THE PRACTICAL EDUCATION OF THE AGROTECHNOLOGY HISTORY BY RESTORING AND PERFORMING A JAPANESE TRADITIONAL TREADLE WATER WHEEL – *FUMIGURUMA*

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ABSTRACT

The Japanese traditional treadle water wheel named '*Fumiguruma*' was invented in Osaka in Kanbun era (1661-1673), and spread out all over the country by Hohreki-Anei era (1751-1781). The treadle water wheel was mainly used as an implement for irrigation to paddy fields and afterward for drainage of river and canal works for more than 300 years. The treadle water wheel was classified into two types from the structural viewpoint, i.e. standard wheel and '*Manuemon*' wheel. The latter is excellent on driving performance and portability, because the casing of impeller was designed rationally to improve the efficiently of the discharge rate of flow and decrease the running loads and the mass. But the latter was probably used only in Northern Kyushu, while the former was used anywhere in Japan. The volume of water lifted horizontally by one impeller plate and the maximum rate of flow were obtained analytically in quasi-static condition. In the case of the treadle water wheel of the 1.51 m diameter having 15 impeller plates which the Kyushu University Farm possessed, the calculated values were 0.0128 m^3/plate, 70.4 m^3/h on the stable revolution rate of 1.53 plate/s, respectively. It is necessary to clarify the optimum installation method of the treadle water wheel considering parameters such as the water depth, the water head, wheel specifications, *etc*. Twenty-four teachers experienced the irrigation work by using the treadle water wheel for two days in July 2002 in the University Farm. The practical education made a deep impression on them and was very useful for understanding agrotechnology and agricultural mechanization.

Keywords: Treadle water wheel, *Fumiguruma*, Irrigation, Discharge rate of flow, Practical education, Agrotechnology.

INTRODUCTION

The Japanese traditional treadle water wheel, '*Fumiguruma*', was invented in Japan and used for more than 300 years. It seems one of the most proud agricultural implements for water lifting by man power. But it is almost only exhibited as an industry legacy in the museum, and the suitable usage of it has been lost. Ishikawa reported Fumiguruma preserved in Kyushu district (2002).
The purposes of this investigation are as follows.

(1) To clarify the whole system of water lifting by using *Fumiguruma* including hardware, the usage, the theory of water lifting, the development progress, *etc*.

(2) To obtain the educational method made to understand the excellent agrotechnology by the experience of carrying, installing, operating, and maintaining *Fumiguruma*.

THE OVERVIEW OF *FUMIGURUMA*

Fumiguruma is a Japanese traditional treadle water wheel for irrigation.
History – The Japanese traditional treadle water wheel named *Fumiguruma* was invented in Osaka in Kanbun era (1661-1673). It replaced the keel wheel, '*Ryukotusha*', of a low efficiency and spread out all over the country by Hohreki-Anei era (1751-1781). Fig.1 illustrates *Fumiguruma* in the famous book of 'Nougu Benriron' written by Ohkura Eijo (1822), who described how to design and make *Fumiguruma* in detail.

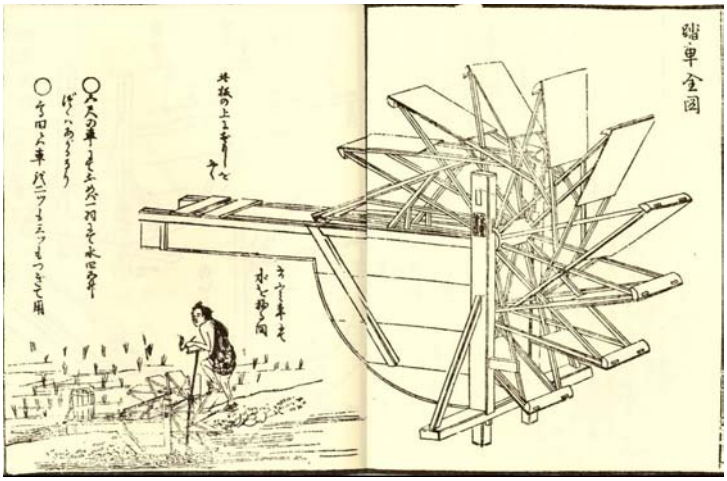

Fig.1: *Fumiguruma* in the famous book of "Nougu Benriron" written by Ohkura Eijo (1822).

Fumiguruma was mainly used as an implement for irrigation to paddy fields, afterward, as an implement for drainage of river and canal works too. Takeuchi *et al.* (1999) reported that *Fumiguruma* influenced Kishu-ryu, a school of civil engineering for helping drain underground water in Kyoho era (1716-1735). In early Showa era (1926-1935), the vertical pump began to replace *Fumiguruma* as a kerosene engine spread. After all, *Fumiguruma* was used for more than 300 years. Now, there is no craftsman making and repairing *Fumiguruma* in Japan.

Structure and Characteristics – *Fumiguruma* consists of two main components, i.e. an impeller and a casing with a discharge trough. Other components are a backflow preventer, an overflow preventer, hanging parts, *etc.* Materials are wood, especially hinoki cypress and Japanese cedar of the finest quality. The gross weight of *Fumiguruma* is usually below 30 kg. Two *Fumigurumas* possessed in Kyushu University Farm are as follows. (a) Total weight, 26.9 kg; Impeller, 1510 mm in diameter, 15 plates, 14.5 kg; Casing with a discharge trough, 12.4 kg. (b) Total weight, 28.8 kg; Impeller, 1740 mm in diameter, 17 plates, 13.1kg; Casing with a discharge trough, 15.7 kg. *Fumiguruma* had good portability because of the light weight and good balance of two components.
The principle of water lifting of *Fumiguruma* is to push water up by flat plates of impeller which the worker turns by foot. The delivery head, the height from the inlet water level to the discharge water level, is less than 70 cm generally. Ohkura Eijo described that the discharge rate of flow was 7.2 to 9.0 l/plate in "Nougu Benriron".
He reported that the price of *Fumiguruma* was nearly equal to the price of 150 kg rice in 1822.

How to use *Fumiguruma* - To our regret, we have not fully inherited the method of the usage including carrying, installation, operation, repair, *etc*. There are few reports on the theoretical and rational usage of *Fumiguruma*.

Preservation of *Fumiguruma* - We can observe the implements used actually only on static exhibition in the museum as shown in Fig.2, and can seldom find the implements working in the field.

Fig.2: *Fumigurumas* exhibited statically in the museum

Though a lot of photographs and very few films and videos of *Fumiguruma* remain, it is difficult to understand how to set and operate *Fumiguruma*. In short there is no dynamic preservation of *Fumiguruma* including software concerning carrying, installation, operation, repair, *etc*.

Theory on the water lifting - The equation on the flow rate of a water lift wheel, '*Oshiagesha*', was proposed by Shohji (1965). But it would not seem that the equation suits *Fumiguruma* which is a kind of water lift wheels, because the lifted water by flat plates falls gradually and considerably inside the wheel. The theory on the water lifting of *Fumiguruma* has not been established fully.

SURVEY ON THE PROGRESS OF *FUMIGURUMA*

As a result of the survey on the progress of *Fumiguruma*, we could recognize two types of *Fumiguruma*, i.e. a standard type of *Fumiguruma* and '*Manuemon-sha*'.

(1) The standard type is from original type which was invented by Kyoya Shichibei and Kyoya Seibei in Ohsaka in 1661 to 1673. Several similar or improved types were made at various districts in Japan.

(2) *Manuemon-sha* is invented by Inokuchi Manuemon in Fukuoka, 1777. It was probably used only in Northern Kyushu. It's a fine farm implement like a work of art as shown in Fig.3.

Fig.3: '*Manuemon-sha*' like a work of art

Characteristics of *Manuemon-sha* – The shape of the casing is shown in Fig.4. The upper is the casing of a standard type of *Fumiguruma*, and the lower is that of *Manuemon-sha*. *Manuemon-sha*'s side boards are not only small but also designed rationally to scoop up only the volume of water discharged finally (see Fig.8). The shape of the discharge trough of *Manuemon-sha* is also shown in Fig.4. *Manuemon-sha* can be used rationally according to the delivery head really needed in the field, because the casing can be tilted owing to the short discharge trough. The Shape of the impeller is shown in Fig.5. There are some remarkable points in the impeller as below. Two rims made of the long tie plate of Japanese cedar are set in all the treadles of the wheel in order to increase the strength of the wheel. The wooden spokes and impeller plate frames are very thin (15 x 11 mm) to save precious lumber and to lighten weight of the wheel. It is surprised that the impeller plate frames are bent and assembled taking into consideration of the stepping force in operation as shown in Fig.7.

Fig.4 Fig.5 Fig.6

Fig.4 - Fig.6 The comparison between a standard type *Fumiguruma* and '*Manuemon-sha*'

Fig.7 The bent impeller plate frames

Fig.8 *Manuemon-sha*'s side boards designed in the rational scoop curve

EVALUATION OF THE RATE OF FLOW

The volume of water lifted horizontally by one impeller plate and the usual rate of flow were obtained analytically in quasi-static condition. By using the dimensions of the impeller component as shown in Fig.9, the maximum volume of water lifted by a plate can be expressed by means of the next equation as a function of the rotation angle from the plumb line.

Fig.9 The dimensions of the impeller component

Fig.10 A decrease in the volume of lifted water

$$V_{max}(\theta)=\frac{1}{2}(r_1^{\,2}\theta_1-r_4^{\,2}\sin\theta_1)w$$

As the wheel rotates, the lifted water by the plate falls gradually inside the wheel as illustrated in Fig.10. The volume of water lifted horizontally by the plate, which is equal to the volume of discharge water, can be calculated using the following equation.

$$V_{min}(\theta) = \frac{1}{2} r_1 (r_1 \theta_9 - r_4 \sin\theta_9) w$$

In the case of *Fumiguruma* (a) of the 1.51 m diameter having 15 impeller plates, the maximum volume of water was 0.0213 m^3/plate and the volume of water lifted horizontally was 0.0128 m^3/plate. Therefore, only 60.1% of the maximum volume of water would be discharged toward the trough.

Finally, the calculated rate of flow reached 70.4 m^3/h on the stable revolution rate of 1.53 plate/s.

As the delivery head of *Fumiguruma* would be smaller than the radius of the impeller wheel, more than one *Fumiguruma* were installed in series as in Fig.11 in order to raise water to the higher place.

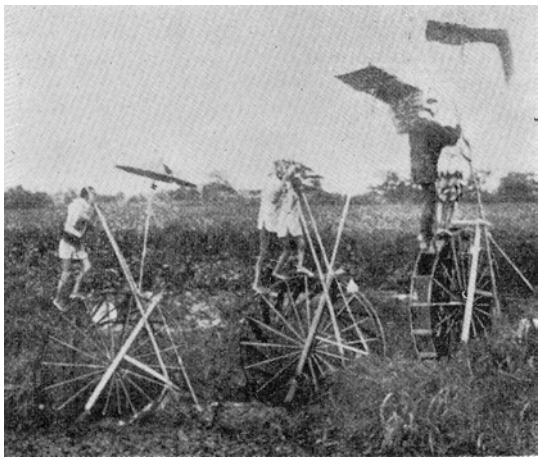

Fig.11 Working by three *Manuemon-sha*s located in series (near Saga city, Mori, 1935)

THE PRACTICAL EDUCATION OF THE AGROTECHNOLOGY

Twenty-four teachers experienced the irrigation work by using *Fumiguruma* for two days in July 2002 in the University Farm. Fig.12 shows the scene of practical training education on the whole system of *Fumiguruma* including carrying, setting, installing, operating, and maintaining. The completed farm implement and the performance made a deep impression on them. They understood that;

(1) *Fumiguruma* was as good as a powered irrigation pump on the flow rate of water.

(2) For the restoration of the agrotechnology, it was necessary that both the implement and the usage were exactly restored.

Fig.12 The scene of practical training education on the whole system of *Fumiguruma*

DISCUSSION AND CONCLUSIONS

We recognized that *Fumiguruma* had been a very useful agricultural implement for a long time. *Manuemon-sha* was especially superior to the standard type of Fumigiruma. But why hadn't it spread out of Kyushu? At present we are afraid of disappearance of the usage of *Fumiguruma* as well as disappearance of the making/manufacturing technique and know-how.

To begin with, it will be necessary to clarify the optimum installation method of *Fumiguruma* considering parameters such as the inlet water level, the water depth, the discharge head, wheel specifications, *etc*., though hardware will directly affect the water lifting performance of *Fumiguruma*

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