BIOMASS GASIFICATION IN SMALL-SCALE UNITS FOR THE USE IN AGRICULTURE AND FORESTRY IN SERBIA

by

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This paper is the survey of the state-of-the art and prospects of biomass gasification in Serbia, Yugoslavia. Combustion in small-scale units is the most common at present. Potentials of available biomass from agriculture and forestry for energy production are estimated. Prospects for application of various and forestry for energy production are discussed. Results of biomass gasification experiments performed at the Department of Process Engineering at the Faculty of Mechanical Engineering, University of Belgrade are presented. One concept of small-scale gasification unit for farms or sawmills is proposed.

Introduction

Biomass is widely considered to be an important potential fuel and renewable energy resource for the future. In terms of size of the resource, there is the potential to produce at least 50% of Europe's total energy requirement from purpose grown biomass using agricultural land no longer required from food, and from wastes and residues from agriculture, commerce and consumers (Gvero, 1997, Bridgwater, 1995, Grassi and Brigwater 1991, Kohan, 1981, Van Heek, 1994, Beenakers and Maniatis, 1996). Biomass is atractive fuel as far protection of environment is concered, because of the closed circle of carbon-dioxide: carbon-dioxide produced in combustion processes is used for oxygen production in photosynthesis.

The common usage of biomass is in small boilers or furmaces for local household, or farm heating, what is the simplest and the cheapest way, but unefficient and not suitable for extensive energy production. There is a wide range of thermal processes under development from experimental to demonstration stage for secondary fuels (gas, liquid), or heat production. Priority in Europe is given to the gasification combined with heat and electricity production. Two concepts are in consideration: centralized district combined power plants, or small scale gasificators coupled to boiler or diesel engine for local use of heat or/and electricity.

Biomass after production is material with high moisture content and very low bulk density what requires additional treatment (cutting or grinding, drying and transportation) prior to combustion, or its conversion to other secondary fuels.The most important source of biomass in Serbia is in agriculture and forestry. The quantity potentially available for energy production is evaluated. According to the present situation in Serbia (investment limitations, ways of collecting, storage and transportations of biomass), the good estimations of the research team of the Department of Process Engineering are that the small scale local usage is more realistic for near future than big centralized combined power plants. The focus is on gasificators with the output from 0.1 to 1 MW. Because of the number of advantages, priority is given to the down-draft gasificators.

Potencial of biomass production

Biomass as a potential energy resource can be divided in the following three categories: wood, agriculture wastes, purpose-grown biomass.

Third category is not considered in this paper, as it could be only of hypotetical interest in this moment for Serbia.

There are no exact figures for the amount of wood wastes in Serbia, but energy potential evaluations have been made on the basis of the amount of timber felled and on the basis of the technical properties and norms of machines for different kinds of timber processing.

The important feature of wood waste is the heating value and it depends of wood and the part of plant. Higher heating value (HHV) ranges for decidious wood from 17.3 MJ/kg (d. b.) for poplar wood to 18.8 MJ/kg (d. b.) for beech wood. HHV of coniferous wood is much higher and it ranges from 19.5 MJ/kg (d. b.) for the fir to 21.2 MJ/kg (d. b.) for pine. These values of HHV are given for core of wood and differ for other parts of tree. HHV decreases from core to the surface for decidious wood and it is opposite for coniferous wood (Danon *et al.*, 1996).

Amount of timber felled in Serbia, estimated on average amounts for years 1985 to 1989, is approximately $4.1 \cdot 10^6$ m^3/yr. ($2.8 \cdot 10^6$ m^3/yr. in state owned forests and $1.3 \cdot 10^6$ m^3/yr. in private owned forests) (Danon *et al*, 1996). The amount of wood wastes depend on kind of timber processing. For the present technique, it is estimated that appr. 63% of total timber felled in state owned forests remind as wastes ($1.76 \cdot 10^6$ m^3/yr.) and 88% for private forests ($1.58 \cdot 10^6$ m^3/yr.). This is considerable energy potential, but because of present timber production technique, dispersion of wood wastes and different features of wastes, possible available amount for energy production is only 25% (Danon *et. al.*, 1996).

Total amount of agricultural wastes is estimated to be $21.85 \cdot 10^6$ t/yr. and this is made according to the waste-product ratio and average crop production. There is growing importance of these wastes as components of cattlefeed, or as row material for further industrial processing. Large quantities are burned, or rot in fields and only $5.97 \cdot 10^6$ m^3/yr. (27%) are evaluated as potentials for energy production. The state owned farms share in total amount with 20% and private farms 80%, but share is 40% and 60% for energy potentials. Table 1 gives average amounts of certain types of wastes from crop production and forestry. The shares of different wastes are the following:

Table 1. Estimated amount of biomass wastes in Serbia

No.	Biomass type	Amount of wastes					
		Overal amount			Energy potentials		
		Total	State[1]	Private[2]	Total	State	Private
		(In 10^6 m^3/yr. for wood wastes; in 10^3 t/yr. for agricultural wastes)					
1	Wood	3.34	1.76	1.58	0.84	0.44	0.4
2	Wheat	3525	1250	2275	1700	700	1000
3	Rye	16.3	1.3	15	5.7	0.7	5
4	Barley	230	100	130	110	60	50
5	Corn	17700	2700	15000	4000	1500	2500
6	Sunflower	90	50	40	33	25	8
7	Soya	272	200	72	115	100	15
8	Rape	16.8	14	2.8	7.5	7	0.5
Total (2 to 8)		218450.1	4315.3	17534.8	5971.2	2392.7	3578.5

[1] State owned
[2] Private owned farms or forests

wastes of stubble origin (cereals) are 30%, corn reminders (stalks, cob) 67%, oil-seed appr. 3% (Novaković and Djević, 1997).

Low heating value (LHV) of crop differs in range 13 to 18 MJ/kg (straw 15.8, sunflower seed shall 16.7, corn cob 15.7, corn stalks 16.5 MJ/kg, d. b., *etc*.) (Raveendran *et al.*, 1995). As the total amount of wastes of plant origin which can be used for energy production is shown to be around $4.1 \cdot 10^6$ t/yr. (wood $0.53 \cdot 10^6$ and crops $3.57 \cdot 10^6$ t/yr.), the energy potentials of these wastes comes near $1.6 \cdot 10^6$ t/yr. of fuel oil. This amount is near to 20% biger than overal fuel oil production in Serbia ($1.2 \cdot 10^6$ t/yr. in years 1994 to 1997), or almost equal to total oil consumption ($1.56 \cdot 10^6$ t of eqvivalent oil/yr.) in 1997 (SYB, 1997).

The state at present is that the importance of biomass as energy resource is not adequately recognized and only the small amount is used, primarily for combustion. The main reasons for this are the following: (a) the low density and apparent density of biomass (three to five times less than coal - 0.29 dm^3/MJ for corn cobs) greatly increase the costs of their application because of the high costs of transport and storage; (b) the lack of appropiate technologies for the use of biomass as a fuel in the market; (c) low prices of energy in the past (d) the importance of this energy source is still ignored by state and financial institutions.

Principles of biomass gasification

Gasification is thermochemical conversion of solid carbonaceous feedstock (biomass, coal, or wastes) into gaseous fuel which contains carbon monoxide, hydrogen, carbon dioxide, methane, traces of higher hydrocarbons, water, nitrogen (if air is used as gasifying agent) and various amounts of tar and solid particles (ash, char). Gasification occurs at temperatures over 500 °C when devolatilized char chemicaly react with oxygen and/or hydrogen introduced by gasifying agent (air, oxygen, steam, hydrogen, carbon dioxide or mixture of some of these gases). Air gasification gives poor quality gas (HHV lower than 7 MJ/m^3) which is used localy in boilers, gas turbines, or IC engines. Oxygen gasification produces a better quality gas (10–18 MJ/m^3), but because of high oxygen costs, it is prefered only in case of desulphurization of produced gas prior to combustion in coal gasification processes. Gasification with air is widely used technology for wastes and biomass conversion (Bridgwater, 1995).

There are two types of gasifiers more commonly used for small scale gasification, as shown in Fig. 1. Fixed bed gasifiers – Fig. 1(a) – are caracterised by rotating grid which supports descending packed bed of solids and cocurrent, or conutercurrent flow of gases through the bed. In a bubbling fluid bed gasifiers, crushed fuel is introduced into

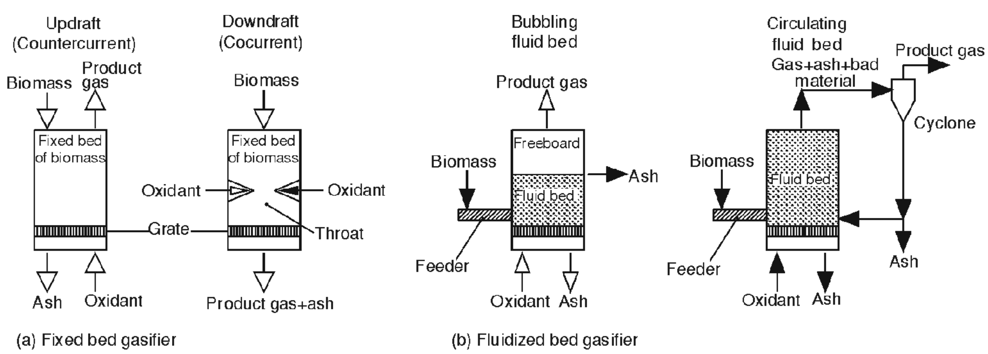

Figure 1. Basic principles of gasification for small-scale biomass conversion systems (Bridgwater, 1995)

the fluidized bed of inert material. Excelent mixing and high heat and reaction rates distigwish this type of reactors. The gasification takes place within the bed, but some conversions of produced gas (mostly tars and hydrocarbons) ocurr in the section of gasifier above the bed (free-board). Circulating fluidized beds are caracterized by entrained flow of fine particles of solid fuel and inert matrial (ash) through the reaction space. Material is carried by gases out of the gasifier, collected in cyclon and returned to the bottom of the gasifier. No inert material is used. Fluidized bed gasification principles are shown in Fig. 1(b).

Down-draft fixed-bed gasification is generally favoured for small-scale heat and/or electricity generation, owing to the simple and reliable gasificators and to the low content of tars and dust in produced gas. It is limited to relatively dry fuels (up to 30% wt of moisture) in shape of blocks, chips, or pelets. As the ash fusion and clinker formation on grate is possible, fuels with non-slagging ash are preffered. The limitations of diameter and particle size mean that there is a practical upper limit to the capacity of standard configuration of 500 kg/h or 500 kW_e (Bridgwater, 1995). Even with special design, its maximum size is probably limited to about 1 MW_e. Experience in wide number of development programs has shown that the clasical down-draft gasifier cannot be scaled. The latest trend in down-draft gasification research is development of small-scale, fully automatic units, dedicated to a single well defined fuel (Beenakers and Maniatis, 1996).

Biomass gasification activities in Europe

Climate change and other environmental impacts in energy production are the main reason for recent interest for biomass gasification in Europe. In 1994 Directorate for Energy of the European Commission approved a specific Program of Research and Technological Development, Including Demostration, in the field of biomass gasification.The state of biomass gasification varies considerably within the European countries. Biomass gasification has not yet reached commercial scale in Europe. Additionaly, many gasification projects have been supported by public funds, and their continuation is not always certain due to the shortage of public coffers. Despite the resulting uncertains, about 48 projects are presently under development in Europe. Most of them are in Scandinavian countries (18), Benelux state (7), Great Britain (8), Germany (7), Switzerland (6), Austria and Italy (3), France and Spain one. The presented projects describe the stage of usage, as well as the routes of development that are currently pursued (Dinkelbach and Kaltschmit, 1996).

Research and development in small-scale systems are mainly focused on down-draft gasifiers connected to an IC engine. Since most of the plants have been built in recent years and are funded by private sources, detailed information are not availeble in most cases (Dinkelbach and Kaltschmit, 1996).

The 100 kW_e down-draft gasifier at Enniskillen College In Northen Ireland is in use. It was developed at the University of Louvain, Belgium, for CHP (Combined Heat and Power) application. Due to excessive production of tar and dust that caused fouling in the downstream equipment, the gasifier has only been in operation for a few hundred hours (Dinkelbach and Kaltschmit, 1996).

The Belgian project TCR Gazel deals with a modified version of the above mentioned gasifier. The aim of the project is to commercialise down-draft gasifier diesel system (0.1–1 MW_e) for gasification of short-rotation-wilow for peak power production (Dinkelbach and Kaltschmit, 1996).The Italian company DANECO is operating a down-draft gasifier with downstream tar cracking and dust removal in a scrubber and an activated carbon filter. The cleaned gas is combusted in a Diesel engine for electricity generation. Currently, a gasification efficiency of 65% is achieved. The installation of a heat recovery system for production of superheated steam that will be led back to the gasifier and the tar cracker is expected to increase the efficiency up to 75%. Additionally, the efficiency of the Diesel engine is to be improved so that an overall efficiency of almost 30% can be achieved (Dinkelbach and Kaltschmit, 1996).

German company, Wamsler Umwelttechnik GmbH, successfuly implemented down-draft gasification systems. Three units were realised in Germany in '94 with capacities of 600 and 1500 kW_{th} (total power), whereas five others from 1.5 to 11 MW_{th}, are planned. Other fuel than wood, such as plastics and textiles is foressen. Wamsler has experience in wet gas cleaning and in operating a 200 kW_e gas engine (Beenackers and Maniatis 1996).

Recently, a 135 kW_e unit from Martezo (France) was implemented in Hoglid, Denmark. Gasifiers of old Imbert type, already used in World war II. Start-up problems have been significant and the char burn-out turned out to be lower than expected for an optimally designed and properly operating unit (Beenackers and Maniatis 1996).

MHB Multifunktionelle Heiz-und Bausysteme GmbH, Furstenwalde, Germany, claims to have upscaled a traditional down-draft gasifier, up to 750 kg/h (3.3 MW_{th}), what is presently the largest down-draft gasifier. However no further data on phase of implementation and performance are available (Beenackers and Maniatis 1996).

NIHPBS, Loughall, Ireland, operates a down-draft wood fueled combined heat and power facility since 1993. It provides 100 kW_e of electricity and 120 kW_{th} for space heating to the Agricultural College at Ennishillen. The design is based on the clasical Imbert gasifier with a dual fuel engine. During its three years of operation, a number of operating and design problems were solved. NIHPBS plans to install a fully commercial plant, probably of the same size, in 1998. The fuel will be coppice from short forestry rotation (Beenackers and Maniatis 1996).

At the present, there is only a small number of gasifiers that operating commercially (most of them are pilot, or demo units). As a result of extensive R&D efforts during the last decade, the technology of biomass gasification (fuel pre-treatment, feeding, bioamss conversion, and gas cleanup) is highly developed and available in laboratory and pilot scale. Activities on small-scale gasification systems are mainly focused on down-draft gasifiers. Although, in general, the interest in up-draft gasification has decreased, there is still some work on up-draft gasification of straw in Denmark.

Biomass gasification activities at Faculty of Mechanical Engineering

In Serbia, the process of agricultural wastes gasification has been tested on an experimental counter-current fixed bed gasificator at the Department for Process Engineering of the Faculty of Mechanical Engineering, University of Belgrade. The heart of unit is stainless steel reactor vessel with inner diameter of 200 mm and length 2500 mm. A 25 kg/h closed tube section at the top of the reactor was used to introduce the biomass to the reaction space.

In the following experiments air, which was used as the gasification medium, introduced at he bottom of gasifier. The gas composition was analysed by an on-line programmed gas chromatograf, which took a sample every 10 min. The concentracions of H_2, N_2, CO, CO_2, O_2 and CH_4 were determined.

Corn cob has proven to be an ideal row material for gas production. Raw material was cut, sieved and classified to obtain fraction of uniform size (<100 mm), with a LHV of 14.3 MJ/kg (15% wt. of moisture and 3% wt. ash). Gas of the following average composition (in % vol.) was produced (gasification with air under atmospheric pressure): CO – 24%, CO_2 – 22%, H_2 – 10%, O_2 – 1.9%, N_2 – 37.7% and CH_4 – 4.4% (LHV – 5.7 MJ/m^3).

An experimental co-current fixed bed reactor for gasification under atmospheric pressure, with a capacity of 5 kg/h was used in the same laboratory for gasification of wood wastes. The fuel was a mixture of deciduous wood wastes 5–30 mm in size, with a moisture content of 5–50%. Produced gas did not contain tar and the average composition of dry gas was as follows (in % vol.): CO – from 9.8 to14.6%, CO_2– from 9.6 to14.1%, H_2 – from 11.3 to18.4%, O_2 – from 0.6 to1.1% and N_2 – from 47.2 to 59.3%.

Results obtained from these expiriments are in the good agrement with results obtained elsewhere (Bridgwater, 1995, Raveendran *et. al*., 1995, Raveendran and Ganesh, 1996, Raveendran, *et. al*., 1996, Jankes, 1986).

With the application of recuperation, or the use of hot gas directly after the gasificator, the gasification efficiency of 90% can be achieved.

Not a single gasification system for comercial use has yet been built, but the process and system have been developed to the point that they can be safely offered to the potential customers.

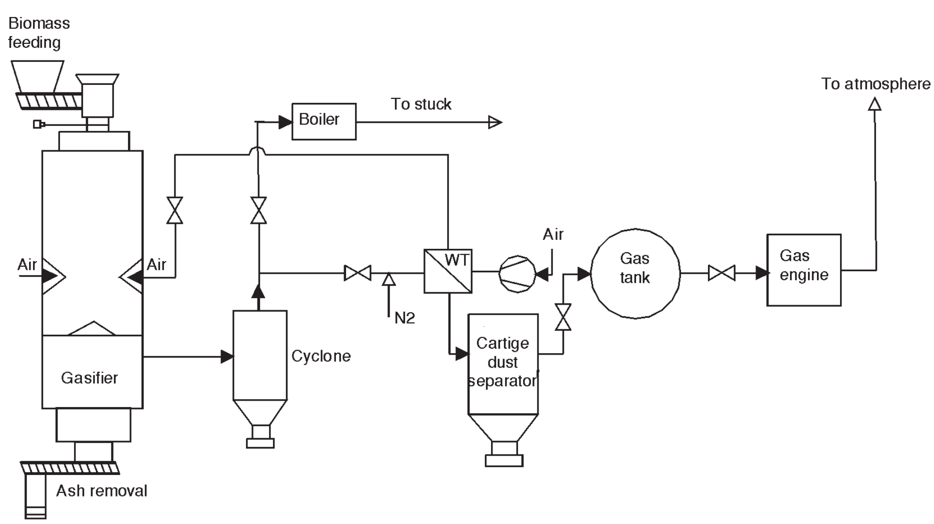

Figure 2. Scheme of biomass gasification demonstration unit

According to the results of biomass and waste gasification experiments carried out on laboratory scale reactors of the Faculty of Mechanical Engineering, Belgrade, but also on the results of wide number of R&D projects recently presented in literature, the concept of demonstration unit is developed. The aim of the demonstration plant is to test the gasification of corn cob, which is agricultural waste of significant quantity in Northen part of Serbia and to prepare the comercialization of this technology. It is based on down-draft fixed bed gasifier with capacity 120 kg/h of corn cob (LHV app. 16 MJ/kg d. b.) and the thermal output 0.4 MW_{th} (calculated on a dry cold gas). The sheme of the plant is shown on Fig. 2. The location of the plant is planned to be on a state owned farm nearby Belgrade and produced gas will be used as additional fuel for the existing hot water boilers of the farm, or alternatively, after cooling and dust separation, for electricity production.

Conclusion

Potentials of biomass as a fuel is significant in Serbia, and it is estimated to be $1.6 \cdot 10^6$ t/yr. for energy production, what is almost equal of total fuel oil consumption in Serbia in 1997 (SYB, 1997).

Small-scale gasification is conveniant and well tested technology. After demostration unit operation it is expected to be comercialized and used for heat and/or electricity production in farms, corn dryers, or wood processing plants.

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