Operation Results of High-Temperature and -Pressure Fluidized Bed Boiler with Recycled Waste Fuels

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This is a bubbling fluidized bed boiler that is highly adaptable to the environment and which operates on recycled waste fuels such as cut tires, wood products, sludge, RPF (refuse paper & plastic fuel) as substitute for fossil fuels. This plant is able to generate high-temperature and high-pressure steam with reduced fossil fuel consumption and lower CO_2 emission. Steel wires contained in tires can be safely and continuously discharged from the fluidized bed furnace without accumulating on the furnace bottom. Further, even when a mixture of different recycled waste fuels is combusted, NOx and dioxins reduction can be achieved simultaneously by M-STAR (the Mitsubishi multi-stage air re-firing) combustion method, a combustion system[(1)] patented by Mitsubishi Heavy Industries, Ltd. (MHI). At present, two fluidized bed boilers are commercially operating with recycled waste fuels containing cut tire at Nagoya Pulp Corporation and Mitsubishi Paper Mills Limited.

1. Introduction

While the reduction of greenhouse gases (such as CO_2) is being promoted for prevention of global warming, 130 million tires (approximately 1.03 million tons) were discarded in Japan in 2003, of which 44% (451 thousand tons) was utilized for the purpose of thermal recovery and electric power generation[(2)]. It is also reported that woody biomass (wood chips, lumber from thinning, waste wood derived from construction work, etc.) has a potential supply capacity of approximately 8 million tons per year[(3)]. Accordingly, if these materials were used to replace fossil fuels, not fuel costs and but CO_2 emissions could be reduced.

However, as tires contain about 10% to 20% of steel wires (hereinafter called wires), in order to ensure stable combustion of tires on the fluidized bed, the wires must be continuously discharged from the furnace without accumulating in the fluidized bed. In this way, stable combustion can be achieved even when multiple recycled waste fuels are used simultaneously. Therefore, MHI has developed its proprietary high-temperature and high-pressure fluidized bed boiler that operates on recycled waste fuel combining the waste materials fluidized combustion technique for environmental systems and the high-temperature and high-pressure fluidized bed boiler technique for power generation systems. This paper gives an outline of the engineering and operation performance of this kind boilers that have been delivered to Nagoya Pulp Corporation and Mitsubishi Paper Mills Limited.

2. Characteristics of recycled fuels

Table 1 shows the properties of various fuels.

Table 1 Properties of various recycled waste fuels

Contents \ Fuel		Cut tires	Nagoya Pulp		Mitsubishi Paper Mills		Reference
			Wood products	RPF	Wood products	PS	Coal
Moisture	(%)	0.56	23.3	2.41	13.2	58.4	9.00
Ash	(%)	2.46	1.91	4.73	1.34	44.1	13.85
Combustibles	(%)	97.54	98.09	95.27	98.66	55.9	86.15
Carbon	(%)	81.3	48.9	63.1	43.0	25.0	71.0
Hydrogen	(%)	7.47	6.34	9.64	6.51	3.52	4.56
Nitrogen	(%)	0.37	0.69	0.74	0.21	0.93	1.72
Total sulfur	(%)	1.72	0.06	0.07	0.09	0.15	0.52
Total chlorine	(%)	0.14	0.15	0.23	0.41	0.18	-
Oxygen, etc.	(%)	6.54	41.95	21.49	48.44	26.12	8.35
Higher heating value	(kJ/kg)	38 720	19 420	29 600	19 010	8 620	28 870
Lower heating value	(kJ/kg)	37 050	18 000	27 420	17 540	7 830	28 110
Notes		● Moisture is on an arrival basis, and others on a dry basis. ● Ash and combustibles are based on 800°C x 2 h.					

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(1) Cut tires

The higher heating value of cut tires is 38 720 kJ/kg, which is approx. 30% higher than that of coal, which is 28 870 kJ/kg. Cut tires are cheap and suitable as an alternative to coal. However, their sulfur content is 1.72%, which is comparable to that of heavy oil, so that consideration must be given to related problems of corrosiveness. In addition, tires contain 10–20% of wires which can accumulate on the fluidized bed and hinder fluidization. Therefore, prevention of such defective fluidization that could cause inadequate combustion on the fluidized bed is an important objective. Further, as shown in **Fig. 1**, small-size tires are cut into 16 pieces (approx. 200 mm each) and large-size tires are cut into 32 pieces (approx. 330 mm each). These pieces, though comparatively large in size, must be made to combust stably in the fluidized bed.

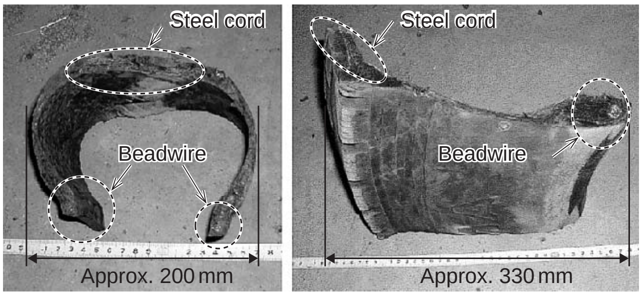


Fig. 1 Appearance of cut tire
Small-size tires are cut into 16 pieces of approx. 200 mm each and large tires into 32 pieces of approx. 330 mm each (car tires at left and truck tires at right).

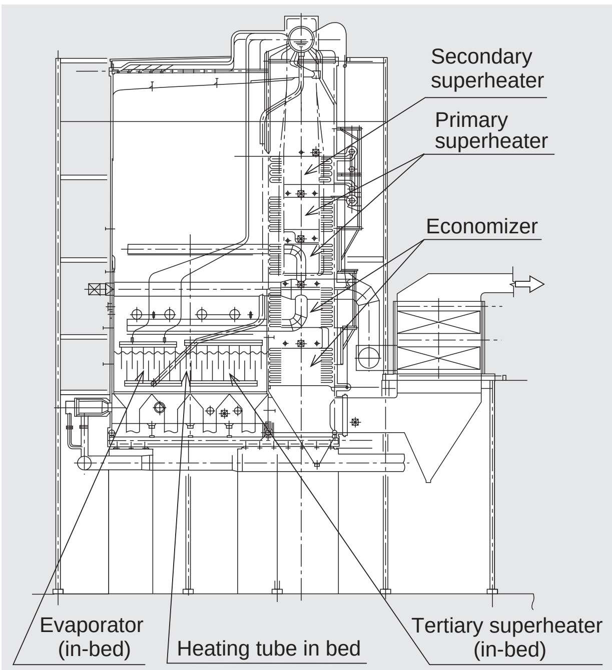


Fig. 3 Boiler assembly
In case of higher temperature and pressure conditions, a final superheater protected by refractories is installed in the fluidized bed (an example at Nagoya Pulp Corp.).

(2) Wood-product fuels (wood chips)

Moisture content is 10–20%, which is comparatively low, the higher heating value is as high as 19 000 kJ/kg, the ash content is only 1–2% and its combustibility is excellent. The sizes of chips to be charged are, as shown in **Fig.2**, about 50 mm or less on the longer sides. Wood chips also come with incombustibles such as stones and metal pieces (wires, nails, pieces of iron, etc.) which also need to be prevented from accumulating in the fluidized bed.

(3) Others

RPF is a solid fuel made of waste plastics and industrial type waste paper, whose moisture content is only 2–3% and higher heating value 29 600 kJ/kg, which is as high as that of coal and next to that of cut tires. The higher heating value of paper sludge (PS) is 8 620 kJ/kg, which is lower than that of any other fuel; its moisture content and ash content are as high as 58.4% and 44.1%, respectively, making this material hard to burn.

3. System characteristics

Table 2 shows the main elements of boiler engineering, and **Fig. 3** shows the boiler configuration.

Fig. 2 Appearance of wood products (wood chips)
Charging size is about 50 mm or less on longer sides.

Table 2 Boiler planning main elements

Item \ User	Nagoya Pulp	Mitsubishi Paper Mills
Main steam flow rate (t/h)	117.5	77
Main steam pressure (MPag)	12.65 (superheater outlet)	10.20 (superheater outlet)
Main steam temperature (°C)	541 (superheater outlet)	515 (superheater outlet)
Fuels	Wood products, cut tires, RPF, kerosene (for starting and aiding combustion)	Wood products, cut tires, sludge, other combustibles, AC blend oil (for starting and aiding combustion)

Fig. 4 shows an example of an overall plant system configuration. The boiler delivered to Nagoya Pulp Corporation, which is a bubbling fluidized bed boiler, achieves high power generation efficiency through application of highest class high-temperature and high-pressure steam condition (12.65 MPag x 541°C) in Japan. In the meantime, the boiler delivered to Mitsubishi Paper Mills Limited is operating on cut tires as the main fuel, occupying approximately 75% of the total heat input. Both of these power generators are friendly to the environment.

In the case of higher temperature and pressure conditions, an superheater (final superheater) protected by refractories, as shown in **Fig. 5**, is installed in the fluidized bed to reduce corrosion from sulfur content and abrasion by sand, enabling high-efficiency heat recovery (MHI patent). In addition, a stepped inclined furnace bottom structure, as shown in **Fig. 6**, has been adopted and the air supply near the bed drain extraction section has been made adjustable to discharge wires smoothly. Incombustibles such as wires has been discharged from the fluidized bed along the bed ash treatment system, as shown in **Fig. 7**, and wires has been separated and recovered from the sand by magnetic separators. Other incombustibles will be segregated subsequently by a vibrating sieve, discharged from the system and recovered.

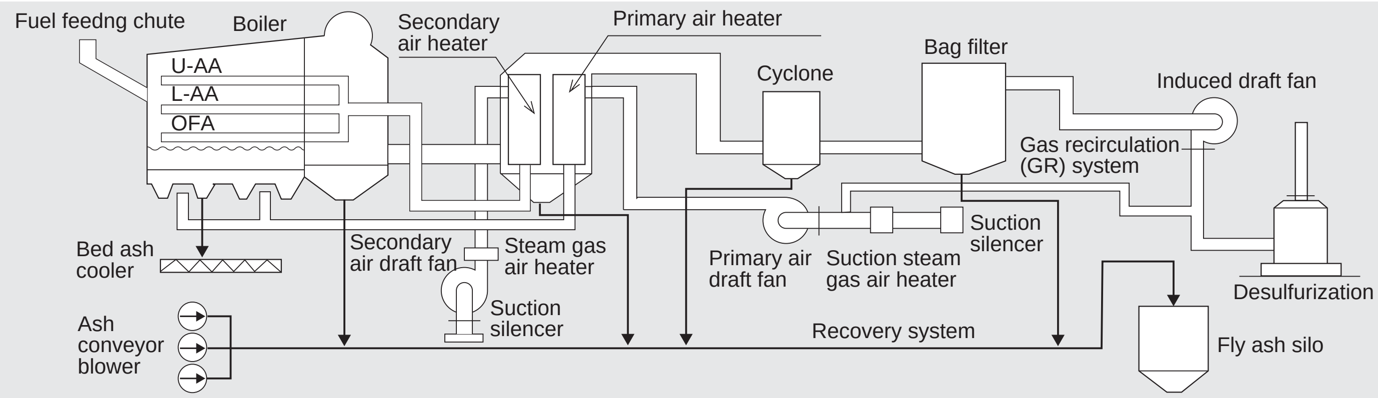


Fig. 4 Total plant system configuration
An example of plant delivered to Mitsubishi Paper Mills. The plant delivered to Nagoya Pulp operates on a smaller amount of cut tires so exhaust gas (SOx) in the downstream stage is treated by a dry-type treatment method (dry-type desulfurization by bag filter).

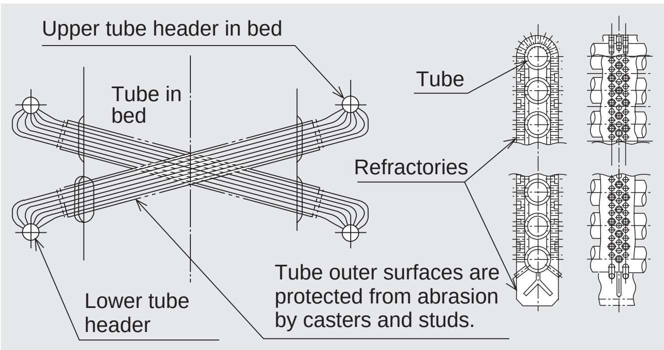


Fig. 5 Outline of superheater structure in bed
Abrasion and corrosion are prevented by installing an in-layer superheater protected by refractories.

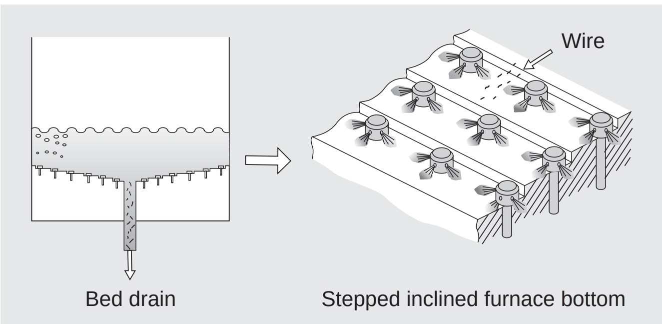


Fig. 6 Stepped inclined furnace bottom structure
The furnace bottom is inclined so as to discharge steel wires from the furnace without their accumulating.

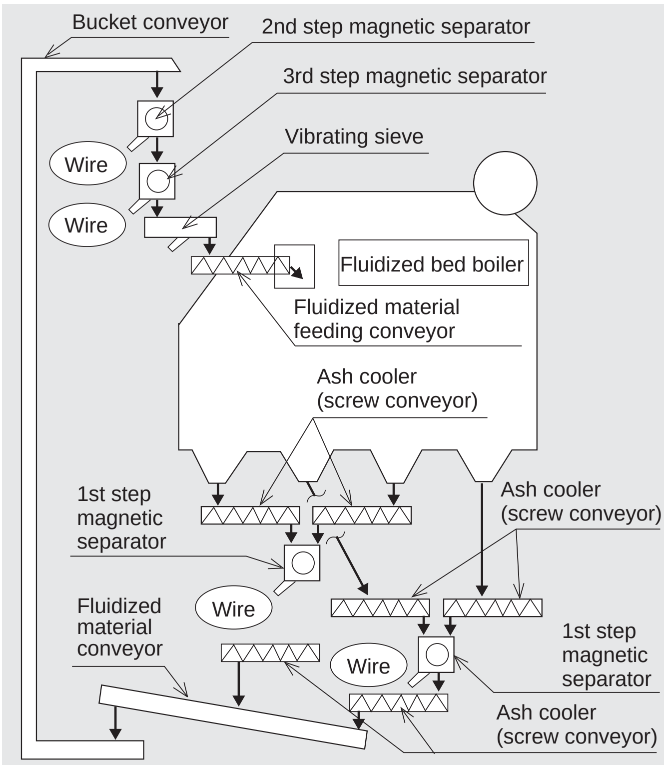


Fig. 7 Bed ash treatment system
Incombustibles containing wires and sand discharged from the furnace bottom are cooled on a water-cooled conveyor. Wires and other incombustibles are separated from sand, respectively, by magnetic separators and a vibrating sieve, allowing the sand to return inside the furnace.

By optimizing the feeding rate of the secondary air supplied from three stage ports at the free board, low NOx and low dioxins can be attained simultaneously even in the case of multiple type recycled waste fuel combustion by the M-STAR combustion method.

4. Operating conditions

4.1 Combustion stability

Fig. 8 shows the time trends of temperatures, boiler evaporation and exhaust gas concentration during the performance test. **Table 3** shows the results of the performance test.

In the case of mixed recycled waste fuel combustion including cut tires, wood products and RPF (at Nagoya Pulp), both evaporation and steam temperature apparently tended to become stabilized as the supply of fuels was stabilized, and when the fluidized bed average temperature was 842°C, the exhaust gas contained 146 ppm of NOx, 2 mg/m^{3}N of soot (both @ O_2 6% dry), 122 ppm of SOx (@ actual concentration of O_2 dry) and 74 ppm of CO (@O_2 12% dry), their guaranteed values ware achieved. In the case of mixed fuel combustion, including cut tires, wood products and PS, at Mitsubishi Paper Mills, stabilized combustion was also attained. When the fluidized bed average temperature was 821°C, the NOx concentration was 66 ppm, the soot concentration 0.9 mg/m^{3}N, the CO concentration 50 ppm, dioxins concentration less than 0.098 ng-TEQ/ m^{3}N (so far @ O_2 12% dry) and the SOx concentration 35 ppm (@ actual concentration of O_2 dry), their guaranteed values were achieved.

Table 3 Boiler performance test results

Item \ User		Nagoya Pulp		Mitsubishi Paper Mills	
		Target value	Test result	Target value	Test result
Evaporation	(t/h)	117.5	117.5	77.0	79.5
NOx	(ppm)	150	146	80	66
Soot	(mg/m^3_N)	50	2	10	0.9
SOx	(ppm)	140	122	100	35
Dioxins	(ng-TEQ/m^3_N)	-	-	0.098	0.098 or less
CO	(ppm)	100	74	100	50
Remarks		NOx and soot values are as converted to O_2 6% dry values, and CO value as converted to O_2 12% dry value.		NOx, soot, dioxin and CO values are as converted to O_2 12% dry values.	

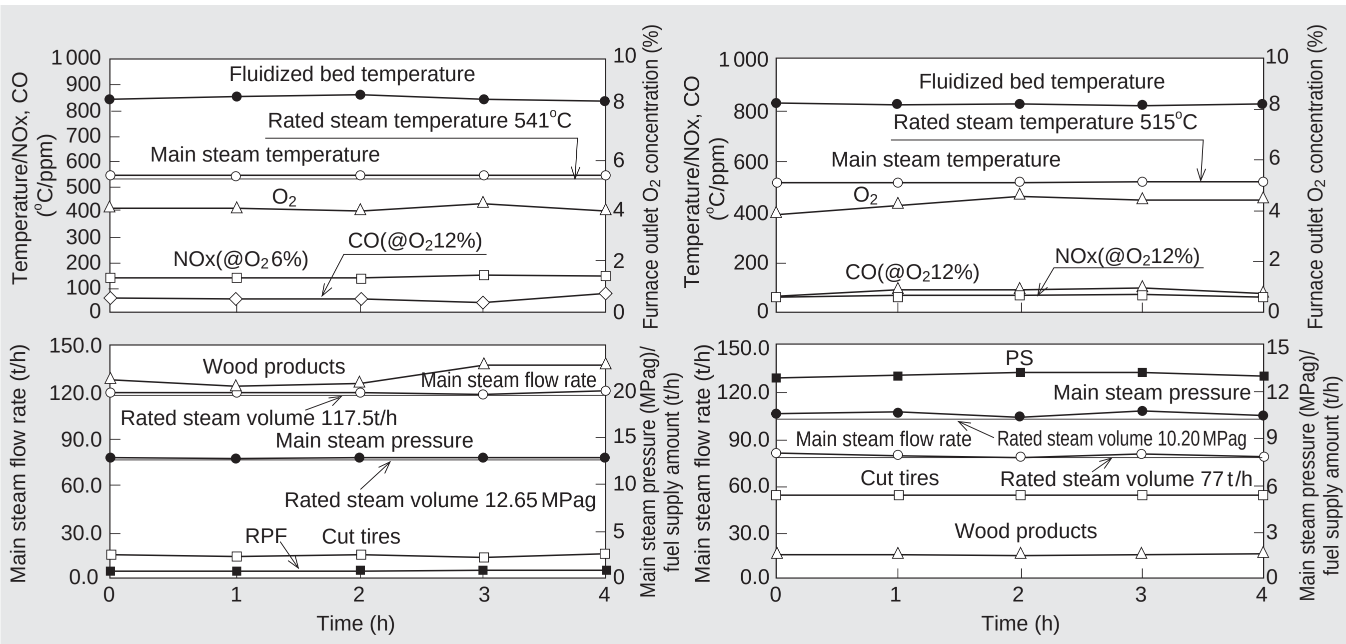


Fig. 8 Time trends of temperatures, boiler evaporation and exhaust gas concentration
Stable combustion was attained and the performance guaranteed values were achieved both in the case of mixed fuel combustion involving cut tires, wood products and RPF, and mixed fuel combustion involving cut tires, wood products and PS (Nagoya Pulp at left and Mitsubishi Paper Mills at right).

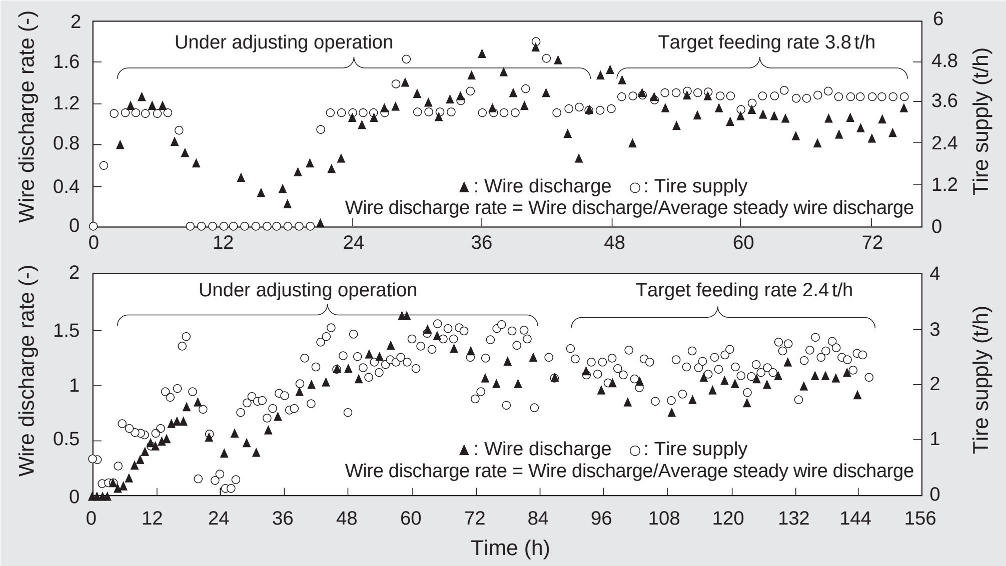
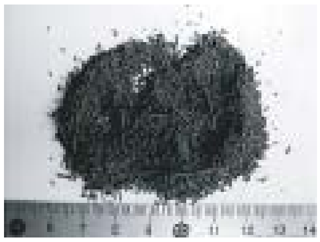


Fig. 9 Time trends of wire discharge
Stable steel wire discharge was confirmed in both cases of mixed fuel combustion (upper figure: Mitsubishi Paper Mills, lower figure: Nagoya Pulp).

(a) Wires about 60 mm long are recovered by upstream magnetic separator



(b) Wires pulverized into pieces about 2 mm long are recovered by downstream magnetic separator

Fig. 10 Appearances of wires recovered by magnetic separators

Table 4 Wire recovery rates by magnetic separator

Item \ User	Nagoya Pulp	Mitsubishi Paper Mills
Upstream magnetic separator recovery rate (%)	87.8	84.9
Downstream magnetic separator recovery rate (%)	6.9	9.1
Total recovery rate (%)	94.7	94.0
Remarks	Total recovery rate indicates value of outlets of two magnetic separators installed at downstream.	One downstream magnetic separator installed.

4.2 Wire dischargeability

Fig. 9 shows the time trends of wire discharge during the wire dischargeability verification test. The wire discharge variation related on the tire supply changes during the initial adjustment time, but as the tire supply was stabilized, the wire discharge took place at a more or less constant rate and the capability of smooth wire discharge was confirmed. Also, no wire deposit was found on the furnace bottom during the inspection period.

4.3 Wire recovery performance

Table 4 shows the wire recovery rates of magnetic separators installed in the bed ash treatment systems. As can be understood from Table 4, in both cases, the wire recovery rate indicates more than 94%, the discharged wires are almost recovered.

Fig. 10 shows the appearances of wires recovered by the magnetic separators installed upstream and downstream. Compared with the wires recovered by the upstream separators, those recovered by the downstream separators are finer. Approximately 6% of wires not recovered by the downstream separator seem to have been oxidized in the fluidized bed, further pulverized and finally discharged together with combustion exhaust gas.

5. Conclusion

High-efficiency power generation through application of highest class temperature and pressure steam conditions in Japan to the bubbling fluidized bed boiler was verified, and adaptability to the environment/energy of MHI's proprietary high-temperature and high-pressure fluidized bed boiler technology utilizing a mixture of recycled fuels such as cut tires, wood chips, RPF and PS was also confirmed. In future, MHI will continue its efforts to ascertain the clients' needs and offer products excelling in adaptability to the environment with a view to global warming prevention and efficient utilization of the earth's limited energy resources.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