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DESIGN OF FLUIDIZED BED DRYER OF THE SUPER CEREAL PLANT

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쌀밀 製造工場의 流動層乾燥裝置設計

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Abstract

The details of design procedure, practically used for the construction of fluidized bed dryer system of the Super Cereal Plant of 250, y capacity were presented.

The plant was in its entirety designed and constructed solely by domestic engineering potenality with local construction materials. In the drying process, the water content of cooked kernel of wheat is reduced from about 23% to about 14% and the conversion of starch contained in the endosperm to α-starch is to be completed by contacting with hot combustion gas of kerosene at about 90-130°C.

I. Introduction

Super Cereal is made from the wheat which is cooked as main dish mixed with the rice. In its manufacturing process, outer bran layers are removed, and the inner part mainly consists of endosperm and alourone cell are cooked with slightly super heated steam. In the cooking process, starch is converted into α-starch which is about 83% of endosperm in weight.

The treated kernel of wheat is dried to the water content of about 14%, polished, and flattened to remove the pigment strand and the germ so that the favorite quality of the super cereal is obtained as main dish. (c. f. Fig. 1)

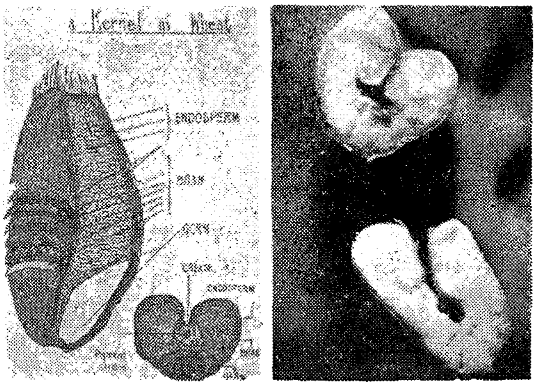

Fig. 1 Kernel of wheat.

Among the unit processes of the super cereal manufacturing, continuous drying process of the cooked kernel of wheat was found to be the most troublesome technically.

The basic studies for the development were carried out using rotary kiln, flash dryer, fluidized bed as the process equipment, and the fluidized bed dryer system was evaluated to be the most suitable one. In the fluidized bed, the contact efficiency of fluid and solids is relatively high and the rates of heat and mass transfer are also observed to be very high.

In this report, details of design of multi-stage fluidized bed dryer system for the drying of about 140 tons per day of cooked kernel of wheat are introduced.

II. OUTLINE OF SUPER CEREAL PROCESSING AND DESIGN BASIS OF DRYER SYSTEM

II-I. Outline of Super Cereal Manufacturing Process

The simplified flow diagram of the super cereal plant erected is as shown in Fig. 2. Raw wheat is refined through the screen shaker and washer

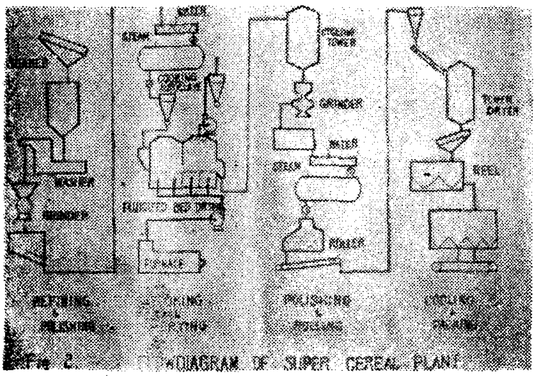

Fig. 2 Flow diagram of super cereal plant.

and at the same time, moisture content is increased for the convenience of removal. of epidermis and hypodermis. By the grinder the layer of nucellar tissue is removed.

In the cooking autoclave, most of starch content is converted into α-starch and dryed to the water content of about 14% in the fluidized bed dryer. After the removal of pigment strand and germ in the secondary polishing machine, moisture content is increased again to about 18% so that the flattening process could be performed without creacking loss. Again it is dried in the drying tower and dusty fragments are separated from the refined product at reel separator unit.

II-2. Design Basis of Dryer

Capacity: 600 ton/hr (144 ton/day)

Moisture content of the feed: w_f=0.23 (dry super cereal basis)

Moisture content of the product: w_d=0.14 (〃 〃 〃)

Maximum temperature of the kernel of wheat: T_s=85°C

Average residence time (time of drytng): θ_d=10 min. (assumed*)

Type of dryer: 4-stage fluidized bed with cross flow of drying gas (c.f. Fig. 3)

*deduced from the experimental study using a pilot scale rotary kiln carried out at Pusan Factory of Shin Han Flour Mills Co., Ltd., 1971-1972.

III. DESIGN OF FLUIDIZED BED DRYER

III-I. Determination of Uo

Incipient(or minimum) fluidization velocity U_{mf} and terminal velocity U_t of kernel of wheat are calculated by semi-empirical equations and superficial linear velocity Uo of fluidizing gas(hot flue gas) is determined referring to the numerical value obtained from the equations.

III-I-a. Calculation of U_{mf}

According to the Ergun's correlation,[1] U_{mf} is found in a quadraic equation:

$$\frac{1.75}{\phi_s\varepsilon_{mf}^3}\left(\frac{d_pU_{mf}\,\rho_g}{\mu}\right)^2+\frac{150(1-\varepsilon_{mf})}{\phi^2{}_s\varepsilon_{mf}^3}\left(\frac{d_pU_{mf}\,\rho_g}{\mu}\right)=\frac{d_p{}^3\rho_g(\rho_s-\rho_g)}{\mu^2}g \quad \cdots\cdots\cdots\cdots (1)$$

putting the values

$\phi_s=0.7$, $\varepsilon_{mf}=0.5$, $d_p=\sqrt{d_1\cdot d_2}=\sqrt{3\times6}=4.24$

$\rho_g=0.88$ [kg/m^3], $\mu=2.2\times10^{-5}$ [kg/m·sec.] (for air at 126°C)

$\rho_s=1.3\times10^3$ [kg/m^3]

$g=9.8$ [m/sec^2]

U_{mf} iscalculated using eq. (1); $U_{mf}=1.7$ [m/sec], where $Re_{mf}=\frac{d_pU_{mf}\,\rho_g}{\mu}=288$ [−]

III-I-b. Calculation of U_t

The ratio (U_t/U_{mf}) is usually between 10 and 90, indicating the flexibility of possible operations. For large solids as the kernel of wheat, the ratio can be assumed to be about 10, and the Reynolds number exceeds 500.

$$Re_p>500 \quad \cdots\cdots\cdots\cdots (2)$$

using the equation (3) of terminal velocity of spherical particles estimated from fluid mechanics[2],

$$U_t=\left[\frac{4gd_p(\rho_s-\rho_g)}{3\rho_gC_d}\right]^{1/2} \quad \cdots\cdots\cdots\cdots (3)$$

U_t is given

$$Ut=\sqrt{\frac{3.1(\rho_s-\rho_g)}{\rho_g}}=\sqrt{185}=13.6 \text{ [m/sec]}$$

where $Re_t=\frac{d_pU_t\rho_g}{\mu}=2,300>500$

and $C_d\doteqdot0.43$ $\cdots\cdots\cdots\cdots (4)$

the ratio (U_t/U_{mf}) is found to be,

$$\frac{13.6}{1.7}=8.0 \quad \cdots\cdots\cdots\cdots (5)$$

III-1-c. Determinatio U_o

By the suggestion of W. J. Rice et al.[3] and J. B. Romero et al. 4), the mode of fluidization is classified by the product of the four dimensionless groups, each of these four groups rises with decrease in the bed stability.

$$\left(\frac{U_{mf}^2}{d_p\,g}\right)\left(\frac{d_pU_{mf}\,\rho_g}{\mu}\right)\left(\frac{\rho_s-\rho_g}{\rho_g}\right)\left(\frac{L_{mf}}{d_t}\right)$$

$$=\left(\frac{(1.7)^2}{4.24\times10^{-3}\times9.8}\right)\left(\frac{4.24\times10^{-3}\times1.7\times0.88}{2.2\times10^{-5}}\right)\times\left(\frac{1.3\times10^{-3}-0.88}{0.88}\right)\left(\frac{0.38}{2.25}\right)$$

$$\doteqdot5.04\times10^5>100 \quad \cdots\cdots\cdots\cdots (6)$$

then the optimal ratio (U_0/U_{mf}) is taken to be 2.0 and finally U_0 is determined:

$U_0=2\times1.7=3.4$ [m/sec]

III-2 Specification of Air Blowers

III-2-a. Determination of Type of Dryer

The simplified sketch of fluidized bed dryer system is shown in Fig. 3.

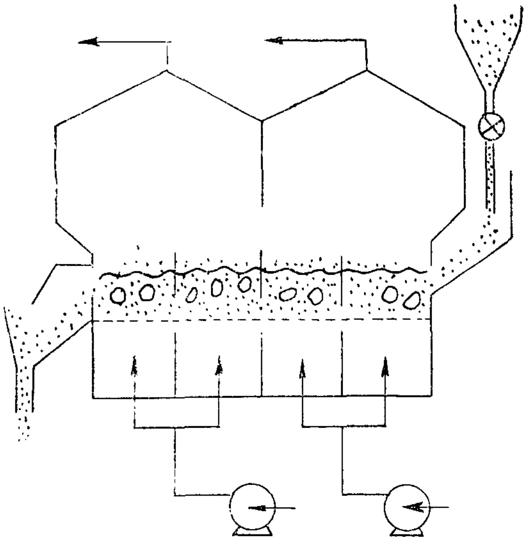

Fig. 3. Schematic Diagram of Fluidized Bed Dryer

The number of stages and the other engineering data were obtained from the previous papers of the authors[5),6)] and the cross sectional area of each stage of the fluidized bed, A and bed height at incipient fluidization, L_{mf} were determined by a series of trial calculation to confirm whether the domestic air blower meets the specified requirement in due consideration of operating safety.

III-2-b. Pressure Drop ΔP_f across the Fluidized Bed

$$\Delta P_f=L_{mf}(1-\varepsilon_{mf})\cdot(\rho_s-\rho_g)\left(\frac{g}{gc}\right)$$

$$=0.38(1-0.5)(1.3\times10^{-3}-0.88)$$
$$=247\,[kg/m^2]=247\,[mmAq]$$

III-2-c. Pressure Drop ΔP_d across the Gass Distribution[7)]

$\Delta P_d=0.1\times\Delta P_f$ (taken)

$=0.1\times(247)=24.7$ $[kg/m^2]$

$=24.7$ [mmAq]

then the gas distribution is design using following equations:

Gas velocity through an orifice8) U_{or} is given by equations (7) and (8):

$$U_{or}=C'_d\left(\frac{2g_c\cdot\Delta P_d}{g}\right)^{\frac{1}{2}}\cdots\cdots\cdots(7)$$

$$C'_d\fallingdotseq0.6 \text{ for } Re_T=\left(\frac{D_T\rho_g U_0}{\mu}\right)>10^4 \cdots\cdots\cdots(8)$$

and the fraction of open area of the gas distributor plate is found to be:

$$U_o/U_{or}=\frac{3.4}{14.1}=0.241=24.1\%$$

decide the number of orifices per unit area of distributor and corresponding orifice diameter by using eq. (9)

$$U_0=\frac{\pi}{4}d_{or}^2U_{or}N_{or}\cdots\cdots\cdots(9)$$

and

$$N_{or}=\frac{4U_o}{U_{or}\cdot d_{or}^2}=\frac{4\times3.14}{3.14\times14.9\times(1\times10^{-3})^2}=29$$
$$=2.9\times10^5\,[m^{-2}]=29\,[cm^{-2}]$$

square pitch was taken as a mode of orifice hole arrangement.

III-2-d. Pressure Drop ΔP_p in Pipelines

ΔP_p is calculated as follows by using the Fanning's equation:

$$\frac{2fU^2L\,\rho_g}{g_cD}=\frac{2\times0.007\times(3.4)^2\times5\times0.88}{9.8\times0.6}$$
$$=0.11\,[kg/m^2]=0.11\,[mmAq]$$

where, $f\fallingdotseq0.007$ for $\frac{DU\rho_g}{\mu}=2,3000$

III-2-e. Determination of Delievery Pressure and Powe

The minimum delivery pressure of air blower is equal to the total pressure drop ΔP_{total}

$$\Delta P_{total}=\Delta P_f+\Delta P_d+\Delta P_p$$
$$=247+24.7+0.110=271.8\,[kg/m^2]$$
$$=271.8\,[mmAq]$$

then the delivery pressure is taken

$$\Delta P_T=400\,[mmAq]\cdots\cdots\cdots(10)$$

Capacity of blower, W [m³/min] and the power requirement K [HP] is decided. 9)

$$W=U_0A=(3.4)(4)\left(\frac{60}{1}\right)=816\ [m^3/min]$$
$$\fallingdotseq420\times2\,[m^3/min]$$

$$G=\frac{W}{2}=\frac{6,120\times\eta\times K}{P_T\times\rho_g}\cdots\cdots\cdots(11)$$

$$420=\frac{(6,120)(0.5)K}{(400)(0.88)}\quad\therefore K=64\ [HP]\cdots(12)$$

actually 2 each of air blowers driven by the motor of 75 HP were installed.

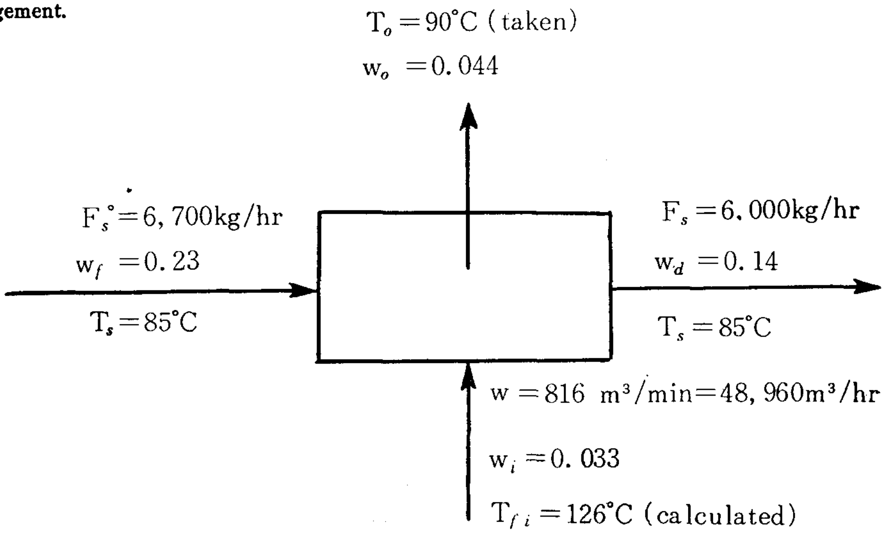

Fig. 4 Enthalpy and Mass Balance of Drying Process

IV. ENERGY PLAN

IV-1. Determination of Fluidizing Gas Temperature, T_{fi}

The enthalpy balance and material balance are shown schematically in Fig. 4.

The temperature of fluidizing gas T_{fi} is obtained by the enthalpy balance equation:

$$C_p(T_{fi}-T_0)M=Q_{evap}=(F_s^\circ-F_s)\ \lambda \qquad \cdots(13)$$

$$\therefore\ T_{fi}=126.3°C$$

where $\lambda=540$ kcal/kg

$M=(816)(60)/(32.9)$; number of k_g-kg-mole air at 126.3°C

$C_p=7.0$ kcal/kg-mole

IV-2. Fuel Consumption

$$Q=C_p(T_{fi}-T_a)M$$
$$=7\times(130\text{-}15)(816)(60)/(32.9)$$
$$=1,196\times10^3\text{kcal/hr}$$

and consumption of diesel oil is;

$$Z_{oil}=(1,196\times10^3)/(9.0\times10^3)(0.8)$$
$$=166\,[\text{lit./hr}]$$

where calorific value of diesel oil$=9.0\times10^3$ kcal/l /lit. and thermal efficiency of the burner system, $\eta=0.8$.

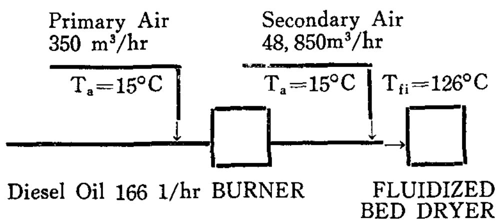

Fig. 5 Fuel Consumption and Fluidizing Gas Temperature of Combustion Burner System

V. RESULTS AND DISCUSSION

Comparison of design values and operation data were made as shown in Table 1 below. The design values are coincident with the actual operation data.

Table 1. Comparison of Design Values and Operation Data

		Design Values	Operation Data
F_s	[kg/hr]	6,000	5,500-6,000
w_f	[%]	23	21-23
w_d	[%]	14	14-15
t	[min]	10	6-8
T_s	[°C]	85	80-92(lst stage)
G_{130C}	[m³/min]	816	672-912
Z_{oil}	[lit/hr]	166	150-155
K	[kw]	48	40-52
D_{or}	[mm]	1	1 —
T_{fi}	[°C]	126	120-130

VI. FEATURE OF THE SUPER CEREAL PLANT

The production capacity of the super cereal plant which has been design and constructed in Bupyung Factory of Shin Han Flour Mills Co., Ltd. is about 250,000 tons per year.

Six series of the plant units of 140 tons per day are smoothly operated since late 1973.

Views of the main equipment are shown by photographs.

VII. ACKNOWLEDGEMENT

The authors are indebted to the president Yong Sung Kim for his encouragement and deep understanding of the cooperative project between industry and university which enabled the domestication of the plant engineering technique successfully.

NOTATION

A : cross sectional area of fluidized bed [m²]

C_d : drag coefficient [—]

C_p : specific heat of gas [kcal/kg-mole]

D_T : equivalent diameter of fluidized bed [m]

d_{or} : orifice diameter [mm]

F_s : drying capacity [kg/hr]

G : flow rate of drying gas [m³/min]

K : power consumption of blower [HP]

L_{mf} : bed height of minimum fluidization condition [m]

N_{or} : number of orifices per unit area of distributor [m^{-2}]

ΔP_d : pressure drop across a distributor [kg/m^2]

ΔP_T : pressure drop [kg/m^2] or [mmAq]

Q : heat capacity [kcal]

S : pitch of orifices [mm]

T_a : ambient temperature 15°C (taken)

T_f : temperature of fluid [°C]

T_s : temperature of solid [°C]

U_0 : superficial fluid velocity [m/sec]

U_{mf} : superficial fluid velocity at minimu fluidization [m/sec]

U_t : terminal velocity [m/sec]

U_{or} : velocity of gas through an orfiice [m/sec]

w_f : water content of the feed [%]

w_d : water content of the product [%]

Z_{oil} : kerosene consumption [lit./hr]

ε_{mf} : void fraction in a bed at minimum fluidization —

η : efficiency [—]

μ : viscosity of fluid [kg/m·sec]

ρ_g : *fluid density* [kg/m^3]

ρ_s : density of solids [kg/m^3]

ϕ_s : sphericity of a particle [—]

θ_d : average residence time of particles in the fluidized bed [min]

要 約

年產 25萬톤의 민쌀 工場의 流動乾燥裝置의 設計의 詳細를 紹介했다.

當 工場은 國産資材와 國內技術에 依하여 設計建設되었다. 乾燥工程을 通하여 蒸煮된 小麥粒의 含水量은 約 23%로 부터 14%까지 乾燥된다. 胚乳에 含有된 澱粉은 거의 完全히 α-澱粉으로 轉化되며 90～130°C의 流動化 가스는 燈油를 完全燃燒시켜 얻는다.

REFERENCES

1) Ergun, S. E. : Chem. Eng. Progress **48**, 89 (1952)

2) Kunii D. and O. Levenspiel : Fluidization Engineering, p. 76 John Wiley (1962)

3) Rice, W. J. and R. H. Wilhelm : *Am. Inst. Chem. Eng. Journal* **4**, 423 (1958)

4) Romero, J. B. and L. N. L. N. Johanson : Chem. Eng. Progr., Symp. Series, **58**(38), 28 (1962)

5) Namkoong, S. and W. C. Chung : J. of *Korean. Inst. Chem. Eng.* **3**, 142(1965)

6) Namkoong, S. and W. C. Chung : J. of *Korean. Inst. Chem. Eng.* **3**, 34 (1965)

7) Agarwal, J. C. : Chem. Eng. Progr. **58**, 85 (1962)

8) Perry, J. H. : Chemical Engineers' Handbook, third ed., McGraw-Hill, (1963)

9) "Catalogue of Air Blower" Suh Won Iron Works, Ltd., Seoul, Korea (1971)

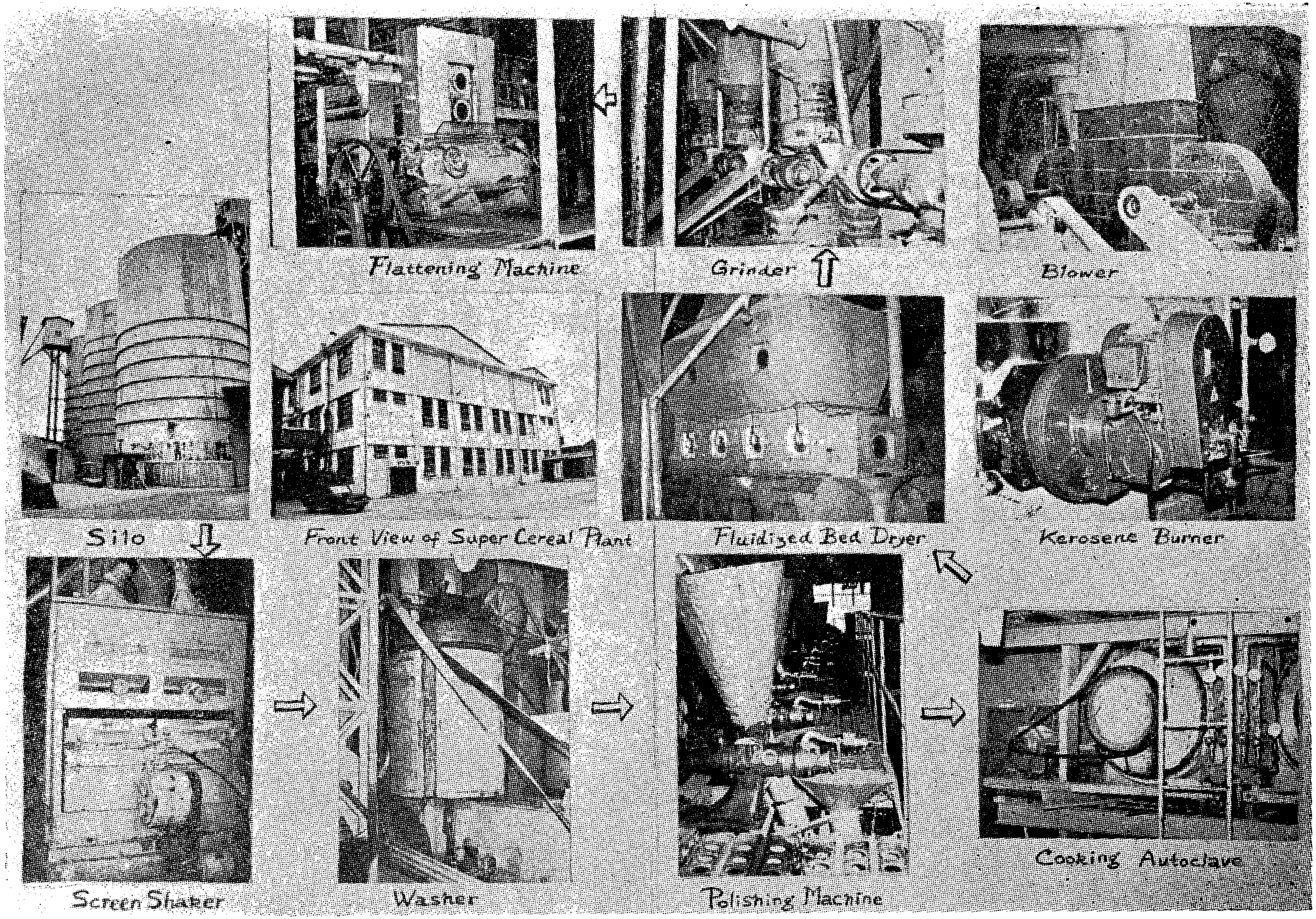

Photo. 1. Feature of Super Cereal Plant of Shin Han Flour Mills Co., Ltd., Inchon.