Historical Background of the Invention of Electrode Rice Cooker/Bread Machine and Reproduction Experiment with Evaluation

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1 Overview of Method

Today, we are converting electrical energy into thermal energy and making use of it. There are various devices on the market for baking bread. In the days after World War II, when supplies were scarce, people made their own bread baking machines like the one shown in Fig.1, and they became quite popular. This is called an electrode bread machine ,or simply a "Denki-Pan" machine in Japanese. Liquid steamed bread dough made of flour, salt, and sugar dissolved in water is poured between two electrode plates, and an altenating current of 100 volts(V) is applied.

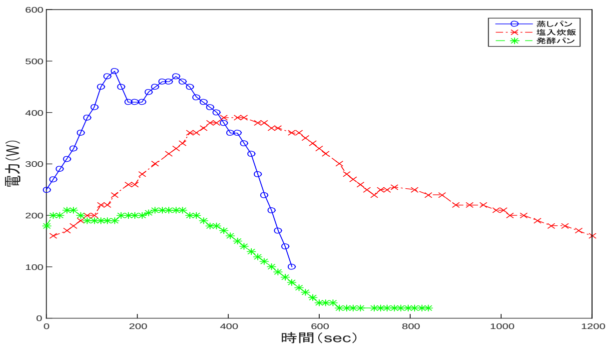
At the Faculty of Science, Kanagawa University, we have been conducting experiments with students since 1990, making our own bread making machine(Fig.1) and evaluating its performance. The bread making machine is a wooden case with two titanium plates(length 18cm, height 10cm, thickness 0.5mm) enclosed in width 6cm in ,so they can face each other in parallel. The bottom of the case can be removed so that the bread can be removed ,and the gaskets are used to prevent water leakage. The current between the plates changes exponentially with the distance between the plates. In 1cm, the current flows 5 times as much as the width of 6cm. The input of salt will also alter the flow rate. In the case of plate spacing of 6cm in width, the current is 20 times that of tap water at a saline solution of 0.2 %

As a result of an evaluation, We found out that the thermal efficiency of those simple devices, which consistents of just two electrodes in a wooden box, is as high as approximately 70 %. The reason for this is that the dough itself generates heat through Joule heat (electrolytes dissolved in water interferes with the movement of electrons and receives heat enaergy), instead of applying heat to the dough from the outside, as in an oven. 70 % of the added electrical energy is used for baking bread as heat of evaporation at 100 ℃. It was also found to have an excellent property to automatically turn off the electric current without a microcomputer after baking.

The liquid steamed bread dough was made of flour 150g, water 150g, salt 0.4g, baking powder 6g and sugar 25g. When an altenating current of 100V is applied for 9 minites in the process of baking, the current (top) and water temperature (bottom) characteristics of that dough are shown as the ○ mark in Fig.2 (finished product is shown in Fig.3 (top)). The horizontal axis shows the time. The representation of the current is reduced to power value(Watt) which is current(A) × 100(V). The water temperature rises monotonously and evaporates at 100 ℃, resulting in a two-peak current. This two-peak characterristic of current was found to occur as the starch gelatinization progressed and water evaporated. First, in light wheat flower, the starch grains starts to absorb water by heating at 55 ℃ and expands (start of gelling) at the same time. At this time, the current drops and reaches its first peak.

Fig.1. Configuration of the bread baking machine experiment.

In addition, when the water absorption continues and the expansion of starch grains reaches the maximum limit at 68 ℃ in light wheat flour, the starch grains burst. Then, the current begins to rise (valley of the current value at the end of gluing). Furthermore, when the temperature of water is close to the evaporation tempreture (95 ℃), the electrolytes dissolved in the water(such as sodium ions) start to precipitate again, and the current drops to the second peak. Thus, the first peak occurs at the start of the starch gelling and the second peak occurs at the evaporation temperature. The shape of the two peaks of the current will change because the sizing temperature range depends on the types of the starch.



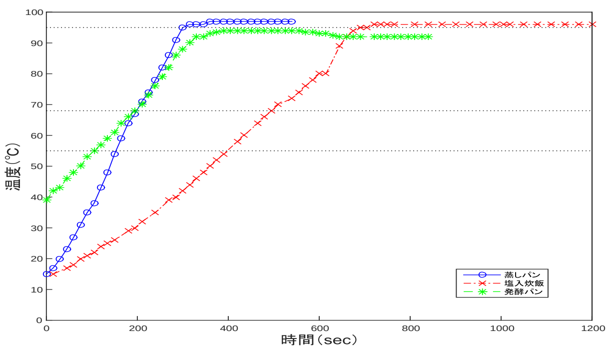


Fig.2. (Top) Power value for steamed bread (○), cooked rice (×), and yeast-fermented bread (∗). (Bottom) Time variation of water temperature. (power is current value × 100) Current is a two-peak characteristic due to gelling and evaporation.

Table 1. Sizing temperature range and precipitation start temperature of wheat flour and rice

	Start of gelling 1st peak	Gluing end valley	Precipitation start 2nd peak
Flour Light	55 ℃	68 ℃	95 ℃
Flour Strong	50 ℃	63 ℃	95 ℃
Rice	60 ℃	93 ℃	95 ℃
Glutinous Rice	64 ℃	95 ℃	95 ℃

This same mechanism was used in the student experiment of cooking rice in a bread baking machine (rice, water, and salt, marked with an × in Fig.2: finished product is shown in Fig.3 (middle)). It was confirmed that even a dough of yeast-fermented bread similarly had a two-peak characteristic (made of strong flour, water, dry yeast, salt, sugar, and unsalted butter, and marked with an ∗ in Fig.2: finished product is shown in Fig.3 (bottom)). The rice can be cooked 20 minutes and the yeast-fermented bread can be baked in 14 minutes through energization. In the electrode type, the water temperature does not exceed 100 ℃, meaning the bread would not properly bake. The thermal efficiency of all three experiments are about 70 %. The start and end temperature of starch sizing are shown in Table 1.

Fig.3. (Top) Finished original steamed bread: in 9 minutes. (Middle) Cooked rice: in 20 minutes. (Bottom) Yeast-fermented bread: in 14 minutes.

2 Electrode Type Bread Baking Machine

I donated the university's homemade bread baking machine to the Museum of Showa Life in Tokyo, which I visited about 20 years ago. As a result, Kazuko Koizumi, the directer of the museum, asked me if I would like to demonstrate the electrode-type bread baking machine at the museum's 13th special exhibition, "Bread and the Showa Era" held in August of 2016. I took that opportunity to start studying the electrode bread maker, which later led to this paper with the help of many people.

I found that this electrode type bread baking machine was invented by Shozo Akutsu, who formerly served the army in 1935. At that time, the reserch was not on steamed bread made of light wheat flour and baking powder, but on yeast-fermented bread made of strong flour dough that was energized. This technology was introduced for home use after World War II, mainly as steamed bread (today's so-called "Denki-Pan" in Japan).

In a bread baking machine used for student experiments, a yeast dough kneaded with strong flour is first fermented and then divided into three equal portions. Each one can be put in a wooden case. The second fermented dough in this case is then energized for 14 minutes as shown in Fig.3 (bottom). This corresponds to the reproduction of the electrode bread baking invented by Shozo Akutsu.

In addition, the electrode bread later became bread crumbs for business use. In 1949, after World War II, electrode bread was dried in the sun and sold. Since then, manufacturers of bread crumbs have appeared. In 1958, the production of bread crumbs was shifted from small quantities to larger and more modern production facilities under the guidance of companies such as Mikawa Electric Manufacturing Co. in Nagoya.

Even today, half of the breadcrumbs used for commercial purposes are made by the crushing of the mentioned yeast-fermented electrode type pans. The process in the fermentation of the dough is the same at the factory, but when baking the dough, depending on the nature of the desired breadcrumbs, it is either the roasting type or electrode type that is used. The roasting method, in which heat is applied from the outside by an oven, requires preheating and is less efficient than the electrode method, where the dough itself generates heat, and the equipment is larger and less economical. Thus, after World War II in southern Japan(called Kansai), The electrode method was easy for new entrants, and ultimately become widespread.

Since the electrode type does not truly bake the bread, the bread will not rise above 100 ℃ and produce white breadcrumbs that are harder than those of the roasting type and will not absorb oil as easily. The texture of the breadcrumbs did not degrade over time, so it was used by TableMark Co., Ltd.("Katokichi" in Japan) in Kagawa Prefecture, as batter for frozen fried shrimp, which became popular since the 1962. With the evolution of freezing technology, as more and more frozen foods became available in supermarkets, the Kansai electrode method spread to the Kanto region (in nothern Japan). Since 1960s, the export of breadcrumbs significantly increased, especially to the United States, where the electrode production method was also exported. A factory was set up in Los Angeles, and electrode type breadcrumbs were widely used for frozen foods in the United States.

Additionally, in an electrode-type bread baking machine, the material of what the electrode plates made out of is crucial. This is because the material of the electrode plates are electrolytically corroded by energization and are leached out the dough. Thus, the material is stipulated in the standards for food additives, etc. of the Food Sanitation Law in Japan. Initially, iron was used, but it was shown to rust quickly due to salt, causing many problems with the quality of breadcrumbs. Food poisoning caused by illegal electrode plates in factories also became a problem. Thanks to the efforts of Mr. Yasuo Shimizu, who was the chairman of the technical committee of the National Federation of bread Crumb Industry Cooperatives, the government finally approved the use of pure titanium electrode plates in 1988, which are extremely resistant to corrosion. The Food Sanitation Law was also partially amended to allow this use, which solved the problem of the material of the electrode plates.

In the experiment, it was confirmed that the current characterristics of the stainless steel electrode plate (0.6mm thickness), in which chromium is leached out, and the titanium type 1 electrode plate(0.5mm thickness) were almost the same. In student experiments and reproduced experiments, we use titanium 1 electrode plates for food safety precautions.

"Breadcrumbs are a food ingredient that was developed in Japan. The production technology of breadcrumbs in the Japanese style is remarkably excellent, especially the electric current bread-making method, which is unique to Japan. It is interesting to note that electric bread, which was originally developed for military use, was used as a household bread baking machine during the post-war food shortage, and this was further developed into a bread baking method for breadcrumbs," said Yasuo Shimizu. Breadcrumbs called "PANKO" in Japan were also recognized by the European Union, and "PANKO" was adopted as an English word in the Oxford English Dictionary in 2012.

And then, the electrode type breadcrumbs was introduced by NHK broadcasting TV program "Got it trying" in 2020.

We also introduce an electrode type yeast-fermented bread, which is actually still manufactured in factories today. As shown in Fig.5, a titanium type 1 electrode plate of 50cm × 50cm is placed in a polypropylen case as an insulator, and the electrode plates are spaced about 12cm apart and energized with 200V. At this time, the polypropylen eliminates the possibility of wood from the previous wooden mold getting mixed in with the bread. However due to the fact that it does not absorb water, it is still a work in progress.

Fig.4. Reproduced yeast-fermented bread for breadcrumbs (Left: Equal 3,in 14 min. for electrode method, Right: Equal 5,in 29 min. for roasting method).

Fig.5. (Top) Professional electrode bread baking case for business use (pure titanium plate 50cm × 50cm) (Bottom) And actual baked electrode bread for breadcrumb.

To further my reserch, I conducted an experiment between the electrode type and the roasting type of bread crumb making. The process up to the second fermentation of the bread dough is the same for both. In the case of the baking in the original bread baking machine in the student's experiment (shown in Fig.1), the dough from the first fermentation is divided into three equal parts, formed and placed in this case. The second fermented dough is then energized for 14 minutes with the dough in contact with the electrode plates as shown in Fig.3 (bottom) (White pan). The thermal efficiency is 65 %. On the other hand, in the roasting method using a home oven, the dough from the first fermentation was divided into five equal portions and placed in a bread mold for the second fermentation, since the Altaite bread mold was too thin. We first preheated the oven to 190 ℃ for 10 minutes. Next, we bake the dough in the oven at 190 ℃ for 19 minutes. The resulting bread with the electrode method is shown in Fig.4 (left) (Fig.3 (bottom), divided into three equal parts). And the bread baked in the oven (divided into five portions) is shown in Fig.4 (right) and bread is browned.

Without any methods, it takes 29 minutes, including preheating, in the oven to bake the dough. But, with electrode type method, it implements the process in 14 minutes due to the process of energization. With this, we can feel the thermal efficiency. The white electrode type bread is not baked, so the aroma of yeast is more pronounced and delicious.

3 Electrode type rice cooker

The bread baking machine invented by Shozo Akutsu in 1935 was started with the former Army's orders of creating a food service vehicle ,which would be able to cook rice and bake bread, promptly as military equipment, no matter much it costs. Before the invention of the bread baking machine, a utility model of an electrode-type rice cooker with opposing electrode plates was developed by the former army in 1934. The electrode plates used for cooking rice were improved in 1936 to make them suitable for baking bread, and a bread making machine was incorporated. In 1937, the former army commercialized a food service vehicle(as the 97 model year type) that could cook rice and bake bread as a system that included a power supply. It was also deployed in the field. The materials required to create a bread making machine consists of a wooden box with electrode plates, voltage of 115V, current of 100A, 50Hz, electrode plate spacing of 7cm, and the ability to cook 500 meals per hour in 18 case boxes. Therefore, cooking rice comes first and baking bread comes later in electrode type. In fact, the instruction manual for the feeding equipment of the food service vehicles of April 1939, ultimately only described the procedure for cooking rice, suggesting that it could potentially be used for both purposes but was not used for baking bread.

In contrast, in the same year 1934, A patent for a method of cooking rice using the electrode type from Shuzo Hidaka was issued by the Japan Patent Office. This patent was issued 5 months before the utility model of rice cooking device using electrodes with opposing plates by Shozo Akutsu of the former army.

Shuzo Hidaka made the distance between the plates about 1cm so that rice could be cooked, even with tap water. If the distance is too wide, it will not be energized unless there is salt, etc. And the plates were arranged in a concentric circle along the bottom of a round rice container(called "Ohitsu" in Japan) without opposing. Hidaka invested the electrode type rice cooker shown in Fig.6 (right), despite not being commercialized for customer use. The former army made the electrode plates stand upright, while Shuzo Hidaka made them bottom-mounted. Using Hidaka's patent the National Nutrition Association, which was established within the Ministry of Health and Welfare, commercialized and sold an electrode rice cooker of the "welfare type"(for cooking 5 cups of rice) in May 1946 after the war(shown in Fig.6). In the instruction manual of this cooker, it is written that the National Nutrition Association took over the patent of Shuzo Hidaka, whose technology was converted by the army to home use in 1934 and manufactured it. However, at present, the relationship between Shuzo Hidaka, the former army, and Shozo Akutsu is entirely unknown, and the basis for this statement in the instruction manual cannot be confirmed. Shuzo Hidaka's patent publicity also does not confirm his relationship with the former army. The original two "welfare type" electrode rice cookers have been found for now.

Furthermore, a new utility model was proposed in March of 1946, which made a comb tooth shape(type) out of the electrode plate of the concentric circles of the "welfare type" and placed it on the bottom. Similar to what is shown in Fig.7 (right) and the "comb-tooth type" electrode rice cooker, which was called "Takara-Ohachi", was commercialized and sold. There are at least four "Takara-Ohachi"s in Japan, and they have become quite popular.

The two bottom-mounted electrode plates, which can be made into consentric circles or comb tooth, is a device to make the facing length of the electrode plates at 1cm intervals longer than that of the strip type. The current flows mainly in proportion to facing length of this 1cm interval through the electrode. The electrode-type rice cooker was a stopgap until the invention of Toshiba's automatic electric rice cooker ER − 4 in 1955, which uses the current method of applying heat from outside.

Fig.6. (Left) "welfare type" rice cooker(from the collection of Hiratsuka City Museum) (Right) Concentric circlar plate at the bottom of the container.

Fig.7. (Left) "comb-teeth" type rice cooker called "Takara-Ohachi" (from the collection of the Osaka City Museum) (Right) comb teeth shaped plate at the bottom of the container(released around 1947).

These two bottom-mounted electrode type rice cooker has an iron electrode plate. And, in the case of the bottom-mounted rice cooker, boiling bubbles attached to the electrodes during boiling interferes with the electric current, causing the current to fluctuate by roughly 50 %. When rice is cooked with the stand-upright electrode type, the current does not fluctuate, and can cook evenly. I confirmed that by a reproduction experiment. I am sure that the marketed bottom-mounted electrode rice cookers and the stand-upright electrode rice cooker of the former army, of the post-war period had the same characteristics as in the reproduction experiment. In both cases, the electrode type is difficult to control the current.

We made our own electrode type rice cooker using a commercial 180ml size(called 1"go" in Japan) sawara-wood "Ohitsu" (inner diameter: 11.6cm, height:6.2cm) ,which is similar to the one used in the "welfare" type (Fig.6 and Fig.9) and "comb-teeth" type of "Takara-Ohachi" (Fig.7 and Fig.8). In addition, we made a bottom-mounted electrode plate that resembles the "Takara-Ohachi" by bending the opposite electrode plates of the stand-upright case(shown in Fig.1), and made one in which electric current flows even with tap water (like Fig.10). In tap water, only 6 Watt current can flow through the side opposing plates(Fig.1), so rice cannot be cooked. The performance of each of these was evaluated in a reproduction experiment. All cooking rice was rice 150g, water 230g, salt 0.4g(if we needed) in any rice cooker.

In three cases with the electrode plate spacing of 1cm at the bottom, it was confirmed that the rice could be cooked in about 20 minutes, even with tap water. The thermal efficiency of upright case(like Fig.10) was 70 %, while that of the "Ohitsu" case(like Fig.8 and Fig.9), with its wide bottom and small internal volume, was 80 % and increased from 10 % (is shown in Table 2). In the upright case, the thermal efficiency is same as 70 %, even when salt is added.

The X mark in the upper panel of Fig.11 indicates a graph of the current characteristics of the rice cooked on a concentric circlar shape(Fig.9) with tap water. The lower figure shows change in water temperature over time on the horizontal axis(the same as upper figure). According to the X mark of Figure 11, The current characteristics show that gelling occurs even without salt, but the current is not affected by gelatinization because there is little electrolyte. For that reason, the first peak due to the start of gelling does not appear, it turned out to be one peak characteristics, and then only the second peak due to evaporation appears.

According to the reproduction experiment, although not shown in the graph of Fig.11, in all three cases(Fig.9, Fig.8 and Fig.10), the current characteristics of tap water cooking are similar to the current characteristics of the concentric cercles in the bottom of case(Fig.9) and only the second peak due to evaporation appears as one peak characteristics. And in all three cases, the current becomes two peaks if salt is added. Additionally, as shown the X mark of Fig.11, the system of the bottom-mounted electrode type (Fig.8, Fig.9 and Fig.10) will wobble and become unstable at about current peak. The current fluctuates by about 50 % and becomes unstable, because of the bubbles on the bottom electrode plates when boiling. The current peaks at only 2A. The heat source is only at the bottom of the rice as bottom-mounted elctrode types, so the rice cannot be cooked evenly and does not taste very good. The current of a three types of rice cookers becomes unstable when salt is added as well (the current becomes two peaks, though). In the case of the old army method(Fig.1), where only opposing stand-upright plates are used, there is no wobble in the current and the rice can be cooked evenly from the sides, resulting in good performance.

Fig.8. (Left) Rice cooker with bottom-mounted comb teeth in the shape of a rice container(reproduction of "Takara-Ohachi" made by myself) (Right) Cooked rice: in 25 minutes.

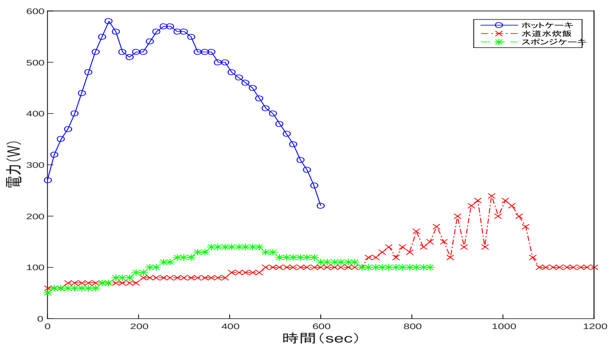
Fig.9. (Left) Concetric rice cooker with a bottom-mounted rice container(reproduction of "welfare type" made by myself) (Right) Cooked rice: in 20 minutes.

Fig.10. Bottom-mounted comb-tooth shaped electrode plates in a stand-upright case of original (self-made reproduction) (Right) Cooked rice: in 20 minutes.

We confirmed that, on the other hand, wheat flower has about 4 times as much minerals(electrolytes) as rice, so even if the flower is just dissolved in the tap water and the dough is energized, it will have a two peak characteristic.

4 Electrode Sponge Cake

In addition to conventional liquid dough and yeast-fermented kneaded dough, we investigated the characteristics of foamy dough made with whipped whole eggs. I have never examined an electrode type sponge cake mentioned in previous research. The type with the electrode plate at the bottom of the container has a rapid rise in current and a rapid fall. The opposing type rises and falls slowly, and has an equal heat source from the sides, so it is suitable for powdered foods that are made to expand by means of baking powder, fermentation, or egg whipping. Rice is an excellent starch that does not need to be inflated because it is a grain food.



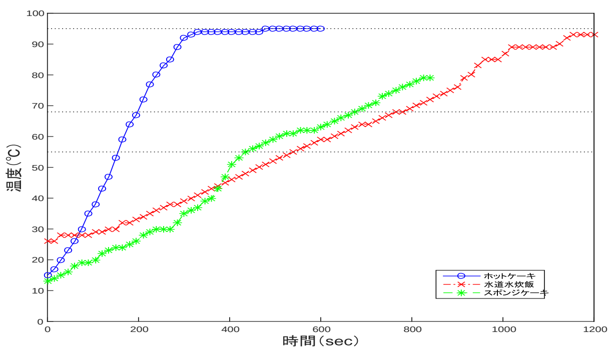


Fig.11. (Upper) Power values for rice cooked with tap water(×) in the concentric circle type with the bottom of the rice container, pancake with whole egg mixture(○) and sponge cake with whipped whole egg(∗) in a stand-upright case of original (Bottom) Time variation of water temperature: two peak for pancakes, one peak only for the second peak(evaporation) for cooking rice with tap water, one peak only for the first peak(the start of gelling) for sponge cake.

The current characteristics are shown in the ○ mark of Fig.11, when pancake batter is made by just mixing whole eggs with liquid steamed bread batter(shown in the ○ mark of Fig.2) on the opposite electrode plate of the student's experiment case. We confirmed that the current characteristic of the pancake is the same as that of the steamed bread(a two peak characterictic), even with whole eggs mixed in.

Next, I made an electrode sponge cake by whipping whole eggs with a mixer, adding sugar and salt, shaking wheat flour, baking powder, melted unsalted butter, and milk to make a foamy dough, and then energizing it. The foamy batter is the same, but when it is baked in the oven, it needs to be preheated for 10 minutes to reach 180 ℃ and then baked at 180 ℃ for 25 minutes. So it is for a total of 35 minutes. With the electrode method, however, it can be done by only energizing for 14 minutes. It tastes good, although it only rises to 100 ℃ and does not bake.

Fig.12 "Electrode cake" with whole egg whipped batter energized.

Table 2. Two peak characteristics of each electrode type cooking

	1st	2nd	Finish ed time (min.)	Efficie ncy (%)	Peak current (W)
Steam ed bun	○	○	9	70	500
Ferment ed bread	○	○	14	63	200
Rice and salt water	○	○	20	70	400
Rice and tap water	×	○	20	80	250
Electrode Cake	○	×	14	-	150
Pancake	○	○	10	70	580

The current characteristics are shown by the ∗ mark in Fig.11. The finished product is shown in Fig.12. At this time, for the foamy dough, the second current peak due to evaporation does not appear, but only the first current peak due to the start of gelling appears as one peak characteristics. The first peak appears because of the electrolyte. It is different from the one peak characteristic where only the second peak appears for the tap water cooking of rice (shown in the × mark of Fig.11). This is because the whole egg whipped foam dough solidifies the sponge structure of the dough after the end of gluing, and the current drop due to precipitation does not occur during evaporation. Also, due to the water content in the whole egg, the thermal efficiency cannot be calculated by the conventional method. Although the electrode method is difficult to adjust the current and there is a risk of electric shock, it was found to be a sufficiently useful technology(Table 2).

literature

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3) Takashi Aoki (2020) Reproduction Experiments Using Electrode Rice Cooker ／ Bread Machine. Science Journal of Kanagawa University **31**: 25-32.
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5 Electrode Cooking Recipe Collection(0.5mm thick titanium type 1 electrode plate)

5.1 Basic Steamed Buns(liguid dough)

(1) Flour(wheat flour) ： 150g

(2) Baking powder ： 6g (or 1.5g of baking-soda:)

(3) Salt：0.4g

(4) sugar：25g

(5) Water：190g

(6) It will drop to 1A in 9 minutes.

5.2 Basic rice cooking

(1) Rice：150g, increase by 14g after draining.

(2) Salt：0.4g

(3) Water：230g, soak for 30 minites.(For gulutinous(mochi) rice, 180g)

(4) When the tempereture at the end of gluing reaches 93 ℃, the lid is closed just before the minimum current(2.5A in 11 minutes).

(5) After the tempereture drops to 1A in 23 minutes, turn off the power and wait for 5 minutes.

(6) Mochi rice is first-glutinizing and can be cooked in 20 minutes. There is no need to soak the rice in water after draining. The sizing tempereture range of mochi rice shifts to a higher 4 ℃ tempereture range than that of leach rice. Therefore the second peak overlaps with the evaporation tempereture and is small and hidden.

5.3 Yeast Fermented bread: Bread crumbs in parentheses For(kneaded)

(1) Flour(strong flour)：150g

(2) Dry yeast：4.5g

(3) Salt：2.0g （1.5g）

(4) Sugar：10.0g （2.5g）

(5) Unsalted butter：15g （5g）

(6) Water(33 ℃)：100g

(7) After kneading, primary fermentation is carried out at 42 ℃ for 25 minutes.

(8) Remove gas, divide into equal parts, roll and shape into a electrode bread case.

(9) Secondary fermentation at 42 ℃ for 25 minutes, while still in the electrode bread case.

(10) After 11 minites, the current becomes 0.3A, and the power is turned on and the lid is put on to steam until 14 minutes.

5.4 Electrode-type cake(whipped whole egg)

(1) Medium whole egg：100g as 2 eggs(without shell)

(2) Flour(wheat flour)：50g

(3) Sugar：40g

(4) Unsalted butter：13g

(5) Unadjusted milk：15(24)g（or "ricotta cheese 20g ＋ milk 9g" for better taste）

(6) Baking powder：1.0g

(7) Salt：0.6g

(8) Whip the whole eggs, sugar and salt, mix in the flour and baking powder, add the melted unsalted butter and milk, make a dough. Cover it and let it stand for 14 minutes.