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Definition of a methodology for compactors and baler presses selection

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Abstract

The following report intents to show an elaborated methodology for compactors and baler presses selection based on volume displacement calculations, as opposition to traditional mass displacement calculations.
Traditional methods based on mass displacement by time unit (kg/h) show the following disadvantages:

- The amount of processed mass (pressed) is not constant, but rather depends on the material characteristics (density), and therefore the hourly mass production depends on the material type.
- The compaction grade depends on material mechanical characteristics (elasticity), therefore the hourly mass production depends on the material type.
- In some machines, cylinder displacements also depends on material mechanical characteristics.

Based on these effects, we can deduce that the production data given by manufacturers are applicable alone to a concrete kind of material and under some certain conditions, not being able to predict the equipment behaviour in front of new materials.
This paper relates how to calculate the influence of these effects over the machine hourly production, showing a new selection point of view focused in the hourly volume production (m3/h) rather than the hourly mass production.

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1 Introduction

Usually the manufactures have expressed baler presses hourly production as mass hourly production (kg/h). This method drives to wrong production selection when trying to use it for new materials.

A typical example of equipment selection errors happened using this method can be found in plastics baler presses, where the production values given by the manufacturers for the cardboard are taken. Logically it is absurd to seek that the machine processes the same kilograms of plastic and cardboard hourly, since the densities of the departure materials are different and therefore a plastic bale won't weigh the same that a cardboard bale. Neither we should obviate the fact that most of these machines are moved through variable flow pumps, which makes them sensitive to the exercised force and therefore to the material elasticity.

Next a new method is developed to accurate calculate the volume hourly production for any material.

2 Parameters definition

2.1 Material flux

It is defined as the processed or carried volume per time unit.

$$\Phi = \frac{V}{t} \quad \left(\mathrm{m}^3/h\right) \tag{1}$$

2.2 Press chamfer volume

It is defined as the material displaced and compressed on each cylinder stroke. It can be calculated as:

$$V_p = a \cdot b \cdot l_t \tag{2}$$

Where:

a: bale width
b: bale height
l_t ; hopper length.

2.3 Hopper volume

It is defined as the volume inside the machine hopper acting as material reservoir, ensuring the continuous machine running. To ensure a correct chamfer press filling, it is recommended to be approximately double times (as minimum) the chamfer press.

$$V_t = 2 \cdot V_p = 2 \cdot a \cdot b \cdot l_t . \tag{3}$$

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2.4 Bale volume

It is obtained from the bale size. $V_b = a \cdot b \cdot l_b$ (4)

Where:

a: bale width
b: bale height
l_b ; bale length.

Width and height dimensions depend on the machine geometry (press tunnel size), so are invariable, but length can vary as desired. If excessive lengths are employed the bale density decreases. It is recommended that the bale length is as least 60% from the press tunnel length. Usually the press chamfer length is equal to the hopper length. So,

$$V_b = a \cdot b \cdot l_t \quad (5)$$

2.5 Specific press pressure

It is obtained by dividing the press force by the press area. In baler presses it is equal to the bale height and width.

$$p = \frac{F}{A} = \frac{F}{a \cdot b} \quad (6)$$

3 Material flux trough a baler press

Due to the only process inside the press is material compression, we can affirm that the conservation mass law is observed: $m_{input} = m_{ourput}$ (7)
By the other hand, the material mass can be obtained from its volume and apparent density.

$$\rho = \frac{m}{V} \rightarrow m = \rho \cdot V \quad (8)$$

The apparent density must be experimentally obtained by filling the chamfer press and weighting this volume.
By substituting (8) in (7) we obtain.

$$\rho_{input} \cdot V_{input} = \rho_{output} \cdot V_{output} \quad (9)$$

Rewriting (8)

$$\frac{\rho_{input}}{\rho_{output}} = \frac{V_{output}}{V_{input}} \quad (10)$$

3.1 Compression ratio

It is defined as the quotient between the input apparent density and the output apparent density.

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$$i = \frac{\rho_{input}}{\rho_{output}} = \frac{V_{output}}{V_{input}} \tag{11}$$

An experimental determination of the apparent output density must be done before calculating the compression rate. These creates a problem: if we have not the machine, there is no possibility to make the experiments, and so there is no way to determine the compression ratio.

This report shows an alternative experimental method to determine the compression ratio.

In order to develop the method, several experiments were done. In them, we take a material with a known input apparent density, and we applied different forces (and so specific pressures), measuring the output apparent density for each one.

Then these experiments were plotted correlating specific pressure – density. The next illustration shows the graphs obtained:

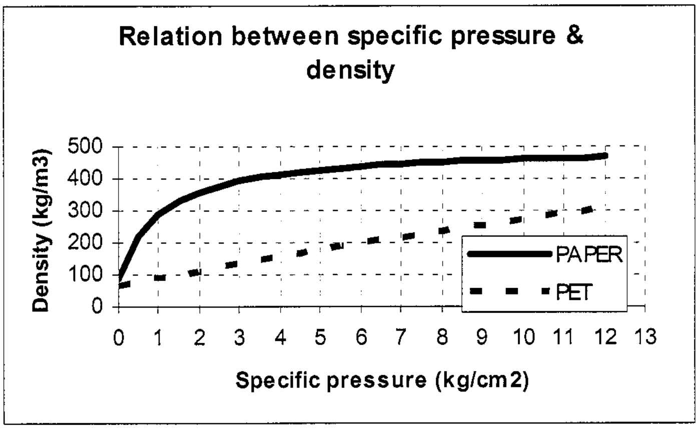

Figure 1: Relation between the specific pressure and apparent density

These graphs are adjusted to the experimental data trough the following equation:

$$\rho_s = \rho_e + \frac{p}{A + B \cdot p} \tag{12}$$

A, B are constants that can be obtained in laboratory by running only two experiments and replacing the obtained values in (12).

The expression (11) can be rewriting by replacing (12) in (11).

$$i = \frac{\rho_{input}}{\rho_{output}} = \frac{\rho_{input}}{\rho_{input} + \dfrac{p}{A + B \cdot p}} = \frac{1}{1 + \dfrac{p}{\rho_{input} \cdot (A + B \cdot p)}} = \frac{1}{1 + \dfrac{1}{\rho_{input} \cdot \left(B + \dfrac{A}{p}\right)}} \tag{13}$$

This equation shows that the compression relation depends from:

- The material apparent density.
- The constants A,B, which depend from the material physic properties.

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- The specific press pressure, which depends from the machine features.

3.2 Number of cylinder strokes for obtaining a bale

Applying the mass conservation law as in (11), we will write:

$$m_{bale} = m_{processed} \tag{14}$$

Replacing the mass by its density and volume:

$$\rho_{bale} \cdot V_{bale} = \rho_{input} \cdot V_{processed} \tag{15}$$

The processed volume will be calculated multiplying the volume displaced in each cylinder stroke (chamfer press volume) by the number of strokes:

$$V_{processed} = n \cdot V_p \tag{16}$$

Replacing (16) in (15):

$$\rho_{bale} \cdot V_{bale} = \rho_{input} \cdot n \cdot V_p \tag{17}$$

From (17) we can deduce:

$$n = \frac{\rho_{bale} \cdot V_{bale}}{\rho_{input} \cdot V_p} = \frac{\rho_{output} \cdot V_{bale}}{\rho_{input} \cdot V_p} \tag{18}$$

Replacing (5), (11) in (18) we can deduce:

$$n = \frac{V_b}{V_p \cdot i} = \frac{a \cdot b \cdot l_b}{a \cdot b \cdot l_t \cdot i} = \frac{l_b}{l_t \cdot i} \tag{19}$$

Obtaining an expression, which allows us to determine the number of cycles that must be done before making a bale from the machine geometry and the compression ratio. Logically if the compression ratio depends from the material characteristics, the number of strokes will also depend from them.

4 Presses Flux capacity. Production capacity

Presses production capacity are obtained form the presses processed flux:

$$\Phi = \frac{V_{processed}}{t_{processed}} \tag{20}$$

By replacing (19) in 16 we can obtain the processed volume:

$$V_{processed} = n \cdot V_p = \frac{V_b}{i} = \frac{a \cdot b \cdot l_b}{i} \tag{21}$$

The time needed to process a bale volume will be calculated from the time needed while pressing the bale and the needed while tying the bale. The time needed while pressing the bale can be calculated by multiplying the time needed to make a pressing cycle (forward, backward) per the number of cycles (cylinder strokes).

$$t_{processed} = t_{pressing} + t_{tying} = n \cdot t_{cycle} + t_{tying} = \frac{l_b}{l_t \cdot i} \cdot t_{cycle} + t_{tying} \tag{22}$$

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The time needed to make a cycle can be experimentally determined using a chronometer. In some cases, this is not possible and can be approximated, as shown in the next point.
The time needed to tie the bale is a machine constant taking as typical value 30 seconds. So:

$$t_{tying} = 30s \cdot \frac{1h}{3600s} = \frac{1}{120}h \qquad (23)$$

Replacing (21), (22) in (20) we will calculate the press capacity:

$$\Phi = \frac{\frac{a \cdot b \cdot l_b}{i}}{= \frac{l_b}{l_t \cdot i} \cdot t_{cycle} + t_{tying}} = \frac{a \cdot b \cdot l_b}{\frac{l_b \cdot t_{cycle}}{l_t} + i \cdot t_{tying}} = \frac{a \cdot b}{\frac{t_{cycle}}{l_t} + \frac{i \cdot t_{tying}}{l_b}} \; (m^3/h) \qquad (24)$$

5 Pressing cycle time calculation

In baler presses the press pressure is given by hydraulic cylinders. The time spent during a complete cycle will be calculated as the time needed for the cylinder to go forward and backward. In order to calculate these times we will need to use hydraulics formulations. The cylinder displacement speed can be calculated from the pump flow and its transversal section.

$$Q = A \cdot v \Rightarrow v = \frac{Q}{A} \qquad (25)$$

Where:

Q: is the pump flow.
A: is the cylinder section.

By the other hand, the relation between speed and time can give us the time spent in a cylinder stroke.

$$v = \frac{x}{t} = \frac{Q}{A} \Rightarrow t = x \cdot \frac{A}{Q} \qquad (26)$$

Where:

x is the cylinder stroke.

As can be observed, displacement time depends on the pump flow. This forces us to use a different calculation in function of the cylinder impulsion system. Following we will develop the cycle time calculations for three systems: constant flow pumps, variable flow pumps and variable flow pumps with differential circuit.

5.1 Cycle time calculation with constant flow pumps

This system is only used with small baler presses and compactors, due to the needed power is very high. If pump flow is constant, the time needed in de forward and backward displacement will be calculated as:

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$$t_{forward} = x \cdot \frac{A_{forward}}{Q} \qquad (27)$$

$$t_{bacward} = x \cdot \frac{A_{backward}}{Q} \qquad (28)$$

$$t_{cycle} = t_{forward} + t_{backward} = \frac{x}{Q}\left(A_{forward} + A_{backward}\right) \qquad (29)$$

5.2 Cycle time calculation with variable flow pumps

Variable flow pumps are used because the maximum pressures is not required while all the cylinder stroke, so the maximum power is not ever needed. Additionally, during the times where the cylinder is not working, it lets the pump to give a null flow, so the energy waste is null.
Taking into account this fact, a power control systems are added to the pumps in order to mount smaller motors rather than in constant flow pumps.
The main disadvantage of this regulators resides in the fact that the higher is the pressure, the lower is the pump flow. Then there are two working sections: a first section were the press will displace with minimum pressure and maximum flow, and other where the press will displace with maximum pressure and minimum flow. Logically the more time we are working with low flow, the less hourly production will have the machine.
The minimum pump flow working with maximum pressure will be:

$$Q_{min} = \frac{600 \cdot P}{p_{max}} \qquad (30)$$

The pressure that causes the pump flow decrease will be:

$$p = \frac{600 \cdot P}{Q_{max}} \qquad (31)$$

This pressure will exert a cylinder force:

$$F = \frac{p}{A_{cilindro}} \qquad (32)$$

This force will exert the following specific pressure over the material

$$p_{change} = \frac{F}{A_{bale}} = \frac{\frac{600 \cdot P}{Q_{\max} \cdot Ac}}{a \cdot b} = \frac{600 \cdot P}{Q_{\max} \cdot A_{cylinder} \cdot a \cdot b} \qquad (33)$$

As shown before, the output density when the speed changes can be obtained from the specific pressure which generates this change (p_{change}). This increment of density is obtained by the chamfer press volume variation while pressing. This volume varies only in longitudinal way, due to the other dimensions (width and height) are invariables
So the densities after and before the speed change:

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$$\rho_{input} = \frac{m}{a \cdot b \cdot L_{input}} \tag{34}$$

$$\rho_{change} = \frac{m}{a \cdot b \cdot L_{change}} \tag{35}$$

Where

L_{input} . length of the press chamfer before pressing.

L_{change}: length of the press chamfer when the speed changes.

Dividing both expressions, we will obtain:

$$\frac{\rho_{input}}{\rho_{change}} = \frac{L_{change}}{L_{input}} \Rightarrow L_{change} = L_{input} \cdot \frac{\rho_{input}}{\rho_{change}} \tag{36}$$

Cylinder displacement can be calculated by difference with input length:

$$\Delta L = L_{input} - L_{change} = L_{input} - L_{change} \cdot \frac{\rho_{input}}{\rho_{change}} \tag{37}$$

Replacing (37) in (36) we will write:

$$\Delta L = L_{input} \cdot \left(1 - \frac{\rho_{input}}{\rho_{change}}\right) \tag{38}$$

Replacing (13) in (38) we will write:

$$\Delta L = L_e \cdot \left(1 - \frac{1}{1 + \frac{1}{\rho_e \cdot \left(B + \frac{A}{p_{cambio}}\right)}}\right) = L_e \cdot \left(1 - \frac{1}{1 + \frac{1}{\rho_e \cdot \left(B + \frac{A}{p_{cambio}}\right)}}\right) \tag{39}$$

This expression gives us the cylinder displacement with maximum speed. It can be deduced that this displacement depends on:

- The press specific pressure: which produces the speed change, which also depends on the power, flow, cylinder and bale sections, being so independent from the material characteristics.
- Constants A,B: which depend on material and define the graph as shown in Figure 1.

The following illustrations shows the difference between displacements obtained for a same specific pressure for paper and PET.

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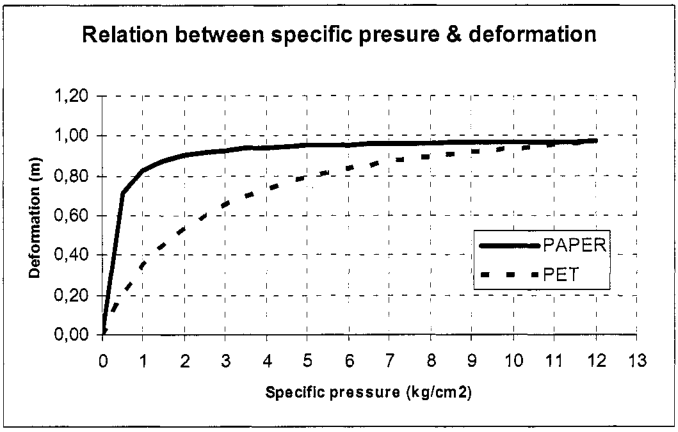

Figure 2: Relation between the specific pressure and displacement

Figure 2 shows that with equal specific pressure, paper is pressed with maximum flow during a higher length than PET, and so, the paper baler press production will be higher than PET, being justified the observations made at the paper beginning. This difference will be higher as lower is the specific press pressure when the speed change is made.

From previous reasoning we can calculate the cycle time as shown:

$$t_{cycle} = t_{fastforward} + t_{slowforward} + t_{backward} \tag{40}$$

$$t_{cycle} = \frac{\Delta L \cdot A_{forward}}{Q_{\max}} + \frac{(L_{input} - \Delta L) \cdot A_{forward}}{Q_{\min}} + \frac{L_e \cdot A_{backward}}{Q_{\max}} \tag{41}$$

5.3 Cycle time calculation with variable flow pumps with differential circuit

Hydraulic differential circuits allow the output flow recirculation at cylinders towards the input flow, while working at low pressure. Meanwhile, it can been obtained an additional flow while the cylinder forward, increasing the machine hourly production.

Taking this reasoning in (41) we will write:

$$t_{cycle} = \frac{\Delta L \cdot (A_{forward} + A_{backward})}{Q_{\max}} + \frac{(L_{input} - \Delta L) \cdot A_{forward}}{Q_{\min}} + \frac{L_e \cdot A_{backward}}{Q_{\max}} \tag{42}$$

6 Conclusions

This report has shown both an experimental and a theoretical-experimental method to determinate the real hourly volume production for baler presses. Through this methodology it can be predicted the machine hourly volume production working with materials which have never been proved with it, avoiding the machine to be built and tested. It can be also predicted other useful parameters as the bale density and weight, numbers of bales per hour, etc…

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This method is also more accurate than the mass production method used by manufacturers as has been demonstrated in this paper, so it leads to make a better machine selection.

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