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Development of high-efficient waste power generation technologies: feasibility study on the high-efficient waste gasification process

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Abstract

Optimization and feasibility study on the waste gasification technology applied high-efficient power generation system has been conducted with the aim of further improving net efficiency and economic performance, as well as reducing adverse environmental impacts The preliminary feasibility study showed that the waste pyrolysis and gasification power generation system with gas engine would be suitable for small and medium size of municipal solid waste (MSW) facilities less than 300 t/d. In detailed feasibility studies, four categories of MSW wastes (1,600 - 3,400 kcal/kg) and four different scales of facilities (50 - 300 t/d) were set up as parameters. The waste of 2,100 kcal/kg and the facility of 100 t/d were selected as a references. For the reference facility, the following values were set as the targets relative to the basic performance of a system; the effective cold gas efficiency (>69%), the gross power efficiency (>25%), the net power efficiency (>14%) the emission of DXN (<0.01 ng-TEQ/m3N), and the cost of wastes processing (¥20,000/ton). As a result of system optimization, it was quantitatively confirmed that the high-efficient waste pyrolysis and gasification system would offer greater advantages than the conventional type waste to power systems and development issues involved in the high-efficiency technologies are identified. High-efficient waste pyrolysis and gasification power generation project, which is supported by METI/NEDO, has been conducted since FY2001.

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1. Introduction

The New Energy and Industrial Technology Development Organization (NEDO) launched a three-year project in fiscal year 2001 to develop a "New high-efficiency waste power generation technology." The aim of the project is to establish and promptly introduce and spread an attractive new waste -to-energy power generation technology for relatively small-sized waste treatment facilities in a throughput class of 50 - 200 t/d, which have been seldom provided with a power generating installation.

The proposed technology will first separate wastes into thermal decomposition gas (containing tar and soot) and a solid component by baking the wastes at 500 – 600 degrees Centigrade (C) and then recover aluminum, iron and other metals from the solid component. The residue will be melted at 1,400 - 1,500 C and recovered as glasslike molten slag while the carbon component will be converted into carbon monoxide (CO) gas. The thermal decomposition gas mentioned above will be reformed at 1,000 - 1,200 C and recovered as a clean, combustible gas (syngas) with hydrogen (H_2) and carbon monoxide (CO) as main flammable components. The syngas thus recovered will be used as fuel for power generation by a high-efficient gas engine that will be newly developed under the project. The following are the target values of performance and economic efficiency set for the technology development project:

Targets of the technology development for a general MSW treatment capacity of 100tons/day facility with gas engine power generation system.

1) Effective cold gas efficiency:>69%, Efficiency of gas engine:>36%
2) Gross efficiency: 25%, Net efficiency: > 14%
3) Dioxins concentration (in exhaust gas): < 0.01 ng- TEQ/Nm^3
4) Recovery of aluminum, iron and other metals in a reusable form
5) Recovery of ash as reusable molten slag by the self-heat of the wastes
6) Economic efficiency comparable/competitive to conventional furnaces and waste gasification and combustion melting ash furnaces power generation

This paper discusses features of the high-efficiency waste power generation technology to be developed under the project and suitability for small-sized waste treatment facilities, compared with conventional waste-to-power generation systems using stoker-type furnaces plus separate melting ash furnace or waste pyrolysis and combustion with melting ash furnace.

2. Challenges facing waste treatment technology in Japan

Recently the attitude of Japanese public toward environmental protection and resources conservation has been shifting, accordingly, toward what is expected of waste treatment. More specifically, social requirements are shifting from the concept of mere waste treatment and disposal to the need for technologies that can attain the reduction of adverse environmental impacts including, among others, measures to mitigate global warming and, in addition, effective

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use of available energy. Major requirements expected for future waste treatment facilities include:

(1) Contribution as a new energy source to the reduction of greenhouse gases
First, steps should be taken to generate electric power as much as possible when incinerating wastes. Efforts should also be exerted to improve the power generating efficiency of waste incineration facilities, which has been low in the past, and supply the electricity generated for use as in-site auxiliary power or back to the grid in order to save fossil energy consumption, thereby contributing to the reduction of carbon dioxide emissions.

(2) Reduction of dioxins (DXN) emissions
Measures should be taken to lower the concentration of all DXN emitted from waste treatment facilities. The recent amendment to the Air Pollution Control Law (1999) has led to regulations on the concentration of discharged DXN in ash and waste water as well as in exhaust gases, of which the last had already been regulated before the amendment.

(3) Volume reduction and main and fly ashes recycling
Arrangements should be made to melt ashes, recover precious metals and recycle molten slag in a bid to minimize loads at final disposal sites.

From these points of view, the following measures have been taken for the waste treatment facilities:

A. Waste-to-power generation by Stoker type furnaces, etc. [Conventional Furnaces]
Steps are being taken to provide high-temperature (>850 C) combustion control for thermal decomposition of DXN, improve the power generating efficiency of the conventional facilities by increasing the steam temperature and pressure, and install a separate ash melting furnace.

B. High-efficient waste pyrolysis and combustion melting ash power generation furnace [New high performance furnace]
The new furnace melts ash into slag using the internal temperature as high as one thousand and several hundred degrees C given by combustion of wastes itself while decomposing DXN. The furnace system generates electric power at high efficiency by prepared steam conditions, higher than the previous levels, in the boiler and optimizing the process for efficiency improvement.

C. High-efficient waste pyrolysis and gasification power generation furnace [The next-generation furnace]
The proposed furnace will drive thermal decomposition of wastes, melt ash at one thousand and several hundred degrees C by partial combustion of decomposed wastes, and decompose DXN. Furthermore, the thermally decomposed gases are reformed at high temperature over 1000 C, refined and recovered as clean combustible gas (syngas). It generates electricity using the syngas thus produced and brings a new gas-fueled power generation facility with higher efficiency.

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The development of waste gasification and combustion melting ash power generation technology was initially promoted in Europe. In recent years, the technology get more attention in Japan due to the reason mentioned above. In Japan, the efforts to commercialize the power generation system are being exerted both using technologies abroad and domestically developed ones. Putting more emphasis on reducing adverse environmental impacts and improving financial base for management of the facility, the Ministry of Economy, Trade and Industry (METI) and NEDO launched a three-year project "Development of Waste Gasification Ash Melting Power Generation Technology with Steam Turbine" in fiscal 1998. Research activities were carried out under the project to develop a technology for efficiency improvement, with the Institute of Applied Energy acting as coordinator and with equipment manufacturers. These efforts resulted in the efficiency improvement technologies that could attain high-temperature and high-pressure steam conditions of 500 C x 100 ata for waste-to-energy power generation. Conceptual design and feasibility studies on the new technologies showed that the gross power efficiency of 30% could be attained for 600 t/d class plant using MSW (2100kcal/kg). The details of the technology are described in references [1] and [2] and, to be also presented by NARAMOTO (NEDO) in this proceedings.
This paper focuses on a "high-efficient waste to power generation system" based on the waste pyrolysis and gasification technology. The following sections will discuss the basic concept and features of the system, the results of feasibility studies, current stage of its development, and the tasks involved in the new R&D project.

3. Basic concept and the features of waste pyrolysis and gasification melting ash power generation technology

The waste gasification technology gasifies wastes through their thermal decomposition at 500 – 600 C. After completely gasifying non-decomposed components (including char and tar) at a high temperature ranging from 1,000 to 1,500 C, it reforms, refines and recovers the gas as syngas with high cleanliness while melting ashes. Fig. 1 gives an example of conceptual diagram of a fluidized bed reactor type pyrolysis and gasification system. In addition to the fluidized bed reactor, some other types of system, including a rotary kiln reactor type and a shaft reactor type, are available for the waste pyrolysis and gasification systems, of which several typical configurations are shown in Fig. 2. The waste pyrolysis and gasification system is similar to the waste pyrolysis and combustion melting ash system up to the process of melting the ash content of the residue at a high temperature, but the two systems basically differ. The waste pyrolysis and combustion system completely burns the combustible component of wastes while the waste pyrolysis and gasification system is designed mainly to recover syngas from wastes at high efficiency. The ratio of the calorific value of syngas used for power generation to that of the wastes is called "effective cold gas efficiency."

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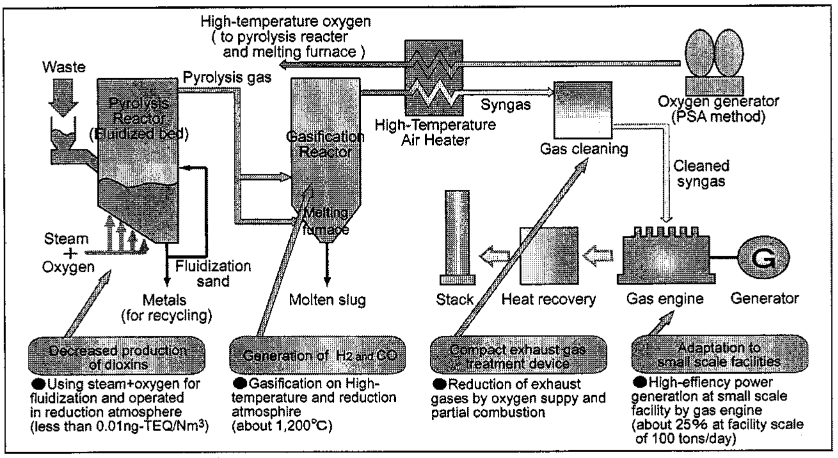

Figure 1: A conceptual diagram of fluidized bed type pyrolysis and gasification power generation system

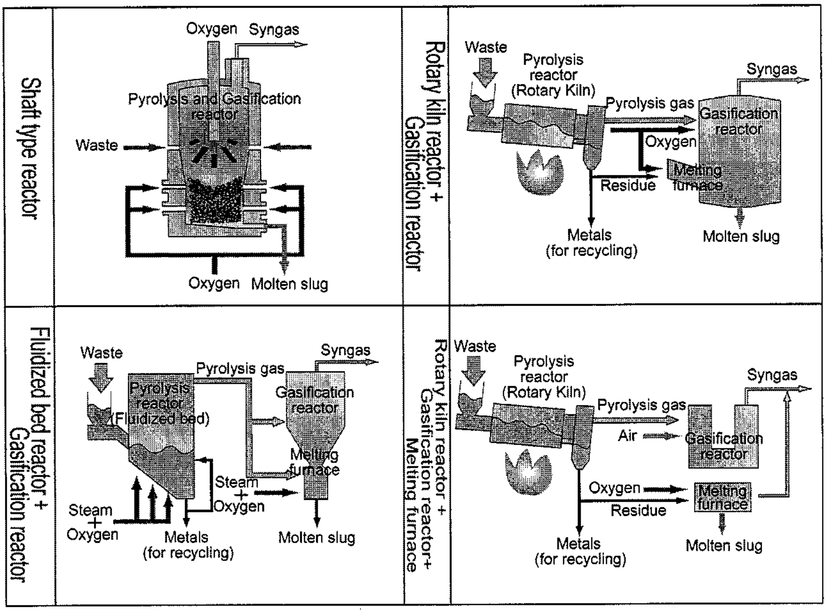

Figure 2: Various concepts of pyrolysis and gasification reactor to produce syngas

A waste pyrolysis and gasification system with high gasification efficiency (hereinafter referred to as "Waste gasification system") is expected to raise the effective cold gas efficiency to somewhere around 70%. The waste

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gasification can generate electric power by a gas engine (GE), a gas turbine combined cycle (GTC) or a fuel cell (FC) unit using the syngas thus recovered. It can be expected to achieve higher power generating efficiency than the steam turbine system, especially in small size facilities. In addition, the system is expected to be the next-generation technology with much less impacts on environment. In the gasification process, the system exhaust gases cleaner than conventional systems by suppressing synthesized DXN, decomposing DXN and their precursors, and rapidly cooling them in the temperature range where these substances should be re-synthesized. Since the combustible component of the syngas consists mainly of H_2 and CO while its incombustible component mainly comprises N_2 and CO_2, it is conceivable that the gas can be used as chemical feedstock for production of hydrogen, methane, methanol, and etc. Even if the same type of waste is treated, the composition ratio of syngas differs widely, depending on whether the waste gasification system is oxygen-blown or air-blown. The calorific value of gas produced from general wastes ranges from 1,200 kcal/ Nm^3 to 2,400 kcal/ Nm^3 according to the types of the pyrolysis and gasification melting ash system. Compared with town gas with a calorific value of about 11,000 kcal/ Nm^3, the syngas produced from the treatment of general MSW is considered low-calorific-value gas. However, a basic combustion test recently conducted on a single-cylinder gas engine found that the pre-combustion chamber, pilot oil-ignited gas engine to be developed under the METI/NEDO project would be able to maintain stable combustion of such low-calorific-value gas with high efficiency.

4. Results of optimization study on high-efficient waste pyrolysis and gasification system

Recently some manufacturers in Japan have started developing this waste gasification system by introducing relevant European technologies and others have begun developing it with their own technologies. From the viewpoint of realizing high-efficiency power generation or reducing CO_2 emissions, however, these technologies have not yet fully utilized the energy contained in wastes. From the viewpoint of reducing adverse environmental impacts, such as DXN emissions, it is considered there still remains much room for developing new waste-to-power generation systems and, accordingly, various improvement requirements have been pointed out. As stated earlier in this paper, a feasibility study was conducted on the waste pyrolysis and gasification technology in the hope of attaining high-efficiency power generation and reducing adverse environmental impacts. Contracted out to several manufacturers engaged in developing the waste pyrolysis and gasification technology, the study aimed at ensuring that these manufacturers would develop elements of the technology assigned to them and clearly identify the development tasks to be carried out for total system and achieving the target. The items of the feasibility study comprised a conceptual design of the system, energy-balance and mass-balance analyses, the estimation of power generation costs, and the unit cost of waste treatment. For comparing relative merits, a

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similar study was conducted on stoker furnaces with ash melting furnace to be installed separately and, on the waste pyrolysis and combustion melting ash technology. The following are the results of these studies in the case of general MSW with a reference calorific value of 2,100 kcal/ Nm^3:

1) Results of preliminary feasibility studies
First, comparative studies among several power generation systems have been performed. Fig.3 shows the relationships between gross power efficiency, net power efficiency and the throughput of the waste to power generation facilities which use gas turbine combined cycle (GTC), gas engine (GE) and fuel cell (FC) power generation systems, respectively. Molten carbonate type fuel cell was chosen for the feasibility studies, because this type of cell is available to use CO gases by internal reforming process. The figure shows power generation performance for FC, GTC and GE from the top. However, the order of economical performance and the degree of technical completion are inverse. From the practical viewpoint, the waste gasification power generation system with high efficient gas engine is selected as the most suitable system for small and medium size MSW facilities.

2) Results of system optimization and detailed feasibility studies
In detailed feasibility studies, four categories of MSW wastes (1,600 – 3,400 kcal/kg) and four different scales of facilities (50 – 300 tons/day) were set up as the parameters. The waste of 2,100 kcal/kg and the facility of 100 t/d were selected as a reference case. For this reference facility, the following values were the targets relative to the basic performance of a system; the effective cold gas efficiency (>69%), the gross power efficiency (>25%), the net power efficiency (>14%), the emission of DXN (<0.01 ng–TEQ/m3N), and the cost of wastes treatment (¥20,000/ton). The other main assumptions to perform detailed feasibility studies are summarized in table 1.
The results described below are in each terms of the performance.

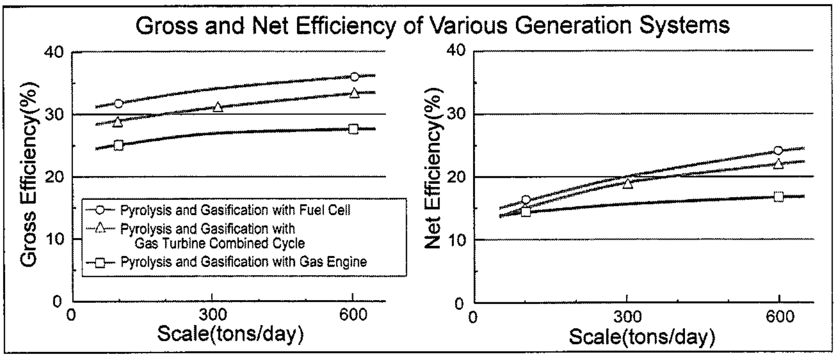

Figure 3: Comparison of gross and net power generation efficiencies of three pyrolysis and gasification systems

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Table 1. Main assumptions for feasibility studies of waste-to-power generation systems

Systems / Items	1. Stoker type furnace + Melting ash furnace	2. Waste gasification and combustion melting ash furnace	3. Waste pyrolysis and gasification melting ash reactor*
Waste specification	Municipal solid waste (2100kcal/kg, with 42% water content)		
Availability	80%		
Steam condition of steam turbine	100t/d:450 C × 60ata ≧300t/d:500 C × 100	500 C × 100ata	
Back pressure of condenser	≦300t/d:0.22ata 600t/d:0.1ata	0.2ata (Air Cooling)	
Gas engine			Efficiency of GE: 36%
Financial condition	1) Depreciation of the facility: 15 years 2) 25% subsidized for the waste treatment system by MHLW 3) 10% subsidized for the power generation system by METI		

*: A case which following R&D four items are solved and applied;

a. Optimization of pyrolysis process conditions
b. Optimization of gasification and ash-melting process conditions
c. Sensible and waste heat recovery and its optimum utilization technology
d. High-efficient gas engine ignited by micro-pilot-fuel oil technology

a. Gross efficiency and net efficiency

Concerning the gross efficiency of the waste gasification power generation system, estimates by the studies indicate that optimizing the pyrolysis, gasification, and melting ash processes respectively can improve the gasification efficiency. Furthermore, recovering the sensible heat of high-temperature reformed syngas and using waste heat as process heat, the gas engine power generation system will have higher efficiency than the waste pyrolysis and combustion melting ash power generation with a steam turbine system. Fig. 4 shows the relationship between gross efficiency, net efficiency and waste throughput among three different waste to power generation systems. It is notable that the power generation efficiency for both stoker furnace and the waste pyrolysis and combustion melting ash technology decline largely in a smaller throughput range < 300 t/d. Both technologies generate electric power by relatively small steam turbine, steam loss results in an appreciable decline in efficiency. The waste pyrolysis and gasification technology tends to require larger in-site auxiliary power than the waste pyrolysis and combustion melting ash technology because it uses an oxygen-blown system to maintain the efficiency of gasification and the calorific value of syngas at high levels and, consequently, electric power is needed to produce oxygen by PSA.

As is apparent from the figure, the waste gasification power generation system has higher net efficiency than the waste pyrolysis and combustion system in a small throughput range (around 300 t/d). However, in a larger throughput range, its net efficiency falls below that of the latter. This is presumably because, in the higher throughput range, a rise in steam turbine efficiency

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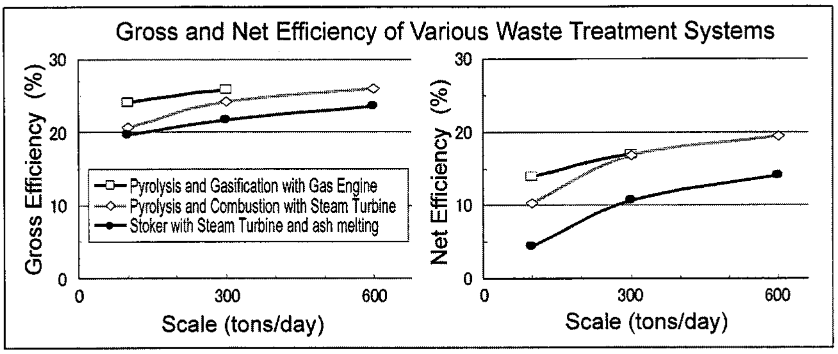

Figure 4: Comparison of the gross efficiency and net efficiency of three waste to power generation systems

makes a greater contribution to the improvement of the waste pyrolysis and combustion melting ash system in net efficiency.

b. Unit cost of waste treatment

Fig. 5 shows the unit cost of waste treatment by each of the proposed systems among the size of throughput. The waste pyrolysis and gasification system does not differ appreciably from the waste pyrolysis and combustion ash melting system in the unit cost of waste treatment but, in a small throughput range up to 200 t/d, the former achieves a lower unit cost than the latter. The stoker furnace system with a separate melting ash furnace has a higher unit cost of waste treatment in the throughput ranges covered by the estimates. In a throughput class of 50 - 200 t/d, the waste gasification system earns larger income from the sale of electricity than the waste pyrolysis and combustion melting ash system.

c. Reduction of adverse environmental impacts

The waste gasification system technology is approximately equal to the waste pyrolysis and combustion melting ash system technology in terms of valuable metal recovery, slag-making rate, etc. As it recovers already refined clean gas, the waste gasification system reduces the amount of exhaust gases directly discharged from the waste treatment facility into the air, which are released through combustion at the gas engine power generation facility. The remaining problem with this system is the emission of nitrogen oxides (NOx) but the lean-burn gas engine used for the system can hold down the NOx content of exhaust gases to around 200 ppm. Where the release of exhaust gases as they are is not permitted under the applicable emission standards, the system could, meet such standards by adopting the existing catalytic denitrification technology. As for DXN emissions, the waste pyrolysis and gasification system can essentially hold down the production of DXN lower than the boiler combustion systems. Because it performs the pyrolysis,

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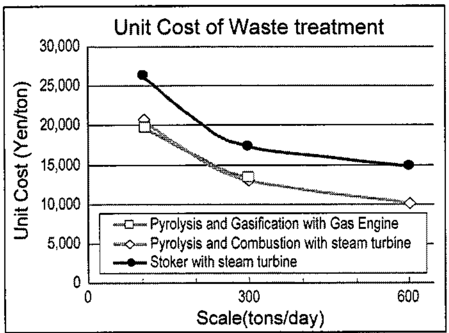

Figure 5: Comparison of unit cost of three waste to power systems

gasification, reforming, and melting processes in a reduction atmosphere and accelerates the decomposition of these pollutants in a temperature range above 1,000 C. Test data collected in the studies prove that the system can hold DXN emissions much lower than, the conventional technologies and the waste pyrolysis and combustion melting ash technology. The waste gasification technology, including its CO_2 reducing effect resulting from high-efficient power generation, is considered conducive to the reduction of adverse environmental impacts.

d. Summary of comparative assessment
The foregoing results of the studies indicate that the waste gasification with gas engine power generation system is suitable for relatively small size facilities in a through put range up to 200 t/d. Although the gas turbine combined cycle power generation system and fuel cell power generation system have high performance, especially in terms of power generating efficiency, efforts are needed to further reduce the costs of these systems when used for small facilities for future commercialization.

5. Tasks involved in high-efficient waste pyrolysis and gasification power generation technology

In order to establish the waste pyrolysis and gasification technology as a high-efficient power generation technology suitable for relatively small size MSW facilities with reducing adverse environmental impacts, efforts are needed to realize the following fundamental issues:

1) Grasping of high-temperature thermal decomposition characteristics of wastes and development of technology to optimize waste pyrolysis and gasification processes

Considering the lack of data on the thermal decomposition characteristics of waste composition in a reduction atmosphere in a high-temperature range (> 1,000 degree C), efforts are needed to experimentally identify these basic characteristics and develop a technology for optimizing of a pyrolysis and gasification process including gas reforming process, and ash melting process in order to improve effective cold-gas efficiency, reduce adverse environmental impacts such as DXN emissions, and provide high-efficiency power generation capability.

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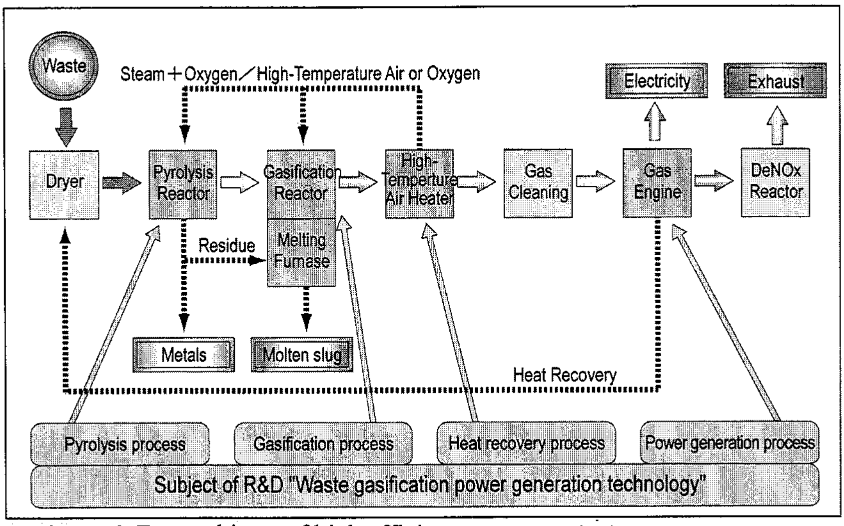

Figure 6: Four subjects of high efficient waste pyrolysis and gasification reforming power generation technology

2) Sensible heats and waste heats recovery and the optimum utilization system
In the existing waste pyrolysis and gasification systems, sensible heat of produced gas are cooled rapidly, and high temperature exhaust gas from gas engine are wasted, resulting in the disadvantage of involving a significant calorific power loss. The high-efficiency power generation requires the development of a technology to recover those sensible and waste heats in such a form in which these heats can be effectively used for the waste drying, waste pyrolysis and gasification processes or power generation process.

3) Development of technology to optimize power generation facility for syngas having low calorific value
Syngas is a low-calorific-value gas of which major combustible components are H_2 and CO, as stated earlier in this paper. There are sufficient records on the use of liquefied natural gas and other high-calorific-value gases for power generation by gas engine, gas turbine or some other system, but a low-calorific-value gas with the combustible components mentioned above has seldom been used for power generation. Therefore, to experimentally find optimal, stable combustion conditions for the gas at power generation facilities, its serviceability as plant fuel should be demonstrated by a series of long-term tests. As a result of the preliminary test and evaluation study of various gas engine types, micro-pilot-fuel oil ignited type lean burn gas engine using pre-combustion chamber is selected to be developed.

4) Study on optimization of waste treatment including waste pyrolysis and gasification technology

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The waste pyrolysis and gasification system has diverse potentials. A practical feasibility study should be conducted on these potentials, which include, for example, the use of the system as a peak-load power source or as a supply source of external fuel and chemical raw materials. Another important consideration is to study and assess waste treatment issues in response to future changes in the circumstances around waste treatments, covering such topics as the simultaneous treatment of different types of wastes and the optimization of the system's compatibility with conventional furnaces and the waste pyrolysis and combustion melting ash furnace.

6. Postscript

The waste pyrolysis and combustion melting ash technology is entering upon the commercialization stage. Meanwhile, continued efforts are exerted to push on the development of the waste pyrolysis and gasification technology as a next-generation system, which is considered to have an advantage in meeting some conditions of use including, among others, its suitability for relatively small-sized facilities. The waste pyrolysis and gasification technology has not only excellent characteristics as a waste-to-power generation system in attaining high efficiency and reducing adverse environmental impacts but also has diverse potentials from the viewpoint of recycling raw materials, especially for chemical products. It is considered a useful technology to properly respond to future changes in circumstances around waste treatment.
We tender our sincere acknowledgment to officials of the Ministry of Economy, Trade and Industry for their continuous support to this project. This project has been collaborated with Mitsubishi Heavy Industries LTD.(Optimization of pyrolysis process), NGK Insulators LTD.(Optimization of gasification melting ash process), TOSHIBA Corporation (Sensible heat recovery and optimum utilization) , Sumitomo Metal Industries LTD. (High-efficient gas engine), and The Institute of Applied Energy (Total system optimization and feasibility study). We are deeply grateful to their conducting R&D efforts.

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