ENERGY FROM BIOMASS: COMBUSTION AND GASIFICATION

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1. ABSTRACT.

Some fundamental facts of the combustion of BIOMAS are outlined and discussed. It is suggested that these provide guidelines for the development of successful practical combustors. Furthemore, a realisation of energy conversion from the same in gasfier is presented.

2. INTRODUCTION.

Few countries capture as high a proportion of the solar radiation falling on their territory by the process of photosynthetic carbon fixation as does Tanzania. Some of this energy is harvested to provide marketable products. Yet of this energy harvest, less than half resides in such products; the remainder is in what is classed as waste. Clearly, this waste energy is a political national asset of some significance and its utilisation is deserving of detailed research and development. Some of the waste may be used as a construction material but the importance of most of it is as fuel.

It is the purpose of this paper to outline both the fundamental problems in the utilisation of such fuels, and also the relevant knowledge that has been derived from the combustion of coal. Uncontrolled combustion, by definition, is a hazard and here we can delineate three categories.

The first is forest fires which every year cause vast devastation, waste of energy and pollution. Another category is thermal explosions in which stored material, either the desired product or waste, undergoes bacterial oxidation. If the released heat is not conducted away and transferred at the boundary, the temperature rise can further increase the oxidation rate and ignition of the whole mass may ensue. It is for this reason that the surface to volume ratio is increased by the preference for several small piles rather than one large one. Finally, when the product is a dry dust it is potentially explosive in the gas phase. Ignition can occur from unintended sparks. This type of explosion has proved a significant hazard in grain elevators in Developed Countries.

Controlled combustion of vegetation wastes occurs in four principle modes:

(i) Production of biogas. Again bacterial action can react the waste, on this occasion yielding a combustible gaseous mixture, in which the principle constituent are CH_4 and CO_2. This route is more economic than direct combustion when the waste is excessively wet.

(ii) Burning on a grate. This is conventionally used for bagases, palm oil fibres and coconut husks.

(iii) Fluidised bed combustion. This operates at relatively low temperatures, heat and mass transfer are increased and, potentially, the combustion can be under closer control. Much research has been devoted to this mode of coal combustion.

(iv) Cyclone combustion. This requires smaller sizes of the solid material and also can operate at relatively low temperatures, with good heat and mass transfer and control. Valuable experience has been gained with coal combustion.

3. THE COMBUSTION PROCESS

As the solid is heated up combustion gases are evolved. These may comprise CH_4, other hydrocarbons and H_2. These usually mix rapidly with the air and gas phase combustion ensues. It is the heat from this process that, by back conduction, and sometime radiation, heats up the cold reactants. The chemical volumetric heat release rate, q, of the gaseous premixture varies with gas temperature, T, as shown in Fig[1].

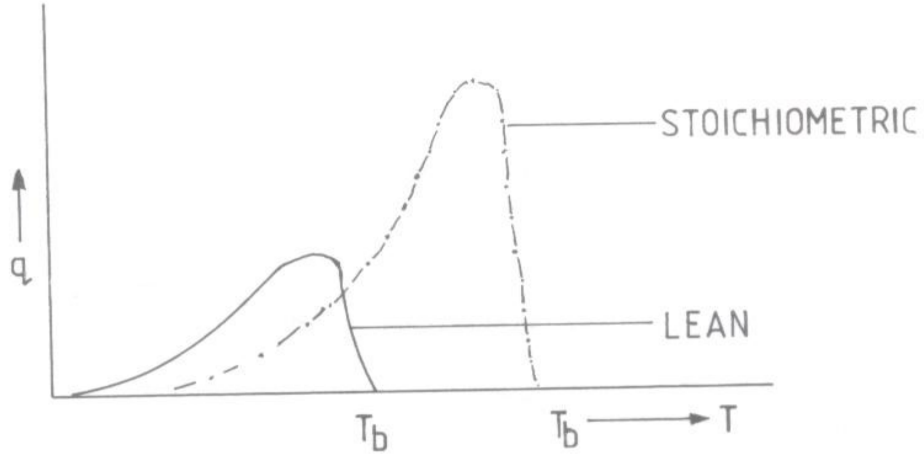

Figure 1. Heat release rate profile.

Most of the heat release occurs close to the adiabatic temperature, T_b. In gaseous flames it is the area under the q-T profile that determines the burning velocity[1]. In combustion, the fuel is not directly oxidised by oxygen molecules but by more reactive radicals, such as OH, O and H, formed in chain branching reactions. These exist in concentrations far in excess of equilibrium amounts in the reaction zone. The hydroxyl radical is particularly important in oxidation For example in the CH_4 flame[2]

$$CH_4 + OH = CH_3 + H_2O \quad (1)$$

$$CO + OH = CO_2 + H \quad (2)$$

3.1 LOW CALORIFIC MIXTURES

Most vegetation wastes fall into this category. For example whereas coal has a calorific value of about 30 MJ kg^{-1}, the value for rice husks is about 14 MJ

kg^{-1}. Coal is not such an easy fuel to burn, but it becomes easier the greater the content of volatile matter. For a bituminous coal this may be in the region of 30%, whilst rice husks benefit from a higher value of 60%.

Predominantly, hydrocarbons are devolatalised and many experiments with coal dust-air mixtures and methane-air mixtures, to which dusts have been added, show that the maximum temperature of the gaseous products of combustion at the lean limit lies between 1500 and 1550 K [3]. Particles of char may have temperatures that are some hundreds of degrees more than this. Furthermore, it has been shown for coal dust-air mixtures that at this limit the heat of reaction of the overall mixture is about 48 kJ (g mole)$^{-1}$ [4].

Vegetation wastes are often near this limit and sometimes combustion is impossible. Larger units are advantageous in that heat loss, that aggravates the problem, is reduced. Because rice husks contain silica - a good heat conductor, this condition is beneficial but ash temperatures above 1400 K can lead to slagging thus preventing heat losses. The problem of obtaining sufficient temperature for gas phase combustion can be solved by creating a thermal "dam". Consider the temperature distribution in the system shown diagrametically in Fig. 2 (a) in which C is some sort of a combustion chamber and T_u is the initial temperature.

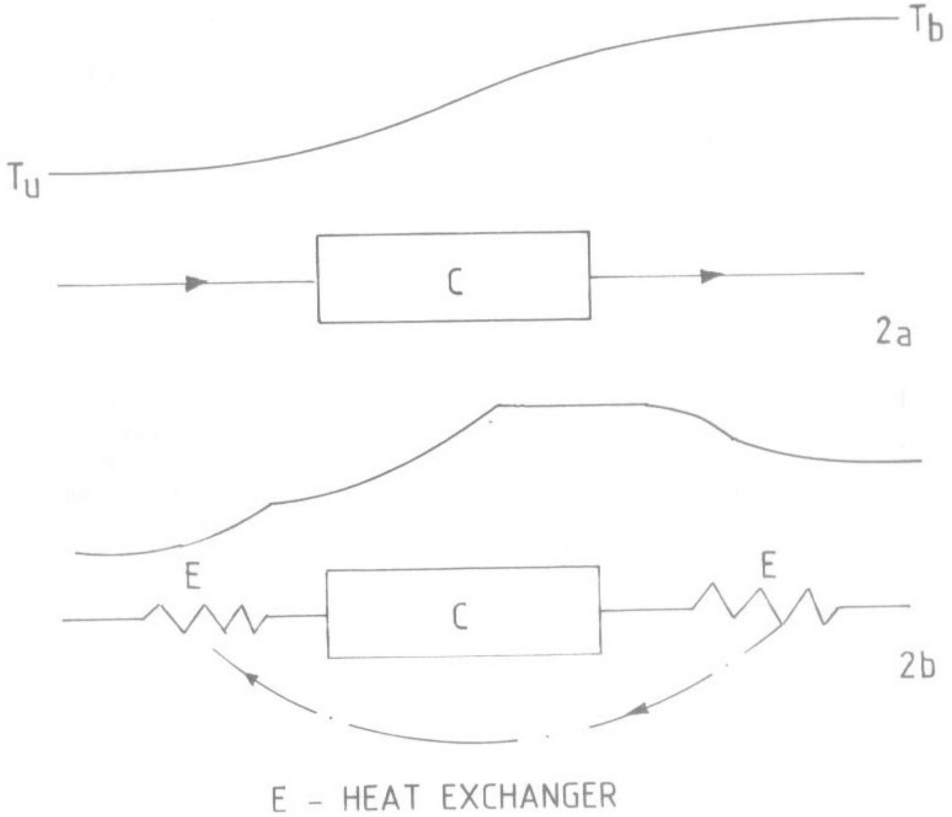

Figure 2. Thermal dam effect.

In Fig 2 (b) the letters E indicate two sides of a heat exchanger. The dotted curve represents heat transfer from hot products of combustion to preheat the reactants above T_u. The peak temperature just after combustion is above T_b. This does not represent any overall increase of the energy within the system, but merely the creation of a thermal dam. After the final exchanger the temperature falls to T_b.

This effect can be achieved without a conventional heat exchanger. In a fluidised or spouted bed combustor, the inert solid material, such as sand, can be heated by hot gases and cooled by cold reactants. In a cyclone combustor the hot char itself can transfer energy to the cold air. Both devices require good control of the flow field. However, a simple case is to heat the incoming material by exhaust gases from the system as will be shown on the practical realisation section.

3.2 COMBUSTION OF CHAR

Although devolatisation and gas phase oxidation are rapid, the oxidation of the remaining solid carbonaceous char is comparatively slow. For this reason a longer residence time in the combustion chamber is required for the char than for the gases. For char particles diameters above 80μm the rate of char oxidation is controlled by the rate of diffusion of the gaseous reactant to the surface[5]. For diameters below about 5μm the oxidation rate is controlled by the rate of chemical reaction at the surface[6]. Between these two sizes is a mixed regime.

In the burnt gases oxidation of the char predominantly is by O_2 and H_2O[7]. However in the gaseous reaction zone the oxidation rate by transient species, OH, O and H can be much greater[4]. It is therefore advantageous for the char to have the longest possible residence time in this reaction zone. To tailor the residence time is not easy. Both gravitational and centrifugal forces can be used to control it, and these are utilised in fluidised bed and cyclone combustors. A further interesting possibility is for electromagnetic fields to control the motion of charged char particles.

4. MODELLING OF THE REACTING FLOW

The basic requirements for successful combustion of vegetation wastes have emerged in the above discussions. Hot recirculated particles should heat up the reactants. This can also be aided by recirculating hot reacting gases. Devolatilisation and the gas phase combustion follow, but the char should recirculate into both the cold reactants and the gaseous reaction zone. These processes should occur with minimal pressure drop, and hence pumping power.

They are exacting requirements and the means of achievement include pilot plant measurements of the flow field, water and air models and mathematical modelling. Initially, cold flow models can give a useful guide, but the ultimate goal must be a mathematical model of combusting flow.

Flow field modelling requires a model of turbulent flow. The concept of an eddy viscosity has proved useful and this has been evaluated from the transport equation of turbulent kinetic energy, k and its rate of dissipation, ε. This assumes the eddy viscosity is isotropic which, in general, it is not. More recently, anisotropy has been allowed for and the different Reynolds stresses computationally evaluated for cold flows. It has been found that higher order of closure of the turbulent flow equations requires a higher order for the finite difference discretization for the partial differential equations. Care must also be taken to achieve numerical stability, as well as accuracy.

Modelling of the combustion is even more difficult. Some progress has been made on the basis of experimentally-based devolatilisation data and assumption that gaseous turbulent combustion occurs in arrays of laminar flamelets. Char motion and oxidation must be modelled separately.

Although mathematical modelling is a most challenging area of research and will ultimately give reasonably accurate performance predictions, the development of combustors for vegetable wastes cannot await the successful evolution of comprehensive mathematical models. Progress probably rests upon experimental pilot plant studies combined with more limited mathematical intuitions, of which this has been tested on many devices like gasifiers.

4. EXPERIMENTAL RESULTS AND DISCUSSION

For realisation of thermal dam effect, experiments were conducted on a gasifier system[8] similar to that designed by Mjema E.M.[9] but utilising wood pieces. A diesel engine coupled to a generator was partially supplied with diesel and producer gas. On one occasion the wood pieces were 'toasted' by a heat exchanger which utilised engine exhaust gases, while on the other occasion it was only air dried pieces of wood. The electric generator was connected with loads of differing capacity as indicated in the table of results, Table I

Where as the realisation does not include highly moisture biomas, it does reflect an increase in the overall efficency of the plant without including the benefit of the ('toasting' section heat) exchanger section.

For fully experimental arrangement a report at C.N.E.N. should be consulted[8]. However, gas analysis were by gas chromatograph. Fig.3 is a schematic arrangement of the testing rig. Some experimental results are given in table I and also presented in Fig.4 and Fig.5. From table I and Fig.5 it is clear that the overall efficiency of the plant increases for toasted case, this situation definitely can't originate from the effects of the quality of produced gas, table I, but could arise from the effects of amount of biomas required per amount of KWH produced, which is an effect caused by the utilisation of the thermal dam effect. (Low biomas consumed per energy produced).

However, as mentioned in my earlier paper on pyrolysis[10], these energy options are much suitable for remote places where the National grid is difficult to reach.

BIOMASS	TOASTED				UNTOASTED			
Nominal Power KW	6	9	12	15	6	9	12	15
Measured Power KW	5,6	8,7	12,6	13,2	5,5	8,8	11,7	13,5
Gasifier Efficiency	70,4	70,4	73,0	72,9	73,7	72,3	66,8	68,3
Total Plant Efficiency % (including Toasting Part)	12,2	15,8	16,6	14,7	9,5	11,5	13,6	13,7
kg biomass/KWH Produced	1,78	1,37	1,30	1,48	2,2	1,81	1,53	1,52
Gas Produced Nm/h	23,8	30,8	39,5	51,1	29,2	37,9	48,8	49,3
Calorofic Value of Produced gases kcal/Nm	1160	1080	1200	1100	1250	1250	1010	1170
Gas Composition								
H_2 % vol	14,1	13,7	15,6	15,9	17,6	18,2	14,0	16,0
CO "	20,1	17,2	18,7	16,6	18,9	20,5	14,5	16,0
CH_4 "	1,9	1,8	2,0	1,5	1,7	1,6	1,9	1,3
C_2H_6 "	0,2	0,3	0,3	0,3	0,3	0,1	0,2	0,2
CO "	12,0	12,4	13,0	12,8	11,6	11,2	12,5	11,3
N_2 "	50,2	52,2	49,8	52,2	48,8	56,5	53,9	50,7
O_2 "	1,6	2,3	0,6	0,7	0,5	0,3	3,0	0,2

TABLE I Experimental results From a Gasifier For Toasted and Untoasted Pieces of Wood

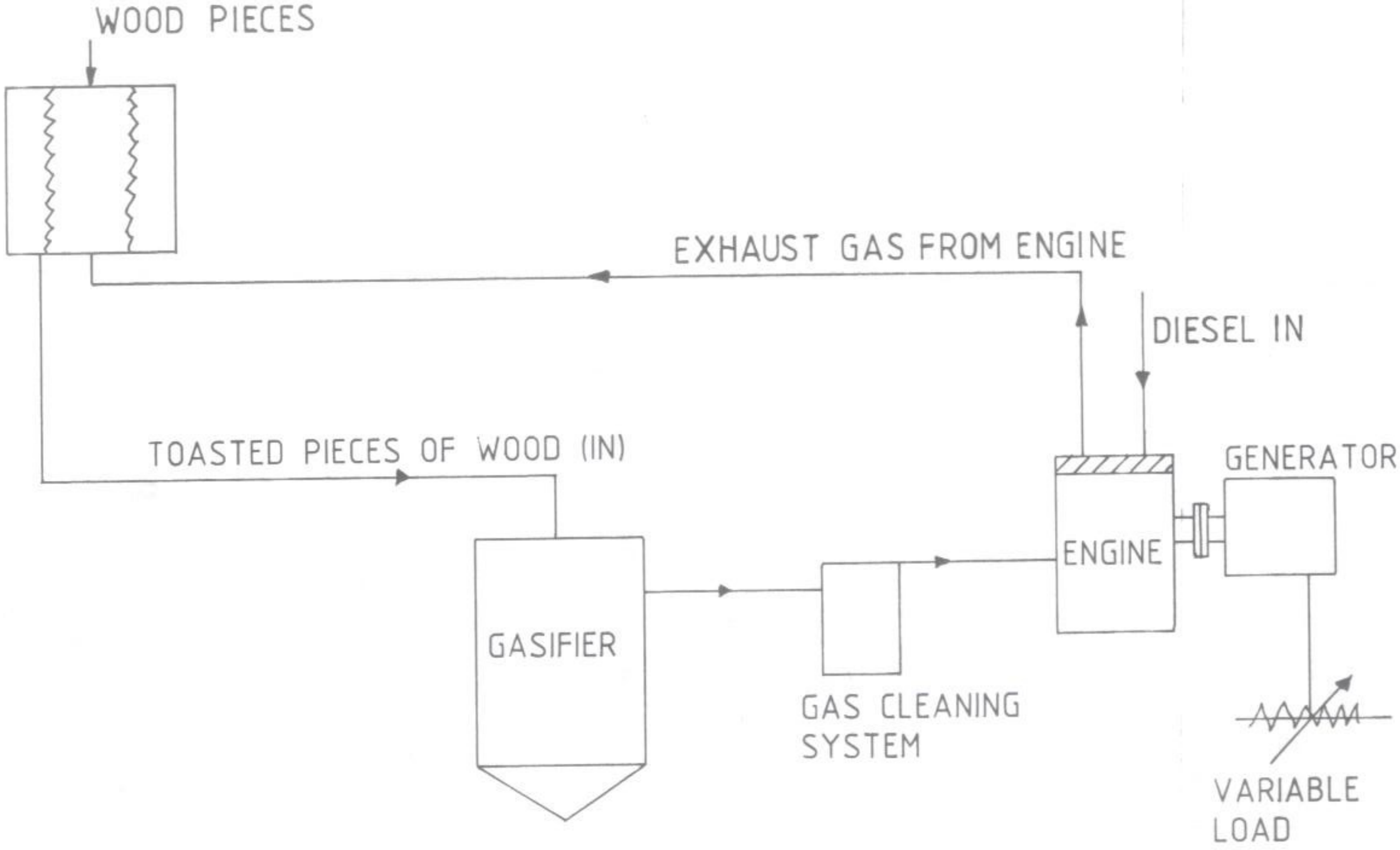

FIG.3 SCHEMATIC ARRANGEMENT OF MATERIAL FLOW FOR TOASTED CASE

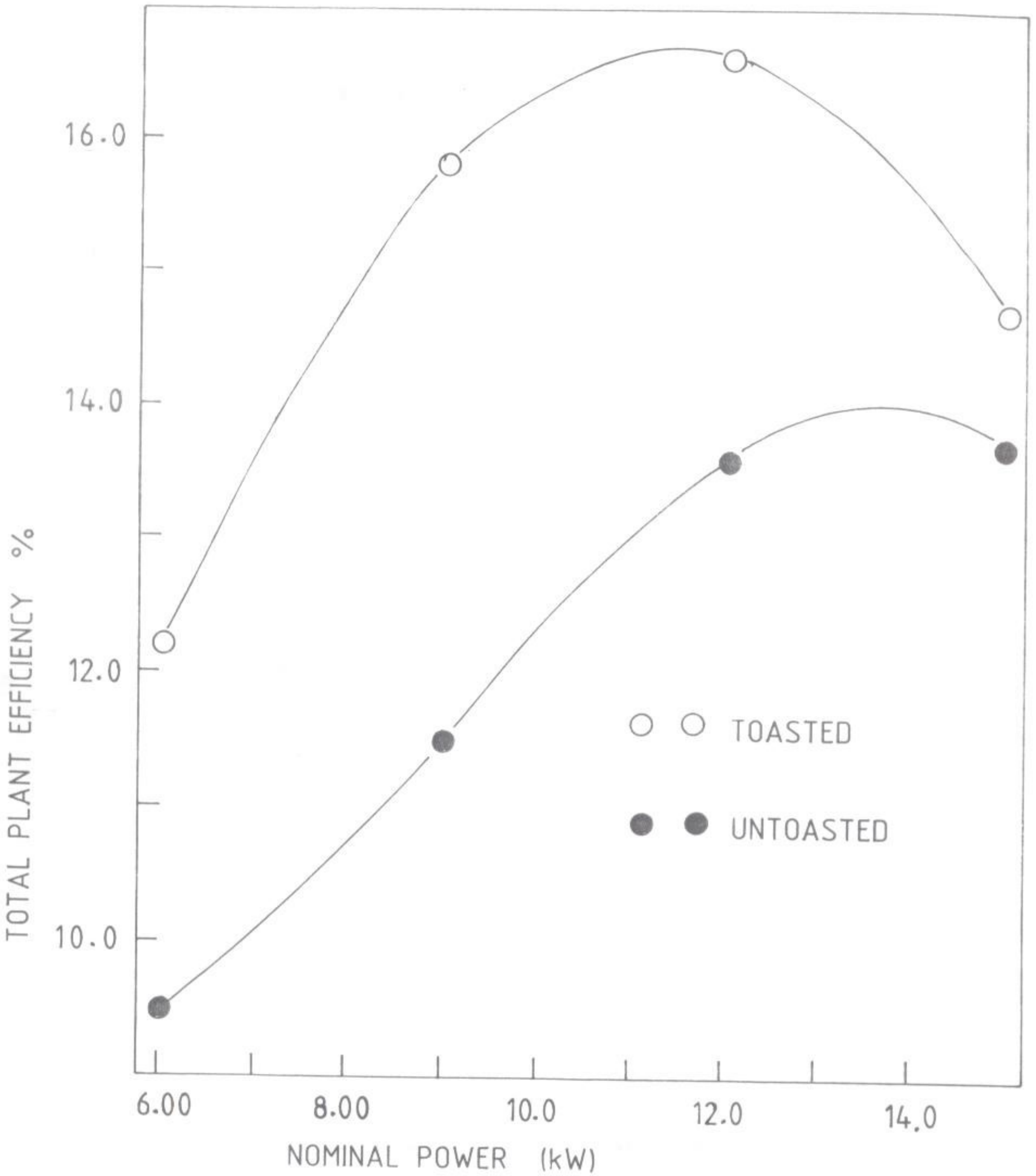

FIG.4 SYSTEM EFFICIENCY Vs GENERATOR NOMINAL POWER

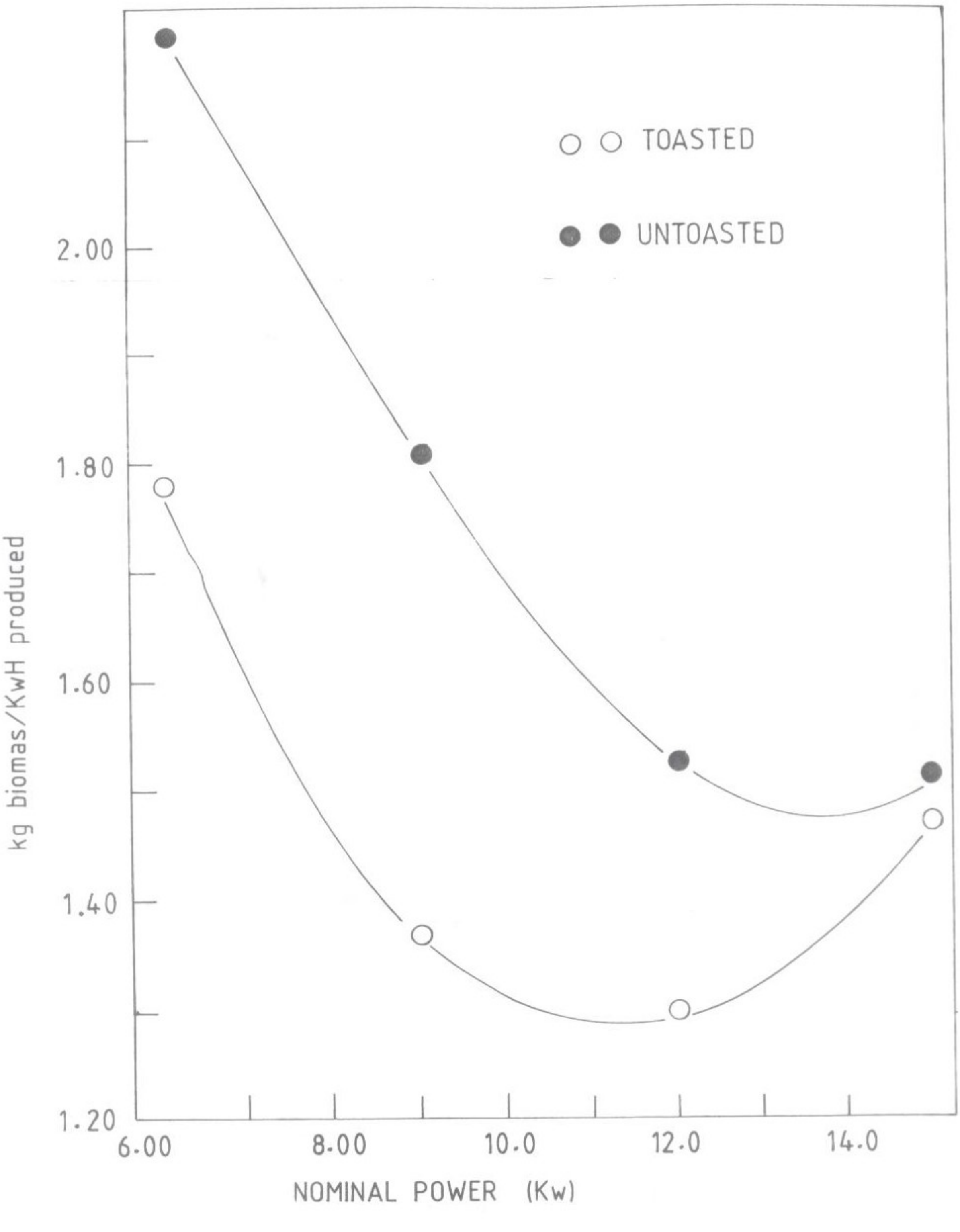

FIG.5 BIOMASS CONSUMPTION PER KWH PRODUCED Vs
NOMINAL POWER GENERATOR

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