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Development of a Low-cost and High-efficiency Post-harvest Bulk Handling Machinery System of Onion – Performance Evaluation and Control

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Abstract As post-harvest processes of onions are carried by a 20 kg-net package which results in high-cost and low-efficiency, especially, the insufficient drying and physical damage of onions after harvesting leads to a huge second loss in storage, we had developed a low-cost, high-efficiency post-harvest bulk handling machinery system by collecting onions on a farm using ton-bags, drying with forced air circulation, and sorting/packaging. The post-harvest bulk handling machinery system consisted of 6 devices, and this study designed an automatic feed hopper with a feeding rate control device, an inclined belt conveyor with a two-step chute, and an automatic pallet unloading device for feeding onions into the sorting/packing line. This study also analyzed the performance and control of the total system. The device had 1-ton handling capacity, but the operational condition was set to increase the capacity. The three-step filling method of pallet by the velocity control of the inclined belt conveyor was applied in the post-harvest bulk handling machinery system for the prevention of physical damage. If one worker was set to operate the total system, the time required to complete one palletized load was approximately 5 minutes and 5 seconds. The calculated daily handling capacity was approximately 94 tons, when the daily actual working time was 8 hours. When the developed system was applied to the managerial size of 2,000 ton, the processing cost per ton of the system was decreased by 19.5%, compared with the existing 20 kg-net package-based handling. The developed post-harvest bulk handling machinery system would be a good substitute for the rapid decline and aging of rural labor.

Keywords Onion, Local logistics efficiency, Post-harvest bulk handling machinery system, 20 kg-net package, Box pallet, Palletized load

Introduction

The consumption of onions has increased in Korea due to the diversification in consumption patterns and changes in dietary patterns. The best storable crops, onions (*Allium cepa* L.), account for 50% of the entire agricultural stocks[1].

Post-harvest processes of onions are carried by a 20 kg-net package which results in high-cost and low-efficiency. Especially, the insufficient drying and physical damage of onions after harvesting leads to a huge second loss in storage[2].

A 20 kg-net package-based handling causes compression damage during storage and decreases the handling efficiency. Also, it becomes impediments in planned shipping of the stored onions because of poor cold air circulation, high cost, and labor intensive process for screening of decayed onions (Fig. 1)[2,3]. Therefore, thorough processes covering from the packaging on the farm to the processes of pickup, carrying, drying, storage, and sorting/packaging for shipping are needed

Fig. 1. Onion 20 kg-net package storage.

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to maintain the quality of onions and reduce the post-harvest processing cost.

We have developed a low-cost, high-efficiency post-harvest bulk handling machinery system for onion harvesting on a farm using ton-bags, including drying function with forced air circulation, and sorting/packing devices. The system comprised six unit machines (Fig. 2): (1) box pallets for thorough processing of onions, (2) an automatic feed hopper with a feeding rate control device for automatic supply to system and temporary loading of onions warehoused by the ton-bag from the farm, (3) an inclined belt conveyor with a two-step chute, (4) an auto-dump for lifting box pallet to a certain degree and descending after loading onions, (5) an automatic empty-pallet feeding device for continuous operation, and (6) an automatic pallet unloading device for feeding onions into the sorting/packing line.

The primary requirements in designing the system was as follows:

· Generality: selective expansion in system design and working condition on the basis of 1-ton (handling capacity)

· Connectivity between the processes: ton bag-based handling, forced-air drying, and sorting/packing line

· Quality maintenance of onions: physical damage, air circulation during storage

· Local logistics efficiency and purchase function: matching with standard pallet (1,100 × 1,100 mm)

· Ease of system maintenance: automatic & semi-automatic

We have published several research papers regarding the characteristics of friction and airflow resistance for onions[4], design of a box pallet for thorough process[5], and auto-dump design[6] to develop this post-harvest bulk handling machinery system. The objective of this study was to design an automatic feed hopper with a feeding rate control device [(1) and (2) in Fig. 2], an inclined belt conveyor with a two-step chute [(3) and (4) in Fig. 2], and an automatic pallet unloading device [(8) in Fig. 2] for feeding onions into the sorting/packing line. We also analyzed the performance and controllability of the total system.

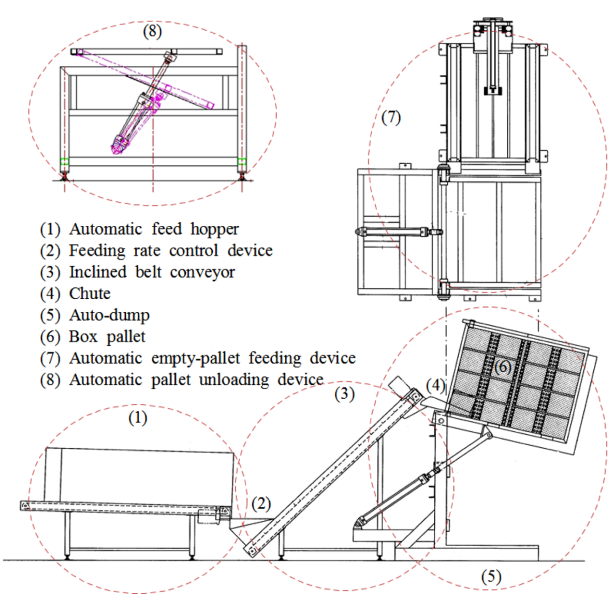

Fig. 2. Block diagram of the post-harvest bulk handling machinery system.

System Design and Control

1. Automatic Feed Hopper

The hopper type was designed for easy of the ton bag-based handling for temporary loading of onions and continuous supply to the system. The hopper type was applied, since the structure should be easy for the ton bag-based handling for temporary loading of onions and continuous supply to the system The device had 1-ton handling capacity, but operational condition was set to increase the capacity to achieve generality.

The following specifications of the belt conveyor was applied to the bottom of the automatic feed hopper, and the maximum height of the hopper was limited to 1.5 m to handle ton bags

· Velocity of conveyor belt: 16 m/min (typical velocity of conveyor belt: 15~20 m/min)

· Width of conveyor belt: 800 mm

· Maximum height of hopper: 1.5 m or less including support fixture

· Onion outlet: width of 790 mm and height of 50 mm with controlling of 6 stages

The automatic feed hopper with 1-ton capacity was shown in Fig. 3; the bulk density of onions used in the design was 541.80 kg/m^3.[4]

Power requirement of the automatic feed hopper was the drive shaft power which can send 1 ton onions stacked on the belt conveyor to the onion outlet, and it was calculated as a

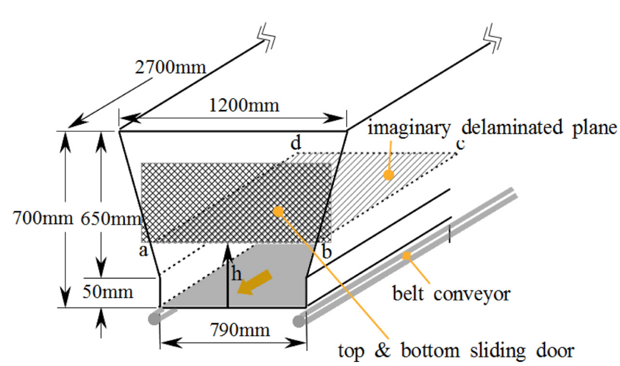

Fig. 3. Schematic representation of the automatic feed hopper for 1-ton.

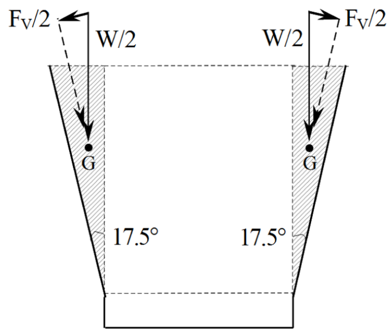

Fig. 4. Normal force acting on both slopes of the hopper.

sum of no-load power (N_1), horizontal moving load power (N_2), and frictional power caused by horizontal friction force (between hopper wall and stacked onions) and internal friction force (by delamination of stacked onions) (N_3) [equation (1)][7].

$$N = N_1 + N_2 + N_3 = \frac{\mu \omega v L}{1,000} + \frac{\mu Q_{afh} L}{1,000} + \frac{(f_1 + f_2) \times v}{1,000} \tag{1}$$

where, N = drive shaft power (kW), μ = frictional coefficient (0.1~0.3), ω = weight per unit length of moving part except carried objects [conveyor belt: 15.70 N/m (width 800 mm)] (N/m), v = velocity of conveyor belt (m/s), L = length of conveyor (m), Q_{afh} = carrying quantity of the automatic feed hopper (N/s)

Horizontal friction force between stacked onions and hopper wall is exerted on the slopes of the hopper, and this frictional force was calculated from the normal force (F_v) acting on the slopes as shown in Fig. 4.

W in Fig. 4 represents the total weight of onions corresponding to the total volume (shaded area) of both slopes of the hopper, and F_v represents the vertical component force acting on the slopes. Therefore, the total horizontal friction force (f_1) acting on the slopes was calculated as follows. The static-frictional coefficient between the onions and the hopper wall was 0.35, and the bulk density of onions was 541.80 kg/m^3.[4)]

$$W = \left(\frac{1}{2} \times 0.205 \times 0.650 \times 2.7 \times 2\right) \times 541.80 \times 9.81 = 1912.22\text{N}$$

$$F_v = W \sin 17.5^\circ = 575.02 \text{ N}$$

$$f_1 = F_v \times 0.35 = 201.26 \text{ N}$$

Internal frictional force by delamination of stacked onions varied depending on the position of the sliding door of the onion outlet. Table 1 provides the horizontal separation force (internal friction force, f_2) that was calculated from the normal force acting on each imaginary delaminated plane *abcd* when h was set by 100, 150, 200, 250 and 300 mm as shown in Fig. 3. Internal-frictional coefficient between stacked onion layers was the estimated value using the angle of repose 22°.[4,8,9)] The

Table 1. Horizontal separation force (internal friction force) and vertical force applied on imaginary delaminated plane

Height of outlet (h) (mm)	Vertical force (kN)	Horizontal separation force (f_2) (kN)
100	7.08	2.86
150	6.72	2.71
200	6.35	2.56
250	5.91	2.39
300	5.44	2.20

Note : internal-frictional coefficient, $\mu_i = \tan \ \Phi_i = \tan \ 22° = 0.4040$ (assume $\Phi_i \doteqdot \Phi_r$), Φ_i, Φ_r = angle of internal friction and angle of repose of onions, respectively.

height of onion outlet was set to 150~200 mm because the geometric mean diameter of onions was 85 mm.[4)]

N_1, N_2 and N_3 were calculated as 0.0034 kW, 0.7976 kW, and 0.7860 kW respectively from equation (1) because the carrying capacity of the automatic feed hopper was $Q_{afh} = A \times v \times D_b g = 0.6862 \text{ m}^2 \times 0.27 \text{ m/s} \times 541.80 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 = 984.74$ N/s. The distance of the carried objects was less than 1 m due to the short operation of the automatic feed hopper, therefore the drive shaft power was determined as 50% of the calculated horizontal moving load power (N_2). The drive shaft power also took 50% of the calculated frictional power because the delamination was occurred over a short distance and the high porosity of onions influenced the delamination.

Thus, the power of drive shaft was calculated as 0.8 kW, and the required power of the motor was determined as 1.50 kW (2 hp) considering the power efficiency of conveying machinery and safety factor.

2. Feeding Rate Control Device of the Automatic Feed Hopper

The feeding rate control device controls the velocity of the automatic feed hopper to maintain a constant feeding rate for the operation stability of the total system. As shown in Fig. 5, the sensing plate was operated by the pressure of onions stacked on the hopper (shaded part), and it controls the velocity of the automatic feed hopper.

The appropriate position of the spring attached on the plate and spring constant should be determined for optimum working of the sensing plate. When the position of the spring was determined as $\frac{2}{3}a$ for the convenience of maintenance, the spring constant was calculated from static equilibrium condition as follows.

$$W = \gamma V = D_b g \times V = 541.80 \times 9.81 \times \left(\frac{1}{2} \times 0.498 \times 0.418 \times 0.8\right)$$

$$= 442.56\text{N}$$

$$R_1 = W \sin\theta = 442.56 \sin 38^\circ = 272.47\text{N}$$

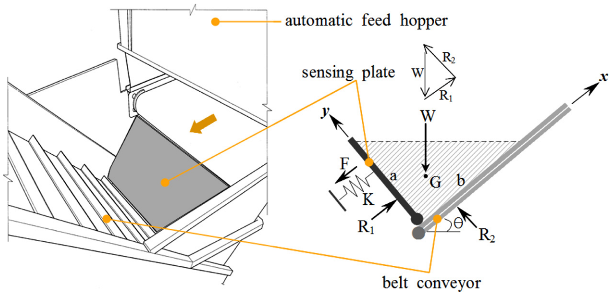

Fig. 5. Schematic representation of the feeding rate control device.

$$\sum M_o = 0 \rightarrow R_1 \times \frac{a}{3} - F \times \frac{2a}{3} = 0 \rightarrow F = \frac{R_1}{2} = \frac{272.47}{2} = 136.23\text{N}$$

Where, θ = Inclination angle of the inclined belt conveyor (38°), γ = specific weight (N/m^3), V = volume of hopper (m^3), W = weight of carried objects in hopper (N), R_1, R_2 = reaction force (N)

When the sensing plate was installed at $\frac{1}{3}a$, the spring should support the power of 136.23 N. With 10 mm of working length and two sensing plates on both sides, the spring constant was calculated as follows.

$$F = K_{eq}x \rightarrow K_{eq} = \frac{136.24}{0.01} = 13{,}624 \text{ N/m} \rightarrow K = 6.81 \text{ kN/m}$$

3. Working Conditions and Power Requirement of the Inclined Belt Conveyor

Onions from the automatic feed hopper were loaded in the box pallet using the inclined belt conveyor while the box pallet lifted by the auto-dump were rotating 77°. The vertical lifting distance and horizontal moving distance of the conveyor were determined as 1,800 mm and 2,300 mm, respectively (Fig. 2)[6]. The length and inclination of the conveyor were 3,000 mm and 38°, respectively.

The operation of the inclined belt conveyor and box pallet (outer dimension: $L \times W \times H$ = 1,300 × 1,100 × 1,600 mm, inner dimension: $L' \times W' \times H'$ = 1,220 × 1,020 × 1,520 mm)[6] should be done continuously. Therefore, the outer width of the conveyor was determined as 890 mm (inner width: 800 mm) based on the inner length of the pallet L'.

The data used in the calculation of the carrying capacity and power requirement of the inclined belt conveyor were as follows.

· Belt (up-belt): length × width = 3,000×800 mm

· Geometric mean diameter of onion: 85 mm (classified as 'Large')[4,10]

· Bulk density: 541.80 kg/m^3 [4]

The carrying capacity of the belt conveyor is the product of the stacking cross-sectional area and the carrying velocity. However, the inclined belt conveyor used in this system was

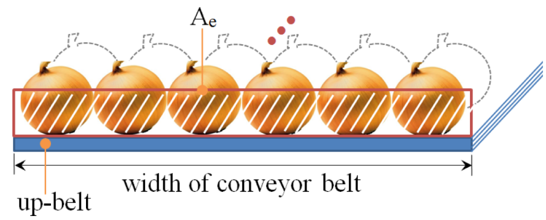

Fig. 6. Concept of average equivalent stacking cross-sectional area.

installed with a belt attachment to prevent onions from rolling on the inclined belt and to increase the transport efficiency. Thus, this study introduced the term, an average equivalent stacking cross-sectional area, in order to calculate the carrying capacity more accurately.

When the interval of the belt attachment (length × width = 740 × 40 mm) on the conveyor belt was 170 mm for double stacking of the onion (average diameter of 85 mm), the area rate occupied by onions was calculated as 70% theoretically, considering the occupied area of the belt attachment and the projected area of onion bulb.

The theoretical area rate occupied by onions was proven from empirical experiments with the inclined belt conveyor (angle of inclination 38°) having same belt attachment. The ratio of total projected area and area of conveyor belt was calculated as 69~72% by counting the number of carried onions during the time of Δt = 25, 20 and 15 seconds (length of the conveyor 3,000 mm) at the speed of a conveyor belt of 7.0, 9.5 and 12 m/min, respectively (Fig. 7 and 8).

Thus, the actual carrying capacity of the inclined belt conveyor was calculated with equation (2).

$$Q_{ibc} = A_e \times v \times D_b \tag{2}$$

where, Q_{ibc} = carrying capacity (kg/s), A_e = average equivalent stacking cross-sectional area (m^2), v = velocity of conveyor belt (m/s), D_b = bulk density of onions (kg/m^3)

The average equivalent stacking cross-sectional area was calculated as follows.

$$A_e = (\textit{belt width}) \times (\textit{geometric mean diameter of onion bulb}) \times (\textit{area rate occupied by onions}) = 0.8 \times 0.085 \times 0.7 = 0.0476 \text{ m}^2$$

Fig. 8 shows the analysis of the carrying capacity based on the velocity of the conveyor belt [equation (2)] using the average equivalent stacking cross-sectional area. When the time for operation of the conveyor to load onions in a box pallet was determined as 4 min considering the replacement of the pallet and connection with other operation, the feeding rate of onions was 250 kg/min at the velocity of the conveyor belt of 9.69 m/min.

The power of drive shaft of the inclined belt conveyor was represented as a sum of no-load power (N_1), horizontal-moving load power (N_2), and vertical-moving load power (N_3)

Fig. 7. View of measuring test of area rate occupied by onions of inclined belt conveyor.

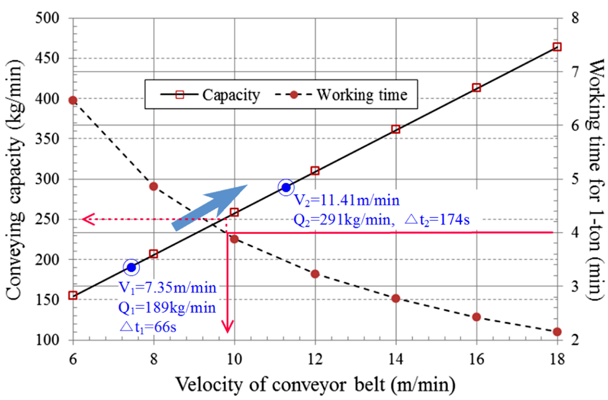

Fig. 8. The relationships between the velocity of conveyor belt and carrying capacity.

as shown in equation (3)[7].

$$N = N_1 + N_2 + N_3 = \frac{\mu \omega v L}{1000} + \frac{\mu Q_{ibc} L}{1000} + \frac{Q_{ibc} h}{1000} \qquad (3)$$

where, N = power of drive shaft (kW), μ = frictional coefficient (0.1~0.3), ω = weight per unit length of moving part except carried objects [conveyor belt (width 800 mm): 15.70 N/m, belt attachment : 0.4414 N/m] (N/m), v = velocity of conveyor belt (m/s), L = length of conveyor (m), Q_{ibc} = carrying capacity (N/s), h = vertical lifting height (m)

The power of drive shaft of the inclined belt conveyor was calculated as 0.1129 kW using the above data. However, power requirement for the motor was determined as 0.76 kW (1 hp), considering the power efficiency of conveying machinery and safety factor. In addition, a geared motor with hollow shaft worm reducers was recommended for a direct connection between drive shaft and motor.

$$N = \frac{0.3 \times 17.76 \times 0.1616 \times 3}{1000} + \frac{0.3 \times 40.87 \times 3}{1000} + \frac{40.87 \times 1.8}{1000}$$
$$= 0.1129\text{kW}$$

4. Design of an Automatic Pallet Unloading Device

The automatic pallet unloading device unloads the stacked onions on the box pallet and feed onions automatically to the sorting/packing line. The bottom loading plate of the pallet was opened at a constant speed by a hydraulic cylinder. One side of the device was supported by hinge, and the other side was supported by the hydraulic cylinder as shown in Fig. 9(a).

The capacity of the hydraulic cylinder of the device was determined based on the maximum load on the cylinder. The maximum load of the hydraulic cylinder acted on the moment that loading plate was lifted to remove the fixing pin of the bottom loading plate of the box pallet as a first step in emptying onions, and the size of it was calculated as follows. V_R in Fig. 9(b) was the total reaction force acting on the loading plate when the bottom loading plate of the box pallet was lifted by lifting bar of the automatic pallet unloading device, and it was represented as a sum of total weight of the loaded onions and frictional force between onion and pallet

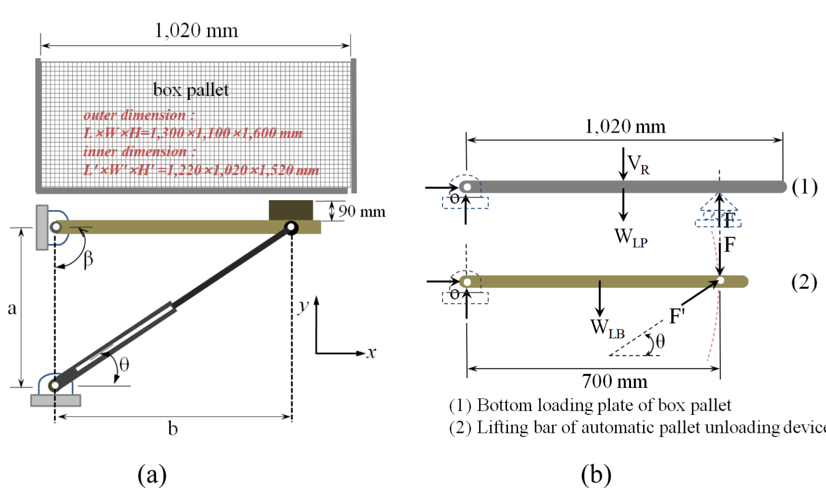

Fig. 9. Schematic representation of the automatic pallet unloading device, and free body diagram for the lifting bar of the device and loading plate of box pallet.

wall as shown in equation (6).

To analyze the frictional force acting on the side wall of the box pallet, the total horizontal force acting perpendicular to the side wall should be calculated. The total horizontal force was calculated by integrating along the stacking depth or stacking width using Janssen equation [equation (4)] which represents distribution of parabolic lateral pressure with stacking depth[8,9].

$$P_y = \frac{\gamma R}{\mu}\left\{1-\exp\left(-\frac{\mu k}{R}y\right)\right\} \tag{4}$$

$$P = \left(\int_0^{H'} P_y\,dy\right)\times p_L = \frac{\gamma R}{\mu}\left\{h + \frac{R\exp\left(-\frac{\mu k}{R}h\right)}{\mu k} - \frac{R}{\mu k}\right\}\times p_L \tag{5}$$

$$V_R = \gamma hA + \mu P = \gamma hA + \gamma R\left\{h + \frac{R\exp\left(-\frac{\mu k}{R}h\right)}{\mu k} - \frac{R}{\mu k}\right\}\times p_L \tag{6}$$

where, p_y = horizontal pressure on the lateral wall at stacking depth of y (Pa), μ = frictional coefficient between onions and the pallet wall, γ = specific weight of the onions (N/m^3), R = hydraulic radius (ratio of cross-sectional area to perimeter) (m), k = lateral pressure coefficient [=(1-sin Φ_i)/(1+sin Φ_i)], Φ_i = angle of internal friction between the onions (deg), P = total horizontal force acting vertically on the pallet wall (N), H' = inside height of the box pallet (m)

Using the following data, the total reaction force is calculated by equation (6) to be V_R = 14.6 kN.

$\mu_i = \tan\ \varphi_i = 0.4040$ (assume $\Phi_i \fallingdotseq \Phi_r$)[4,8,9]
$\Phi_r = 22°$ (angle of repose of onion)[4,8]

$$k = \frac{1-\sin\varnothing_i}{1+\sin\varnothing_i} = 0.4550$$

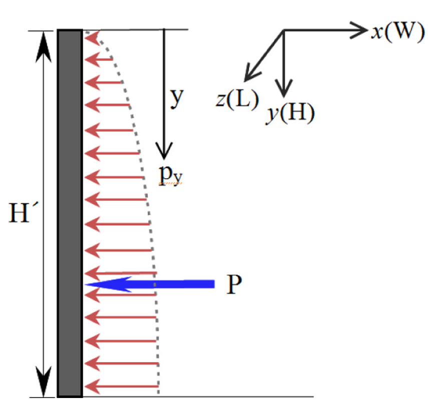

Fig. 10. Horizontal pressure distribution on the lateral wall of box pallet (Janssen equation).

$\gamma = \rho g$ = 541.80 kgf/m^3 = 5,315.06 N/m^3

$$R = \frac{L'W'}{2(L'+W')} = 0.2778$$

$p_L = 2(L' + W') = 4.48$

$A = L' + W' = 1.22 \times 1.02 = 1.24$ m^2

The maximum load on the hydraulic cylinder from each moment equilibrium equation for two elements is calculated as 18.60 kN when a=500 mm and b=700 mm in Fig. 9(a) taking into account the connectivity with the current sorting/packing line and the weight of the lifting bar and the bottom loading plate (simplification to simple supported beam with one hinged end and one roller end)[5] is V_{LB} = 68 N and V_{LP}=203 N, respectively.

$$\sum M_o = 0 \rightarrow V_R\times 0.51 + W_{LP}\times 0.51 - F\times 0.7 = 0$$

$$\sum M_o = 0 \rightarrow W_{LB}\times 0.35 + F\times 0.7 - (F'\sin\theta)\times 0.7 = 0$$

The main points in determining specifications for the hydraulic cylinder were optimum diameter and stroke of cylinder. The inner diameter was calculated as 4 mm as shown in equation (7) under the conditions that the maximum force acting on the piston rod end of the hydraulic cylinder was determined as 18.60 kN, the working pressure of the hydraulic cylinder as 9.81 MPa, and safety factor as 2 because the environment was close to static load. The inner diameter of the cylinder and diameter of the piston rod were determined as φ80 and φ35, respectively, because piston stroke was not large in the actuating mechanism.

$$F = A\times p\times\beta \tag{7}$$

where, A = cross-sectional area of piston (m^2), p = working pressure of hydraulic cylinder (Pa), β = effective efficiency (80%)

The buckling strength of the piston should be considered. Euler's equation [equation (8)] was applied in the calculation of critical load (P_{cr}) because the slenderness ratio was calculated over 90[11].

$$k = \sqrt{\frac{1}{A}} = \sqrt{\frac{\pi d^4}{64}\times\frac{4}{\pi d^2}} = \frac{d}{4} = 0.0087\text{m}\ ,\quad \lambda = \frac{L}{k} = \frac{0.86}{0.0087} = 98.85 > 90$$

$$P_{cr} = \frac{n\pi^2 EI}{L^2}\times\frac{1}{S} \tag{8}$$

where, k = radius of gyration of area (m), I = moment of inertia (m^4), λ = slenderness ratio, L = distance between both ends in hydraulic cylinder ($0.86 = \sqrt{0.5^2+0.7^2}$) in Fig. 9(a), n = modulus of end ('1' in case of hinged end at both ends), E = Young's modulus (205 GPa in case of S45C)[12], S = safety factor (over 4)

Moment of inertia of the tube of hydraulic cylinder was larger than that of the piston rod. However, normal piston rod was used in this study for the simplification of the calculation and safety design. The critical load was calculated using equation (8) as follows.

$$I = \frac{\pi d^4}{64} = \frac{\pi \times 0.035^4}{64} = 7.3624 \times 10^{-5} \mathrm{m}^4$$

$$P_{cr} = \frac{n\pi^2 EI}{L^2} \times \frac{1}{S} = \frac{1 \times \pi^2 \times (2.06 \times 10^{11}) \times (7.3624 \times 10^{-8})}{0.86^2} \times \frac{1}{4}$$
$$= 50,300\mathrm{N}$$

It can be considered as safe because the maximum force acting on the hydraulic cylinder was in 16.80 kN < 50.30 kN. Therefore, 80C-250 (working pressure, 70~140 MPa) was determined for the suitable hydraulic cylinder[13].

Result and Discussion

Ten limit switches to control the unit devices, four hydraulic solenoid valves to control the unit device, and three inverters to control the motor were used in this study.

Fig. 11 shows the prototype of the post-harvest bulk handling machinery system, and Fig. 12 shows the working sequence of the system. Performance analysis and economic analysis of the prototype of the post-harvest bulk handling machinery system were conducted.

1. Performance Analysis for the Prototype Post-harvest Bulk Handling Machinery System

When the basic operation conditions of the system were limited to six minutes or less for one worker to operate the entire system and complete the one palletized load considering the connection with other tasks such as feeding to the storage and pallet replacement, the operation and performance analysis of the total system was performed.

· Conveyor belt velocity of the automatic feed hopper: 16 m/min, velocity control by sensor plate (limiting value, 272.47 N) of feeding rate control device

· Box pallet: 3 steps loading

1st, 2nd: rotational loading of pallet (90%), 77° rotation of pallet (Δt=4 min×90%=216 s)

3rd: vertical loading of pallet (10%), stand of pallet (Δt=4 min×10%=24 s)

· Velocity of inclined belt conveyor: 2 steps (Fig. 8)

1st: 7.35 m/min (Δt=66 s), 2nd : 11.41 m/min (Δt=174 s)

· Ascent of auto-dump: (velocity of hydraulic cylinder) 0.9 m/min, (average angular velocity of auto-dump) 1.5 deg/s

· Descent of auto-dump: (velocity of hydraulic cylinder) 3.59 m/min, (average angular velocity of auto-dump) 0.36 deg/s

· Automatic empty-pallet: (velocity of hydraulic cylinder) 1.2 m/min, (conveying velocity of empty-pallet) 40 mm/s

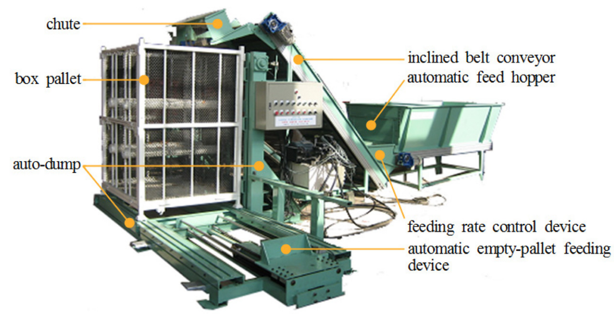

Fig. 11. Prototype for post-harvest bulk handling machinery system.

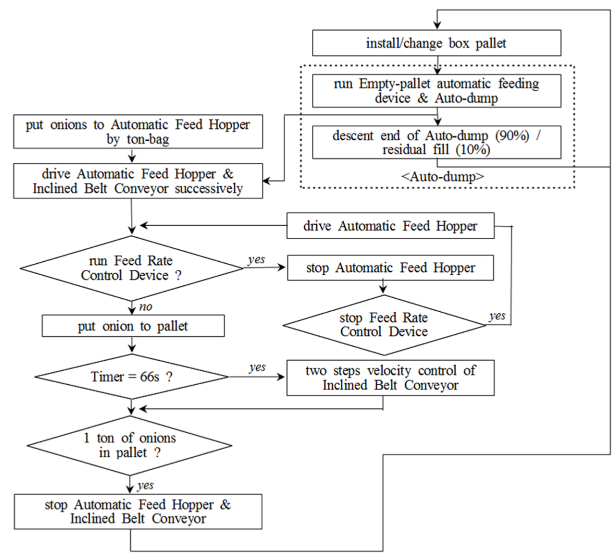

Fig. 12. Flowchart indicating working sequence of the post-harvest bulk handling machinery system.

The total time required for one palletized load to be completed from the installation of the empty-pallet by analyzing the time required for each step of system operation was approximately 365 s (Δt_1~Δt_5. The theoretical maximum daily handling capacity was approximately 94 tons, while operating an average of 8 hours per day.

The three-step filling method of pallet adopted in the post-harvest bulk handling machinery system was analyzed to be very effective in achieving uniform loading and preventing physical damage.

<installation of empty-pallet by forklift truck> → <conveying empty-pallet (Δt_1=37s)> → <ascent of empty-pallet (Δt_2=51s)> → <1st rotational loading of pallet (Δt_3=66s)> → <2nd rotational loading of pallet (Δt_4=150s)> → <3rd vertical loading of pallet (Δt_5=24s)> → <transfer of palletized load by forklift truck >

2. Economic Analysis for the Prototype Post-harvest Bulk Handling Machinery System

Economic analysis was performed by applying the developed system to the size of management storing 100,000 nets (2,000 ton) on a 20 kg-net package basis.

To compare the cost between 20 kg-net package-based handling and the system developed in this study, All onions were considered to be purchased through the kitchen garden

Table 2. The results of economic analysis for the post-harvest bulk handling machinery system

Classify		Post-harvest bulk handling machinery system			20 kgf-net package based handling	
		main body	box pallet(1)	(labor) cost	pallet(1)	(labor) cost
Purchase price(₩)		40,000,000	720,000,000	–	360,000,000	–
Service life(year)		10	10	–	10	–
Annual fixed cost (₩/year)	depreciation(2)	3,600,000	64,800,000	–	32,400,000	–
	repair(3)	2,000,000	14,400,000	–	7,200,000	–
	interest(4)	1,100,000	19,800,000	–	9,900,000	–
	subtotal	6,700,000	99,000,000	–	49,500,000	–
Fixed cost per ton (₩/ton)		52,850			24,750	
Annual variable cost (₩/year)	labor(5)	–	–	240,000,000	–	370,000,000
	net(6)	–	–	13,600,000	–	30,600,000
	ton bag(7)	–	–	3,000,000	–	–
	electricity(8)	40,107	–	?	–	–
	Subtotal	40,107	–	256,600,000	–	400,600,000
Variable cost per ton (₩/ton)		128,320			200,300	
Total cost per ton (₩/ton)		181,170			225,050	

Note: (1) new purchase : 2,000 pallet [(developed box pallet) 360,000 ₩/unit, (existing pallet) 180,000 ₩/unit]
(2) depreciation : (purchase price–dispose price)/service life, dispose price = 10% of purchase price
(3) repair cost : (main body) 5%, (pallet) 2%
(4) interest : 5%/year, [(purchase price + dispose price)/2]×5%
(5) labor cost (based on the local price in 2019)
· onion harvest ~ warehousing (harvest, stem cutting, net packaging or ton-bag working and transport) : (in case of net packaging) 3,000 ₩/20 kgf-net package, (in case of ton-bag working) 1,700 ₩/20 kgf
· sorting/packaging for shipment : 700 ₩/20 kgf-net package
(6) net price : 170 ₩/20 kg capacity net, assume 20% storage losses
(7) ton bag price : 10,000 ₩/600 kg capacity ton-bag
(8) electricity : (agricultural) 39.2 ₩/kWh

(a) (b)

Fig. 13. Demonstration of the post-harvest bulk handling machinery system (a) and the automatic pallet unloading device to target onion farmer (b).

transaction. Also, based on the working process of the practice, only harvesting, cutting onion set, net-packaging and ton-bag working in field, handling in warehouse, and packaging for shipment were selected for analysis. Processing cost (per ton) of the developed system was decreased by 19.5% compared to the 20 kg-net package-based handling.

Fig. 13 shows the demonstration sight of the post-harvest bulk handling machinery system to onion farmers.

Conclusions

The post-harvest bulk handling machinery system consisted of six devices, and this study designed an automatic feed hopper with a feeding rate control device, an inclined belt conveyor with a two-step chute, and an automatic pallet unloading device for feeding onions into the sorting/packing line. This study also analyzed the performance and control of the whole system. The results of the study are as follows.

1) The device had 1-ton handling capacity, but the operational condition was set to increase the capacity to achieve generality. The velocity of the automatic feed hopper was controlled by the feeding rate control device to supply onions to the system stably.

2) An inclined belt conveyor with two-step chute was designed to feed onions without physical damage to the box pallet that was slanted by the auto-dump and descended. The three-step filling method of pallet was possible due to the two-step speed control of the inclined belt conveyor in the post-harvest bulk handling machinery system, and it was effective in the prevention of physical damage and uniform loading. This study introduced the term, average equivalent stacking cross-sectional area, considering the actual occupied area ratio of onions to calculate the accurate carrying capacity of the inclined belt conveyor.

3) An automatic pallet unloading device for unloading the onions stacked on the box pallet or feeding onions into the sorting/packing line was designed.

4) The operating condition of the post-harvest bulk handling machinery system was determined as one operator operates the system. Five minutes and five seconds was required for one palletized load to be completed from the installation of the empty-pallet. The theoretical maximum daily handling capacity was approximately 94 tons, when the daily working time was 8 hours.

5) When the system developed in this study was applied in the managerial size of 2,000 ton, the processing cost per ton of the system was decreased by 19.5% compared to the 20 kg-net package-based handling.

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