

Development of Chemical Recycle Technology to Methanol by Partial Oxidation of Waste Plastics

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Abstract

Through the experiments of a demonstration plant with waste plastic feeding capacity of 5 tons per day, a chemical recycle process of waste plastic has been established. Waste plastic including polyvinyl chloride was partially oxidized by oxygen and steam to produce synthetic gas (syngas), mainly composed of CO and H₂, by using an entrained single stage reactor at the pressurized condition and from this syngas methanol was synthesized by means of liquid phase catalytic process. C conversion and cold gas efficiency of this entrained gasifier were attained 96% and 63%, respectively. Methanol purity synthesized by liquid phase method reached more than 98%. Long-duration experiment proved a reliability of this process and encouraged us toward commercialization.

1. Introduction

Waste plastics discharged domestically amount to approximately 9 million tons, with municipal and industrial wastes sharing almost the same volume of about 4.5 million tons. Those waste plastics are treated as follows: 11.3% for recycling, 28.1% for power generation or thermal use by incineration, and remaining 61% for land filling or simple incineration without any effective use¹⁾. While even thermal recycle is utilized inefficiently, there is a task to develop a highly efficient utilization technology accompanied by a high added value.

With many environment- and recycling-related laws enacted to reform the social structural, the industrial, governmental, and private sectors are actively working toward the realization of a sustainable recycling-oriented society. For waste plastics, an effective recycling technology is urgently needed because of the enforcement of the Law for Promotion of Sorted Collection and Recycling of Containers and Packaging and the Law for Recycling of Specified Kinds of Home Appliances amidst the limitations of simple incineration and land filling. Particularly, an efficient chemical recycling (feed-

stock recycling) technology is much expected.

The technology under development aims at 1) producing synthetic gas (syngas) by partial oxidation with oxygen/steam of a variety of waste plastics, including polyvinyl chloride (PVC), supplied to an entrained single stage reactor, 2) recovering hydrochloric acid, and 3) developing a recycling technology by which methanol is synthesized by the liquid phase catalytic process (**Fig. 1**). The experiments at a demonstration plant, with a daily capacity of treating 5 tons of waste plastics, are expected to solve a process-technology problem, and establish a commercialization technology for an integrated process from the production of synthetic gas from waste plastics to the synthesis of methanol with the engineering data collected for commercial plant design and economic feasibility study.

2. Partial oxidation of waste plastics using an entrained single stage reactor and liquid phase methanol synthesis

2.1 Technology of partial oxidation of waste plastics using an entrained single stage reactor

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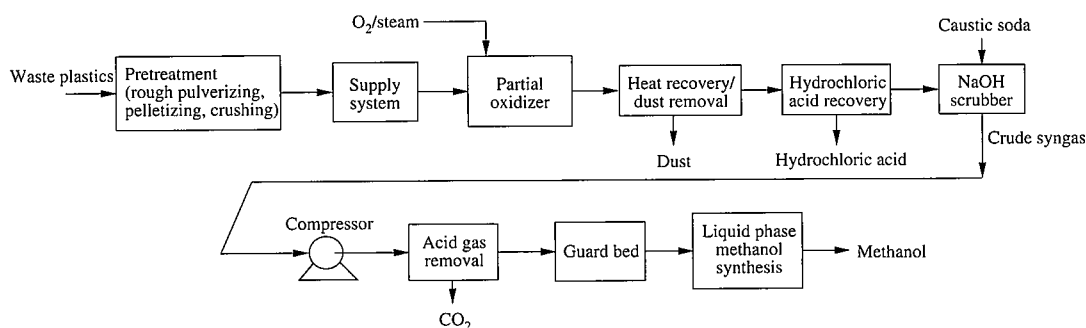


Fig. 1 Process of methanol synthesis by partial oxidation of waste plastics

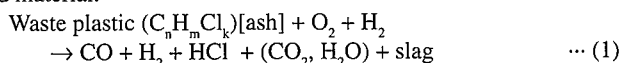
The technology of partial oxidation (gasification) of waste plastics is a feedstock recycle technology, characterized by enabling the recycling of waste plastics to highly value-added chemical products.

The partial oxidation technologies under development comprise 1) EUP Process (Ebara Seisakusho and Ube Kosan Process)²⁾ in which hydrogen gas is produced for ammonia synthesis by the gasification of waste plastics in two steps by an inner circulation fluidized bed (low-temperature gasification) and a high-temperature gasifier with a circulating entrained bed (high temperature gasification), 2) Texaco Process³⁾ in which waste plastics are liquefied into a slurry to feed to a high temperature entrained bed gasifier for gasification, and 3) Schwartze Pumpe System⁴⁾ in which waste plastics are treated together with coal and other wastes for gasification by a fixed bed (Lurgi gasifier). Those processes leave much to be desired in terms of thermal efficiency, limitations of subject waste plastics (thermo-

setting resins and a limit of applying PVC treatment techniques), and the cost of equipment.

The process under development here is characterized by a single stage gasification technology using an entrained single stage reactor, which enables to produce synthetic gas from waste plastic containing 100% PVC highly efficiently by dry feeding. Fig. 2 shows a conceptual diagram of the method of a single stage gasification with a circulating entrained bed. Waste plastics, including municipal and industrial wastes are sent to a lock hopper feeding system after the pretreatment processes of separating, crushing, pulverizing, and pelletizing. The feeding hopper is equipped with a feeder and a distributor, and a given quantity of waste plastics, several millimeters in pellet diameter, is conveyed and distributed to plural gasification burners (waste plastics/oxygen burners) arranged in the partial oxidizer (gasifier). The waste plastic pellets are transported pneumatically by nitrogen or gas formed by partial oxidation in a maximum weight ratio of solid to gas.

Partial oxidation proceeds as given below by equation (1) with O₂/steam under the pressurized condition at a temperature above 1,200°C (to the extent of 1,300 to 1,500°C) in the partial oxidizer to form synthetic gas (syngas) composed mainly of CO₂ and H₂. Mineral matter (ash) contained in the waste plastics is discharged as molten slag via the slag lock hopper to be effectively used for road bed material.



The crude gas, produced at a high temperature of over 1,200°C by the single-stage circulating entrained-bed reactor under the pressurized condition, is rapidly quenched in the quenching furnace to the extent of 700 to 900°C with water sprayed from the two fluid spray nozzles using the formed gas as a spray medium. This rapid quenching solidifies part of the molten slag that entrained from the partial oxidizer thus to avoid the sticking of dust to and the blocking of the heat transfer tube of the waste heat boiler (heat recovery part) behind.

In the waste heat boiler the sensible heat of the crude gas formed is recovered to the extent of 250 °C under the conditions such as the recovery of 200°C steam at 14 atm, to avoid chlorine erosion. The gas recovered in the waste heat boiler is cooled in the gas cooling tower down to below the heat resistance temperature of the bag filter. The dust in the gas is removed with the bag filter, and discharged out of the system via the lock hopper. The dust may be recycled to the partial oxidizer depending on its properties. Hydrochloric acid is recovered from the HCl-containing gas, dedusted in dry condition, in the hydrochloric acid recovery tower, and is expected to be recycled for industrial use (hydrochloric acid concentration: 35%). A

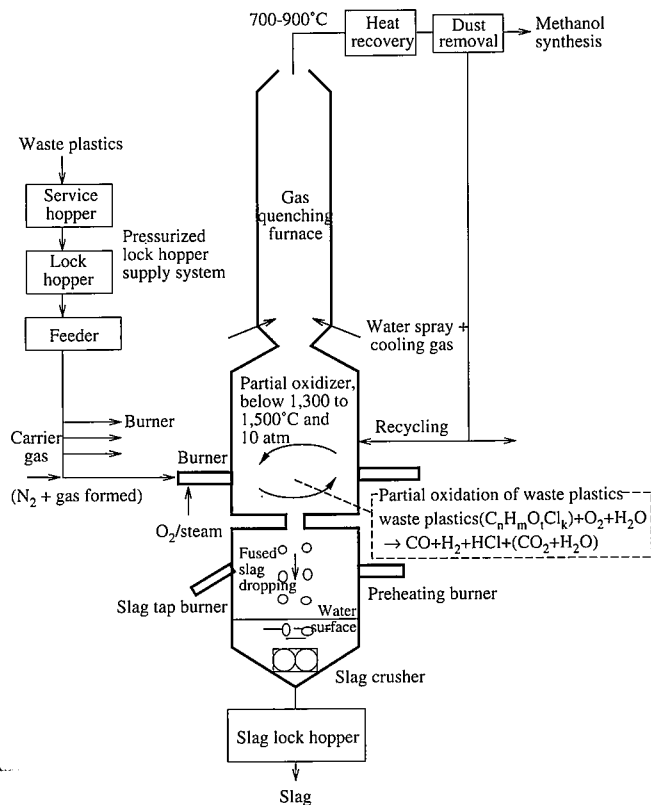


Fig. 2 Conceptual diagram of the single stage gasifier with a circulating entrained bed

trace amount of hydrochloric acid remaining in the gas is removed in the NaOH scrubber for use as the raw material of synthetic gas for methanol. The synthetic gas from the NaOH scrubber is forwarded to the process for liquid phase methanol synthesis.

2.2 Technology of liquid phase methanol synthesis

Although the gas phase method has already been established for methanol synthesis, the liquid phase method has come to attract public attention in recent years, because it removes the heat generated during methanol synthesis effectively with a rate of conversion expected to increase. Fig. 3 and Table 1 give respectively the conceptual diagrams of the gas and liquid phase methods, and the comparison between the two.

The use of waste plastics as raw material has several limitations in comparison with that of natural gas, such as the difficulty in collecting the amount required (limitation in plant scale), changes in raw material composition, mixing of impurities attached, and production of CO-rich synthetic gas. Therefore, the technology of methanol synthesis should desirably be established by the application of the liquid phase method.

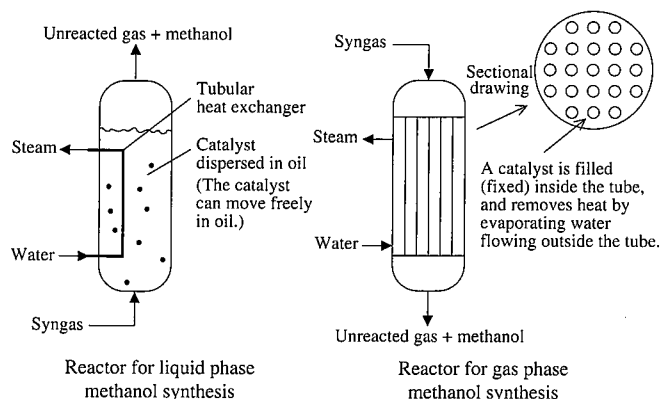


Fig. 3 Conceptual diagram of gas-phase and liquid-phase methods in methanol synthesis

Table 1 Comparison of the processes for methanol synthesis between liquid phase and gas phase methods

	Liquid phase process	Gas phase method
Reaction type	Gas-liquid-solid phase reaction	Gas-solid contact reaction
Catalyst	CuO-ZnO-(Al ₂ O ₃)	CuO-ZnO-(Al ₂ O ₃)
Reaction conditions	Temperature: 200 to 300°C (250°C) Pressure: 50 to 100kgf/cm ²	Temperature: 200 to 300°C (250°C) Pressure: 50 to 100kgf/cm ²
Reaction performance	Single pass conversion rate (CO + H ₂) = 20 to 40%	Single pass conversion rate (CO + H ₂) = 10 to 20%
Reaction temperature control	Advantageous for reaction equilibrium because of small ΔT and presence of no high temperature part	Disadvantageous for reaction equilibrium because of large ΔT and presence of high temperature part
Syngas composition	Suitable for CO-rich gas	Shift reaction required for CO-rich gas
Catalyst exchange	Can be extracted and supplemented during operation	Total exchange after operation stop
MeOH quality	Water content in crude MeOH: about 1%	Water content in crude MeOH: about 5 to 20%

3. Demonstration Tests

3.1 Tasks for technology development

The main task for technology development in the demonstration test of producing synthetic gas toward process commercialization can be summarized as follows:

(1) Establishment of optimal partial oxidation conditions

The performance of the partial oxidizer is generally expressed in terms of cold gas efficiency (Definition: Equation (2)) representing how much energy (latent heat) of the raw material waste plastics was recovered as the energy (latent heat) of the gas formed. It is necessary, therefore, to increase this value for a wide range of waste plastics. For the improvement of the cold gas efficiency it is necessary not only to increase the C conversion (= C in gasified gas/C in waste plastics), but also to have a partial oxidizer with a small heat loss. In other words, it is important to control the quantity of unreacted residue (soot) of the waste plastics as well as to design a partial oxidizer with a small oxygen consumption and establish partial oxidation conditions. It is particularly worthy to note that waste plastics tend to produce soot in gasification reaction. Therefore, it becomes a task to establish soot controlling conditions in terms of both efficiency improvement and operation stability.

$$\text{Cold gas efficiency (LHV Standard Based)} = \frac{(\text{amount of synthetic gas produced} \times \text{gas heat value})}{(\text{amount of raw material waste plastics supplied} \times \text{waste plastics heat value})} \dots (2)$$

(2) Establishment of the technology to remove halogens, including chlorine and metal compounds, contained in the gasified gas

Many elements contained in waste plastics, such as halogens, including chlorine and bromine, alkali metals Pb, Cu and Zn, are discharged into the gasified gas. Most of them are recovered and removed with a bag filter, a hydrochloric acid recovery tower, and a NaOH scrubber. However, their behavior during the process of partial oxidation still leaves much room for clarification. It is therefore important to establish their removal and recovery conditions in this technology development thus to optimize the gas purification equipment.

(3) Confirmation of recovered hydrochloric acid quality and establishment of production technology

Chlorine in the gas gasified gas is recovered as a HCl solution in the hydrochloric acid recovery tower. It is indispensable to increase the yield of recovery and concentration. How much and in which form trace elements, containing the metal elements in the hydrochloric acid, are present also have much to do with the resulting quality of the product. Since no expertise has been available until now, relative to the technology of recovering hydrochloric acid, it is important to confirm the quality of recovered hydrochloric acid as well as to establish the technology of producing commercial grade hydrochloric acid.

(4) Establishment of a method of stable pneumatic transport of waste plastics to the partial oxidizer

The gas for methanol synthesis should have a stable composition that will not allow the mixing of inert ingredients, such as nitrogen (N₂), as much as practicable. It is a task to establish stable conditions of the pneumatic transport of waste plastics under the conditions with a maximum weight ratio of solid to gas so that the changes in properties of gasification can be controlled and the value as syngas can be improved. It is another task to establish a method of distributing waste plastics to several gasification burners with high accuracy and a technology of transporting waste plastics by using crude synthetic

gas formed.

(5) Establishment of a technology of liquid phase methanol synthesis

It is a task to establish a technology of identifying and quantifying impurities, contained in the synthetic gas resulting from the partial oxidation of waste plastics, that may possibly become poisons to the catalyst of methanol synthesis and further of removing those catalyst poisons as well as to establish a method of evaluation of a catalyst life in prolonged continuous operation, and liquid phase synthetic conditions.

(6) Verification of operation stability and changeability of load during prolonged operation

This aims at forming a clear view of the operation of an commercial plant by verifying the stability of operation and the response to the changes in load during prolonged operation of the partial oxidizer and the integrated plant system.

3.2 Demonstration plant and testing methods

The demonstration plant, with a capacity of 5 ton/day, consists of the facilities of receiving and supplying waste plastics, the partial oxidizer, the waste heat recovery boiler, the gas cooler, the dust remover, the hydrochloric acid recovery tower, the NaOH scrubber, and the equipment for testing liquid phase methanol synthesis (Fig.

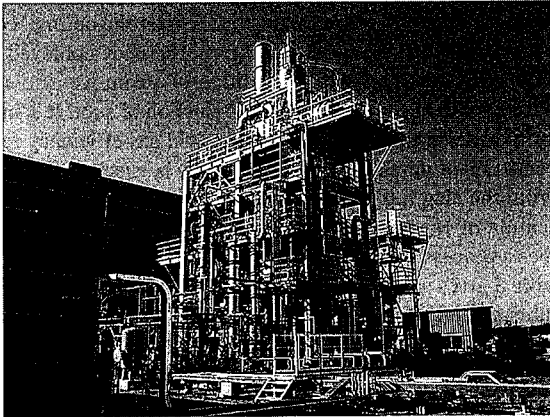


Photo 1 Demonstration test equipment for conversion of waste plastics to methanol

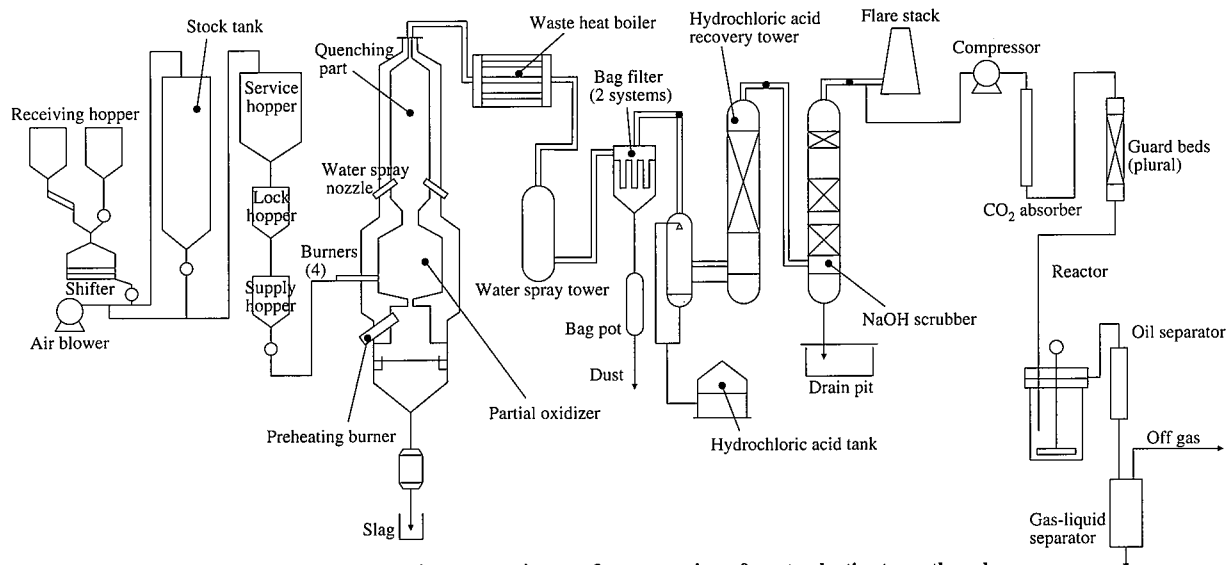


Fig. 4 Demonstration test equipment for conversion of waste plastics to methanol

4 and Photo 1).

The demonstration tests were carried out for crushed hard pieces and soft pellets of PVC-containing waste plastics. The waste plastics, crushed and pelletized by pretreatment, were put in a flexible container bag, adjusted by adding PVC resin of a given concentration, and stored in the stock tank, from which they were air-borne to the service hopper. Then, they were gas-carried using N₂ and crude synthetic gas formed from the pressurized lock hopper type feeder to the partial oxidizer at a metered feeding rate of 200 to 250 kg/h.

They were then gasified using oxygen and steam in the partial oxidizer at 1,300 to 1,500°C and 4 atm to investigate the influence on the performance of gasification (the C conversion and cold gas efficiency) under the gasification conditions. The syngas, produced in the partial oxidizer, consisting mainly of CO and H₂, was cooled by spraying from the 2 fluid spray nozzles, and then the heat was recovered in the waste heat boiler. We grasped the gasification behavior of the metal and halogen compounds, contained in the crude syngas from the partial oxidizer, and evaluated the dust-stuck and hydrochloric acid-eroded waste heat boiler, and the performance of dust removal of the bag filter. The gas from the bag filter was sent to the hydrochloric acid recovery tower, where HCl was recovered almost entirely as a hydrochloric acid solution, while a trace amount of HCl remaining in the NaOH scrubber was neutralized with caustic soda.

The hydrochloric acid recovered from the crude syngas was analyzed for evaluation as a product for industrial use. In the test of methanol synthesis, part of the crude syngas from the NaOH scrubber was compressed, and purified with the gas absorber using cold methanol and the guard beds (plural) for removal of catalyst poison to synthesize methanol by the liquid phase method. The impurities present in the crude syngas produced from waste plastics were identified and a technology for removing catalyst poison components was studied. The quality of crude methanol that was synthesized was also a focus of the study. For verification of plant operation performance, equipment performance, and a catalyst life as commercialization equipment, a one-week continuous plant operation was program was executed.

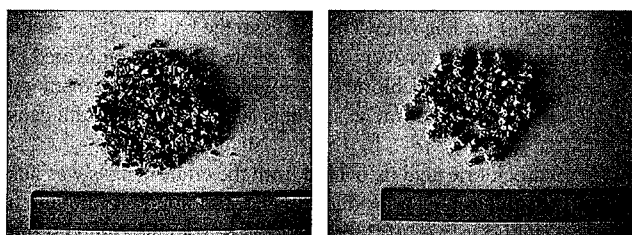
3.3 Demonstration test results

(1) Waste plastics raw material samples

Table 2 Analytical values of waste plastic samples

Waste plastic sample name	Kind of waste plastics	Total water content (wt%)	Industrial analysis value (wt%-dry)				Elemental analysis value (wt%-dry)						Low-level calorific value (kcal/kg)
			Ash	VM	FC	C	H	N	Odiff*	Incombustibility S	Cl	Br	
Rigid non-PVC (1)	Electric wire insulation (cross-linked PE + PP), crushed pieces	0.41	2.49	92.3	5.24	78.3	8.49	0.53	10.01	0.05	0.17	N.A.	8,376
Rigid non-PVC (2)	Electric wire insulation (cross-linked PE + PP), crushed pieces	0.47	1.75	95.5	2.78	79.7	10.3	0.72	7.36	0.04	0.11	N.A.	8,863
Rigid non-PVC (3)	Electric wire covering insulation (cross-linked PE + PP), crushed pieces	0.28	5.34	92.2	2.43	78.4	11.3	0.55	4.3	0.09	1.26	0.34	8,868
Rigid PVC (1)	Flooring, crushed pieces	0.35	37	55.2	7.8	27.9	2.88	0	17.27	0.08	14.8	N.A.	2,288
Rigid PVC (2)	Flooring, crushed pieces	0.38	36.6	55.5	7.93	27.8	2.75	< 0.1	32.82	0.05	15.4	0.01	2,185
Soft non-PVC	PE film, pellets	0.81	9.03	85.9	5.03	67.6	10.8	0.88	10.42	0.1	1.07	0.05	7,715
Soft PVC	Agricultural vinyl sheet, pellets	0.33	0.71	88.8	10.5	49.2	6.79	0.09	12.09	0.16	31	0.01	6,085

*Odiff = 100 - (CHN + incombustible S + Cl + Br) - Ash



(a) Rigid crushed pieces (b) Soft molded pieces
Photo 2 Waste plastic raw material samples for gasification

Two kinds of waste plastics raw material samples were used for the test: one is a hard piece crushed to below 6 mm, and the other, a soft pelletized piece, 6 mm in diameter and 8 mm in length. In this test, industrial wastes were used. An electric wire insulation (cross-linked polyethylene + polypropylene) and a flooring were used for a rigid non-PVC material and a rigid PVC material respectively. A polyethylene film and an agricultural vinyl sheet were used for a soft non-PVC material and a soft PVC material, both to be pelletized, respectively. Table 2 shows the values of analysis of waste plastics, while Photo 2 gives crushed and pelletized samples. For the material for gasification was used a mixture of non-PVC and PVC so that the concentration of PVC attains 10%.

(2) Performance of gasification of the entrained bed and evaluation

of the function of the process equipment

Under the conditions of a gasification temperature of 1,350 to 1,400°C, the performance of the gasifier was above 92% in the C conversion, and above 51% in cold gas efficiency, a value higher than a target value of 50% set in this test. Under the optimal conditions, the C conversion and the cold gas efficiency achieved 96% and 63%, respectively. With the addition of steam we also established the conditions of reducing the production of soot. It is important for increasing the C conversion and cold gas efficiency reduce the production of unreacted waste plastics to be discharged with the slag from the slag tap and the soot. It was demonstrated that the gasification of waste plastics in the entrained single stage reactor becomes a process high in cold gas efficiency.

Table 3 gives an example of the composition of the syngas.

Although an H₂/CO ratio depends mainly on the composition of

Table 3 Syngas composition

Gas composition (N ₂ , H ₂ O-free, vol%)	PE electric wire covering + PVC 10%
H ₂	34.3
CO	38
CH ₄	0.0068
CO ₂	24.5
H ₂ /CO	0.9

Table 4 Values of analysis of chlorine-based gases in gasified gas

Test No.	Sampling site	Cl ₂ (vol.ppm)	HCl (vol.ppm)	O-Cl (vol.ppm)	T-Cl (vol.ppm)
RUN-4 (1)	Bag filter outlet	≤ 0.1	3,300 (calculated)	9.5	
	Hydrochloric acid recovery tower outlet	≤ 0.1	1.9	10	11.9
	NaOH scrubber outlet	≤ 0.1	1.6	9.5	11.1
RUN-4 (2)	Bag filter outlet	≤ 0.1	3,300 (calculated)	4.9	
	Hydrochloric acid recovery tower outlet	≤ 0.1	3	7.5	10.5
	NaOH scrubber outlet	≤ 0.1	1.3	4.2	5.5
RUN-5 (1)	Bag filter outlet	≤ 0.1	3,900 (calculated)	5.5	
	Hydrochloric acid recovery tower outlet	≤ 0.1	0.8	5.5	6.3
	NaOH scrubber outlet	≤ 0.1	1.6	3.5	5.1
RUN-5 (2)	Bag filter outlet	≤ 0.1	3,900 (calculated)	7.7	
	Hydrochloric acid recovery tower outlet	≤ 0.1	0.4	5.4	5.8
	NaOH scrubber outlet	≤ 0.1	0.8	5.4	6.2

Analytical methods Cl₂: Chlorine measurement according to Environment Agency's atmospheric pollutants measuring method 19. HCl: JIS K 0107 Ion chromatography O-Cl: Combustion-ion chromatography T-Cl: (HCl) + (O-Cl) + Cl₂

raw material, it is also influenced by the amount of addition of steam and the temperature of gasification. The concentration of CH_4 , which is an inert component in the synthesis of methanol, was as low as 100 ppm. During the entire run, the concentration of CO_2 ranged between 15 and 25%. It is expected, however, to decrease to 10% in the actual operation with the improvement of the cold gas efficiency arising from a decrease in the rate of heat loss due to an increase in scale.

Table 4 shows the values of analysis of chlorine-containing gases in the gasified gas. The gases were sampled at the outlets of the bag filter, hydrochloric acid recovery tower, and NaOH scrubber (corresponding to the numbers in the Fig. 4). The concentration of HCl at the outlet of the bag filter was calculated by the amount of Cl in the raw material waste plastics. Chlorine in the gasified gas is present almost as HCl and organic Cl, but not as Cl_2 . 99.9% of HCl is absorbed in the hydrochloric acid recovery tower with a small portion absorbed in the NaOH scrubber. Organic Cl is scarcely absorbed in the hydrochloric recovery tower and the NaOH scrubber. The Cl-containing gas remaining in the purified syngas, neutralized with caustic soda in the NaOH scrubber, is several to ten-odd ppm in concentration with most of them containing organic chlorine gas.

The concentrations of dioxins in the syngas were measured actually at the outlet of the NaOH scrubber several times, and found unexceptionally lower by two orders than 0.1 ng-TEQ/m^3 , a new control value of emissions from the incinerator. Similarly, the concentrations of dioxins in the bag dust are also very low. This accounts for the high temperature reaction in the reduction atmosphere.

The soot produced in the partial oxidizer could be removed stably with the bag filter. This bag dust is a particle, 1 to 2 μm in diameter, containing some 90% carbon, expected to be used as a reducing agent in the iron manufacturing process.

The concentration of recovered hydrochloric acid is determined depending on the concentration of Cl contained, gasification conditions, and hydrochloric acid recovery temperature after waste plastics containing PVC have been gasified. It is expected to be able to secure the quality of hydrochloric acid for industrial use through the process of purification although a trace amount of impurities is present in the recovered hydrochloric acid. It has been verified that the system of gas purification, including the bag filter, hydrochloric acid recovery tower, and NaOH scrubber, enables the primary purification of the crude syngas.

The conditions of the diameter of a pipe for stable transport and the rate of flow have been established relative to the pneumatic transport of the crushed pieces of rigid plastics and the pellets of soft plastics. It has also been confirmed that, besides pure nitrogen as a carrier gas, the syngas formed can also be used for transport. No significant influence was observed on gasification performance and gas composition even when the syngas formed was used for transport. After the establishment of transport technology using the syngas formed, it has become possible to control the mixing of inert gas in the syngas thus to enhance the quality of raw material gas for methanol synthesis as a chemical raw material gas.

The controllability and operation stability of the demonstration plant after the continuous one-week (165 hours) prolonged operation of gasification was verified. Fig. 5 shows the transition of times versus temperatures at the gasifier, quenching furnace and boiler outlet in 165-hour continuous operation. Neither the erosion of the boiler tubes and the piping nor the damage to bag filter cloth was observed. It was confirmed that the heat transfer performance of the waste heat boiler with dust stuck to it could be maintained stably by providing

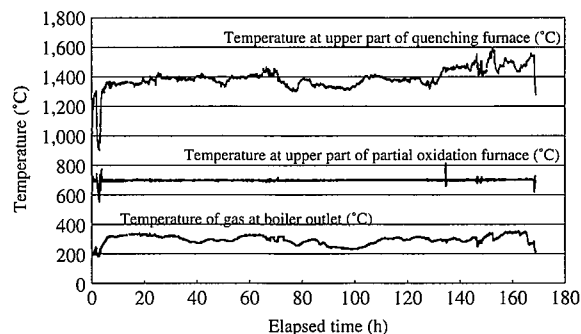


Fig. 5 Transition of time in respective parts during prolonged operation

the mechanism of dusting off.

(3) Liquid phase methanol synthesis

An analysis was made of the components and a ratio of components of the syngas produced from waste plastics along with another analysis of a trace amount of impurities contained in the resulting syngas, considered to be a poison to the catalyst for methanol synthesis, including sulfur compounds, halogen compounds, and metal carbonyls. This enabled to identify and quantify a trace amount of impurities in the synthesis of methanol.

The syngas contains a variety of additives or blending and other impurities derived from the foreign matter adhered. Among those impurities, there are some that may possibly be a poison to the catalyst for methanol synthesis. Therefore, it is necessary to remove those impurities from the syngas so that methanol can be synthesized efficiently. The behavior of absorption by a very small quantity of those impure gases with the popular gas absorber using cold methanol as a method of removal by absorption with acid gas of sulfur compounds, halogen compounds, and other impurities in very small quantities was investigated.

With the guard bed installed, filled with an adsorbent, whose effect of absorbing acid gas and a small quantity of impurities was confirmed, a method has been established of removing a catalyst poison with a single or plural guard beds. This gas purification technology enabled to completely remove sulfur compounds and a small quantity of impurities, both of which are harmful components to the catalyst for methanol synthesis, with the absorber using cold methanol and the guard beds, demonstrating that it is possible to produce methanol, a typical chemical raw material, by the liquid phase method by using the gas purified as described above.

In parallel with the prolonged continuous operation of the gasification plant, another prolonged continuous operation was carried out by charging the resulting gas into the liquid-phase-method methanol reactor after removing a catalyst poison for purification by utilizing the gas purification technology as described above. In the above operation, the changes over time in methanol catalyst activity to evaluate a life of the methanol catalyst were measured. As a result, it was confirmed that the syngas, produced from waste plastics and purified by this method, has no adverse effect on the synthesis of methanol and that the resulting crude methanol that achieved a purity of over 98% poses no particular problem.

4. Conclusions

Syngas was produced by partial oxidation of waste plastics using the entrained single stage reactor in this demonstration test, and the synthesizing of methanol by the liquid phase method using this syngas was successful. Technologies in respective fields, including a stable

pneumatic transport of waste plastics, partial oxidation, waste heat recovery, hydrochloric acid recovery, gas purification for the raw material of methanol synthesis, and synthesis of methanol by the liquid phase method were developed and demonstrated. This has opened one of the routes toward the possible development of chemical products with a high added value from waste plastics.

In the future, there is a need to expand on the kinds of subject waste plastics, establish a technique of enlarging a scale, study the applications of process by-products, such as dust and slag, and to confirm a catalyst life by furthering prolonged operation in the process of methanol synthesis. At the same time, we should study the optimization of reaction conditions necessary for operation on an industrial scale, the collection of engineering data, and the establishment of the technology of purifying produced methanol so that technical tasks left for commercialization can be solved and a commercial plant can be realized at an earlier date. Indeed, making contributions to the establishment of a recycling-oriented society is the source of great satisfaction and pride.

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