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A STUDY ON DESIGN FACTORS RELATED TO PLANT RESIDUES FORMING MACHINES

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ABSTRACT

This study was done to investigate design factors relating to auger-pelleting machine performance. For this, two augers of high and small pitch to diameter ratios: (5.2/3.92) and (3.1/11) were used with 5, 8, and10 mm multi-hole die plates. Wheat sifting residues as mill byproducts of 25, 30, 35, and 40% moisture content on wet basis were pelleted at 10, 30, 60, and 100 rpm auger speed. Molass was mixed at 5, 10, and 15% retaining the mixtures at 25% m.c.

Pelleting pressure determining and torque measuring instruments were constructed. Tumbling tester was carried out according to ASAE standards 1996. Residues temperature rise was measured by a thermocouple 'k'. To estimate the role of heat addition, the mixture was preheated to 50 and 70 °C.

Results for the high pitch to diameter ratio auger-pelletizer showed over (25-40%) m.c. with 5 mm die, an increase of 14.4% in productivity from 2.214 kg/h, 10% decrease in torque from 14.833 N.m., 21% decrease in specific energy from 7.016 kW.h/ton and 22% decrease in forming pressure from 58.93 bar. For (5-10) mm die, specific energy decreased 50 % due to less dead area ratio and less friction area for open die, but it augmented 58.7% over (10-100) rpm because of less productivity per revolution as well as higher material forming resistance at higher compressing rates. Unit-density for the sun-dried pellets reached 1188.5 kg/m^3. Power efficiency ranked 18.1% due to high power dissipation in pelleting machines. Material temperature-rise reached 14.4 °C. Durability. index reached 98.2% for residues mixed with 15% molasses over 90% for the untreated sample.

Results for heat addition showed an improvement in pellets durability and a reduction in torque requirement, but total specific energy including heating highly increased.

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Results for the small pitch to diameter ratio auger-pelletizer showed that specific energy, pelleting pressure, density, etc. were all fairly less than those for the high ratio auger-pelletizer due to lower forming-die resistance.

Establishing a general theory on pelleting operation showing predicted equations of productivity increases with auger speed at a diminishing rate but almost linear with auger volume. Power increases with speed at a higher increasing rate rather than with pelletizer size.

I- INTRODUCTION

Agglomeration or densification facilitates handling, feeding, etc. This technology comprises compression of bulk materials against closed or open-end forming die plates.

Simmons (1963) showed that pelleting machines have stationery or revolving, flat or ring type dies in a vertical or horizontal plane through which the meal is extruded by compression pistons, worms or rollers, the resulting cubes or pellets are cut off by stationery or revolving knives.

Bernacki et al. (1972) illustrated the principle of baling in an open chamber consisting of a piston pushing a newly delivered material portion to a series of previously formed wafers, to form a new wafer piece. Reaction required to form a wafer is thus caused by the shifting resistance of all the wafers situated in the chamber. In such a device, the work spent to overcome shifting resistance is useless. In a closed chamber, the delivered portion is compressed against the chamber outlet wall that deflects at a certain pressure releasing the wafer outside. A continuous baling process with a tapering auger also absorbs a considerable amount of energy during shifting the material.

Factors affecting pelleting technology are material properties such the species, the material's structure, temperature and moisture content, etc. and the machine specifications such the pressure applied, velocity of pelleting and die geometry design, etc., **Pickard et al. (1961) and Rehkugler and Buchele (1969).**

Sitkei (1986) stated that energy requirement in pelleting machines comprises pressing work and pushing or friction work. The latter increases as die hole decreases. Energy requirement also increases for thicker dies that produce stronger pellets.

Heldman and Lund (1992) illustrated that the operating point for an extruder as the intersection of the screw and the die characteristic curves.

Sitkei (1986) stated that with increasing moisture content, many agricultural materials assume plastic properties, facilitating compression.

Orth and Löwe (1977) found in experiments done with an experimental reciprocating extrusion press that the density, durability, and system temperature was dependent on the moisture content of the material. Below 12% m.c. on wet basis, stable wafers could not be formed. With increasing moisture content, the durability and the density increased to a maximum at 14% m.c. and up to 20%, decreased.

Watfa (1999) used a screw-manual pelletizer fitted with multi-hole die plates to form wheat dust conditioned with water and binding agents. He found that heat application is a complementary part in pelletization. Further research is required to investigate the effect of the auger dimensions on the process.

II-MATERIALS AND METHODS

3-1-Auger-pelleting machine:

This machine, Fig.1 and schematically shown in Fig.2 consists of an auger, housing with feeding bin, a set of multi-hole forming die plates and an iron base for mounting all the components. The motor (0.5 kW) fitted with a speed reducer (28:1 ratio) is coupled with the auger by a coupling. A "T.verter" (0-120 Hz) is an electrical device that controls the motor speed by varying the current frequency. Two auger-shell sets (shown in Fig. 3) with their die plates detailed in table (1) were used in this study.

Table 1: Auger-shell pelletizers specifications:

ITEM	PEL.1	PEL.2
Auger pitch to dia. ratio (cm/cm).	5.2/3.92	3.1/11
Auger inside dia. and length (cm).	1.92-16.5	8.5-9.0
Shell outside and inside dia. (cm).	5.0-3.93	12.5-11.01
Die plate hole diameter, length (mm)	5-8-10, 22	5-8-10, 10

3-2-Test plant residues:

Plant residues included wheat sifting residue mixture from Shubra Mill in Cairo.(مطاحن شبرا ، القاهرة).

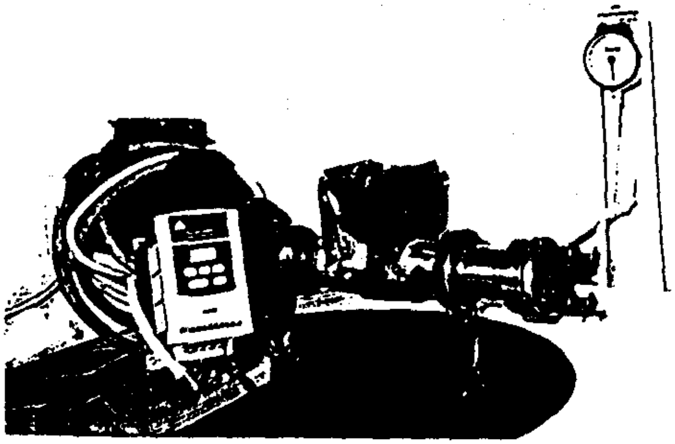

Fig. 1. Photo of pelleting machine.

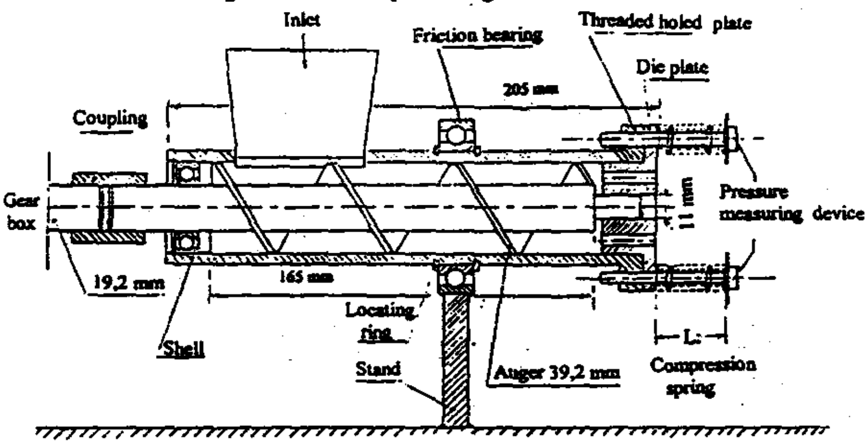

Fig. 2. Schematic of the pelleting machine.

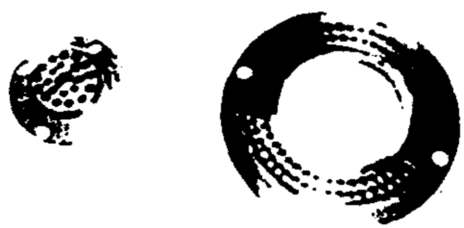

Fig. 3- a. Photo of augers.

Fig. 3-b. Photo of die plates.

3-3-Bonding materials:

Bonding materials comprise:

Water: tap water, and

Molasses: from "Sugar-Cane Co."(شركة قصب السكر، الحوامدية)

3-4-Machine productivity:

Pelletizer productivity was measured with the help of a digital stop-watch of 0.1second accuracy and a balance of 1 g. accuracy.

3-5-Forming pressure:

To measure pelleting pressure developed upon the die plate, the latter (Fig. 2) was set free to be pushed out by the moving mixture against compression springs whose reduction (ΔL) indicates the pelleting force. Then:

$$P = k \cdot \Delta L / A \quad (N/cm^2) \;\ldots\ldots\ldots\; (1)$$

Where:

k: springs set stiffness, N/cm; ΔL: springs' reduction, cm. A: total die plate passage area, cm^2 as:

$A = N_h \cdot (\pi/4) \cdot d^2$, where:

N_h: die plate holes number; d: die hole diameter, cm.

3-6-Torque measurement:

To measure torque required to operate the auger-pelletizer, the barrel (Fig.4) was installed inside a frictionless bearing and was free to rotate relative to the auger axis. An arm was fixed with the barrel to keep it from rotating together with the auger by means of a spring dynamometer holding the arm. Then:

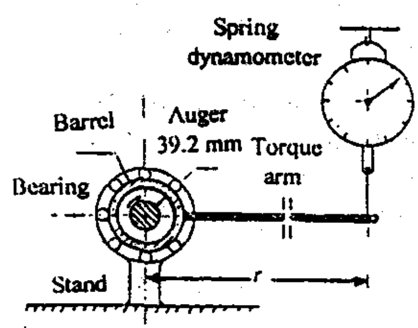

Fig. 4: Schematic of torque measurement setup.

$$T = F \cdot r \quad (N.m) \;\ldots\ldots\ldots\; (2)$$

Where:

T: torque (N.m), F: the force reading on the dynamometer scale, N.

r: the distance from the dynamometer to the auger axis, m.

3-7-Power efficiency:

Power or pumping efficiency is determined as:

$$\eta \% = (q \cdot \Delta p / P) \times 100 \;\ldots\ldots\ldots\; (3)$$

Where:
q: volume flow rate through the die plate, m^3/s, and
$q = m^{\cdot}/\rho$, where: $m^{\cdot}$: productivity (kg/s) and ρ: pellets density, kg/m^3.
Δp: forming pressure, N/cm^2; P: mechanical power input (Watt) as:
$P = T.\ 2\ \pi\ n/60$, n: rpm.

3-8-Energy requirement:

Energy requirement is determined as:

$S.E. = (P+H)/m^{\cdot}$ ....(4)

Where:
H: heating power, (Watt) as:
$H = m^{\cdot}.C_P.\Delta t$, where:
C_P: material specific heat, (J/kg. °C.) upon Rao and Rizvi model, 1995.
Δt: preheated material temperatue rise prior to feeding, °C.

3-9-Durability test:

A durability tester, Fig.5 was constructed in Eng. Dept., Agric. Col., Ain Shams Univ. according to ASAE standards, 1996. It is fitted with a 23 cm baffle fixed symmetrically to a diagonal of 30 cm dimensions box side for tumbling. It is hand rotated about an axis placed inside friction bearings fixed on a stand. A speed indicator at 50 r/min is connected with the shaft. A 500 g. sieved sample of pellets are placed in the box and tumbled for 10min.

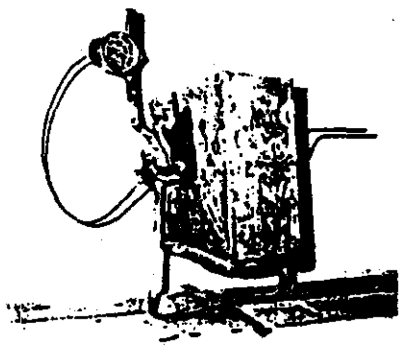

Fig. 5: Photo of pellets durability tester.

Durability index is defined as:

$$\text{Durability }\% = \frac{\text{Intact or undamaged pellets mass}}{\text{pellets mass before tumbling}} .100$$

IV-RESULTS AND DISCUSSION

Experiments for the high and small pitch to diameter ratios : (5.2/3.92) and (3.1/11) auger- pelletizers were done with wheat sifting residues at different operating conditions.

4-1-High pitch to diameter ratio auger-pelletizer results:

Figure 6 shows that productivity increases due to increased material bulk density with increased moisture content. It increased as shown in Fig. 7 at a decreasing rate with speed due to an increased number of flow interruptions by the flighting at the intake. Figure 8 shows that torque generally decreases with moisture content because of improved material's fluidity and formability. It slightly increased with auger speed as shown in figure 9 as a result of shorter duration of compression. Torque decreased over (5-10) mm die because of lower forming die resistance. Figure 10 shows that power varies nearly linear with speed since torque variation is slight as evident from Fig.9.

Specific energy decreased about 21% from7.016 to 5.551 kW.h/ton over (25 - 40%) m.c.. It also decreased about 50% over die hole (5 – 10) mm due to less dead area ratio and less frictional die surface for the last. Anyway it increased 58.7% over (10-100) rpm because of less productivity per revolution as well as higher material forming resistance at higher compressing velocities.

As many agricultural materials assume plastic properties, facilitating compression at increased moisture contents, Fig. 11 shows a 22% decrease in forming pressure from 58.93 to 46.15 bar over (25 - 40%) moisture content. It also decreased about 64.5% over (5-10) mm die due to decrease in dead area proportion by 29% and decrease in die friction surface by 22% that express die plate's resistance to material formation. A slight increase of 6 % over (10 – 100) rpm auger speed for 5 mm die is expected as a result of increasing the velocity of compression.

Unit-density that is determined by dividing pellets weight on their volume, reached 1347 kg/m^3 immediately after extrusion for 5 mm die and1188.5 kg/m^3 after being sun-dried.

Drying period lasted up to 12.5 h for 10 mm diameter pellets of 40% m.c. at June 2001 in Shubra El-Kheima (Fac. of Agric.).

Power efficiency ranked 18.1% due to high power dissipation in pelleting machines. Material temperature-rise reached 14.4 °C as a maximum for 5 mm die at 100 rpm.

4-2-Addition of heat:

Wheat sifting residue at 25% m.c. on wet basis was heated to 50 and 70 °C temperatures inside an oven then fed to the pelletizer inlet.

A slight increase in productivity at about 2 and 5% was observed for wheat sifting residues inlet temperatures 50 and 70 °C respectively over 25 °C. This is attributed to improved material's fluidity and compaction with heating, but the auger feeder is essentially positive displacement.

Fig. 12 shows mechanical power input (article 3-7) as a function of mixture inlet temperature for different die plates. It states a reduction of 16.7% and 33.3% in mechanical power from 15.533 Watt for 5 mm die at 10 rpm due to heating the mixture from 25 to 50 and 70 °C respectively. This insinuates that the mixture cohesion and adhesion decrease with heating, permitting the same volume to protrude at a lower pressure. Anyway total power requirement including heating highly increased as evident from Fig. 13.

A significant improvement of 8.4% in pellets durability was noticed with heating. This could be understood through the action of starch liberation as an adhesive with the existence of sufficient heat and water.

4-3-Small pitch to diameter ratio auger-pelletizer results:

Productivity is almost the same for the three tested dies since their passage areas are very close to each other. Also, productivity per revolution relative to the small pitch to diameter ratio auger capacity is a little higher by 10% than that for the high pitch to diameter ratio auger. This might be attributed to higher forming resistance for the latter die plates. Anyway output with 5 mm die hole plate was greater by only 165% than that for the high pitch ratio pelletizer despite 450% increase in die plates' passage area. This is attributed to the fact that the operating point for an extruder is an intersection between the screw and the die characteristic curves.

Specific energy was in general less than those for the high pitch ratio by 26.7%, 19.6% and 15.5% with 5, 8 and 10 mm die hole respectively.

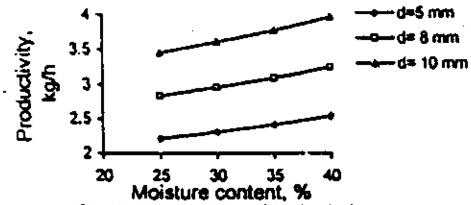

Fig. 6. Productivity of high pitch to diameter ratio auger pelletizer at 10 rpm with wheat sifting residues.

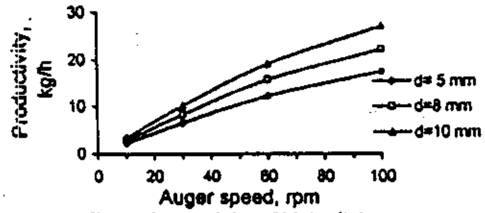

Fig. 7. Productivity of high pitch to diameter ratio auger pelletizer with 25% m.c. wheat sifting residues.

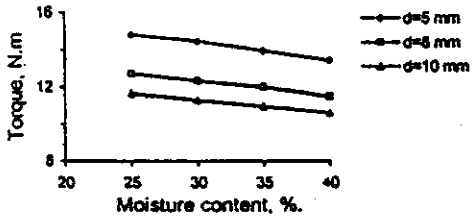

Fig. 8. Torque requirement for high pitch to diameter ratio auger pelletizer at 10 rpm with wheat sifting residues.

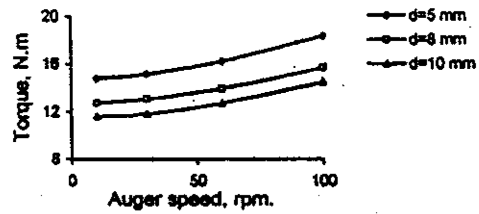

Fig. 9. Torque requirement for high pitch to diameter ratio auger pelletizer with 25% m.c. wheat sifting residues.

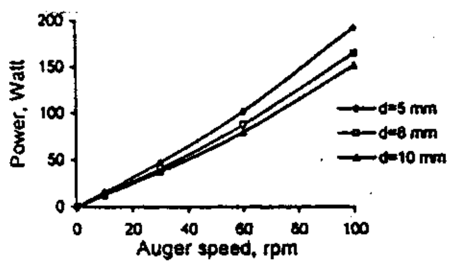

Fig. 10. Power requirement for high pitch to diameter ratio auger pelletizer with 25% m.c. wheat sifting residues.

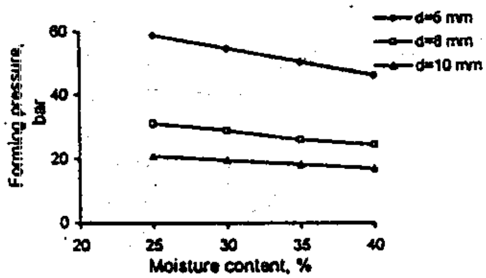

Fig. 11. Forming pressure for high pitch to diameter ratio auger pelletizer at 10 rpm with wheat sifting residues.

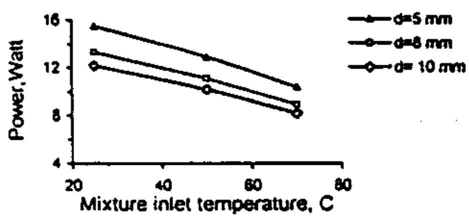

Fig.12. Mechanical power input to wheat sifting residues inlet temperature for high pitch to diameter ratio auger pelletizer at 10 rpm.

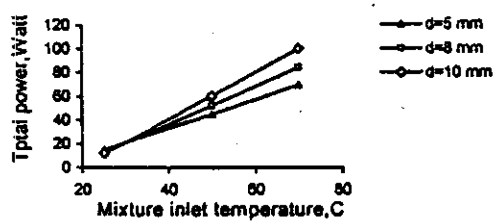

Fig. 13. Total power to wheat sifting residues inlet temperature for high pitch to diameter ratio auger pelletizer at 10 rpm.

This is mostly due to reduction in both dead area ratio by 28.5%, 25.2% and 17% and die length by 220% for 5, 8 and 10 mm die respectively.

Forming pressure was less by 30%, 22.8% and 19.2% than that for the high ratio pelletizer with 5, 8 and 10 mm die respectively due to less passage resistance encountered by the mixture moving through the forming die. Temperature rise, pellets durability and density were all fairly less than those for the high ratio set. Power efficiency reached 18.14% (as highest) which is almost the same for the high ratio.

4-4-General theory for the screw-pelletizer design and operation:

Screw pelletizer performance parameters are functions of: (a) design variables, (b) operation variables and (c) material variables. For dimensional analysis, the pertinent quantities with the basic dimensions in terms of mass (M), length (L), time (τ) and temperature (θ) are listed in the following table:

Table 2. Pertinent quantities in the auger-pelletizer dimensional analysis.

Symbol	Description of quantity	Units
	Geometry	
V	Auger volumetric capacity ~~per revolution.~~	L^3
A	Total die area (passage area).	L^2
	Material	
ρ	Initial bulk density.	M/L^3
t	Feeding temperature.	θ
C_p	Specific heat.	$L^2/\theta.\tau^2$
	Operation	
m˙	Productivity: mass per unit time.	M/τ
T	Torque required to turn the system.	$M.L^2/\tau^2$
p	Forming pressure.	$M/L.\tau^2$
n	Rotational speed of the auger shaft.	$1/\tau$
g	Gravitational acceleration	L/τ^2

Following functional relations could be established:

$\dot{m} = f(\rho, A, V, n, p)$ ....(5)

$T = f(\rho, A, V, n, p)$ ....(6)

Application of Buckingham (pi) theorem (White, 1986) results:

$\dot{m}/A.\rho^{1/2}.p^{1/2} = f(n.V^{1/3}.\rho^{1/2}/p^{1/2}, V^{2/3}/A)$ ....(7)

$T/p.A^{3/2} = f(n.V^{1/3}.\rho^{1/2}/p^{1/2}, V^{2/3}/A)$ ....(8)

$P.\rho^{1/2}/A.p^{3/2} = f(n.V^{1/3}.\rho^{1/2}/p^{1/2}, V^{2/3}/A)$ ....(9)

Where: P: mechanical power input, $(M.L^2/\tau^3)$.

Auger capacity per revolution, V(cm^3):

$V = \pi/4 \cdot (d_f^2 - d_s^2) \cdot (þ - t)$, where:

d_f: auger outside dia. (cm), d_s: auger root dia. (cm) , þ: auger pitch (cm).

t: flighting thickness (cm).

Die plate passage area, A(cm^2):

$A = N_h \cdot (\pi/4) \cdot d^2$, where:

N_h : die plate holes number, d: die plate hole diameter, cm.

Table 3. Auger volumetric capacity per revolution, cm^3.

	d_f (cm)	d_s (cm)	þ (cm)	t (cm)	V (cm^3)
High ratio	3.92	1.92	5.2	0.5	43.115
Small ratio	11	8.5	3.1	0.55	97.635

Table 4. Auger-pelletizers die plates' dimensions.

Pelletizer	Die	N_h	d(cm)	A(cm^2)	$A/V^{2/3}$
High ratio-auger set	1	18	0.5	3.53	0.287
	2	9	0.8	4.52	0.368
	3	7	1	5.5	0.447
Small ratio-auger set	1	99	0.5	19.44	0.917
	2	42	0.8	21.11	0.996
	3	28	1	21.99	1.037

Average of $A/V^{2/3}$ pi term values per pelletizer was adopted as a parameter.

Fig.14 shows that productivity increases at a diminishing rate with auger speed, but fairly less than linear with auger capacity. It could be fitted by a power function according to system dimensions (pi) term values as:

$[m^{\cdot}/A/(\rho.p)^{1/2}] = a_i \cdot [n.V^{1/3}.(\rho/p)^{1/2}]^b$; for $A/V^{2/3} = c_i$ ....(10)

Coefficients of regression for eq. (10) are as follows:

$A/V^{2/3}$	a_i	b_i
0.3673	7.59608E-5	0.911
0.9832	3.11477E-5	0.90432

Assuming coefficients of regression a and b, vary linearly with $A/V^{2/3}$, then eq. (10) could be generalized as:

$[m^{\cdot}/A/(\rho.p)^{1/2}]$ = $[10.287 - 7.276(A/V^{2/3})]E\text{-}5[n.V^{1/3}.(\rho/p)^{1/2}]^{0.908}$ ....(11)

Figure 15 shows that torque increases slightly with auger speed. Fitting then generalizing results:

$[T/(p.A^{3/2})] = a_i + b_i \cdot [n.V^{1/3}.(\rho/p)^{1/2}]$; for $V^{2/3}/A = c_i$ ....(12)

$A/V^{2/3}$	a_i	b_i
0.3673	0.041758	7.35749E-6
0.9832	9.8636E-3	1.38524E-6

$[T/(p.A^{3/2})] = [60.779 - 51.785(A/V^{2/3})]E\text{-}3 + [10.919 - 9.697(A/V^{2/3})]E\text{-}6\ [n.V^{1/3}.(\rho/p)^{1/2}]$ ....(13)

Figure 16 shows that power increases at increasing rate with auger speed, but fairly higher than linear with auger capacity. Fitting then generalizing results:

$[P.\ \rho^{1/2}/A.p^{3/2}] = a_i\ .\ [n.V^{1/3}.(\rho/p)^{1/2}]^b$; for $V^{2/3}/A= c_i$ ....(14)

$A/V^{2/3}$	a_i	b_i
0.3673	1.61694E-3	1.09579
0.9832	0.65267E-3	1.08652

$[P.\ \rho^{1/2}/A.p^{3/2}] = [219.199 - 156.563(A/V^{2/3})]E\text{-}5\ [n.V^{1/3}.(\rho/p)^{1/2}]^{1.091}$ ......(15)

Effect of heating:

$m^{\cdot}= f(\rho, A, V, n, C_p, t, g)$.........(16)

$P= f(\rho, A, V, n, C_p, t, g)$.........(17)

Dimensional analysis approach fabricates:

$m^{\cdot}/(\rho.V^{5/6}.g^{1/2})= f[n/(A^{1/4}.g^{1/2}), A/V^{2/3}, C_p.t/(V^{1/3}.g)]$...(18)

$P/(\rho.V^{7/6}.g^{3/2})= f[n/(A^{1/4}.g^{1/2}), A/V^{2/3}, C_p.t/(V^{1/3}.g)]$ ...(19)

Figure (17) shows a slight increase in productivity at higher mixture feeding temperatures. Fitting then generalizing results:

$m^{\cdot}/(\rho.V^{5/6}.g^{1/2})=a_i.[n/(A^{1/4}.g^{1/2})]-b_i.[n/(A^{1/4}.g^{1/2})]^2$; ...(20)

$A/V^{2/3}$	t(°C)	$C_p.t/(V^{1/3}.g)$	a_i	b_i
0.287	25	1.1268	1.35	0.01464
0.368	50	2.2536	1.3786	0.01522
0.447	70	3.155	1.4174	0.01537

$m^{\cdot}/(\rho.V^{5/6}.g^{1/2})=[1.3103+0.0329C_p.t/(V^{1/3}.g)].[n/(A^{1/4}.g^{1/2})]-0.01508[n/(A^{1/4}.g^{1/2})]^2$ ...(21)

Figure (18) shows a considerable decrease in mechanical power requirement with heating.

$P/(\rho.V^{7/6}.g^{3/2})= a_i.\ [n/(A^{1/4}.g^{1/2})]^b$ ...(22)

$A/V^{2/3}$	t(°C)	$C_p.t/(V^{1/3}.g)$	a_i	b_i
0.287	25	1.1268	5.5805	1.0889
0.368	50	2.2536	4.6488	1.0903
0.447	70	3.155	3.732	1.08633

$P/(\rho.V^{7/6}.g^{3/2})= [6.6317-0.9079\ C_p.t/(V^{1/3}.g)].[n/(A^{1/4}.g^{1/2})]^{1.0883}$ ...(23)

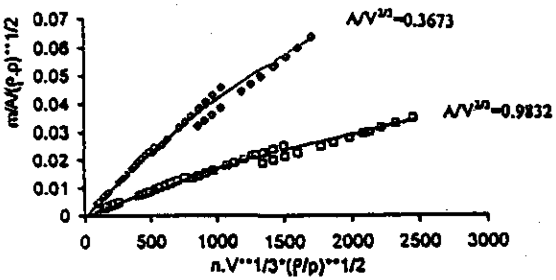

Fig. 14. Productivity as a function of auger speed for different pelletizer dimensions.

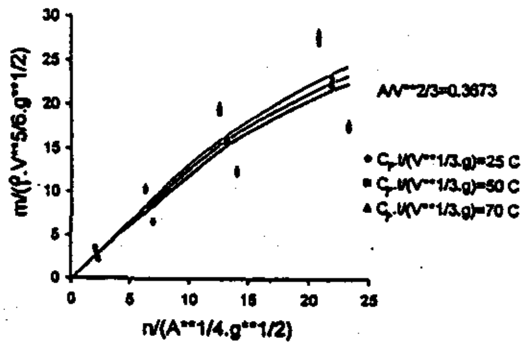

Fig. 17. Productivity as a function of auger speed for different feeding temperatures.

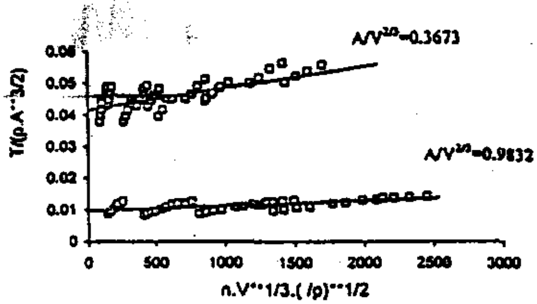

Fig. 15. Torque as a function of auger speed for different pelletizer dimensions.

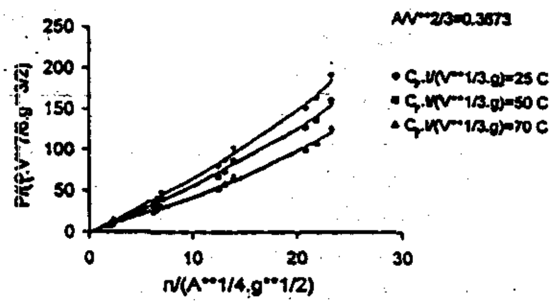

Fig. 18. Power as a function of auger speed for different feeding temperatures.

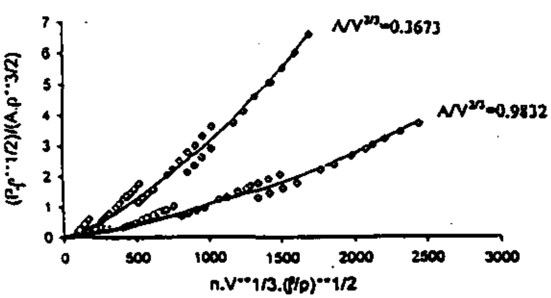

Fig. 16. Power as a function of auger speed for different pelletizer dimensions.

V- CONCLUSION

1-Auger-pelleting machine is suitable for agricultural residues size reduction in little farms.

2-Pellets produced from this unit is appropriate for handling conditions (feeding, storing and transporting).

Establishing a general theory on pelleting auger-machine design and operation showing predicted equations of productivity increases with auger speed at a diminishing rate (powered to 0.908) but almost linear with auger displacement (powered to 0.9693). Power required for pelleting increases with speed of rotation at a higher increasing rate (powered to 1.091) rather than with pelletier size (powered to 1.0303).

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دراسة عن عوامل التصميم المتعلقة بآلات تشكيل مخلفات نباتية

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الملخص العربي

يهدف هذا البحث إلى دراسة عوامل التصميم المتعلقة بأداء آلات التشكيل. لهذا الغرض ، تم تصنيع بريمتين ذات نسبة عالية لخطوة الحلزون إلى قطره الخارجي (٣,٩٢/٥,٢)، و ذات نسبة صغيرة (١١/٣,١). نفذت ثلاثة قوالب تشكيل لكل بريمة متعددة الثقوب بأقطار ٥، ٨، ١٠ مم. تم تجربة مخلفات غربلة القمح كمنتجات ثانوية للمطاحن بمحتوى رطوبة ٢٥، ٣٠، ٣٥، ٤٠% على أساس رطب عند ١٠، ٣٠، ٦٠، ١٠٠ لفة/دقيقة للبريمة. أضيف المولاس الرابط بنسب ٥، ١٠، ١٥ % . تم تنفيذ أجهزة قياس عزم التشغيل وضغط التشكيل . تم قياس دليل التحمل للمصبعات حسب (ASAE standards, 1996).استخدم ازدواج حراري لقياس درجة الحرارة. تم تسخين الخليط إلى ٥٠-٧٠ °م ثم لقم في الآلية.

بينت نتائج تجارب البريمة ذات النسبة العالية ولقالب (٥ مم) ولمجال الرطوبة المدروس: زيادة الإنتاجية١٤.٤% اعتبارا من ٢,٢١٤ كج/س، نقصان العزم ١٠% بدءا من ١٤،٨٣٣ ن.م، نقصان ضغط التشكيل ٢٢ % بدءا من ٥٨,٩٣ ض.ج. نقصت القدرة النوعيــة ٥٠ % لقوالب التشكيل (٥-١٠) مم لانخفاض مقاومة التشكيل للقالب. ولمجال السرعة (١٠-١٠٠) لفة/د، زادت القدرة النوعية ٥٨،٧ % لانخفاض الإنتاجية لكل دورة وازدياد مقاومة المادة للتشكيل عند سرعات كبس أعلى.

بلغ مردود القدرة أو الضخ ١٨,١ % وارتفاع درجة حرارة المادة بالتشكيل ١٤,٤ °م ودليل التحمل ٩٨,٢% للمصبعات المعاملة ١٥ % مولاس وبلغت كثافة وحدة المصبعات ١١٨٨,٥ كج/م³ .بينت نتائج إضافة الحرارة تحسنا في تحمل المصبعات وانخفاضا في احتياجات العزم نظرا لانخفاض التماسك الداخلي والخارجي للخليط بالتسخين، ولكن القدرة النوعية المشتملة لطاقة التسخين زادت بصورة كبيرة.

بينت نتائج البريمة ذات النسبة الصغيرة زيادة الإنتاجية ١٦٥% برغم زيادة مساحة القالب ٤٥٠%. كانت قيم القدرة النوعية وضغط التشكيل والكثافة أقل نسبيا من البريمة ذات النسبة العالية وهذا يعزى إلى انخفاض مقاومة القالب نظرا لانخفاض المساحة المصمتة والمساحة الاحتكاكية (سمك القالب) وانخفاض نسبة خطوة الحلزون إلى قطره .

تم إنشاء نظرية عامة لعملية التشكيل تبين تنبؤ المعادلات بزيادة الإنتاجية بمعدل متناقص مع سرعة الدوران وخطي تقريبا مع إزاحة البريمة. تزداد قدرة التشكيل مع سرعة الدوران بمعدل متزايد وأعلى من تزايدها مع سعة البريمة.

١-أستاذ الهندسة الزراعية المتفرغ بزراعة عين شمس.
٢ -دكتور الهندسة الزراعية بزراعة عين شمس.
٣-باحث مساعد في هندسة الآلات الزراعية بجامعة حلب.