Research & Development for Coal and Woody Biomass Co-Firing Technology in Japan

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Abstract

With the aim of reducing greenhouse gas emissions and securing energy stability, the Japanese government of METI (Ministry of Economy, Trade and Industry) has promoted a new program called “High Efficiency Bioenergy Conversion Project” consisting of seven schemes in various technical fields that started in March 2002. One of these schemes is a co-firing of coal and woody biomass program that aims to develop biomass resource conversion at a high rate of efficiency and create an economical energy from woody biomass in existing coal fired power plants, where levels of CO2 need to be reduced.

The Chugoku Electric Power Co. Inc., Hitachi Ltd. and Babcock-Hitachi K.K. have co-operated and started the R&D work of this co-firing technology for its utilization in both Pulverized Coal firing and Fluidized Bed firing under the subsidy of NEDO (New Energy and Industrial Technology Development Organization). This R&D work has included:

1. Technological investigation for woody biomass
2. Development of fuel-preparation technologies
3. Combustion tests and evaluations
4. Feasibility studies for actual utilization

The final goal is to combust woody biomass by 5 to 10% of the mixing rate in coal-fired power generation plants, maintain stable plant operations, satisfy current environmental regulations and hold the drop in power generation efficiency to a minimum. Approximately 40% level of the existing power generation efficiency is hoped to be attained from co-firing.

In this three years program, our paper describes the items 1 and 2 as intermediary results of the over all program. The investigation of wood energy resources in Japan, the wood industry, fundamental tests of rapid ignition-burnout, grindability, drying and CWP (Coal Water Paste) for pressurized fluidized bed boilers, as well as their results and characteristics were studied and are hereby reported.

*1.**Introduction***

With concern about global warming and the depletion of fossil resources, biomass has drawn attention because of its renewable, clean and carbon neutral properties. In Japan, part of the "Law Concerning Promotion of the Use of New Energy" was revised in January 2002, and biomass as an energy was posited as a new energy. Since then biomass has been readily received and promoted as an energy along with the promotion of photovoltaic power generation and wind power generation, etc. The advisory committee of Resources and Energy has set introductory objectives for new energy and clearly stated the role of biomass power generation and biomass heat use in June 2001. The target for introducing biomass energy is about 6 million kl (30% or more of the total supply target of new energy, 19.1 million kl).

According to the ”Law Concerning the Use of New Energy by Electric Utilities” that determines the industries’ use of new energies at a constant ratio which will be put into effect as of April 2003, biomass is a choice for new energy in power generation. Recently, the introduction of a Carbon-emissions tax has been examined. In addition, the Cabinet office and five Ministries (the Ministry of Education, Culture, Sports, Science and Technology, the Ministry of Agriculture, Forestry and Fisheries, the Ministry of Economy, Trade and Industry, the Ministry of Land, Infrastructure and Transport, and the Ministry of the Environment) established strategies concerning the overall profit use of biomass "BIOMASS NIPPON comprehensive strategy" in December 2002.

NEDO began development for converting various kinds of biomass into useful energy in the form of heat, electric power, gas and liquid fuel, etc. at highly efficient rates as well as economically. This development set out to achieve biomass power generation and biomass heat use in the fiscal year of 2001. The high efficiency attained in the project of biomass energy conversion has been well discussed.

2. Target of R&D work

Japan’s forests cover an area of roughly 25 million hectares, approximately 70% of its land area. The growth stock of forests is approximately 3.9 billion m3 (Annual report on trends of forest and forestry, during the fiscal year of 2001 by the Forest Agency, the Ministry of Agriculture and Forestry and Fisheries of Japan). The focus on woody biomass is understandable considering the vast domestic forest resources available and the potential utilization of these unused resources. Hence, the need is to establish as early as possible a highly efficient, reliable technology for utilizing these resources.

The purpose of this project is to develop biomass resource conversion into a highly efficient, economical energy for coal and woody biomass co-firing in existing coal fired power plants, where huge amounts of CO_2 are produced. Then we can utilize unused energy and reduce CO_2 emissions by substituting coal with biomass. For this utilization, technical aspects including the preparation of storage, crushing/pulverizing, proper co-firing systems for woody biomass supply and combustion for coal fired power plants (both Pulverized Coal firing and Fluidized Bed firing) will be studied.

R&D organizations such as the Chugoku Electric Power Co., Inc. (supplying electricity to the Chugoku region), Hitachi Ltd. and Babcock Hitachi K.K. (power generation plant engineering and manufacturers) are jointly working on behalf of NEDO for commercial usage in the Chugoku region as part of a future nationwide power generation joint effort.

3. Utilization schedule

NEDO aims to combust woody biomass by approximately 5 to 10% of the mixing rate at a coal-fired power generation plant, maintain a stable plant operation, satisfy current environmental regulations and keep the drop of power generation efficiency to a minimum. The final target is to maintain about 40% of power generation efficiency in existing coal-fired power plants. This research and development project is mentioned here in Table-1 showing the R&D schedule.

(1) Technological investigations for woody biomass

The state of forest resources, trends in the forest industry, transportation/distribution of wood are being thoroughly studied.

(2) Development of fuel preparation technologies

General property tests (analysis, physical properties, ash fusibility, grindability, etc.) and fundamental tests (combustion characteristics, grindability, drying, Coal Water Paste (CWP)) are being made. Based on these results, fuel-preparation technologies (separation, storing, crushing, drying) along with burner systems, fuel supply systems, etc. are being studied.

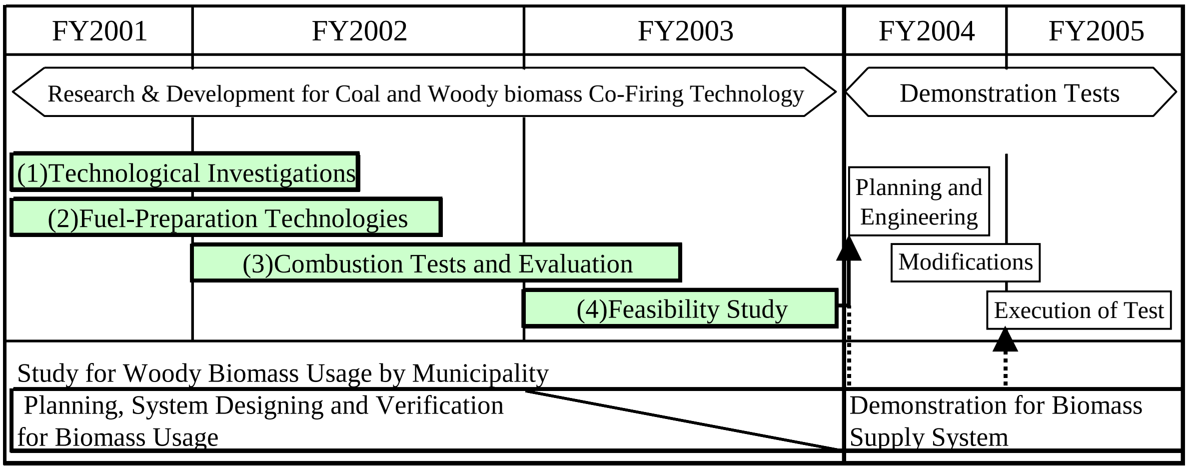
(3) Combustion tests and evaluation procedures

Coal and woody biomass combustion tests are presently being performed using test equipment (pulverized coal test facilities and fluidized bed firing test facilities). Combustion properties, fuel gas characteristics and influences on the boiler as well as related environmental equipment are being evaluated and verified.

(4) Feasibility studies for utilization

For the realization of a concrete system, estimations are being made for thermal efficiency and modification costs in existing coal fired power plants. Technical limitations for practical usage are being looked into, as well.

Table-1　Research and development study schedule



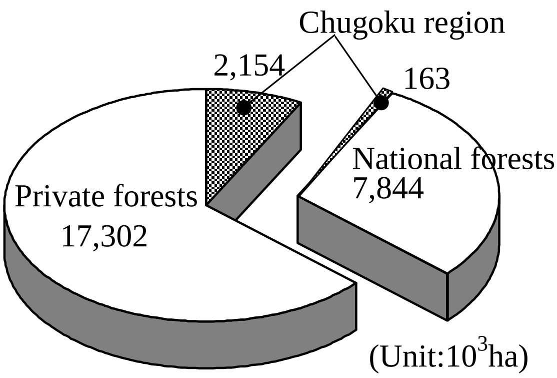
4. ***Investigation***

4.1 Forest resource

Mainly in and around the Chugoku region, resources and collection costs etc. of woody biomass generated from wood and lumbering were investigated and the possibility of supplying them to coal fired power plants was analyzed.

We analyzed this information based on various data from related forestry industries in each prefecture and the forest owners' cooperative etc. We also sought opinions from those directly linked to this industry.

Japan's forest area is about 25,000,000ha and in the Chugoku region there is about 9.2% of it, 2,300,000ha.　In Figure-1, 93% of the forest area in the Chugoku region is private.



(Note: The Illustration of Annual Report on Trends of Forest and Forestry : Association of Agriculture & Forestry Statistics (2001))

Figure-1　The situation of forest resources in the Chugoku region of Japan

The forestry thinning area and volume are shown in Table-2 between trees of 4-8 year class (20-40 years old) that can be expected as a source of energy. It is estimated that the forestry thinning area in the Chugoku region during a year is 2.3% for trees of 4-8 year class in private and communal forest areas; that is an approximate thinning of 710,000m3. The volume used now is roughly 100,000m3. Most forestry thinning areas have not been put to usage.

Table-2 Area between trees of 4-8 year class in private and communal forests

Area between trees of 4-8 year class in private and communal forests		940,000ha
Forest thinning area		22,000ha
Forest thinning volume	Trunk material	440,000m^3
	Branch etc.	270,000m^3

The surplus of wood material in the lumbering process is about 40%, approximately 1.5 million m3 generated from foreign lumber (about 3.1 million m3) and domestic lumber (0.88 million m3). The 0.87 million m3 surplus material is used for raw chip material in paper manufacturing (Both the above values were for a one year period). The remaining 0.63 million m3 of this wood surplus is mainly used for boiler fuel in lumber mill annexes, cattle straw, disposed as waste or is a resource that can be used as energy.

The stock size of woody biomass in forestry thinning, lumbering surplus material and bamboo which exists in rather large quantities in the Chugoku region is estimated to be 1.38 million m3 during a single year. As an energy source about 10PJ is possible. (The coal consumption results of Chugoku Electric Power's fiscal year 2000 are about 160PJ.) Figure-2 shows the stock size of woody biomass resources in the Chugoku region.

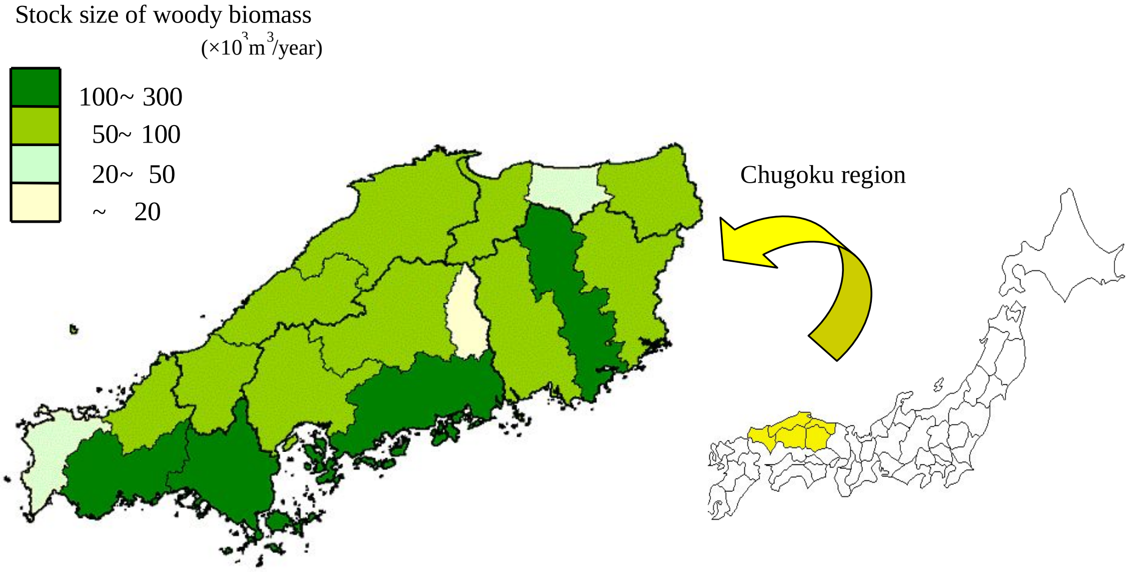


Figure-2 Woody biomass resource map in the Chugoku region (Japan)

4.2 Study fields

To clarify technical fields of study, we carried out surveys on existing power plants where Biomass had already been utilized as a fuel. The main technical subjects to be studied for biomass co-firing utilization are shown in Figure-3. Regarding biomass utilization, according to each country and each individual plant, various methods for actual utilization have been adopted according to types of biomass and their related industrial application. Therefore, fuel preparation systems and firing systems are different in actual utilities. Optimizing the systems available depending on allowable circumstances for Japanese application has become crucial to this project.

The following points are of particular importance.

- Fuel handling and preparation system ----- Crushing and Drying devices
- Fuel supply system ----- Burner construction and feed way
- Safe operation ----- Countermeasures for spontaneous ignition and detection methods

For gathering biomass in sufficient amounts, large scale machinery devices have already been introduced in developed countries for their effectiveness and by way of eliminating human labor. In Japan, too, the promotion of biomass utilization will bring about the necessity of cutting/collection machinery capable of operating on steep mountain slopes. Also environmental considerations shall be made in the construction of any consequential technology as well as a tax system (as with Carbon tax concerning environmental preservation) like that of Nordic countries. The main concerns in carrying out research and development are as follows. Japanese woody biomass produced from wood and lumbering will be used for boilers mainly as wood chips with high moisture content of the supply conditions to the site.

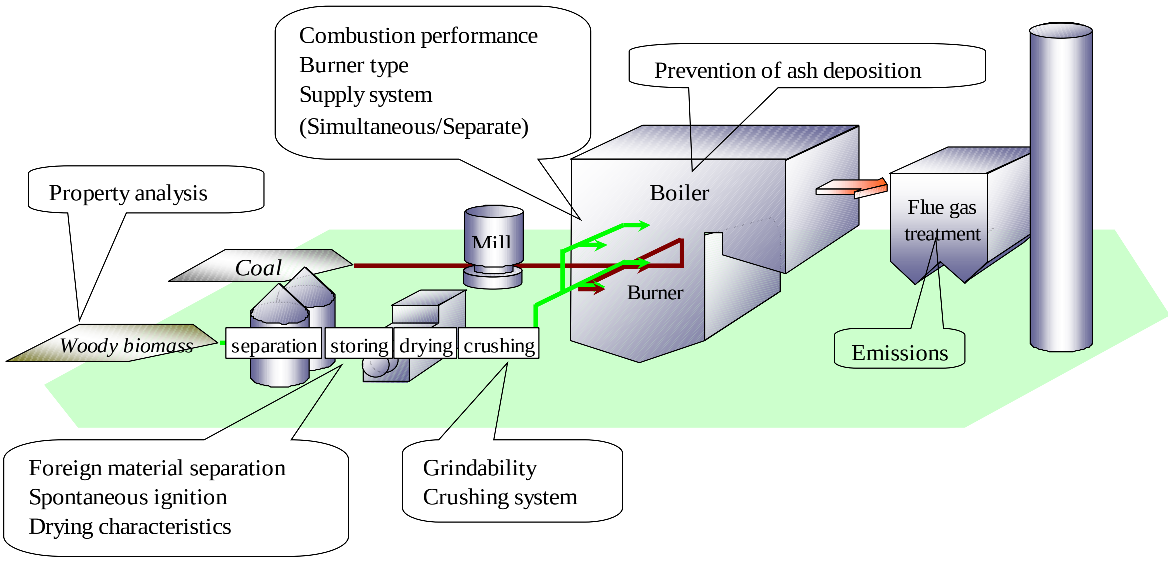


Figure-3 Main fields of study

5. ***Biomass characteristics and fundamental test***

5.1 Fuel analysis

For stable ignition and combustion in a boiler, the pulverized size of biomass material, burner conditions and supply methods have to be optimized in relation to fuel properties. Table-3 lists proximate and ultimate analyses as well as certain woody biomass ash properties in comparison with a representative bituminous coal. Moisture and volatile matter of biomass are higher than those of coal although the contents of S and N are smaller. Biomass ash content is much smaller than coal, however in biomass relatively higher contents of K, Mg, P, Na and Ca are present. In particular, what is seen here is that the content of Cl in Bamboo is approximately 10 times higher than those of other woods.

Table-3 Coal and biomass analysis

Item \ Fuel	Base	Unit	Coal	Pine	Japanese cedar	Bamboo	Cypress	Broad leaved tree
Higher heating value	Air dried	kJ/kg	28,465	19,080	18,560	18,360	17,870	18,280
Water content	As received	%	8.9	51.8	49.1	39.4	44.2	39.3
Proximate analysis								
Volatile matter	dry	%	32.76	80.4	81.25	80.42	81.64	83.31
Fixed carbon	dry	%	51.55	18.63	18.01	18.19	17.64	15.66
Ash content	dry	%	11.62	0.97	0.74	1.39	0.72	1.03
Ultimate analysis								
C	dry	%	72.6	53.42	52.04	49.41	51.96	49.7
H	dry	%	4.61	6.23	6.19	6.11	5.99	6.05
O	dry	%	8.53	39.04	40.74	42.57	40.99	42.89
N	dry	%	4.75	0.30	0.26	0.18	0.32	0.31
S	dry	%	0.46	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Cl	dry	%	–	0.036	0.033	0.34	0.025	0.022
Ash analysis								
SiO_2	dry	%	71.5	14.3	5.29	22.7	12	5.06
Al_2O_3	dry	%	16.6	6.97	1.81	0.69	3.02	9.63
Fe_2O_3	dry	%	4.11	1.49	0.85	0.56	1.49	0.66
CaO	dry	%	2.22	37.6	55.3	3.23	44.5	42.5
MgO	dry	%	1.43	6.19	6.15	10.6	5.65	5.66
TiO_2	dry	%	0.63	0.16	0.07	0.04	0.1	0.05
SO_3	dry	%	1.85	10.7	3.04	3.48	3.12	2.79
P_2O_5	dry	%	0.53	3.77	3.37	7.86	3.72	3.31
Na_2O	dry	%	0.45	1.40	2.41	4.85	1.98	1.49
K_2O	dry	%	0.71	6.64	4.92	30	8.56	10.1
MnO	dry	%	–	2.64	0.16	1.17	1.42	1.95

5.2 Ignition test

A drop tube furnace as depicted in Figure-4 is used to evaluate the combustion rate. It is composed of an alumina tube (ϕ100i.d.×L1300) and a water-cooled sampling probe inserted from the bottom of the alumina tube. The residence time is adjusted by varying the position of the probe. Chipped biomass material (3g/min) is injected from the top of the furnace with primary air (20 l/min) through a burner tube. From the outside of the burner tube, secondary air (30 l/min) is injected into the furnace.

The results are analyzed based on the first order rate equation expressed by

$$-dM/dt = K\ M \qquad (1)$$

$$K = Kv\ \exp(-E/RT) \qquad (2)$$

Where M is the mass of unburned material at time t, K and Kv are the rate constants while E is the activation energy and T is the temperature of solids (assumed by the surrounding gas temperature). Kv is assumed to be proportional to the specific surface area of particles denoted as A_0 at t=0, that is

$$Kv \propto Ao \propto (1/ds) \qquad (3)$$

Where ds is the mean size based on the specific surface area of chipped material.

The temperature dependency of the rate constant K is shown in the figures, those of coal in Figure-5 in comparison with the effect of the screen size passing 100% on K in Figure-6. Then the Arrhenius type equation given by equation(2) may be valid from the straight lines despite the scattering of the data. The size dependency assumed by equation(3) is shown to be valid in Figure-7 indicated by the straight line passing through the zero point.

Thus, examined equations should be used to estimate the optimum biomass size to be ground suitably for a given boiler operation co-firing coal and biomass.

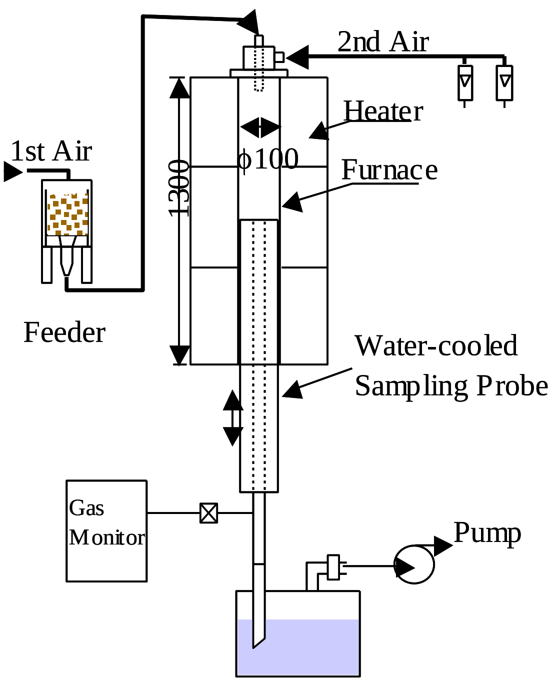


Figure-4 Drop Tube Furnace (DTF)

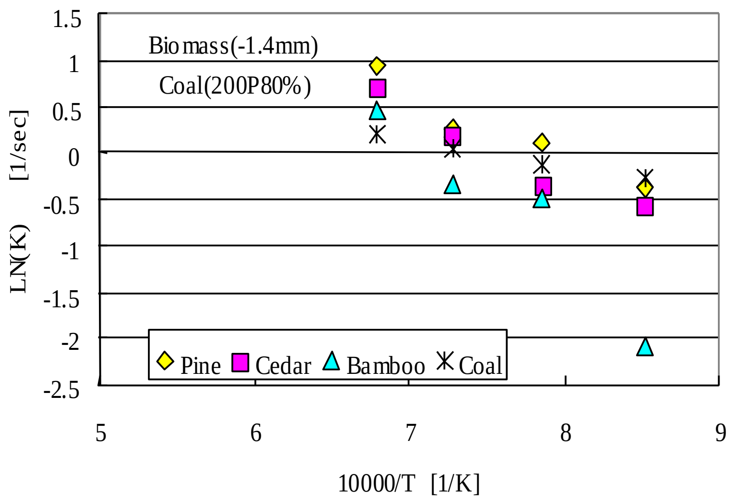


Figure-5 The rate constant K in relation to temperature (Difference of woody biomass)

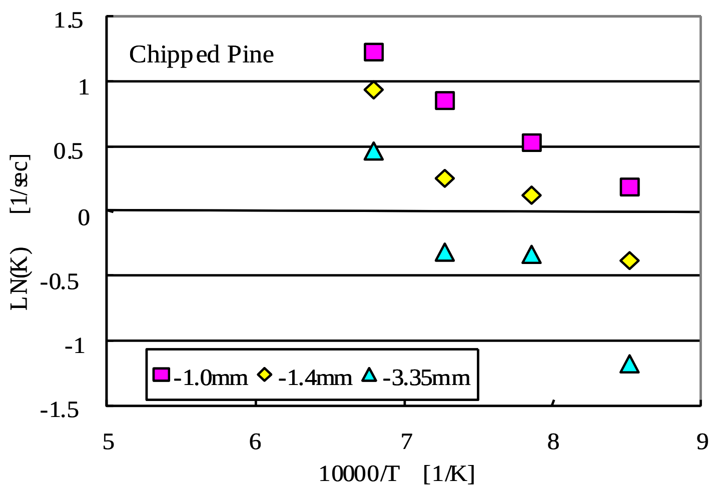


Figure-6 The rate constant K in relation to temperature (Difference of particle size)

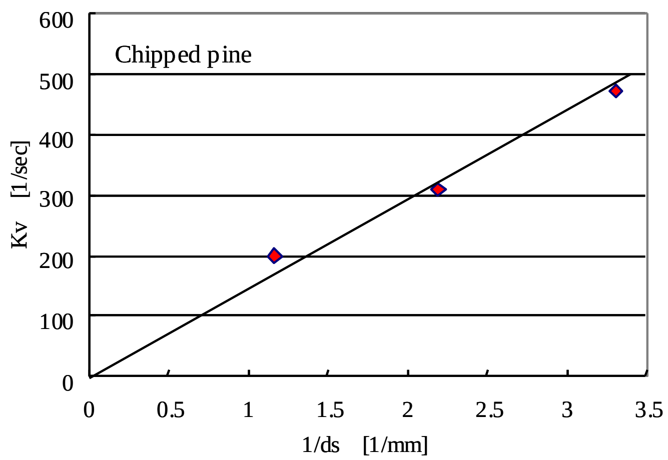


Figure-7 The rate constant Kv in relation to 1/ds

5.3 Grindability test

In coal combustion boilers with biomass co-firing, two methods of biomass grinding were considered; one using conventional roller type mills and the other by installing new grinding mills for biomass only. In designing conventional roller type mills, grindability expressed by the Hardgrove Grindability Index (HGI) is measured. Figure-8 shows the HGI values in relation to the fraction of biomass mixed with coal. The HGI decreases drastically with an increase in the fraction of biomass whereby a cushioning reaction can be caused by mixing biomass materials. From this result, roller type mills may not be suitable for grinding the mixture of coal and biomass.

Figure-9 shows size distributions for certain biomass materials, the moisture content which is 15% and ground by a hammer mill with a screen size of 7mm. The size distributions are affected by the kind of material ground and grindability is possible below 4mm.

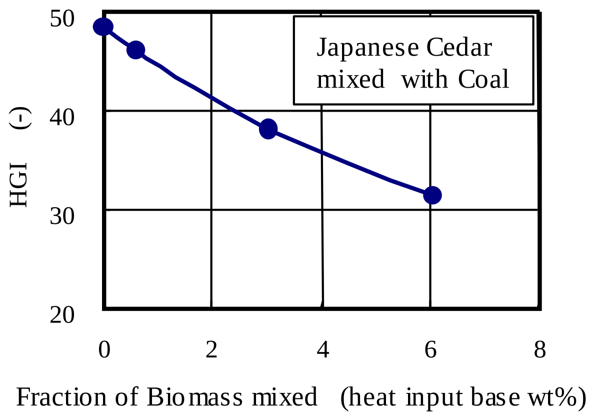


Figure-8 The relationship between HGI and the fraction of biomass mixed

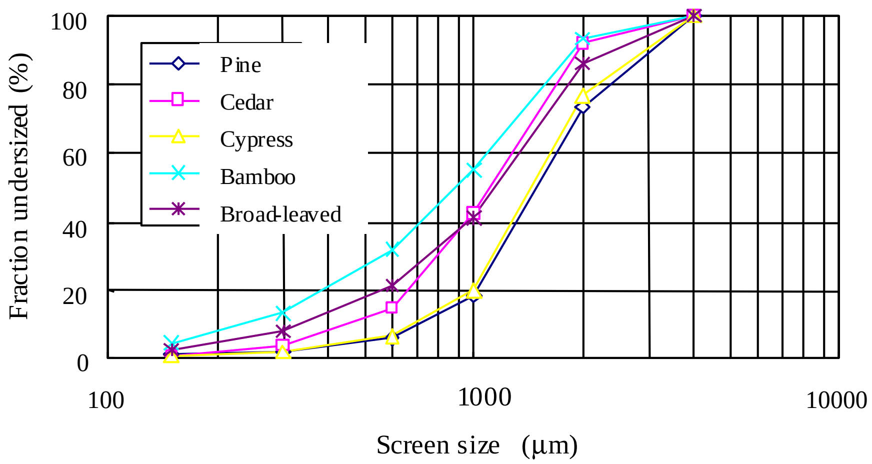


Figure-9 The size distribution of woody biomass ground by Hammer mill

5.4 CWP test

In pressurized fluidized bed combustion boilers (PFBC), CWP fuel is injected into the boilers (see Figure-10). The CWP is a slurry paste composed of coarse coal particles ground to less than 10mm and fine coal particles ground by tube mills mixed with water and limestone which are transported under high pressure by piston pumps and supplied to the fluidized bed through injection nozzles. The water content in CWP is approximately 22% and its viscosity is 10Pa·s. A lesser water content is favorable in maintaining high boiler efficiency. The water content and fluidity are important factors when biomass is added to the CWP. As added biomass to CWP indicates a relatively high viscosity, water is added to reduce its value. For a constant viscosity, water is added in relation to the mixed biomass shown in Figure-11 where the bamboo itself requires smaller water content due to its relatively low moisture adsorption.

Mixing biomass into CWP fuel may not be practical from an economical point of view due to the greater volume of water required for maintaining a constant viscosity in the fuel.

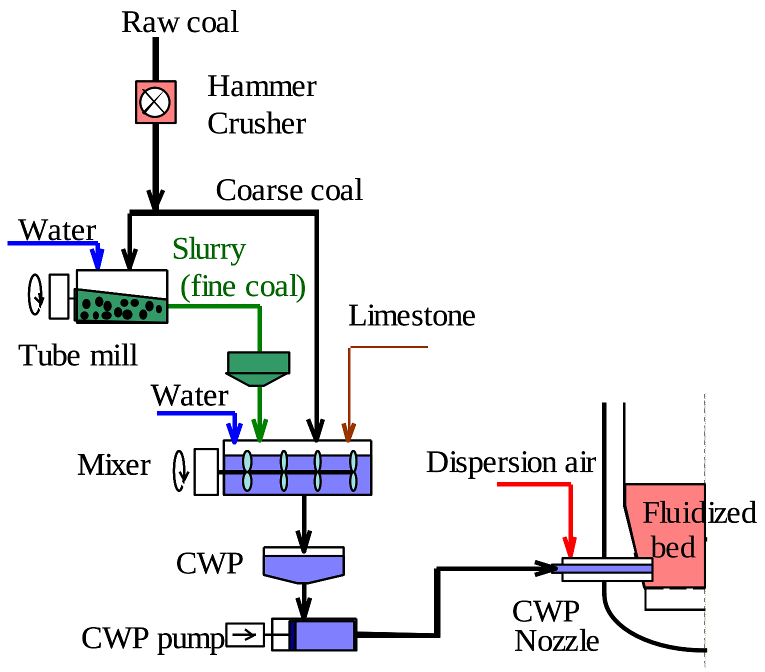


Figure-10 Flow diagram of CWP preparation system for PFBC

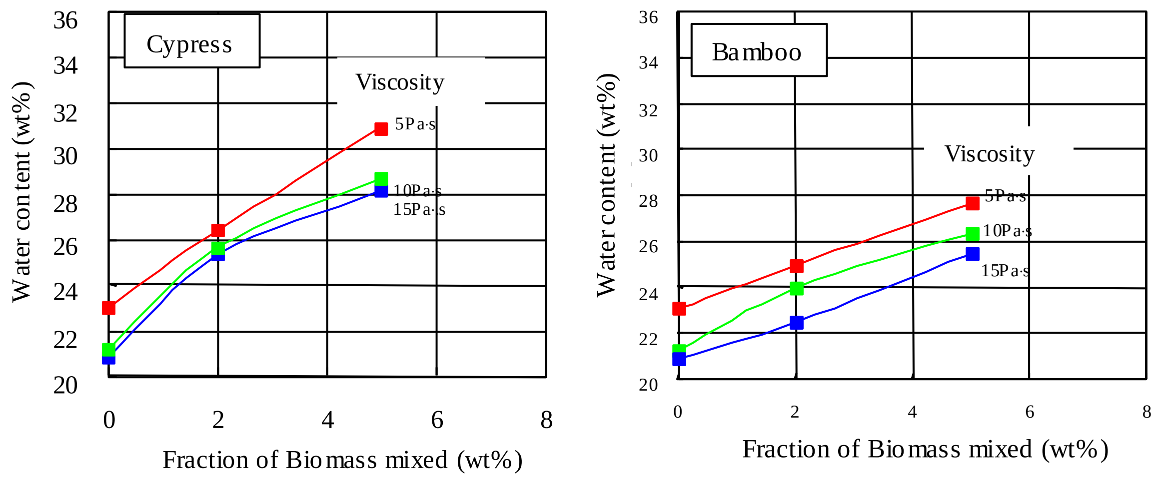


Figure-11　Fluidity during biomass mixing rate and moisture in CWP

6. ***Pilot scale test***

6.1 Test facility

An additional fuel preparation system to existing combustion and flue gas cleaning facilities shown in Figure-13 was designed and manufactured for woody biomass. The flow chart for this woody biomass preparation system is shown in Figure-12. Woody biomass sizes of 50mm, whose moisture content is 50wt%, are carried and stored in the biomass hopper then crushed into 20mm granules by the crusher so that it is a suitable size for the drier. The drier is designed for 100kg/h with 50% weight moisture content to 20% moisture content using combustion flue gas in the drier.

Woody biomass is pulverized to a ground size of 5mm by pulverizer-1 while pulverizer-2 adjusts the size of biomass particles within the range of ≤1 to ≤5mm. The adjusted woody biomass is stored temporarily in 5m3 hoppers in the preliminary, then carried to the furnace pneumatically at a flow rate of 60 kg/h (20%moisture content). The mixing rate of biomass in the co-firing system of coal and woody biomass was made to a maximum of 15%(heat input base).

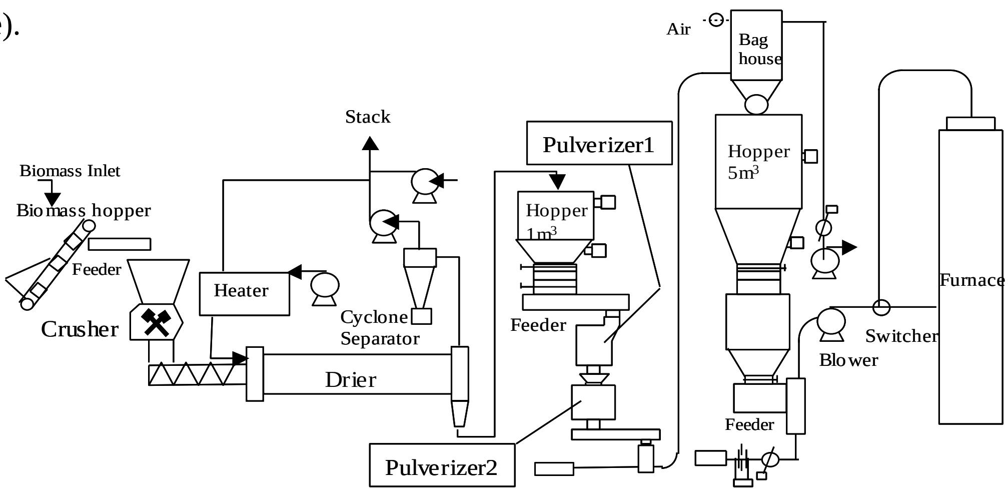


Figure-12　A biomass preparation and combustion system for a pilot test facility

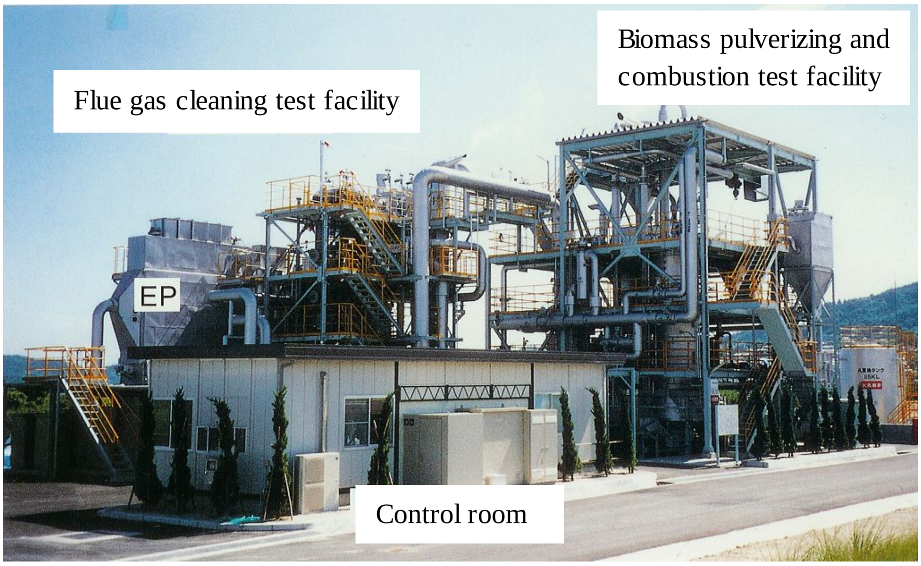


Figure-13　Combustion and flue gas cleaning pilot test facility

6.2 Test results

Figure-14 shows the results of the pine grindability. Chipped pine under the size of 50mm was fed into the crusher at the rate of 100kg/h. Dried biomass was fed again into the pulverizer for a greater fineness of biomass. The water content of the biomass fed into the first crusher and the second pulverizer is adjusted to around 50% and 10% respectively. The first crusher can grind biomass into a size of around 10mm under and the pulverizer allows for a maximum size around 2mm with a mean particle size of 0.6mm. The change in sizes of required biomass particle is very easily achieved by replacing screens in the pulverizer.

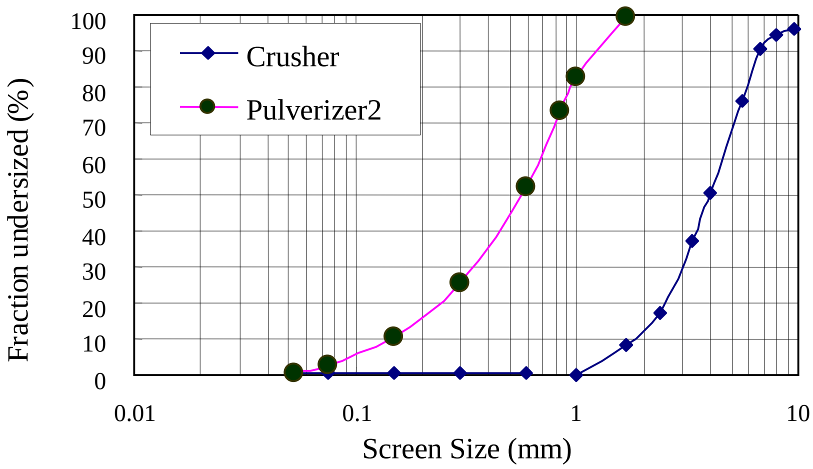


Figure-14　The size distribution of pine biomass ground by mill

7. Summary

The results during the previous year, since March 2002, for developing woody biomass co-firing technology are as follows.

(1) Investigations

- · The stock size of woody biomass in the Chugoku region is 1.38 million m^3/year and its energy is about 10PJ. (The Chugoku region is about 9% of Japan's forest area.)
- · A categorical breakdown of each field of study was established and the prioritization of matters for concern were hierachally determined.

(2) Fundamental tests

- · Several kinds of woody biomass were tested to obtain optimum combustion rates with the best selection of available woody biomass particle sizes.
- · Grindability tests were performed to determine the best grinding system. Roller type mills proved unsuitable for grinding mixtures of coal and biomass.
- · Characteristics of coal water paste with woody biomass were confirmed in view of feeding possibilities. Mixing biomass into CWP fuel is not practical from an economical point of view due to the greater volume of water required.

Hence, combustion tests have been performing in pilot scale test plants and demonstration combustion tests will be carried out from 2004 in an actual thermal power plant in Japan.

References

1. Tajima, et. Al, Development of Technology for High Efficiency Bio-energy Conversion at NEDO, Proc. 12th European Biomass Conf., Amsterdam, Jun.17-21, 2002, pp.1375-1378
2. Nakamura, et. Al, R&D for Coal and Woody biomass Co-firing technology, High efficiency Bioenergy Conversion Project, The Japan Institute of Energy Biomass Div., Tokyo, Aug. 26th, 2002
3. Report of the Basic Survey on Promotion of Introduction of New Energy, etc. (Basic survey on current state of biomass energy), Mar. 2001
4. Report of the Advisory Committee of Resources and Energy (Jul. 2001)
5. Annual report on trends of forest and forestry, Fiscal year 2001, Forest Agency, The Ministry of Agriculture, Forestry and Fisheries of Japan)
6. Nomura, et. Al, Combustion Rate of Woody Biomass, 68th Annual Meeting of the Society of Chemical Engineers, Japan, No.756, Mar.23 (2003)
7. Otani, et. Al, Co-combustion of Woody Biomass in Coal Combustion Boilers, 68th Annual Meeting of the Society of Chemical Engineers, Japan, No.757, Mar.23 (2003)