Reducing CO_2 emissions by using Carburizing Gas Regenerator

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Gas carburized quenching process exhausts much CO_2 because fossil fuels is burned. For this reason, reducing CO_2 is one of the urgent tasks for this process. "Carburizing Gas Regenerator" is an equipment, including polyimide hollow-fiber membrane filter, which allows H_2 to permeate therethrough. As H_2 is generated during carburizing process, by circulating carrier gas using this equipment, H_2 is eliminated by filter, and H_2 eliminated carrier gas is able to reuse to the furnace.

Using Carburizing Gas Regenerator enables to reduce total amount of carrier gas and CO_2 emissions up to 50%, and get less variation of hardness and carbon concentration among carburized quenching specimens.

Keywords: *gas carburized quenching, CO_2-reduction*

1. Introduction

In the conventional gas carburizing process, carrier gas is used at least 6 times of furnace volume per hour [1]. However, only small amount is utilized for carburizing in the introduced carrier gas, and most of it burned and disposed of outside the furnace, resulting in CO_2 emissions. Carburizing reaction produces especially H_2 during process and affects atmosphere compositions. The reason why introducing large amount of carrier gas into furnace is to keep atmosphere compositions stable. If the amount of carrier gas is not enough, variation in carbon concentration and hardness will occur in the carburized quenching test.

In this study, we conducted gas carburized quenching tests with three conditions: conventional amount of carrier gas, 50% reduction of carrier gas using Carburizing Gas Regenerator and 50% reduction of carrier gas without using Carburizing Gas Regenerator. After that, we compared atmosphere compositions, carbon concentration and hardness among three conditions.

2. Method of carburizing gas regenerating

2.1 Gas reactions of during carburizing

During gas carburizing, carrier gas (RX gas) containing CO, N_2 and H_2 as main components is used and added enrich gas to control carbon potential (CP). Carburizing to steel is caused by the reaction of gases containing carbon, mainly CO. Carburizing reaction on the surface of steel is mainly expressed by the following equation.

$$2CO \rightarrow (C) + CO_2 \qquad (1)$$

$$CO + H_2 \rightarrow (C) + H_2O \qquad (2)$$

$$CH_4 \rightarrow (C) + 2H_2 \qquad (3)$$

Above (C) represents carbon, carburized into steel.

If propane gas is used as enrich gas, reaction is expressed by the following equation.

$$C_3H_8 + 3CO_2 \rightarrow 6CO + 4H_2 \qquad (4)$$

$$C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2 \qquad (5)$$

$$C_3H_8 \rightarrow 2(C) + 2H_2 \qquad (6)$$

Thus, H_2 increases due to gas reactions during carburizing. In the conventional gas carburizing, a large amount of carrier gas is introduced to mitigate the effect of increased H_2. Therefore, if the increased H_2 can be removed, carburizing gas in the furnace can be reusable.

2.2 Constitution of gas regeneration equipment

To regenerate carburizing gas, the gas inside furnace is circulated by a circulation pump and H_2 is removed by using "Carburizing Gas Regenerator" at the path of circulation gas, as shown Figure 1. "Carburizing Gas Regenerator" as shown Figure 2 can selectively permeate H_2 through polyimide hollow-fiber membrane filter by using educator pump and exhaust it. In addition, in order to prevent excessive H_2 exhausting, it is possible to control the amount of H_2 exhausting by CO concentration monitoring.

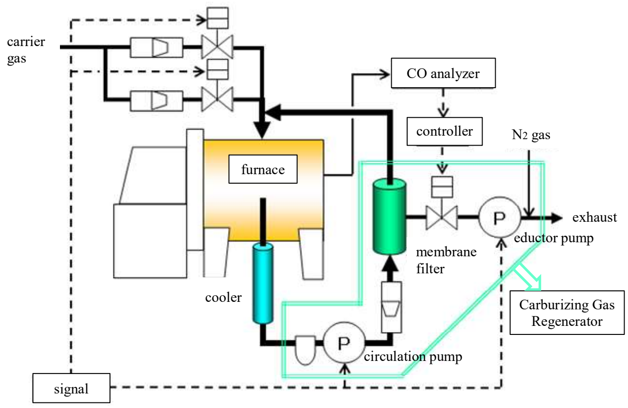

Figure 1 Constitution of gas regeneration equipment.

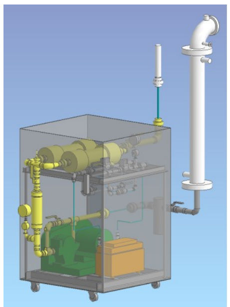

Figure 2 Appearance of "Carburizing Gas Regenerator".

3. Experiment

3.1 Specimens

The specimens used for experiment were cylindrical shape (φ18×50mm) and made of chromium steel (JIS SCr420). To investigate carburizing variation, we set corner and center position of loading position. In order to increase the surface area of specimens, we loaded dummy steel plates to make the surface area about 11m^2.

3.2 Test furnace

A batch-type test furnace shown in Figure 3 was used for carburized quenching test. Effective dimensions were 600mm in width, 600mm in length, 600mm in height, and the maximum load capacity was 200kg. The atmosphere during carburizing was controlled with CP using O_2 sensor. The carrier gas was based on butane gas, and CP was calculated with a constant CO concentration of 23.5%.

Figure 3 Batch-type test furnace.

3.3 Heat treatment condition

Heat cycle of carburized quenching is shown in Figure 4. Three heat cycle conditions were conducted as below.

(a) Base condition:
Volume of carrier gas is conventional.

(b) Reduce carrier gas:
Not using Carburizing Gas Regenerator.

(c) Reduce carrier gas:
Using Carburizing Gas Regenerator.

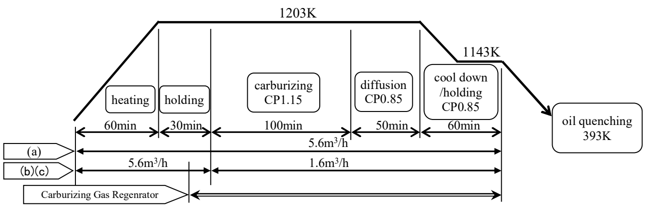

Figure 4 Heat cycle of carburized quenching.

For (a), the amount of carrier gas was 5.6m^3/h throughout the cycle, for (b) and (c), heating period and holding period were 5.6m^3/h and since carburizing periods were 1.6m^3/h. Circulating gas volume was 6m^3/h. Total amount of carrier gas was 28m^3 for (a), and 14m^3 for (b) and (c), which was has half as (a).

4. Results

4.1 Verification of H_2 emissions

Before carburized quenching test, we checked the amount of exhausting gas volume in circulating gas and concentration of H_2 contained in the exhausting gas. The results are shown in Figure 5. As the amount of circulating gas increased, the amount of exhausting gas also increased. At the circulating gas was over 3.6m^3/h, concentration of H_2 in exhausting gas was over 95%.

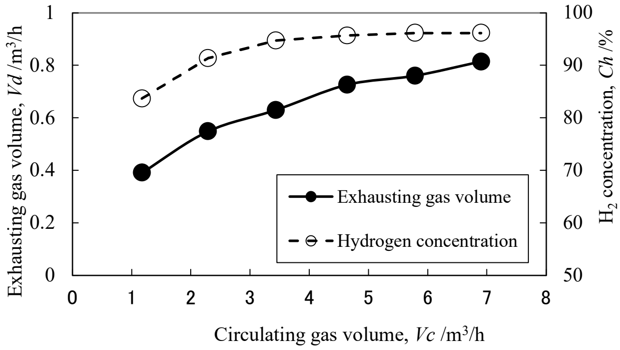

Figure 5 Exhausting gas volume and H_2 concentration.

4.2 Behavior of the atmosphere

Figure 6 shows the behavior of CO and H_2 concentrations for (a), (b) and (c) during carburized quenching test.

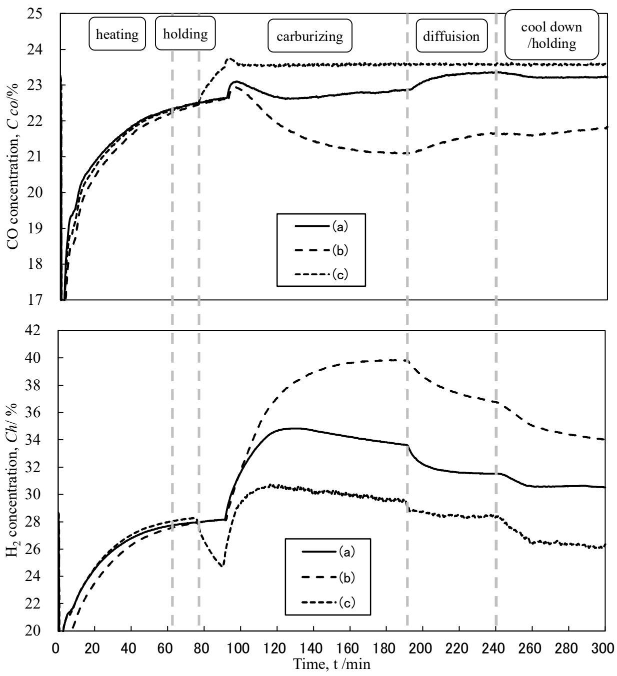

Figure 6 Behavior of CO and H_2 concentrations.

CO concentration was constant at 23.5% since carburizing period under condition of using Carburizing Gas Regenerator (c). On the other hand, under condition of not using Carburizing Gas Regenerator (b), CO concentration decreased to a minimum of about 21%, and was as low as 22% or less even immediately before quenching. In addition, a slight decrease in CO concentration was observed even with the conventional carrier gas volume (a).

Concerning H_2 concentration increased at the same time as carburizing period starts, and CO concentration decreased accordingly for (a) and (b). In (c), the increase of

H_2 concentration was suppressed and the CO concentration was stable.

4.3 Distribution of hardness

The distribution of hardness is shown in Figure 7, and the effective case depth is shown in Table 1. (b) showed shallower effective case depth than (a) and (c), and variation between center and corner was large. Compared to (a) and (c), (c) had a slightly deeper effective case depth and less variation. This is probably due to the stable CO concentration in the atmosphere.

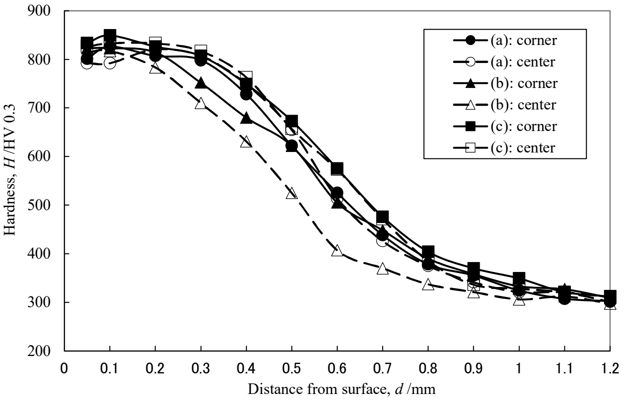

Figure 7 Distribution of hardness of loading position.

Table 1 Effective case depth of loading position.

	Effective case depth, *de*/mm	
	Corner	Center
(a)	0.57	0.57
(b)	0.56	0.48
(c)	0.63	0.62

4.4 Distribution of carbon concentration

Figure 8 shows the distribution of carbon concentration. As with the distribution of hardness, (b) had a shallower distribution of carbon concentration than (a) and (c), and showed variation.

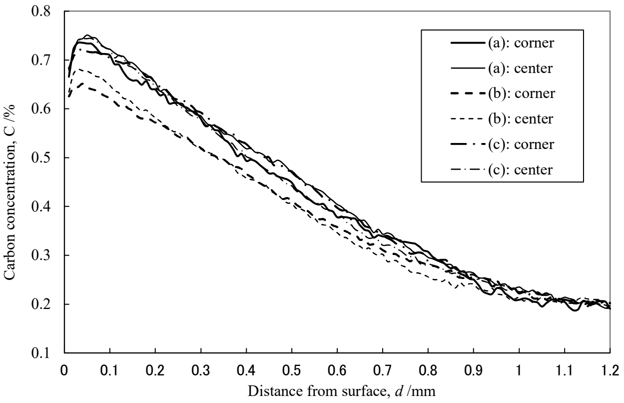

Figure 8 Distribution of carbon concentration.

4.5 The amount of CO_2 emissions

The amount of CO_2 emissions generated by carrier gas at this test, using a formula of Ministry of the Environment was open to the public [2], were 14kg in (a), 7kg in (b) and (c), which was reduced 50% to (a).

5. Discussion

Figure 9 shows minimum volume of carrier gas by using Carburizing Gas Regenerator. The minimum volume of carrier gas represents the limit at which the furnace pressure and atmosphere can be maintained. According to Figure 9, the smaller total surface area of specimens and lower CP, the more carrier gas can be reduced.

Table 2 shows the simulation results of CO_2 emissions in actual production process. In this simulation, carrier gas is assumed 20m^3/h, heat cycle is assumed as same as Figure 4 and total surface area of specimens is assumed 10, 15 and 20m^2. As a result, annual CO_2 emission can be reduced by more than 50%.

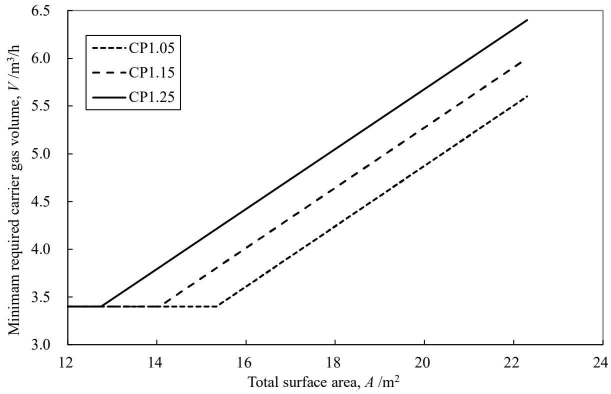

Figure 9 Minimum volume of carrier gas

Table 2 Annual CO_2 emissions.

	Total surface area, *A* /m^2	Annual CO_2 emissions, *E* /ton	ratio
Conventional	-	73.6	1.0
Using carburizing gas regenerator	10	30.9	0.42
	15	31.1	0.42
	20	35.8	0.49

6. Conclusions

The carburized quenching test using Carburizing Gas Regenerator got following results.

(1) Compared to conventional carburized quenching, total amount of carrier gas could be reduced by 50%, and distribution of both hardness and carbon concentration were deeper and less variation than conventional results.

(2) In case of reducing carrier gas not using Carburizing Gas Regenerator, distribution of both hardness and carbon concentration were shallow, and showed variation.

References

1) The Iron and Steel Institute of Japan: *Hagane no Netsusyori* (Heat treatment of steel) (5th edition), pp. 334.

2) Japanese Ministry of the Enviroment: Calculation method and list of emssion factors. https://ghg-santeikohyo.env.go.jp/files/calc/itiran_2020_rev.pdf.