AP-42 Section Number: 9.9.1

Reference Number: 8

Title: Rice Chemistry And Technology

American Association Of Cereal Chemists, Inc.

1985

AP-42 Section 9.9.1
Reference 8
Report Sect. ___
Reference ___

Rice: Chemistry and Technology

Edited by
Bienvenido O. Juliano

Department of Cereal Chemistry
International Rice Research Institute
Los Baños, Laguna, Philippines

Published by the

The American Association of Cereal Chemists, Inc.
St. Paul, Minnesota, USA

(612) 454-7250
(800) 328-7560

ɪrs: Semidwarf rice—an IR selection.
Courtesy B. O. Juliano

ry of Congress Catalog Card Number: 85-073192
ıational Standard Book Number: 0-913250-41-4

shed 1972. Second Edition 1985

d in the United States of America

ican Association of Cereal Chemists, Inc.
Pilot Knob Road
ul, Minnesota 55121, USA

CONTRIBUTORS

M. M. Bean, Cereals Research Unit, Western Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Albany, California, U.S.A.

D. B. Bechtel, U.S. Grain Marketing Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Manhattan, Kansas, U.S.A.

K. R. Bhattacharya, Discipline of Grain Science and Technology, Central Food Technological Research Institute, Mysore, India

E. E. Burns, Department of Horticultural Sciences, Texas A&M University, College Station, Texas, U.S.A.

D. L. Calderwood (*retired*), Agricultural Research Service, U.S. Department of Agriculture, Beaumont, Texas, U.S.A.

R. R. Cogburn, Stored Products Insects Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Texas A&M University Agricultural Research and Extension Center, Beaumont, Texas, U.S.A.

D. L. Gerdes, Department of Food Science, Louisiana State University Agricultural Center, Louisiana Agricultural Experiment Station, Baton Rouge, Louisiana, U.S.A.

B. O. Juliano, Cereal Chemistry Department, International Rice Research Institute, Los Baños, Laguna, Philippines

V. J. Kelly, Gerber Products Company, Fremont, Michigan, U.S.A.

S. Kishi, Production and Technical Control Department, Kirin Brewery Co, Ltd., Yokohama, Japan

O. R. Kunze, Texas Agricultural Experiment Station and Texas A&M University, College Station, Texas, U.S.A.

M. Misaki, Food Products Division, Takeda Chemical Industries, Ltd., Tokyo, Japan

K. D. Nishita, Cereals Research Unit, Western Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Albany, California, U.S.A.

CONTENTS

Rice:
Chemistry and Technology

OWBHAGYA, C. M., and BHATTACHARYA, K. R. 1976. Lipid autoxidation in rice. J. Food Sci. 41:1018-1023.
IBBA RAO, P. V., and BHATTACHARYA, K. R. 1966. Effect of parboiling on thiamine content of rice. J. Agric. Food Chem. 14:479-482.
BRAHMANYAN, V., SREENIVASAN, A., and DAS GUPTA, H. P. 1938. Studies on quality of rice. I. Effect of milling on the chemical composition and commercial qualities of raw and parboiled rice. Indian J. Agric. Sci. 8:459-486.
BRAHMANYAN, V., DESIKACHAR, H. S. R., and BHATIA, D. S. 1955. Commercial methods of parboiling paddy and improvement of the quality of parboiled rice. J. Sci. Ind. Res. 14A:110-114.
VAMINATHAN, M. 1941. The effect of washing and cooking on the nicotinic acid content of raw and parboiled rice. Indian J. Med. Res. 29:83-88.
VAMINATHAN, M. 1942. The effect of washing and cooking on the vitamin B_1 content of raw and parboiled milled rice. Indian J. Med. Res. 30:409-416.
TA, S. N. 1962. Parboiled rice. Rice News Teller 10(2/3):50-52.
YLOR, J., MARTIN, C. DE C., and THANT, U. 1928. Preliminary inquiry into beri-beri in Burma. Indian Med. Res. Mem. No. 8. (Cited by Aykroyd et al, 1940)
NIKRISHNAN, K. R., and BHATTACHARYA, K. R. 1981. Swelling and solubility behaviour of parboiled rice flour. J. Food Technol. 16:403-408.
NIKRISHNAN, K. R., and BHATTACHARYA, K. R. 1983. Cold-slurry viscosity of processed rice flour. J. Texture Stud. 14:21-30.
NIKRISHNAN, K. R., VIRAKTAMATH, C. S., KRISHNAMURTHY, H., and BHATTACHARYA, K. R. 1982. Parboiling of paddy by simple soaking in hot water. J. Food Technol. 17:499-506.
SAN, B. S., and KUMARAVEL, S. 1982. The role of dissolved oxygen in the improvement of cold soaking process of paddy. J. Food Sci. Technol. 19:31-34.
SAN, B. S., IENGAR, N. G. C., SUBRAMANYAM, T. V., CHANDRASEKARAN, R., and SUBRAHMANYAN, V. 1971. Effect of processing on the movement of oil in the rice kernel and its relation to the oil content of paddy and the yield of oil from rice bran. Interregional Seminar on the Industrial Processing of Rice. Food and Agriculture Organization, ECAFE, and Government of India, Madras.
VASAN, B. S., IENGAR, N. G. C., NAGASUBRAMANIAN, M., BHASKER, R., SHIVANNA, C. S., MOHANADOSS, R., and SUBRAHMANYAN, V. 1973. Studies on the action of cations on paddy, with particular reference to the role of sodium ion and its application in the preservation, parboiling and drying of paddy. Proc. Indian Natl. Sci. Acad. 39B:32-62.
VASAN, B. S., BASHEER, J., and VENKATESAN, V. 1980. Use of hot air for parboiling and drying of paddy. J. Food Sci. Technol. 17:246-247.
VEDDER, E. B. 1913. Beri-beri. William Wood, New York.
VINACKE, W. R., HARTZLER, E., and TANADA, Y. 1950. Processed rice in Hawaii. Tech. Bull. 10. Univ. Hawaii Agric. Exp. Stn., Honolulu.
VIRAKTAMATH, C. S., and DESIKACHAR, H. S. R. 1971. Inactivation of lipase in rice bran in Indian rice mills. J. Food Sci. Technol. 8:70-74.
VITTI, P., LEITAO, R. F. F., and DIZZINATTO, A. 1975. Parboiling of rice varieties. (in Portugese) Coletanca Inst. Technol. Alimentos 6(1):103-119. (Food Sci. Technol. Abstr. 8:5M618, 1976)
WASSERMAN, T., FERREL, R. E., BROWN, A. H., and SMITH, G. S. 1957. Commercial drying of Western rice. Cereal Sci. Today 2:251-254.
WASSERMAN, T., FERREL, R. E., KAUFMAN, V. F., SMITH, G. S., KESTER, E. B., and LEATHERS, J. G. 1958. Improvements in commercial drying of Western rice. I. Mixing type dryer—Louisiana State University design. Rice J. 61(4):30-32, 34-36, 38; 61(5):40, 42-46.
WEBB, B. D., and ADAIR, C. R. 1970. Laboratory parboiling apparatus and methods of evaluating parboil-canning stability of rice. Cereal Chem. 47:708-714.
WILLIAMS, K. T., and BEVENUE, A. 1953. A note on the sugars in rice. Cereal Chem. 30:267-269.

CHAPTER 9

RICE MILLING: AN OVERVIEW

HARRY T. L. van RUITEN
Directorate General for International Cooperation[1]
Ministry of Foreign Affairs
Royal Netherlands Government
The Hague, Netherlands

I. INTRODUCTION

The performance of a rice mill, in terms of milled rice recovery and quality, not only depends on the type or condition of the equipment and on the skill of the operators, but is largely determined by the quality of the rough rice (paddy) to be converted into milled rice. This chapter therefore includes a review of the impacts of rough rice quality, specific varietal characteristics, and parboiling on the performance of rice mills before dealing with rice milling as an important link in the postharvest processing of rough rice.

Close to 50% of the total rough rice production is not marketed but kept at the farm or village level to meet subsistence requirements and is converted into milled rice at that level. In view of the importance of rice milling at the village level, this subject has been given special attention in this chapter.

The marketable surplus of rough rice is processed in different types of rice mills in both the developing and the industrialized rice-producing countries of the world. Basically two systems are applied, namely, the conventional system and the Japanese system; however, a mixture of the two is frequently utilized. The chapter therefore discusses the basic differences between the two systems. Finally, attention is paid to the different sections of the rice milling process, with summaries of the latest developments.

Through this approach, discussion is general, avoiding emphasis on a specific process in one rice-producing country.

II. ASPECTS OF IMPORTANCE IN ROUGH RICE MILLING

The milling potentials of the rough rice largely determine the performance of a rice mill in terms of milled rice recovery and quality. These milling potentials can

[1]Assigned through the Southeast Asia Regional Center for Graduate Study and Research in Agriculture, Los Baños, Philippines, to the technical team of the ASEAN Crops Post-Harvest Programme.

be of varietal origin, can be related to the quality condition of the rough rice, or can be added through premilling processes.

A. Varietal Characteristics

Varieties of rough rice are differently grouped. They are classed as short, medium, long, and extra long. A subclassification—round, bold, and slender—refers to the ratio between the length and the width of the brown rice. Although exceptions exist, as a general rule, most of the short varieties are round or bold, whereas most of the medium varieties are bold or slender, and practically all of the long and extra long varieties belong to the slender subtypes. Most of the japonica varieties are short and round, and most of the indica varieties belong to the medium, long, and extra long types and are therefore bold or slender (van Ruiten, 1979e).

HULL WEIGHT OF ROUGH RICE

In general, the short, round grains have a hull (husk) weight below 20% of the rough rice weight. In japonica varieties, this percentage fluctuates between 17 and 20%. The medium, bold and slender varieties have hull weights between 20 and 23%, whereas most of the long and extra long, slender varieties have hull weights fluctuating between 22 and 24%. Therefore, the weight of hull as a percentage of the weight of rough rice ranges from 17 to 24%.

Even within a pure variety, the hull weight fluctuates depending on the condition of the individual grain, with the thicker grains having the lowest percentage of hull weight and the thinner grains having the highest. Consequently, it *cannot* be said that rough rice has a uniform percentage of hull weight.

With those differences in the weight of the hull, fluctuations will be found in the weight of the brown rice after dehulling. The milled rice recovery is directly related to the brown rice yield; therefore, a lower hull weight will result in a higher milled rice recovery and, conversely, a higher hull weight will result in a lower milled rice recovery.

GRAIN SHAPE

This refers to the length-width ratio of the brown rice. Round grains have a low ratio and are difficult to break, whereas the slender grains, with a high ratio, break rather easily. Since breakage reduces milled rice recovery through increased bran and brewers' rice production, it is to be expected that the milled rice recovery and quality of slender grain will be lower than that of the bold-shaped grains, and the same can be expected when comparing the rice mill performance of bold-shaped grain with that of round-shaped grain. Consequently, better milling results can be obtained on japonica varieties, which are round, than on the slender indica varieties.

HARDNESS

The surface hardness of the brown rice kernel is a varietal characteristic that determines the extent to which the grain can resist the forces applied during milling. Lower surface hardness facilitates breakage during milling, resulting in lower milled rice recovery and quality.

CHALKINESS

Chalkiness is also a varietal characteristic, although chalkiness can be developed as result of prevailing weather conditions during the growth period or introduced as result of premilling processes such as improper parboiling. Chalkiness reduces the grain's resistance to applied milling forces, resulting in lower milled rice quality through increased breakage and in reduced milled rice recovery.

B. Quality of Rough Rice

The quality or grade of rough rice is determined by a number of aspects that are sometimes interrelated. These aspects are the moisture content of the rough rice, the purity of the rough rice (which is related to the presence of impurities), cracked grain, immature grain, discolored grain, damaged grain, red rice, and the varietal purity (van Ruiten, 1979c).

The extent of these quality aspects is determined by prevailing weather conditions during the production periods, applied production practices, soil condition, applied harvesting methods, and applied postharvest practices such as field handling, threshing, winnowing, drying, and storage.

In other words, the quality of rough rice is determined partly by prevailing conditions beyond human control and partly by conditions under control of the people involved in the application of the production and postproduction processes. Each of these quality aspects influences the milling potential of the rough rice, and it is essential to be aware of their impacts on processing, most of which are negative.

MOISTURE CONTENT

Rough rice has its optimum milling potential at a moisture content of about 14%. Therefore, freshly harvested and threshed rough rice must be dried. The drying process is critical, for it determines whether or not fissures and/or full cracks are introduced in the grain structure (Araullo et al, 1976) (see Chapters 5 and 6).

The presence of these fissures and/or cracks leads to breakage in milling, resulting in lower milled rice recovery and quality. Milling of overdried rough rice, for instance at a moisture content level of 12%, makes the grain too brittle, which then also results in unnecessary breakage (Araullo et al, 1976).

DEGREE OF PURITY

Normally a small percentage of impurities or foreign matter is allowed, with 3% as a generally accepted indicator. Frequently, however, and especially in developing countries, the level of impurities can be extremely high, sometimes reaching 20%. To a large extent, these impurities are chaff (empty hulls), although a wide range of other foreign matter is included.

Since in many countries rough rice is bought on a wet basis and since determination of the degree of purity on a wet basis is very difficult, large quantities of rough rice are received for milling at much too low a purity level. No milled rice can be produced from impurities, and an excessive level of impurities therefore seriously reduces the milled rice recovery below the level that would be expected from the initial weight of the "high purity" rough rice.

Very high levels of impurities also disturb the smooth operation of the rice mill by overloading the precleaning section and the built-in aspiration systems.

CRACKED GRAINS

Overexposure of matured rough rice to fluctuating weather conditions, especially in the humid tropics, leads to the development of numerous fissures, ultimately resulting in a number of full cracks. Since breakage in milling results in increased bran and brewers' rice production, the presence of cracked grains suppresses the milled rice recovery and lowers the quality of the milled rice through a reduction of the head-rice yield. This quality aspect is largely ignored in the procurement of rough rice, but its negative impact on the performance of a rice mill should not be underestimated and deserves utmost attention.

IMMATURE GRAINS

The impact of immature rough rice on the performance of a rice mill is far more critical. Immature grain has a very high hull weight and consequently a very low yield of brown rice. Furthermore, the immature brown rice kernels are very slender and dominantly chalky, resulting in excessive production of bran, brokens, and brewers' rice. Altogether, the result is a sharp reduction in milled rice recovery and quality.

In the milling process, the presence of immature grain disturbs the smooth operation of the unit. It requires special provisions for separation or reprocessing. When immature grains are separated and bagged off, the milled rice recovery is reduced but the milled rice quality is upgraded. If they are recirculated through the milling process, the recovery loss is minimized but the negative impact on milled rice quality is maximal.

The processing problems with immature grain are very serious in the humid tropics, especially with the wet-season crops of the high-yielding varieties. These problems, in fact, are a source of great concern not only to breeders but also to the rice industry in general.

FERMENTED (YELLOW) GRAIN

This problem is not as serious in rice-producing countries with a moderate climate but is very serious in the humid tropics, especially on the wet-season crops of the high-yielding varieties. The cause of yellowing has been identified as a combination of microbiological and chemical activities triggered by overexposure of harvested, unthreshed rough rice in the field to extremely wet environmental conditions that result in overheating of the grain before it is dried. The percentage of yellow grain can be as high as 50%. In milling, yellow kernels mainly downgrade the quality of the milled rice because of their unattractive appearance.

The heat/water exposure, however, introduces a mild form of the parboiling process, thus improving the dried grain's resistance to the forces applied in milling. As result, milled rice recovery in general does not suffer from the presence of fermented grains.

DAMAGED GRAINS

This term refers to the presence of black spots around the germ end of the brown rice kernel. When processed, the milled rice is distinctly black near the grain point. This damage is caused by the development of microorganisms (fungi) and is increased by unfavorable weather conditions in the humid tropics. Here again, the wet-season crop of the high-yielding varieties is most susceptible. In the process of milling, these black spots are only partly removed; consequently, the presence of damaged grain lowers the quality grade of milled rice through its appearance.

In quality-oriented markets, rice mills can remove these grains with color-sorting machines. This requires a high investment, and the removal of damaged grains as rejects reduces the milled rice recovery. However, the quality is then upgraded.

RED RICE

These are grains with a strongly discolored pericarp. When fully milled rice is to be produced, the pericarp is normally completely removed and does not cause any problem. Red rice causes difficulties if *not fully* milled rice is to be produced and when the presence of red streaks (remnants of the reddish pericarp) on the milled rice grain is not allowed and is subject to penalties. Under those conditions, the rice mill owner experiences economic losses because of penalty discounts.

VARIETAL PURITY (MIXED VARIETIES)

Especially in the developing countries, the rough rice produced is a mixture of different varieties. Through improved seed production and distribution systems, attempts are being made to correct this situation, but it is likely to remain a problem in the rice milling industry for many years to come.

A problem it is indeed, especially when the mixed varieties have different grain dimensions. The rice mill then encounters a series of difficulties such as reduced capacities, excessive breakage, lower milled rice recovery, and reduced milled rice quality. These interlinked difficulties are caused by the limited adjustability of the individual processing machines, resulting in low initial dehulling efficiencies, a too-high percentage of recirculated (return) rough rice, nonuniform whitening, and milled rice grading problems. Only through a more complicated machine layout can the impact of these problems be reduced or eliminated. However, the extra investment involved is normally uneconomical.

C. Impact of Parboiling

Through the intensive water/heat treatment to which rough rice is exposed during parboiling, a number of changes are introduced that affect its milling potential. From the rice milling point of view, the most important changes are the breaking of the tight hull seal, a structural change of the outer bran layer, gelatinization of the starchy endosperm, hardening of the brown rice grain as whole, and discoloration of the grain. The intensity of these changes strongly depends on the applied parboiling method, which can be based on either primitive, traditional practices or scientifically developed processes.

BREAKING OF THE HULL SEAL

The hull halves (lemma and palea) are beautifully and tightly sealed together, making the hull difficult to separate from the brown rice in the dehulling section of the rice mill. However, as a result of the enormous swelling of the brown rice kernel during the soaking and steaming of the rough rice when it is parboiled, this hull seal is broken.

After parboiled rough rice is dried, the two hull halves are no longer held tightly together. This is a great advantage in dehulling the rough rice, resulting in high dehulling efficiency, an increase in machine capacity, reduction of breakage during the dehulling, and longer life of machine components. Under these circumstances, the dehulling and consequently the whole of the milling process become more efficient.

STRUCTURAL CHANGES IN THE BRAN LAYER

As result of the steaming, but also through the soaking, the structure of the bran layers is changed and their components redistributed; the heat treatment results in a more sticky bran. This means that the outer bran layer can no longer be removed in a full powdery form during the first stage of the whitening process and results in frequent clogging of the whitening screen by a rather oily bran paste. This problem requires special processing provisions but frequently is not given full attention and then seriously disturbs the smooth and uninterrupted operation of the rice mill.

GELATINIZATION OF THE STARCHY ENDOSPERM

The gelatinization of the starch cells during the steaming eliminates all fissures and cracks, and the overall structure of the starchy endosperm becomes more compact. The brown rice kernel therefore obtains an optimum ability to resist the forces applied to the grain during milling, especially during the different whitening stages. Consequently, breakage is very low, resulting in an increase in the milled rice recovery and the head-rice yield. Production of brewers' rice is also minimal.

INCREASED HARDNESS

The hardness of the brown rice kernel is increased after parboiling and drying, improving the grain's resistance to the milling forces. This change in hardness results in higher milled rice recovery and head-rice yield.

DISCOLORATION OF THE GRAIN

In the parboiling process, the rough rice is soaked in hot water over a rather long period. Depending on the process, the soaking time varies from 4 hr up to 48 hr, during which the color of the brown rice kernel changes from translucent white to a yellowish and sometimes brownish color. These color changes result from microbiological activities, chemical changes, and the pigment of the hull being absorbed into the brown rice kernel with the water. The degree of discoloration of the parboiled rough rice determines the degree to which the quality of the milled rice is affected. In modern parboiling processes, the utmost is done to shorten the soaking time in order to avoid or at least reduce the economic losses resulting from a down-grading of the milled rice quality through discoloration.

III. RICE MILLING AT THE VILLAGE LEVEL

In developing countries, a huge quantity of rough rice is kept by farmers and, in the villages, by the rural labor force involved in rice farming. Whenever needed, small quantities of this rough rice are converted to milled rice to meet subsistence requirements and are sometimes milled and sold for cash.

Traditionally, the rough rice is either hand-pounded or processed by steel-roll huller mills of the well-known Engelberg type. After World War II, small-scale village-type milling units of Japanese origin, using a rubber-roll huller for dehulling and a friction mill (whitener) for bran removal, entered the markets of Southeast Asia, Asia, the Pacific, Africa, and Latin America. As a result of the steady growth of the local manufacturing industry in developing countries, most of the originally imported small-scale village-type rice mills are now locally manufactured, and in some countries, such as Thailand, small mills based on local processing concepts were designed and produced.

The processing methods used for the conversion of rough rice into milled rice at the village level can therefore be grouped into traditional methods, i.e., 1) hand pounding and 2) Engelberg-type milling units, and postwar developments, i.e., 1) the rubber-roll huller/hull aspirator combined with a separate friction whitener (split units), 2) the single-pass rubber-roll huller/hull aspirator/friction whitener unit, and 3) other locally developed concepts.

A short discussion of these processing options will clarify the prevailing processing situation at the village level.

A. Traditional Methods

HAND-POUNDING

Hand-pounding is still practiced in many developing countries, especially in Africa, although this practice is slowly but surely diminishing in importance with the steady and expanding demand for small-scale village-type milling units. In some countries, hand-pounding will continue to be used for years to come under the pressure of prevailing social conditions in the rural areas.

From a nutritional point of view, the hand-pounding of rough rice has an advantage over mechanized rice milling, since only the outer bran layer is removed, leaving most of the germ and bran attached to the grain. The nutritional value of the cooked rice is increased because the germ and bran contain high levels of oil, minerals, protein, and vitamins.

ENGELBERG RICE MILL

This machine was originally developed in the United States. After expiration of patent protection, the Engelberg unit was manufactured in Europe for export. In the course of time, the local manufacturing industries in developing countries largely reduced the importation of the Engelberg-type rice mill through their own production programs. Use of this type of small-scale rice mill is widespread, and the machine can be found in operation in large numbers in practically all rice-producing developing countries of the world (van Ruiten, 1979d).

The mill is a single-pass rice milling machine that converts rough rice into milled rice in a single operation. The main component is a fast-running, horizontal, cast-steel cylinder provided with hard steel obstructions (Fig. 1). The lower half of the cylindrical working chamber is provided with a hard steel screen with slotted perforations. An adjustable steel blade, positioned in the lower frame half of the machine and parallel to the cast-steel cylinder introduces the necessary resistance and friction. The actual pressure on the grain inside the machine is controlled by the adjustable grain discharge valve in the grain outlet spout.

Rough rice enters the working chamber of the machine through a hopper. At this point of entry, the cast-steel cylinder has inclined hard steel obstructions, partly to function as a horizontal feeder but mainly to introduce obstructive forces through friction, resulting in the dehulling of the rough rice.

The mixture of brown rice and hull then enters the actual whitening section of the working chamber, where the cast-steel cylinder is provided with parallel obstructions and where the perforated screen is installed over the full length of the section.

The mixture of brown rice and hull is exposed to high-frequency friction under high pressure. Assisted by the abrasiveness of the hull, and through intensive friction under pressure, the germ and bran are removed. Simultaneously, a large percentage of the grain is broken. The fully milled rice is continuously discharged through the grain outlet spout.

In view of the high breakage, the milled rice recoveries and qualities are low. During the milling, the hull is disintegrated and is discharged through the perforated screen together with the germ, bran, small brokens, and brewers' rice. This screen discharge, called "huller bran," plays an important role as feed for backyard animals and is therefore extremely valuable for farmers and villagers in meeting their subsistence requirements.

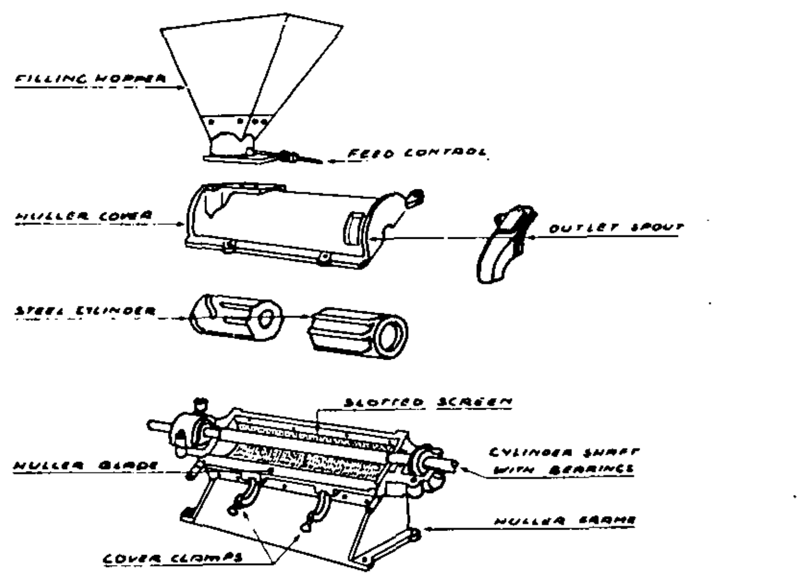

Fig. 1. Main parts of an Engelberg huller.

For the rural population, the Engelberg rice mill unit is a combination of a rice mill and a feed mill, which explains its widespread popularity in developing countries, especially in the more remote areas. The machine operates on very small quantities of rough rice and is very robust; replacement parts are normally readily available. Its lifetime is extremely long, 20–40 years depending on its use rate and maintenance.

Clearly, the role of this machine is strongly related to socioeconomic conditions prevailing in the rural areas of developing countries. The Engelberg machine will probably remain popular as long as farmers' income is low and farmers are forced to pay hired rural laborers in kind instead of in cash.

Use of the Engelberg mill in the rice milling industry is gradually self-liquidating as the standard of living of the rural population improves. This, however, is a long-term process.

B. Postwar Developments

RUBBER-ROLL HULLER/HULL ASPIRATOR UNIT COMBINED WITH SEPARATE FRICTION WHITENER (SPLIT UNIT)

These small-scale village-type rice mills actually consist of two machines, a brown-rice production unit and a friction-type whitener. Normally, but not

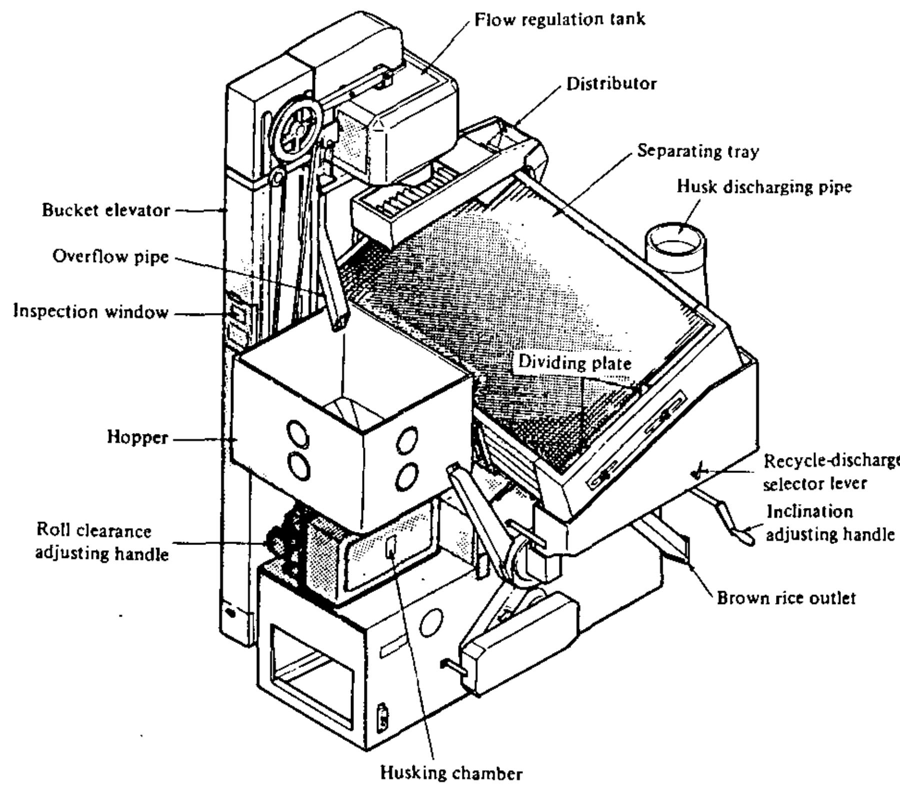

Fig. 2. Independent brown-rice production unit. (Courtesy Satake Engineering Co., Ltd.)

always, these two machines are interconnected and centrally driven by a diesel engine. The history of this type of rice mill is strongly related to conditions in the Japanese rice industry. The millions of small farmers in Japan do not store rough rice but brown rice. Therefore, a well-established, large market exists in Japan for small-capacity brown-rice production units, to which demand the Japanese manufacturing industry has responded. Having established a certain level of mass production of these units, the Japanese manufacturers have been successfully trying to secure continuous optimal production by creating export markets for their equipment. However, prospects for selling brown-rice production units in developing countries are practically nonexistent *unless* the brown rice produced by these machines can also be converted into milled rice.

It was therefore necessary to introduce a separate whitener. The friction whitener was chosen and generally accepted. A wide range of brown-rice production units of basically Japanese concept exist. Practically all of these machines consist of a small rubber-roll huller combined with a hull aspirator. The operation of the rubber-roll huller is discussed below.

Some Japanese manufacturers have been promoting the use of centrifugal or impact hullers. In view of the enormous wear on expensive components and the

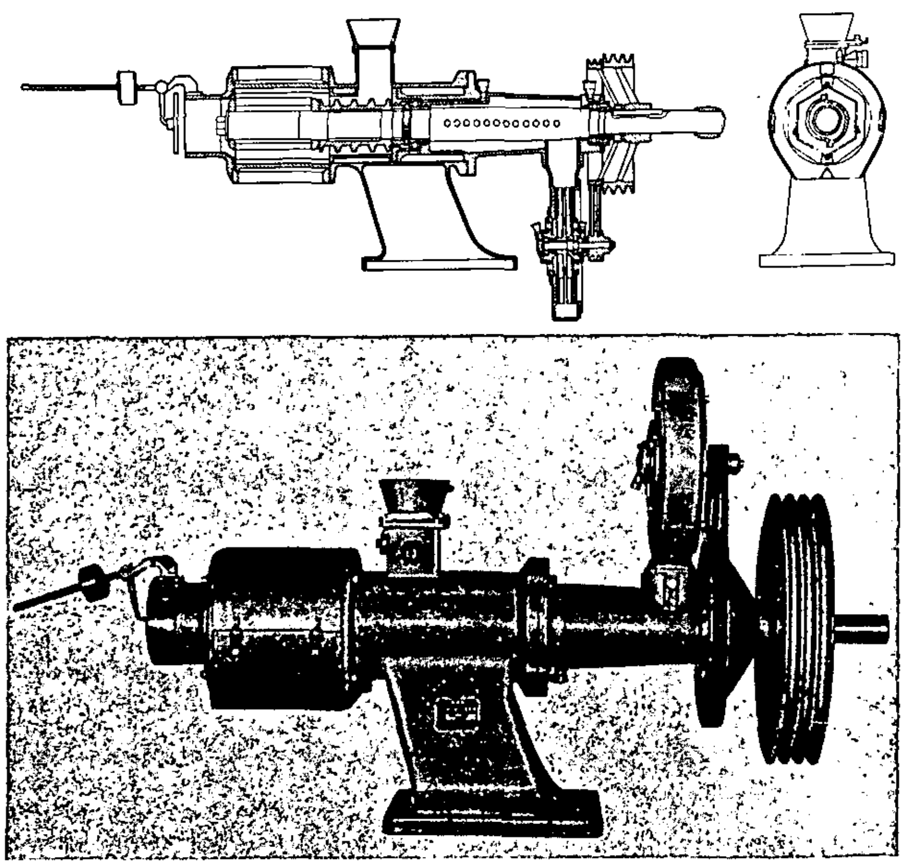

Fig. 3. Cross section (top) of a jet pearler (bottom). (Courtesy Satake Engineering Co., Ltd.)

inconsistency in performance, this type of huller is not very popular and is disappearing from the market.

A number of manufacturers in Japan have extended the machine specification of brown-rice production units by incorporating a rough-rice separator. This machine separates rough rice from brown rice and recirculates it as return rough rice over to the rubber-roll huller (Fig. 2).

The originally developed jet pearler (Fig. 3) and the more compact friction whitener (Fig. 4) are also used. Both machines are friction-type whiteners and operate on the same principles.

On a partially hollow horizontal shaft provided with air holes, a feed screw is mounted, followed by a cast-steel milling cylinder with hard steel obstructions and air slots in parallel position. This assembly rotates at high speed inside a hexagonal working chamber formed by the two halves of a screen with slotted perforations. High-pressure air is blown through the hollow shaft, passes through the air holes of this shaft and the air slots of the cast-steel cylinder, then passes through the grain mass, and finally leaves the machine through the slots of the hexagonal screen. This air is important because it cools the grain and simultaneously supports the discharge of bran.

By means of the obstructions of the cast-steel cylinder and the hexagonal shape of the working chamber, very high-frequency friction is introduced, which results in the full removal of the germ and the bran in a single-pass operation. The germ, bran, and some of the brewers' rice are removed through the slots of the hexagonal screen. The pressure on the grain inside the working chamber is controlled by the adjustment of the weight-loaded grain-discharge valve. This pressure largely controls the required whitening performance.

SINGLE-PASS RUBBER-ROLL HULLER/HULL ASPIRATOR/ FRICTION WHITENER COMBINATION (SINGLE-PASS UNIT)

The split units described above have the disadvantage of comprising two separate machines, which makes the drive mechanism rather complicated. When individual engines are used as prime movers for the two machines, the investment expenses are high, and the space required for a split-unit arrangement is quite large. In view of these disadvantages, a Japanese manufacturer has developed a compact, single-pass, village-type rice mill for export to developing countries (Fig. 5). This unit combines in one machine the three main functions of the split unit, namely: 1) dehulling through a *rubber-roll huller,* 2) *hull aspiration,* immediately followed by 3) friction whitening.

The unit is compact, not much bigger than a medium-sized refrigerator. It has no market value in Japan, since it converts rough rice immediately into milled rice in a single pass. It has become very popular in developing countries and in some countries is already mass produced under a license agreement.

It popularity has triggered the interest of manufacturers in other countries, and presently a number of identical models are marketed.

OTHER LOCALLY DEVELOPED CONCEPTS

Throughout the developing countries, a wide selection of alternative solutions to rice milling at the village level is found. Most of these solutions are combinations of different types of commercially available machines such as: 1) a rubber-roll huller combined with a locally made hull aspirator, followed by an Engelberg machine used as a whitener, 2) an abrasive small-diameter disk huller,

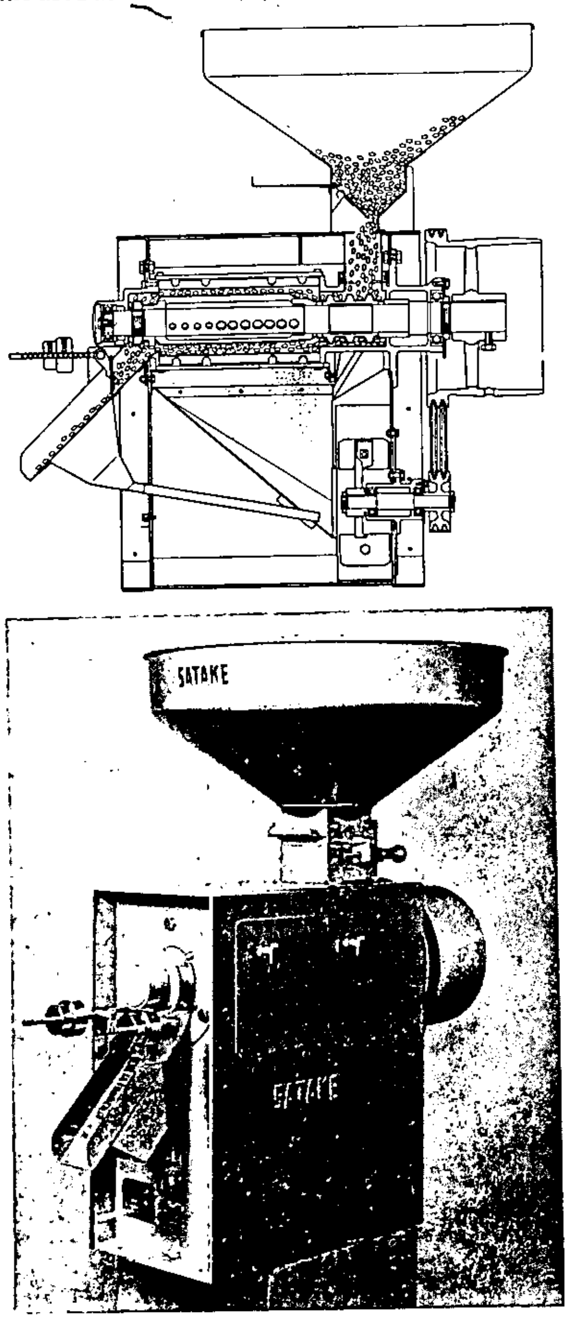

Fig. 4. Cross section (top) of a compact friction whitener (bottom). (Courtesy Satake Engineering Co., Ltd.)

again combined with a locally made hull aspirator followed by an Engelberg whitener, 3) an Engelberg machine used mainly for dehulling, followed by a second Engelberg machine for completion of the milling process, and 4) a small rubber-roll huller combined with a hull aspirator, followed by a small abrasive whitening cone.

In Thailand, a village-type milling concept has been developed, in which the dehulling is performed by a horizontal abrasive roll with rubber brakes, and a similar type of horizontal abrasive roll with rubber brakes is used for the whitening in a single- or double-pass operation. This concept is widespread throughout Thailand. There are as many models as manufacturers, which indeed are many!

Abrasive rolls for dehulling and milling are applied in Thailand for a range of capacities, and numerous combinations of machines are recorded. In an effort to introduce a certain level of standardization, the Ministry of Agriculture and Cooperatives of Thailand, has developed, through a research project, a rather compact small-scale village mill, using horizontal abrasive rolls for both the dehulling and the whitening processes. The initial results are promising and, with

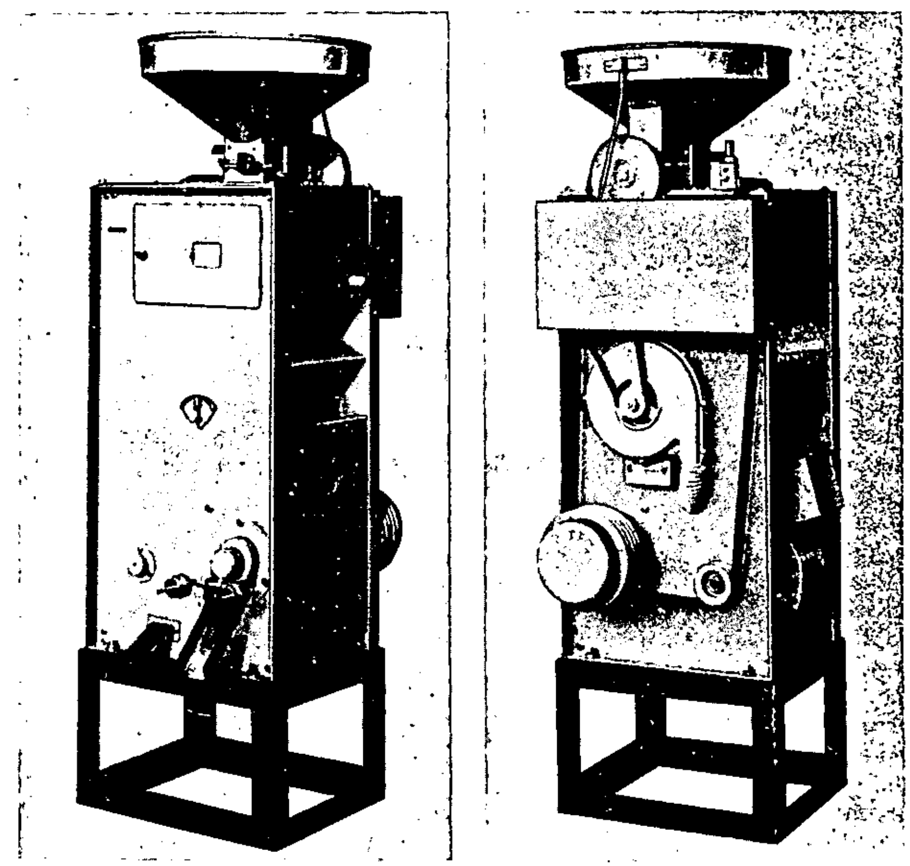

Fig. 5. Single-pass village-type rice mill: front (left) and back (right). (Courtesy Satake Engineering Co., Ltd.)

this unit, prospects for a breakthrough toward standardization are quite favorable. Although the author of this chapter is directly involved as technical consultant to this project, it is still too early to refer to more details.

IV. COMMERCIAL RICE MILLING

A. Overview of Applied Systems

Although a limited percentage of the marketable surplus of rough rice is converted into milled rice through the use of small-scale, village units, the bulk of this rough rice is processed in commercial rice mills with much more complicated machine layouts.

Some commercial rice mills have a rather small capacity for rough rice intake, e.g., 1–3 t/hr, and other mills have much larger capacities, ranging from 3 to 100 t/hr. These bigger mills satisfy their capacity requirements by installing smaller machines in parallel operation.

The layout of the machines critically depends on the prevailing customer/consumer demands, and specific quality demands necessitate installing additional machines and/or altering the flow diagram in such a way that the required processing objectives can be met. Consequently, commercial rice mills cannot operate following a standard operational procedure based on a more or less rigid machine layout. On the contrary, commercial rice mills can be, and mostly are, specially designed to meet the specific quality requirements dictated by the selected market outlets.

Basically two milling systems are applied: the conventional milling system and the Japanese milling system. To a large extent, the rice milling industry, especially in developing countries, is injecting certain aspects of the Japanese system into conventional systems, thus using a combination of both in the machine layout.

Section V of this chapter describes in details the grain flows through an improved conventional milling system and through a Japanese milling system. The present section summarizes the basic differences between the two systems, by comparing how they perform the main processing functions of a rice mill, and describes the machines (van Ruiten, 1979a) applied by both systems.

B. Basic Differences Between the Conventional and Japanese Rice Milling Systems

PRECLEANING FUNCTION

Many of the smaller conventional rice mills are equipped with open, double-tray, precleaning machines responsible for a serious dust-producing problem. In the larger conventional rice mills and in most of the Japanese rice mills, the precleaning machine is connected to a dust aspiration system or has independent built-in aspiration provisions. The design of the larger precleaning machines in conventional rice mills is entirely different from that of the Japanese machines. In general, however, the cleaning objectives for both systems are met.

In the smaller conventional mills, a stoner (gravity separator to remove small stones) is seldom used. The larger conventional mills and practically all Japanese rice mills have stoners. As a rule, all Japanese-made precleaning machines have provisions to trap and separate immature rough rice, but many of the precleaning machines used in conventional mills do not. Only in the larger mills has this aspect been taken into account.

DEHULLING FUNCTION

Pure conventional rice mills use abrasive disk hullers for both the initial hulling and, when applied, the return hulling. In some conventional rice mills, rubber-roll hullers are used to process the return rough rice. All Japanese rice mills use rubber-roll hullers. Return hulling is normally not done in separate rubber-roll hullers, unless the capacity of the mill is so large that installation of separate return hullers becomes practical.

The disk hullers of the conventional rice mill produce a coarse bran of commercial value that is separated before the aspiration of the hull. This requires the installation of a coarse bran sieve between the disk huller and the hull aspirator of conventional rice mills. The rubber-roll huller does not produce any

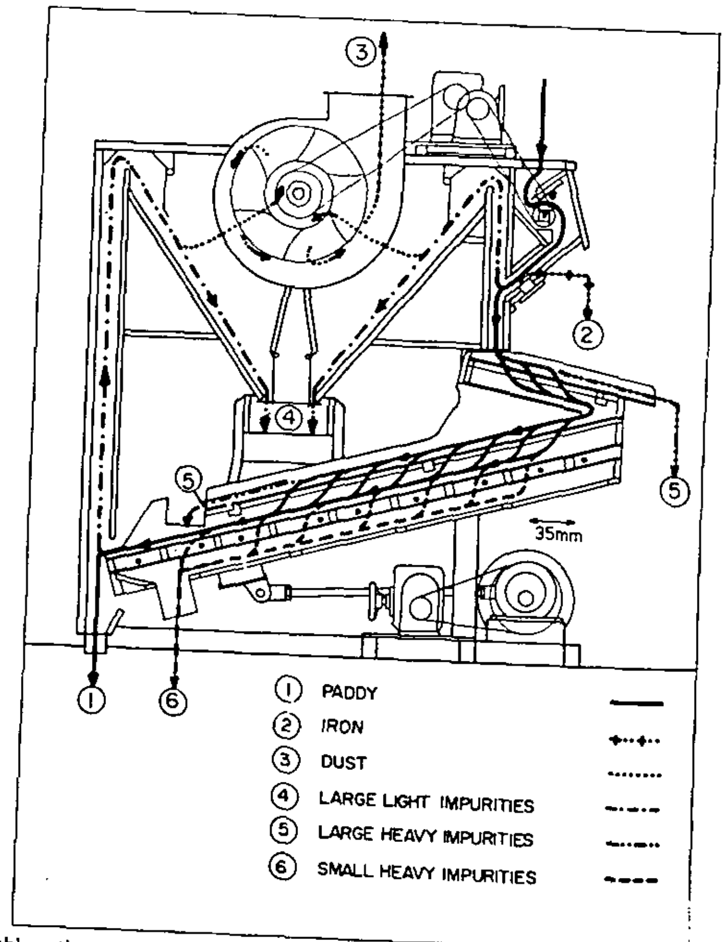

Fig. 6. Double-action rough rice cleaning machine.

coarse bran. Consequently, it can be mounted immediately on top of the hull aspirator, and a coarse bran sieve is not required in Japanese rice mills.

ROUGH RICE SEPARATOR FUNCTION

Conventional rice mills use a compartment-type rough rice separator. This machine produces two products: rough rice, which is returned to the dehulling section for reprocessing, and brown rice, which is conveyed to the whitening section.

Japanese rice mills, however, use a multitray type of rough rice separator. This type of machine produces three products: rough rice, which is returned to the rubber-roll huller; brown rice, which is sent to the whitening section; and a mixture of brown and rough rice, which is immediately recirculated over the rough rice separator. This recirculation requires an extra bucket elevator.

WHITENING FUNCTION

In conventional rice mills, exclusive use is made of the abrasive whitening cones. These machines are sometimes operated in a single- or double-pass process but are preferable in a multipass process using three or four abrasive whitening cones in series. The abrasive coating is rather coarse, normally being made of emery grit or a mixture of emery grit and silicon carbide (carborundum). Conventional rice mills do not install friction whiteners.

In Japanese rice mills, and depending on the rice variety, whitening machines are always used in a multipass process. Normally the first and second whiteners are of the abrasive type, and a friction whitener is installed only for the last whitening pass. If four whiteners are installed for multipass whitening in series, then only the last machine is a friction whitener.

By applying a friction whitener for the final pass, the Japanese rice mills produce milled rice with a smoother grain surface than that of rice produced by conventional rice mills. For the abrasive stone of Japanese whiteners, a rather fine silicon carbide grit is used.

C. Sectional Review of Machines Installed in Commercial Rice Mills

CLEANING ROUGH RICE

Properly designed cleaning machines should be able to remove large heavy impurities, large light impurities, small heavy impurities, small light impurities, and small stones—which are about equal in size to rough rice!

In many conventional rice mills and in some smaller Japanese rice mills, these objectives are not fully met, especially when no aspiration is applied. These open, oscillating sieves are normally not in a position to separate empty hulls and a large portion of the small light impurities. The larger conventional rice mills frequently have double-action cleaning machines, which are provided with sieves and aspiration of sufficient capacity to meet the overall objectives (Fig. 6).

The larger Japanese rice mills have different types of cleaning machines. Here the large light and large heavy impurities are separated by a rotating screen, and the small heavy impurities are removed by an oscillating sieve (Fig. 7). Aspiration is applied to separate chaff and light small impurities. The machines in general meet the objectives.

None of the cleaning machines in either the conventional or the Japanese rice mills are able to separate heavy impurities of about the same size as the rice grain. These are mainly small stones. If these stones are to be separated, then installation of destoners or "stoners," also called "gravity separators," is necessary (Fig. 8). Stoners make use of the difference in density weight of rough rice and stones. A large volume of air is blown through an inclined, specially designed perforated screen, which oscillates with, simultaneously, a slightly bent upward movement. The air passing through the screen makes the rough rice float on an air cushion; it moves downward by gravity and is discharged. The air pressure, however, is not strong enough to lift the stones. These are therefore thrown up over the screen, which has a special surface that does not allow the stones to slide back. This make the stones move upward over the inclined screen for discharge at the elevated open end of the screen. Stoners are normally installed immediately after the cleaner. However, in some mills, stoners are installed in the milled rice grading sections.

Iron particles can be considered heavy impurities and should be removed by the cleaners. In the larger rice mills, however, it is quite normal to have permanent magnets installed to trap iron particles. These magnets must be cleaned at regular intervals. Self-cleaning, rotating electromagnets are also available but seldom used.

Finally, a properly designed rice mill, whether of conventional or Japanese concept, should be equipped with grain weighing equipment for use immediately after the cleaning. This is important because, by knowing the weights of the

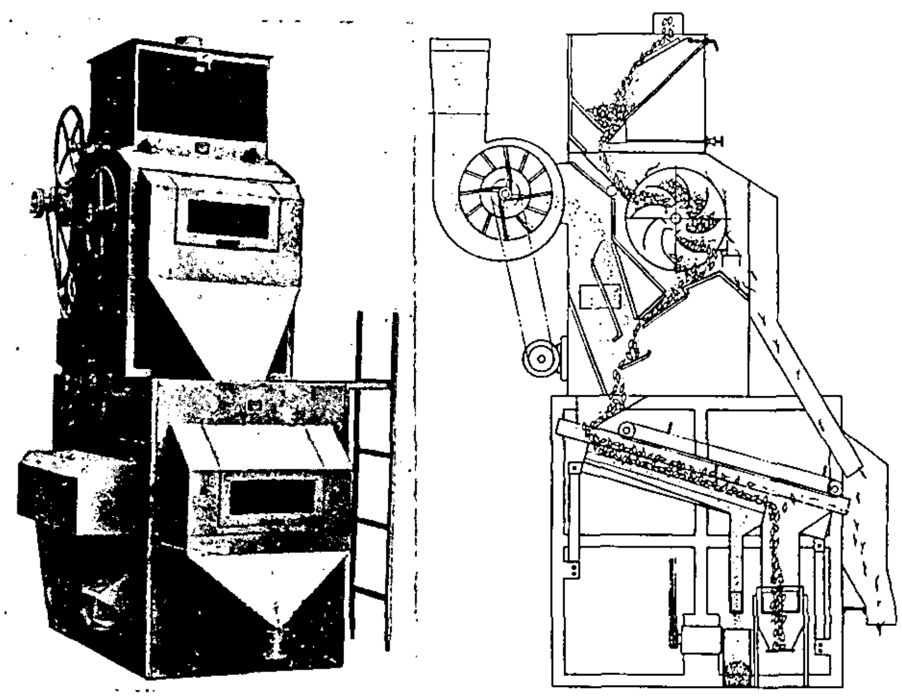

Fig. 7. Japanese-made rough rice cleaning machine with aspiration (left) and its cross section (right). (Courtesy Satake Engineering Co., Ltd.)

uncleaned and cleaned rough rice, the operator can determine the degree of purity of the rough rice, which gives an initial indication of the expected milled rice recovery.

DEHULLING

In conventional rice mills, under-runner disk hullers, also called "disk hullers," are normally installed (Fig. 9). Within the huller frame of the machine, a cast-iron disk is installed, partially covered with a ring of abrasive emery coating. Under this disk, but mounted on a vertical shaft, a second disk of identical diameter is installed, also partially covered by a ring-shaped abrasive emery coating. The clearance between the two abrasive disks can be adjusted by lowering or lifting the vertical shaft. The lower disk rotates either clockwise or counterclockwise. Rough rice enters the machine through a central inlet and, by centrifugal force, is forced through the clearance between the two disks and is dehulled.

For many decades, it was assumed that the clearance between the disks should be based on the length of the grain, thus allowing the grain to topple over its full length when passing through the machine. Special research, however, determined that optimum huller efficiency is obtained with a clearance slightly more than half the length of the grain. Normally, 75–80% huller efficiency at minimum breakage level is obtained, which implies that between 20 and 25% of the rough rice is not dehulled and must be recovered for reprocessing. Most of this rough rice has not been dehulled by the initial dehulling process because of the smaller (thinner) size of the grain. Therefore, a separate but smaller return huller must be installed, thus allowing a different dehulling setting for smaller grains.

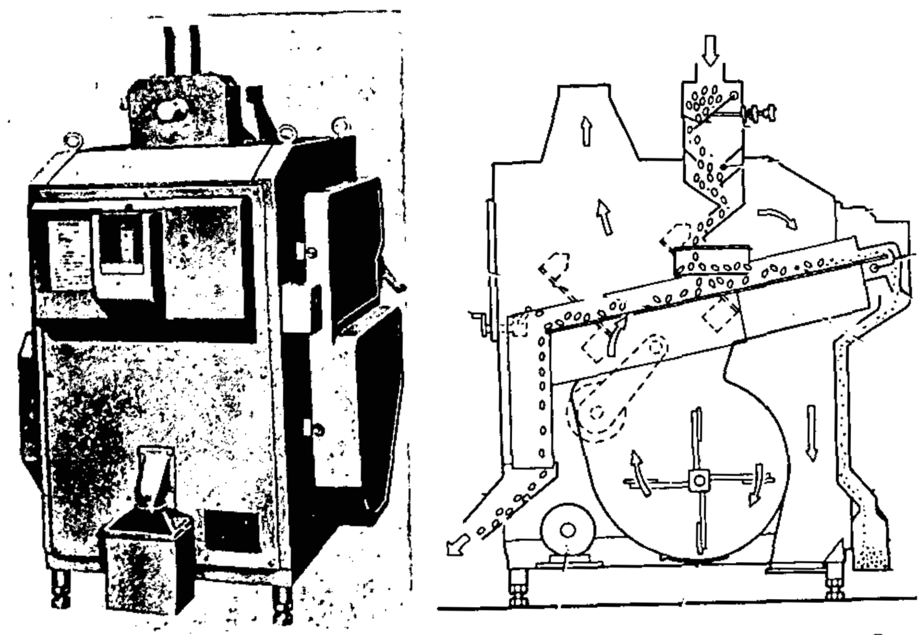

Fig. 8. Stoner (gravity separator) (left) and its cross section (right). (Courtesy Satake Engineering Co., Ltd.)

In all Japanese rice mills, rubber-roll hullers are installed to dehull rough rice (Fig. 10). The main components of this machine are two rubber-rolls of identical diameter, one rotating clockwise and the second counterclockwise. The clearance between the two rolls is adjustable, to control the efficiency and to correct the clearance when it widens as a result of wear on the rubber rolls. This clearance setting is done manually on the small-capacity hullers and normally pneumatically on the large-capacity hullers.

Recently, and in preparation for automation in the rice milling industry, modifications have been introduced so that the clearance can also be adjusted by a small adjustment control motor, which operates on minimum and maximum fluctuations in the power consumption of the machine as controlled by ampere readings.

HULL ASPIRATION

A wide range of hull aspiration systems and machines is applied in both the conventional and Japanese rice mill systems. Many conventional rice mills, e.g., those locally manufactured in the Philippines, use a double air-trap aspiration

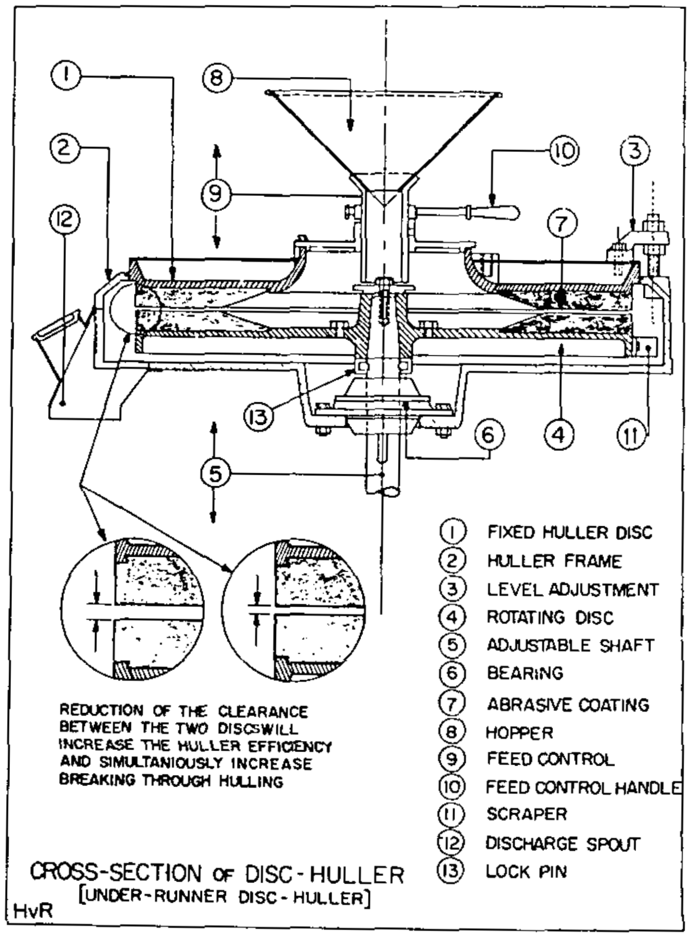

Fig. 9. Cross section of the under-runner disk huller.

system, in which the hull is partially removed by aspiration as the rice passes over a coarse bran sieve and the remaining hull is aspirated by an air-trap system installed above the rough rice separator. Most of the hull aspirators used in conventional rice mills have no special provisions to trap immature grain. Because of the simplicity in the average design, many of the hull aspirators in conventional rice mills are locally manufactured.

Japanese hull aspirators are slightly more complex in design, mainly because all Japanese rice mills aim at the separation of immature rough rice wherever possible and the hull aspirator is one of the machines in a Japanese rice mill in which separation of immature grain occurs. One of the best machines ever designed for the aspiration of hull is of Japanese origin and is called the "closed-circuit hull aspirator." The machine is combined with the rubber-roll huller and has the big advantage that the abrasive hull does not pass through the aspiration fan, thus avoiding excessive wear and tear. The machine is called "closed circuit" because the air produced by the fan recirculates through the machine and is not

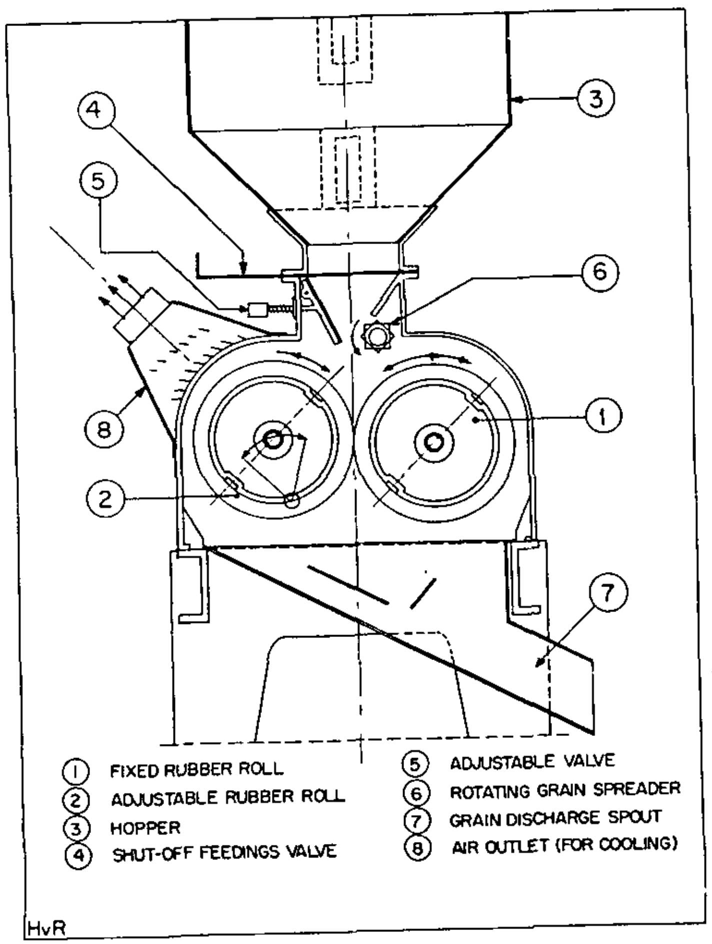

Fig. 10. Cross section of the rubber-roll huller.

blown out (Fig. 11). Briefly, the air from the built-in fan passes through the film of grain and picks up the hull and immature grains. The immature rough rice is trapped and discharged by a screw conveyor. The air plus hull enters the back section of the machine, which is circularly shaped and operates as a cyclone, separating the hull from the air. The air, now free of hull, enters the built-in fan and is recirculated, thus completing the closed circuit of the airflow. The hull is discharged by an open screw conveyor and drops through an air valve into the hull discharge tube. A high-pressure air booster then takes over the further transport by blowing the hull outside the mill into the hull bin. The hull does not pass through the booster since the positive pressure side of this booster fan is used.

ROUGH RICE SEPARATOR (PADDY SEPARATOR)

In conventional rice mills, the compartment-type rough rice separator is used (Fig. 12). These machines are equipped with a number of identical separation compartments. These compartments, varying from 12 to 80, are positioned within the separator table in two, three, or four decks. Each compartment has a smooth steel bottom and zig-zag shaped sides. The compartments are positioned crosswise over the table. The table moves lengthwise in perfect horizontal

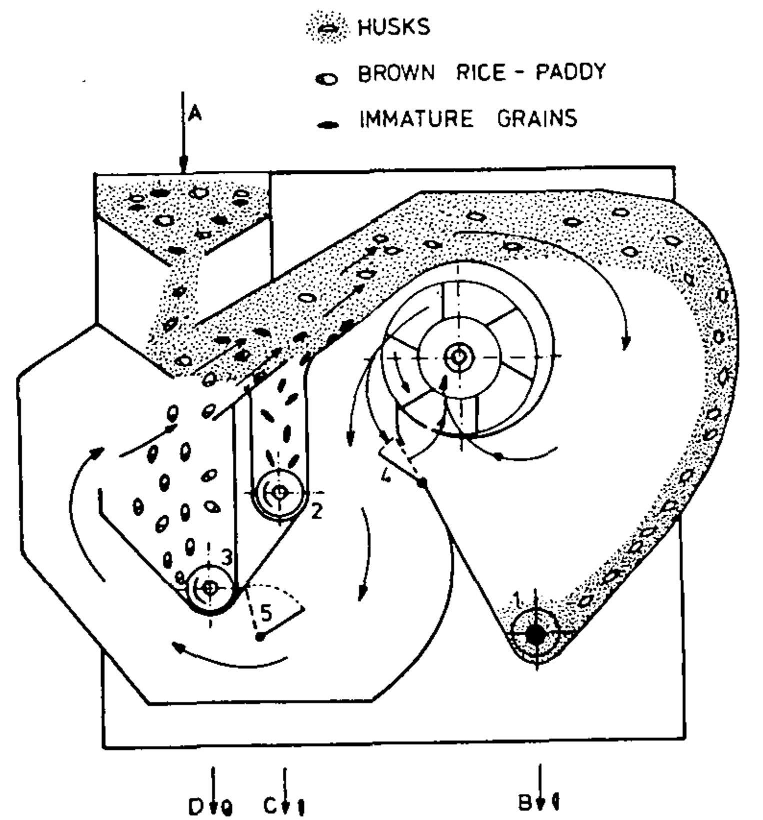

Fig. 11. Cross section of the closed-circuit hull separator. A = huller discharge, B = hulls, C = immature grains, D = paddy and brown rice (mixed), 1–3 = screw conveyors, 4 and 5 = air-control valves.

position with a rather low frequency and a rather short stroke. The table inclination, crosswise, is slightly adjustable.

The grain mixture, rough rice and brown rice, is fed into each compartment through a spout connected with the central grain distribution box. This distribution box covers the full length of the table and is positioned about halfway along the width of the table.

Separation of the rough and brown rice is achieved by means of the low-frequency movement and the zig-zag shape of the compartments. The rough rice leaves the compartments at the high side of the inclined table and is discharged into a bucket elevator for transport back to the dehulling section of the rice mill. The brown rice leaves the compartment at the low side of the inclined table and is discharged into a bucket elevator for transport to the whitening section of the rice mill.

Study of the operation of the machine reveals that it uses differences in the physical characteristics of rough rice and brown rice—namely, density, surface smoothness, and buoyancy—in achieving the separation.

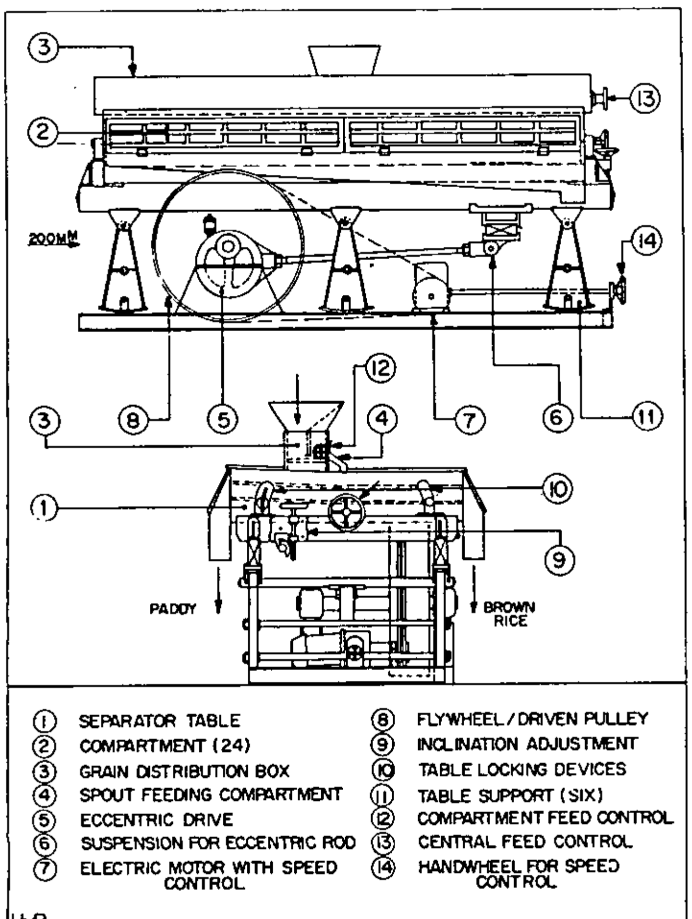

Fig. 12. Cross section of a compartment-type rough rice separator.

The compartment separator has many adjustments for controlling the separation. It can control the central feeding, the input capacity of each compartment individually and of the compartments collectively, the table inclination, the frequency of the strokes, and, for some patented designs, the adjustment of the stroke length.

Practically all Japanese rice mills use the multilayer tray-type rough rice separator (Fig. 13). This machine is multilayer in nature because it holds three to seven identical separation trays clamped together as one solid separation table. The bottom of each tray is a steel plate with numerous indents of special shape. The assembly of trays has a double inclination, of which the lengthwise inclination is fixed and the crosswise inclination is adjustable. The tray assembly has an upward, slightly bent movement over its width. The mixture of rough and brown rice is fed onto the tray in the highest corner of the double-inclined tray. In the course of operation, this mixture spreads equally over the full width of the tray and moves downward toward the end of the tray opposite the feeding end.

Because of the differences in physical characteristics of rough rice and brown rice, the double inclination of the separator trays, and the tray movement, the rough rice concentrates at the lower part of the tray, whereas the brown rice

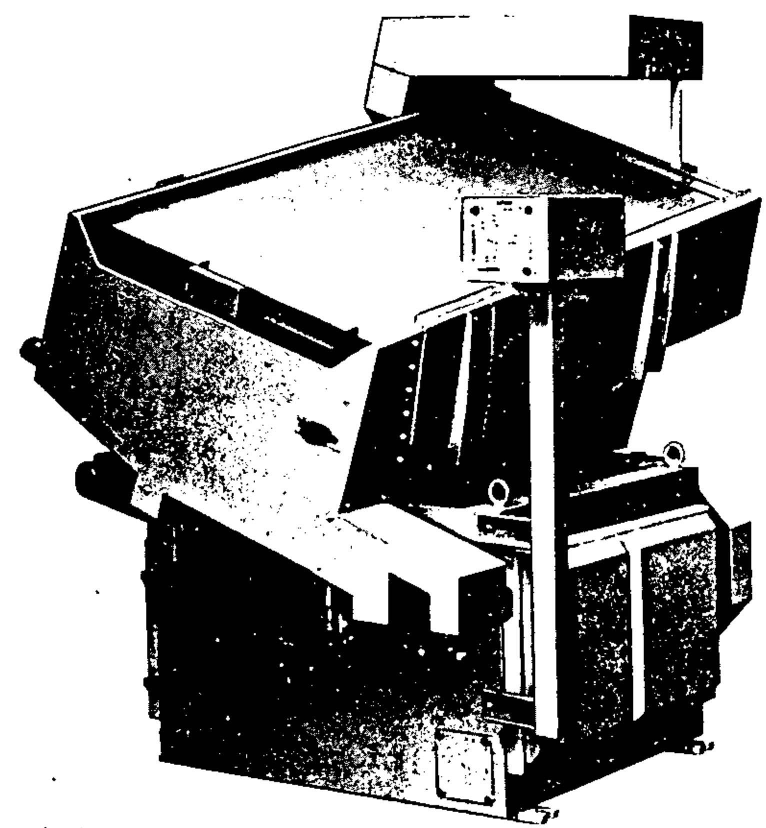

Fig. 13. Japanese-type multitray rough rice separator. (Courtesy Satake Engineering Co., Ltd.)

concentrates at the higher part of the tray. At the point that the grain reaches the overflow end of the tray, a total of three products is discharged, namely: 1) rough rice at the lowest corner, which is unloaded into a bucket elevator for reprocessing over the rubber-roll huller, 2) brown rice at the highest corner, which is unloaded into a bucket elevator for transport to the milling section, and a mixture of brown and rough rice, which is discharged into a bucket elevator for immediate recirculation over the rough rice separator.

Each tray receives an equal quantity of grain mixture, which is secured by a distribution box on top of the rough rice separator. The separation of rough rice from brown rice is achieved by making use of the different physical characteristics of the rices: density, surface smoothness, length of the grain, and recently also difference in color. This last aspect plays a role in the process of automation, which has recently been developed.

In preparation for a fully computer-controlled rice mill operation, fully automatic control of the performance of the individual machines must be established. One of the most difficult machines is the rough rice separator, which

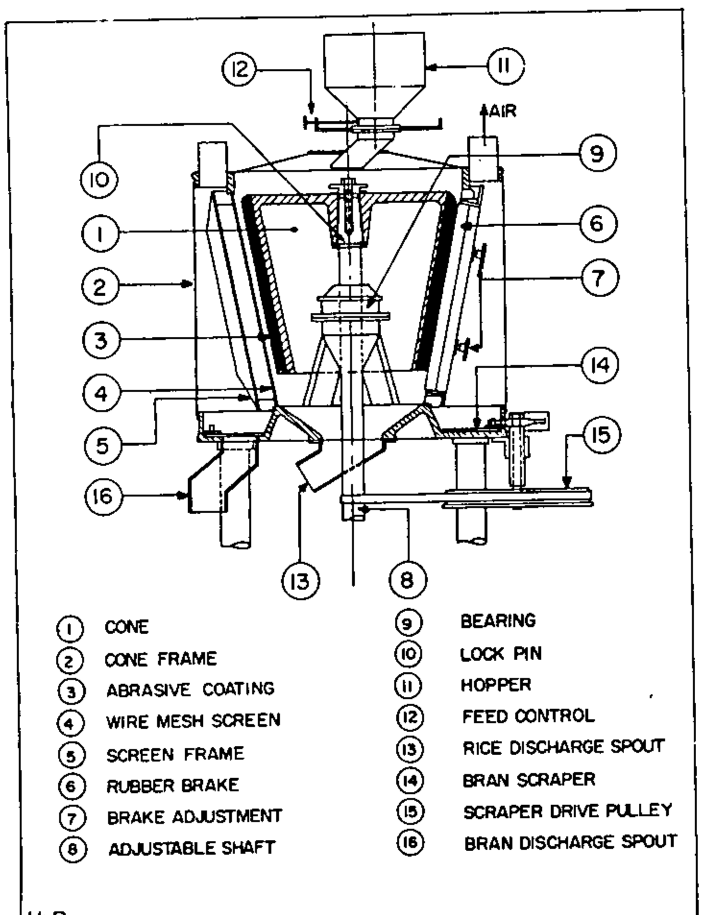

Fig. 14. Cross section of the whitening cone.

normally requires much of the operator's time in view of the numerous built-in adjustments. The Japanese have developed an automatically operated tray-type rough rice separator that uses electronic sensing equipment to control the operation of air cylinders and small electrical control motors for automatic machine adjustment. Through this complex system, the performance of the rough rice separator can be automatically controlled. The system regulates the feeding, the recirculation of grain, the table inclination, and the separation purity, paying special attention to the purity of the brown rice discharge. The electric sensors are fixed in the top tray and respond to no-load, correct-load, and overload conditions.

In view of the sensitivity of the electronic instruments involved, the fully automatic machines require special attention to maintain optimum operational conditions, and their maintenance requires a higher level of skill in rice mill operators.

WHITENING MACHINES

For the conversion of brown rice into milled rice, the conventional type of rice mills only use whitening cones in single-pass, double-pass, or multipass operation. For a given capacity, the single-pass whitening cone is bigger than the two cones used for double-pass whitening, and the two cones used for double-pass whitening are bigger than the three or more cones used in multipass whitening. The whitening cone is an abrasive whitening machine, which still is very popular in the rice milling industry.

A cast-iron, cone-shaped cylinder coated with an abrasive material is mounted on a vertical shaft (Fig. 14). The composition of this abrasive coating is normally emery grit or a mixture of emery grit and silicon carbide (carborundum). The size of the grit can be bigger for the first cone than for the last one. When used in a double-pass or multipass system, the cones are used in series operation. A perforated screen is mounted around the cone-shaped whitening stone and fixed within the machine frame. This screen therefore follows the cone shape of the whitening stone. At regular intervals, adjustable rubber brakes are installed, each of which covers the full length of the cone. Therefore, two clearances can be identified, namely, that between the cone and the screen and that between the cone and the brakes.

The clearance between the cone and the screen can be adjusted by lifting or lowering the vertical shaft/cone assembly. This adjustment largely controls the residence time of the grain and the machine capacity. The clearance between the rubber brakes and the cone can be adjusted by adjusting the position of the rubber brakes. This adjustment largely controls the degree of whitening, since adjustment has an impact on the degree of resistance introduced on the grain mass. The screen that surrounds the abrasive cone is normally wire mesh, but frequently perforated steel plates with slot perforation are used.

In Japanese rice mills, two types of whitening machines are normally used in multipass operation. The first is always an abrasive whitening machine; the last is always a friction-type whitening machine. Whether the machines between the first and last passes are of the abrasive or the friction type is largely determined by the shape of the rough rice variety to be processed.

For multipass whitening in four passes on japonica variety, the first pass can be abrasive and the remaining passes of the friction type. For processing an indica variety, the first, second, and third passes should be abrasive and only the last pass can be of the friction type. The coating used for the abrasive machines is based on silicon carbide fine grit, which is formed under high pressure, heat treated, and finally properly dimensioned on a lathe using a diamond-tipped bit. Local manufacture of replacement rolls is therefore very difficult, and normally the mills depend on direct supply from the manufacturers.

In summary, the machine is composed of the following main components. On a partially hollow horizontal shaft, a feed screw is mounted, followed by the abrasive cylinder, which is composed of different segments (Fig. 15). Between each segment is a clearance of about 3 mm. The positions of these clearances correspond with air holes in the hollow shaft.

On the full length of this divided cylinder, a perforated cylindrical steel screen with slotted perforation is mounted. A small clearance between this cylindrical screen and the fast-rotating abrasive cylinder forms the actual working chamber

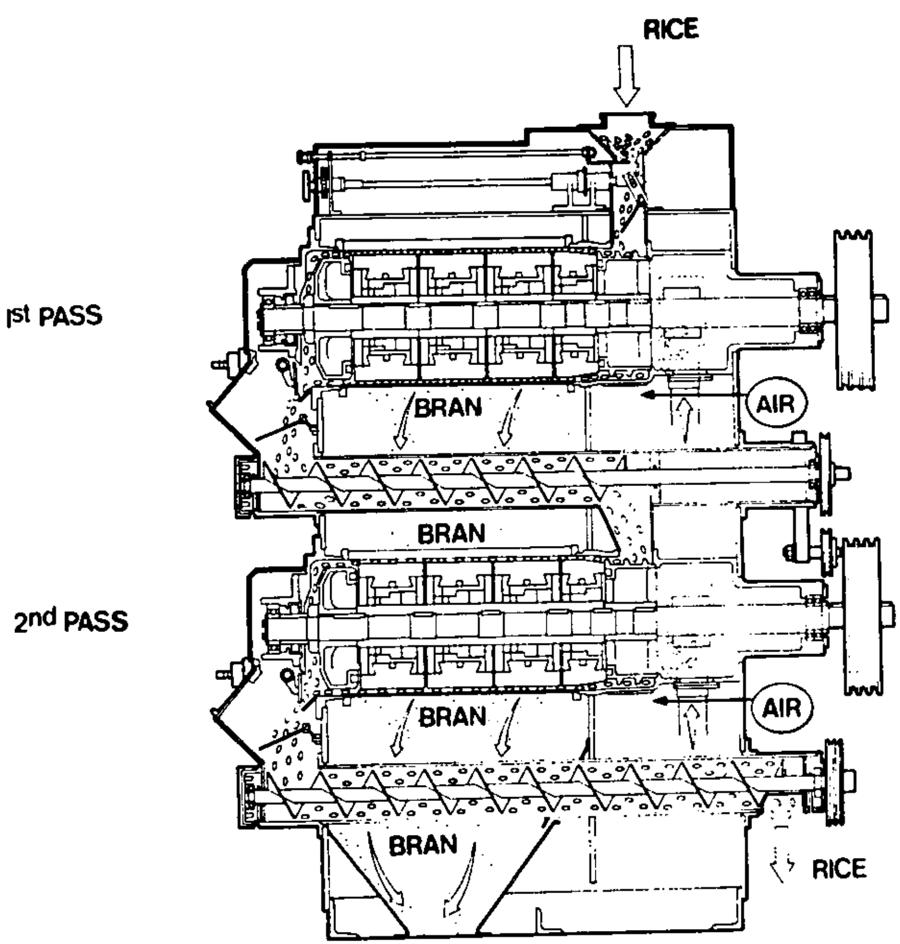

Fig. 15. Cross section of a Japanese double-pass abrasive whitener. (Courtesy Satake Engineering Co., Ltd.)

of the machine. Instead of using rubber brakes, the Japanese installed three rows of adjustable steel resistance pieces that control the positioning of the grain within the working chamber as it passes through the machine, while simultaneously introducing friction through their obstructive impact.

The pressure on the grain, the capacity, and the whitening performance are controlled by the adjustment of the weight-loaded grain discharge valve. High-pressure air is blown into the machine through the hollow shaft. It passes through the air holes in this shaft, through the clearance between the different segments of the abrasive cylinder, and through the grain in the working chamber and finally leaves the machine through the slotted screen. The function of this air is to cool the grain and support the discharge of bran. The bran leaves the working section of the whitener through the perforated screen and is blown into a cyclone by a bran fan.

The friction whitener used as the last milling pass of Japanese rice mills is basically the same design concept as described under village milling except that the machines in the commercial mills are of larger capacity.

In the larger Japanese rice mills, two whitening passes are combined into one machine. A number of combinations are possible to meet processing requirements, e.g., two abrasive passes, one abrasive pass followed by one friction pass, and two friction passes (applied only on japonica varieties).

Quite recently, the Japanese industry introduced a new milling concept, i.e., humidified friction whitening. This friction whitening machine is used as the last whitening pass and has as its overall objectives improved milled rice quality through less breakage, increased milled rice recovery, and improved grain appearance through surface smoothening. The friction impact on the grain is moderate, which results in the increase in recovery and head-rice yield. The machine is called a humidified whitener because a small quantity of atomized water is added through the hollow shaft with the high-pressure air. This water softens the grain surface, which facilitates bran removal and smooths the surface. In the process of whitening, the water is evaporated and, through evaporative cooling, the grain temperature is kept at a lower level.

For larger-capacity rice mills using this humidified whitening principle, the grain is first cooled with humidified air, for which purpose an industrial air cooler, a water vapor machine, and a grain cooling machine are installed. The overall objectives of the precooling of grain are to lower the grain temperature without changing the moisture content level and to harden the grain before the final whitening pass.

In preparation for computer-controlled rice milling, a higher degree of automation has been developed and is being introduced. As far as whitening is concerned, it is presently possible to fully automatically control the performance of the whitening section in multipass operation from brown rice intake to milled rice discharge. The whole operation is then preprogrammed for the required percentage of bran removal. Through an automatic double-sampling system, any fluctuations in the percentage of bran removal are recorded, and the machine performance is automatically corrected by adjustment of the weights on the grain discharge valves. For this purpose, an electric motor-driven weight adjustment device has been developed. This operation uses a microcomputer (Fig. 16).

POLISHING MACHINES

The terminology used in the rice milling industry is quite confusing. The Japanese are responsible for this confusion; they call a whitening machine a "polisher" and a polishing machine a "refiner." Polishing machines are used in some commercial rice mills immediately after completion of the whitening process. The objective of the polishing machine is to remove the loose bran which, after completion of the whitening process, adheres to the surface of the milled rice. Removal of this loose bran is necessary if length graders are installed because the bran can fill up the indents of the grading cylinders, which will then gradually reduce the grading efficiency of the grader. A second advantage of the use of polishers is that the storability of the milled rice is improved. Loose bran attracts insects and accelerates quality deterioration through conversion of bran oil to free fatty acids, resulting in fat rancidity. In addition, the application of polishers upgrades the overall appearance of the milled rice through better translucency.

In conventional rice mills, the polishing machine has a cone shape similar to

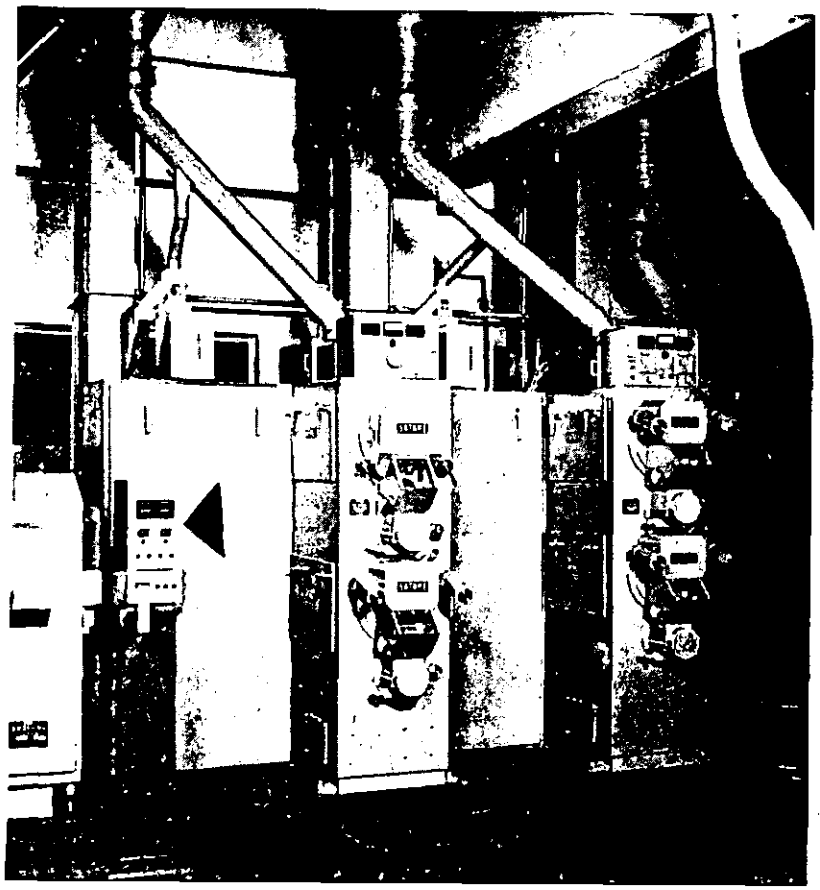

Fig. 16. Automatically operated multipass whitening section controlled by a microcomputer. (Courtesy Satake Engineering Co., Ltd.)

that of the whitening cone. Instead of an abrasive coating, the cone is covered with numerous leather strips, which gently brush the grain as it passes through the machine. No rubber brakes are applied, so hardly any grain is broken.

In Japanese rice mills, the polishers are different in design. The cylindrical drum can be mounted on either a horizontal or vertical shaft. Here too, the cylinder is covered with leather strips for gentle removal of the loose bran. Both types of polishers, the cone-shaped and the cylindrically shaped, rotate in a working chamber made of a wire-mesh screen or a steel screen with slotted perforations. The bran removed from the milled rice passes through these screens, is white in color, and is called "polishing bran."

MILLED RICE GRADING MACHINES

The milled rice produced by the milling section of commercial rice mills is a mixture of head rice, brokens, and brewers' rice. Brewers' rice is composed of rice particles passing through a sieve with a 1.4-mm round perforation (as defined by the Food and Agricultural Organization of the U.N.). This brewers' rice is removed by oscillating sieves or plansifters. Preferably, these sieves should be self-cleaning to avoid clogging.

For most of the commercial rice mills in developing countries, milled rice grading is restricted to the separation of brewers' rice only. Depending on the market requirements, a more complicated grading system can be introduced, which then separates the head rice from the brokens and can classify the brokens into different groups depending on the ultimate quality objectives.

Grading of milled rice into different groups, such as small brokens, large brokens, and head rice, is done in slow-rotating length graders (trieurs) that use the difference in length of the different groups of milled rice..

In the United States, however, the use of the disk-type length grader is quite popular. This machine is different in design but operates on the same separation principle as that of the trieur. The trieur is mainly composed of a slowly rotating cylinder provided with numerous indents. Each indent has the ability to catch a grain or grain particle, which is then lifted from the grain mass and discharged by gravity when the indent cannot hold the grain any longer. The longer grain particles are discharged earlier. The smaller (shorter) particles are discharged later.

A built-in adjustable catch trough catches and discharges the smaller particles, thus achieving grading by length. By selecting the proper indent and adjusting the catch trough, the separation efficiency can be controlled. Depending on the required degree of grading, a number of trieurs can be installed, each given a special grading assignment.

The grain flow through a grading section of commercial rice mills therefore can be very complex. All of the grading equipment described above refers to the sizing of milled rice. However, sizing does not upgrade the milled rice by removing any rough rice, damaged grains, or strongly discolored grain. This last can be done by electronic color-sorting machines that check each individual grain on its color by using electronic sensors. When a color deviation is recorded, an electrical impulse activates a pneumatic system that removes the discolored grain as a reject.

Color-sorting machines are very expensive and are normally used only in the large-capacity commercial rice mills that meet the high-quality market requirements of the United States, Europe, and Japan (Fig. 17).

MILLED RICE MIXING

Commercial rice mills aimed at the quality-oriented markets must produce milled rice in accordance with the specifications of the customers. This requires grading the milled rice into head rice and different grades of brokens. These groups of milled rice are then stored separately.

To produce a predetermined mixture of milled rice, the unloading of each of the stored grades of milled rice must be controlled. This is done by using motor-driven volumetric unloaders for which the unloading speed can be preset in accordance with the milled rice quality requirements. Once preset, the volumetric unloaders discharge the correct quantity of milled rice from each of the bins. The rice is received by a belt-conveyor and discharged into a mixting bin for final bagging and weighing.

In preparation for fully computerized rice mill operations, the mixing of milled rice from different bins can now be fully automatically programmed and

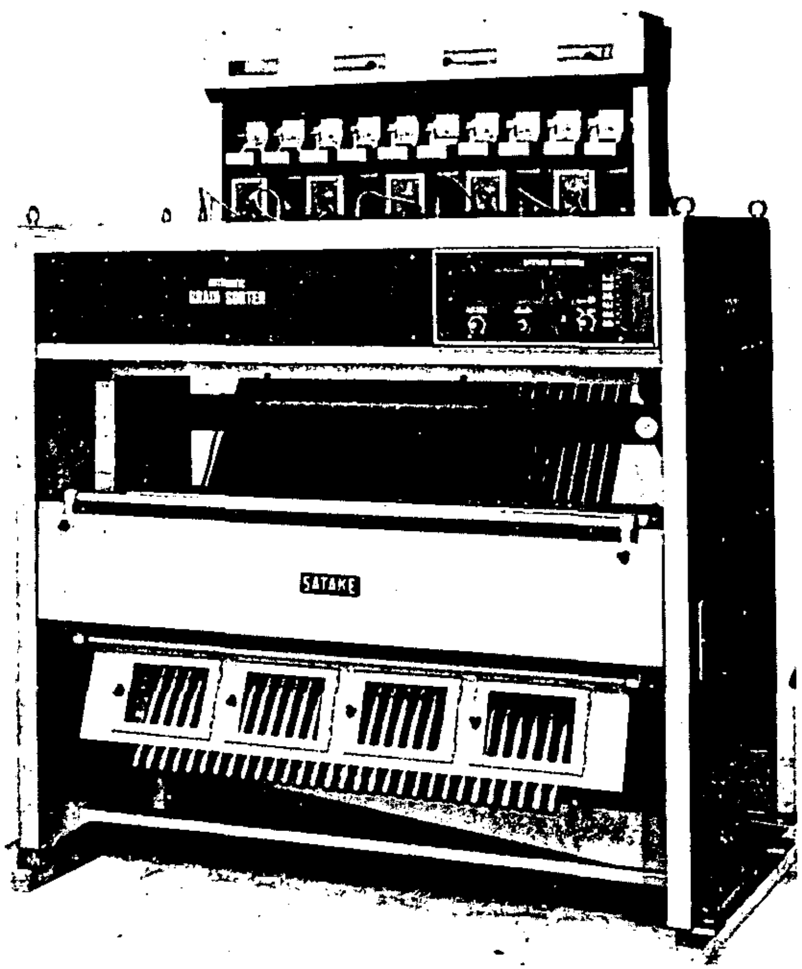

Fig. 17. Color-sorting machine for milled rice. (Courtesy Satake Engineering Co., Ltd.)

controlled. The system can simultaneously correct for the slight differences in the density weight of the different groups of graded milled rice. A screen projection of the bins automatically informs the operator of the actual amount of stock in each bin, thus avoiding disturbances in the mixing caused by an empty bin.

ASPIRATION PROVISIONS IN RICE MILLS

Finally, most of the conventional rice mills and many of the small-capacity Japanese rice mills are *not* provided with a proper aspiration system, which disturbs the environment within the mill and results in economic losses through lower production of by-products and downgrading of milled rice qualities.

When properly designed, a rice mill should have two independent aspiration systems, one to collect the dust and one to collect the bran. Each system should be connected with the various dust- or bran-producing machines, the bucket elevators used for the transport of the commodity, and the different intermediate or final storage bins.

For the dust collection, cyclone operation on a positive fan pressure can be used. For the bran collection, cyclone operation on a negative fan pressure should be applied, thus avoiding the bran passing through the fan. Both systems should have provisions to control the airflow, thus enabling the operator to adjust the separation efficiency if and when necessary.

V. RICE MILL SYSTEMS

A. Introduction

Before World War II, rough rice was processed in commercial rice mills of different sizes or grain flow patterns, but all of these used more or less the same type of machines, *especially for removal of the hulls, separation of rough rice* from brown rice, and removal of the germ and bran.

Since the end of World War II, however, the Japanese rice mill manufacturing industry has developed, initially for local use only, a type of rice mill using an entirely different concept to remove hull, separate rough rice from brown rice, and remove the germ and bran. About 30 years ago, the Japanese manufacturing industry started exporting its equipment, and nowadays Japanese-type rice mills are installed in practically all rice-producing countries throughout the world. A large range of capacities and different grain flow patterns exists. The purpose of this section is to describe the two principles involved, with the use of machine layouts and grain-flow projections (van Ruiten, 1979b).

B. Conventional Rice Mill

The descriptions below refer to an improved conventional rice mill; the layout in Fig. 18 and grain flow pattern in Fig. 19 could refer to conventional rice mills with a rough-rice intake capacity of about 2 t/hr or more. For smaller mills, the machine layout is normally much simpler.

Uncleaned dry rough rice still mixed with a large range of impurities is unloaded into a hopper and, by means of an elevator, is discharged into a holding bin. From there, the rough rice is weighed in an automatic hopper scale that determines the weight of the uncleaned grain. This weighing inside the rice mill

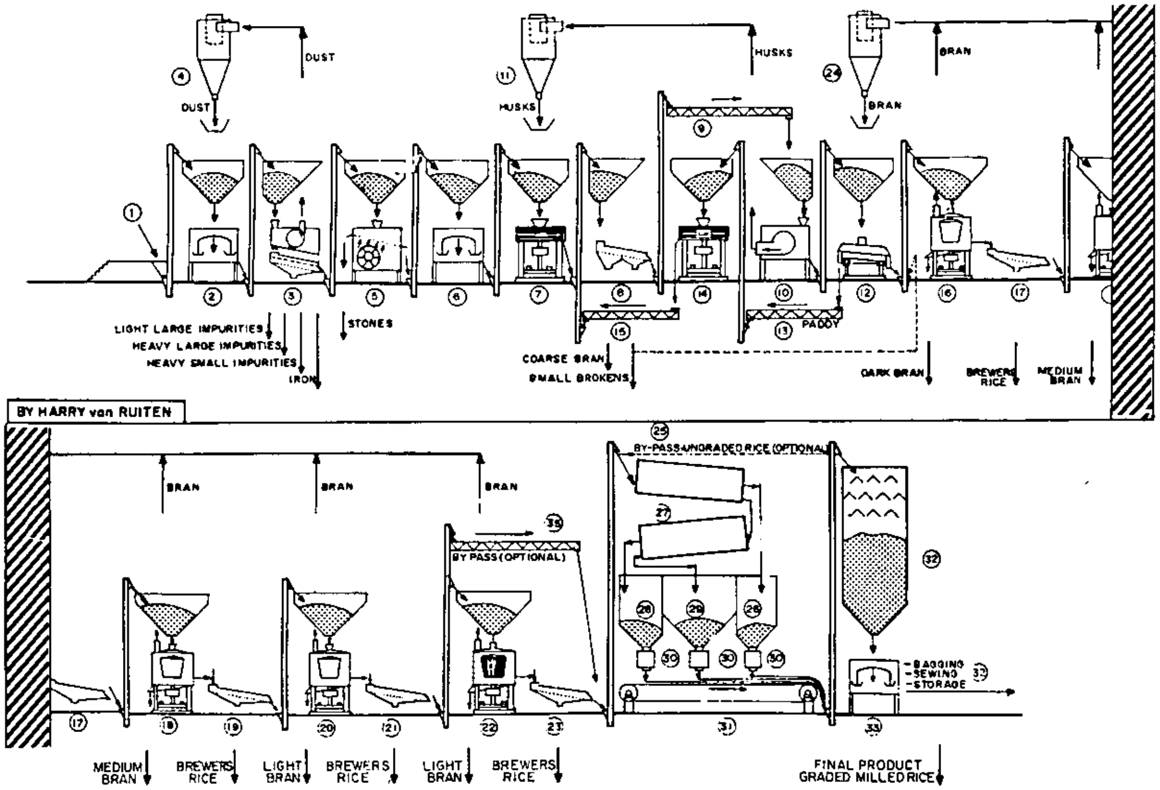

Fig. 18. Machine layout of an improved conventional rice mill. 1 = Holding bin, 2 = hopper scale, 3 = precleaner, 4 = cyclone, 5 = gravity separator, 6 = second hopper scale, 7 = under-runner disk huller, 8 = double sieve, 9 = screw conveyor for transport of mixture of paddy, brown rice, and hulls to aspirator, 10 = hull aspirator, 11 = cyclone, 12 = rough rice (paddy) separator, 13 = conveyor for rough rice, 14 = under-runner disk huller for return rough rice, 15 = conveyor, 16 = first whitening cone, 17 = oscillating sieve, 18 = second whitening cone, 19 = second oscillating sieve, 20 = third whitening cone, 21 = third oscillating sieve, 22 = polishing cone, 23 = fourth oscillating sieve, 24 = cyclone, 25 = first trieur, 26 = bin for small brokens, 27 = second trieur, 28 = bin for large brokens, 29 = bin for head rice, 30 = volumetric unloaders, 31 = belt-conveyor, 32 = mixing bin, 33 = bagging, etc.

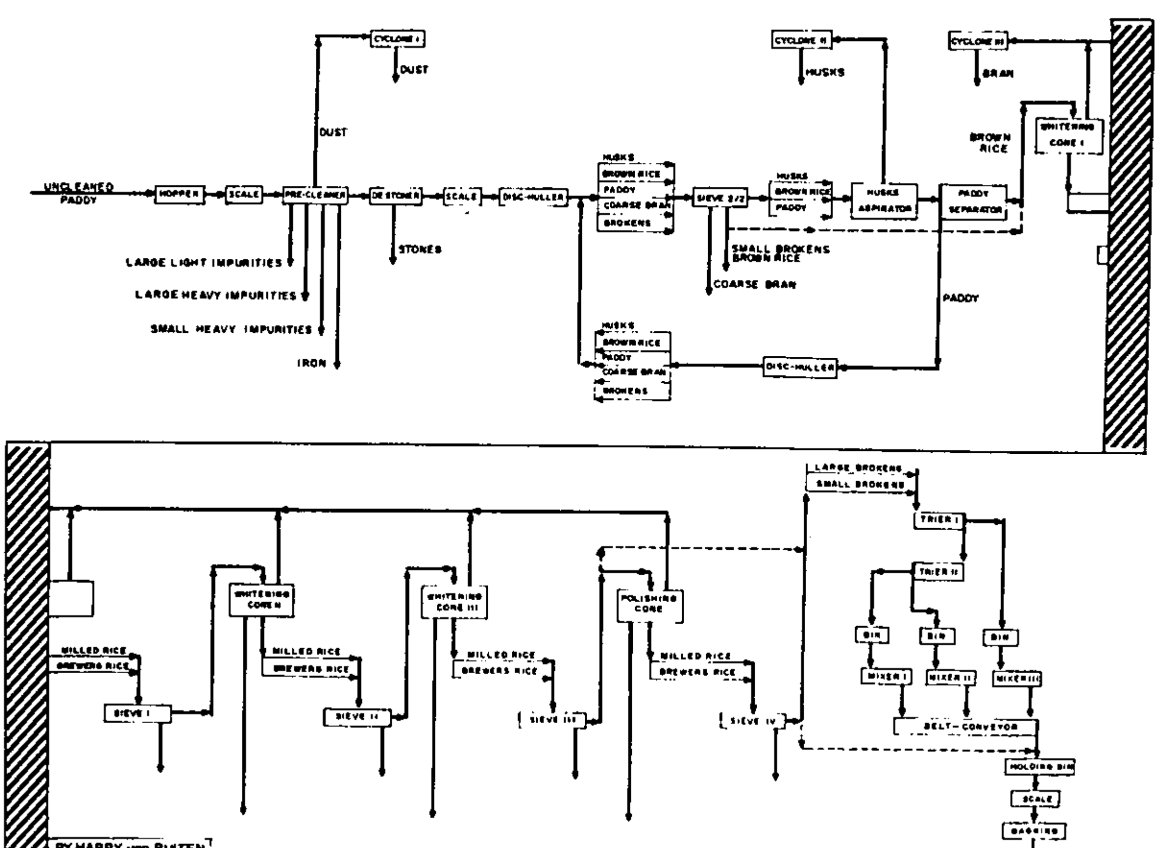

Fig. 19. Grain flow through an improved conventional rice mill.

can be bypassed if outside weighing facilities for the determination of the intake weights are available.

After weighing, the grain is elevated again, unloaded into a hopper, and discharged into a precleaner with built-in aspiration for light impurities, an oscillating double sieve for heavy impurities, and a magnet to trap any iron particles.

Light small impurities, mainly dust, are blown inside a cyclone for separation and discharge. All other impurities are discharged into sacks or containers. In general, this type of precleaning machine cannot separate the small stones of about the same size as the rice grains. To separate these, the rice grain passes a stoner or gravity separator that separates the stones from the grain by using the differences in density of stones and rough rice. The grain then passes a second automatic hopper scale that determines the weight of the clean rough rice that will actually be processed in the rice mill. By having the weight determined twice, on an "uncleaned" and a "clean" basis, the degree of purity of the rough rice can be determined for purchasing and efficiency purposes.

The clean rough rice is elevated and unloaded into a holding bin for discharge into the under-runner disk huller. The abrasive coating used for the dehulling slightly damages the pericarp of the brown rice, which produces a coarse bran. Cracked rough rice produces brokens the moment the pericarp is damaged, in addition to some breakage as result of the dehulling operation. The huller discharge is unloaded onto a double sieve that first separates the coarse bran and then the small brokens (brown rice). The coarse bran, which is a commercial by-product, is bagged off. The same can be done with the small brokens, but normally these are unloaded into the elevator feeding the first whitening machine. The huller discharge is now free from coarse bran and small brokens, which can no longer be blown out with hull. The huller discharge is elevated, unloaded into a bin, and fed into the hull aspirator for the separation of the hull. The hull is blown out of the building for discharge and separation in a cyclone.

The main product, discharged by the hull aspirator, is now a mixture of rough rice and brown rice. Normally, the presence of immature grain is ignored in the conventional processing methods. This mixture, elevated and unloaded into a bin, is discharged into a compartment-type rough rice separator. The rough rice, to be reprocessed in the dehulling section, is conveyed into a separate holding bin and dehulled in a separate under-runner disk huller. This huller can have the fixed disk coated with rubber instead of abrasive material. Sometimes, a rubber-roll huller is used as a return huller.

The discharge from the second under-runner disk huller (also called "return huller") is conveyed into the same holding bin feeding the double sieve installed after the first under-runner disk huller. The brown rice discharged from the compartment-type rough rice separator is unloaded into a holding bin feeding the first whitening cone.

In the first whitening cone, the pericarp of the brown rice and the outer bran layer are removed. To a certain extent, points, germ, and small rice particles are removed from the brown rice during this first whitening pass. A dark-colored bran, holding some germ, is discharged from the machine through a built-in bran scraper and by gravity. The discharge of this first whitening cone is a mixture of undermilled rice and brewers' rice (points and small rice particles). This

discharge of the whitening cone is unloaded onto an oscillating sieve with small round perforations for the separation of the brewers' rice.

The overflow of the sieve, i.e., the undermilled rice, is elevated and unloaded into a small holding bin. Out of this bin, the undermilled rice is fed into a second whitening cone for more bran removal. Here again, brewers' rice will be produced. The bran discharged from the machine by gravity is lighter in color and is called "medium bran." The discharge of the second whitening cone is a mixture of medium milled rice and brewers' rice. This mixture is unloaded onto a second oscillating sieve with small round perforations for the separation of the brewers' rice. Normally, the sieve for separation of brewers' rice after the first whitening pass and the sieve for the separation of brewers' rice after the second whitening pass are combined into one double-layer sieve for a still independent separation of brewers' rice after each pass. The overflow of this second sieve, called "medium milled rice," is discharged into an elevator for unloading into a holding bin. The medium milled rice passes the third whitening cone for final bran removal. Here, too, brewers' rice is produced. The bran produced by this machine and discharged by gravity is very light in color. The discharge of this third whitening cone is a mixture of fully milled rice and brewers' rice. This mixture passes the third oscillating sieve with small round perforations in order to separate the brewers' rice.

The milled rice overflow of this third sieve is elevated into a small holding bin. This fully milled rice does not look shiny because a small quantity of loose bran is still stuck to the grains. For that reason, the fully milled rice is passed through a polishing machine with a cone-shaped cylinder covered with leather strips. In this machine, the loose bran is removed and, to a very limited extent, some points and small rice particles are produced as brewers' rice. The light bran is discharged by gravity, and the brewers' rice is removed by passing the polished milled rice over a fourth oscillating sieve with small round perforations. The three whitening cones, all three coated with an abrasive material, and the polishing cone, covered with leather strips, are connected to an aspiration system for grain cooling. At the same time, this aspiration system removes some bran, which is recovered through one or more cyclones.

Normally, the grain discharge from the polishing machine is considered to be the final product of the rice mill; it consists of a mixture of head rice, large brokens, and small brokens. This mixture is discharged into an elevator and conveyed into a holding bin, bypassing any grading equipment, for final weighing, bagging, sewing, and storage. When, however, a final milled rice of a given composition in terms of head rice, large brokens, and small brokens is to be produced, grading of rice becomes necessary.

Under these circumstances, the milled rice discharged by the polishing cone and its sieve is elevated and unloaded into a first indented grading cylinder, also called a "trieur." In this machine, milled rice is graded by length. In this first trieur, the small brokens are removed and immediately discharged into a special holding bin.

The overflow of the first trieur is a mixture of head rice and large brokens. This mixture is fed into the second trieur for separation of the large brokens, which too will be discharged into a special holding bin. The overflow of the second trieur, head rice only, is unloaded into a holding bin for head rice. Under each bin is a volumetric unloader, also called a volumetric mixer. The unloading capacity per unit of time of each volumetric unloader can be preset upon requirement so that, for instance, 80% head rice, 12% large brokens, and 8% small brokens (or any other combination with a total of 100%) can be discharged.

After the volumetric unloaders have been properly set, the head rice, large brokens, and small brokens can be unloaded simultaneously in preset quantities onto a belt-conveyor for elevation into a holding bin with a built-in mixing device. After that, the milled rice is weighed, bagged, sewn, and stored for final distribution through the existing trade channels.

The final product is then "graded fully milled polished rice." However, polished rice is not always required and, for that reason, quite often the polishing cone and its sieve are bypassed, which can normally be done through adjustments of a simple change valve in the elevator discharge spout.

C. Japanese-Type Rice Mill

The two leading manufacturers of rice milling machines for commercial rice mills in Japan use more or less the same principles. The description below refers to a Japanese-made rice mill of the Satake concept, and the machine layout (Fig. 20) and grain flow pattern (Fig. 21) could refer to a rice mill with a rough rice intake capacity of about 2 t/hr or more.

Uncleaned rough rice, with a moisture content of about 14%, still mixed with a wide range of impurities, is unloaded into a receiving hopper and elevated into a holding bin. The rough rice is then weighed in an automatic hopper scale and the weight of the uncleaned rough rice received for processing is recorded. If outdoor weighing facilities are available, this weighing can be done in the warehouse instead of in the rice mill. After weighing, the grain is transferred into a holding bin.

The next operation is the precleaning of the rough rice, and here a single-drum precleaning machine is normally used. The machine is connected to a large-capacity suction fan that separates the light impurities. A magnet can be included to separate iron particles. The light small impurities (dust) are blown by the suction fan into a cyclone for separation and discharge. The large impurities and the heavy small impurities are separated by gravity and discharged into sacks or containers. Iron is trapped by magnets and is removed manually. This type of separator does not separate stones that are of about the same size as the rice grain. These stones are removed by a gravity separator or destoner. The stones are discharged by this machine into a small iron container. After this final cleaning, the grain is elevated, unloaded into a holding bin, and weighed out for a second time into an automatic hopper scale, so that the actual weight of clean rough rice to be processed by the rice mill can be determined. The weighing of rough rice on an "unclean" and a "clean" basis is important for purchasing and efficiency computations.

After being weighed, the clean grain is transferred to a holding bin for further processing in the rice mill. The hull is removed by rubber-roll hullers. Breakage during the actual hulling operation is very low. Therefore, separation of coarse bran and brokens before the aspiration of the hull is not a concern. However, the Japanese rice mills normally emphasize the separation of immature grains in two stages. For that reason, the discharge of the rubber-roll huller is a mixture of mature brown rice, immature brown rice, hull, mature rough rice, and immature

rough rice. Since separation of any coarse bran or small brokens is not necessary, the rubber-roll huller is normally combined with a hull aspirator and its contents discharged directly into this aspirator.

The hull aspirator separates the hull from the grain mixture and blows the hull into a cylcone for final discharge. The hull aspirator has provisions to trap immature rough rice grains; these are discharged through a screw conveyor for bagging. Frequently, rice millers feed these immature rough rice grains back into the rubber-roll huller by changing the original grain flow pattern. The main discharge of the combined rubber-roll huller and hull aspirator is now a mixture of rough rice (about 5–10%), mature brown rice, and immature brown rice. This mixture is elevated for unloading into a holding bin.

The next step is the separation of the unhulled grain from the brown rice. The Japanese use the tray-type rough rice separator (normally called a tray-type paddy separator). The machine, however, does not fully separate rough rice from brown rice, and its discharge recognizes these products: rough rice, rough rice still mixed with brown rice, and brown rice.

The rough rice discharged by the rough rice separator is conveyed back to the rubber-roll huller for dehulling. The mixture of rough rice and brown rice is recirculated back into the rough rice separator. The brown rice is transferred into a holding bin for further processing. In Japanese rice mills, mainly as result of quality requirements in Japan, the immature brown rice kernels are removed before the whitening process. Therefore, the brown rice passes a number of rotating thickness graders to separate immature brown rice, which is collected in containers.

The mature brown rice, now ready for whitening, is discharged into a holding bin. For medium- and long-grain bold or slender varieties, the Japanese use two or three horizontal abrasive whitening machines equipped with steel resistance pieces for performance control and weight-loaded discharge valves for pressure control. During each pass through one of these abrasive whiteners, a certain quantity of brewers' rice is produced but not separated during the actual whitening process.

The brown rice is fed by gravity into the first horizontal abrasive whitening machine, which removes the pericarp and the outer bran layer. Immediately after leaving this machine, the undermilled rice is fed into the second horizontal abrasive whitener, which removes some germ and bran. The discharge is weakly medium milled and still mixed with the brewers' rice. This mixture is elevated, unloaded into a holding bin, and fed out of this bin into the third horizontal abrasive whitening machine, during which pass more germ and bran are removed. The product leaving the third abrasive whitener is strongly medium milled and still mixed with brewers' rice.

The abrasive whiteners, using a sharp abrasive material, make the grain surface look dull and not very shiny. Therefore, the last whitening pass is through a friction-type whitening machine. The milled rice, still mixed with the brewers' rice as discharged by the third abrasive whitener, is normally fed directly into the horizontal friction-type whitening machine, which removes more bran and finally produces the fully milled rice still mixed with the brewers' rice and germ. Normally, the grain flow through these four whitening machines is not interrupted, which makes intermediate elevation optional. The fully milled rice discharged by the friction-type whitener looks shinier, but loose bran is still stuck

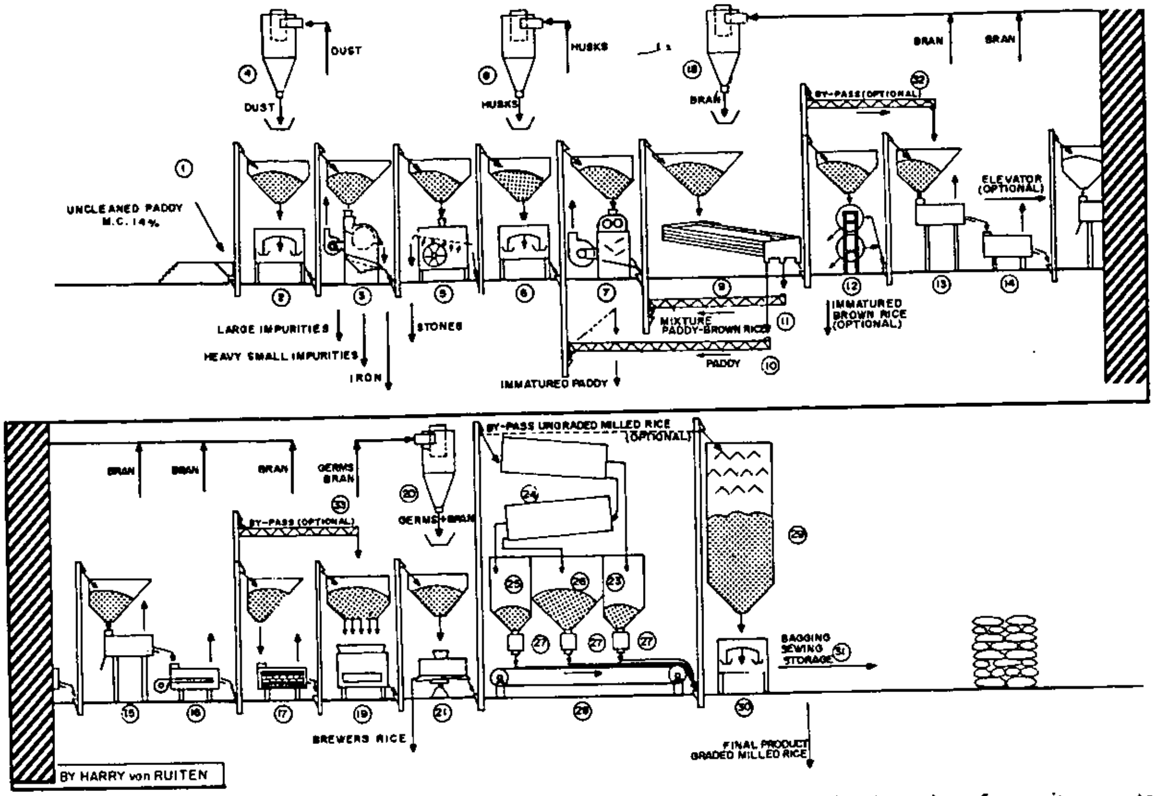

Fig. 20. Machine layout of a Japanese rice mill. 1 = Receiving hopper, 2 = automatic hopper scale, 3 = suction fan, 4 = cyclone, 5 = gravity separator, 6 = second automatic hopper scale, 7 = rubber-roll huller and hull aspirator, 8 = cyclone, 9 = rough rice (paddy) separator, 10 = conveyor back to huller, 11 = conveyor back to separator, 12 = thickness graders, 13 = first abrasive whitener, 14 = second abrasive whitener, 15 = third abrasive whitener, 16 = friction whitener, 17 = refiner (polisher), 18 = cyclone, 19 = aspirator, 20 = cyclone, 21 = plansifter, 22 = first trieur, 23 = bin for small brokens, 24 = second trieur, 25 = bin for large brokens, 26 = bin for head rice, 27 = volumetric unloaders, 28 = belt-conveyor, 29 = mixing bin, 30 = automatic hopper scale, 31 = bagging, etc.

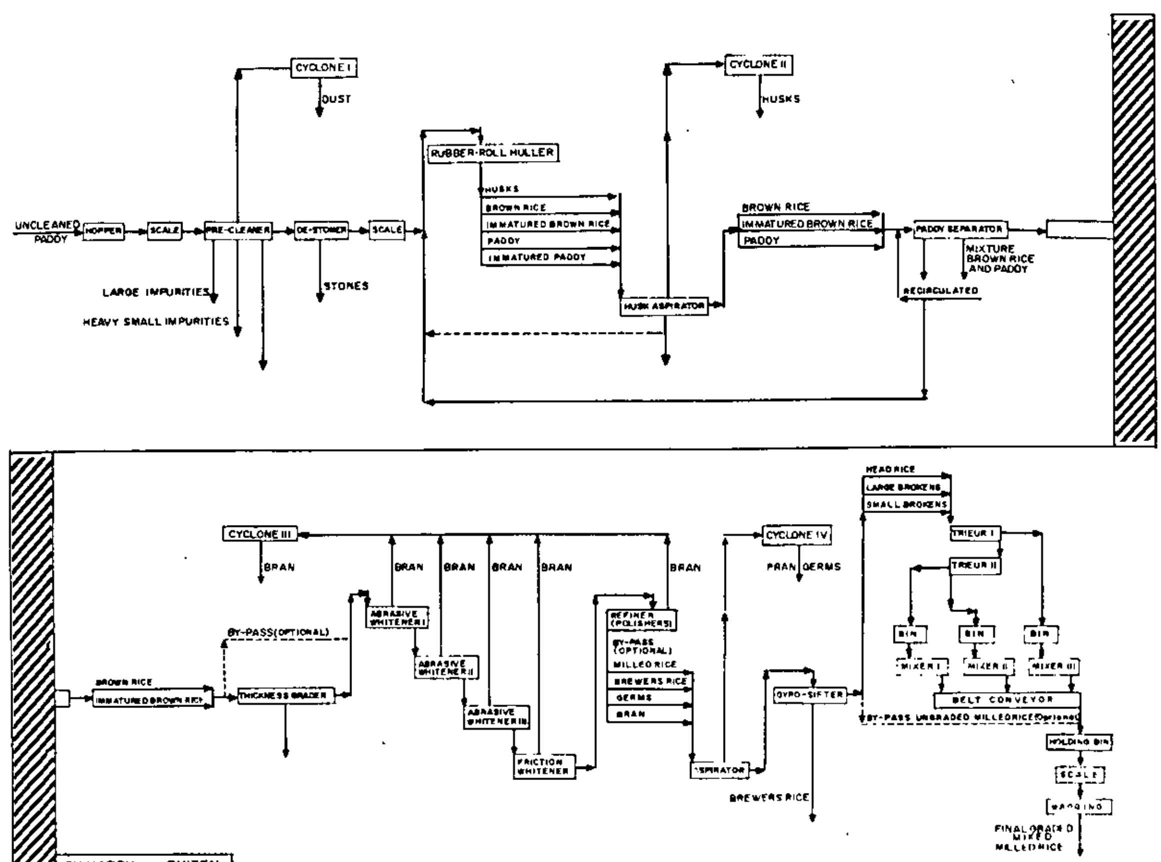

Fig. 21. Grain flow through a Japanese rice mill.

to the grain surface. For that reason, the rice passes a polishing machine, also called a refiner.

The bran produced by the three abrasive whiteners, the friction-type whitener, and the polishing machine is discharged by suction through a central suction fan and blown into a cyclone for separation and discharge. Different grades of bran can be collected if more suction fans and cyclones are installed. The product produced by the polishing machine is not a final product yet, since the milled rice is still mixed with germ, maybe some loose bran, and brewers' rice.

Therefore, the polisher discharge is transferred to a holding bin and the grain passes through an aspirator, which removes the germ and bran (if any) for collection through a cyclone. The product discharged by the aspirator is a mixture of milled rice and brewers' rice. This mixture passes a plansifter, using sieves with round perforations for the separation of the brewers' rice. The brewers' rice is collected in containers. The milled rice discharged from the sifter is normally the final *ungraded* product of the rice mill and is a mixture of head rice, large brokens, and small brokens.

When graded milled rice is to be supplied, the same grading procedure is followed as for the conventional method, i.e., a trieur for small brokens, which are discharged into a special holding bin; a second trieur for large brokens, which are discharged into a special holding bin; head-rice overflow discharged into a special holding bin; and head rice, large brokens, and small brokens discharged in preset quantities onto a belt conveyor through three volumetric unloaders or mixers.

The conveyor unloads the grain into a special holding bin with a built-in mixing device. The mixed milled rice is weighed by an automatic hopper scale and is ready for bagging, sewing, and storage. The final product of the rice mill is then "graded fully milled polished rice without immature grains." However, it is possible to bypass the thickness grades for the separation of the immature brown rice grains. In that case, the final product of the rice is "graded fully milled polished rice."

LITERATURE CITED

ARAULLO, E. V., DE PADUA, D. B., and GRAHAM, M., eds. 1976. Rice Postharvest Technology. Publ. 053e. International Development Research Centre, Ottawa, Canada. 394 pp.

van RUITEN, H. T. L. 1979a. The Milling of Paddy. Southeast Asia Cooperative Post Harvest Res. Dev. Programme, SEARCA, Los Baños, Philippines.

van RUITEN, H. T. L. 1979b. Rice Mill Systems. Southeast Asia Cooperative Post Harvest Res. Dev. Programme, SEARCA, Los Baños, Philippines.

van RUITEN, H. T. L. 1979c. The Quality of Paddy Related to the Performance of Rice Mills. Southeast Asia Cooperative Post Harvest Res. Dev. Programme, SEARCA, Los Baños, Philippines.

van RUITEN, H. Th. L. 1979d. Village Type Rice Mill Units. Southeast Asia Cooperative Post Harvest Res. Dev. Programme, SEARCA, Los Baños, Philippines.

van RUITEN, H. Th. L. 1979e. Physical Properties of Paddy and Milled Rice. Southeast Asia Cooperative Post Harvest Res. Dev. Programme, SEARCA, Los Baños, Philippines.

CHAPTER 10

RICE ENRICHMENT AND FORTIFICATION

MASARU MISAKI
KATSUHARU YASUMATSU
Food Products Division
Takeda Chemical Industries, Ltd.
Tokyo, Japan

I. INTRODUCTION

In evaluating the quality of foods, several viewpoints can be taken. Nutritional quality is the most important of the many attributes of foods, but palatability, high yield, and price are indispensable factors in food evaluation. In the countries where food is not abundant, the principal role of food is to supply energy and indispensable nutrients. In the more economically developed countries, however, palatability is the primary factor for selecting dishes, which sometimes causes an imbalance in nutrient intake.

Rice constitutes one of the most important of human food sources. Good nutritional quality of rice is of primary interest all over the world. Milled (polished) rice is superior to brown rice in palatability and digestibility; therefore, people usually eat milled rice. The milling process, however, decreases the quantity of nutrients from that in brown rice. Many vitamins and amino acids and much dietary fiber located in the outer endosperm and embryo are removed as bran in the process (Table I).

The enrichment of rice has stirred continued interest. Many elaborate research studies have been conducted by experts in nutrition and rice science. Their achievements were reviewed by Mitsuda (1969), Altschul and Planck (1960), Rubin et al (1977), and Peil et al (1982). In this chapter, the technology of rice enrichment is briefly summarized, and then the present status of rice enrichment in Japan, as well as a new enriched rice product, is described in detail.

II. METHODS OF RICE ENRICHMENT

A. Parboiled Rice

This process has been well known as a method of rice enrichment for many years. Parboiling rice has been recognized as useful in India, Burma, and other