MANUFACTURING AND IDENTIFING THE OPTIMUM OPERATING PARAMETERS OF A LOCAL PELLET MILL MACHINE TO PRDUCE AQUATIC FEED

Kaddour.U. and Elmetwalli A. H.

ABSTRACT

This research aimed to evaluate and identify the optimum processing parameters of a locally manufactured flat die pellet mill machine to produce high quality aquatic feed pellets at a minimum cost. The machine includes mixing and pelleting the formula in one step. The study examined the influence of feeding rate, roller speed, and rollers teeth width on pellets quality indicators (pelleting efficiency, pellets durability). The operating parameters under this study were roller speed (155, 185, 215 and 230 rpm), machine feeding rate (200,300,400 and 500 kg/h) and roller teeth width (6 and 10 mm). The results demonstrated that the optimum pelleting efficiency and pellets durability of 94.8 % and 87.5% were obtained at 215 rpm roller speed and 400 kg/h feeding rate with 10mm teeth width. The best pellets water stability of 90% obtained after 15 min at 215 rpm roller speed, 400 kg/h feeding rate and rollers teeth width of 10 mm. These optimum values were chosen according to the production rate low energy consumption and cost of unit mass. It can be concluded from the obtained results that roller speed, roller teeth width and feeding rate are among the most interacting process variables affecting pellets durability, consumed energy, pelleting efficiency and pellets water stability.

INTRODUCTION

Aquaculture is considered an important source of production for facing the increasing demand for protein. In general, Protein shortage in Egypt results from high prices of protein production lines especially those imported from abroad. In this context, manufacturing local pelleting machines will serve to solve the problem and reduce the production cost in comparison to imported machines. In aquaculture, pelleting quality is of importance since any fines that are generated will be wasted when thrown into water.

***Assoc. Prof. Agric. Eng., Dept. Eng. Sci., Fac. of Fish Res., Swiss Univ., Egypt**
****Assis. Prof., Agric. Eng. Dept., Fac. of Agric., Tanta Univ., Egypt**

Apart from that, it will also pollute water, which has a detrimental effect on oxygen supply and filter capacity. Therefore, producing high quality feed pellets is basically important to enhance the production of aquaculture. Choosing optimum processing variables is important to have higher pellets quality and thus maximizing animal production. Previous studies investigated the effect of different processing conditions on pellets properties. For example, **Thomas et al. (1997)** suggested low die speed range (10 m/s) to produce small and large pellets and high die speed range (around 6-7 m/s) to produce cubes.

Kaddour et al. (2005) illustrated that extruder productivity decreased by 3.12 and 17.81% when using single screws with one twin screw and single screws with two twins screws respectively, in comparison to single screws at a clearance of 1.5 mm and number of one steam lock and width of flat sector in steam lock of 0.4 cm. Their results also showed that increasing the clearance between steam lock and case to 3 mm decreased productivity by 3.78 and 10.53 % under the same previous conditions.

Sokhansani (2005) identified the proper moisture content to pellet cellulosic materials at 8-12% (w.b) while the optimum moisture content for starch and protein materials mostly for animal feeds can reach up to 20%.

Abdel Wahab et al. (2011) evaluated the performance of a flat die pelleting machine under some operating parameters including hole diameter (4 and 5 mm), formula particle size (1, 2 and 3 mm), die total thickness (25, 27.5, 30 and 32.5 mm), roller clearance (0.5, 2 and 4 mm) and roller teeth width (4, 6 and 8). They concluded that 8 mm roller teeth width is the optimum for flat die pelleting machines.

Kaliyan and Morey (2009) concluded that feed moisture content, biomass constituents, feed particle size, feed conditioning temperature, added binders and densification equipment variables as process parameters all affect feed durability.

Lundblad et al. (2009) pointed out that steam conditioning is commonly used in pelleting operations to add moisture and heat to the mash. A certain temperature is needed during the pelleting process to minimize bacteria and microorganism and thereby ensure hygienic quality. Moreover, moisture is important for gelatinisation of starch and denaturation of proteins, important for adhering particles into pellets. Use of steam during the pelleting process therefore improves pellets durability index (PDI) as well as pelleting efficiency compared to dry pelleting.

Serrano et al. (2011) identified the optimum moisture content (19-23%, w.b.) to achieve the highest durability of 95.5%. They also added that decreasing moisture content below 19% did not result in pellet formation.

Tumuluru (2014) investigated the effects of die rotational speed and preheating temperatures (30-110 C^o) on the density and durability of pellets made from high moisture corn stover. He concluded that preheating and die rotational speed are the interacting process variables influencing pellet moisture content, bulk and tapped density and durability. The overall aim of this research was to manufacture, evaluate and choose the optimum operating parameters of a flat die pellet mill machine to produce high quality aquatic feed pellets.

MATERIALS AND METHODS

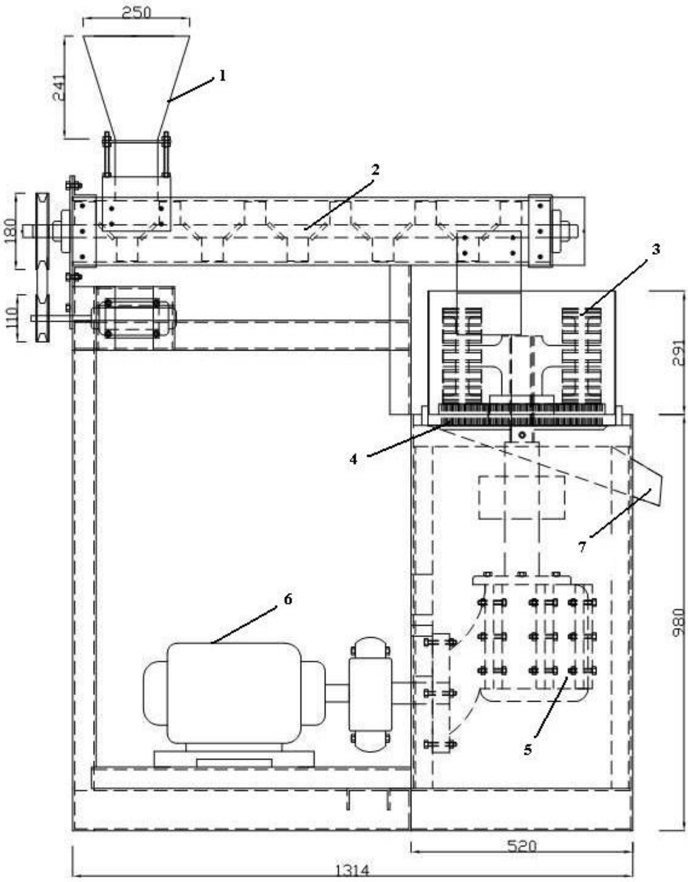
The experiments were carried out during 2014 on a flat die pellet mill machine manufactured in Zagazig city and evaluated at the Agricultural Engineering Research Institute, Cairo, Egypt.

Specifications of the pellet mill Machine:

The pellet mill machine base was made from L shape steel sections, having dimensions of 980 mm length, 520 mm width and 980 mm height. Fig. (1) shows the layout of the pellet mill machine showing main parts including feeding unit, mixing unit, compressing and forming unit.

Forming unit (Die):-

The flat die is considered the most important part in disk pellet mill machines. It is responsible to form the mach to pellets with the required diameter. The die material was made from very hard steel (C52). As illustrated in Fig. 2 it has dimensions of 440 mm outer diameter, 50 mm inner diameter and thickness of 45 mm.



Dim. in mm

1- feeding unit, 2- mixing unit, 3- compressing rollers, 4- forming die, 5- gear box, 6- main motor, and 7- output product gate

Fig (1): Layout of the local flat die pellet mill machine showing different parts

The compressing unit (Rollers):-

The compressing unit was responsible to compress and form the mach to pellets through the die holes. It consisted of two rollers, fabricated from hard steel and installed by conical bearings on two horizontal bars which was fixed on a central iron block. Each roller is cylindrical in shape with the rollers cam base having dimensions of 225 mm outer diameter, 50 mm inner diameter and 90 mm width. The compressing unit was constructed on the top main moving shaft passing through the center of fixed die machine.

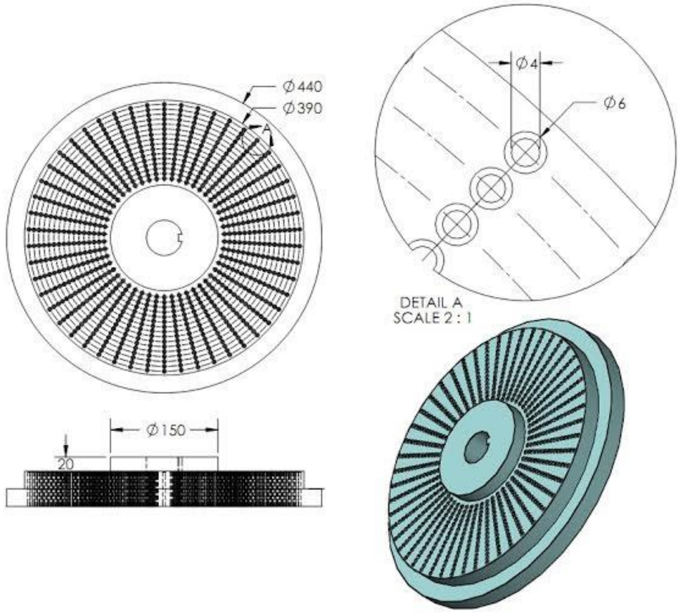


Fig (2): Forming unit (Die)

The rotating motion of the rollers was stable around the horizontal bar which was yielded from the main shaft rotating motion. There was a 0.5 mm clearance between the die and the rollers which was extended according to the motion of the rollers around the horizontal bar for agreement with capacity of row materials to force pressing through the die holes as shown in Fig. 3.

Composition of the experimental ration:

An aquatic feed pellets experimental ration was used in the present study, which has the following composition as listed in Table 1. The formula was prepared using a hammer mill having a concave of 2mm holes diameter and fed to pellet mill through mixing unit to mix it with adding water as a pending material. Water was added at 7% by injection in the pre-conditioner unit at the beginning and controlled by a valve.

Table 1: The composition of stander aquatic feed pellets ration.

Ingredients	**Wheat flour**	**Wheat bran**	**Soy bean**	**Fish meal**	**Shrimp meal**	**premix**	**Fish oil**	**Total**
Percentage,%	20.5	24	15.5	24	9	2	5	100

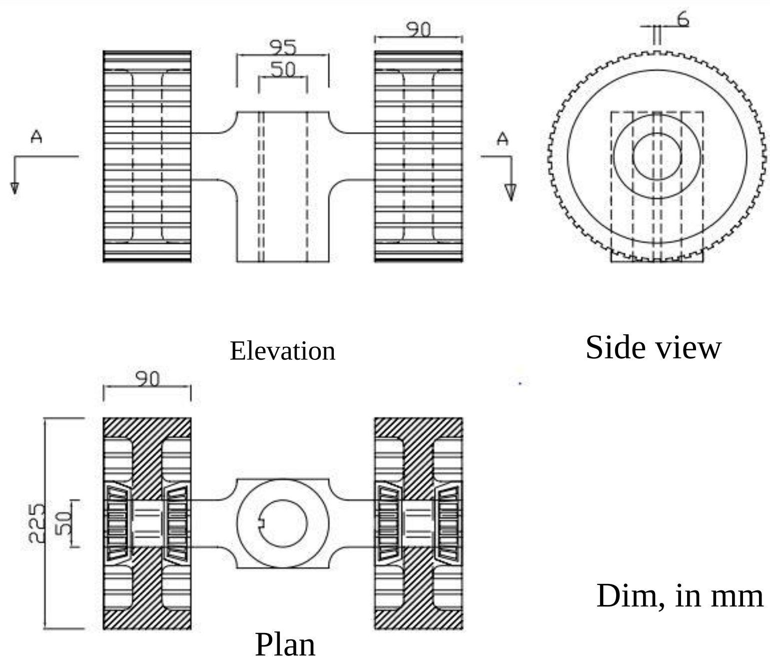


Fig (3) Elevation, plan and side view of the compressing unit (Rollers)

Methods:

Processing Parameters:

Aquatic feed pellets formula was pelleted by a local flat die pellet mill system using dies with 4 mm diameter circular openings to investigate operating factors affecting the pellet mill machine efficiency and product quality. The factors investigated to evaluate the performance of the pellet mill machine were;

Four different levels of roller speed of 155, 185, 215 and 230 rpm. The main shaft rotating speed was measured using a digital tachometer (Cole-Parmer 8204-00, kit– Japan).

Machine feeding rate of 200, 300, 400 and 500 kg/h and

Roller teeth width of 6 and 10 mm.

Evaluation of flat die pellet mill efficiency and product quality

To evaluate the performance of the flat die pellet mill machine the following indicators were measured and calculated to assess the efficiency of the tested machine:

Pellet mill production rate

Pellet mill production rate was measured for each treatment by taking samples for 2 min. The machine was operated for 10 min before taking any samples to have steady experimental condition.

Pelleting efficiency: It was calculated from the following equation:

$$Pelletingefficiency = \frac{Wp}{Wm} x100$$

Where :

Wp = pellets yield weight (g)

Wm = ration sample weight (g).

Product durability was determined according to ASAE standards method S269.4 DEC01(2000), at 3 replicates (mass of each one was 500 g) using durability turning box for 10 min. The durability turning box consists of four cells rotated at a constant speed of 60 rpm.

$$Durability(\%) = \frac{Wa}{Wb} x100$$

Where:

Wa : pellets mass after treatment (g),

Wb: pellets mass before treatment (g)

Water stability time was measured after 15, 30, 45, 60, 75, 90, 105 and 120 min using a stopwatch (Casio-fx 81, Japan).

Consumed power

The energy requirement in (kW.h/ton) was calculated by the following equation:

$$Energy\, consumed = \frac{P}{Q} = kW.h / ton$$

Where:

P = The consumed power for mixing ration, kW

Q = Machinery line productivity, ton/h.

Consumed power was calculated using the following equation:

$$P = \frac{\sqrt{3} \quad I \;\; V \;\; \eta \quad \cos\theta}{1000}$$

Where:

P = total consumed power, kW

I = Line current strength in amperes.

V = Potential difference (Voltage) being equal to 380 V.

Cos θ = Power factor (being equal to 0.84).

η = Mechanical efficiency assumed (assumed 90 %).

$\sqrt{3}$ = Coefficient current three phase (being equal 1.73),

Cost per mass unit

Cost per mass unit = $\frac{Total\ \mathrm{cost}}{production}(LE/Mg)$

The total cost took into consideration both fixed cost and total operational cost including machine price, labor cost, operating hours, life expectancy, price of raw material and cost of energy consumed. The machine price was about L.E. 20000 and workers wage was taken L.E. 50 per worker a day and was operated by two workers.

RESULTS AND DISCUSSION

1- Pellet mill Production rate

Moisture content and particle size, rotating speed and feeding rate are the most important measurements affecting flat die mill machine productivity. Fig. 4 depicts the effects of roller speed on the pellet mill machine productivity at different feeding rates. The obtained results demonstrated that increasing roller speed from 155 to 215 rpm with 10 mm teeth width increased pellet mill production rate from 178.4 to 191.9 kg/h; from 273.6 to 287.1 kg/h; from 370.3 to 383.9 kg/h at 200, 300 and 400 feeding rate respectively. Any further increase in roller speed decreased the production rate at all roller speeds. Furthermore, increasing roller speed over 215 rpm decreased the production rate at all tested feeding rates. Similar results were obtained using 6 mm teeth width (Fig. 5) since increasing roller speed from 155 to 215 rpm increased the production rate at various feeding rates. The increase in pellet mill production rate by increasing the roller speed up to 215 rpm could be due to the increase of die compressing and the decrease in formula retention time in die holes. Meanwhile increasing roller speed to 230rpm reduced the production rate that could be due to motor overload that increases the treatment consumed time and reduces the mass of product in time unit. The increase in production rate by increasing machine feeding rate from 200 to 400 kg/h may have been a result of increasing the mass of formula between rollers gap which increases the compressing of rollers in time unit. Broadly, any further increase in feeding rate up to 500 kg/h decreased the productivity that could be attributed to the overload of mass in front of the rollers that makes the rollers slip. The results therefore demonstrated that choosing the optimum operating parameters particularly roller speed and feeding rate can inhance the performance of pelleting machines.

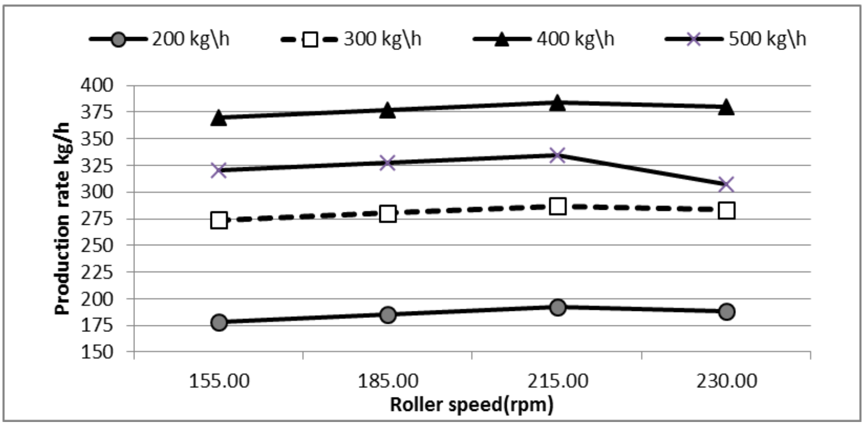


Fig.(4): Effect of roller speed and feeding rate on flat die pellet mill machine productivity using rollers teeth width of 10 mm.

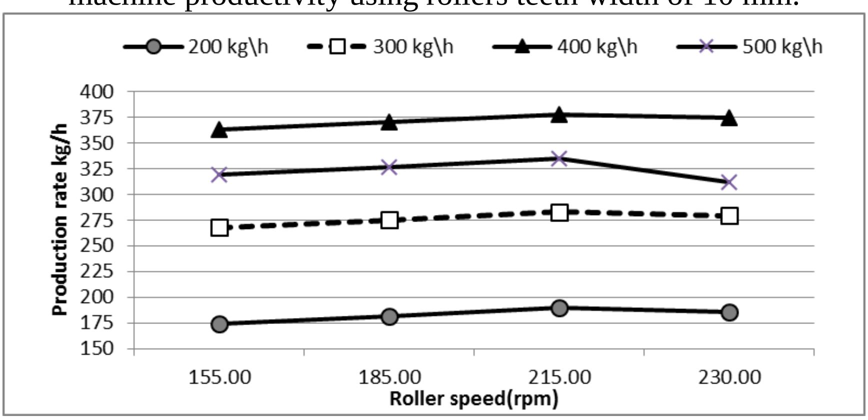


Fig.(5): Effect of roller speed and feeding rate on flat die pellet mill productivity using rollers teeth width of 6 mm.

2- Pelleting efficiency, %

The effects of rollers speed and feeding rate on pelleting efficiency is illustrated in Figures 6 and 7. The results showed that higher rollers speed produced higher pelleting efficiency at all feeding rates since the highest pelleting efficiency of 98.6 and 97.04% was recorded at 230 rpm rollers speed and 500 kg/h feeding rate when using 10 and 6 mm teeth width respectively. The results showed that increasing roller speed from 155 to 230 increased the pelleting efficiency from 79.96 to 92.95 %, from 81.41 to 94.4%; from 83.72 to 96.71% and from 85.62 to 98.61% using feeding rate of 200, 300, 400 and 500 kg/h respectively.

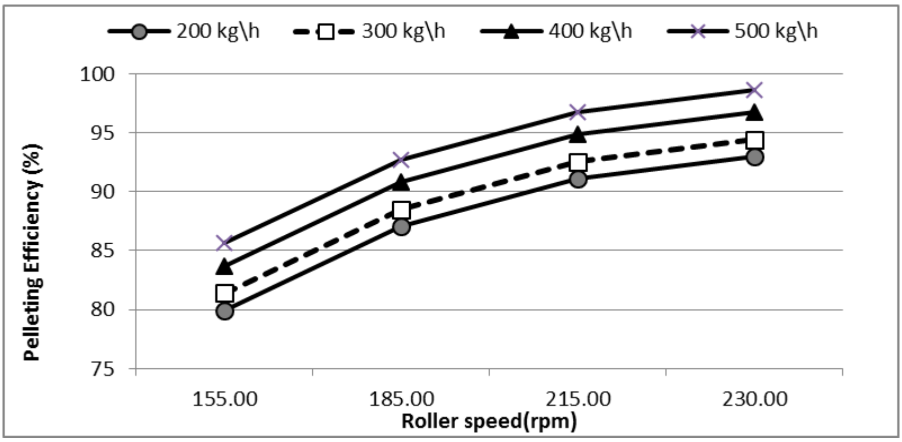


Fig.(6): Effect of roller speed and feeding rate on pelleting efficiency using rollers teeth width of 10 mm.

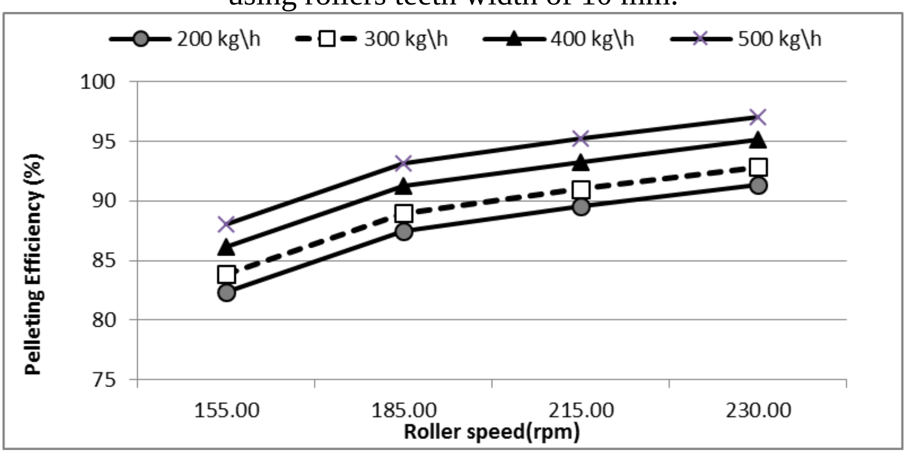


Fig.(7): Effect of roller speed and feeding rate on pelleting efficiency using rollers teeth width of 6 mm.

Smaller teeth width of 6 mm produced the same trend as pelleting efficiency increased by increasing roller speed and feeding rate. The increase of product pelleting efficiency by increasing rollers speed and machine feeding rate could be due to the increase of compressing ratio and the more compact of formula through die holes that reduce the mash formula percentage in the final product and thus increasing pelleting efficiency.

3-Pellets durability:

Rollers speed is mainly one of the most important parameters affecting pellets durability in pelleting processes. Figures 8 and 9 depict the effects of roller speed on pellets durability at different feeding rates. The obtained results demonstrated that increasing roller speed from 155 to 230 rpm with 10 mm teeth width increased pellets durability from 77.7 to 87.4%; from 79.7 to 89.4%; from 80.9 to 90.6% and from 83.4 to 93.16 at 200, 300, 400 and 500 kg/h feeding rate respectively. It is therefore obvious that at all tested feeding rates, pellets durability increased with increasing roller speed. Similar results were obtained when using 6 mm roller teeth width since pellets durability increased by 12.6, 12.3, 12.2 and 11.8 when roller speed increased from 155 to 230 rpm at 200, 300, 400 and 500 kg/h feeding rate respectively. The increase in pellets durability by increasing roller speed and feeding rate could be attributed to the higher compact of the formula inside die holes that leads to decrease the porosity between formula granules and thus produce un-cracked pellets and increased pellets resistance.

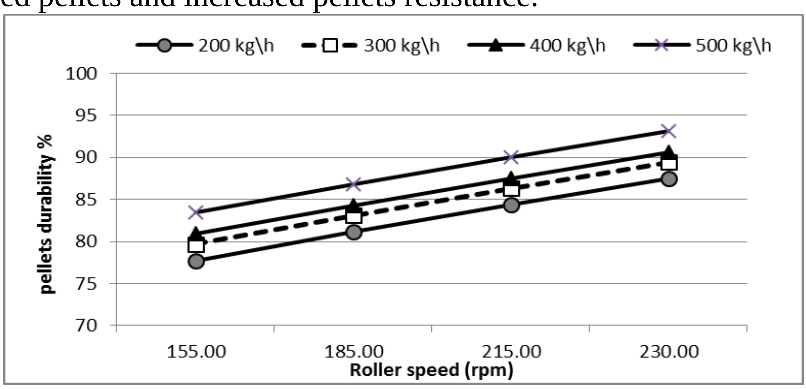


Fig.(8): Effect of roller speed and feeding rate on pellets durability using rollers teeth width of 10mm.

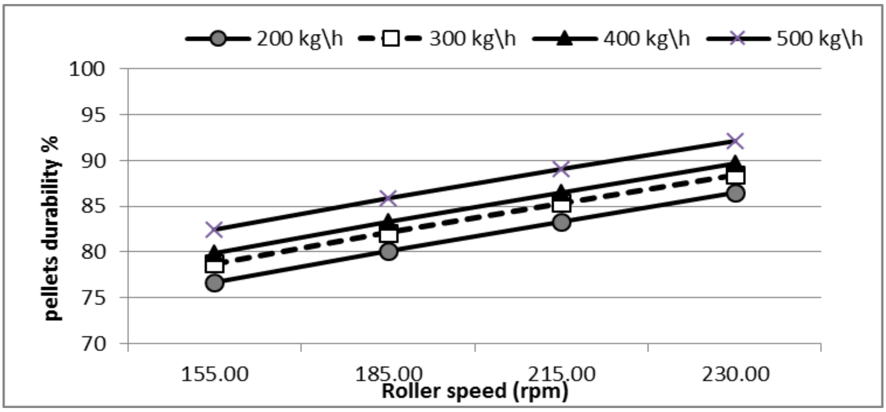


Fig.(9): Effect of roller speed and feeding rate on pellets durability using rollers teeth width of 6mm.

4- Water stability:

Water stability is fundamentally considered one of the most important indicators for aquatic feed pellets quality. Fig. 10 reports that at all roller speed rates water stability of pellets decreased to reach a minimum at 120 min. The results also showed that increasing feeding rate from 200 to 500 increased water stability at all roller speed values reaching a maximum at the combination of 500kg/h feeding rate and 215 roller speed. From these results, it can be noticed that water stability is a function of feeding rate since feeding rate increased pellets water stability.

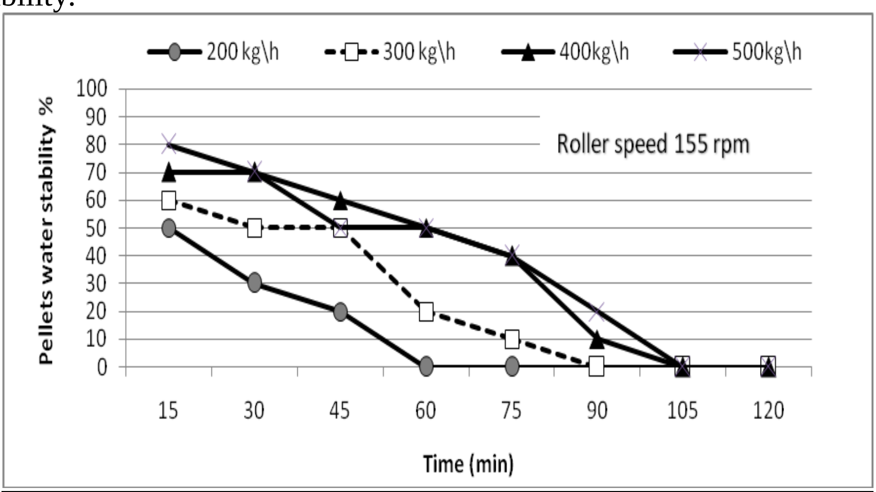


Fig.(10): Effect of feeding rate and time on pellets water stability using rollers teeth width of 10 mm at 155 rpm roller speed .

Same trend was also noticed at all tested roller speed as illustrated in figures 11, 12 and 13. The results demonstrated that the increase in pellets water stability percentage after dropping pellets into water for 120 minutes by increasing the roller speed and feeding rate could be due to small air volume between pellets granules that results from the compressing ratio of formula in die holes, which make the flow of water through and between granules so slow. The slow movement of water into pellets granules leads to higher water stability of pellets.

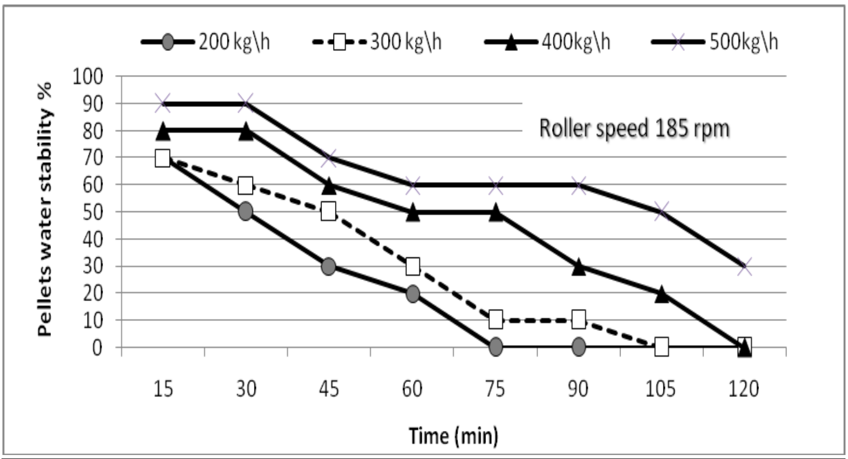


Fig.(11): Effect of feeding rate and time on pellets water stability using rollers teeth width of 10 mm at 185 rpm roller speed.

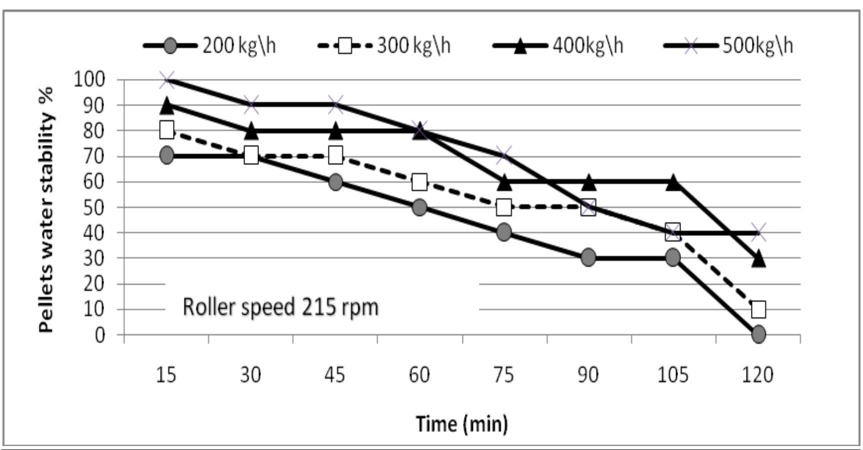


Fig.(12): Effect of feeding rate and time on pellets water stability using rollers teeth width of 10 mm at 215 rpm roller speed.

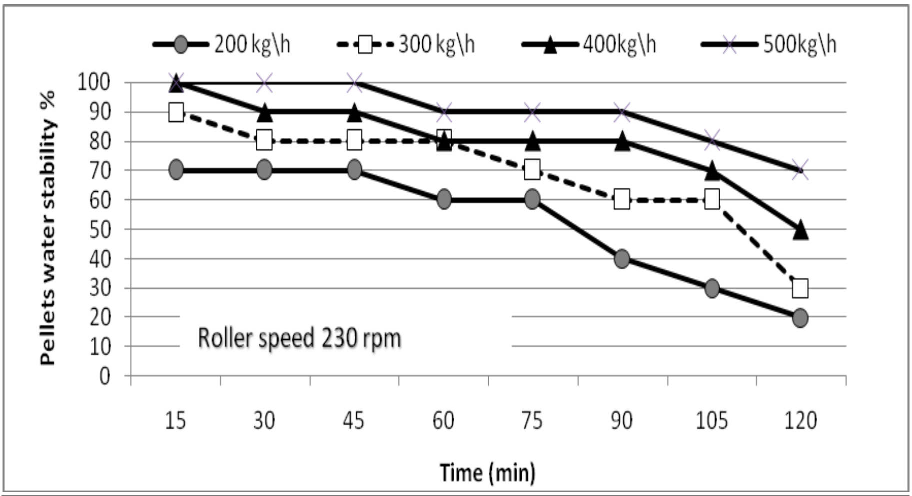


Fig.(13): Effect of feeding rate and time on pellets water stability using rollers teeth width of 10 mm at 230 roller speed.

5- Consumed energy

Energy requirements are very important indicator in economical analysis for any industrial process. The effects of roller speed and feeding rate on energy requirements were investigated and illustrated in Figures 14 and 15 using roller teeth width of 10 and 6 mm. The figures depict the relationship between energy and roller speed at various feeding rates. It is indicated that increasing roller speed from 155 to 230 rpm increased the pellet mill energy consumption at all feeding rates. The consumed energy increased by 46.7, 41.8, 39.9 and 37% at 200, 300, 400 and 500 kg/h feeding rate respectively. Same results were recorded with 6mm teeth width since the energy consumed increased by 48.6, 43.3, 41.4 and 35.8 % at 200, 300, 400 and 500 kg/h feeding rate respectively. The increase in consumed energy by increasing rollers speed from 155 to 230 rpm could be due to high increase in machine power consumed with the same production rate. However, increasing the machine feeding rate from 200 to 400 kg/h decreased the consumed energy that could be due to high increase in machine production rate more than the increase in power consumed in the same treatments, while increasing the feeding rate up to 500 kg/h sharply increased the consumed energy that could be due to higher increase in power consumed by the motor overload with sharp decease in machine production rate.

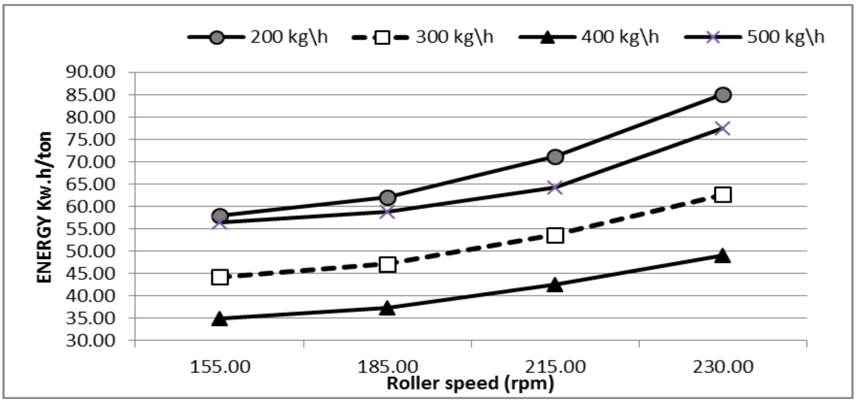


Fig.(14): Effect of roller speed and feeding rate on Energy requirements using rollers teeth width of 10 mm.

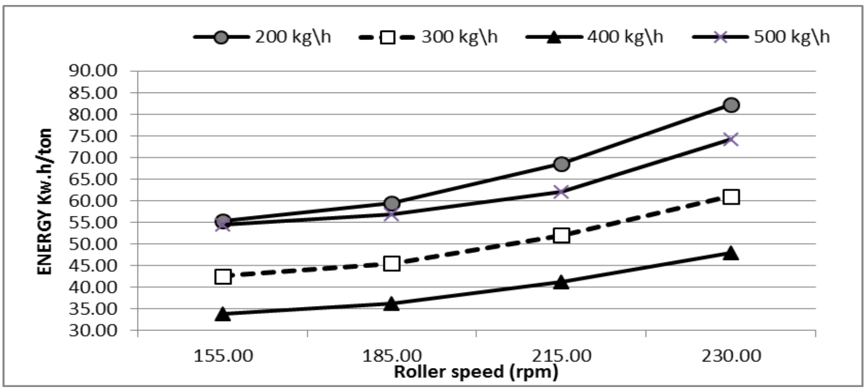


Fig.(15): Effect of roller speed and feeding rate on energy requirements using rollers teeth width of 6 mm.

Cost of mass unit

Table (2) details the effect of different processing parameters including roller speed, roller teeth width and feeding rate on the total cost of mass unit. The obtained results showed that cost of mass unit decreased by increasing roller speed up to 215 rpm at all feeding rate levels. Increasing roller speed to 230 increased the cost which means that 215 rpm is the optimum roller speed from economical point of view in both cases of 6 and 10 mm roller teeth width. The minimum cost of mass unit of 1529.2 and 1520.9 LE/ton recorded at 215 rpm and 400 kg/h feeding rate with 6mm and 10 mm roller teeth width respectively. Therefore the optimum operational conditions are 215 rpm roller speed, 400 kg/h feeding rate and 10 mm roller teeth width.

Table 2: Effect of various operating parameters (roller speed, roller teeth width and feeding rate on cost of unit mass (LE/ton)

Teeth width, mm	**Feeding rate, kg/h**	**Roller speed (rpm)**			
		155	**185**	**215**	**230**
6	**200**	2148.4	2102.6	2055.2	2076.4
	300	1746.9	1727.3	1706.4	1779.4
	400	1551.6	1540.8	**1529.2**	1534.4
	500	1626.1	1612.2	1597.3	1642.3
10	**200**	2121.3	2080.9	2041.9	2063.8
	300	1731.1	1713.7	1696.5	1706.2
	400	1540.1	1530.5	**1520.9**	1526.4
	500	1623.1	1610.4	1597.8	1649.7

CONCLUSIONS

The reported study aimed to concern the operational factors and evaluate the performance of a locally manufactured pellet mill machine for producing high quality aquatic feed pellets. The pellet mill machine was evaluated at different roller speed, feeding rate and roller teeth width to choose the optimum operating conditions that produce high quality aquatic pellets. The important results obtained can be summarized in the following recommended points:

- 215 rpm roller speed was shown to be the optimum for achieving high machine efficiency and pellets quality.
- 400 kg/h feeding rate is recommended for high machine efficiency and pellets quality.
- 10 mm rollers teeth width for flat die pellet mill machines is recommended since it produced higher machine efficiency and pellets durability, production rate and pellets water stability.
- 1520.9 LE/ton cost per mass unit is the minimum recorded cost which was observed with 400 kg/h feeding rate, 215 rpm and 10 mm roller teeth width and consequently these values are the optimum since they reduced the energy consumption and therefore the total cost of pelleting process.

It can be concluded that choosing the optimum processing parameters can increase the final return.

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الملخص العربى

تصنيع و تحديد عوامل التشغيل المثلى لمكبس أعلاف محلى لإنتاج أعلاف الاسماك

أسامة قدور* عادل المتولى**

تهدف الدراسة ألي تقييم واختيار عوامل التشغيل المثلى لمكبس أعلاف مسطح لإنتاج أعلاف اسماك غاطسة. حيث تم تصنيع المكبس بورشة بمدينة الزقازيق محافظة الشرقية وتم تقييم الآلة وعمل التجارب بمعهد بحوث الهندسة الزراعية بالدقي. وقد تم استخدام تركيبة أعلاف أسماك قياسية تستخدم لإنتاج أعلاف اسماك البلطي الغاطسة بقطر4مم وكانت عوامل الدراسة هى:

سرعة بكرات الكبس ١٥٥ – ١٨٥ – ٢١٥- و٢٣٠ لفة/ د

معدل التغذية ٢٠٠-٣٠٠-٤٠٠ و ٥٠٠ كجم/ساعة

عرض أسنان بكرات الكبس ٦ و١٠ مم

وقد تم دراسة تأثير العوامل السابقة على كل من متانة العلف ، معدل الإنتاجية، الطاقة المستهلكة، كفاءة عملية التكعيب ، فترة ثبات العلف فى الماء.

وكانت أمثل النتائج المتحصل عليها كالأتي:

٣٨٣.٩ كجم/ ساعة لإنتاجية المكبس - ٤٢.٥ كيلو وات –ساعة/ طن للطاقة المستهلكة لإنتاج وحدة الكتلة من العلف المنتج و ٩٤,٨ % لكفاءة الكبس –٨٧,٥ % لمقاومة العلف للانهيار وثبات العلف في الماء٩٠% بعد زمن غمر ١٥ دقيقة و٣٠% بعد زمن غمر ١٠٥ دقيقة وذلك عند سرعة بكرات ٢١٥ لفة/د ومعدل تغذية للمكبس ٤٠٠ كجم/س وعرض أسنان بكرات ١٠ مم بينما كانت هذه القيم ٣٧٧,٩ كجم/ ساعة لإنتاجية المكبس ٤١,٤ كيلو وات –ساعة/ طن للطاقة المستهلكة لإنتاج وحدة الكتلة من العلف المنتج و ٩٣,٣ % لكفاءة الكبس –٨٦,٦ % لمقاومة العلف للانهيار وثبات العلف في الماء٩٠% بعد زمن غمر ١٥ دقيقة و٣٠% بعد زمن غمر ١٠٥ دقيقة وذلك عند سرعة بكرات ٢١٥ لفة/د ومعدل تغذية للمكبس ٤٠٠ كجم/س وعرض أسنان بكرات ٦ مم.

وتوصى الدراسة باستخدام ٢١٥ لفة/د لسرعة بكرات الكبس و معدل تغذية ٤٠٠ كجم/س ، وعرض أسنان بكرات ١٠ مم للحصول على أعلى معدل إنتاجية ممكن ومواصفات جودة للعلف المنتج.

* أستاذ مساعد الهندسة الزراعية – قسم العلوم الهندسية – كلية الزراعة والثروة السمكية – جامعة السويس

** مدرس الهندسة الزراعية – قسم الهندسة الزراعية – كلية الزراعة –جامعة طنطا.