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DESIGN AND DEVELOPMENT OF MECHANICAL DRIED CHILLIES COMPACTION MACHINE

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Abstract: Dried chillies are packed in gunny bags non-uniformly in different packing sizes. Dried chilies, being low bulk material occupies large volume, need to be compacted before it is bagged to gunny bags. Conventionally, dried chilies are compacted by labor in the field itself by tying gunny bag to a tripod stand and simultaneous filling of dried chilies and trampling by feet till overall weight of the bag reaches 40-45 kg. Conventional method is highly labor intensive involves drudgery, low productive (3 laborers can compact a quantum of 8 bags per hour) and causes burning sensation to the labor. An attempt has been made to design and develop portable mechanical machine to compact dry chilies and bag. Evaluation of developed machine has been conducted at farmer's field in Guntur district of Andhra Pradesh - India. The capacity of the developed machine was found to be 18 bags/h, technically feasible and economically viable. There is a saving of Rs 9.68 per bag in mechanized compaction and bagging process with an improvement in productivity over 150%.

Key words*: Chilli compaction machine, Power pack unit, Platen, Hydraulic motor, Bulk density, Moisture content*

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INTRODUCTION

Dry chilies are mostly pungent fruits of *capsicum annum L* and *capsicum frutescence* majorly used as condiment or culinary for its pungency, spicy taste, besides the appealing color it adds to the food. It's powder is used in pickles, sauces, ketchup, essences, oleoresins and is an inevitable ingredient in all Indian dishes. The major chilli producers in the world are India, China, Pakistan, Morocco, Mexico, Turkey and Bangladesh. Chilies are mostly grown in all regions of India particularly Andhra Pradesh and Telangana contributing $2/3^{rd}$ of India's total production. Andhra Pradesh alone has a production of 8.83 lakh MT from 2.06 lakh hectares, which accounts for 24 percent of area and 47 percent of production in the country (www.indiastat.com, 2016-2017. statistics). In Andhra Pradesh, major production catchment include Guntur, Prakasam, Krishna and Kurnool districts. About 65% of the total chillies produced in India are exported to Srilanka, Bangladesh, Malaysia, USA, Nepal, Indonesia, UAE and Italy in the recent past (1).

In Andhra Pradesh, dried chillies are usually packed in gunny bags for transportation and storage. It is found that there is no uniformity in the packing size of chillies in the country. Packing material used and the capacity of packages are varying in different states. The size of gunny bag is generally 20-25 kg in North Eastern States and in Punjab (2). In Andhra Pradesh and Tamil Nadu, the pack size is about 40-45 kg. Generally all the farmers use old gunny bags to pack chillies before selling. Only the exporters repack them in new gunny bags sometimes with polythene liners.

Dried chillies, being low bulk material occupies large volume, need to be compacted before it is bagged to gunny bags. Conventionally, dried chillies are compacted by farm labour in the field itself by tying gunny bag to a tripod stand and simultaneous filling of dried chillies and trampling by feet till overall weight of the bag reaches to 40-45 kg.

Conventional method is highly labor intensive involves drudgery, low productive (3 labourers can compact a quantum of 8 bags per hour) and causes burning sensation to the labor trampling the chillies in bag. This paper aims to design and develop a dried chillies compaction machine in order to avoid drudgery in conventional compaction method using labourers and to conduct its evaluation studies.

MATERIAL AND METHODS

Basic principle employed for development of dried chillies compaction machine was hydraulic press to produce compressive force by means of hydraulic fluid using Pascal's principle (3)(4). Thus an attempt has been made to automate the process of press work using hydraulic mechanism in press machine. The inputs and outputs of the control system in hydraulic mechanism are solely mechanical such as reciprocating plunger operated by means of hydraulic components such as actuators to initiate the movement in the form of lever to apply manually so that the compaction of the dried chillies can be achieved in to and fro motion. Furthermore, direction control valves have been implemented to control the directions of piston movements and regulate the same. The principal parameters of the design included the maximum load, the distance the load resistance has to move, the system pressure, the cylinder area and the volume flow rate of the working fluid (5).

Design of hydraulic components

The following assumptions were made in the design of hydraulic components:

Particulars	*Assumption*
Stroke length	*1000 mm*
Inner diameter of cylinder (d_{ci})	*110 mm*
Size of moving platen	*360×360 mm*
Maximum working pressure	*1000 kPa or 1 N/mm^2*
Allowable tensile stress for cast steel cylinder and end plate (σ_{tc})	*80 MPa or 80 N/mm^2*
Allowable tensile stress for piston rod (σ_{tp})	*60 MPa or 60 N/mm^2*
Allowable compressive stress for mild steel for ram (σ_c)	*75 MPa or 75 N/mm^2*
Allowable shear stress for mild steel for hinge (τ)	*45 MPa or 45 N/mm^2*

Maximum capacity of pressing machine (F)

Maximum capacity of pressing machine was determined by multiplying maximum pressure with the contact area of moving platen.

Pressure exerted inside the cylinder (*p*)

Pressure inside cylinder (*p*) was computed by equating to the work done by the cylinder

$$\text{Thus, } F = (\pi/4)\times d_{ci}^2 \times p \quad (1)$$

$$p = 4F/\pi\, d_{ci}^2 \quad (2)$$

where d_{ci} is the diameter of inner cylinder, F is the maximum capacity of pressing machine

Design of ram

It is a round bar attached to piston at one end and to moving platen at other end and it moves in and out from cylinder for pushing and pulling operation. Let d_r be the diameter of the ram and maximum force exerted by ram is given as

$$\sigma_t = (\pi/4)\times d_r^2 \times p. \quad (3)$$

$$d_r = \sqrt{4}\sigma_{tc}/\pi p \quad (4)$$

where σ_{tc} is the tensile stress for cast steel

Design of cylinder

It is the important component of the machine. It develops pushing or pulling force to carry out desired operation using pressurized hydraulic fluid. For the compaction cum bagging machine, a double action cylinder is used which can take power stroke in forward as well as reverse direction. Both forward and reverse stroke was achieved by pumping oil under controlled pressure and flow direction from both oil port of cylinder.

Wall thickness of the cylinder (*t*) can be found out by Lame's theorem (5)

$$t = (d_{ci}/2)\{\sqrt{\ [(\sigma_{tc} + p)/\ (\sigma_{tc} - p)]}-1\} \quad (5)$$

Design of piston rod

Let d_p is the diameter of piston rod.

Force acting on piston rod is given as (F)= $(\pi/4)\times d_{ci}^2\times p = (\pi/4)\times d_p^2\times \sigma_{tp}$

$$d_p = \sqrt{(d_{ci}^2 \times p/ \sigma_{tp})} \quad (6)$$

Design of hinge pin

Let d_h is the diameter of hinge pin of piston rod. Load on the pin is equal to the force acting on piston rod and hinge pin is in double acting shear as per procedure stated (6), therefore

$$F = 2\times (\pi/4)(d_h)^2\tau \quad = 70.7\ (d_h)^2 \text{ (Taking } \tau\text{=45 N/mm}^2\text{)} \quad (7)$$

$$d_h = \sqrt{F/70.7} \quad (8)$$

When cover is hinged to cylinder, one can use two hinge pins only diametrically opposite to each other. Thus, diameter of hinge pins for cover $d_{hc} = d_h/2$

Design of flat end cover

Let t_c is the thickness of end cover (7)

Force on end cover is given as $F = d_{ci}\times t_c\times \sigma_{tc}$ (9)

$$t_c = F/(d_{ci}\times \sigma_{tc}) \quad (10)$$

Design of cylinder end cover plate

The thickness t_{ce}, of the end-cover-plate, which is supported at the circumference by bolts and subjected to an internal pressure uniformly distributed over the area as per procedure suggested (6).

$$t_{ce} = k_1 d_{ci}\sqrt{(p/ \sigma_{tc})} \quad (11)$$

where, the coefficient k_1 depends on type of material of the plate and method of holding the edges, the value k_1 is given as 0.44 for cast steel,

Power output of cylinder

Stroke length of piston is L and time required for working stroke is S. Distance moved by piston per second is given as L/S

Work done per second = Force × distance moved by piston per second

$$= F \times L/S$$

Power of motor

Power of required for motor was determined (8) by the following equation

Pump discharge (Q_p) = Cross-Section Area of Cylinder (m^2) × Working Speed (m/s)

$$= \pi/4\ (d_{ci})^2\times L/S \quad (12)$$

Calculation of displacement of pump

The displacement of the pump was calculated based on a 3- phase induction motor operating at N RPM. Assume a volumetric efficiency of η_v. The pump must deliver sufficient flow to advance the cylinder at the maximum speed, hence displacement of pump was calculated as (D_p)

$D_p = Q_p/N\eta_v$ where, N is motor RPM,

Torque required to drive the pump at system pressure (T) = $D_p.p/\eta_m$ where, η_m is the mechanical efficiency)(9)(10)

Power of electric motor = T (N.m/rad).N (2π rad/rpm) (min/60 s)/ η_e (13)

RESULTS AND DISCUSSION

Physical properties of dried chillies before and after compaction in conventional method

In a conventional method of compaction, a special bamboo tripod stand is formed and erected in the yards and gunny bag was held in between and a person tramples the pods by standing in the gunny bag, to achieve good compaction (11) (Figure 1). Generally, gunny bags used for bagging dried chillies have a diameter of 480±20 mm and a length of 1100 mm. Certain properties of dried chillies before and after compaction and bagging was presented in Table 1. The data indicated that loose bulk density of the dried chillies was low and after compaction, the bulk density increased from 91 to 223 kg/m^3.

Figure 1. Conventional compaction and bagging of dried chillies

Table 1. Certain properties of dried chillies during conventional bagging

Parameter	Before compaction and packing	After compaction and packing
Weight (kg)	20.1±2.2	39±2.2
Bulk density (kg/m^3)	91±14	223±16
Moisture content (%w.b.)	12.35±0.25	12.35±0.25

Determination of maximum force to achieve required compaction

In conventional system, a farm labor of 70 kg body weight approximately tramples the dried chillies in the gunny bags around 35-40 times to achieve the bulk density of 230±5 kg/m^3. Pressure applied on the chillies was calculated as 0.54 N/mm^2 (Approximating force applied as 600 N and area of foot as $0.15\times 0.075 = 0.011$ m^2 thus pressure applied was calculated as 54545 N/m^2).

Assuming factor of safety as 2, maximum compaction pressure required for design purposes was assumed as 1 N/mm^2 (or 1000 kPa).

Important limitation regarding assumption of maximum compaction pressure is that the dried chillies pod should not break while compaction. Hence, compressive pressure for compaction of 1000 kPa was considered for design purposes.

Design of hydraulic components

Maximum capacity of pressing machine

Maximum capacity of pressing machine is determined by multiplying maximum pressure with the contact area of moving platen.

Maximum capacity of pressing machine = 1000×10^3 (N/m^2) $\times (0.36)^2$ = 129.6 kN or 130 kN

Now, pressure inside the cylinder (*p*). Load on pressing machine is equated to the work done by the cylinder

Thus, 130×10^3 (N) = $(\pi/4)\times d_{ci}^2\times p = (\pi/4)\times(70)^2\times p$

p= 33.79 N/mm^2

Design of ram

It is a round bar attached to piston at one end and to moving platen at other end and it moves in and out from cylinder for pushing and pulling operation. Let d_r be the diameter of the ram and maximum force exerted by ram is given as $\sigma_{tp}= (\pi/4)\times d_r^2\times p$.

On substitution of σ_t and p, the value of d_r was obtained.

60×10^3 (N) = $(\pi/4)\times d_r^2\times 33.79$

d_r = 47.56 mm or 48 mm

Design of cylinder

Let d_{co} is the outer diameter of hydraulic cylinder and d_{ci} is the inner diameter of cylinder.

Assuming clearance of 20 mm between ram and cylinder bore, therefore, inner diameter of the cylinder (d_{ci}).

$d_{ci}= d_r+$ clearance = 48+15 = 63 mm or say 70 mm

Wall thickness of the cylinder (*t*) can be found out by Lame's equation

$t = (d_{ci}/2)\{\sqrt{[(\sigma_{tc} + p)/ (\sigma_{tc} - p)]}-1\}$

substituting the values of r_{ci}, σ_t and p,

$t=35\times\{\sqrt{[(80.00 + 33.79)/(80.00 - 33.79)]}-1\}=35\times(1.569-1) = 19.92$ *mm or 20 mm*

Diameter of outer cylinder = $d_{ci} + 2t = 70+(2\times20)=110$ *mm*

Design of piston rod

Let d_p is the diameter of piston rod.

Force acting on piston rod (F)= $(\pi/4)\times d_{ci}^2\times p= (\pi/4)\times(70)^2\times 33.79$ = 130039.15 *N*

Force acting on piston rod is also given as$=(\pi/4)\times d_p^2\times\sigma_{tp} = (\pi/4)\times d_p^2\times 60=47.13\ d_p^2$

Equating above two gives $d_p = \sqrt{(130039.15/47.13)}$= 52.52 mm or say 52 mm

Design of hinge pin

Let d_h is the diameter of hinge pin of piston rod. Load on the pin is equal to the foce acting on piston rod and hinge pin is in double acting shear, therefore

$F = 2\times (\pi/4)(d_h)^2\tau = 70.7\ (d_h)^2$ (Taking τ=45 N/mm^2)

$130039.15 = 70.7\ (d_h)^2$

d_h = 42.88 mm or 44 mm

When cover is hinged to cylinder, one can use two hinge pins only diametrically opposite to each other.

Thus, diameter of hinge pins for cover $d_{hc} = d_h/2 = 44/2 = 22$ mm

Design of flat end cover

Let t_c is the thickness of end cover.

Force on end cover is given as $F = d_{ci}\times t_c\times \sigma_{tc}$

$130039.15 = 70\times t_c\times 80$

t_c=23.22 mm or say 23 mm

Design of cylinder end cover plate

The thickness t_{ce}, of the end-cover-plate, which is supported at the circumference by bolts and subjected to an internal pressure uniformly distributed over the area, is given by Eq. (2) as:

$t_{ce} = k_1 d_{ci}\sqrt{(p/\sigma_{tc})}$,

where, the coefficient k_1 depends on type of material of the plate and method of holding the edges, the value k_1 is given as 0.44 for cast steel,

$t_{ce} = 0.44\times 70\sqrt{(33.79/80)} = 20.01$ mm or 20 mm

Power output of cylinder

Stroke length of piston = 1.0 m

Time required for working stroke = 24 s

Distance moved by piston per second = 1.00/24 (m) = 0.041 m

Workdone per second = Force × distance moved by piston per second

= 130039.15 × 0.041 = 5331.60 Nm

Power output of the cylinder = 5331.60 Nm/s = 5.33 kW

Platens

The platens provide point of direct contact with the object being compressed. Hence, they are subjected to pure bending stress due to an equal and opposite couple acting in the same longitudinal plane. The design consideration is essentially for bending and consists primarily upon the determination of the largest value of the bending moment (M) and shear force (V) created in the beam which was found to be 45 kN/m and 150 kN, respectively. These were computed using the adopted procedure (12).

Bending moment of platen is given as
$M = FL/4 = 130\ (kN)\times 0.36/4\ (m) = 11.7\times 10^{6}$ N-mm
Similarly, section modulus for a square platen is
$Z = b^3/6 = (0.36)^3/6 = 7.776\times 10^6$ mm^3
Now bending stress acting upon platen is given as
$\sigma_b = M/Z$, where Y is yield stress (250 MPa)
$\sigma_b = 11.7\times 10^6 / 7.77\times 10^6 = 1.505$ N/mm^2.
Factor of safety = Yield stress/ Bending stress = 250 /2.104 = 118.82

Power of motor

Pump discharge = Cross-Section Area of Cylinder (m^2) × Working Speed (m/s)
$= \pi/4\ (d_{ci})^2\times$ working speed (m/s)
$= \pi/4\ (70/1000)^2\times 0.041$(m/s) $= 157.78\times 10^{-6}$ m^3/s
= 0.157 Lps or 9.42 Lpm

Calculation of displacement of pump

The displacement of the pump was calculated based on a 3- phase induction motor operating at 1750 RPM. Assume a volumetric efficiency of 0.70. Note that the pump must deliver sufficient flow to advance the cylinder at the maximum speed,

$D_p = Q_p/N\eta_v = 9.42\times 10^{-3}$(m^3/min) /[1750(Rev/min)× 0.70] $= 7.68\times 10^{-6}$ m^3/rev
Torque required to drive the pump at system pressure:
(T) $= D_p.p/\eta_m$ (Assuming $\eta_m = 0.7$)
$= 7.68\times 10^{-6}$ (m^3/rev)(rev/2π rad)× 2×10^6 (N/m^2)/0.7 = 3.494 N·m/rad
Power of electric motor = T (N.m/rad).N (2π rad/rpm) (min/60 s)/ η_e
= 3.494 × 1750×2π /(60×0.7) = 914.28 W or 0.91 kW or 1.22 HP
= or say 2.0 HP electrical motor was selected.

Design of hydraulic power pack unit

Reservoir capacity: Tank capacity could be between 3 to 10 times of the pump discharge capacity. Thus, a tank capacity of 3 times of pump discharge capacity *i.e.*, 30 L was selected. An oil reservoir tank of size 0.45 ×0.38 ×0.38 m was fabricated to hold hydraulic oil. Bottom of tank has sloping, where drain plug was provided. This facilitate removal of all contamination settled at bottom, when oil is drained-out. Further, externally visible oil level indicator was provided. Further, tank was provided with air-breather filler assembly and return line filter. Tank was provided with suction filter and baffle plate to protect pump from sucking heavy or light contamination returning to tank along with exhaust oil.

A relief valve with maximum pressure setting of 2 MPa was provided at delivery side of pump to avoid any pressure build-up. A pump operating without relief valve is bound to cause an accident or damage to system or for itself.

A single manifold block has connection port for connecting pump, exhaust port, and two oil port for cylinder, and on its various ground surface provision to mount the valves. After providing manifold and relief valve, a direction control valve is fitted on it. Oil is filled through filter up to maximum level of oil level indicator.

The technical specifications of dried chillies compaction machine are shown in Table 2 and specifications of components of manifold block are depicted in Table 3. Various components of mechanical dried chillies compaction machine is shown in Figure 2.

Table 2. Technical specifications of the dried chillies compaction machine

Description	*Specification*
Type	*Hydraulic double acting cylinder compaction machine*
Stroke length	*1 m*
Compaction pressure	*1000 kPa*
Maximum pressure	*2000 kPa*
Cylinder diameter	*110 mm*
Piston diameter	*40 mm*
Moving platen dimension	*360 ×360 mm*
Power pack unit hydraulic oil capacity	*30 L*
Dimensions	*965 × 920 ×2850 mm (L×W×H)*
Capacity of hopper	*7 kg*
Power	*2 HP single phase*

Table 3. Specifications of components of manifold block

Component	*Technical specifications*
Hydraulic suction pipe	*Connect thread size G 3/8; shapes (Curve – 73, 29 mm; Straight – 120, 180, 280, 320 mm*
Hydraulic return pipe	*Connect thread size M12, Shape straight - 120, 180, 280, 320 mm*

Figure 2. Mechanical dried chillies compaction and bagging machine

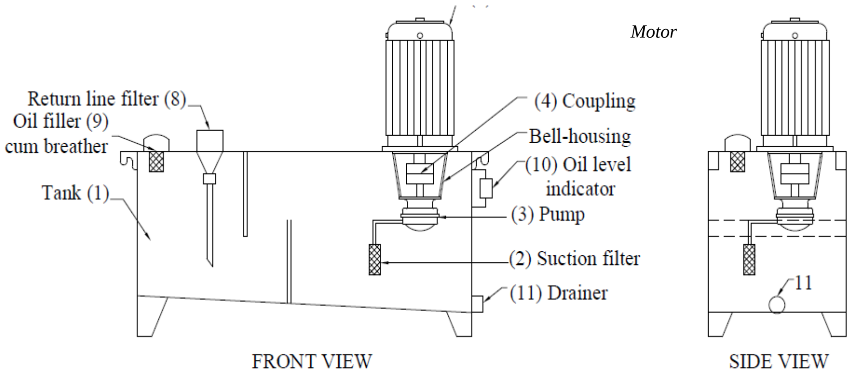

Figure 3. Various components of power pack unit

Performance evaluation of the developed compaction machine

The details of the evaluation of chillies compaction machine was shown in Table 4. Time required for compaction and bagging of dried chillies was recorded to vary from 3 to 3.5 min where as in conventional method, it varied from 8.5-10 min. Average bulk density of chillies compacted in mechanical system was noted as 239.4 kg/m^3 and average compacted weight of chillies was recorded as 42 kg (Figure 4). The capacity of mechanized compaction and bagging unit worked out to be 18 bags/h.

The economic analysis of conventional and mechanized compaction cum bagging of dried chillies shows that the cost of compaction and bagging in conventional system was Rs. 30/ bag of 40-45 kg where as in mechanized system; the cost was worked out to be Rs.20.31 per bag. There was a saving of Rs.9.68 per bag in mechanized compaction and bagging. Total savings in a day of 10 h of working, was estimated to be Rs. 2343. Further, productivity in mechanized system was worked out be 150% over conventional system. Economic analysis suggested that return on investment was worked out to be 70.3% with a payback period of 1.42 years.

Table 4. Evaluation of mechanical dried chillies compaction machine

Parameter	*Mechanical compaction cum bagging method*
Time for compaction and bagging per bag (min)	*3.0-3.5*
Capacity (bags/h)	*18±1*
Breakage of pods	*Nil*
Weight of the bag	*42.0±2.2*
Bulk density	*239.4±7.2*

Figure 4. Compaction of dried chillies in gunny bags using compaction machine

CONCLUSIONS

Conventional method of compaction and bagging of dried chillies is low productive and involves drudgery and burning and day long scorching sensation to the laborers involved. An attempt was made to develop a mechanical compaction machine for packing of capacity 18 bags/h. Evaluation of developed machine has been conducted at farmer's field. Developed machine is technically feasible and economically viable. There is a saving of Rs. 9.68 per bag in mechanized compaction and bagging process with an improvement in productivity over 150%.

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PROJEKTOVANJE I RAZVOJ MAŠINE ZA MEHANIČKO SABIJANJE OSUŠENE ČILI PAPRIKE

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Sažetak. Osušene čili paprike se pakuju (konvencionalno sušenje u polju na vazduhu) u vreće bez nekog određenog oblika u različitim veličinama pakovanja (vreće). Na ovaj način osušene čili paprike imaju veliku ukupnu zapreminu, koju treba smanjiti na manju zapreminu, pre nego što se upakuju u vreće. Tradicionalno se osušeni materijal čili paprika sabija na samom polju gaženjem nogama radnika sve dok ukupna težina vreće ne dostigne 40-45 kg. Ova konvencionalna metoda je radno intezivna, ima malu produktivnost (3 radnika sabijanjem napune 8 vreća/čas), i izaziva snažan neprijatan i nelagodan osećaj ljutine kod radnika.

Dizajnirana je i napravljena prenosna mehanička mašina za sabijanje (kompakciju) osušenog čilija u vreće. Ispitivanje ove razvijene kompakt mašine je obavljeno na polju u okrugu Guntur u državi Andhra Pradesh - Indija.

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Kapacitet ove razvijene mašine je 18 vreća/čas, što tehnički je izvodljivo i ekonomski isplativo.
Ušteda od 9,68 Rs po vreći u postupku mehanizovanog sabijanja i sakupljanja osušene čili paprike ima poboljšanje produktivnosti od preko 150%.

Ključne reči: *Mašina za sabijanje Chilli paprika, pogonski motor, valjak, hidraulični motor, zapreminska težina, sadržaj vlage.*

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