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A STUDY ON FORMING GRAIN CHAFF BY PRESSING AND BONDING

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ABSTRACT

A screw-manual pelletizer was used on wheat dust conditioned with water. Four perforated plates (4, 5, 6 and 8 mm hole diameter) and forming pressure determining device were constructed. Results showed that pelleting of wheat dust with no heating is inappropriate because of lack of cohesion and durability of pellets. Dust-water mixture in 2:1 weight proportion was heated to 65,85 and 110° C. Pellets bulk density ranged between 391 and 497 kg/m^3. Pelleting pressure reached 4.1 bar. Increasing forming temperature reduced the specific energy from 8.08 to 4.44 kW.h/ton and increased durability by 11%. Increasing die hole from 4 to 8 mm reduced both specific energy by 40% and bulk density by 15%. Bonding additives such as molasses strengthened the pellets, and fat reduced friction.

INTRODUCTION

Grain dust results from rubbing and pressing of grains during handling. Grain coats, damaged and injured grains are the main source of grain dust.

Many investigations have been conducted on the utilization of grain dust as a fuel (Chang et al., 1979), soil conditioner (Chang et al., 1981) or a feed ingredient in cattle, swine and poultry rations by pelleting with different mixtures (Clark, 1978; Behnke and Clark, 1979 and Miller, 1979).

Different types of pelleting machines were used to produce pellets from different mixtures. Simmons (1963) divided cubing and pelleting machines into two classes as moulding machines (which have indentations or pockets in their outer surfaces) and extrusion machines (which have two spur-toothed gear wheels run in opposite directions, each having radial holes at the root of the teeth where the compressed meal is extruded and cut off by stationary knives inside each wheel). Other machines have stationary or revolving flat or ring type dies in a vertical or horizontal plane through which the meal is extruded by compression worms or revolving rollers. The resulting cubes or pellets are cut off by stationary or revolving knives. There are some other types of machines which use the same previous principle for cubing, pelleting or wafering as described by Dobie (1960), Susawa (1978), Bilanski et al. (1985), Sitkei (1986) and singh (1996).

In Egypt, a huge amount of grain dust is collected annually (more than 3000 ton/year, Egyptian Silos Co. (1992)). Such amount of grain dust, when stored in heaps under open conditions, will cause serious problems due to: inflammation and self ignition in hot days, occupies large space, difficult in handling, cheap selling price and prone to pests and rodent aggression.

One way to solve this problem is to pellet the grain dust and utilize it as a feed gradient for Cattle and Poultry. Chemical analysis of grain dust showed the following constituents (Al-Saleh, 1991): protein 6–20%, moisture content (w.b.) 5–11%, lipid 1–4%, ash 5–40%, fiber 7–15%, and carbohydrates 30–70%.

The objective of this study is to develop a prototype screw-manual pelletizer for pelleting wheat dust conditioned with water and investigate the following parameters:

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1- Specific energy required for pelleting.
2- Pelleting pressure.
3- Bulk density of the pellets.
4- Durability index of the pellets.
5- Economic evaluation of wheat dust pelleting.

MATERIALS AND METHODS

1- Screw-manual pelletizer:

Fig. 1 shows the screw manual pelletizer that was used for pelleting wheat dust. It is made of cast iron. It consists of an auger, housing with inlet, a set of four perforated plates, of 4,5,6,8 mm dia. and 12 mm thick with equal net-passage area, a plate holder, and a handle.

A mixture is fed into the housing through the inlet. The revolving auger pushes the mixture along the auger towards the multi-holes of the plate in the form of pellets.

2- Pelleting pressure instrument:

A pelleting pressure instrument was designed and constructed (as shown in Fig. 1) in the Ag. Eng. Dept., Fac. of Ag., Ain shams Univ.. It consisted of two round plates, joined together with four anchor bolts. One plate was threaded to mount on the housing at the outlet. A spring presses against the protrusion plate resting on the other plate. Increments in spring reduction were made until the moving mixture is no longer able to push the protrusion plate away from the housing. Then the spring force balances the pelleting force acting on the inside surface of the protrusion plate. Then, pelleting pressure is determined as follows:

$$p = \frac{F}{A} \quad \text{.......... ..(1)}$$

Where:
P: is the pelleting pressure (N/cm^2).
F: is the compression force of the spring (N).

$$F = 105\ \Delta L, \quad \text{.........(2)}$$

since 105 N/cm is the average stiffness of the used spring.
ΔL : is the spring reduction (cm), measured by a graduated scale.
A: is the net area (cm^2) of the protrusion plate acted upon by the mixture.

$$A = \frac{\pi}{4}\left[D^2 - d_s^2\right] = 18.85\ cm^2 \quad \text{......:(3)}$$

Where:
D: is the protrusion plate outer diameter, (5 cm).
d_s: is the diameter of the middle hole of the protrusion plate where the auger is mounted (1.0 cm).
Then: $p = 0.557\ \Delta L \quad (bar)$ .... (4)

3-Binder materials:

Binder materials were added to the control mixture (dust-water mixture 2:1 by weight) in the following proportions, related to the wheat dust by weight:
- molasses: (5,10 and 15:100) produced by sugar cane Co.,
- glue (2.5 : 100) animal origin;
- poultry by products: fat (3:100), crude protein (2:100) manufactured separately by the United Co. for chicken production, Heliopolis slaughter house (الشركة المتحدة للإنتاج الداجنى) .

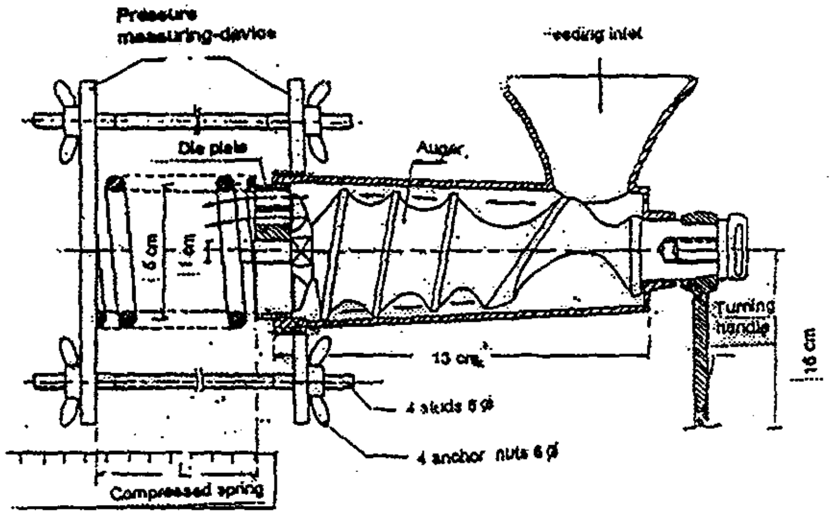

Fig. 1: Manual-screw pelletizer.

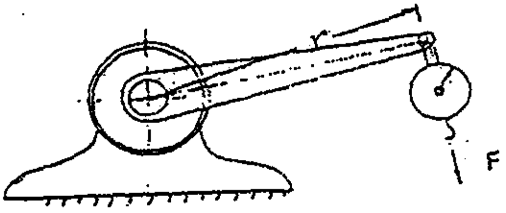

Fig. 2: Measurement of rotation torque.

- lignosulfonate; (2:100) produced by Atmida Co. for investments, Mit Ghamr, Egypt (شركة أتميدة ، ميت غمر) .

4- Preparing the mixture samples:

Samples of 100 g. of wheat dust were hand mixed with water in (2:1) proportion by weight using a compression sprayer for all additives. Wheat dust was brought from the Egyptian Silos Co. Shubra branch (الشركة العامة للصوامع والتخزين ، فرع شبرا) . Each binder was separately mixed with dust, then sprayed with water.

5- Heating the mixture:

The mixture, wrapped with aluminum foil, was heated inside a gas oven. The housing was heated by a gas flame for a few seconds till the gadgets become as hot as the mixture. The temperature was measured by a thermometer (range: up to 250°C).

6-Specific energy:

A spring dynamometer (100N) was hooked with the handle turning the auger (Fig.2) to measure force of rotation.

$$S.E. = \frac{E}{M} \quad \text{..........} \quad (5)$$

Where:

S.E.: is the specific energy, kJ/kg.

M: is the mass of the air-dried pellets produced per revolution (g/rev.).

E: is the work done per revolution (N.m/rev.) as:

$$E = F.2\pi.L \quad \text{..........} \quad (6)$$

Where:

F: is the dynamometer reading (N).

L: is the handle length, 0.16 m.

Then:

$$S.E. = 1.0053\,\frac{F}{M} \quad (kJ/kg) \quad \text{..........} \quad (7)$$

7- Dry matter content:

Dry matter content of the sun-dried pellets is determined as described in ASAE STANDARDS 1996.

$$\%\,DM = \frac{Sample\ \ weight\ - Loss\ \ in\ \ weight}{Sample\ \ weight}.100 \quad \text{..........} \quad (8)$$

8- Bulk density:

Bulk density of the sun-dried pellets was determined according to ASAE STANDARDS 1996, then corrected to zero (m.c.) as:

$$B.D. = B.D._{test}\,\frac{(\%\,DM)}{100} \quad \text{..........}\ldots(9)$$

Where:

B.D.$_{Test}$: is the bulk density indicated by the test, kg/m^3. %DM: is the percent dry matter in tested pellets.

BD.: is the bulk density related to dry matter in kg/m^3.

9- Durability test:

Durability test for the sun-dried pellets was done by dropping them from 2m. height on a hard surface for 10 times (Singh,1996),then:

$$Durability\ \ index\ \% = \frac{retained\ \ or\ undamaged\ \ \ pellets\ \ weiht}{tested\ \ pellets\ \ weight}\ 100 \quad \ldots(10)$$

RESULTS AND DISCUSSION

1- Cold pelleting:

Cold pelleting experiments were done with three additives (water, Molasses, and fat) mixed separately with wheat dust. Each mixture was pelleted through the screw pelletizer with no heating.

Results obtained, with 6mm dia. multi-hole protrusion plate, are represented graphically in Figs. (3, 4 and 5).

Figs. (3, 4 and 5) show that the screw pelletizer should not be operated with less than 0.5 water/dust ratio by weight, 0.6 molasses/dust ratio by weight or 0.4 fat/dust ratio by weight because of the excessive required specific energy and little coherence. In general, cold pelleting of wheat dust with higher ratios of water/dust molasses/dust or fat/dust mixture resulted in no pellets, softer pellets or converting the mixture into a paste, respectively.

In general, cold pelleting of wheat dust using the screw pelletizer is impractical due to little coherence and high energy requirements.

2- Hot pelleting:

Experiments showed that heating the control mixture (0.5 water/dust mixture by weight) over 65°C temperature can make suitable coherent pellets with the tool due to bursting of starch particles and forming of stronger bonds. Further heating to 85, 110°C temperatures has been achieved. Heating over 110°C causes the mixture to burn. More water than that in control mixture makes very soft pellets that require more drying with possibility of breakage. Insufficient water makes pellets crumble.

3-Pellets drying:

Pellets produced are sun-dried by spreading them on trays at nearly 35°C for 3–5 hours until they become strong enough to withstand handling and storing conditions.

4- Pellet lengths:

Pellets ranged 5-8 cm long according to hole diameter of the protrusion plate as shown in Fig. 6. However, pellets tend to bend and fall down under their own-weights on emerging from the plate. Therefore, pellets were cut off by a knife into lengths suitable for bulk density determination of (L/d = 2–3), where L and d are the pellet length and diameter respectively.

Fig. 6 illustrates that, small dies form longer pellets than wide dies. This is because of higher friction resistance, thus higher cohesion for thin pellets.

Thick pellets are more liable to breakage due to higher linear mass compared with thin pellets.

5- Specific energy, forming pressure, bulk density and durability determination:

Results obtained for the determination of specific energy, forming pressure, bulk density and durability index for control mixture using the screw pelletizer and the protrusion plates are shown in Figs. (7, 8, 9 and 10) respectively.

It is clear that:

a-Specific energy, pelleting pressure, bulk density and durability index increased with decreasing the die hole diameter at the same temperature.

b-Increasing the temperature reduced the specific energy due to conversion of the starch particles from crystal form to amorphous form.

c-Decreasing die hole caused larger portion of the to come in contact with the die walls compared with the total die area. Thus more friction is encountered, requiring higher power and causing higher back pressure.

Fig.3 :Specific energy for water-dust mixture using 6 mm die hole.

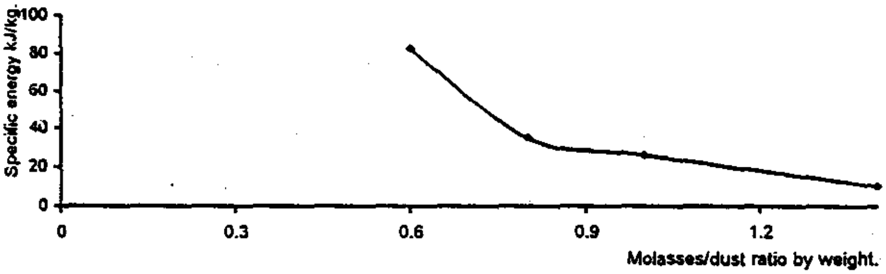

Fig.4: Specific energy for molasses-dust mixture using 6 mm die hole.

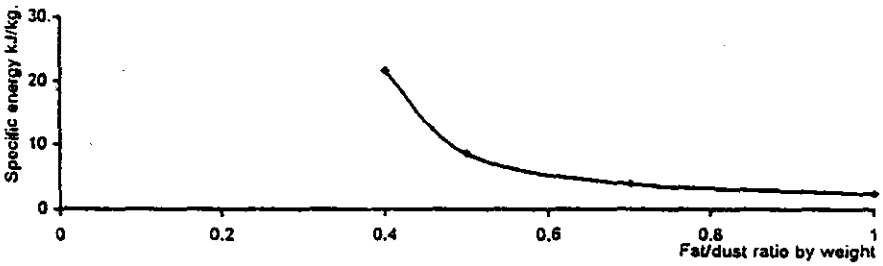

Fig.5: Specific energy for fat-dust mixture using 6 mm die hole.

Fig.6: Pellet lengths from different dies for the control mixture at 65 C temperature.

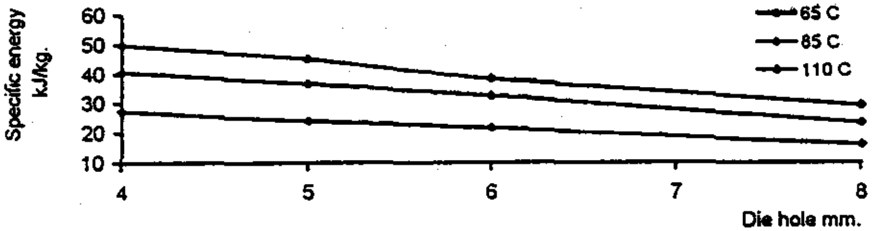

Fig.7: Specific energy for the control mixture for the temperatures and the dies tested .

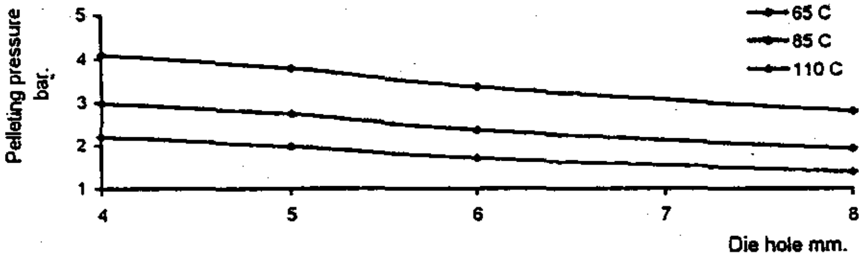

Fig.8: Pelleting pressure for the control mixture for the temperatures and the dies tested .

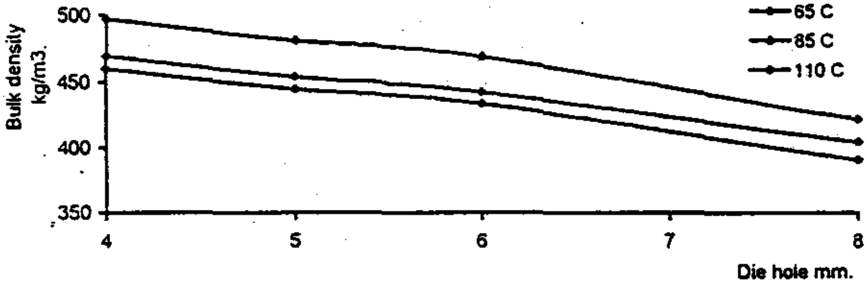

Fig.9: Bulk density for the control mixture pellets for the temperatures and the dies tested.

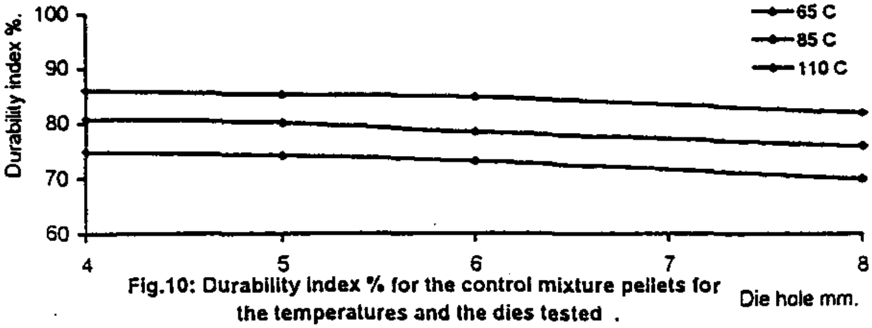

Fig.10: Durability index % for the control mixture pellets for the temperatures and the dies tested .

d-Bulk density was, relatively low (391-497kg/m^3), due to limited pelleting pressure exerted by the auger on the mixture before the die, comparing with the pellets manufactured at Atmida Co. (700 kg/m^3) under 200 bar pelleting pressure and through 4 mm diameter roller-ring die extruder. Higher temperatures cause higher particles compaction, thus higher pellets bulk density. Dry matter percentage increased due to 2 effects:

1-Higher evaporation rates at higher temperatures.

2-Higher moisture loss for thin pellets due to larger surface area regarding pellets weight.

e-Durability was increased by increasing the pelleting temperature from (65 to 110°C for the same die hole diameter and, also, increased by reducing the die hole diameter at the same temperature. This was because higher friction resistance is encountered. for smaller dies, thus more cohesion and durability for thin pellets.

6-Effect of binding additives:

The addition of lignosulfonate, the strong binder, to the control mixture increased the adhesive forces between the dust particles and formed much stronger bonds. It resulted in increasing the pellet lengths by 35%, the specific energy by 15%, pelleting pressure by 9%, bulk density by 10% and durability index by 10%.

The addition of glue to the control mixture gave, approximately, the same pellet lengths and the same bulk density while the durability index increased by 5-6%. Because glue lubricates as it binds, specific energy was slightly lower than those of the control mixture by about 5%.

The addition of crude protein to the control mixture decreased the pellet lengths by 15%. This is due to pellets breakage caused by coarse particles in crude protein which help in compressing, but not in binding.

Since fat is a lubricant more than a binder, it reduced the friction between the particles and the machine. It decreased the pellet lengths by 50%, the durability index of the pellets by 8% and the specific energy by 8%.

The addition of molasses to the control mixture, by using the ratios of 5, 10 and 15% molasses to the control mixture by weight, increased the pellet length by 10, 25 and 40% and the durability index by 6, 10 and 16%, respectively.

The application of heat is responsible for loosening and smoothening the particles of the mixture, thus compressibility of the material is higher.

7- Auger-pelletizer operation dimensional analysis:

Prototype auger-manual pelletizer function is extended through dimensional analysis. Parameters affecting tool performance are:

$$Q = f(V, N, A, \rho) \quad \text{.............}(11)$$

$$T = f(V, g, S, \rho, r) \quad \text{...........}(12)$$

Where: Q refers to capacity M/τ, T torque ML^2/τ^2, V auger-pitch volume L^3, N speed $1/\tau$, A holes area L^2, S lateral holes area L^2, r die-holes area ratio, ρ bulk density M/L^3, g gravity acceleration l/τ^2.

Also: M refers to mass, τ to time and L to length.

Buckingham (Pi) theorem (White,1986) application resulted the following (Pi) terms as:

$$\frac{Q/N}{V.\rho} = f\left(\frac{A}{V^{2/3}}\right) \quad \text{........}(13)$$

$$\frac{T}{\rho . g . V^{4/3}} = f\left(\frac{S}{V^{2/3}}, r\right) \quad \text{.......... ..(14)}$$

Tool dimensions:
Auger dimensions: d_o=5, d_i=3.5 cm, pitch p=1.6 cm.
then:

$$v = \frac{\pi}{4}(D^2 - d_s^2).p = 16\ cm^3$$

Plate diameter, D = 5 cm, central hole, d_s=1 cm. Then:

$$A = r\frac{\pi}{4}\left[D^2 - d_s^2\right] = n . \frac{\pi}{4} d^2$$

Where: n refers to holes number, d hole diameter.

Different net-passage area protrusion plates were used with the control mixture to figure the dimensionless groups relation as shown in table 6, Figs. 11,12.

Table 6: Calculating of dimensionless groups involving the tool operation.

Hole dia., d (cm)	0.8			0.6		
Holes number, n	8	12	16	14	21	28
A (cm^2)	4.02	6.03	8.04	3.96	5.94	7.92
r (%)	0.21	0.31	0.42	0.21	0.31	0.42
S (cm^2)	24.12	36.2	48.25	31.67	47.5	63.33
$A/V^{2/3}$	0.63	0.95	1.27	0.62	0.94	1.25
$S/V^{2/3}$	3.8	5.7	7.6	4.98	7.5	9.98
Q/N (g/rev.)	0.59	0.725	0.86	0.56	0.71	0.86
(g/cm^3) ρ	0.391			0.434		
ρ (Q/N) / V.	0.094	0.116	0.138	0.081	0.102	0.124
F (N).	31.5	21	16.6	37.8	27	20.3
T($g.cm^2/sec^2$)	5.04E7	3.36E7	2.56E7	6.05E7	4.32E7	3.24E7
ρ $T/g.V^{4/3}$	3260	2172	1714	3525	2517	1888
Hole dia., d (cm)	0.5			0.4		
Holes number,n	20	30	40	32	47	64
A (cm^2)	3.93	5.89	7.85	4.02	5.91	8.04
r (%)	0.21	0.31	0.42	0.21	0.31	0.42
S (cm^2)	37.7	56.6	75.4	48.25	70.9	96.5
$A/V^{2/3}$	0.62	0.93	1.24	0.63	0.93	1.27
$S/V^{2/3}$	5.94	8.9	11.9	7.6	11.2	15.2
Q/N (g/rev.)	0.59	0.73	0.87	0.60	0.74	0.90
(g/cm^3) ρ	0.445			0.460		
ρ (Q/N) / V.	0.083	0.103	0.122	0.082	0.101	0.122
F (N).	42.5	32.8	24.9	46	36.8	26.9
T($g.cm^2/sec^2$)	6.8E7	5.24E7	3.98E7	7.36E7	5.89E7	4.3E7
ρ $T/g.V^{4/3}$.	3864	2977	2261	4117	3237	2364

Since: $T = F.L.10^7$

Where:

T: Torque of rotation, $g.cm^2/sec^2$.

F: Force of rotation, N.

L: Arm of the pelletizer handle (0.16m).

10^7: Conversion coefficient.

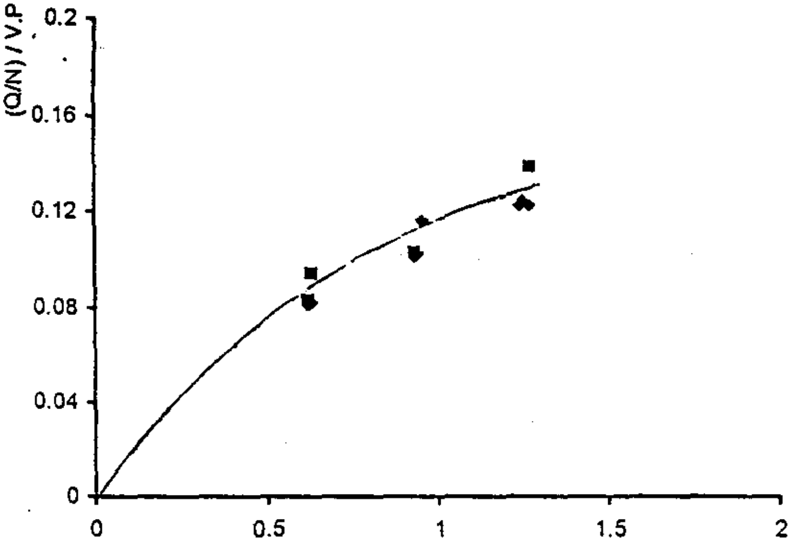

Fig 11: Relationship for dimensionless groups concerning screw-pelletizer operation.

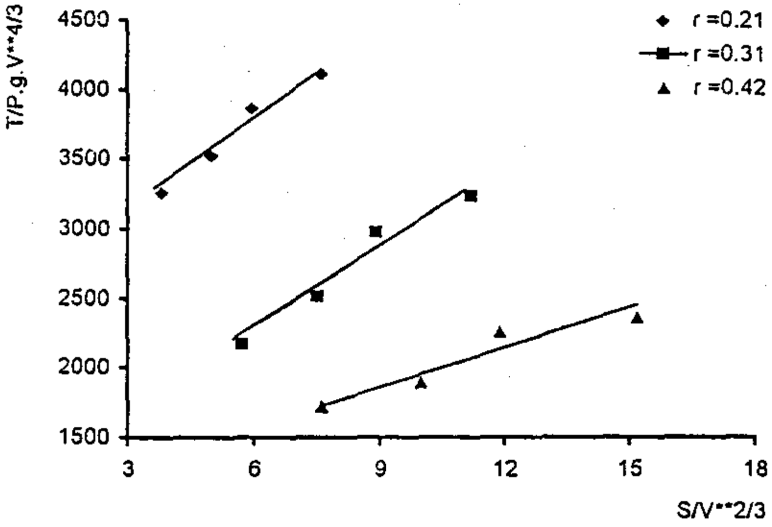

Fig 12: Relationship for dimensionless groups concerning screw-pelletizer operation.

For further work in real production, a theoretical study to design a plant with 0.5 ton/h capacity of steamed dust mixed with molass as binding materail from "Sugar- Cane Co." was undertaken through dimensional analysis of the pelltizer operation. This plant (Fig.13) is driven by 13 kW engine with 50kg/h steam boiler capacity and 25kg/h molass addition. Cost analysis of this plant showed 0.0251 L.E./kg dust pelletizing. Bulk dust price is 8-16% L.E./kg.

SUMMARY AND CONCLUSION

This investigation is about mechanism used in forming of grain dust by pressing and bonding into pellets. A screw-manual pelletizer was used with wheat dust mixed with binding agents, such as: water, lignosulfonate, glue, crude protein, fat and molasses. A control mixture consisted of wheat dust mixed with water in 2:1 proportion by weight.

Four multi-hole (4, 5, 6 and 8 mm diameter) extrusion plates of the same total die area and thickness were used. A pelleting pressure determining device was constructed.

Tests were carried out with and without heat application. Results showed that cold pelleting is inappropriate because of lack of coherence and durability of pellets.

Results showed that durability index ranked first for lignosulfonate addition 90.5 %, followed by molasses 87.6% then glue 87% .

Bulk densities were low (391– 497) kg/m^3 compared with 775 kg/m^3 for the pellets manufactured at Atmida Co.. Pelleting pressures were limited with maximum of 4.1 bar compared with 200 bar available at roller-ring die extruder.

Fat behaved like a lubricant rather than a binder, pellet lengths were (2 - 4) cm for fatted control mixture, (5 - 11) cm for the other binders additions.

Specific energies were little (4.44-13.9) kW.h/ton .

Increasing pelleting temperature from 65 °C to 110 °C , increased the bulk density by 8 %, the durability index by 11 %, and decreased the specific energy by 45 % , the pelleting pressure by 48 %.

Increasing die hole from 4 to 8 mm, reduced specific energy by 42%, pelleting pressure by 35 %, bulk density by 15 % and durability index by 4 %.

Cost analysis showed that pelleting of wheat dust by using this prototype extruder and bonding costs 47.6% L.E. per kg.

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دراسة عن آلات تشكيل مخلفات الحبوب بواسطة الكبس والتماسك

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الملخص العربي

شاع مؤخراً استخدام تكنولوجيا تكثيف المواد السائبة بغرض تسهيل تداول وتخزين وتقليل فرص احتراق هذه المواد.

استخدمت تجهيزة بريمية تدفع خليط غبار الحبوب والماء والمادة اللاصقة إلى قرص التشكيل المثقب في صورة أصابع صغيرة متماسكة . ونفذت آلية على الجهاز لقياس ضغط التشكيل. بينت التجارب أن تشكيل الغبار بدون إضافة الحرارة يؤدي إلى إصبعيات مفككة. تم تسخين خليط الغبار والماء بنسبة وزنية ٢:١ على الترتيب إلى درجات حرارة (٦٥ ، ٨٥ ، ١١٠م°). تم قياس دليل التحمل للمصبعات المجففة بالهواء بتحديد النسبة المئوية الوزنية للمصبعات السليمة إثر السقوط من ارتفاع مترين على سطح صلب لعشر مرات متتالية . بلغت الكثافة الظاهرية للمصبعات (٣٩١ ـ ٤٩٧) كج/م^3. ضغط التشكيل الأعظمي ٤,١بار .

إن زيادة درجة حرارة التشكيل أدى لازدياد دليل التحمل ١١% ونقصان القدرة النوعية من ٨,٠٨ إلى ٤,٤٤ كيلو واط.ساعة/طن. إن ازدياد ثقب القالب من ٤ إلى ٨ مم قد قلل القدرة النوعية اللازمة لتشكيل وحدة الكتلة من الغبار بمقدار ٤٠% وضغط التشكيل ٣٠% والكثافة الظاهرية ١٥% .

إن إضافة الليجنوسلفونيت (lignosulfonate) والمولاس والغراء كمواد رابطة إلى خليط الغبار والماء زاد احتمال وتماسك المصبعات .

بلغت أطوال المصبعات لخليط الغبار والماء المعامل بالدهون (٢ ـ ٤) سم كما بلغت (٥ ـ ١١) سم لباقي المعاملات .

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* أستاذ الهندسة الزراعية المتفرغ بزراعة عين شمس.
***مدرس الهندسة الزراعية بزراعة عين شمس.
***إجازة في الهندسة الميكانيكية - قوى- جامعة حلب - سورية -١٩٨٨.