GASIFICATION/TWO-STAGE COMBUSTION OF SAWMILL WOOD WASTE AND THE PENDING BAN ON BEEHIVE BURNERS BY THE BC MINISTRY OF ENVIRONMENT

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Abstract

The British Columbia Ministry of Environment, Lands and Parks (MoELP) has announced that particulate emissions from about half of BC's 150 or so sawmill beehive burners will not be permitted to exceed 120 mg/Nm^3 (0.052 grains/sdcf) beyond the end of 1997. The burners, therefore, will have to shut down. However, as of this writing, there is some uncertainty as to the actual shut down dates. The remaining beehive and silo burners in BC will have another several years before they too will have to shut down.

This paper discusses five different types of wood waste gasifiers which can be used to transform sawmill wood waste into a burnable "producer gas". Also discussed is a large two-stage combustor (gentle updraft gasification followed by vigorous cyclonic combustion) which meets the Ministry's particulate requirement, which has been in continuous service in the forest products industry for over 16 years and which can directly replace existing beehive burners on a stand-alone basis. An energy recovery system for a typical 120 Million boardfeet per year BC Interior sawmill is presented.

Introduction

Gasification is a special case of *pyrolysis* where *pyrolysis* is the destructive decomposition of wood waste - using heat - into charcoal, oils, tars and a burnable gas. Oils and tars are produced when pyrolysis takes place at temperatures below 1,100^{o}F.

In the case of gasification, all the solid wood waste is converted into a burnable gas; there are no oil, tar or charcoal byproducts. The burnable components of the gas are, typically, carbon monoxide, hydrogen and methane. A common name for this gas is "producer gas".

The word "gasification" conjures up visions of alchemy, i.e., changing common metals into gold; in the present case, dirty hog fuel is changed into a burnable gas. Over the last one hundred years, the popularity of gasification has had its ups and downs. Before natural gas was plentiful, or even available, cities built "gas works" to make "city gas" of various varieties for lighting and cooking. At the beginning of this century, before the arrival of spreader stokers and travelling grates, a number of utility boilers were built with coal gas producers (hence the name "producer gas") instead of furnaces. During World War II, trucks and automobiles in occupied Europe were fuelled with producer gas from on-board wood gasifiers which used, primarily, dried blocks of wood. The latest surge of interest in gasification occurred during the oil shortages of the 1970's occasioned by the Yom Kippur War in 1973 and the fall of the Shah of Iran in 1978.

Today, the main interest in wood waste gasification is primarily in Europe. There, projects are underway to demonstrate that it is possible to gasify wood waste and use the resultant, cleaned, pressurized, producer gas to fuel a gas turbine and generate electricity without using a boiler. The installations are expensive and hard to justify with the low cost of natural gas world wide.

Gasification of Wood Waste

The combustion of wood waste always includes a stage of gasification. Consider, for example, the case of a fresh log placed on top of a stack of logs already burning in a fireplace. The new log hisses while its moisture is driven off; the heat of evaporation coming from the already burning logs in the fireplace. After the log has dried tongues of flame can be seen extending upward, along the length of the log. With time the number of tongues of flame increases. Finally, the flames die out and the now, fissured, black log glows red and yellow as it slowly burns down to a grey, powdery ash. In this fireplace example, the tongues of flame are burning forms of producer gas. The fissured log is made up of fixed carbon.

It so happens that typical bone dry wood is composed of between 75% and 80% volatile matter and 20% to 25% fixed carbon. In other words, if a piece of bone dry wood is placed in a suitably hot, oxygen-free chamber, 75% to 80% of its mass will volatilize. It also so happens that the fixed carbon in the remaining 20% to 25% mass fraction contains about 50% of the wood's initial Btu's. Therefore, converting wood into charcoal increases the energy density by a factor of between 2 and 2.5. This is the reason why, particularly in the third world where, frequently, fuel must be transported on one's back, wood is often converted into charcoal before it is delivered to end users for cooking or heating purposes.

Wood Waste Gasifiers

The fireplace example is a simplified explanation of a batch gasification process. Most gasification processes are continuous. Wood waste gasifiers are designed to ensure that wood waste flows continuously into the gasifier, that the wood waste is dried, that its volatiles are pyrolyzed, that the tarry, long chain molecules contained in the pyrolyzed volatiles are cracked, i.e., thermally "snipped" into short chain molecules which, when cooled, do not condense, that the wood waste's residual char is converted into carbon monoxide and that the mineral matter brought in with the wood is removed by the gasifier's built-in ash removal system. Achieving these sequential steps becomes increasingly more difficult as the wood waste's moisture content rises above about 20%.

As noted, heat is required to bring about the decomposition of the wood waste. While heat can be added by external heaters, the majority of gasifiers generate this heat internally by oxidizing some of their fixed carbon with oxygen brought into the gasifier from outside. In most cases the external oxygen comes from air drawn from ambient by forced draft fans.

Air brings with it a significant amount of nitrogen; each pound of oxygen in air is accompanied by 3.25 pounds of nitrogen. The nitrogen dilutes the Btu value of the producer gas to between 120 and

200 Btu/sdcf (standard dry cubic foot). Substituting pure oxygen for air eliminates the nitrogen and results in a gas Btu value of between 300 and 500 Btu/sdcf. Some processes obtain part of their necessary oxygen by injecting steam; the steam contains oxygen cf., H_2O. For reference purposes the Btu value of natural gas is about 1,000 Btu/sdcf. In what follows, the oxidizing agent is outside air.

The Updraft Gasifier

Figure 1 is a simplified drawing of an updraft gasifier. As can be seen, wood waste is admitted to the gasification chamber from above, falls onto a grate and forms a fuel pile. Air from below the grate (sometimes accompanied by steam), is blown up through the fuel pile. Since the flow of fuel is downward, toward the grate, and since the flow of air is upward, up through the fuel pile, this type of gasifier is also called a "counterflow" gasifier.

As the wood waste works its way down to the grate it dries, its volatiles are pyrolyzed and its fixed carbon (also known as "char") is converted to carbon monoxide. In the process some of the char is completely oxidized to liberate the heat needed for evaporation and pyrolyzation. The carbon dioxide, so formed, is usually reduced to carbon monoxide as it continues its way up through additional layers of char to the top of the fuel pile.

The producer gas leaving the gasifier is at a low temperature. It is laden with condensed tars and oils from the pyrolyzation as well as particulate matter picked up during its passage up through the fuel bed.

The Downdraft Gasifier

Figure 2 is a simplified drawing of a downdraft gasifier. The downdraft gasifier is designed to crack the condensed tars and oils produced by the counterflow, updraft gasifier. In this co-flow gasifier the wood waste and its gasification air both flow in the same direction - downward through the gasifier's fuel bed.

As in the case of the updraft gasifier, the wood waste is admitted at the top. As the wood progresses down through the "reactor" it dries and its volatiles are pyrolyzed. The char is directed into a reduced diameter, cylindrical, "throat" section at the bottom of the gasifier. Gasification air is injected into the throat through openings in the throat wall. The high throat temperatures that ensue crack the tars and oils that tend to form in producer gas, particularly when the wood waste is wetter than about 20% moisture content (wet basis).

The producer gas, leaving the bottom of the gasifier, is usually drawn up through an annulus which normally surrounds the downdraft gasifier reactor, thereby transferring its sensible heat to the fuel bed. The producer gas leaves from a side opening near the top of the gasifier. Because of the reduced tar and oil content, downdraft gasifiers are commonly used to fuel spark ignition and diesel engines. The producer gas is cooled before it is drawn into the engine in order to pack as many Btu's as possible into each cylinder.

The Fluidized Bed Gasifier

Updraft and downdraft gasifiers are limited in the moisture contents of the wood waste that they can readily gasify. Typically, updraft gasifiers are limited to a maximum of about 30% moisture content fuels, on a wet basis; downdraft gasifiers to about 20% moisture content. Above these moisture contents the resultant producer gases are laden with tars and creosote. Fluidized bed gasifiers, because of their large thermal mass, can usually process higher moisture content fuels. It is not clear what their moisture content limits are.

The fluidized bed gasifier features a bed of sand, or of other inert solid granular particles, which is kept in suspension by high pressure gasification air admitted at the bottom of the bed through a perforated grid plate or through a series of individual nozzles. The amount of wood waste in the sand bed at any given time is small - normally less than 1% of the bed mass.

The velocity of the air at which the bed just begins to *fluidize*, i.e., when the particles begin to be suspended, is called the minimum *fluidizing* velocity. Increasing air flow agitates the bed material further, promoting good mixing. Bubbles form in the bed and rise to the bed surface. With further increases in air flow the bed takes on the appearance of a briskly boiling fluid and the bed surface looses some of its definition. If the air flow does not increase much further then the fluidized bed gasifier is called a Bubbling Fluidized Bed Gasifier - BFBG - see Figure 3.

However, if the air flow does increase significantly, so that the bed stretches to fill the entire reactor, and if a hot, refractory-lined cyclone is used to remove the significant amounts of particulate carried along with the exiting producer gas, then the gasifier is called a Circulating Fluidized Bed Gasifier - CFBG - see Figure 4.

Fluidized bed gasifiers, in contrast to updraft and downdraft gasifiers, use the sand in the sand bed to physically abrade away the outer char layers on the wood waste particles contained in the fuel bed. This scrubbing action exposes more dried wood for devolatilization thereby enhancing the conversion of wood waste to producer gas. In addition the large thermal mass of the sand bed acts as a flywheel, smoothing out performance swings due to variability in fuel size, fuel moisture content and fuel Btu value.

CFBG's convert more char to producer gas than BFBG's because of their higher recycle rates. They also produce less tars/oils than BFBG's. However, the need for a high temperature, high efficiency cyclone, and the greater pressure loss this causes, means that the CFBG is more expensive than the BFBG and its electric power bill is higher.

One of the drawbacks of the fluidized bed gasifier is the high particulate loading in the producer gas whether it is a BFBG or a CFBG. As shown in Figures 3 and 4, clean up of the producer gas is required in both cases; Figure 4 shows that additional cleanup is required downstream of the CFBG's hot cyclone.

The bulk of the fluidized bed gasification work today is being carried out in Europe. The Europeans are interested in fuelling gas turbines with pressurized producer gas from wood waste and generating electricity using the popular *combined cycle*. The combined cycle uses both a gas turbine and a steam turbine to make power. It takes advantage of the fact that gas turbines usually exhaust at about 1,000^{o}F. The 1,000^{o}F turbine exhaust is routed to a Heat Recovery Steam Generator (HRSG) where it produces steam to drive a steam turbine generator. Figure 5 shows a combined cycle fuelled with producer gas made in a pressurized CFBG.

The Two-Stage Gasifier

The Two-Stage Gasifier was developed by Heuristic Engineering Inc of Vancouver, BC in the mid-to-late 1980's to gasify wet sawmill wood waste. The development was supported by the Science Council of BC and Energy, Mines and Resources Canada (now known as Natural Resources Canada). The gasifier features a first stage of updraft gasification followed by a second stage of downdraft char gasification. The second stage also serves to crack the tars and creosotes contained in the first stage producer gas as a result of the updraft gasification of the wet wood waste. Successful operation of a 3 Million Btu/h prototype gasifying 45% moisture content cedar wood chips was demonstrated in 1988. Modifications were then made to the gasifier. However the project ran out of funds before final testing of the reworked gasifier could be undertaken. Figure 6 is a schematic of the final configuration.

Two-Stage Combustion of Wood Waste / The Heuristic EnvirOcycler

Heuristic Engineering has also developed a large, two-stage, wet wood combustor to replace sawmill beehive burners - which are soon to be outlawed in British Columbia because they cannot meet particulate levels of 120 mg/Nm^3 (milligrams per normal cubic metre). The combustor - the Heuristic **EnvirOcycler** - meets these levels. The **EnvirOcycler** is shown in Figure 7. Its precursor has been in continuous service in the North American forest products industry since 1981 (Northwood Panelboard, Solway, MN and, since 1983, The Weyerhaeuser Company, Dequeen, AR).

The **EnvirOcycler** gasifies wet (typically) wood waste in a first stage of gentle updraft gasification. The hot producer gas, so formed, is burned in a second stage of vigorous cyclonic combustion located immediately above the first stage.

The first stage contains a large, A-frame grate with ash troughs located on either side of the grate at the bottom of the burner. Underfire air is admitted uniformly over the entire grate surface. Fuel - 3" to 6" minus, depending upon the size of the **EnvirOcycler** - is supplied to the top of the grate. The fuel works its way, down both sides of the A-frame, to the ash removal troughs at the bottom. As it does its moisture is evaporated and its volatile matter is pyrolyzed. The remaining char is burned (converted to carbon dioxide) or gasified (converted to carbon monoxide), leaving residual ash in the ash troughs. The combustion of the char on the grate produces the heat which drives the pyrolysis and evaporation reactions. The ash is removed from the two troughs by a series of wedges which reciprocate back and forth in both troughs.

First stage gases - water vapour, pyrolyzed volatiles, carbon monoxide, hydrogen, some methane, carbon dioxide and nitrogen - rise up from the lower chamber towards the upper second stage. Overfire air is admitted at the top of the first stage. The purpose of the overfire air is to *preheat* the producer gas. It does so by burning *some* of the first stage gases so the temperature of *all* the producer gas is raised above the ignition temperature of the gas mixture.

Primary combustion air is admitted at the inlet to the second stage combustion chamber through a "flame holder". The flame holder acts much like the wire gauze in the centre of a Bunsen burner, in reverse. Primary combustion air issues from the flame holder; the flame holder is surrounded by preheated, combustible, first stage producer gas rising upward into the second stage. Primary combustion air ignites the producer gas and initiates combustion.

Secondary combustion air completes combustion. Secondary combustion air is admitted through a series of tangential openings called tuyères (from the French word for "nozzle") in the walls of the combustion chamber. Because the top of the combustion chamber is fitted with a "choke" - a restriction which reduces the diameter at the exit from the second stage - the injected secondary combustion air is forced to spiral down the walls towards the flame holder at the inlet to the second stage.

Encountering the flame holder, and the rich mixture of burning first stage gases swirling around it, the secondary combustion air reverses axial direction and spirals radially inward and upward. As it does so the air mixes with, and completes the combustion of, the first stage producer gas. The flaming gases burn in an intense, upward spiraling, inner vortex, surrounded by a sheath of secondary combustion air which descends in a spiralling outer vortex towards the bottom of the second stage.

The flame holder also acts as a barrier to prevent the bottom of the second stage inner vortex from extending down into the first stage. Without the flame holder a tornado-like funnel would reach down into the first stage and draw first stage particulate up into the second stage.

The actual amount of first stage particulate carried up into the second stage is minimized by the centrifugal action imparted to the particulate by the tangentially injected, high velocity, overfire air. Particulate which does reach the second stage encounters the vigorously rotating inner and outer vortices of the "double vortex" combustion chamber, is thrown outward against the combustion chamber wall and falls back down into the first stage under the action of gravity. From there it is removed by the first stage's built-in ash removal system.

Energy Recovery From Stand-Alone EnvirOcyclers

Larger Sawmills

Figures 8 shows how energy can be recovered from the **EnvirOcycler**'s 2,000^{o}F products of combustion for both dry kiln/building heat and for electric power generation in typical BC Interior sawmills. Figure 8 is a Flow Schematic for a 120 Million fbm/y sawmill which disposes of all its wood waste - bark, sawdust and shavings - in a 110 Million Btu/h **EnvirOcycler** and which recovers 33 + 15 = 48 Million Btu/h of hot oil and about 3 MW of electric power.

Figure 8 shows how hogged wood waste (3 to 6 inch minus, depending upon the size of the **EnvirOcycler**) is routed from the sawmill to a 400 unit storage bin. A unit is 200 ft^3; it was first defined by Thomas R. Miles of Portland, OR in the late 1940's. 400 units is sufficient to supply a steady 14 tons/h of nominal 46% moisture content (wet basis) wood waste to the **EnvirOcycler** over the 56 hours of a nominal two day weekend (48 hours + 8 hours).

The storage bin operates in an on/off mode and maintains the level of hog in the **EnvirOcycler**'s 7 unit metering bin between its High and Low Level indicators. The metering bin supplies wood waste to the **EnvirOcycler** on an as required basis.

As shown in Figure 8, the 2,000^{o}F products of combustion from the **EnvirOcycler** - with particulate levels which comply with the MoELP limit of 120 mg/Nm^3 - can be routed straight to atmosphere - or they can be drawn down through one or both of the two heat exchangers shown under the action of their induced draft (ID) fans.

The first heat exchanger is a 33 Million Btu/h hot oil generator which recovers **EnvirOcycler** sensible heat in 500^{o}F thermal fluid. The thermal fluid - the hot oil - is piped to the sawmill's dry kilns and used to *indirectly* dry lumber. The word *indirect* indicates that no external fluid - viz., products of combustion from a natural gas or propane burner - are admitted to the dry kiln. The hot oil is cooled to about 400^{o}F in the various coils located within the kiln (which transfer heat to the air circulating through the lumber) and then returned to the hot oil generator for reheating.

Other possible thermal fluids are steam or hot water. Steam is not a commonly used fluid today because of BC Boiler Branch operator requirements. However, the Boiler Branch regards a steam generator fuelled by wood waste products of combustion *remote* from the combustion of the wood waste as an "unfired" steam generator. As such the operator requirements are reduced by one class; a Fourth Class Power Engineer replaces a Third Class Power Engineer for the particular heating surface area application involved, etc.

Both steam and hot water recover more sensible heat from the 2,000^{o}F "flue gas" than does hot oil. This is because the hot oil generator's discharge temperature is typically about 600^{o}F while the discharge temperature from the boiler or the hot water generator is typically about 350^{o}F. As a result, 32% of the heat delivered to a hot oil generator is lost up its 600^{o}F stack while only 14% of the heat supplied is a boiler or a hot water generator is lost up their 350^{o}F stacks.

The second heat exchanger in Figure 8 recovers electric power from the **EnvirOcycler'**s 2,000^{o}F products of combustion in a manner which does not involve steam or the Boiler Branch. The power is generated in 3 MW *recuperated* Solar Centaur gas turbine generator set.

As shown in Figure 8 the Centaur's normal natural gas fuelled combustion chamber is replaced by a 40 Million Btu/h *recuperator* - a gas to air heat exchanger. 2,000^{o}F **EnvirOcycler** "flue gas" is routed down through the *gas side* of the recuperator. 610^{o}F compressor discharge air is ducted from the compressor discharge and up through the *air side* of the recuperator. The 2,000^{o}F "flue gas" cools to 820^{o}F while it heats the 610^{o}F compressor air up to 1,660^{o}F - the Centaur's turbine inlet temperature. The 1,660^{o}F hot air is then ducted from the recuperator back to the turbine inlet.

The turbine drives the compressor (which absorbs, typically, two thirds of the turbine work) *and* the 3 MW electric generator. The air, in expanding through the turbine, cools and leaves the turbine at 820^{o}F. As can be seen from Figure 8, the turbine exhaust air and the recuperator's exhaust gas - also at 820^{o}F - are then routed through a "waste heat" hot oil generator to make an additional 15 Million Btu/h of hot oil.

The 3 MW recuperated, gas turbine driven, generator set and the 15 Million Btu/h of hot oil heat recovery can be regarded as a form of *co-generation*. The thermal efficiency of the overall cycle is high because the **EnvirOcycler** products of combustion finally discharge to atmosphere at 600^{o}F. Of course, if the **EnvirOcycler** products of combustion were cooled to 350^{o}F - say in a boiler or in a hot water generator - before being dumped to atmosphere, then the overall thermal efficiency would be higher (and a total of 30 Million Btu/h of thermal fluid heat could be recovered).

While Figure 7 and the foregoing depict a recuperated Solar Centaur gas turbine generator set *other* recuperated G-T sets are available. One such set is the Nuovo Pignone PGT 5. The PGT 5 is an Italian 5 MW gas turbine generator set manufactured by a subsidiary of the General Electric Company and marketed in North America by GE Power Systems. The PGT 5's design turbine inlet temperature is just below 1,800^{o}F. Its rated output is 5.3 MW.

Replacing its external combustion chamber with a recuperator and reducing its turbine inlet temperature to, say, 1,700 ^{o}F, results in an output of 4.6 MW. If the turbine inlet temperature is reduced further to 1,600^{o}F the output is about 4 MW. Lowering the turbine inlet temperature to a very conservative 1,500^{o}F results in an output of about 3.5 MW. A typical 120 Mbf/y sawmill has an average power draw of between 3 and 3.5 MW. The lower the turbine inlet temperature the less costly and the longer lived the recuperator.

Smaller Sawmills

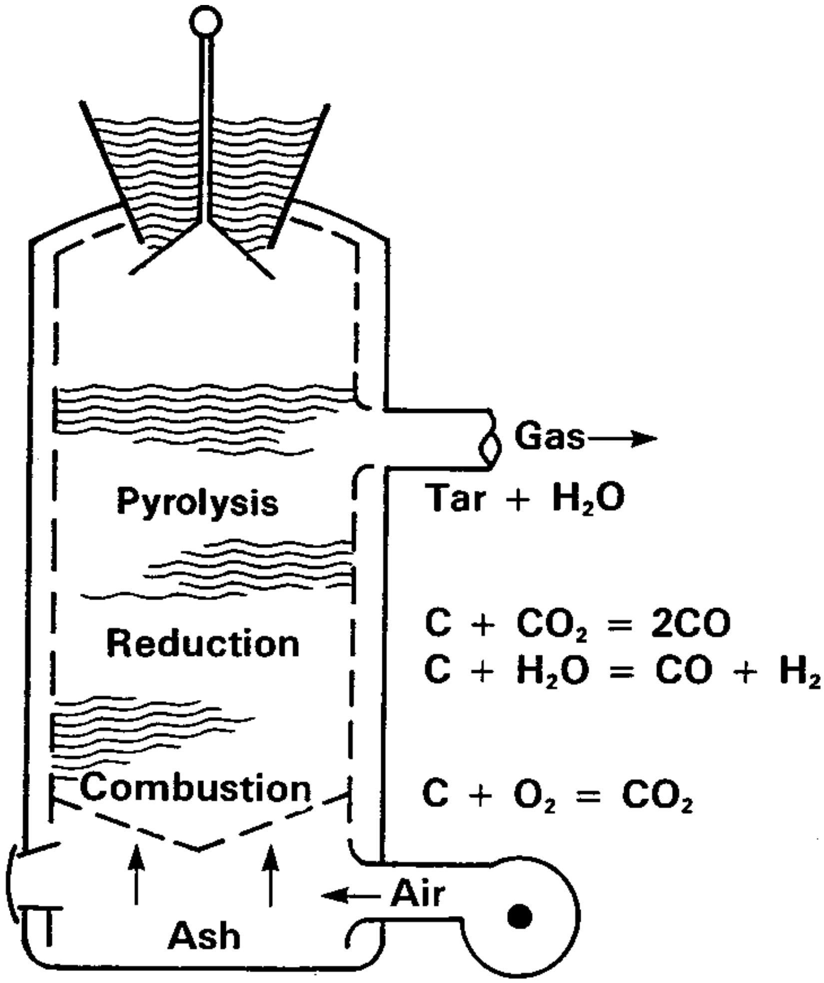
For those sawmills with lumber production under 100 Million fbm/y, sensible heat from the **EnvirOcycler**'s 2,000^{o}F products of combustion can be economically recovered by *direct-firing* the sawmill's dry kilns with **EnvirOcycler** products of combustion. This assumes the dry kilns are already direct-fired by natural gas or propane. Figure 9 illustrates this method of heat recovery for the case of a sawmill with three, double tracked, dry kilns.

The Figure shows a 50 Million Btu/h **EnvirOcycler** disposing of all this particular sawmill's bark and about 10% of its sawdust. This sawmill manages to sell the rest of its sawdust and all its shavings. It spends about $400,000 annually on natural gas to heat its dry kilns.

As can be seen from Figure 9, the **EnvirOcycler**'s 2,000^{o}F "flue gas" is blended down to 1,100^{o}F using air drawn from inside the three dry kilns and/or from the atmosphere. The 1,100^{o}F hot gas is then blown across the roofs of the three dry kilns (using a high temperature fan) to a discharge elbow at the far end of the kiln complex. Along the way, downcomers fitted with butterfly dampers supply pressurized 1,100^{o}F hot gas - under dry bulb temperature control - to the existing dry kiln combustion chambers. Surplus 1,100^{o}F hot gas is dumped to atmosphere via the discharge elbow at the end of the hot duct.

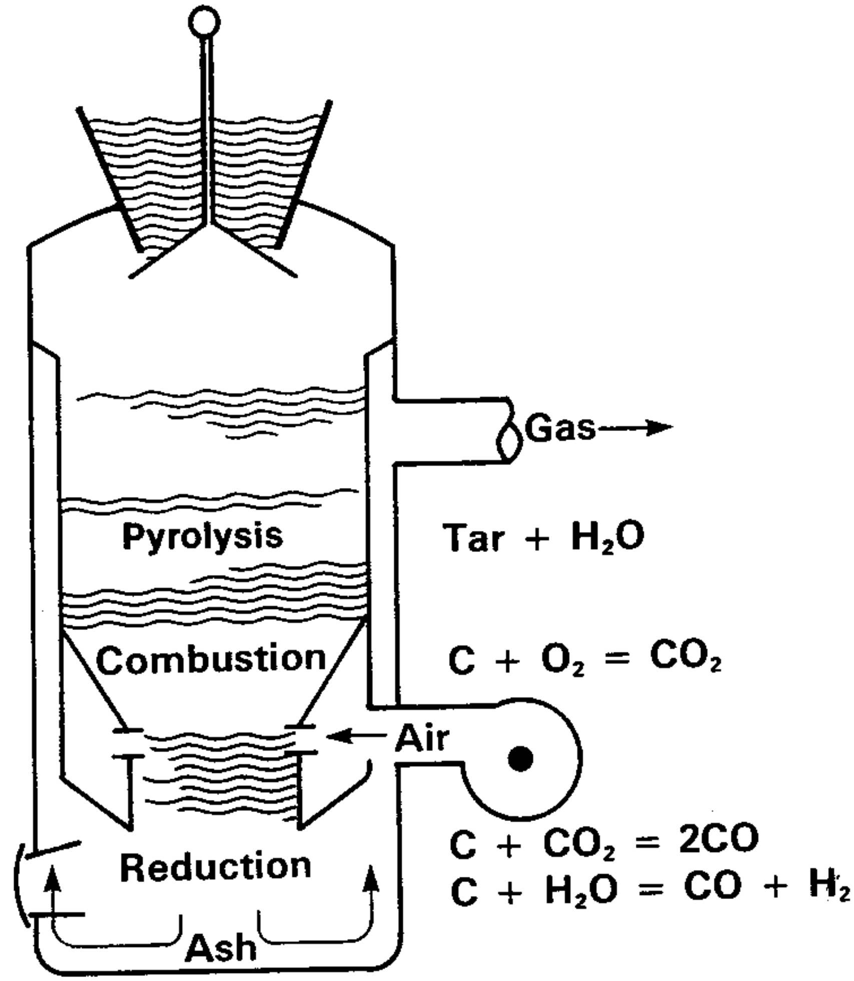
A similar application to that shown in Figure 9 was installed in a BC Central Interior sawmill using the two-stage combustion precursor to the **EnvirOcycler** in the oil crisis period of the late 1970's. That two-stage burner direct-fired two dry kilns. After three years of service this sawmill ordered a larger version of the same two-stage combustor to direct fire its remaining four dry kilns.

Updated 1997 April 10th



Schematic Diagram of Updraft Gasifier

Figure 1



Schematic Diagram of Downdraft Gasifier

Figure 2

BFBG Flow Diagram

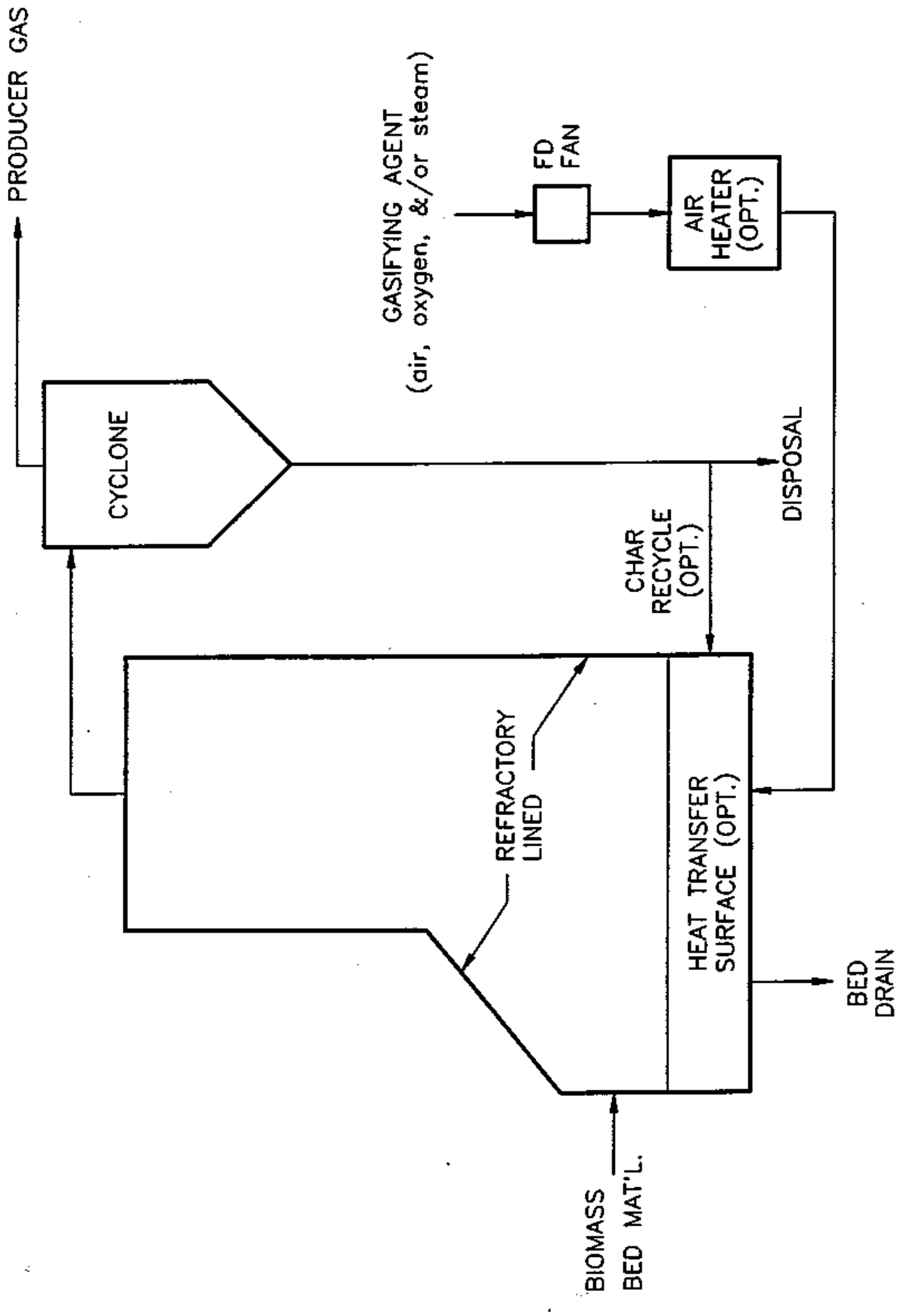


Figure 3

CFBG Flow Diagram

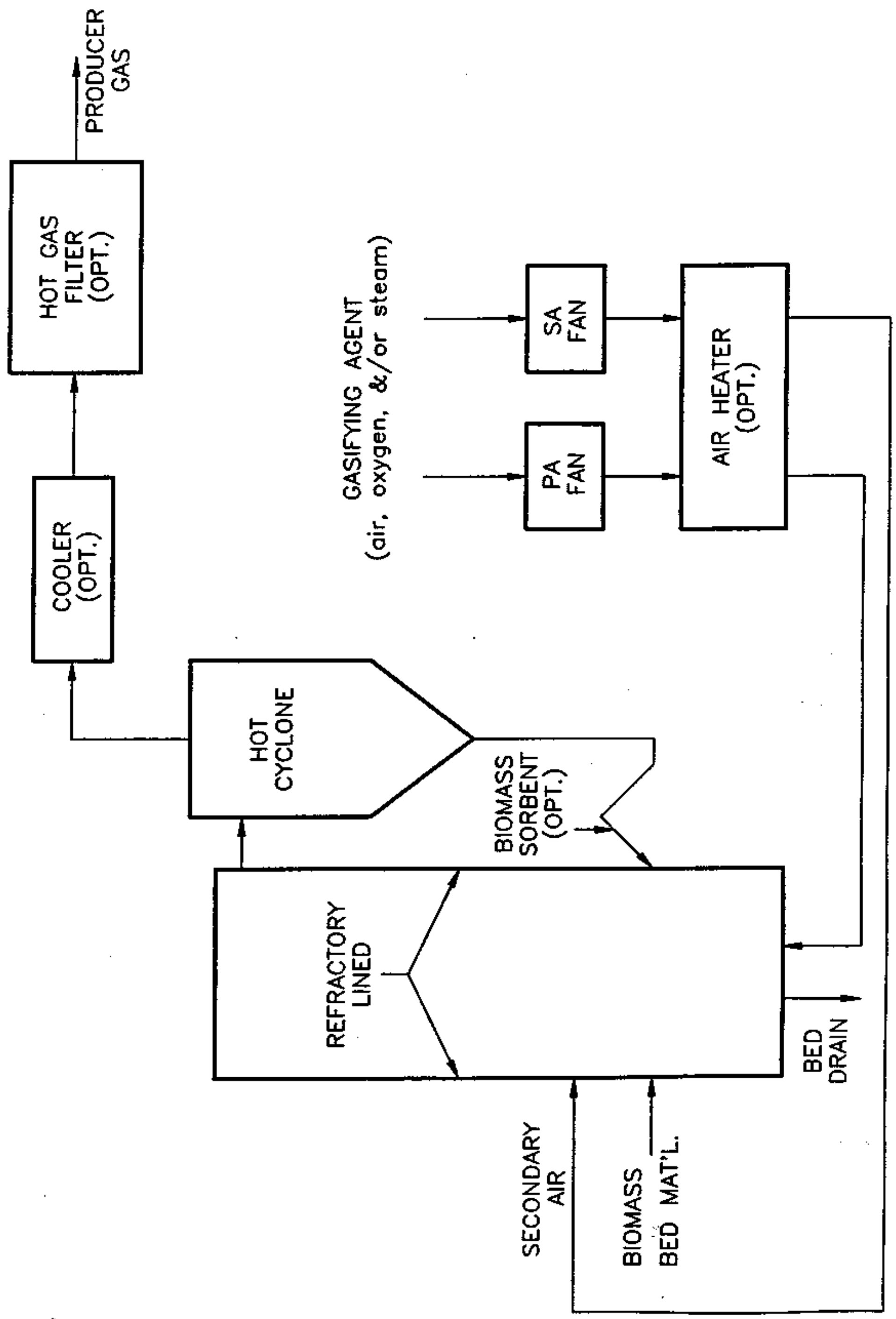


Figure 4

FBG COMBINED CYCLE PLANT (BIG/CC FLOW DIAGRAM)

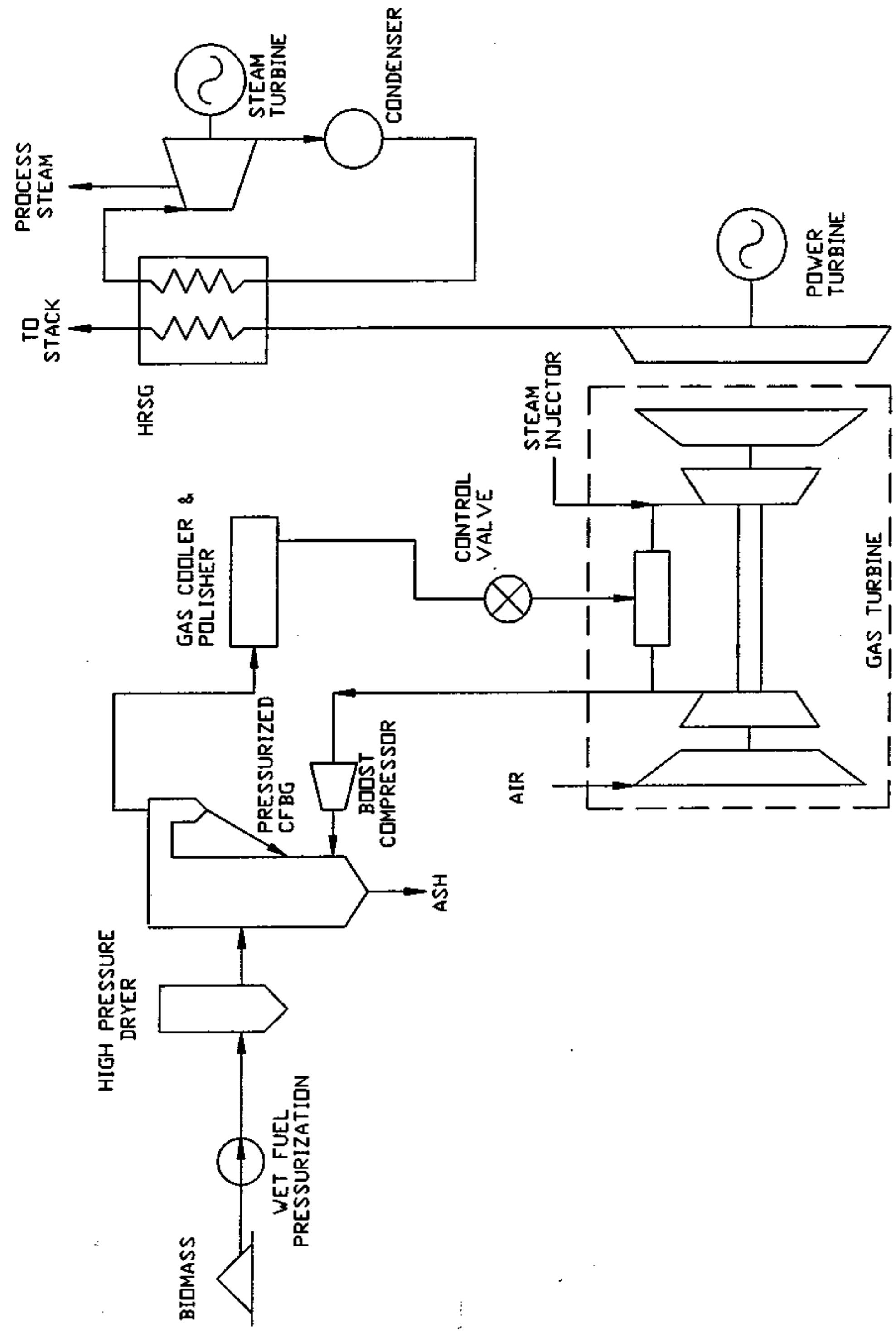
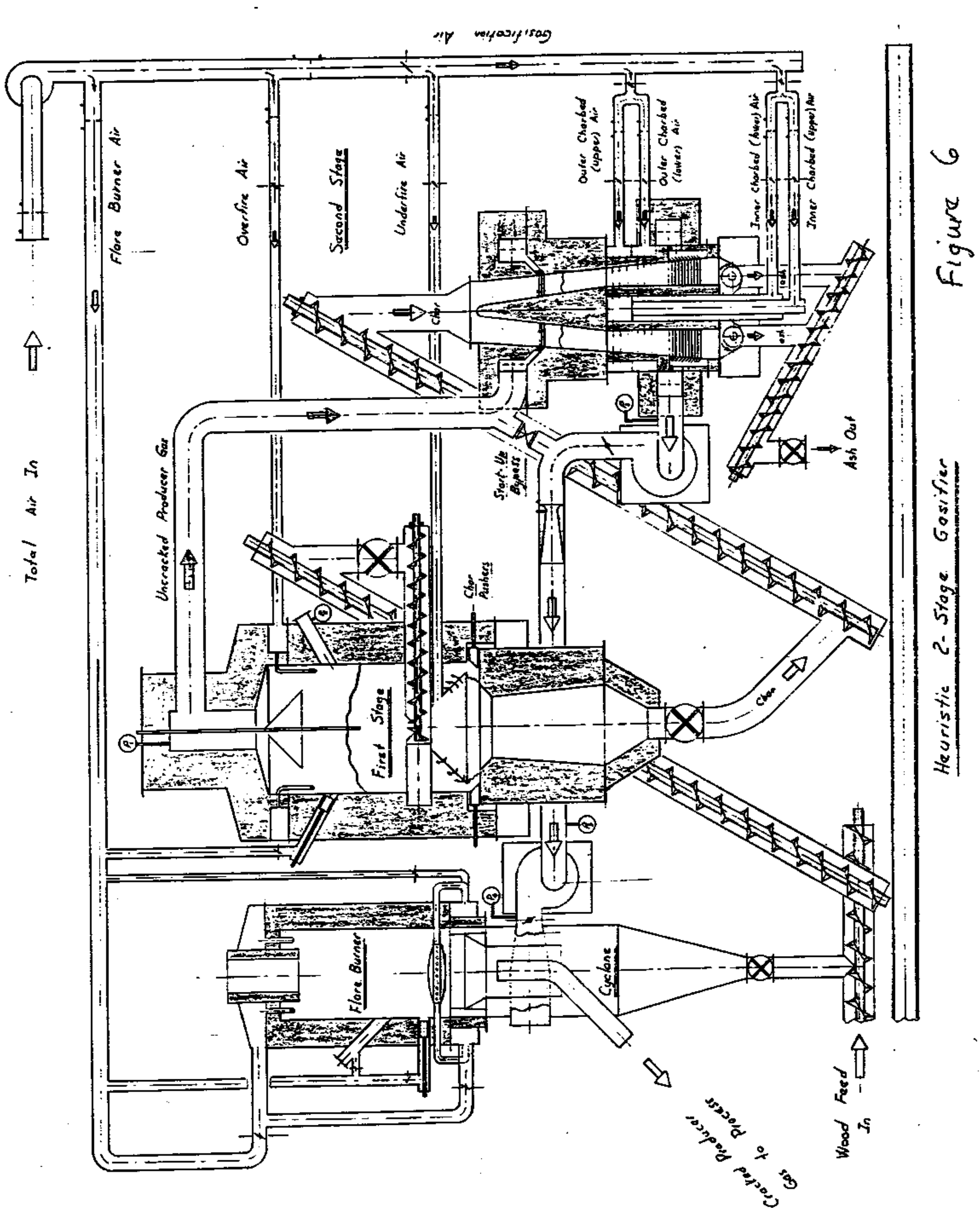


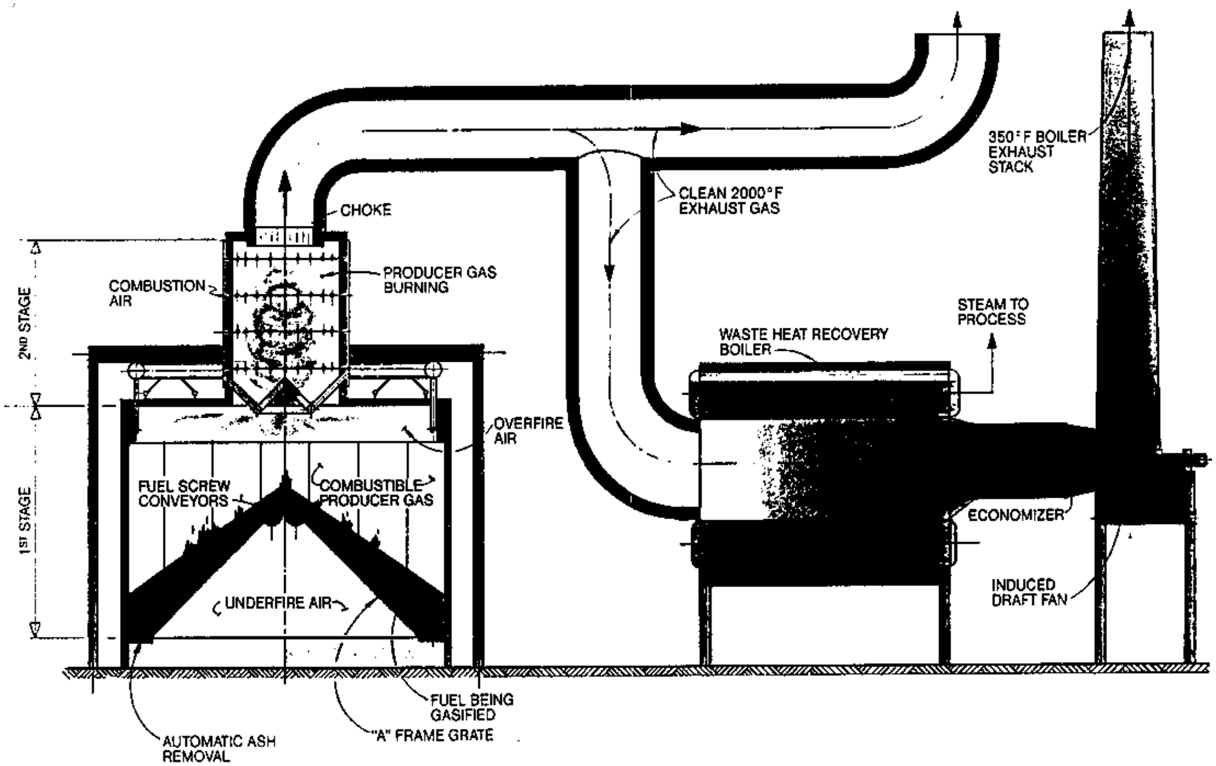
Figura 5



Heuristic 2-Stage Gasifier

Figure 6

HEURISTIC ENVIRO●CYCLER
WASTE DISPOSAL WITH ENERGY RECOVERY



OPERATING PRINCIPLE

First stage: Gentle, updraft gasification generates combustible producer gas at controlled temperatures.

Second stage: Vigorous, cyclonic combustion of first stage producer gas, with minimum excess air, produces high temperature, clean products of combustion.

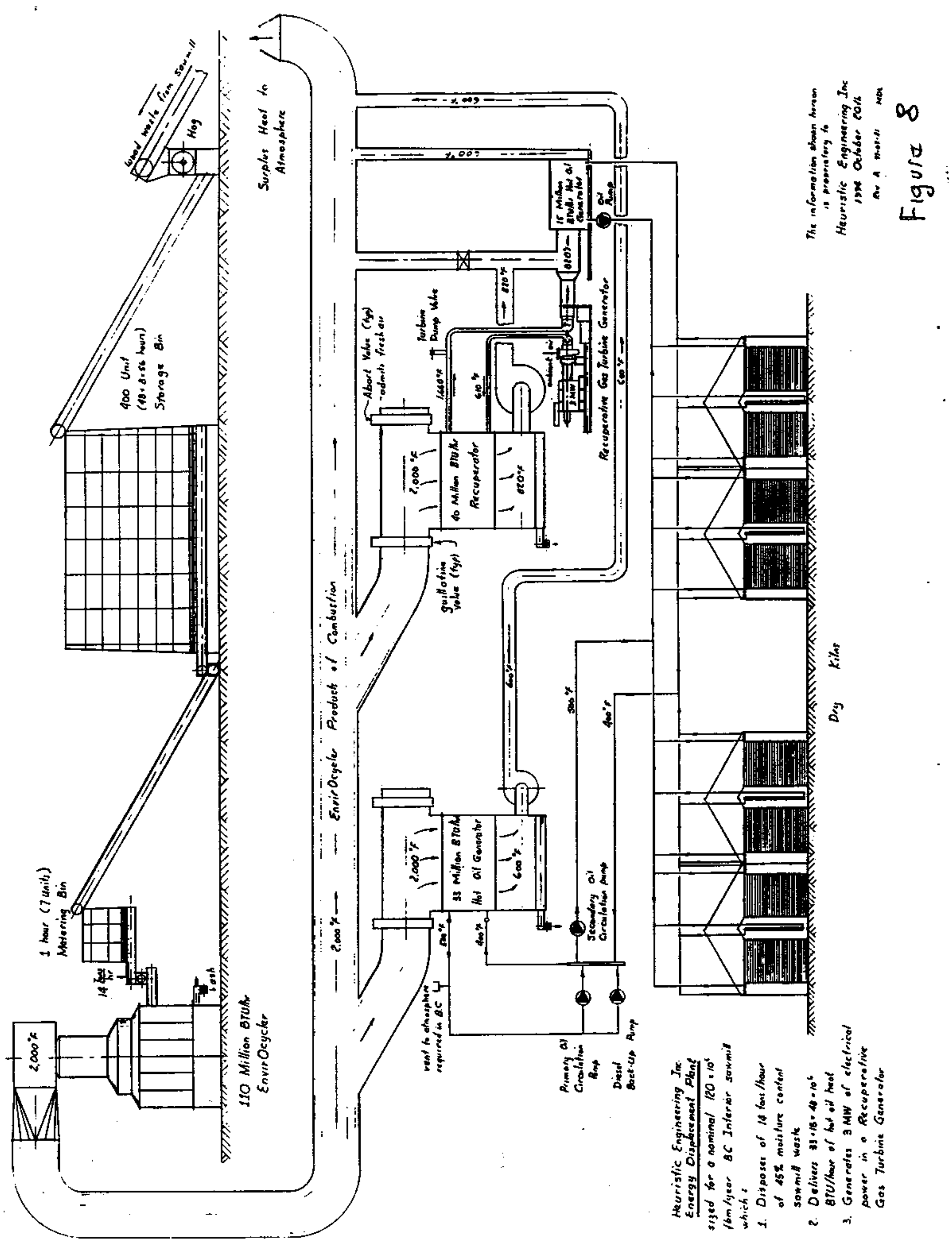
SPECIAL FEATURES

Feed: Robust, dual screw conveyors or dual hydraulic rams.

Grate: Large, stainless steel, low heat-release rate, A-frame grate.

Ash Removal: Reciprocating, wedge-type unloaders on either side of grate bottom (easily removed for servicing).

Figure 7


Wood waste from Sawmill
Hog
Surplus Heat to Atmosphere
400 Unit (48 + 8.56 hours) Storage Bin
1 hour (7 Units) Metering Bin
14 tons/hr
Ash
2,000°F
110 Million BTU/hr EnvirOcycler
EnvirOcycler Product of Combustion
2,000°F
33 Million BTU/hr Hot Oil Generator
600°F
40 Million BTU/hr Recuperator
820°F
Abort Valve (typ) - admits fresh air
guillotine Valve (typ)
Turbine Dump Valve
15 Million BTU/hr Hot Oil Generator
Oil Pump
Recuperative Gas Turbine Generator
vent to atmosphere required in BC
Secondary Oil Circulation pump
Primary Oil Circulation Pump
Diesel Back-Up Pump
Dry Kilns
The information shown hereon is proprietary to Heuristic Engineering Inc 1994 October 20th
Figure 8
Heuristic Engineering Inc. Energy Displacement Plant
sized for a nominal 120 x 10^6 fbm/year BC Interior sawmill which:
1. Disposes of 14 tons/hour of 45% moisture content sawmill waste
2. Delivers 33+15+40 x 10^6 BTU/hour of hot oil heat
3. Generates 3 MW of electrical power in a Recuperative Gas Turbine Generator

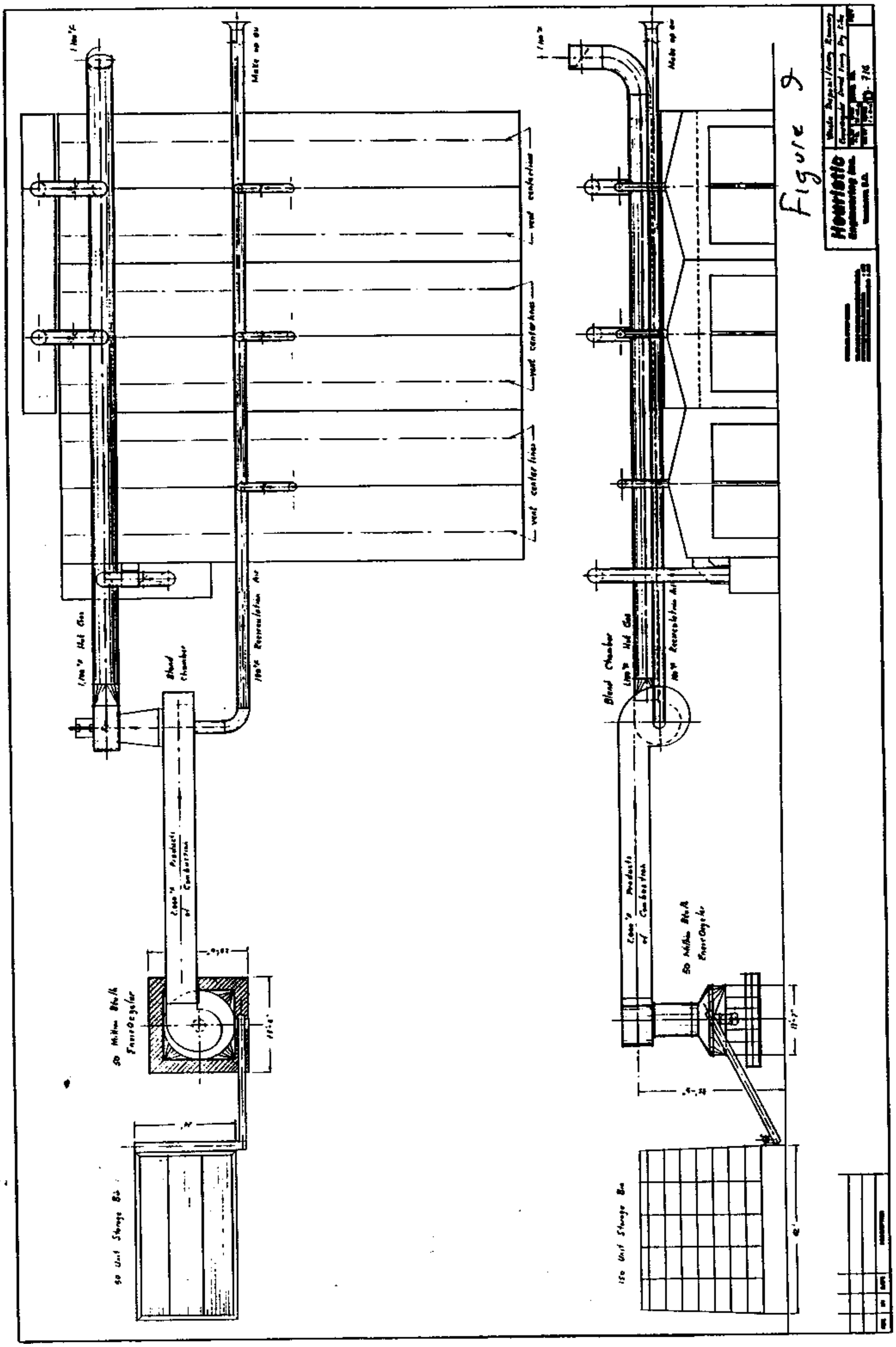


Figure 9