent temperature rise
from graph, 6.2 min

c = time when the temperature rise became
stable after ignition, 10 min

t_a = temperature at time a, 22.32°C

t_c = temperature at time c, 23.92°C

r_1 = rate of temperature change before time a,
0.02°C/min

r_2 = rate of temperature change after time c,
-0.004°C/min

t = corrected temperature rise, °C

Substituting the values in equation 4 and solving for t,

$$\begin{aligned} t &= 23.92 - 22.32 - 0.02(6.2-5) - (-0.004)(11-6.2) \\ &= 1.592 \quad \text{say } 1.6^\circ\text{C} \end{aligned}$$

Length of fuse wire burnt = 10 - 2.1 = 7.9 cm

Amount of Na_2CO_3 used for titration = 5 mL

Gross calorific value

$$\text{Hg} = (W_t - e_1 - e_2 - e_3) / m \quad \text{----(5)}$$

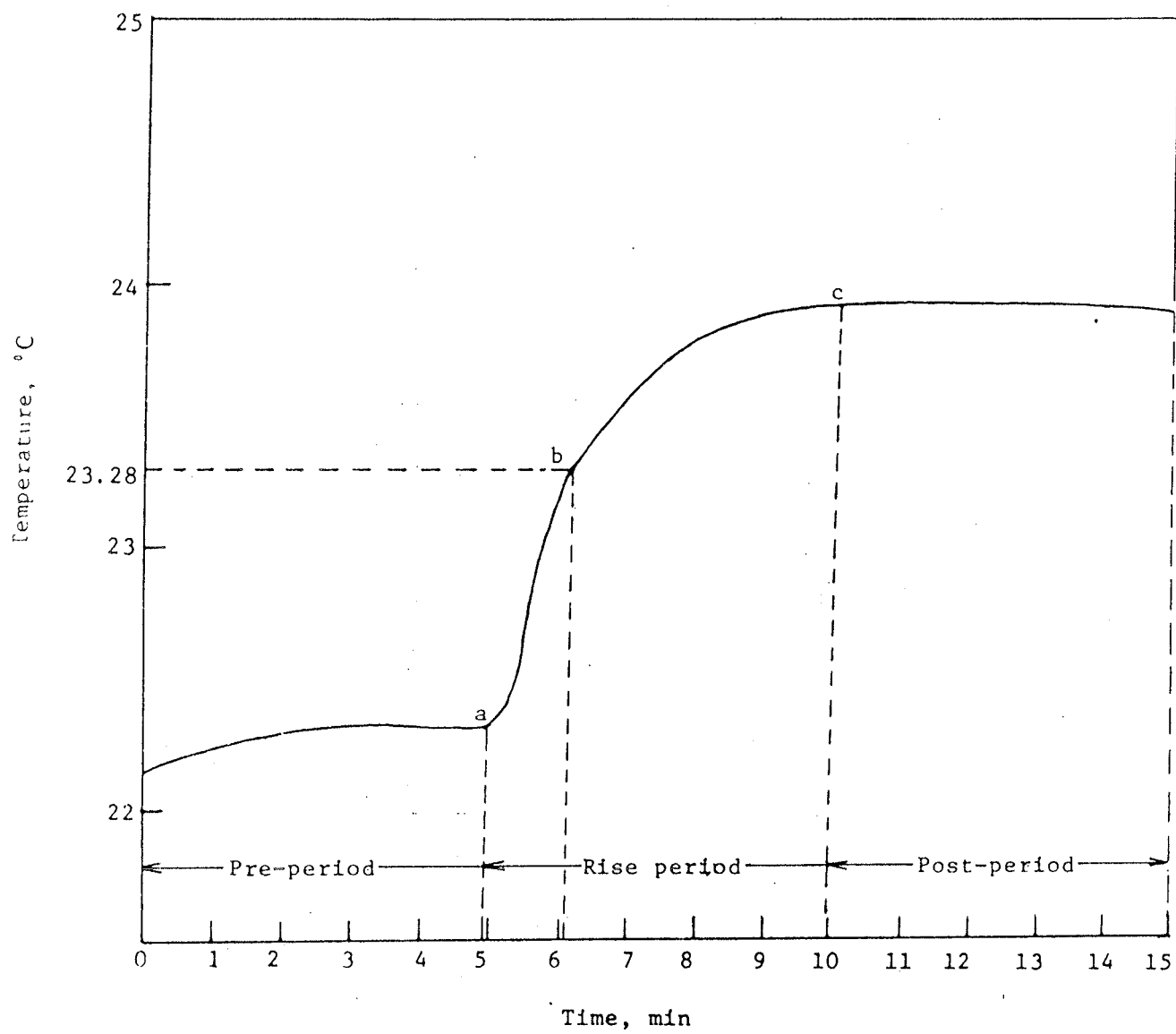


Figure 21: Temperature rise curve for oxygen bomb calorimeter with peat

where:

Hg = gross heat of combustion, MJ/kg

t = corrected temperature rise, 1.6°C

W = energy equivalent of calorimeter, 2458 cal/°C

e₁ = correction for heat of formation of

nitric acid, 5 ml x 1 cal/mL = 5 cal

e₂ = correction for heat of formation of sulphur, 0

e₃ = correction for heat of fuse wire,

7.9 cm x 2.3 cal/cm = 18.17 cal

m = 0.99 g

Substituting the values in equation 5 and solving for Hg,

$$Hg = (1.6 \times 2458 - 5 - 0 - 18.17) / 0.99$$

$$= 3949.1212 \text{ cal/g}$$

$$= 16.54 \text{ MJ/kg}$$

Appendix B
SPECIFICATIONS OF ENGINE AND GENERATOR

Engine

Make	Wisconsin
Model	AEN
Spec No.	61958
Type	4 cycle, gasoline
No. of cylinders	One
Bore x Stroke, cm	7.62 x 8.25
Maximum power	5.59 kW (7.5 hp)

Generator

Make	Generac
Model	6197-0
Voltage output	115 V
Current	34.78 A
Power	4 kW
Phase	One
Frequency	60 Hz
RPM	3600