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THE APPLICATION OF A DOWNDRAFT GASIFIER FOR SHAFT POWER PRODUCTION.

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CONTENTS

- Abstract
- Introduction and theory of gasification
- The state of the art
- Experimental procedures carried out on prototype gasifier-objectives and scope
-Economics of the gasifier system and its enviromental effects
-Conclusion

0 ABSTRACT

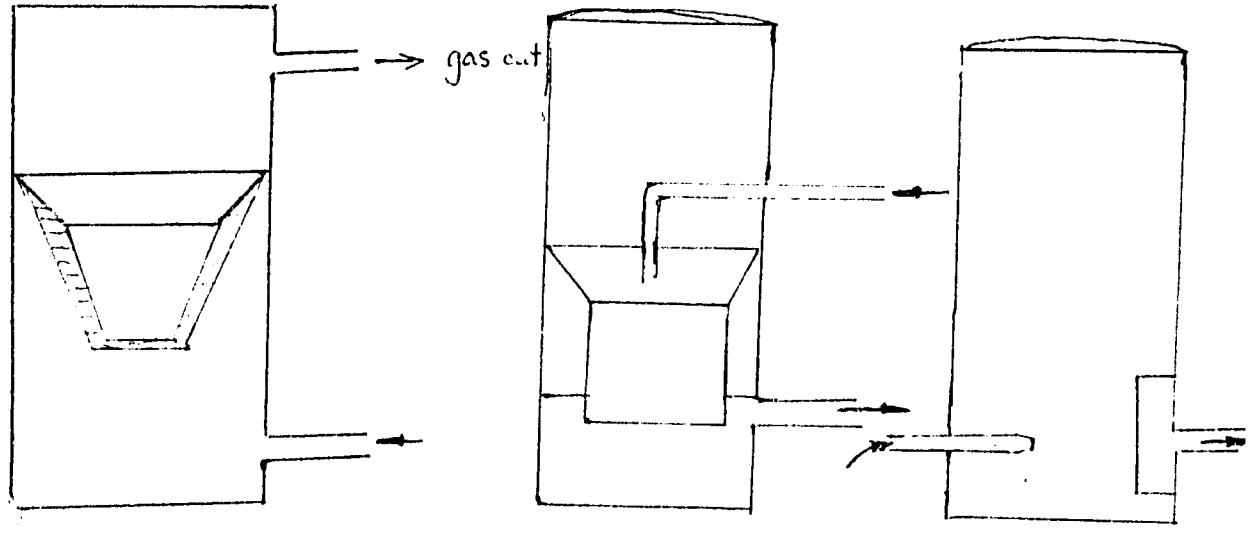
This report presents an outlook on the usefulness of biomass gasification as a renewable source of energy that could play a significant role in providing energy needs to developing countries. Given the present skyrocketing costs of imported fossil fuels, developing countries are facing extreme difficulties in meeting the demand for the fuel energy required for their development. Extrapolation of increases in price of oil will reasonably favor alternative energy sources. Also in the near future Research and Development will most unlikely provide technologies which are independent of environmental conditions for wind, Solar, Geothermal or Minihydro power, which makes biomass gasification more attractive.

0.1 INTRODUCTION

Biomass can be converted to a useful product called producer gas by air gasification. This is done by burning biomass in a limited supply of air oxygen sometimes referred to as partial combustion. The gas so produced is a low energy gas containing non condensable H_2 and CO diluted with nitrogen. Typically the heating value of producer gas is 150-200 BTU/SCF (1240-1653kcal/). This gas is suitable for operation of engines. Producer gas technology goes way back to the second world war times when more than 70,000 vehicles were converted into using producer gas, in Europe alone. After the war, with the advent of cheap fossil fuels and electricity, the use of gasifiers declined tremendously. Some countries, e.g. Sweden continued biomass gasification as part of the Nations Energy Strategy. The present energy crisis in the world, much more pronounced in developing countries has brought about the rebirth of gasifier applications. The revival of gasifier applications is now made in many countries, e.g Sweden, Germany, Phillipines, USA, Thailand, Netherlands, Tanzania etc. just to name a few. Many countries are now considering introduction of gasifier application a fact demonstrated by the large number of participants from all over the world at the first Producer Gas Technology Conference held in Sri Lanka in 1982.

1. THE STATE OF THE ART

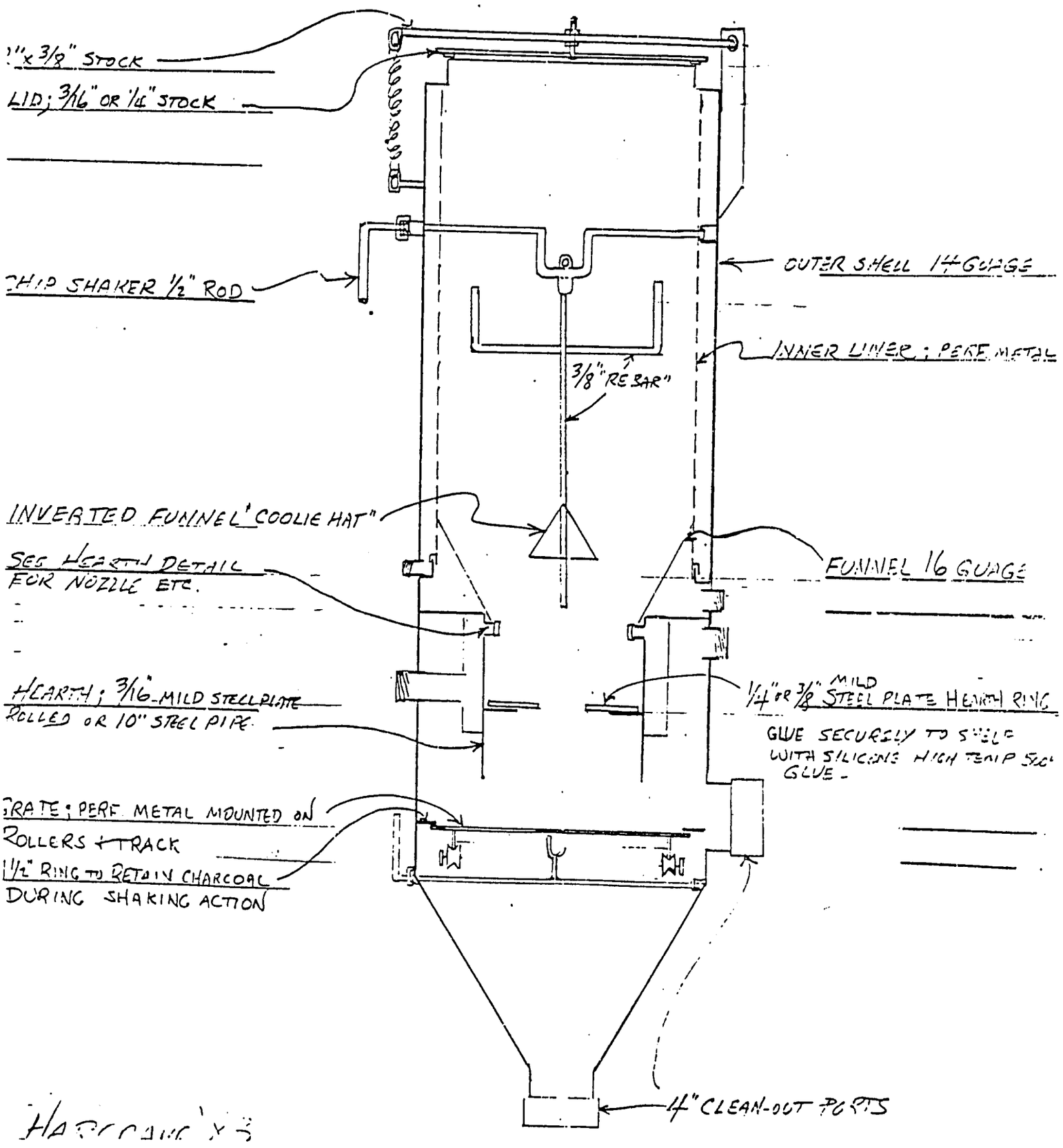
The equipments used for producing producer gas are called gasifiers (gas, generators). There are three types of gasifiers a) Updraft gasifiers, where the gas is carried from the bottom upward. b) Downdraft gasifiers where the gas is carried from the top downward. c) Crossdraft gasifiers are those with horizontal burning. Gasifiers meant for shaft power production should as far as possible be free from tars. The downdraft gasifiers provide gas which is as free from tar as possibly could. This is the type of gasifier the group worked on. See diagram attached



Updraft gasifier Downdraft gasifier Crossdraft gasifier

PARTS OF A WOOD GAS GENERATOR, ADAPTED FOR WOOD CHIP FUEL

SCALE: 1/8" = 1"



1.1 Principal reaction:

Gasification or partial combustion of a solid fuel is a reaction at high temperatures (> 600°C) between the oxygen in the air and the solid fuel. In gasification the solid fuel is always in surplus. It is this surplus of solid fuel that may provide for water vapor and carbon dioxide to pass through a glowing layer of charcoal and be reduced to combustible gases, carbon monoxide, and hydrogen. There are three distinct reaction zones in a gasifier namely, Pyrolysis zone, Oxidation zone and reduction. zone. In the pyrolysis zone, small amounts of hychocarbons and tar vapor are formed when the solid fuel is heated. In the oxidation zone, carbon dioxide and water vapor are formed. These reactions are represented by the following chemical formulas: - $C + O_2 \rightarrow CO_2$

$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

In the reduction zone the following reactions take place.

$C + CO_2 \rightarrow 2CO - 164.9$

$C + H_2O \rightarrow CO + H_2 - 122.6$

$CO_2 + H_2 = CO + H_2O - 42.3$

$C + 2H_2 = CH_4 + 83.3$

$CO + 3H_2 = CH_4 + H_2O + 205.9$

The combustible components of producer gass are CO, H_2 and CH_4.

The gas composition based on wet basis was determined in an experimental analysis and the readings were as follows:

1. CO_2 = 10% V/V
2. CO = 32% V/V
3. H_2 = 42% V/V

and the remainder was nitrogen gas.

2.1 Cleaning and Cooling the gas:

The gas producer in a gasifier has a high temperature and is mixed with impurities such as, soot, tar and vapors etc. This could be harmful to the engine if they were allowed to get in. Impurities and temperature have therefore to be reduced to a reasonable level. Cooling tends to increase the volumetric efficiency of the engine and cleaning prevents corrosion, wear, etc. of the engine. The cooling and cleaning system should not cause a high flow resistance either by construction or function. Normally a presure drop of less than 6 in. of H_2O over the cleaning system is recommended. The impurities separated by cooling or cleaning are periodically redrained or removed so that no hindrance is caused to the gas flow. The conditions of cooling demand that the gas temperature does not drop beyond the dew point to prevent condensation. Cleaning of coarser material or particles is done in a cyclone cleaner. The remaining impurities (<60) is separated by the filter system. Glass fibres have proven to be the most preferred and efficient cleaners (filters). This is the type of filters the project used in cleaning the gas. The filters have to be changed after a pressure drop of over 6 in. of H_2O is indicated over the filter system.

2.2 Retrofiting of Existing Engines:

Engines that depend on spark ignition can be converted to producer gas fueled 100%. However a loss in rated ower of the engine up to 30% is experienced. Engines that depend on compression ignition can not be 100% fueled with producer gas. A pilot fuel for ignition purpose is required.

3 THE EXPERIMENTAL PROCEDURES CARRIED OUT ON THE PROTOTOYPE GASIFIER:

3.1 Objectives and Scope:

The objectives of this group project was to test the equipment, study the gas cleaning system, learn how to modify an existing engine to using producer gas fuel and establish the economics of the gasifier system and its environmental effects. When testing the equipment the following feedstocks were used, woodchips, maize cobs and peanut shells. Due to limited time only producer gas from woodchips was tested for gas analysis. Gas components were determined by absorption and slow combustion methods in the Fisher Orsat gas apparatus. The components determined by absorption were CO_2, and CO; using Alkaline solution (P-395^{B} and cuprous chloride (Fisher N^{o} SO-C-162) as absorption reagents respectively. Determination of oxygen and the unsaturated hydrocarbons wasn't done due to absence of appropriate reagents (alkaline of pyrogallate, Fisher NO. A-302) respectively. Absorption was done in the following sequence CO_2, CO and the remaining sample which was assumed to contain hydrogen and saturated hydrocarbons was analysed in a slow combustion procedure (Refer to Fisher Orsat Gas apparatus Instruction Manual) Gas from the gasifier was collected in a blow bottle set where one bottle was filled with colored water for easy vision of displacement and the other was empty. The tubing from the bottle with water was connected to the gas-source whose pressure forced the colored water into the other bottle and the sample was collected in the bottle which had water. The experimental results obtained were:

CO_2: 10% V/V

CO: 32% V/V

H_2 42% V/V

Sources of errors in the experiment.

1) Some of the components were not determined as such they could have introduced errors in the results.

2) During the combustion test there was a loss of the sample gas from the combustion chamber through bubbling off the pipet levelling bottle.

Method of calculating the gas components: CO_2 and CO

$$\% \text{ component} = \frac{\text{decrease in vol}}{\text{Volume Sample}} \times 100$$

A 100 ml sample was used

For hydrogen the volume is calculated by multiplying 2/3 contraction.

<u>Finding the oil equivalent to wood or agricultural waste.</u>

The engine was first ran using gasoline and the fuel rate was found to be 52C.C per min. The engine was later ran using producer gas and the rate of wood consumption was found to be 0.5 lb per minute. During the test the engine ws maintained at 2200 rpm.

From these data:

$$\frac{0.5 \text{ lb/Min}}{52 \text{ CC/Min}}$$

$$= \frac{0.5 \text{ lb}}{52 \text{ cc}}$$

$$= \frac{0.5 \times 1000 \text{ lb}}{52 \quad \text{litre}}$$

$$= \frac{0.5 \times 1000}{52 \times 2.2} \frac{\text{kg}}{\text{litre}} = 4.4 \text{ kg/litre of gasoline.}$$

Theory reports a 2.7 kg of wood per litre of gasoline on idling basis.

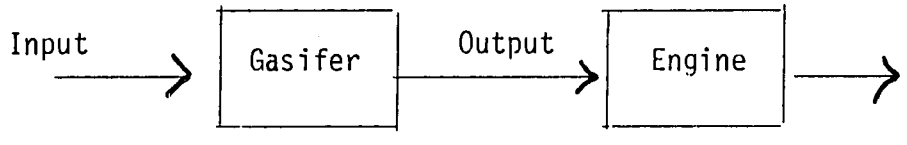
Gasifier Fuels:

Feedstocks for gasifiers are largely forestry and agricultural wastes. In testing the equipment, three types of feedstocks were used; wood chips, corn cobs and peanut shells. Woodchips and corn cobs gave satisfactory results. Peanut shells gave not enough gas to light at the flare off pipe.

Efficiency of the gasifier system.

Efficiency of a system is the ratio of the output to the input of the system.

$$\eta = \frac{\text{output}}{\text{input}}$$



It is obvious that the output from the gasifier is equal to the input to the engine.

To find the efficiency of the gasifier the engine was ran on gasoline in a given time and calculated the specific consumption. On average the engine consumed 52.CC per minute of gasoline at 2200 rpm. Later the engine was ran on producer gas and the rate of solid fuel (woodchips) was 0.5lb per minute at 2200 rpm. All tests were done on idling basis. From literature the effective heat value of gasoline is 7665 kcal/litre and that of wood is 4400kcal/kg.

$$= \frac{\text{Energy output}}{\text{Energy Input}}$$

$$= \frac{52q \text{ cc}}{1000 \text{ cc}} \times \frac{7665 \text{ kg}}{\text{litre}} \frac{}{0.5\ (0.4536) \times 4400}$$

$$= 0.3999$$

40%

The total efficiency = x

Design efffects on efficiency:

From the application point of view a gasifier should be universally usable for all types of solid fuels. This is not possible because of the classification of solid fuels into tar-free and tar emitting. Category one is normally meant for charcoal and category two for uncarbonized solid fuels. A gasifier design is therefore fuel specific. The designs should as well be able to provide high temperatures at the oxidation zone. This is made possible by matching the hearth diameter with the pull of the engine or power of the engine.

The bunker should be designed in a way that no bridging of the fuel occurs. To enable chemical reactions come to an equilibrium in the reduction zone a prolonged residence time is required. This is accomplished by increasing the cross-section area below the hearth constriction which decreases the velocity of the gas.

Insulation of both the hearth and reduction zones seems to increase the efficiency of the gasifier. Use of refractory cement provides a good insulation at such tempratures.

3.2 The Gas Cleaning System

The glass fibre filter and cyclone were tested during this group project work. The cyclone was opened after each three hours of operation, dry soot was collected from it. Also the glass fibre filter was examined after each run of about 6 hours. Some condensate was observed in the glass fibre drum housing. Very much so when moist woodchips was used as feedstock. However, the recorded pressure drop measured by a water manometer never went above 2 in. of H_2O for the whole period of operation (about 21 hours). This was good indication that the filters were not clogged up with tar or soot a fact which was consistent with the observations made.

3.3 Modification of a Gasoline Engine to Producer Powered Engine

power of the engine:

The group observed that it was better to control the engine by having a gas/air premixing chamber before introducing the mixture into the intake manifold.

Also an advance timing of the engine was necessary for better combustion of the gas/air mixture in the cylinders.

Economics Analysis

In general the objective of the performance assessment is to be able to provide necessary information so that the technical and economic feasibility of the system can be evaluated. In order to make a full scale performance assessment of a wood gasifier system, a lot of equipment will have to be available for obtaining necessary data. As the facilities and data assessment time at TREEO center are limited, full scale performance assessment could not be carried out. It was only possible to obtain some important data which were necessary for the evaluation of the main technical and economic parameters of the systems.

The technical and economic parameters of the system when operating on wood gasifier and gasoline are shown in Table I.

Based on the system parameters in Table I, the energy production cost and payback period by wood gasifier system can be evaluated and compared with that when operating by gasoline.

For the gasoline engine system, the capital cost is 150 U.S. dollars and the life-time and annual discount rate can be assumed to be 5 years and 12% respectively. The annual labor, maintenance and operating cost is 400 U.S. dollars. The specific gasoline fuel consumption is 0.418 litre/hp-h at 20% engine efficiency and the price of gasoline fuel is 0.30 U.S. dollars/litre. The daily energy output is 45 hp-h and the annual energy inflation varies from 0-10%. Based on these figures, the energy production cost with gasoline can be evaluated to be 10.97-13.82 ¢/hp-h.

For the wood gasifier system, the cost is 2,650 U.S. dollars (2,500 U.S. dollars for the gas generator and filter system and 150 U.S. dollars for the gasoline engine) and the annual labor, maintenance and

operating costs is 750 U.S. dollars (approximately 30% of the capital cost) The specific wood consumption is 1.823 kg/hp-h at 20% engine efficiency, 40% gas generator efficiency and 4400 kcal/kg heating value of wood. The price of wood varies from 0.4-0.8 ¢/kg. Based on these figures and the same condition of the gasoline engine system, the energy production cost with wood gasifier can be evaluated to be 7.04-7.90 ¢/hp-h as shown in Figure I.

The energy production cost of gasoline engine system and wood gasifier system are composed and shown in Table II.

For the payback period analysis of wood gasifier system, based on the energy output 45 hp-h/day and taking into account the labor, maintenance, operating and capital cost of the wood gasifier system. The payback period is 2.11-3.11 years depends on the wood chip cost and the annual energy inflation rate when comparing with gasoline fuel as as shown in Figure II.

It can be seen from the ecomonies analysis that the wood gasifier system has significant advantage when compared with a gasoline engine system. It should also be pointed out that for remote areas, the transportation cost for gasoline may be quite considerable and has not been taken into account in this analysis.

ITEMS	WOOD GASIFIER SYSTEM	GASOLINE ENGINE SYSTEM
1) Fuel		
-specific fuel consumption	1.823 kg/hp-hr	0.418 lr/hp-hr
-heating value	4400 kcal/kg	7.665 kcal/lr
-annual fuel consumption	29,942.77 kg	6,865.65 lr
2) Daily energy output (shaft power)	45 hp-hr/day	
3) Gas generators unit efficiency	40%	-
4) Gasoline engine unit efficiency	20%	20%
5) Cost		
-capital cost	2.650 $	150 $
-fuel cost	0.4-0.8 ¢/kg	030 $/lr
-annual labor cost	500 $	300 $
-annual maintenance & operation cost	250 $	100 $
-annual discount rate	12%	
-annual energy inflation rate	0-10%	
6) Life time	5 years	

Table I System parameters for wood gasifier system and gasoline engine system

Annual Energy Inflation Rate (%)	Energy Production Cost (¢/hp-h)			
	Wood Gasifier System			Gasoline Engine System
	Wood=0.4¢/kg	Wood=0.6¢/kg	Wood=0.8¢/kg	Gasoline=0.3¢/lr
0	7.04	7.31	7.57	10.97
4	7.11	7.40	7.69	12.03
8	7.17	7.50	7.83	13.20
10	7.21	7.56	7.90	13.82

Table II Energy production cost comparison between wood gasifier system and gasoline engine system.

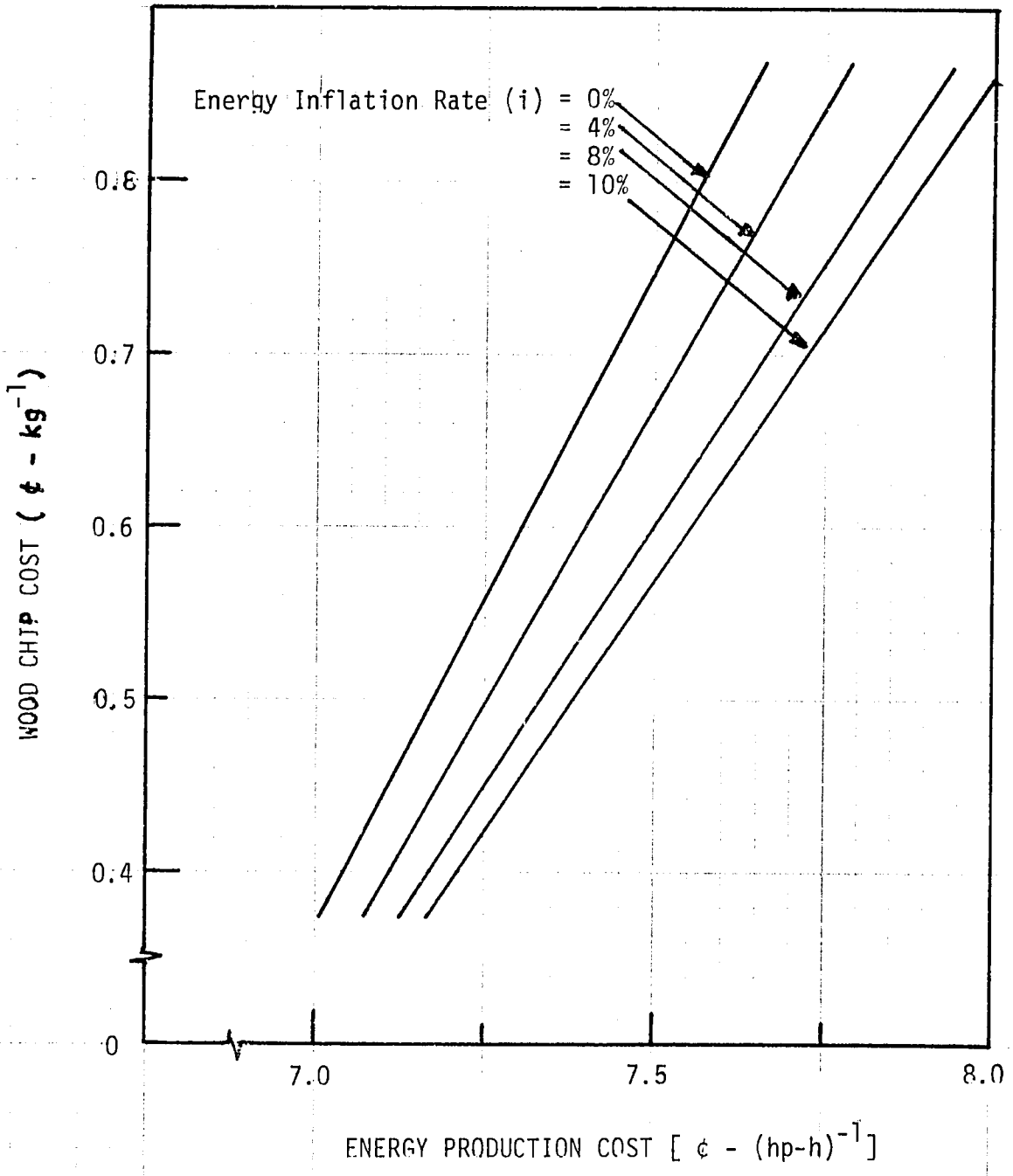


Figure I Relation between energy production cost and wood chip cost at 0-10% annual energy inflation rate

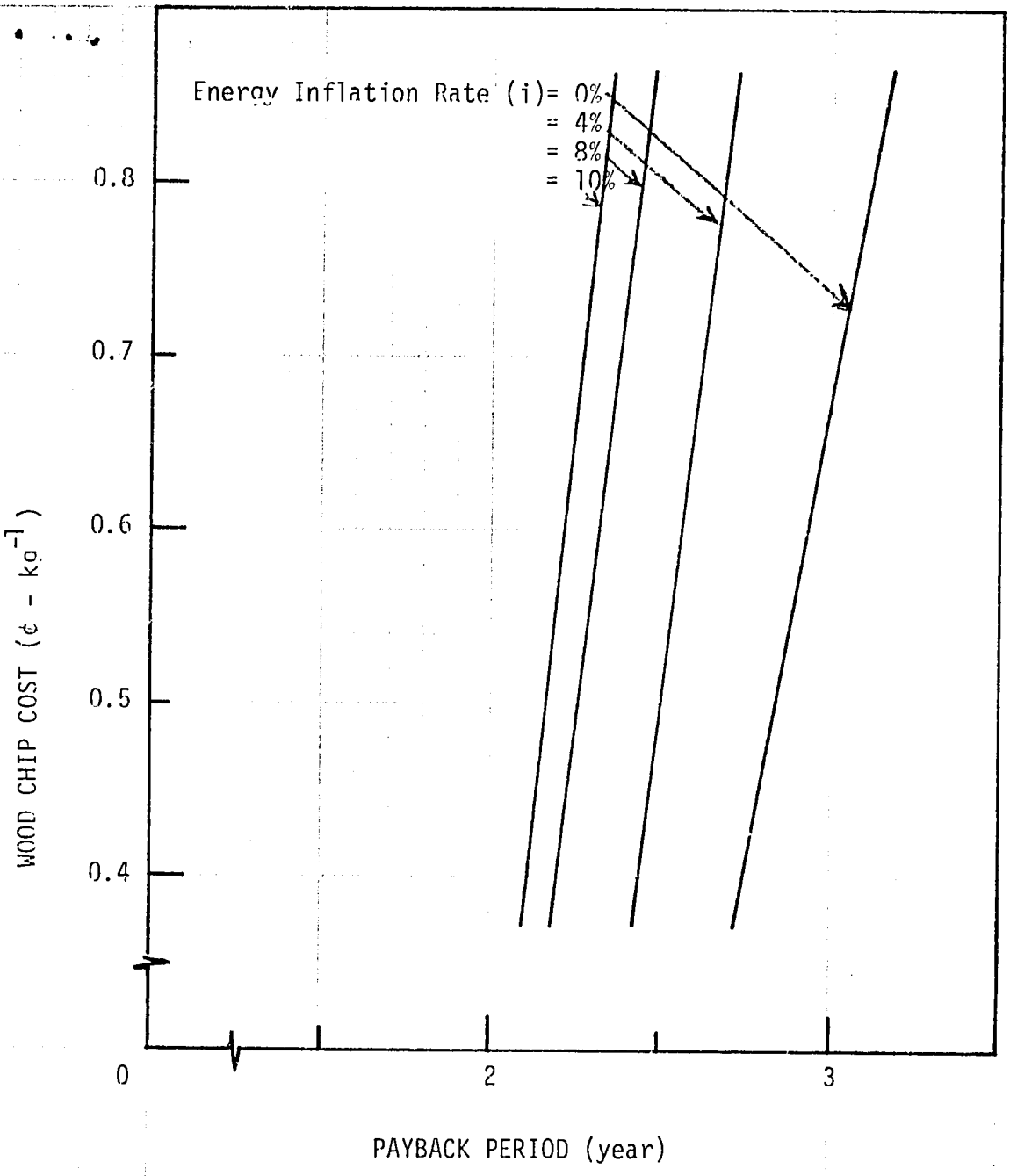


Figure II Relation between payback period and wood chop cost at 0-10% annual energy inflation rate

Appendix A

The calculation example of the economic analysis

A.1) Energy production cost

The energy production cost is expressed as

$$C_E = \frac{1}{E \cdot n} \left[C_c + (c_L + C_{mo})^{\eta} \left(\frac{1}{1+d} \right)^{\eta} + C_F^{\eta} \left(\frac{1+i}{1+d} \right)^{\eta} \right]$$

where, C = energy production cost

C_c = capital cost

$_L$ = annual labor cost

C_{MO} = annual maintenance and Operating cost

C_F = annual fuel cost

E = annual energy production

n = life-time

$\overset{0}{1}$ = annual energy inflation rate

d = annual discount rate

From Table 1, the energy production cost from wood gasifier system at 10% annual energy inflation rate and 0.4 /kg of wood chip cost is

$$C_E = \frac{1}{45x36x5x5} \; 2,650 + 250)^{5} \; \frac{1}{1.12}^{5} + 29,942.77 \times 0.004^{5} \; \frac{1-10}{1\ 12}^{5}$$

$$= 7.21 \text{ ¢1hp-h}$$

A.2) Pay back period is impressed as:

$$(C_{FG} - C_{FW}) \quad \frac{1+}{1+d} - (\quad + \quad) \quad \frac{1}{1+d} \quad - C_c = 0$$

where; C_c = capital cost

C_{FG} = annual energy saving cost

C_{FW} = annual wood fuel cost

C_L = annual labor cost

C_{MO} = annual maintenance and operating cost

= annual energy inflation rate

d = annual discount rate

n = pay back perios

From Table 1, the pay back period of wood gasifier system at 10% annual energy inflation rate and 0.4 ¢ /kg of wood fuel cost when comparing with gasoline is

$$(6865.65 \times 0.3 - 29{,}942.77 \times 0.004) \quad \frac{1.10}{1.12} - (500+250) \quad \frac{1}{1.12} - 2.650 = 0$$

An alternative solution for the pay back period gives n = 2.11 years.

Environmental Effects:

- Gasifier application could lead to deforestation if wood was used as feedstock and no schemes to promote the growing of trees for the purpose was available.

- Producer gas is a poisonous gas if inhaled in great quantities. Therefore the sheds for gasifier operation must be as open as possibly could be and training of the operators is necessary.

Conclusions:

Producer gas technology could be a good alternative energy source if the feedstock and market for the application of gasifiers are established. Long running hours applications are prefered for better payback periods. Stationary units work better than trackionary units with producer gas.