穀物의 乾燥,貯藏을 위한 사일로 시스템의 시뮬레이션

Simulation of Silo System for Drying and Storage of Grains

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摘　要

米穀綜合處理場의 곡물 건조 및 저장시설의 적정 설계를 위해서 시뮬레이션 모델링이 요구되었다. 이에 곡물 건조 및 저장시설인 곡물 사일로 시스템을 설계하기 위해서 SLAMSYSTEM을 이용한 시뮬레이션 모델을 開發하였다. 곡물 사일로 시스템은 搬入장치, 粗選장치, 計量장치, 乾燥用 사일로, 貯藏用 사일로 그리고 移送장치들로 구성되었으며, 이들 장치와 시스템의 공정들이 네트워 (network)과 프로세스(process) 중심의 시뮬레이션 모델로 表現되어 分析되었다. 이 시뮬레이션 모델로 1) 각 공정에서의 원료 처리시간 및 대기시간 그리고 병목현상, 2) 각 기계 및 장치들의 活用度 및 利用狀態, 3) 물벼의 처리용량 및 건조조건에 따른 건조시간과 건조에 소요되는 에너지 그리고 건조중 발생되는 熱損失, 4) 반입에서부터 저장에 도달할 때까지의 총 처리시간 및 처리량 등을 분석하였다. 이러한 시뮬레이션 결과 자료를 기초로 하여 각 기계 및 장치의 種類와 容量 및 크기를 결정하여 곡물 사일로 시스템을 設計하였다. 그리고 시뮬레이션에 의해 설계된 사일로 시스템이 실제로 전북 남원에 設置되었다.

I. Introduction

Recently, Korean agriculture is in difficulties due to the opening of agricultural product market by Uruguay Round. Especially, Korean rice market is very threatened by the international rice market with low price.

The opening of Korean rice market should be considerate bacause rice is a major agricultural crop as a source of main income of farms in Korea. Rice processing plants have being constructed with a rice mill plant and a facility of drying and storage to overcome problems caused by UR and to produce good quality of rice in Korea.

A simulation modeling was needed for an optimal design of a silo (grain bin) system for rice drying and storage in Korea. The simulation modeling is an effective and proven computer-aid to decision making in industry and business. It is a powerful tool for designing and analyzing a facility of rice drying and storage. Especially today's rice processing plants are more complex in operation and construction than the plants of a few years ago. The rice processing industry is extremely competetive and capitally intensive in Korea. The shortage and high cost

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of agricultural labor and the requirement of high rice quality place a great emphasis on the development of a rice drying and storage system in bulk. A simualtion was conducted for the efficient plan and optimal design of the rice processing plant using a simulation system, SLAM-SYSTEM(Simulation Language for Alternative Modeling System, Pritsker, 1986, 1990).

Rice drying involves a process of simultaneous heat and mass transfers and balances. Prediction of drying time for a rice batch in a drying silo with stirring device is an important factor in the production scheduling and allocation of resources. The general theories of grain drying are conferred in Brooker' and Hall's (1980) books. Chung(1989) developed a simulation model using SLAM II to predict energy amount and drying time for a batch drying of rough rice in a drying silo.

SLAMSYSTEM is used as a simulation tool because it supports model building, analysis of models, and the presentation of simulation results.

A simulation model using SLAMSYSTEM was developed to design a silo system for rice drying and storage and evaluated the performance of the rice silo system without building a pilot plant. The simulation model can be adapted to provide effective and efficient evaluation of various alternative models for scheduling and to design improvements of the silo system. The model includes all the processing equipments and main operating parameters of the silo system from the input of rough rice to drying and storage. The model provided the system performance measures such as bottlenecks in processes, prediction of drying time, allocation and utilization of all the major equipments, mean flow time, total processing time, weekly production of dried rice.

The main purpose of this study was to develop a simulation model of a silo system for rice drying and storage as a part of a rice processing plant, and then to analyze and design the grain silo system using the developed simulation model.

II. General Description of Silo System

The total storage capacity of a grain silo system to be designed is 1,200 ton, which consists of four silos of 300 ton. The grain silo system is used for drying and storage of rice as a part of a rice processing plant. The layout and flowchart of a facility of grain drying and storage is shown in Fig.1.1 and Fig.1.2. The facility represents a continuous/semi-continuous system. The facility consists of a receiving hopper, bucket elevators, grain cleaners, a hopper scale, continuous moisture meters, a input drag conveyor, two drying silos, two storage silos, an unloading drag conveyor, monitoring and control systems and auxiliary equipments of silos. Most of the above processing equipments are designed in the basis of a treating capacity of 20 t/h.

The wet rough rice harvested by combines is delivered to a facility of drying and storage, a silo system. After a truck scaling, the rice is received and cleaned by a grain cleaner and is again weighed by a hopper scale. Then, it is dried in the form of a batch in a drying silo, and after scaling by the hopper scale is stored in a storage silo. Finally, the dried rough rice is delivered to a rice mill plant (4.5t/h) and is processed to milled rice in package. The chracteristics of each process in the system are followings.

A. Weighing and Grading

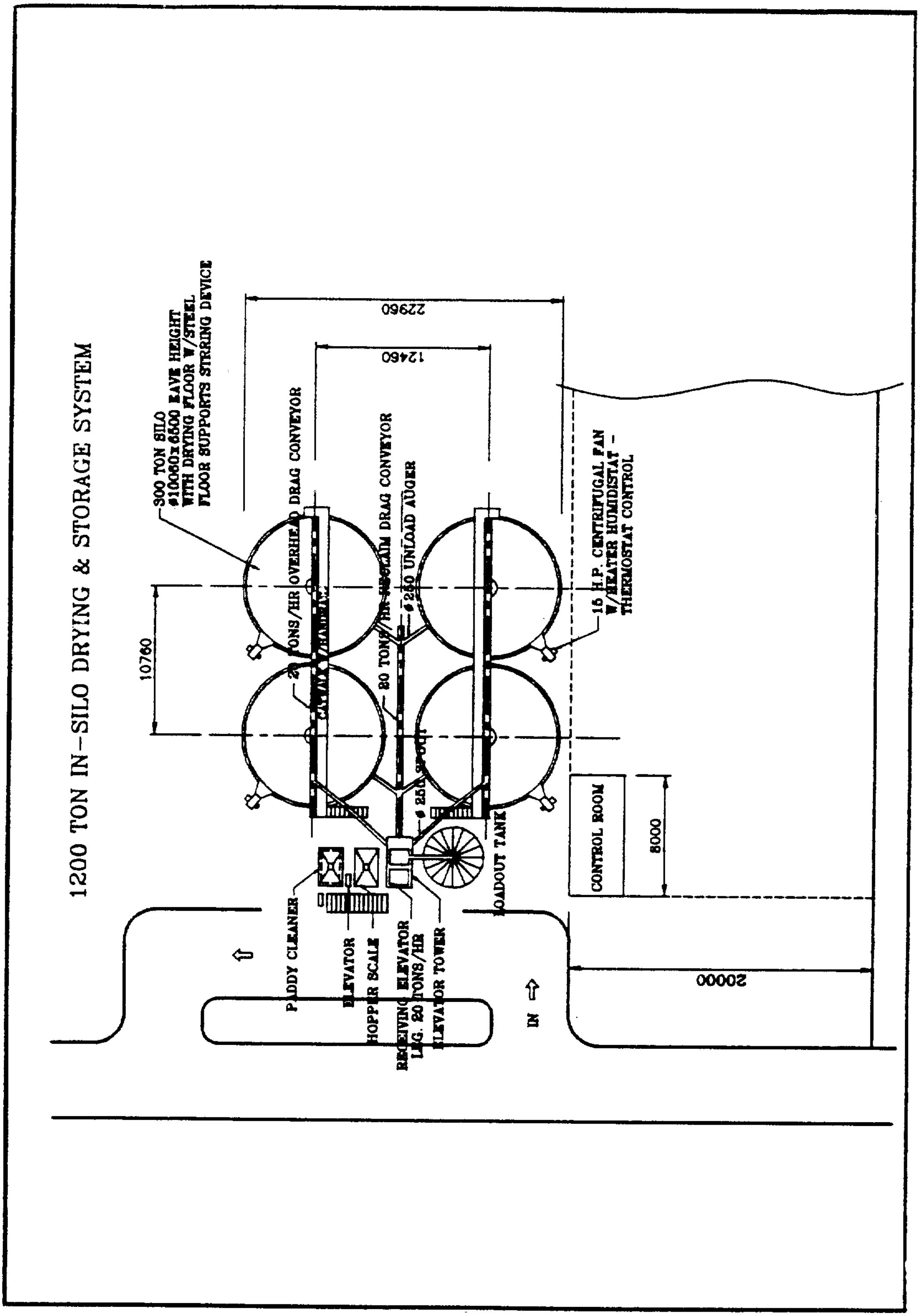
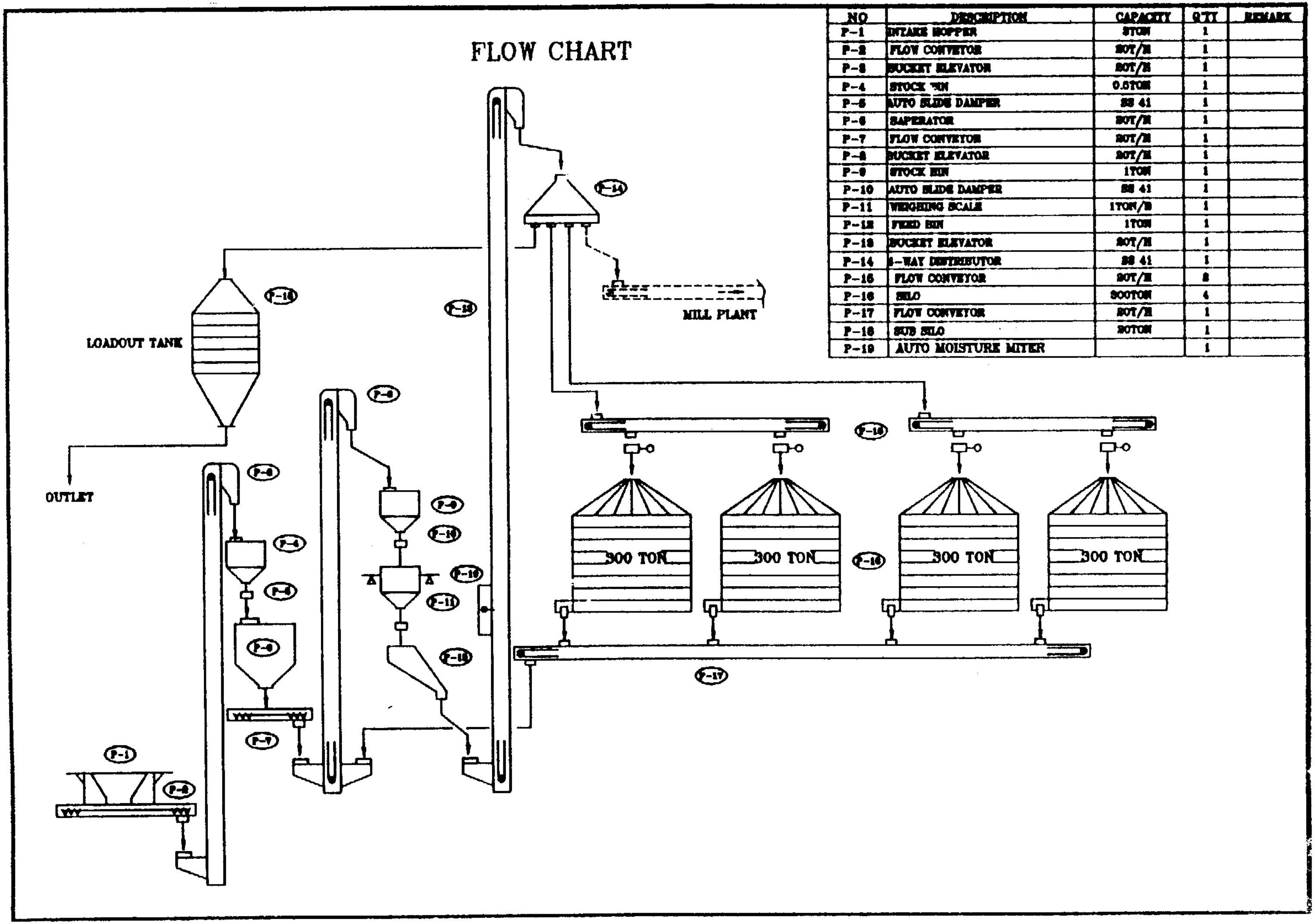


Fig. 1.1 Layout of grain silo system



NO	DESCRIPTION	CAPACITY	Q'TY	REMARK
P-1	INTAKE HOPPER	5TON	1	
P-2	FLOW CONVEYOR	30T/H	1	
P-3	BUCKET ELEVATOR	30T/H	1	
P-4	STOCK BIN	0.5TON	1	
P-5	AUTO SLIDE DAMPER	SS 41	1	
P-6	SAPERATOR	30T/H	1	
P-7	FLOW CONVEYOR	30T/H	1	
P-8	BUCKET ELEVATOR	30T/H	1	
P-9	STOCK BIN	1TON	1	
P-10	AUTO SLIDE DAMPER	SS 41	1	
P-11	WEIGHING SCALE	1TON/B	1	
P-12	FEED BIN	1TON	1	
P-13	BUCKET ELEVATOR	30T/H	1	
P-14	3-WAY DISTRIBUTOR	SS 41	1	
P-15	FLOW CONVEYOR	30T/H	2	
P-16	SILO	300TON	4	
P-17	FLOW CONVEYOR	30T/H	1	
P-18	SUB SILO	30TON	1	
P-19	AUTO MOISTURE MITER		1	

Fig. 1.2 Flowchart of grain silo system

Wet rough rice is harvested in the moisture contents of 20~24% (w.b.) after A.M. 10, and is delivered to a drying and storage facility of silos. The transported rice is weighed by an electronic truck scale installed in the facility. The weighing is accomplished with a 3.0 m by 18.3 m electronic, pitless, drivethrough motor truck scale. Its capacity is approximately 50 ton, and it is sized to weigh any commercially available truck actually. The truck weights is read within a control room. The readout is digital with a ticket printer for record-keeping. The grading of the grain from each truck is done in a small lab. A sample of the grain is taken from each truck for a quality test.

B. Intake Process

The unloading/receiving system consists of a receiving hopper/pit such that the facility can receive grain both in bags and in bulk simultaneously. The capacity of the receiving hopper/pit is total approximately 20 t/h. The rice is received through a receiving hopper.

From a steel chain conveyor with a capacity of 20 t/h, the rice is lifted to be cleaned by a centrifugal bucket elevator with a capacity of 20 t/h.

The elevator is drived in the power of a geared motor.

C. Cleaning Process

From the elevator, the rice is accumulated in a buffer tank to be cleaned by a rice cleaner. The capacity of the cleaner is about 20 t/h. It is equipped with sets of screens and a fan.

D. Hopper-Scaling Process

The cleaned rice is transported to a buffer tank for a hopper scale by a chain conveyor and a bucket elevator. The opening of the buffer tank is controlled with a pneumatic control gate with two step action of 90% feeding and 10% limit feeding. The hopper scale weighs rough rice by a batch of 500kg. The scaled rice is transported through a feeding tank and an elevator to a four-way distributor, which controls the direction of rice flow to a drying silo(or a storage silo or a mill plant or loadout tank).

E. Rice Drying Process

A batch of rice is dried in a drying silo with a stirring device. The drying silo with a diameter of 10.05 m and a height of 6.5 m has a capacity of 300 ton. The silo can be used for a storage silo after drying.

The drying silo is equipped with a 11 kW fan, a diesel oil heater with a thermostat and a humidistat, a 3-auger stirring device, airways, an automatic drying system with moisture sensors, an aeration system and sweep and unloading augers. The silo may be insulated with uretan foams of 5 cm thickness for efficient batch-in-silo drying, if required.

The batch-in-silo drying process involves the following procedures ; 1) Placing a 1m-layer of grain in the silo. 2) Forcing natural or heated air to temperature of about 30℃ through the grain and using a stirring device for the uniform drying until the average moisture of the batch has reached the desirable final moisture(below 17%,w.b.). Typically, the drying silos have airflow rates of about 5 cmm/㎡ (402 cmm), Koh et al.(1990). 3) Cooling the grain by running the centrifugal fan with the heater off. 4) Moving the dried grain to the other storage silos for dryeration to get grain with the moisture below 15 %, w.b.

The drying time for a batch of rough rice in the drying silo is predicted by a model based on a heat balance equation between sensible heat of drying air and latent heat of vaporization for grain drying. The heat loss during rice drying in a drying silo also was analyzed. The heat balance equation for the drying process can be written as follows :

$$\frac{cmm \times 60}{v} (Ca) (Ta - Tg)\ t\ E = h_{fg}\ DM\ (M_i - M_f), \text{ Brooker et al.(1982)}$$

$$E = Q_{dry} / (Q_{in} - Q_{exit})$$

where, cmm : airflow rate, cmm

- v : specific volume of air, kJ/kg℃ (Koh et al. 1990)
- C_a : heat capacity of air, kJ/kg℃
- T_a : plenum air temperature, ℃
- T_g : exit air temperature, ℃
- h_{fg} : heat of vaporization, kJ/kg (2,742 kJ/kg)
- DM : dry matter, kg
- M_f : final moisture content, d.b., decimal
- M_i : initial moisture content, d.b., decimal
- t : drying time required for a batch drying of rice, h
- E : drying efficiency of drying silo
- Q_{in} : heat input from a heater
- Q_{exit} : heat loss from exhaused air
- Q_{dry} : heat of vaporization in rice drying, $(Q_{in} - Q_{exit}) - Q_{loss}$
- Q_{loss} : $Q_{wall} + Q_{bottom} + Q_{duct} + Q_{heater}$

F. Re-Scaling and Storage Process

The dried rice is rescaled by the same hopper scale and is transported to a storage silo (or loadout tank, or paddy tanks(30 ton) of the mill plant) by the bucket elevator and the four-way distributor. The rice delivered is dryerated in the storage silo by the aeration system, and then is stored under the automatic aeration systems ; a fan, a heater, airways, and a stirring device.

Ⅲ. SLAMSYSTEM Simulation Modeling

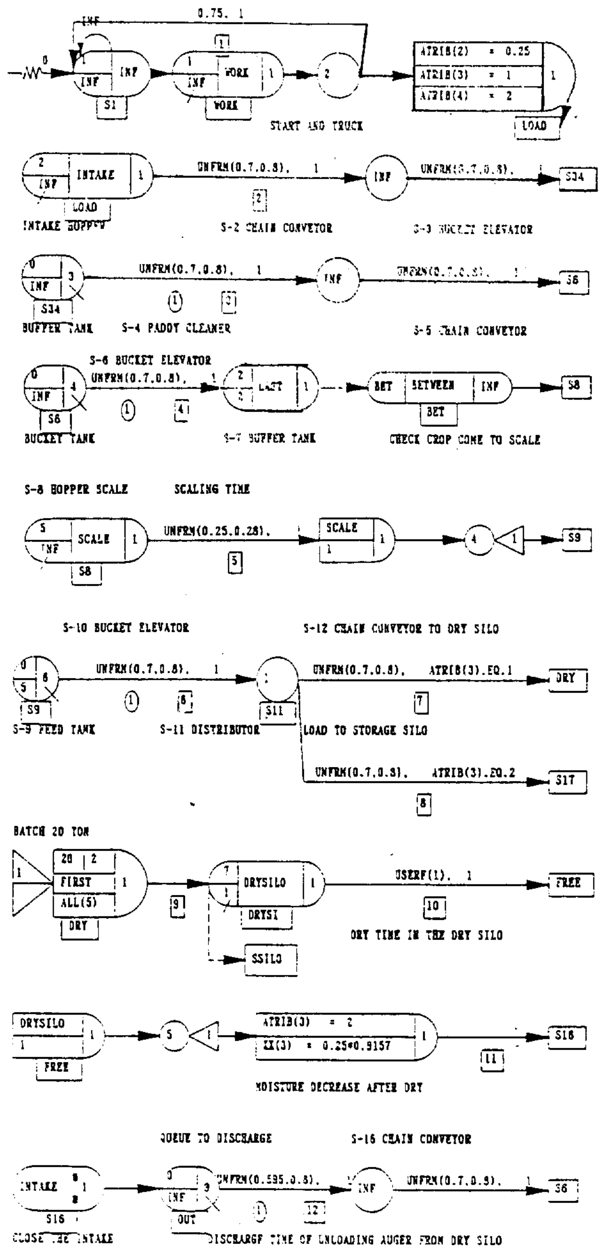
The simulation model for a drying and storage facility of rough rice was developed using a combined network orientation of SLAMSYSTEM. The simulation model consists of a network model and an user-insert subprogram. The conceptual network of SLAMSYSTEM helps in formulating the model, and it also aids in focusing attention on the elements and characteristics of a real system which must be modeled. The user-insert subprogram supports the limited flexibility of the network model. The network model is structured of some specialized symbols, called nodes, and branches which are combined to represent the system as queues, servers, batches, and logical decision points. The practical representation with nodes is automatically translated into an equivalent statement model for input to the SLAM processor. Standard programs are built within SLAM for automatic collection of operational statistics. For a detailed explanation of SLAMSYSTEM see Pritsker et al.(1990).

A. Network Model

The overall operation of the facility is modeled correctly with the network nodes. The model can determine the status of the system over time by processing various activities such as cleaning, scaling, drying, and conveying. The objects within the boundaries of a system are called entities. In this model an entity represents a batch of 250 kg rough rice.

The network represents the semi-continuous flow of these entities through the system from intake to storage in silos. The capacity of each unit machine and equipment is not fixed in the model because it should be determined with the results of the simulation.

The SLAMSYSTEM network, as shown in Fig. 2, consists of three independent networks, resource Blocks, and gate Blocks.



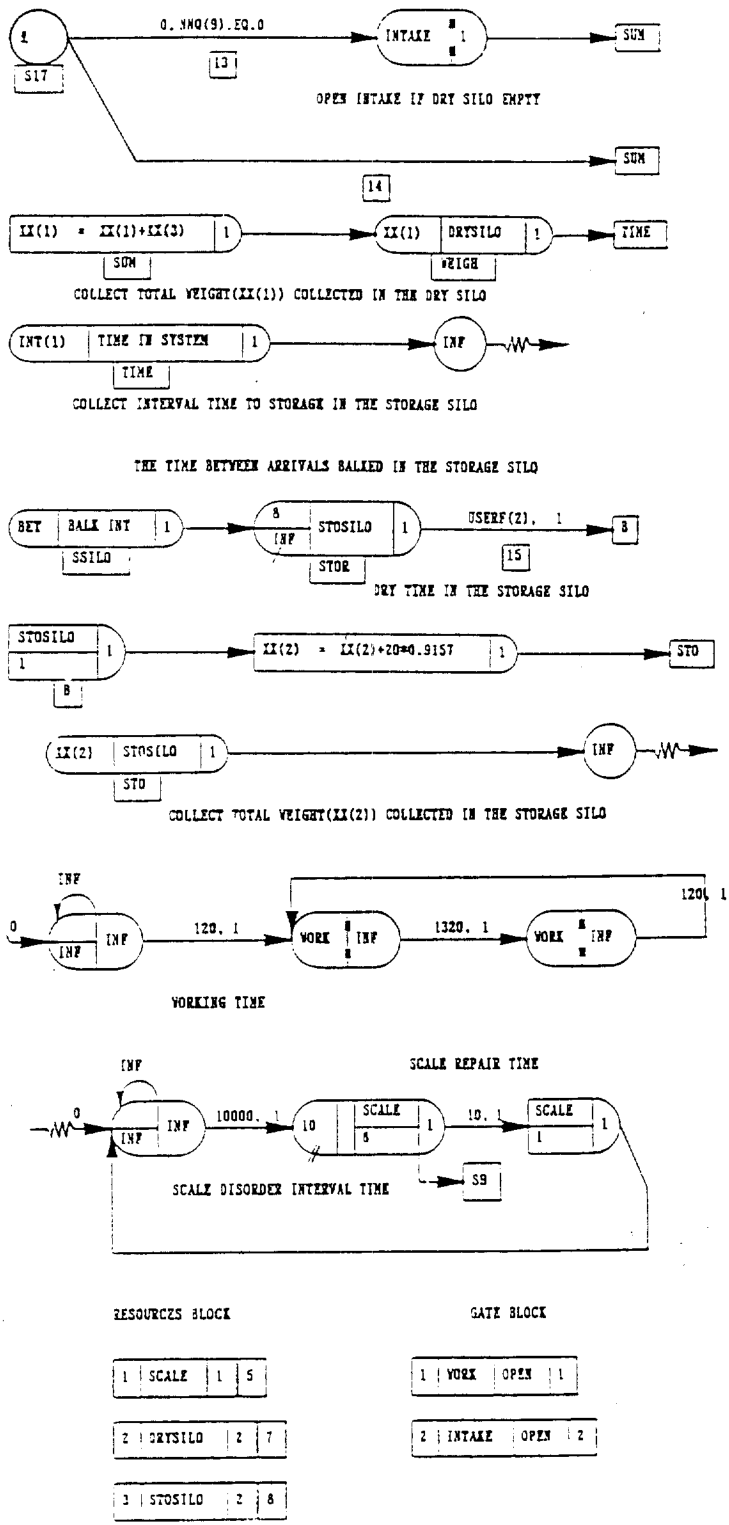


Fig. 2 SLAM NETWORK MODEL

The first network starts with a CREATE node, which creates entities, the rough rice harvested and delivered to the facility from the field. The CREATE node can create only entities according to working time of the day using a GATE node as WORK, and do it with a specified time of 0.75 min. between creations. The time interval between creations means that rough rice is routed into the network on the speed of 20 t/h. The characteristics of entities are represented by a ASSIGN node using ATTRIBUTE variables. The intake hopper is represented by a GATE node as INTAKE, which is blocked when the hopper scale is used for discharging the dried rice from the drying silo to the storage silo, otherwise it is always often. The routed entities are delivered to a feeding tank for a paddy cleaner through a chain conveyor and a bucket elevator, which is represented to indicate the time delay by REGULAR ACTIVITY nodes. The feeding tank is expressed by a QUEUE node, and the operation of the paddy cleaner is done by a SERVICE ACTIVITY node. The cleaned rough rice is delivered through a chain conveyor and a bucket elevator to a feed tank for a hopper scale. The lower buffer tank of the bucket elevator is expressed by a QUEUE node and the elevating function is done by a SERVICE activity.

Then, the rice is accumulated for a batch of 500 kg to be weighed by the hopper scale. An ACCUMULATE node is used to indicate a batch of rice to be weighed, and a AWAIT node with the RESOURCE of the hopper scale is used for weighing a batch of rice. After weighing the batch, the batced rice is unbatched into an entity of 250 kg by the UNBATCH node. The weighed rice is distributed by a four-way distributor to drying silos or storage silos. The wet rice is batched into a 20 ton entity by the BATCH node. The batched rice is dried in the drying silo during the drying time of USERF(1). The drying time is estimated by a user-insert subprogram, a USERF function. The subprogram provides a drying time required for a batch of rice according to the drying conditions. If the waiting entity, batched wet rice, exceeds a queuing capacity of the AWAIT node with 2 RESOURCEs of drying silos, the batched rice is balked and routed to the AWAIT node waiting for the RESOURCEs of the storage silo.

As the rice is dried in the drying silo during the drying time of USERF(1), the drying silo is freed by the FREE node in case the dried rice is completely discharged, otherwise the drying silo is not freed until the drying silo is empty. The dried rice is unbatched by the UNBATCH node and is discharged to the storage silo through the chain conveyor and the hopper scale. The weight of a dried entity is reduced against original weight of the wet entity and the dried rice is separated from the wet entity using the ASSIGN node with the variable of ATRIB(3). When the dried rice is moved to the storage silo through the hopper scale, the intake hopper is blocked by closing the GATE node of INTAKE. After the drying silo is completely empty, the intake hopper is opened by the open GATE node of INTAKE. The total weight of the dried entities is summed up by assigning the total weight to the XX(1) at the ASSIGN node and is collected by the COLLECT node with SLAM variable of XX(1). The total time in the system from intake to storage is also collected by the COLLECT node with the variable of INT(1) and is terminated by the TERMINATE node. The terminated entity indicates being stored in the storage silos.

The wet entity balked at the AWAIT node for drying silos is also dried at the storage silo during the drying time of USERF(2). The time interval between balked entities is collected by the COLLECT node. The total weight of balked entities is summed up by the ASSIGN node and is collected by the COLLECT node with the SLAM variable of XX(2). Then, the balked entites are terminated by the TERMINATE node, which indicates being storing in the storage silo.

The second network starting a CREATE node indicates off-time and working time to generate entities harvested in the field during a day. As the working time is set like 120 min., the CREATE node can only create entities during the working time with the time interval of 0.75 min. and generate total amount of 40 ton. It means that the total amount of rough rice harvested during a day is 40 ton and that the time interval of 0.75 indicates the intake speed of 20 t/h. The gate of WORK is normally open at the GATE BLOCK. However, if the GATE node of WORK is closed by the closed GATE node, the CREATE node can not generate entities at the CREATE node of the first network.

The third network represents a breakdown of the hopper scale. The breakdown of the scale is expressed by the PREEMPT node. The breakdown is assumed to be occurred at a time interval of 10,000 min. with a repair time of 10 min. If the scale is out of order, the entity to be scaled can pass by the scale without weighing or should wait for a repair time of 10 min. In this model it is assumed to pass by the scale. The hopper scale, drying silos and storage silos are defined by RESOURCE BLOCKs, and the gates of WORK and INTAKE are expressed by GATE BLOCKs.

B. FORTRAN User-Insert Model

The drying process of rough rice is modeled by a FORTRAN language. The User-Insert Model is programmed in dialogue and is linked to the network model of the SLAMSYSTEM. The model can determine total heat required for a batch drying, heater capacity, drying time, heat loss during drying, and effect of insulation. The input parameters of the model are drying air temperature, ambient air temperature, exhausted air temperature, airflow rate, initial moisture content, final moisture content, thermal properties of air, weight of grain, dimension of silo, drying efficiency, coefficients of heat conductivity of concrete, corrugated steel, and insulation material, etc.

C. Simulation Conditions and Alternative Models

The main factors of grain silo system in the simulation model were drying temperature, daily intake amount, grain initial moisture content, drying efficiency of silos. The main factors and their levels of simulation are shown in the Fig. 3.

The developed simulation model was executed at the following conditions with alternative models : total simulation time of 6 days, daily intake amount of 40, 60, and 80 ton, initial moisture content of 22%, 23% and 24% (w.b.), final moisture of 17% (w.b.), use of a 11 kW centurifugal fan with 1.244 kPa static pressure and 402, 425, and 459cmm, drying air temperature of 30 ℃ and 18℃, daily average temperature of 13.8℃ and daily average relative humidity of 73% of ambient air during October at Namwon city in South Korea.

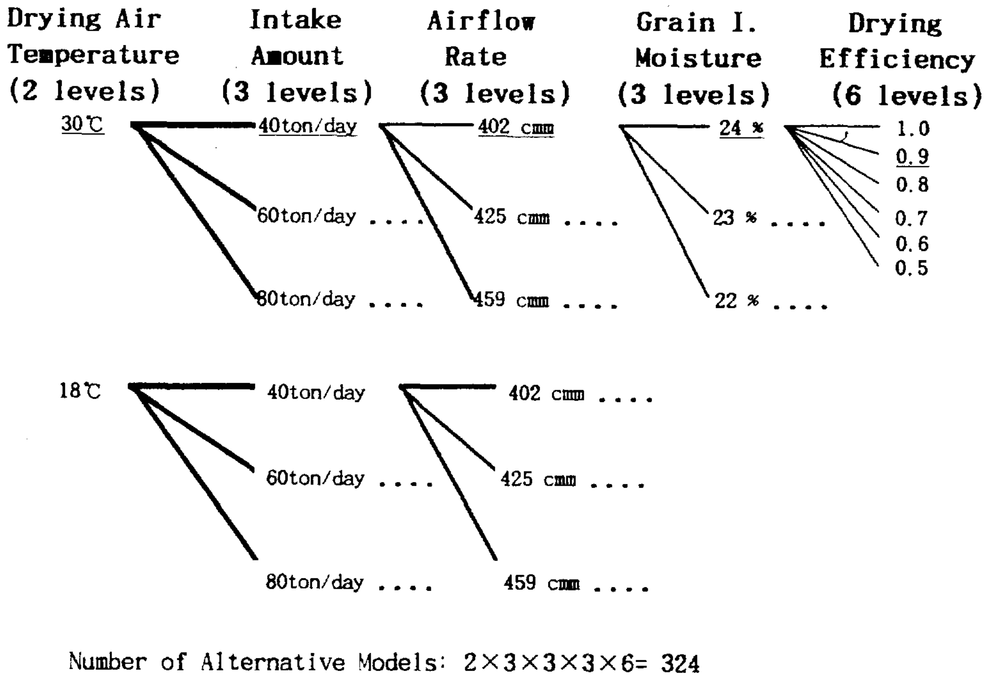


Fig. 3 Factors and levels of simulation model

Ⅳ. Results and Discussion

The grain silo system was modeled with SLAMSYSTEM as shown in Fig. 2.

As results of simulation, the effect of the batched weight and the initial moisture content of rough rice on the drying time under 402 cmm airflow rate is shown in Table 1. The drying times of rice with 24% initial moisture content in the silo system with 132 kW heater were respectively 29 h, 22 h, and 15 h according to daily intakes of 80 t/h, 60 t/h, and 40 t/h, while those in the silo system with 31 kW heater were respectively 98 h, 73 h, and 46 h. The total weight of rice dried in the drying silo during the given simulation time, 6 days was 293 ton and that dried in the storage silo was 73 ton at the initial moisture content of 24%. This meant that the capacity of drying silos was insufficient due to lots of 80 t/d intake, but it was sufficient at intake amount of 60 t/d.

The performance measures of the silo system at intake amount of 40 t/d are shown in Table 2 and in most of figures. Especially, the time open percentage of the intake hopper was about 93% of total simulation time at intake amount of 40 t/d in Table 2. Namely the intake hopper was blocked during the only 7% of total simulation time because of withdrawing the dried grains from drying silos to storage silos.

The following results were simulated at the conditions of intake amount of 40 t/d, initial moisture content of 24%, final moisture content of 17%, airflow rate of 402 cmm.

Table 1. Effect of the batched weight and the initial moisture on the drying time under 402 cmm airflow rate.

Item / Batch Type	Initial Moisture (w.b.%)	Drying Time(h) Model A	Drying Time(h) Model B	Total Weight of Dried Grain(ton) Model A Dry-.Silo	Model A Sto-.Silo	Model B Dry-.Silo	Model B Sto-.Silo	Remark
80 ton/day (40 ton/batch)	24	29	98	293	73	73	37	XWf=17%
	23	25	84	334	37	74	74	Wt=40,000
	22	21	70	376	0	113	75	E=0.9
60 ton/day (30 ton/batch)	24	22	73	275	0	55	55	XWf=17%
	23	19	63	334	0	111	56	Wt=30,000
	22	15	52	338	0	113	85	E=0.9
40 ton/day (20 ton/batch)	24	15	46	220	0	73	55	XWf=17%
	23	13	40	223	0	111	56	Wt=20,000
	22	11	33	226	0	132	56	E=0.9

1. Moldel A : silo system with a 132 kw heater.
   Model B : silo system with a 31 kw heater.
2. XWf : final moisture content(%, w.b.).
   Wt : weight of a batch of wet rough rice to be dried(kg).
3. E : Drying efficiency of silo.
4. Simulation time was 144 h·, 6 days.
5. Relative humidity of exhausted air was assumed 90 %.

Table 2. Performance measures of 1,200 ton silo system at intake amount of 40 ton/days, 20 ton/batch of drying, initial moisture of 24%, final moisture of 17%, airflow rate of 402 cmm, drying air temperature of 30℃ with different drying efficiency.

ITEM		Drying Efficiency 1.0	0.9	0.8	0.7	0.6	0.5
Drying Time(h)		13	15	17	19	22	27
Time Open of Intake Hopper(%)		93.4	93.4	93.4	93.4	94.5	95.6
INTAKE GATE	Ave. /Max. Length	0	0	0	0	0.8/63	0
	Ave. Wait Time(min)	0	0	0	0	7.6	0
Ave. Utilization(%) of Resources	Drying Silo	60	62	70	80	92	82
	Storage Silo	0	0	0	0	0	26
	Hopper Scale	0.03	0.03	0.03	0.03	0.03	0.02
Ave. Utilization(%) of Service Activity	Rice Cleaner	0.08	0.08	0.08	0.08	0.08	0.08
	Elevator for Scale	0.17	0.17	0.17	0.17	0.15	0.14
	El. for Distributor	0.17	0.17	0.17	0.17	0.15	0.14
	Unloading Auger	0.07	0.07	0.07	0.07	0.06	0.04

Time in the Silo system	Mean(h)	15	16	18	20	25	30
	Minimum(h)	15	16	18	20	24	28
Total weight of Dried Grain(ton)	Drying Silo	220	220	220	220	183	147
	Storage Silo	0	0	0	0	0	37
Length and time for Drying Silo	Ave. Length	0	0	0	0	0	0.12
	Ave. Wait Time(min)	0	0	0	0	1.8	118
Elevator for Hopper Scale	Ave./Max. Length	0.7/17	0.7/17	0.7/17	0.7/17	3.7/99	0.5/17
	Ave. Wait Time(min)	3.1	3.1	3.1	3.1	18.2	2.6

A. Power of Fan and Heater

The power and capacity of a fan and a heater mainly affected the performance measures of the silo system. The power, static pressure drop, and airflow rate of the fan were determined in the basis of optimal airflow rate of about 5 cmm/m^3, which was based on the removal rate of water from grain (about 0.3%/h). The power of a heater was determined by the drying air temperature as shown in Fig. 4. The rated power of the heater required for heating average ambient air of 13.8℃ to 18, 24, and 30℃ was ranged from 31 kW to 82 kW and 132 kW at airflow rate of 402 cmm and the drying efficiency of 0.9, respectively. The energy requird for heating ambient air to 30℃ was, respectively, 132, 139, and 150 kW at airflow rates of 402, 425, and 459 cmm at the drying efficiency of 0.9.

B. Drying Time

The drying time was, respectively, ranged from 15 h to 22 h and 29 h for a batch drying of 20, 30, and 40 ton at the drying air temperature of 30℃, 402 cmm airflow rate, drying efficiency of 0.9, initial moisture content of 24% and final moisture content of 17% as shown in Fig. 5. The drying time was ranged from 11 h to 13 h and 15 h with different initial rice moisture content of 22%, 23%, and 24% (w.b) at the drying of 20 tons/batch and drying efficiency of 0.9 as shown in Fig. 6. The drying efficieny of silos also affected the drying time from 13 h to 15, 17, 19, 22 and 27 h, corresponding to the drying efficiency of 1.0, 0.9, 0.8, 0.7, 0.6 and 0.5 at the drying of 20 t/batch, respectively.

C. Performance of System

The performance measures of the system were time open percentage of intake hopper, average and maximum waiting entities (length) and average waiting time at the INTAKE GATE, average utilization of resources such as hopper scale, drying silo, storage silo, average utilization of service activities such as rice cleaner, elevators, and unloading auger, time in the system from intake to storage, total weight of dried grain through each silo, average waiting entities and time for drying silos, and average waiting length and time for other processes, as shown in Tables 1 and 2.

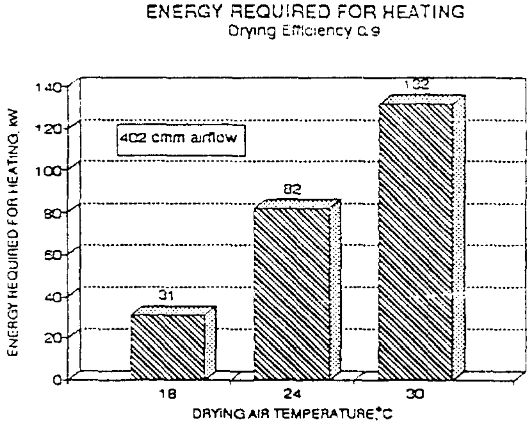


Fig 4. Energy required for heating ambient air temperature of 13.8℃ to 18℃, 24℃, and 30℃ drying air.

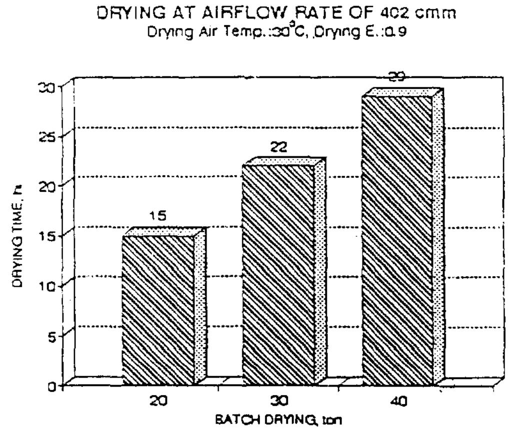


Fig 5. Drying time with different amount of batch drying.

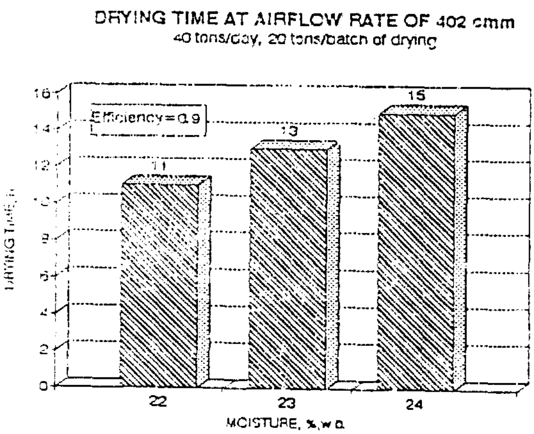


Fig 6. Drying time with different initial moisture content.

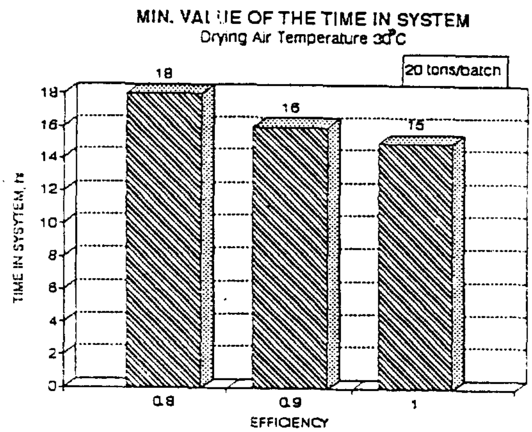


Fig 7. Minimum value of the time in system with different drying efficiency

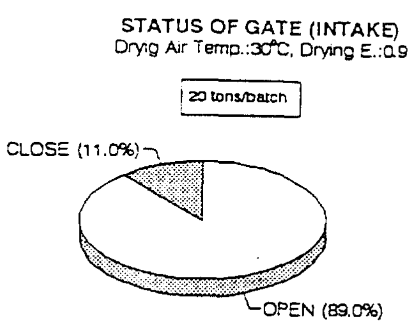


Fig 8. Status of INTAKE gate.

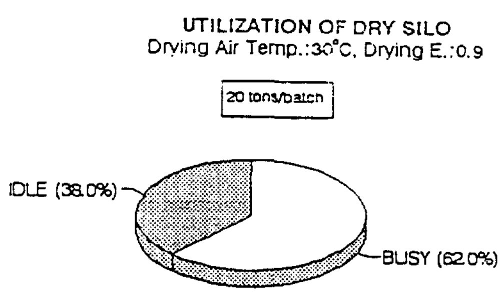


Fig 9. Utilization of drying silos.

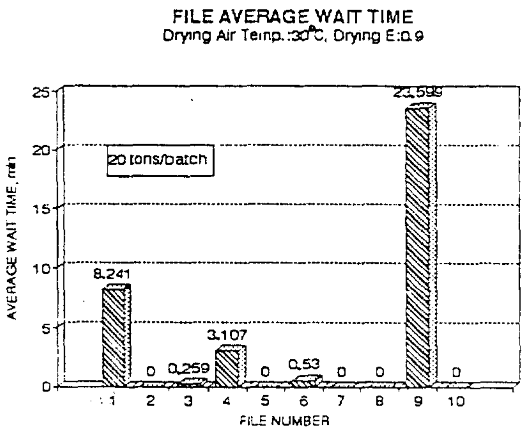


Fig 10. Average waiting time at each file(process).

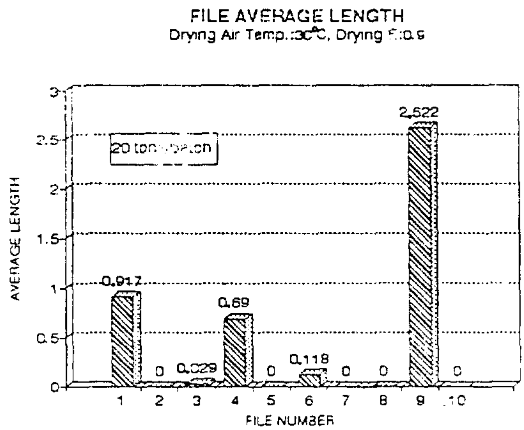


Fig 11. Average waiting entities(length) at each file(process).

The silo system has no bottleneck and no problems at the drying efficiency of more than 0.6. The minimum value of the time in the system from intake to storage of grain is shown in Fig. 7 with the drying efficiency at the initial moisture content of 24%, airflow rate of 402 cmm, batch drying of 20 t. The main time, 15 h, among the minimum time in the system of 16 hrs in Fig. 7 was the drying time at the drying efficiency of 0.9 in Fig. 5. The status of INTAKE GATE, which is closed in case of discharging the dried rice from the drying silos, is shown in Fig. 8. The INTAKE GATE is closed during 11 % of the total simualtion time for discharging the dried rice from the drying silos to the storage silos or the loadout tank or the rice mill plant. However, unloading of the stored rice from storage silos to the loadout tank or the rice mill plant can be carried out at any time except the intake time and the time discharging from drying silos. Fig. 9 shows the utilization of drying silos at drying capacity of 20 t/batch. The average waiting time and entities for each processing unit are shown in Fig. 10 and Fig. 11. The values obtained at drying temperature of 30 ℃, drying efficiency of 0.9, intake of 40 t/d, a batch drying of 20 ton did not indicate bottleneck or any problems in the silo system. The size and capacity of all equipments in the silo system could be determined with the such data through much simulations.

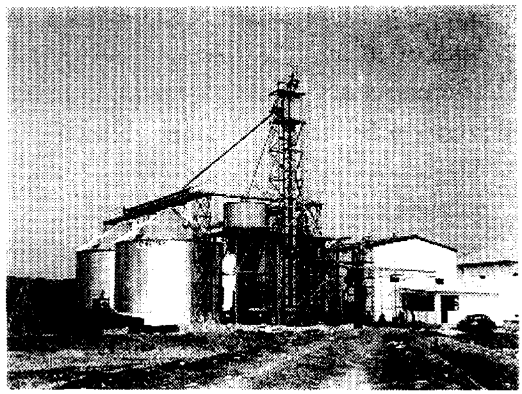
D. Heat Loss during Drying in a Drying Silo

The heat loss during rice drying with 1 m grain depth was analyzed in the drying silo with/without insulation. The main heat loss during drying was heat loss from the exhausted air (Qexit), which was about 27% of total heat input (132kW) as shown in Fig. 12. The heat loss from the plenum chamber to the concrete floor (Qlc) was about 1.8% of total heat input. In the case of the drying silo without insulation, the heat loss from the slio wall of plenum chamber (Qla) was about 0.4%, and the heat loss from silo wall contacted with grain (Qlg) was about 0.6%. And the heat loss from all the silo wall

(Qwall) was about 4.2% of total heat input. The heat used for drying (Qdry) was about 67% of total heat input (132kW).

In a drying silo with the 50 mm insulation of asbestos, the heat loss from the silo wall of plenum chamber (Qlai) was about 0.3% of total heat input, and the heat loss from the silo wall contacted with grain (Qlgi) was about 0.4%. The heat used for drying in the silo with insulation was about 70% of total heat input (132kW).

The effect of the silo insulation on saving of the drying energy was not significant. The silo insulation could reduce only about 0.3% of total heat input though it could reduce about 30% of the heat loss of the silo wall contacted with grain and plenum chamber wall. The silo insulation was not required for saving of the drying energy in a drying silo. In addition, cycling of exhausted air was required for re-use of the air with high enthalpy, and insulation on the bottom floor of the concrete was also recommended to save drying energy.



Picture 1. A grain silo system constructed at Namwon city.

Ⅴ. Conclusions

The conclusions of this study are as follows.

1. A simulation model to design a grain silo system was developed with SLAMSYSTEM.

2. The silo system at intake amount of 40, 60, and 80 t/d was analyzed by the simulation model. The system had no bottleneck in material

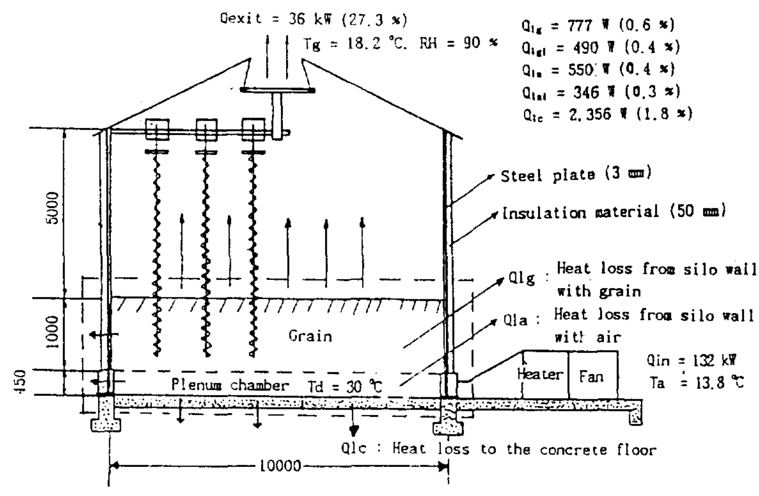


Fig 12. Heat loss during drying in a drying silo with a 132 kW heater.

flow up to intake amount of 60 t/d in a drying batch of 30 ton. The size and capacity of all eqiupments such as fans, heaters, buffer tanks, hopper scale, bucket elevators, conveyors, paddy cleaner, etc could be determined by the simulation data.

3. A hopper scale and a main bucket elevator to the 4 way distributor could be enough used for loading wet rice to the drying silos and for unloading dried rice to the storage silos or a rice mill plant or a loadout tank, not requiring an additional hopper scale and discharging elevator.

4. The drying silo required a diesel oil burner of 132 kW for heating average ambient air of 13.8℃ to drying air of 30℃ at airflow rate of 402 cmm. The drying time was, respectively, 15, 22, and 29 h with 20, 30, and 40 t/batch of drying at drying air temerature of 30℃, airflow rate of 402 cmm, initial and final moisture content of 24% and 17% (w.b), and drying efficiency of 0.9.

5. The main heat loss during drying in the drying silo was the heat loss from the exhausted air, which was about 27% of total heat input. The second heat loss was the 1.8% loss from concrete floor of plenum chamber.

The effect of the silo insulation on saving of the drying energy was a little. As the silo insulation could reduce only about 0.3% of the total heat input, the silo insulation was not required in view of saving of drying energy.

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