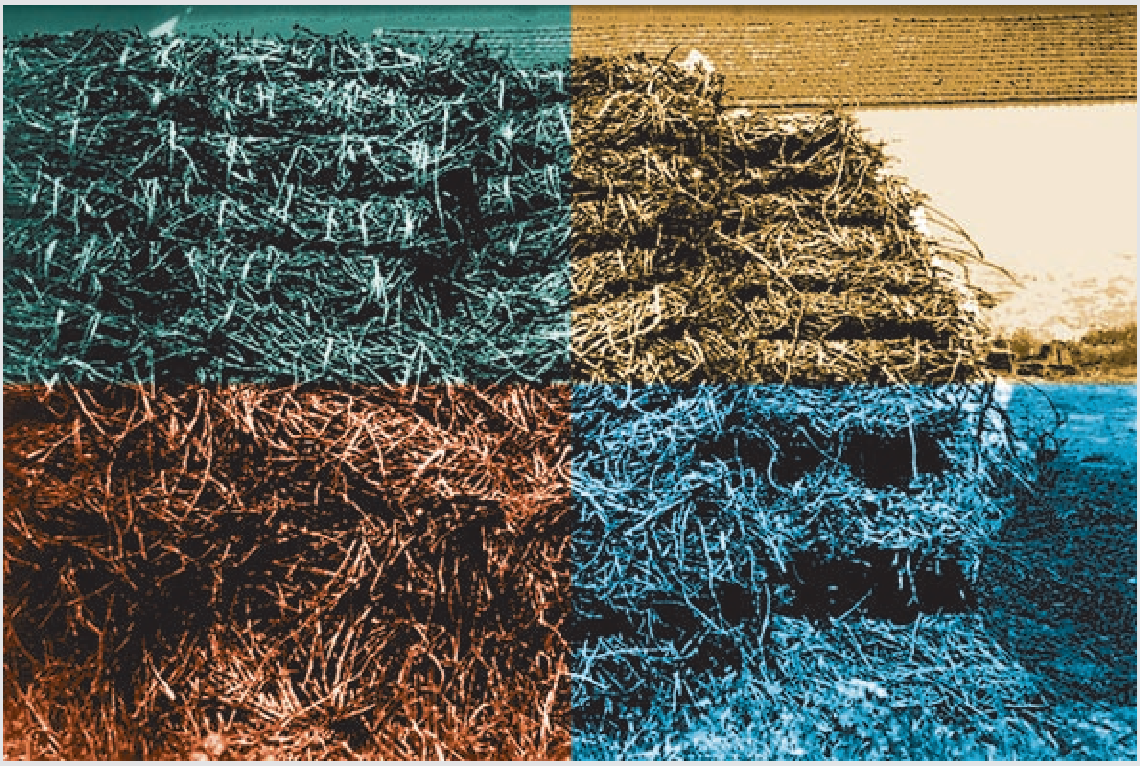
A THERMIE PROGRAMME ACTION

Combustion and Gasification of Agricultural Biomass - Technologies and Applications



European Commission
Directorate-General for Energy (DG XVII)

R.E.S.

THERMIE (1990 - 1994)

This is an important European Community programme designed to promote the greater use of European energy technology. Its aim is to assist the European Union in achieving its fundamental objectives:

- improving the enrgy supply prospects of the European Union;
- reducing environmental pollution by decreasing emissions, particularly those of CO_2, SO_2 and NO_x;
- strengthening the competitive position of European industry, above all small and medium-sized enterprises (SMEs);
- promoting the transfer of technology to Third Countries;
- strengthening economic and social cohesion within the European Union.

The majority of the funds of the THERMIE Programme are devoted to financial support of projects which aim to apply new and innovative energy technologies for the production, conversion and use of energy in the following areas:

- rational use of energy in buildings, industry, energy industry and transport;
- renewable energy sources such as solar energy, energy from biomass and waste as well as geothermal, hydroelectric and wind energy;
- solid fuels, in the areas of combustion, conversion (liquefaction and gasification), use of wastes and gasification integrated in a combined cycle;
- hydrocarbons, their exploration, production, transport and storage.

The THERMIE Programme (1990-1994) includes a provision for the enhanced dissemination of information to encourage a wider application and use of successful energy technologies. This information is brought together, for example, in publications such as this maxibrochure. Maxibrochures provide an invaluable source of information for those who wish to discover the state of the art of a particular technology or within a particular sector. The information they contain is drawn from all Member States and therefore provides a pan-European assessment.

To guarantee the maximum effectiveness of the funds available, the THERMIE Programme (1990-1994) includes an element for the co-ordination of promotional activities with those of similar programmes carried out in Member States and with other European Community instruments such as ALTENER, SAVE, SYNERGY, JOULE, PHARE and TACIS.

JOULE THERMIE (1995 - 1998)

The first THERMIE Programme for the demonstration and promotion of new, clean and efficient technologies in the fields of rational use of energy, renewable enrgies, solid fuels and hydrocarbons, came to an end in December 1994. In January 1995, the programme was renewed as part of the new Non-Nuclear Energy Programme, better known as JOULE-THERMIE, within the European Community's Fourth Framework Programme for Research, Technological Development and Demonstration. As prescribed in the Treaty on European Union, this programme brings together for the first time the research and development aspects of JOULE (managed by the Directorate-General for Science, Research and Development, DG XII), with the demonstration and promotion activities of THERMIE (managed by the Directorate-General for Energy, DG XVII). A budget of 532 MECU has been allocated to the THERMIE component for the period 1995-1998.

THERMIE Colour Coding

To enable readers to quickly identify those maxibrochures relating to specific parts of the THERMIE Programme, each maxibrochure is colour coded with a stripe in the lower right hand corner of the front cover, i.e.:

- Solid Fuels
- Renewable Energy Sources
- Rational Use of Energy
- Hydrocarbons

This maxibrochure was produced in the framework of the former THERMIE Programme (1990-1994).

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Combustion and Gasification of Agricultural Biomass - Technologies and Applications

THERMIE PROGRAMME ACTION BM 40

C E E E T A

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C O N T E N T S

INTRODUCTION

The present competition in the agricultural and agro-food sector calls for better productivity and the creation of new products. Consequently companies should adopt adequate measures aimed at cutting back on production costs and improving the quality of their products.

Competitiveness also requires the adoption by companies of adequate measures in the field of environmental protection, which should encompass a volume reduction of by-products and waste produced, as well as their recycling and use for energy purposes (through either self-consumption or sale). The last aspect is particularly relevant, as this raw material is mostly composed of organic matter and is therefore recyclable, on a variable term.

Various types of waste - namely those resulting from Mediterranean farming (rice husk, olive bagasse, nut shells, etc.) - have been used for energy purposes in power plants equipped with technologies that range from well-established direct combustion systems to gasification systems that are currently being developed.

The state-of-art technologies currently available make it possible for waste utilisation to be adapted to the energy requirements of all sectors (household, services, industry), for the production of both hot water and steam and power, by means of either turbo- or engine-generators.

In spite of the technologies currently available, the projects that have been implemented so far show that in order for waste to have an economic edge on fossil fuels as regards its utilisation for energy purposes, it should be used near the respective location of production. These projects also demonstrated that waste use for combined heat and power generation should be promoted in the countries with a favourable tariff system.

This publication contains a description of processes and technologies related to direct combustion and gasification of agricultural & agro-food waste. This description is anchored by case studies aimed at helping the readers identify applications for the use of the said waste for energy purposes, thus contributing to reduce the energy bills and promote environmental protection.

1 - BIOMASS UTILISATION FOR ENERGY PURPOSES: PROCESSES

Biomass utilised for energy purposes can be divided into two main categories:

- "Wet" biomass (marine algae, manures, organic waste fluids, etc.);
- "Dry" biomass, including forest biomass (wood, forest waste and waste from the lumber industry) and agricultural biomass (waste from pruning, nut shells, rice husks, pine cone scales, olive bagasse, etc.).

Biomass can be utilised for energy purposes by applying a number of conversion processes which can be classified in accordance with the respective processing method, as follows:

- Biochemical routes (anaerobic digestion, microbial digestion, acid hydrolysis) applied to convert "wet" biomass;
- Thermochemical routes (combustion, pyrolysis, gasification, liquefaction) applied to convert "dry" biomass, which consist in using heat to decompose organic matter through chemical reactions (see Table 1).

Agricultural biomass is mainly utilised for energy purposes in the combustion process. It is currently sold as fuel for industrial units and as energy source for the household and services sectors. Although the gasification process has not yet reached a sufficiently mature stage of technological development to be placed in the market, a number of experiments in the industrial sector have shown that it has an interesting potential.

There are in fact no major differences between the combustion process (during which organic materials react against oxygen) and the gasification process. Any process can result in either combustion or gasification, depending on the air/fuel ratio which is applied. Considering that biomass has the composition of cellulose ($C_6H_{10}O_5$), gasification and combustion can be represented through global chemical equations, as follows (it should be noted that combustive reactions release much higher amounts of heat - 17.5 MJ/kg - than gasification reactions - 1.85 MJ/kg):

$$C_6H_{10}O_5 + 0{,}5O_2 \longrightarrow 6CO + 5H_2 \quad \text{- gasification}$$
$$C_6H_{10}O_5 + 6O_2 \longrightarrow 6CO_2 + 5H_2O \quad \text{- combustion}$$

TABLE I

Process		Derived Products	Energy Recovery (kJ / kg)	Global Process Efficiency
Total Combustion		———	14 000 - 16 700	65
Pyrolisis	slow	charcoal oils	19 000 - 31 000 23 000	45
	fast	gas with average C.V. gas with average C.V.	15 000 19 000	(?)
Gasification	with air	gas with low C.V.	7 000	50 - 60
	with $O_{2/steam}$	gas with average C.V.	15 000	
Direct liquefaction		oils (liquid fuels)	27 000 - 40 000	(?)

C.V. - Calorific Value

1.1 - Combustion

Combustion is a process whereby the total or partial oxidation of carbon and hydrogen converts the chemical energy of biomass into heat. This complex chemical reaction can be briefly described as follows:

Burning fuel = Products from reaction + heat

During the combustion process, organic matter decomposes in phases, i.e. drying, pyrolysis/gasification, ignition of volatile substances and charcoal combustion. Generally speaking, these phases correspond to two reaction times: release of volatile substances and respective combustion, followed by charcoal combustion.

Optimised oxidation of both volatile substances and carbon waste depends on how effectively you can control the admission of the oxidising agent (i.e. air), at two levels:

- Primary air, which crosses the fuel and ensures its pyrolysis and the combustion of carbon waste;
- Secondary air, which does not mix with primary air, but ensures the burning of gases released during pyrolysis.

In a heat generator with upstream combustion, the various chemical and thermal reactions occupy areas which are not well defined. Accordingly, the drying, pyrolysis/gasification and charcoal combustion phases overlap one another (Fig. 1).

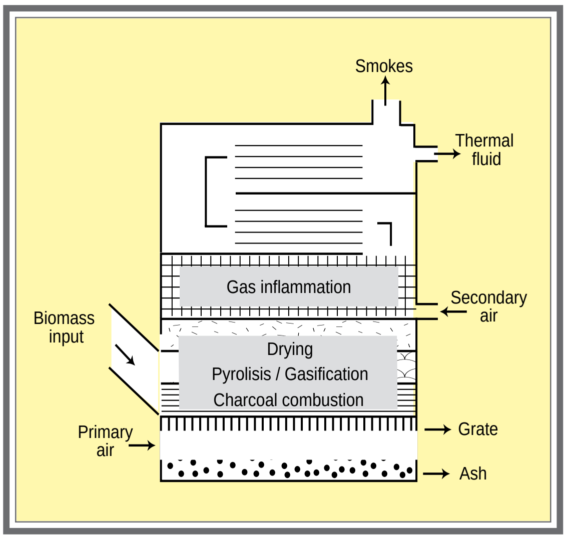

Fig. 1 - Sketch of a heat generator with upstream combustion

1.2 - Gasification

Gasification is a process whereby organic matter decomposes through thermal reactions, in the presence of stoichiometric amounts of oxidising agents. The process generates a combustible gas mix, essentially composed of carbon monoxide, hydrogen, carbon dioxide, methane, steam and, though in smaller proportions, other heavier hydrocarbons and tars..

The process is aimed at converting the energy potential of a solid fuel into a gas product, whose energy content has the form of chemical energy with the capacity to generate work. Consequently this gas product shares the usual advantages of gas fuels over solid fuels, namely:

- easier handling;
- more efficient combustion, due to lower excess air;
- less dirt left on heat exchanging surfaces;
- Optional applications in either internal - combustion engines, gas turbines or CHP units.

During a gasification process, biomass is subjected to a complex sequence of reactions (such as drying, pyrolysis, reduction and combustion or oxidation) which can be grouped into three phases:

Phase 1 - Drying: moisture contained in the fuel is extracted in the form of steam, without chemical decomposition of the fuel.

Biomass with moisture + heat =
= Biomass without moisture + steam

Phase 2 - Pyrolysis: Without air admission, the natural structure of the fuel is broken through a self-sustained exothermal reaction which releases steam, methanol, acetic acid and a considerable amount of heavy hydrocarbons. The solid waste resulting from this operation consists mainly of carbon in the form of charcoal - which will be used during combustion and reduction reactions.

Biomass without moisture + heat =
= carbon waste, CO, CO_2, H_2, hydrocarbons, organic compounds, etc.

PHASE 3 - Gasification: generally speaking gasification consists of two reactions: combustion and reduction. During combustion (or oxidation) oxygen is mixed with carbon from the fuel, in the area of the gasifier where the oxidising agent (i.e. air/steam/oxygen) is admitted, thus generating carbon dioxide. The warm gas flow, with a high CO_2 content (plus H_2O, if steam is used) is then driven to the reduction area. Once in this area, a number of incombustible gases are converted into combustible products through a series of reactions, absent oxygen. The main reaction generates carbon monoxide.

Carbon + steam + heat = $CO + H_2$
Carbon + CO_2 + heat = 2CO

Theoretically speaking in an updraft gasifier the various phases occur in a sequence, each phase occupying a specific separate area where different chemical and thermal reactions take place (Fig. 2).

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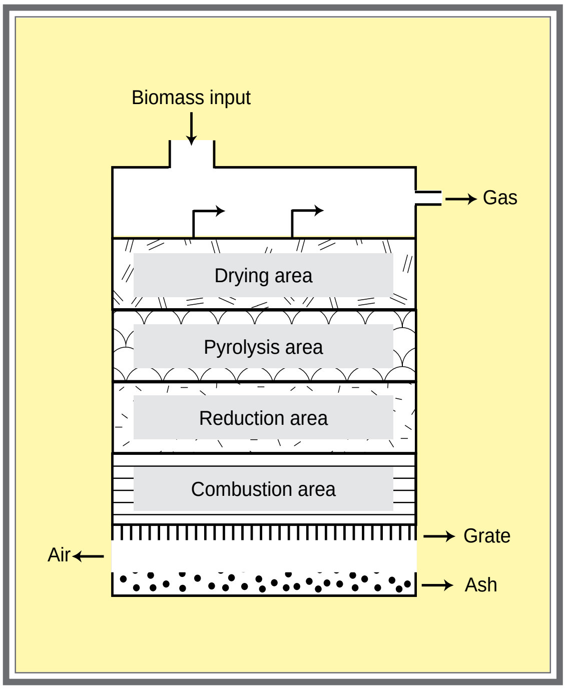


Fig. 2 - Sketch of an updraft gasifier

2.1 - COMBUSTION

Known and applied for many decades, biomass combustion technologies have been considerably improved in the last few years - mainly as regards the development of new combustion systems and the adaptation of automatic feed systems to the various types of vegetal biomass.

Agricultural biomass is mainly applied to heat generation units requiring a regular automatic fuel feed, as it can be used almost like a classical fuel due to its homogeneous dimensions. Nevertheless the efficiency of the combustion process depends upon a number of factors, such as fuel type and attributes, operating conditions (temperature, air surplus rate, stack draught), type of furnace, etc.

The equipment currently available in the market meets a wide range of energy requirements, with satisfactory yields. It can be adapted to the various existing types of agricultural biomass so as to generate all types of fluids (warm water, air and gases; steam; thermal oil; superheated water). In the household and services sectors, agricultural biomass is burned for space heating, domestic hot water production or cold storage through absorption equipment. In industry, applications range from drying to simultaneous generation of thermal energy and electricity by means of steam turbines.

Although there is a wide range of combustion techniques and procedures for each type of fuel, feed system and type of energy utilisation, the existing technologies can be grouped into four categories:

- Generator with integrated furnace : the combustion chamber is integrated in the generator - which has three variants, depending on the type of grate (Fig. 3):

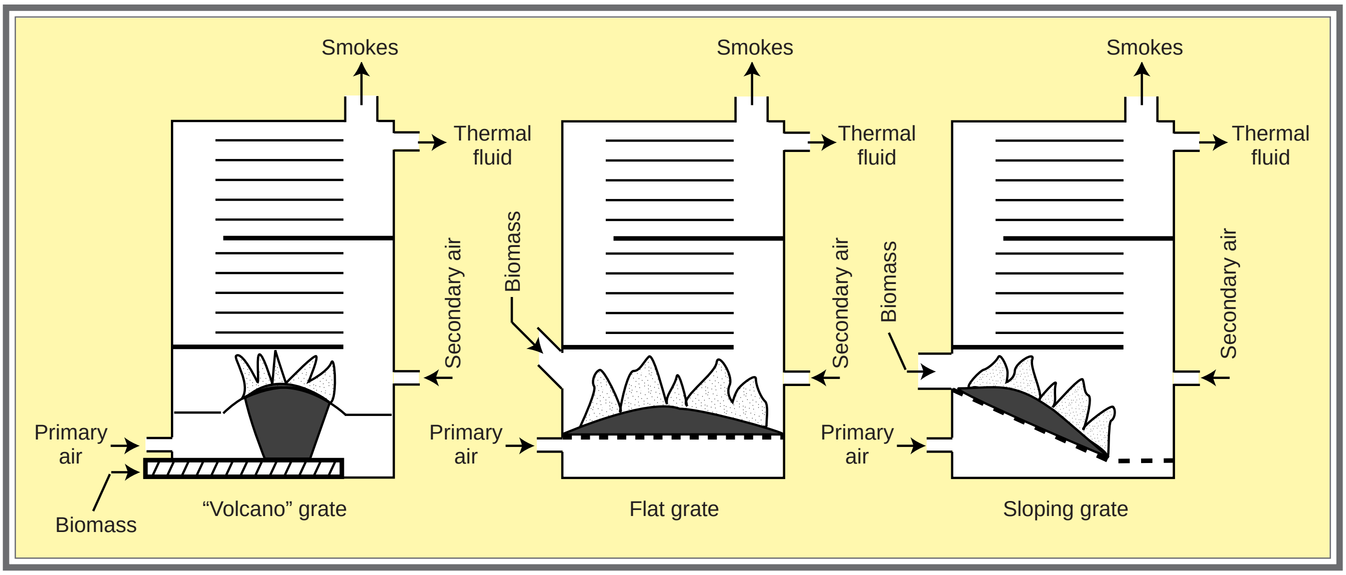


Fig. 3- Generators with integrated furnace

- "Volcano" - grates are exclusively used in feed systems equipped with worm screws. The grate is shaped like an inverted cone and is fed from the bottom. Depending on the feeding and combustion sequences, ashes are deposited on the border of the grate and can be extracted either manually or automatically;
- Flat grates - (either fixed or movable) are associated with feed systems by gravity, worm screw or piston;
- Sloping grates - (either fixed or movable) allow for a better differentiation among the various phases of combustion. They are associated with feed systems by gravity, worm screw or piston.

- Generator with pre-furnace: the combustion chamber is coupled to the generator upstream. The flames develop inside the exchanger through the admission of secondary air. Generally speaking the pre-furnace consists of a large wall made of refractory material which makes it possible to use fuels with a high humidity content. Pre-furnace generators also have three variants, depending on the type of grate (Fig. 4).

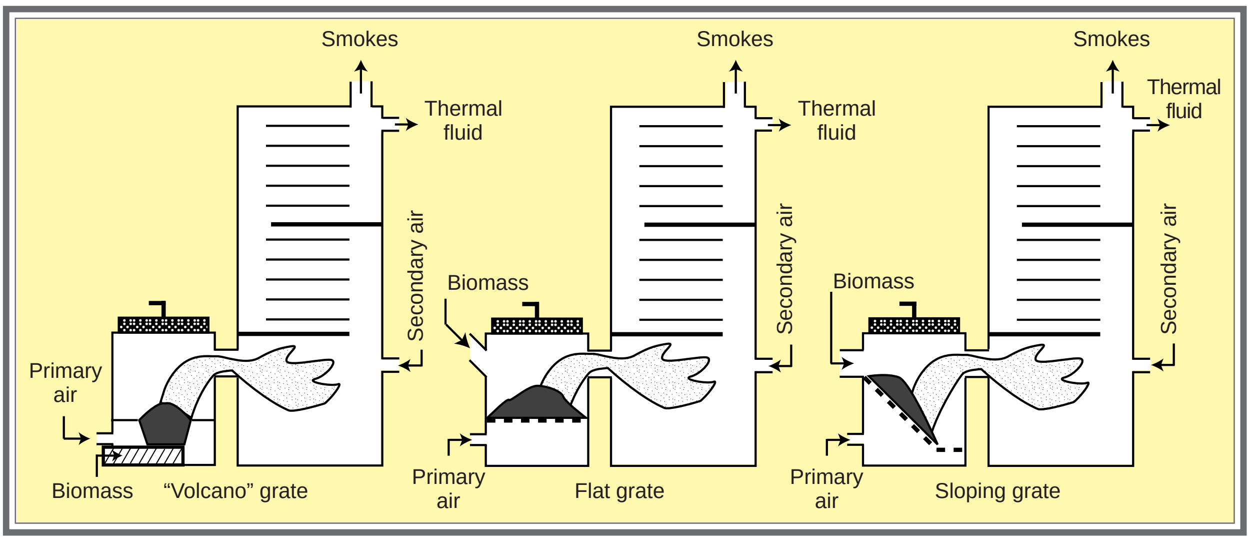


Fig. 4 - Generators with pre-furnace

- Generators with suspended bed: a gas flow holds the fuel particles in suspension, inside the combustion chamber. These generators have an automatic feed system (pneumatic type);
- Generators with fluidised bed: fuel (in small particles) mixed with inert material is held in suspension by an ascending gas flow, inside the combustion chamber. Equipped with either worm screw or piston feed systems, these generators are mainly used in industry, to produce energy.

2.2 - Automatic feed in combustion systems

Automatic feed systems are aimed at transporting fuel from the silo to the furnace. They usually operate in three phases:

- Extracting fuel from the silo: fuel can be extracted from the silo by gravity or by mechanical means, i.e. rotating or alternating extractors:

• Extraction by gravity - is the simpler method. It does not require any mechanical means (except possibly a stirrer) and is mainly used in small bins (Fig. 5);

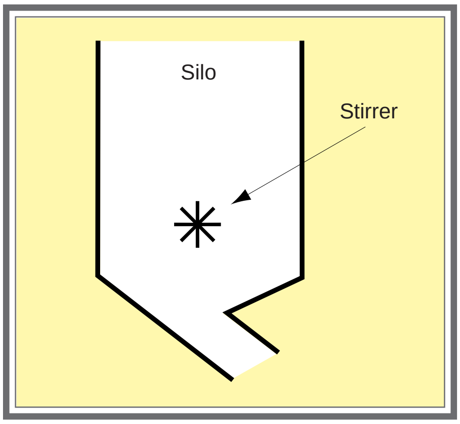


Fig. 5 - Extraction by gravity

• Rotating extractors - are mainly used in cylindrical bins with an average capacity (Fig. 6);

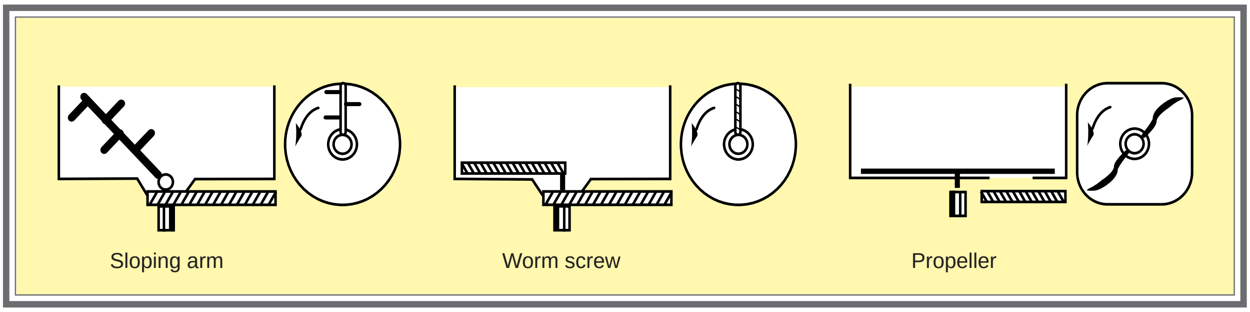


Fig. 6 - Rotating extractors

• Reciprocating extractors - usually hydraulic, they consist of triangular scrapers with an alternating movement (to-and-from) and are used in high capacity parallelepiped-shaped bins (Fig. 7).

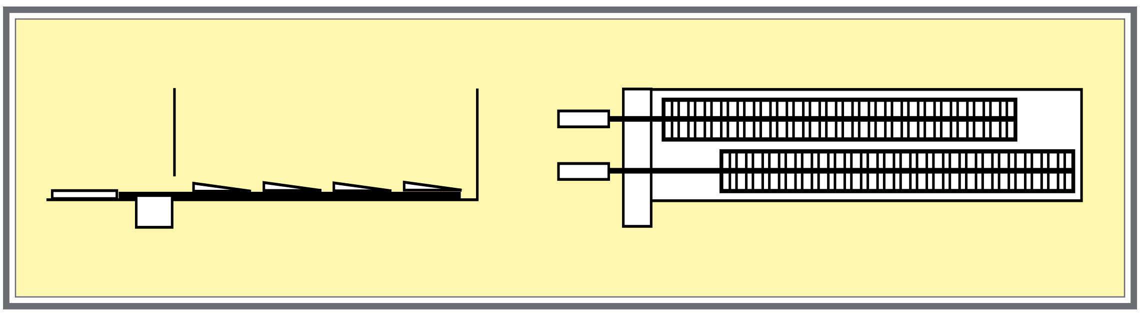


Fig. 7 -Reciprocating extractor

- Transporting the fuel to the furnace: fuel can be transported to the furnace (i) pneumatically, (ii) inside a sheath, or (iii) by means of a trough:

    - The pneumatic mode - consists of a fan, coupled to rotating extractors, which propels fuel into the furnace. It is used to transport dry fuels with small grain size;

    - Transporting fuel inside a sheath - makes it possible to carry out the operation in horizontal and sloping plans, by means of a worm screw or a piston;

    - The wide deep trough - (made of steel or masonry) incorporates hydraulically powered horizontal scrapers. It is usually associated with alternating extractors.

- Feeding fuel into the furnace: four processes can be used to execute this operation:

    - Admission by gravity - this process has two alternatives: a) direct admission - generally associated with a pre-furnace and fuels with small regular grain size; or b) indirect admission, by means of a guillotine-type valve which allows for admission of fuels with irregular grain size (Fig. 8);

    - Pneumatic admission - this process makes it possible to feed fuel into the base of the furnace or a separating cyclone. It is usually associated with pneumatic fuel transporters and dry fuels with small regular grain size (Fig. 8);

    - Admission by worm screw - the worm screw is generally installed on the base of the furnace and is usually associated with a sheath transporter or a pneumatic transporter. It allows for a regular homogeneous fuel feed (Fig. 9);

    - Admission by piston - this hydraulically-powered system allows for admission of fuels with irregular grain size. Although it can be adapted to any transport system, it is more frequently associated with fuel transport by trough. Generally speaking, pistons are installed on the base or on one of the sides of the generator (Fig. 9).

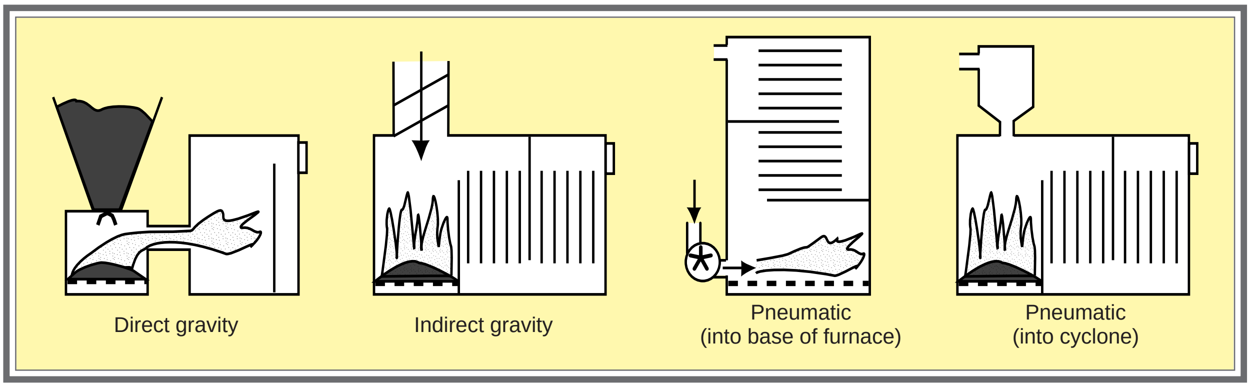


Fig. 8 - Feeding fuel into the furnace by gravity and pneumatically

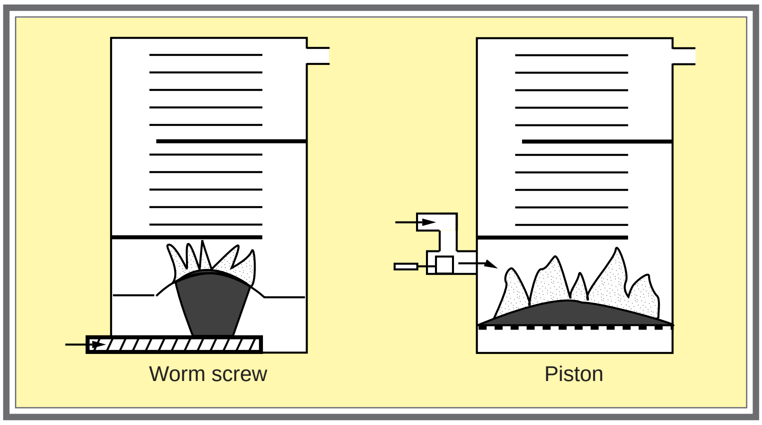


Fig. 9 - Feeding fuel into the furnace by worm screw and piston

2.3 - Thermal power plant layout

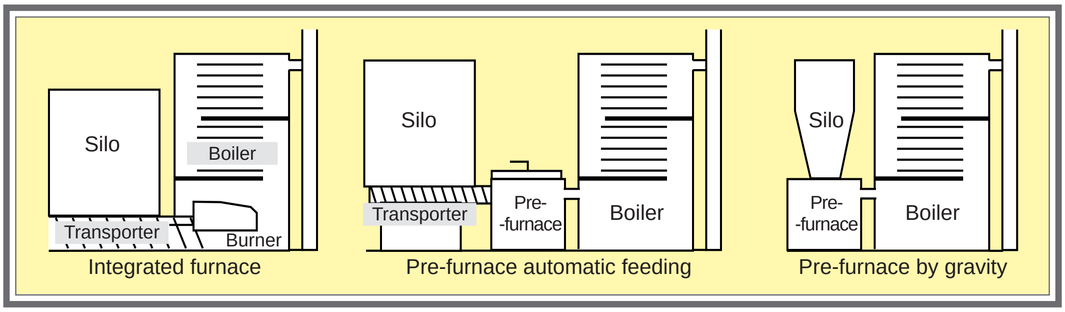


Fig. 10 - Compact unit

Technologies should be selected in accordance with (i) required power, (ii) attributes of the biomass available, (iii) type of use assigned to the thermal fluid, and (iv) architectural integration. Generally speaking, the following types of automatically fed thermal power plant are currently in operation:

- Low-power compact units (<100kW), with a 24 hour autonomy. Serving the household and services sectors, they are designed to run on fuels with regular grain size (Fig. 10);
- Pneumatically fed units, designed to run on dry fuel with small grain size (Fig. 11);
- Worm-screw fed units, for households, services and industry. They are designed to run on fuel with regular grain size (Fig. 12);
- High-power units, fed by means of alternating transporters (conveyor-belt or piston), for services and industry. They are designed for a possible utilisation of wet fuel with irregular grain size (Fig. 13).

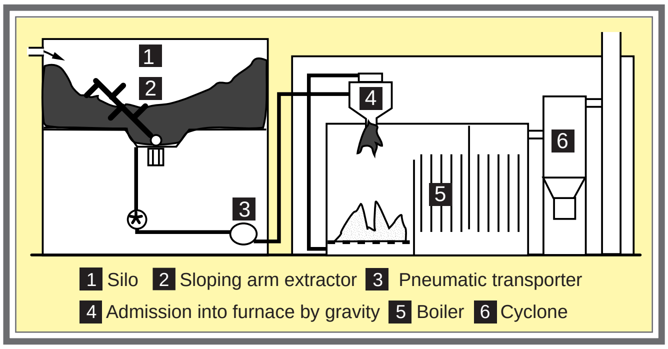


Fig. 11- Unit with pneumatic fed

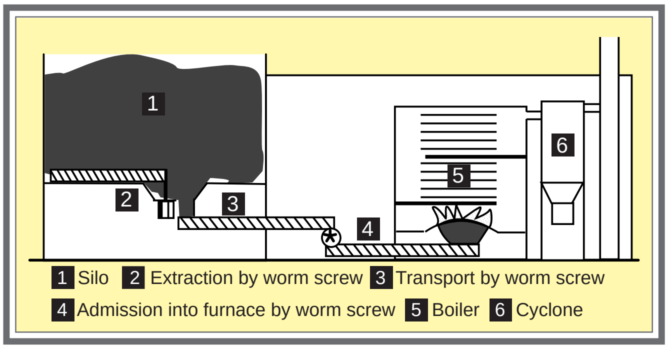


Fig. 12 - Worm screw fed unit

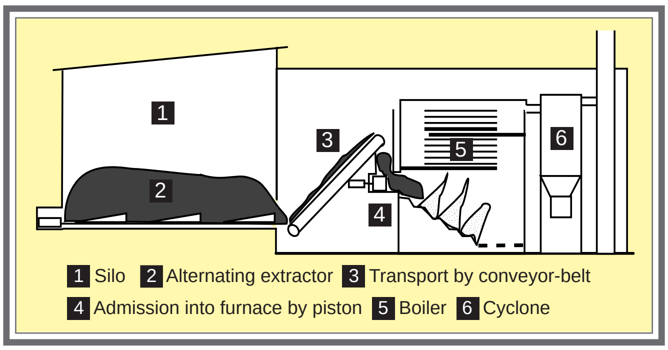


Fig. 13 - Unit fed by alternating transporter, conveyor-belt and piston

2.4 - Gasification

Although many gasification technologies are available today worldwide, with variable degrees of development, all existing gasifiers basically fall into three main categories:

- Fixed bed gasifiers: in these gasifiers no variations occur on opposite extremes of the bed, in stationary conditions. This category has three variants, depending on the way in which gas is extracted from the unit (Fig. 14);
- Suspended bed gasifiers: a gas (usually air or oxygen with steam) flow holds the fuel particles in suspension inside the gasifier (Fig.15);

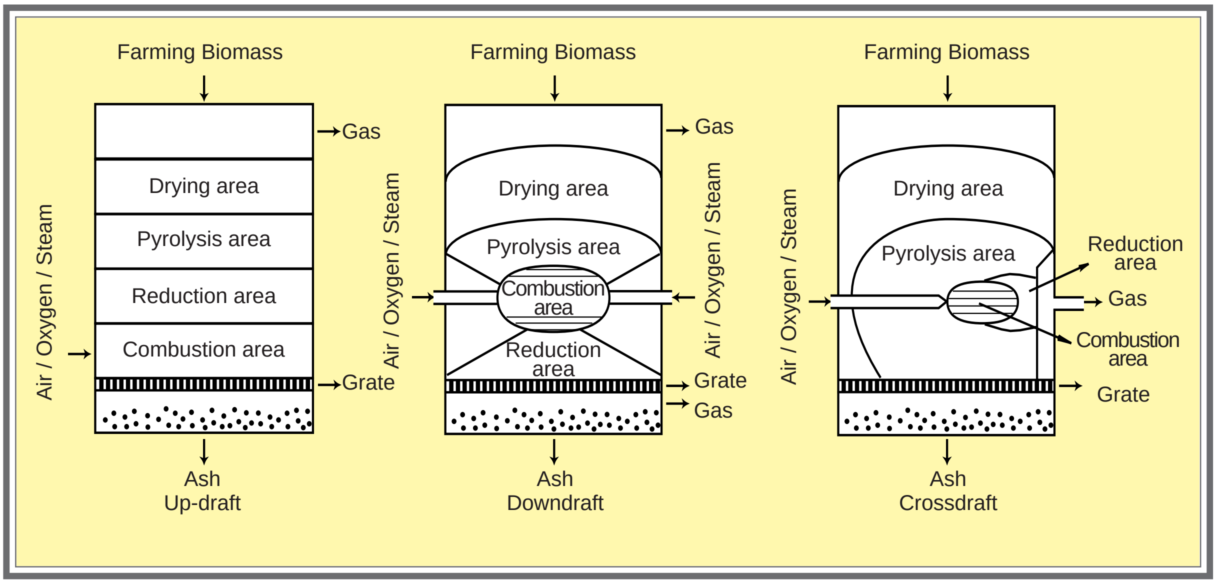


Fig. 14 - Simplified sketch of fixed bed gasifiers

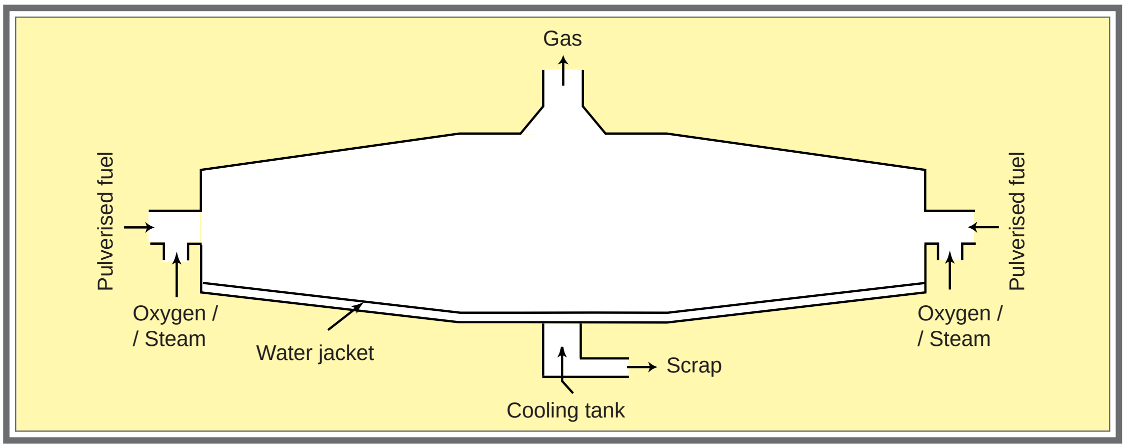


Fig. 15 - Simplified sketch of a suspended bed gasifier

- Fluidised bed gasifiers: a distributor introduces a fluid which crosses a bed of particles - consisting of inert material and small particles of fuel - and causes it to become suspended. Reaction phases in this category of gasifier occur simultaneously across the whole fluidised bed, in a homogeneous manner (Fig. 16).

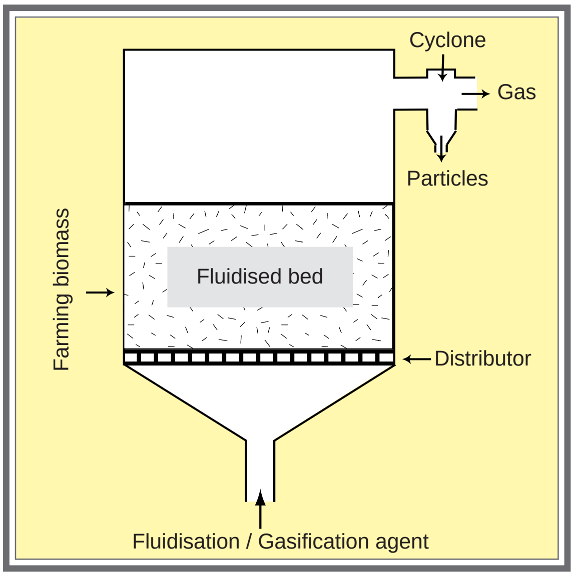


Fig. 16 - Simplified sketch of a fluidised bed gasifier

Reactions within a gasifier depend on a number of factors, e.g. fuel type and attributes (grain size, moisture), operating conditions (temperature, heating rate, residence time, heat losses, etc.) and, mainly, the selectedgasification agent (air, oxygen, carbon dioxide, steam, hydrogen or a mix of the previous gases). These reactions may generate various gases which can be roughly grouped into three categories - i.e. Low (LCV), Average (ACV) and High Calorific Value gas (HCV) -, each having its typical production process (Fig.17, 18 and 19). These gases may be used to obtain chemical products (such as methanol, combustible alcohol, etc.) but also have other industrial applications, namely:

- Burning in combustion equipment, to generate heat for heating or drying processes and electricity by means of steam turbines;
- Burning in gas turbines for electric power generation;
- Burning in internal-combustion engines, diesel engines or combustion engines, to generate electric or mechanical power.

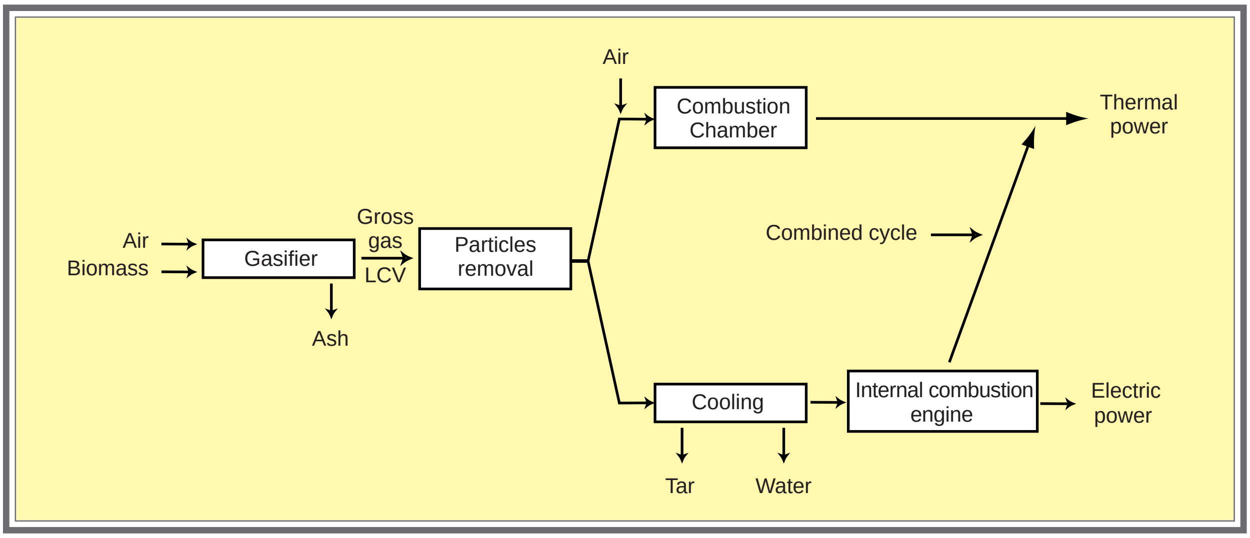


Fig. 17 - Production and applications of LCV gas (3.5 - 7 MJ/m^3)

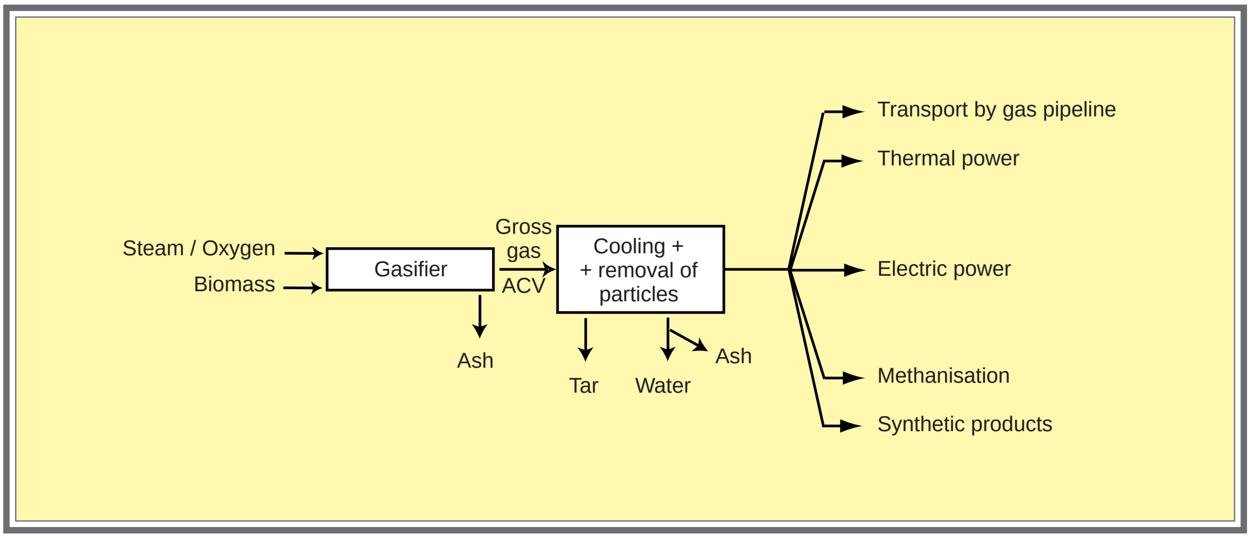


Fig. 18 - Production and applications of ACV gas (9 - 15 MJ/m³)

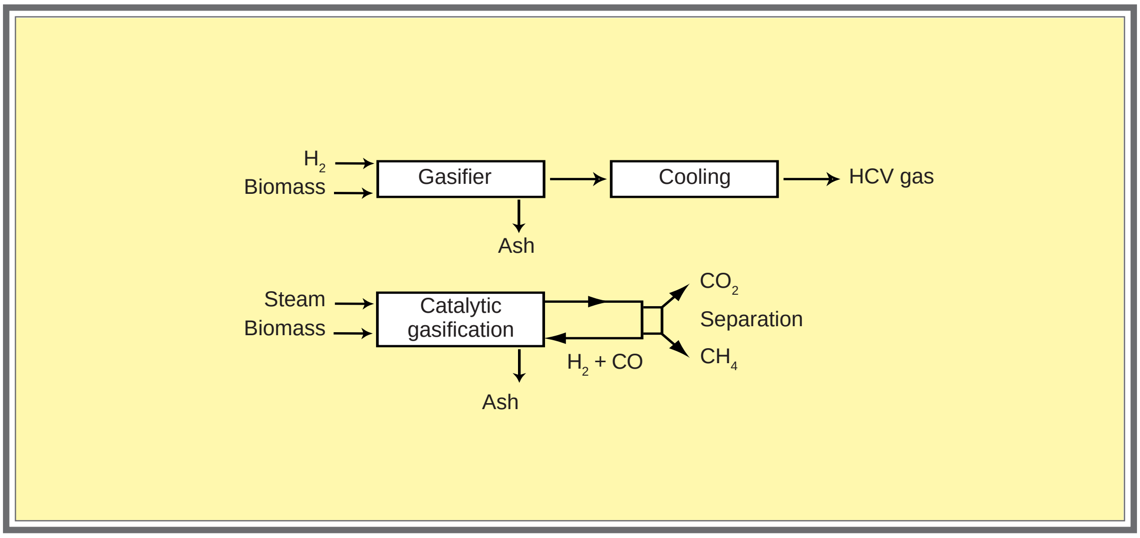


Fig. 19 - Direct production of HCV gas (20 -36 MJ/m³)

3.1 - Combustion of pine cone scales for space heating in primary schools

The Municipality of Alcácer do Sal (South of Portugal) decided to utilise pine cone scales - a waste from the pine nut industry, abounding in the region - for energy purposes. Twenty primary schools (with one to four classrooms) were provided with salamander-type heaters, specially prepared to be automatically fed with pine cone scales. Each 10 kW heater consists of a silo (with a 10-15h storage capacity), a feed system by gravity, a pre-furnace and a air/air heat exchanger (Fig. 20).

The average energy requirements per annum of each classroom, for space heating purposes, amount to 9 500 kWh. A warm air generating salamander was installed in each classroom to keep a space temperature ranging from 18º to 20º C , so as to replace the previous heating system which consisted of electric radiators. Total investment amounted to ECU 24 100 (including installation of the salamanders, thermal insulation of school roofs, doors and windows and removal of the electric radiators). The annual consumption of pine cone scales in the 20 schools amounts to 200 tonnes.

Comparison with the former electric heating system shows that annual savings of ECU 20 060 were achieved- which means a gross investment pay-back time of 2,7 years.

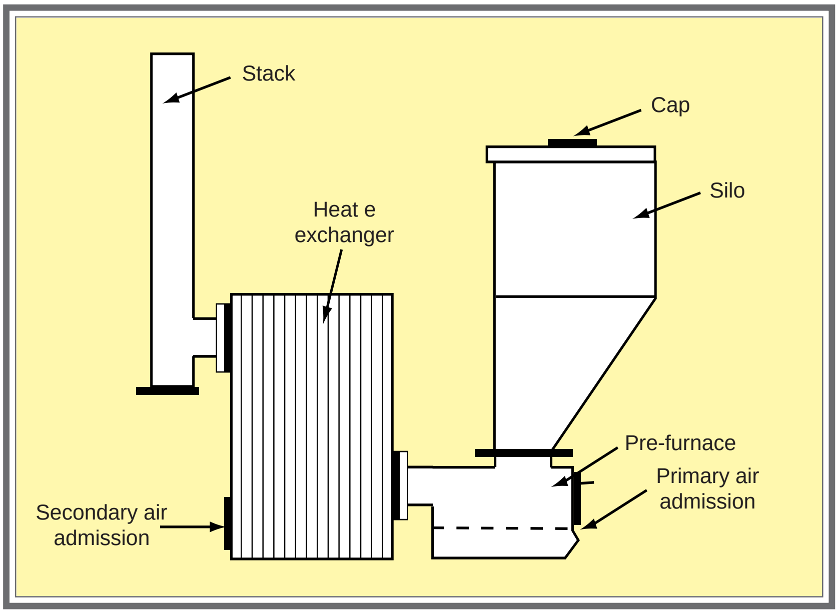


Fig. 20 - Sketch of salamander fed with pine cone scales

3.2 - Combustion of pruned vine twigs for space heating in a primary school

In the wine producing area of Redondo (South of Portugal), a total amount of 510 tons of pruned vine twigs (sarmenta) is made available every year. In order to utilise this waste for energy purposes, the Municipality of Redondo decided to equip the local primary school with a centralised space heating system designed to burn vine twig bundles.

Vine twigs are collected and packed in bundles (diameter = 0,5 m; length = 1 m) by the Municipality, by means of a combine. Bundles required for the school are stored in a barn to be used in the following year.

The heating system relies on water storage and can therefore take up the heat "peak" during combustion of the vine twigs (3 times faster than wood combustion), thus enhancing its efficiency and autonomy.

The school has 13 classrooms in 3 buildings and a total energy consumption per annum amounting to 114 500 kWh. The centralised space heating system consists of a 150 kW horizontal hot water boiler with reversed flame, fed with round bundles of vine twigs or wood.

The total energy released is stored in a water tank with a 5 000 litre capacity, connected to the boiler by means of a 4-way valve which keeps the return temperature to the boiler higher than 55º C (dew temperature). Hot water is independently piped to the radiators of each building, in accordance with the respective outside temperature and occupancy rate (Fig. 21).

Total investment amounted to ECU 36 100. It included not only the installation of the space heating system but also thermal insulation and disassembling of the previous system based on electric radiators. When compared to the previous electric heating system, the new one allows for annual energy savings of ECU 10 900, allowing for a gross investment pay-back time of 3.3 years.

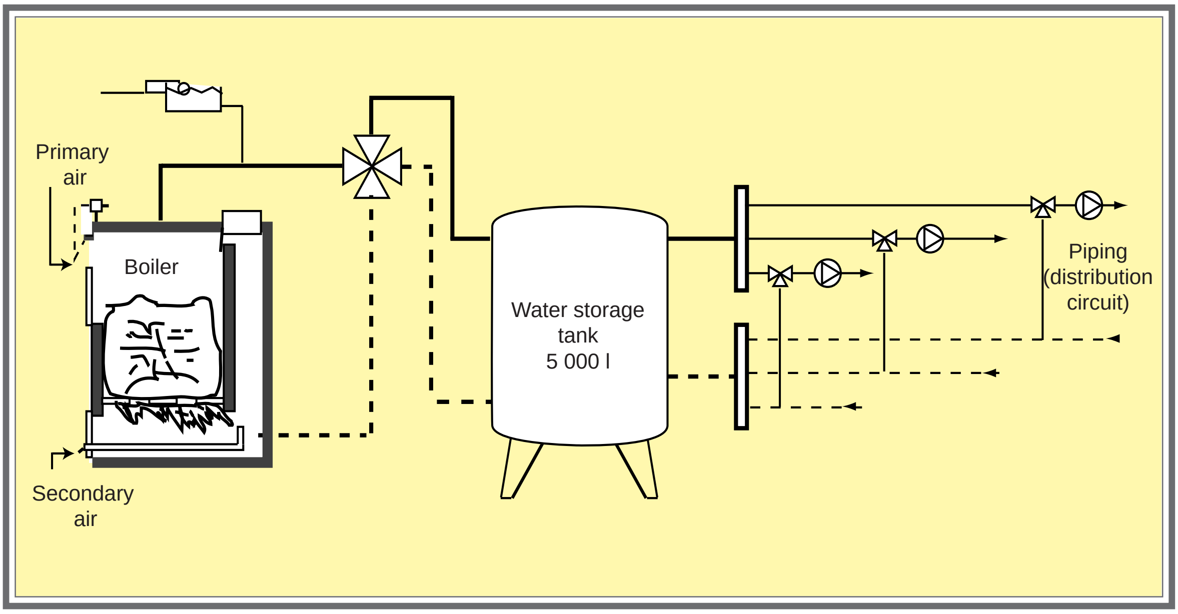


Fig. 21- Operating schedule

3.3 - Automatic utilisation of almond shells for space heating and domestic hot water (DHW) production in a Youth Hostel

Pioneering efforts have been made in Bragança (North of Portugal) to utilise an abundant waste available in the region - i.e. almond shells - for energy purposes. The Bragança Youth Hostel has been using this type of waste to secure a daily 1 000 litre supply of domestic hot water (DHW) to its facilities. The Hostel is installed in an old building, divided into three main areas: services, multi-purpose and lodging. Its annual energy requirements amount to 390 000 kWh.

The space heating system consists of a 200 kW boiler (equipped with an automatic feed device) specially fitted for almond shell burning and a back-up 40 kW boiler that secures DHW production during summer. The DHW distribution network is composed of three independent branches, with "octopus-shaped" circuits. Space heating is provided by radiators (in areas with a permanent occupancy) and fan-coils (in areas with an irregular occupancy). Indoor temperature is automatically controlled and regulated, in accordance with the outdoor temperature and the pre-set indoor temperature (Fig. 22).

The system required for a total investment of ECU 143 300, including the installation of the DHW distribution network and the re-servicing of the building's thermal insulation. Annual consumption amounts to 110 tons of almond shells and 0,8 tons of gas, while annual operating costs amount to ECU 8 600. When compared to the previous propane gas heating system, the new system allows for annual savings of ECU 7 450. The pay-back time is 3,5 years.

The design of this facility clearly demonstrates that the automatic utilisation for energy purposes of agricultural waste like almond shells can be suitably adapted to space heating in the residential and services sectors.

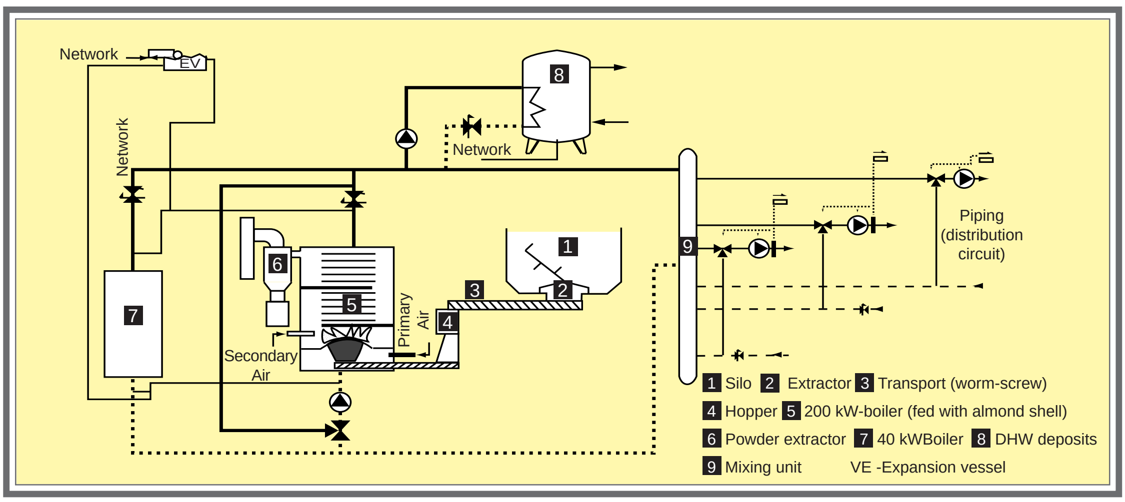


Fig. 22 - System schematic

3.4 - Automatic utilisation of olive bagasse and solar energy for space heating, swimming-pool water heating and DHW production in a swimming-pool compound

Olive bagasse resulting from the olive oil industry is an abundant waste available in the municipality of Vidigueira (South of Portugal). Therefore the Town Council decided to utilise it for energy purposes, by (one 50 x 21 m Olympic pool and a diving pool). The compound uses 4 500 liters of DHW per day, and its annual energy requirements amount to 1 035 000 kWh.

Solar energy is used to produce DHW by means of two boilers specially prepared with an automatic feed system of olive bagasse. The solar system is composed of 25 solar collectors (corresponding to a 50 m^2 collection area) and supplies the energy required to heat 4 500 liters of DHW per day. The 2 boilers (with 400 and 300 kW, respectively) are automatically fed with olive bagasse (2nd distillation) and supply hot water to four distribution circuits (Fig. 23).

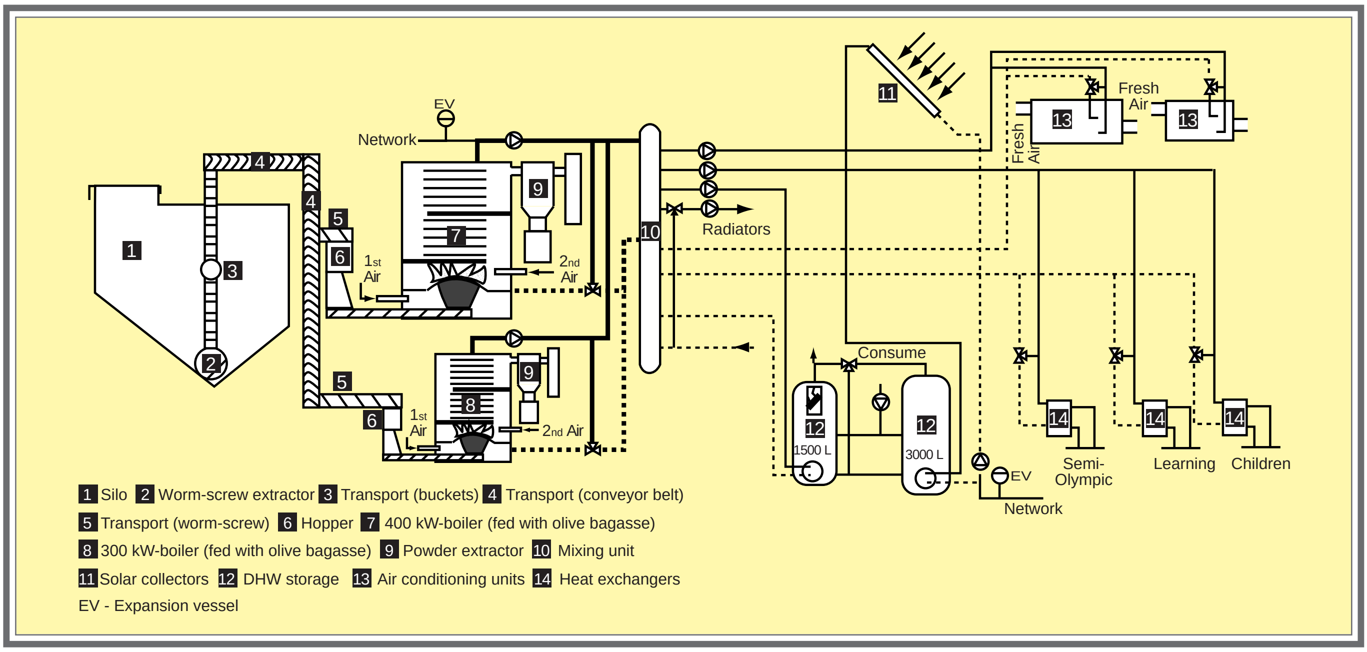


Fig. 23 - System schematic

installing a central heating system in the municipal swimming-pool compound that runs on automatically fed olive bagasse (2nd distillation) and solar energy. The system is adapted to local temperature conditions and the occupancy profile of the facilities.

The compound has a total 3 000 m^2 area and consists of a main building, three indoor swimming-pools (a semi-olympic 25 x 12,5 m pool, a 12 x 7 m learning pool and a children's pool) and two outdoor swimming pools

The first circuit supplies energy to the main building, for heating purposes (by means of radiators). The second circuit supplies energy to the indoor swimming pool building, for space heating purposes (by means of double-flow air conditioning units). The third circuit feeds the plate exchangers which heat the water of the indoor swimming pools. The fourth circuit is a back-up unit that supports the solar system. Comfort conditions are automatically controlled and regulated. During empty hours, the swimming pools are covered with a floating protection.

Total investment amounted to ECU 523 500, including the installation of the DHW distribution network and the solar system. Annual consumption of olive bagasse corresponds to 340 tons. When compared to the previous propane gas heating system, the new system gives annual savings of ECU 26 140. The pay-back time is 5,3 years.

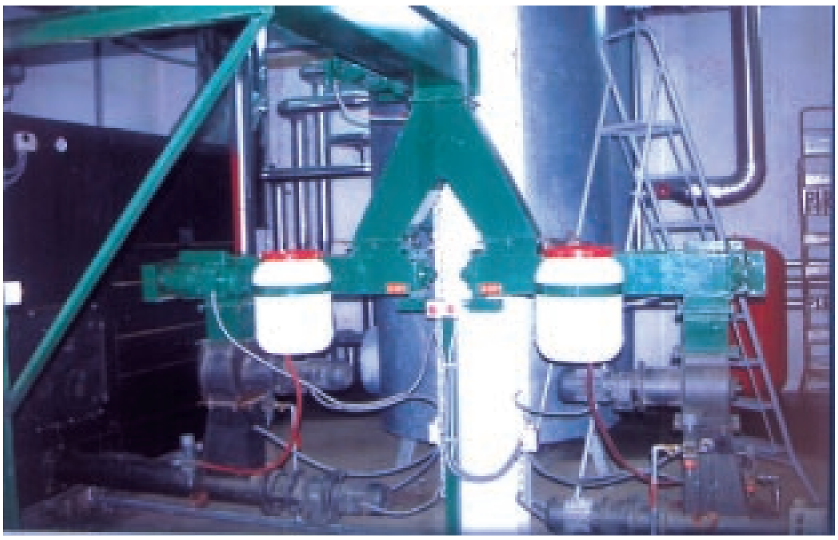
In terms of design and equipment, this facility clearly demonstrates that automatic utilisation for energy purposes of agricultural waste (i.e. olive bagasse) and solar energy can be suitably combined to meet the energy requirements of a swimming-pool compound. This solution makes it possible to (i) directly reduce energy costs (by upgrading two local energy resources) and create jobs, and (ii) indirectly promote local development

3.5 - Co-generation from nut shells and fruit stones

Faced with significant amounts of waste from their factories (roughly 500 000 tons/year), a group of Spanish and Italian companies of the fruit production and marketing sector created a company called ENERGONUT to process the said waste (consisting of nut shells and fruit stones) into fuel and thus generate heat and electricity.

Located near the industrial area of Asi-Flumeri, in Italy, the plant is composed of (i) a waste collection unit equipped with pre-treatment (drying and grinding), storing and handling facilities, (ii) a fluidised-bed steam generator equipped with a special feed system, having a production capacity of 50 ton/h of steam at 420º C and 50 bar, and (iii) a turbo-generator (mechanical power = 11,4 MW; electric power = 10 MW). The plant generates 39,9 MWh/year of electric energy and 112 MWh/year of thermal energy (used for greenhouse heating). Globally speaking, the co-generation system has a 82% efficiency. The plant uses 36 000 tons of waste per year.

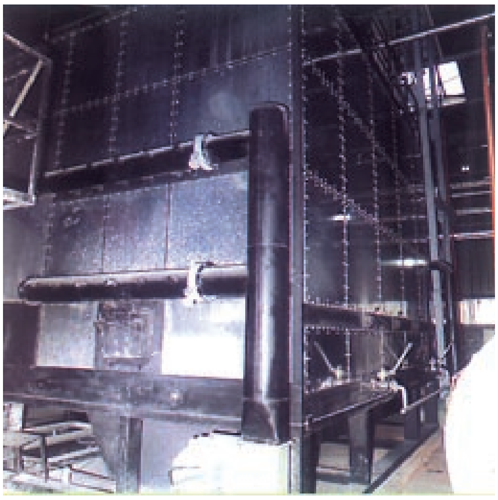
Total investment amounted to MECU 18,350, including design, building, connection to the grid and research work. Total electricity sold by the company to the public grid amounts to MECU 5,5/year. Operating & Maintenance costs of the plant amount to MECU 2,2/ year. The investment has a gross pay-back time of 5 years.



3.6 - Steam generation from sun flower seed husk

As a result of a significant price increase of ground husked sunflower seed bagasse imported from Argentina, the Chemical Industries Syndicate of Aquitaine (France) asked Aquitainergie to look into the possibility of carrying out a pilot experiment at Bassens, aimed at processing French products likewise.

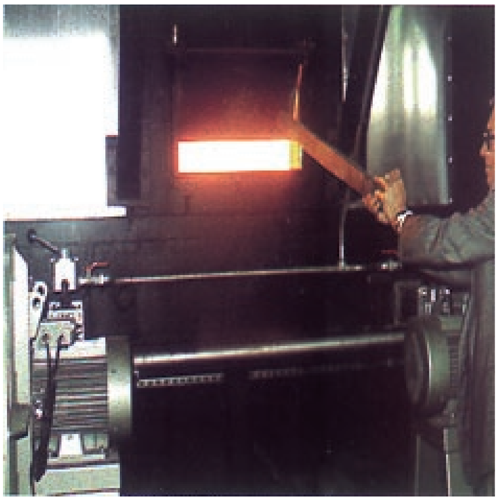
In view of the results of the experiment, Comexol - a company established in Bassens, with a processing capacity of 280 000 tons of sunflower seeds per year - decided to adapt its production to market demand (ground husked sunflower seed bagasse, with a high protein content) by setting up an efficient husking & milling unit for sunflower seeds with the capability of utilising its waste (i.e. sunflower seed husks) for energy purposes, namely steam production.



The annual production of 32 000 tons of ground husked bagasse generates 13 500 tons of sunflower seed husks. This low-density product (150 g/litre) has a good potential as fuel (i.e. 7% of moisture, a 4,400 kcal/kg calorific power and an ash content of 12,5%).

Seed husks are utilised for energy purposes by means of combustion in a steam boiler with a production capacity of 15 tons of steam/hour (pressure = 15 bar; yield = 75%), representing a total steam production of 47 000 tons/year.

Total investment amounted to MECU 1,3. When compared to the gas combustion alternative, the new system induced savings of 4,950 toe/year, allowing for a 2 years pay-back.



3.7 - Gasification of almond shells for electricity production

The utilisation of almond shells for energy purposes is interesting only when sizable amounts of the waste are available in specific locations. Among various possible processing alternatives, gasification with air has proved to be one of the most suitable methods of utilising this type of waste for energy purposes, as it allows for the economical generation of a gas with a low heating power that can be locally used for the production of heat and/ or electricity.

In view of almond shell characteristics and the production scale required to render the above operation viable, the use of downdraft moving-bed gasifiers can be considered as an interesting solution. This type of gasifier makes it possible to produce an almost tar-free gas, as it is equipped with Oxidation and Reduction areas following the Pyrolysis area.

The experience in this field of the Department of Chemical and Environmental Engineering of the University of Zaragoza (Spain), combined with the business prospects of a company interested in the application of this technology, led to the development and construction of a power plant (processing capacity = approximately 500 kg/h of almond shells) aimed at generating electricity (Fig. 24).

After being generated by the gasifier, the gas passes through a cyclone in order for the gas stream particles to be removed. Then it is slightly cooled by a heat exchanger, which simultaneously heats the air stream used as a gasifying agent. Subsequent to this process, the gas is channelled to a dry filter which removes the small fraction of condensates built up during the previous stage. After being fully cooled by a heat exchanger that uses water as a cooling agent, the gas stream is aspirated into a blower - preceded by a small "for-safety" heat exchanger that brings its temperature down to the highest level permitted by the operation of the said blower. Likewise, there is a second "for safety" heat exchanger installed after the blower that is aimed at controlling the temperature levels before the gas stream is transferred to the power generating system.

The power generating system consists of two Diesel engines converted to dual fuel (for diesel-gas operations) that are directly coupled to a generator. The Diesel engines work down to a 6% diesel fuel and they have an electric power of 250 kWe, at 1,500 rpm. Power is produced by three-phase asynchronous AC Alconza generators (250 kW each, with an efficiency of nearly 0,83).

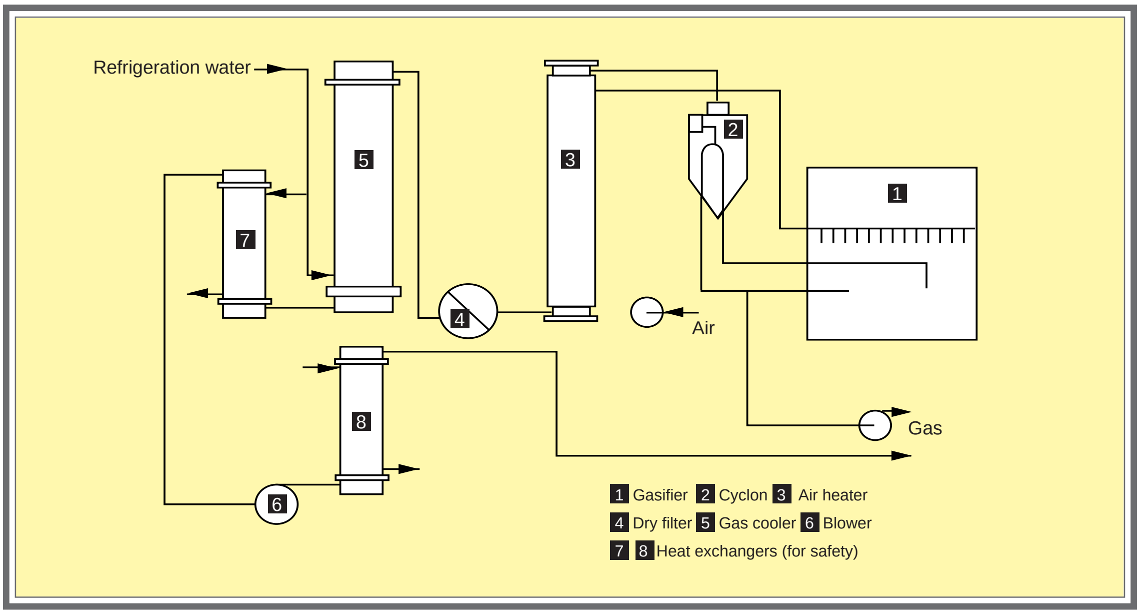


Fig. 24 - Plant Diagram

3.8 - Electricity and heat generation from rice husk in a distillery

Distilleries require significant amounts of electricity and process heat and their energy costs usually amount to 50% of their overall expenditure. Therefore it is reasonable for them to install a co-generation plant that uses a fuel available all year round at a lower cost/energy ratio.

A large co-generation plant using biomass (rice husk) as fuel has been in operation at the SEDA Distillery (Saluzzo, Italy) since 1983. As rice husk is an industrial by-product generated by rice processing factories all year round, it was chosen as fuel instead of oil. Having a calorific power of about 3 000 kcal/kg and a high ash content, rice husk is sourced from sites located near the rice processing factory. Accordingly, transport costs can be kept within acceptable limits. On the other hand, rice husk does not contain any sulphur or heavy metals and its ash (15-20% d.m.) is a marketable product (Fig. 25).

Plant operations are based on a back-pressure Rankine cycle (7 920 working hours/year in average conditions). To a mass flow rate input of 1,300 kg/h of truck-transported rice husk corresponds an output of 195 kg/h of husk ash, which is automatically packed into sealed plastic bags. Taking into account the input of auxiliary fuel, combustion air and water, on the one hand, and the output of combustion products and process steam, on the other hand, one may consider that mass conservation is fully guaranteed in the whole plant.

Input power is mainly associated with the incoming rice husk flow. In fact, after a 14% loss caused by the combustion equipment, the husk is partially converted into mechanical (and then electric) energy. The remaining energy is made available in the form of process heat.

Rice husk combustion starts in a special burner with a 50% air surplus, at an air speed that allows for the husk to be burned in suspension. The products of combustion (at atmospheric pressure) transfer heat to a horizontal water-tube steam boiler, linked to a natural circulation system and a radiation furnace.

Part of the husk ash settles at the bottom of the furnace and is collected from this settling area by means of a worm-screw extractor. Combustion products turn through the radiation superheater that lines the body of the furnace, before they are channelled into a convection bank. Gases coming out of the boiler flow through a cyclone, in order for the remaining ash to be separated.

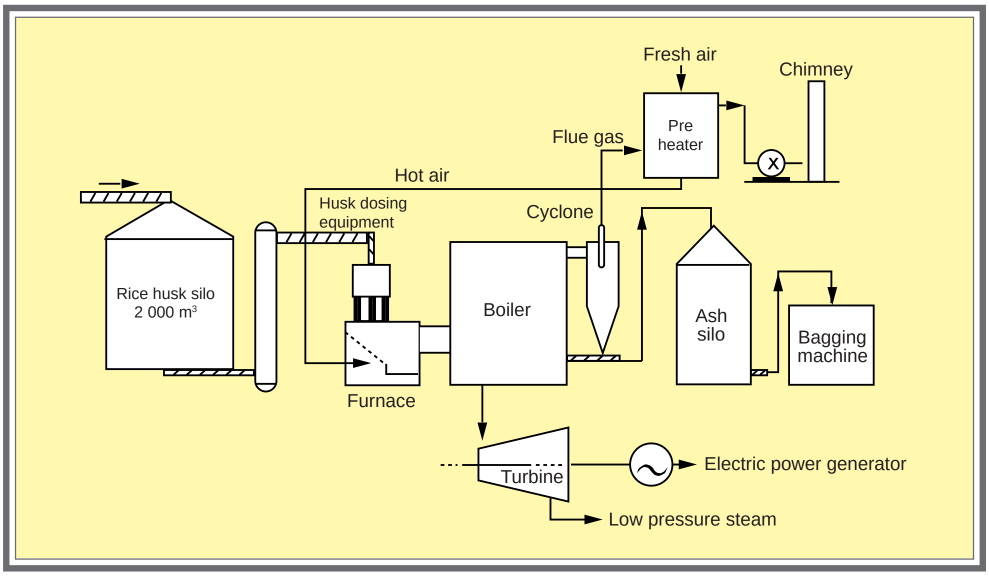
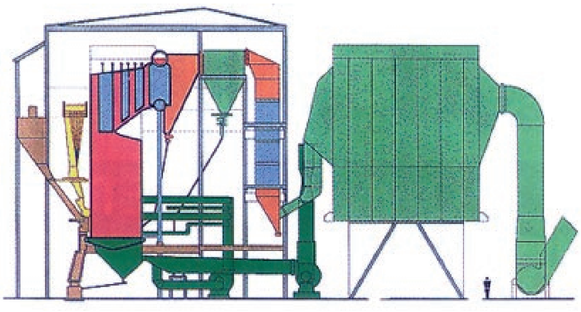


Fig. 25- Diagram of a rice husk combustion plant

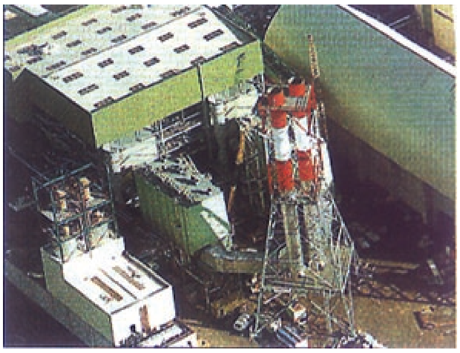
Subsequent to its expansion inside a back-pressure turbine, the superheated steam (430º C, at 43 bar) is transferred to an electric generator rated to 850 kW. The saturated 3,5 bar exhaust steam is used for the distilling process. Rice husk utilisation for energy purposes provides 4,780 kg/h of process steam and 570 kW of electric power

The investment produced quite satisfactory results, with a 3 year pay-back and an anticipated plant life cycle of 10 years.



Le Gol power boiler

3.9 - Electricity and heat generation from sugar cane bagasse in the sugar industry



The Le Gol sugar mill (located in the Réunion Island) decided to build a new power plant equipped with two power boilers fuelled with coal and sugarcane bagasse. The sugar mill processes 900 000 tons of sugarcane per year.

Several companies joined forces to build the Le Gol power station, i.e. the local sugar company, SIDEC (a project-funding specialist) and EDF, the French power utility. Together they set up the Compagnie Thermique du Gol.

Although operations at the new power plant started in early July 1995, sugarcane bagasse only began to be burned by mid-August 1995. This plant will help meet the increasing electricity demand requirements of the island. The old-fashioned boilers of the sugar mill were replaced with new boilers, fuelled with the bagasse that was once stored.

The two boilers burn the 280 000 tons of bagasse produced by the sugar mill during the milling season (5 months per year, from July to November). During the rest of the year, they run on bituminous coal.

The plant has a steam production capacity of 140 ton/h and 117 ton/h, from bagasse and coal respectively. The working steam pressure is relatively high (80 bar) and the superheated steam has a temperature of 250º C.

Relying on the net calorific power of bagasse and coal, the boiler efficiency amounts to 86% and 92% respectively.

The two 32 MW turbo-generators supply 45 MW to the public grid during the milling season (the sugar mill uses part of the steam) and 55 MW during the rest of the year.

Bagasse is burned in the most efficient and appropriate way at the plant. All the bagasse produced during the harvesting period is immediately used, without any storage or particular preparation. The recommended high-pressure steam solution (80 bar, instead of the 45 bar of conventional boilers) yields a 19% increase of electricity generation for a given bagasse input.

Investment associated with the installation of the boilers amounted to approximately MECU 24,8, while the whole plant required a total investment of MECU 89. The total costs related to the new power plant include the following auxilliary equipment: storage, fuel and ash handling systems, water treatment, dust collectors, stacks and other. Estimated energy savings amount to 60 000 toe/ year.

3.10 - CHP GENERATION FROM COTTON-GINNING WASTE IN A COTTON-GINNING FACTORY

In 1992 a CHP system fuelled with cotton-ginning waste was installed at the Davlia Ltd. cotton-ginning factory, in Greece.

In the past the energy requirements (both thermal and electric) of this cotton-ginning factory were provided for as follows: 2 MW of thermal power for the drying process, by two diesel burners (total consumption = 300 000 liters of diesel/year); steam for the seed-oil processing unit, by a boiler-burner system with a 3,5 MW nominal power (total consumption = 450 000 of fuel oil/year); electricity, supplied by the Public Power Utility (total consumption = approximately 3 500 MW).

The newly installed co-generation system made it possible to fully meet the thermal requirements of the plant and part of its electric needs (60%).

Every year, 50 000 tons of seed cotton are dried and ginned at the Davlia Ltd. cotton-ginning factory, while its seed oil unit produces 6 000 tons of cotton-seed oil. Today the total amount of 4 000 to 5 000 tons/year of waste resulting from the ginning process is sufficient to fully meet the thermal requirements of the cotton-ginning factory, as well as part of its electric needs. The waste has a high calorific power, a high volatile content and a low sulphur content. The lowest estimated heating power of the waste amounts to 4 200 kWh/ton.

The heat generation system consists of a specially designed boiler, fuelled by waste from the cotton-ginning process. It has a total capacity of 4,5 MW and produces steam at a 10 bar pressure, with a flow rate of 7,300 kg/h.

The power generation system consists of a single pressure stage steam turbine, a step-down gear, a pump and a generator. 10 bar steam flows into the turbine at a rate of 5,600 kg/h, expanding to a pressure of 0,075 bar and reaching a temperature of 45° C. Within the generator, the heat produced is converted into electric energy with a rated power of 500 kW. Finally the steam is driven to a condensing system to be condensed and returns to the boiler. The existing electric network of the facility is connected to the grid of the public power utility. A diagram of the co-generation unit is shown in Fig. 26.

A significant reduction of the production costs equivalent to the annual cost of conventional fuels and electricity consumed was achieved. The company became energy independent and fire hazards were lessened. The investment has a pay-back of only 3 ginnning seasons.

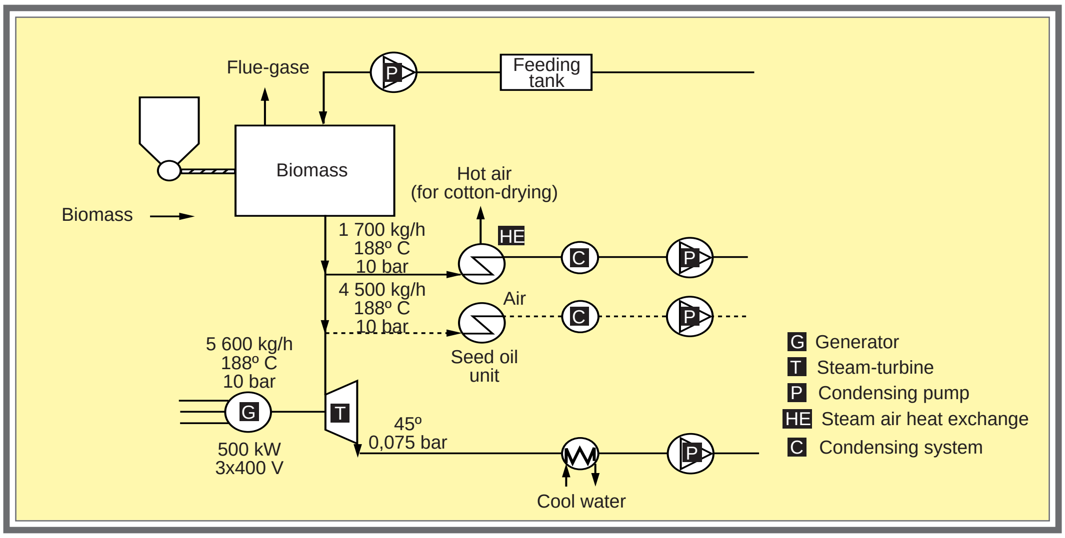


Fig. 26- Diagram of the co-generation unit

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- Brochures and other information on the case study applications

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