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Refuse Derived Fuel Carbonization Technology and Application of Carbonized Refuse Derived Fuel

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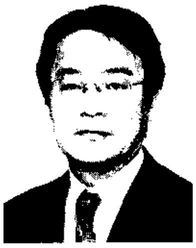

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1 Introduction

The present society in some industrialized countries has been highly developed based on mass production, mass consumption and mass disposal. Consequently, serious waste disposal problems have arisen including;

(1) Shortage of Landfill Sites: The remaining capacities of final disposal sites in terms of number of years in 1996 FY were 8.8 years for municipal waste and 3.1 years for industrial waste.

(2) Formation of Dioxins

In order to cope with these serious problems, the refuse disposal policy has been redirected in recent years to resolution of the problems by positively tackling renovation in consciousness from simple waste incineration toward 3R (reduce, reuse and recycle) and protection of the environment. The Ministry of Health, Labor and Welfare is now promoting integrated large region disposal and matters such as improved exhaust gas treatment, power generation from refuse and ash melting disposal are indispensable. Furthermore, beside energy recovery material recycling and chemical recycling have also become possible through introduction of various state of the art technologies including the gasification-melting furnace. The present society is now emerging from the mass production, mass consumption and mass disposal, and is steadily advancing towards a recycling type society.

Nevertheless, these matters are not always possible with every local government and small-scale disposal must be chosen some cases. The technology which can be best adopted by such local governments is the refuse derived fuel (RDF) facility. For example, the Nanto Recycling Center in Toyama Pref. was built under a government subsidy for the first time in 1994, and by the end of 1999 fiscal year, 23 similar facilities have been built in Japan. Kawasaki Steel has received orders for 11 facilities, including the Nanto Recycling Center.[1] There is no problem in using RDF made of municipal waste for various purposes on a large scale such as large region RDF power generation, however, in the case of small or medium scale utilization, it is impossible for some local governments to fully make use of RDF with only energy recovery applications such as hot water supply for air-conditioning, snow melting, cementing and other public uses.

Kawasaki Steel has been advancing studies on utilization of RDF[2] for many years. Applications of RDF in steel works, in particular as material recycling is of great meaning as compared with simple energy recovery, and the results gained by expanding such applications are considered to be very significant; therefore, we have been positively developed such applications. At the beginning of the development, we tried various applications of RDF, such as partial substitution for coal car-

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bonized, a heat and carbon resources for sintering plant and converters and partial substitution for pulverized coal fed into blast furnaces. Since some problems arise owing to the high contents of volatile matters and chlorine compounds, and the characteristics of RDF, uses of RDF as an alternative material in these ways were found to be impractical.

Another approach to use RDF in steel works was to carbonize RDF through high temperature pylorysis and then, to use carbonized RDF (hereinafter reffered to as RDF-carbon) as an alternative material. To verify the methods of producing and using RDF-carbon we built an RDF carbonization verification furnace having a maximum capacity of 1.25 t/h in our Mizushima Works.

This report explains the RDF carbonization process, details of the verification tests as well as use of RDF in iron works.

2 Laboratory Tests of RDF Carbonizing

2.1 Use of RDF in Iron Works

As for uses of RDF in iron works, studies started in around 1995. **Table 1** summarizes the test results and countermeasures. Concerning use of RDF in coke ovens, sintering plant and blast furnaces, it was found that there are problems, namely, (1) quality of RDF (chlorine content, etc.), (2) high content of volatile matter and (3) characteristics (strength, dust generation, etc.). Therefore, it was concluded that use of RDF in ironmaking processes would be difficult.

2.2 Laboratory Tests of Carbonizing RDF

In order to solve these problems, studies were made on carbonization of RDF.

The behavior of RDF when thermally decomposed in a low oxygen atmosphere in laboratory scale tests is shown in **Figs. 1** and **2**. When RDF was heated to 600–700°C, volatile matters such as tar vaporized and the content was reduced to lower than 10%.

On the other hand, the chlorine content remained unchanged up to about 900°C. When the temperature was further raised and exceeded 950°C, the chlorine content began to decrease, however, the fixed carbon content also began to decrease at the same time. It was made clear from these tests that it is important in controlling chlorine content to ascertain up to what temperature the material must be heated. It was also made clear that the chlorine content can be reduced down to about

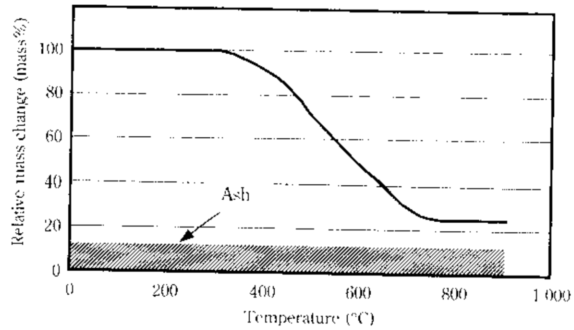

Fig. 1 Heat resolution behavior of RDF

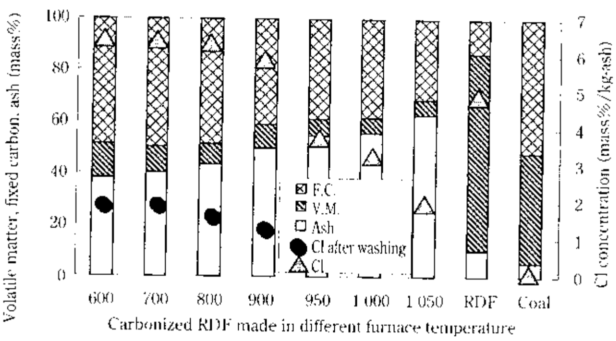

Fig. 2 Heat resolution behavior of RDF

1/3 to 1/4 when RDF-carbon is washed by water.

Furthermore, when piled up for a long time or stored in open air in large scale, RDF can not maintain its cylindrical shape and disintegrates into power, however, RDF-carbon does not easily disintegrate due to its adequate strength. Therefore, it has become possible to store RDF in a large pile for a long time after carbonization.

As explained above, three problems have been resolved by carbonizing and the possibility appears for use of RDF in iron works. Therefore, field tests were carried out to use RDF-carbon in actual machines. The test results of using it in a sintering plant are shown in **Fig. 3**. The electric charge conditions in wet electric precipitator (WEP) when RDF was used are shown on the top and those when RDF-carbon was used are shown in the bottom. In the cases of using RDF, the electric charge remarkably decreased immediately after start using RDF due to the effects of tar, etc., however, changes could hardly be found when using RDF-carbon was used. A stable electric charge could be maintained for about 6 h while using RDF-carbon and it was confirmed that the barriers of applications were solved.

Table 1 Survey of trial applications in ironmaking process

Form	Coke oven	Sintering furnace	Blast furnace	Countermeasure
Gas			Corrosion	Repression of HCl formation
Tar		Lower performance of WEP		Tar removal
Dust	Working environment			Dust removal
Leftovers	Lower strength of coke	Quality problem	Quality problem	Na, K, Cl removal

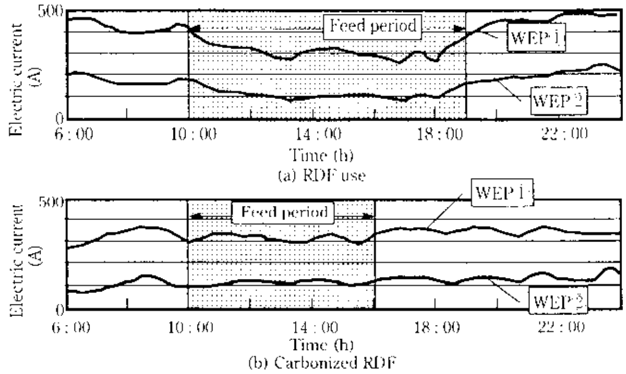

Fig. 3 Electric charge conditon in WEP

As using RDF-carbon appeared promising, development of full scale carbonizing systems and application methods for RDF was developed.

3 Verification Furnace and Results of RDF-Carbon Analysis

3.1 Facilities

In order to a certain the carbonization experiments on a laboratory scale, an RDF carbonization verification furnace was constructed and field tests were carried out. The demonstration plant is shown in **Photo 1** and the furnace is shown in **Photo 2**. The specifications of this plant are shown in **Table 2**.

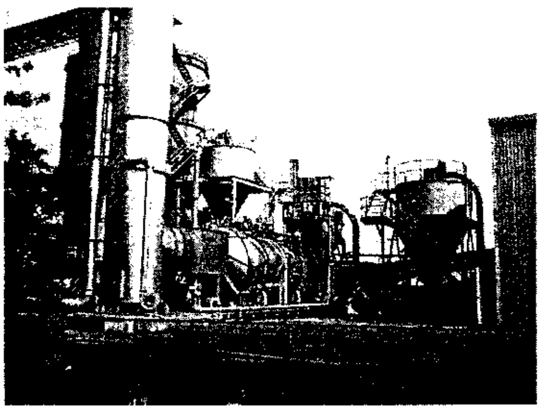

Photo 1 Demonstration plant of carbonized RDF

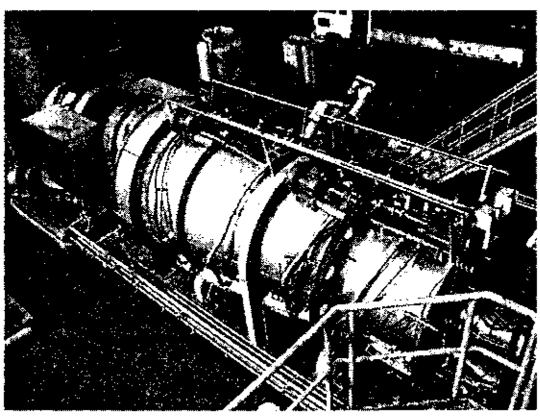

Photo 2 Carbonization furnace

Table 2 Specification of the demonstration plant

Plant capacity	RDF (raw material)	30 t/d
	Carbonized RDF	7.5 t/d
	Operation time	8~24 h/d
Storage capacity	RDF storage	30 t/d
	Carbonized RDF storage	10 t/d
Transportation	RDF	15 t-track
	Carbonized RDF	10 t-dump or continuous supply to PCI conveyer
Operation	Labor	Always one person
	Operation	Filling up RDF

3.2 Operational Results

The results of operating the RDF carbonization verification furnace are shown in **Fig. 4**. The demonstration plant started operation at the middle of May 2000 and has been in operation satisfactorily since. Until the end of June, about 630 t of RDF had been carbonized.

3.3 Results of Analyzing RDF-Carbon

3.3.1 Analysis of the composition of RDF-carbon

(1) Changes in the Calorific Value

During carbonizing, the weight decreased to about 1/4 that of the original as shown in Fig. 1. The lower calorific values of RDF and RDF-carbon are shown in **Table 3**. The calorific value of RDF-carbon was almost in a range of 16 370–17 810 kJ/kg (3 911–4 255 kcal/kg), that is 10% lower than that of RDF.

People concerned have been anxious about the mix-

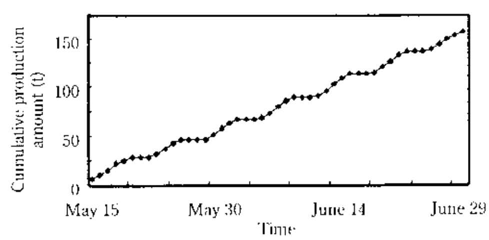

Fig. 4 Cumulative production amount of carbonized RDF

Table 3 Low-heat value

(kJ/kg (kcal/kg))

Item	Low-heat value
RDF	18 300 (4 372)~18 914 (4 519)
Carbonized RDF	16 370 (3 911)~17 810 (4 255)

Table 4 Dioxins analysis

Temperature	DXNs		Co-PCBs		Total
	(pg/g)	(pg-TEQ/g)	(pg/g)	(pg-TEQ/g)	(pg-TEQ/g)
600°C	27	0.000 0	1 900	0.220	0.220
700°C	27	0.036 0	2 900	0.029	0.065
800°C	31	0.001 2	8 700	0.100	0.100

Table 5 Dissolving test

(mg/ℓ)

Item	pH = 4	pH = 7	pH = 12
Cd	N.D.	N.D.	N.D.
Pb	N.D.	N.D.	N.D.
Cr^{6+}	N.D.	N.D.	N.D.
As	N.D.	N.D.	N.D.
T-Hg	N.D.	N.D.	N.D.
Se	N.D.	0.005	N.D.
CN	N.D.	N.D.	N.D.
Organic P	N.D.	N.D.	N.D.
PCB	N.D.	N.D.	N.D.

Measuring method: Notification No. 13 of the environment agency
N.D.: Not detected

ing rate of plastic in RDF being reduced and thus the calorific value of RDF possibly being reduced once the container packing recycling law is fully prepared and enacted in the near future. However, the calorific value of RDF changes very little if carbonized and therefore no serious problem is considered. Even if carbonized, and this can be said to be a system ready for the future.

(2) Dioxins Contents

Dioxins contents in RDF-carbon are shown in **Table 4**. The maximum is 0.22 pg-TEQ/g. These values are much lower than 6.5 pg-TEQ/g[3], the average value in soil nationwide in Japan in 1999. This is extremely low even compared with the 1 000 pg-TEQ/g[4] which is the environmental standard for the soil as specified in the law concerning special measures against dioxins.

3.3.2 Dissolving test

The results of elution tests for RDF-carbon are shown in **Table 5**. The test was carried out under elution conditions (accumulation ratio of solvent in sample: 10% in weight) conforming to the Environmental Agency Notice No. 46 issued in 1991. Furthermore, the elution test conditions were under solvent conditions of pH4–12 in order to cover every possible soil environment. The samples used were carbonized at 700°C.

The results of this test confirmed that the standard values are fully satisfied for all parts of the elution test. It was confirmed that no problem exists with RDF-carbon processed with this system for soil of various kinds such as soil conditioner.

3.4 Advantages of RDF-Carbon

By carbonizing RDF, the three following advantages appear.

(1) Applications to Material Recycling

The carbonization varification furnace is directly connected to a pulverized coal injection system (PCI) and is presently being used to supply RDF-carbon to a blast furnace as a substitute for coal. In addition, RDF-carbon can be used in iron works, as a substitute for various kinds of solid fossil fuels such as coal and coke and as a carbon resources to be added as molten pig iron. In such ways, material recycling is possible.

(2) Volume Reduction of RDF

RDF weighs 1/2 that of refuse and RDF-carbon weighs only 1/4 that of RDF. Thus carbonizing RDF makes possible a reduction to 1/8 the transportation weight, thereby reducing the cost of transporting fuel.

(3) Odorless Feature

When stored for a long period, there were some cases where RDF rotted due to moisture and generated a nasty smell. This bad smell completely disappears after carbonization. This makes it possible to store RDF outdoors whereas it previously could be stored only indoors.

4 RDF Manufacturing and Carbonization System of Kawasaki Steel

The main concept of the RDF manufacturing and carbonization system of Kawasaki Steel, which is designed on a basis of carbonization demonstration plant experiments, is to attach an RDF carbonization process to the RDF manufacturing system. The system flow diagram is shown in **Fig. 5**.

4.1 RDF Manufacturing Process

The RDF manufacturing process is of the so-called RMJ system and produces RDF from garbage through the processes of crushing, primary sorting, drying, secondary sorting, addition of slaked lime and molding. Hot air at about 600°C is used to dry the raw material,

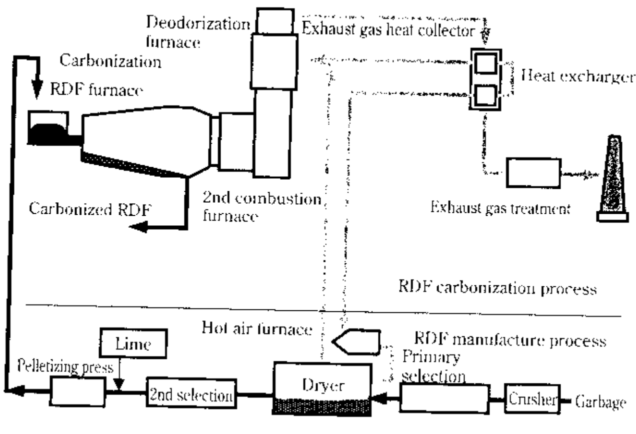

Fig. 5 Kawasaki Steel carbonization system

and the water content in garbage is reduced from 50% to less than 10%.

Through this process, garbage becomes column of RDF cylinders of 10–15 mm in diameter.

4.2 RDF Carbonization Process

The RDF carbonization process is composed of the following three facilities.

(1) RDF Carbonization Furnace

In the Kawasaki Steel RDF carbonizing process, RDF is continuously charged into a rocking carbonization furnace and heated up to high temperature. RDF is then transformed by pyrolysis into "pyrolitic gas mainly composed of inflammable gasses" and "RDF-carbon". Pyrolytic gas is completely burned in the secondary combustion chamber and RDF-carbon is cooled and then conveyed through the storage facility.

The concentration of dioxins in the secondary combustion gas can be reduced to below 0.1 ng-TEQ/Nm^3.

(2) Exhaust Gas Heat Collector

Secondary combustion gas in the RDF carbonization process is used for treatment of the exhaust gas of the RDF manufacturing system. Heat recovery is achieved by the overall system.

(a) Deodorization Heat Source for Dry Exhaust Gas

The temperature of the secondary combustion gas is higher than 1 200°C; therefore, it is possible to decompose malodorous substances in the dry exhaust gas generated in the RDF manufacturing process. The exhaust gas heat collector can be utilized as a deodorization furnace having a high odor removal efficiency.

(b) Garbage Drying Heat Source

Drying in the RDF manufacturing process, garbage is dried by hot air flow of about 600°C. Although dry exhaust gas is already cooled down to about 150°C, a part of the gas is circulated and returned to the hot air furnace forming energy recovery and insufficient heat is supplemented by burning kerosene to raise the temperature to about 600°C. By circulating a part of the dry exhaust gas and exchanging heat with the secondary combustion gas, the kerosene consumption is reduced.

(3) Exhaust Gas Treatment Facility

Heat recovered secondary combustion gas is finally exhausted to the atmosphere after being cleaned through the exhaust gas treatment facility.

4.3 Special Features of the Kawasaki Steel RDF Combustion System and Process

This carbonization process has the following special features.

(1) This carbonization system uses almost no fossil fuel.

Only when starting the system, while the amount of pyrolytic gas generation is small, kerosene is burned for heating up the secondary combustion furnace. Pyrolytic gas from RDF is the main energy source.

(2) The exhaust gas out of this facility contains only a small amount of soot, resulting in low concentrations of Na, K, Cl and dioxins.

The carbonization furnace is operated with soft rocking, so carbonized substances do not curl up, therefore, particles of soot, alkaline metals, chlorine scatter only a little. Because the exhaust gas has low concentrations in Na, K, and Cl, high temperature heat recovery of exhaust gas beyond 600°C is possible by using ceramic heat exchangers. Pyrolytic gas burns at a high temperature; therefore, the concentration of dioxins is less than 0.002 ng-TEQ/Nm^3.

(3) The carbonization furnace is safely designed by considering pressure balances in the furnace of concern.

The main components of pyrolytic gas are inflammable gases including CO, H_2, methane, ethane, ethylene. The furnace structure is designed with a negative pressure control, taking pressure balance in the furnace, so that these inflammable gases do not stagnate in the furnace and backfire into the furnace is prevented.

(4) Operation of the system at high temperatures is easy.

This carbonization furnace uses a woody material carbonization furnace as the carbonization furnace for sole RDF burning. With this furnace, pyrolysis at high temperature becomes possible; therefore, uncarbonized substances do not remain. The high temperature treatment removes the volatile part and RDF-carbon with their calorific values secured only with fixed carbon are produced. Furthermore, as the pyrolytic gas is also burned at high temperatures exceeding 1 000°C, dioxins are completely decomposed.

(5) Making use of thermal recycling of exhaust gas, the running cost is reduced.

Exhaust gas heat can be recovered for drying refuse; the amount of kerosene consumed in the past can be reduced by about 70%.

(6) To improve deodorization ability, the exhaust gas from the dryer can be made to deodorized at a higher temperature.

Exhaust gas used to dry refuse contains a large amount of many malodorous components such as ammonia, hydrogen sulfide, methyl mercaptan, acetaldehyde. In the past, these malodorous components were burned and decomposed by deodorizing at 650°C using kerosene, however, there were some cases in which a part of malodorous components remained. Deodorization at 900–1 200°C has become possible by pyrolytic gas burning, therefore, it is now possible to completely decompose malodorous components.

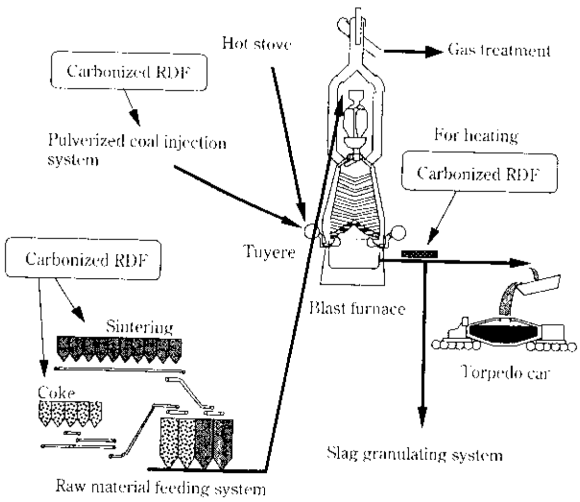

Fig. 6 Applications of carbonized RDF in ironmaking process

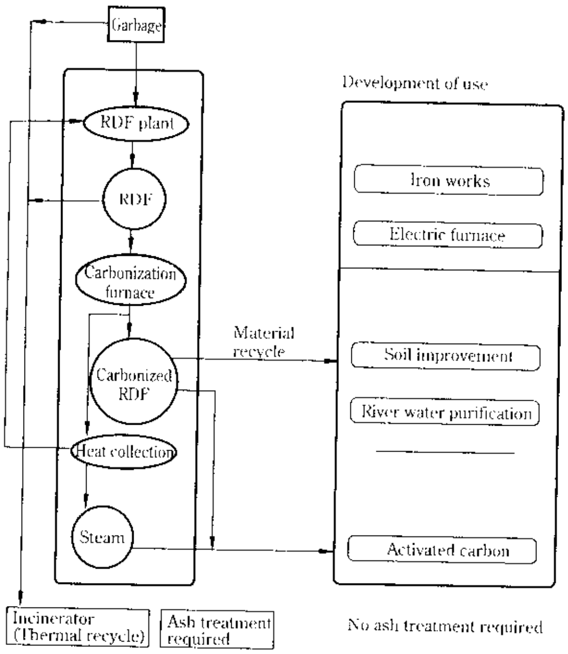

Fig. 7 Carbonized RDF use outline

5 Utilization of RDF-Carbon

As for the uses of RDF-carbon, applications in iron-making works and for those in other field are described in this chapter.

5.1 Application Techniques in Iron Works

Figure 6 outlines the applications of RDF-carbon for blast furnaces. RDF-carbon is produced by carbonizing RDF at a high temperature and positively removing the volatile components, therefore, it can be used as a substitute for coke.

Details of each application are explained hereunder.

(1) Pulverized Coal Injection into Blast Furnaces (Substitute for Pulverized Coal)

For blast furnaces producing pig iron from iron ore or sintered ore through reduction with coke, pulverized coal injection (PCI) facilities are used. These facilities are introduced to expand the use of inexpensive ordinary coal for blast furnaces and inject pulverized coal (ordinarily with a particle size of smaller than 0.7 mm) through tuyeres together with hot air. Nowadays, pulverized coal injection is adopted for all blast furnaces in operation and RDF-carbon is to be used as a substitute for pulverized coal of this purpose.

(2) Uses in Sintering Facilities

Sintering is one of the methods for agglomerating fine ores and sintering plant heat powdered ores to a half-melting condition that is 1 200-1 300°C and make agglomerated ores by consolidating powdered ores through recrystallization or melting. Ordinarily, coke breeze of 3-5% is mixed into the fine ores and fed onto the sintering strand. Coke on the surface of the raw material is ignited and the air is sucked downwards. The coke breeze in the raw material quickly burns and one sintering proceeds. RDF-carbon can substitute for coke breeze for sintering.

5.2 Other Applications

Figure 7 outlines the uses of RDF-carbon. Other than as a source of carbon which is an application in iron works, various applications are under investigation by paying attention more to the physical and chemical characteristics of RDF-carbon. As the major uses, applications as a soil improvement material, purifying agent of river water are promising due to its absorbing capacity, thermal insulation performance, water-holding capacity, ventilation performance, etc. These applications are under various tests now. Furthermore, applications as activated carbon are also under study. Studies to use refuse by carbonizing RDF and producing activated coal through further invigoration are also underway. An interesting report[5] has also been presented showing that activated carbon produced from RDF is perfectly applicable to removing dioxins by adsorption and future development of this study is expected.

6 Conclusions

The process to produce RDF from municipal waste is a necessary system in order to construct a recycling type society. However, the fact that applications of RDF have not been sufficiently secured is an obstacle for increasing construction of such facilities.

In order to expand applications of RDF, we described our approach and efforts to develop new applications of RDF-carbon in this paper. By carbonizing RDF, material recycling type applications become possible in iron works as a substitute for pulverized coal and coke and we could develop applications of RDF as a substitute for exhaustible resources. Furthermore, RDF-carbon has excellent adsorption capacity, thermal insulation performance, water-holding capacity, ventilation performance, etc. and the use of RDF-carbon as a soil improvement material, a purifying agent for river water, activated carbon, etc. is promising. In order to use RDF more popularly; development of the technologies for these applications is essential.

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