UNIVERSITY OF MISKOLC
FACULTY OF EARTH SCIENCE & ENGINEERING
INSTITUTE OF RAW MATERIALS PREPARATION AND ENVIRONMENTAL PROCESSING

INVESTIGATION OF PISTON PRESS COMPACTING OF WASTES

Theses of PhD dissertation

Author:

Sándor Nagy
M. Sc. in Process Engineering

Scientific tutors:

Prof. Dr. habil. Barnabás Csőke
professor
Dr. József Faitli
associate professor

MIKOVINY SÁMUEL EARTH SCIENCE DOCTORAL SCHOOL

Head of doctoral school: Dr. István Lakatos

Professor, Corresponding member of the Hungarian Academy of Sciences

Miskolc

9th July 2012.

I. Introduction

In lot of industry are fine disperse materials and products, which have to be briquetted, because the agglomerated form has many advantages against bulk form.

One of the main quality parameter of briquettes is the breaking strength, which has to be set according to the further utilisation of briquettes. The briquettes have to be easily transportable and feedable, during the utilisation they have to fall apart by a given stress (e.g.: firebox, furnace, etc.). Important parameter is during the production the applied briquetting pressure, binder content and temperature. The equipments should be designed for these parameters. By higher pressure, the parts of the equipments are more demanded. The great mechanical strength and heatproof design increases the initial costs of the equipment.

Exceedingly important is during the agglomeration the specific work and the pressing temperature because of the production costs. The production of the briquettes should be so designed, that the needed briquette quality (strength, abrasion, etc.) should be ensured, with the lowest specific work, temperature and adhesive content. The exact knowledge of the effect of production parameters on briquette quality is crucial. The briquetting of different materials can be well modelled in piston press. In the frame of the dissertation I examine the briquettability of different waste materials and by-products.

The main problem of this subject is that the wastes are quite different, and heterogenic. These were the aspects during the selection of sample materials. It was help in some cases, that the experiments were connected to industrial research works or projects.

During the evaluation of the literature the following conclusions were made: The literature does not go deeply in briquettability of wastes different material properties (mineral or heterogeneous wastes). However, nowadays the significance of briquetting of these materials increases. I did not fond literature which deals deep with economy of briquetting of wastes, especially in the respect of two main parameters (pressure and binder content) of briquetting with binder [1-7].

II. The aims of my scientific work

The main aims of my experiments are:

- Development of briquetting equipment and briquette qualification process, which is able to carry out high numbers of experiments with different parameters, and so the main parameters are dependably determinable;

- To bring in parameters and functions (**$\rho^*(w)$, $\sigma_h(w)$**) which are able to describe and compare the briquettability of wastes with different material properties;

- Elaboration of a method for the economical evaluation of briquetting depending on technical parameters.

III. Experimental equipment and evaluation methods

This research work consists of survey of Hungarian and international literature, developing of experimental apparatus and -methods for testing of briquettability, laboratory scale experiments, developing of economically analysis method, evaluation of results and drawing of conclusions.

Most of my scientific results are based on systematic laboratory experiments carried out at the University of Miskolc, Institute of Raw Material Preparation and Environmental Processing.

I involved in the investigation first of all wastes: brittle mineral materials, viscoelastic materials, and its mixtures. During the experiments tablets with 25 mm diameter were prepared, the pressure, in given cases the binder or moisture content and briquetting temperature were modified. In respect of temperature I made the experiments in room-temperature. In some cases (municipal solid waste) the higher temperature was inevitable, so in these cases the effect of temperature was investigated. The tablets were qualified by density and breaking strength, the specific briquetting work was determined. The relation pressure-density and pressure-tensile strength were also determined.

Experimental equipment

The experiments were carried out with the hydraulic piston press (figure 3.2) designed and produced by the Institute of Raw Material Preparation and Environmental Processing (University of Miskolc). The hydraulic circuit diagram can be seen on figure 3.1. The press is supported by a pump and motor unit (figure 3.1/*8, 7, 6, 5*) with pressure limiter (*5*).

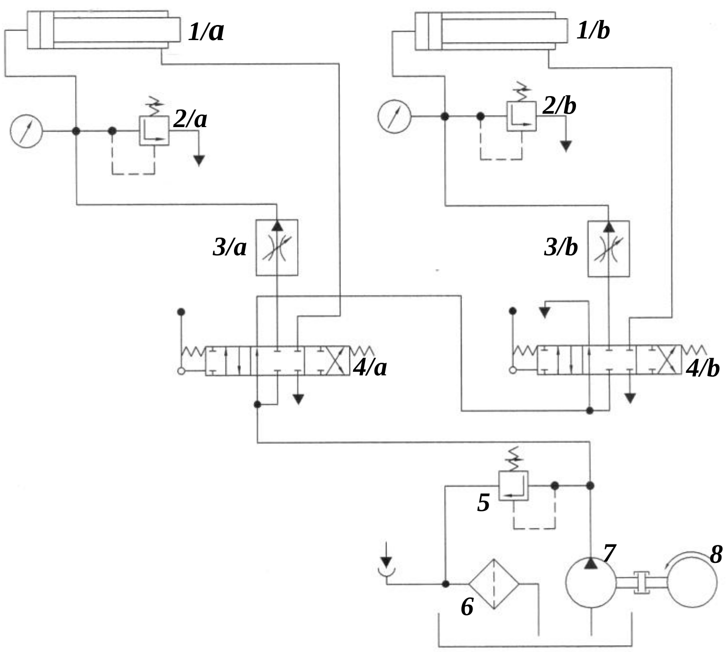

Figure 3.1. Simplified hydraulic circuit diagram of experimental equipment

Two hydraulic pistons are in the equipment. The one (1/a; F_{max}=200 *kN*) is used for pressing, the other is for raising of the tablets. The pistons can be moved through control valves (4/a and 4/b). The pressure of the oil in the pistons can be set by the pressure controller (2/a and 2/b). The speed of pistons can be set by the volume stabilizer valves (3/a and 3/b), the maximal speed is 30 mm/s. The barrel can be heated (20…140 *˚C*).
The following parts were installed on the equipment for my research work: incremental distance meter, force meter, heating unit, data acquiring system. The building of the equipment and the installing of different new units were made by the workshop of the institute (co-ordinated by Gábor Antal), the data acquiring system was developed by Dr. József Faitli.

Main parameters	
F_{max}	200 *kN*
v_{max}	30 *mm/s*
Temperature	20 - 140 ˚*C*
Tablet diameter	25 ill. 40 *mm*
Measuring of distance	incremental
Data acquiring (force, distance)	PC, LabWindows

Figure 3.2. Hydraulic piston press

I determined the speed of the piston by different values of the volume stabiliser valve (Table 3.1).

Table 3.1. Speed of piston

	Value set on the equipment				
	2	**4**	**6**	**8**	**10**
Pressure [MPa]	**Speed [mm/s]**				
100	5,63	12,81	20,15	28,08	34,76
150	5,84	11,69	19,9	27,28	36,57
200	5,54	12,4	19,41	28,4	32,85
250	5,88	12,47	20,19	28,74	33,74
Standard deviation [%]	*2,48*	*3,30*	*1,56*	*1,92*	*4,01*
Average values [mm/s]	**5,72**	**12,34**	**19,91**	**28,13**	**34,48**

Determination of specific briquetting work

I measured the actual position of the piston (distance), and the force acting on tablet. The system acquires 50 data points in a sec, using this points the force-distance curve can be determined.

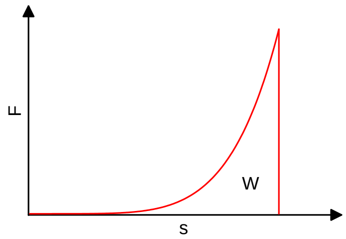

Figure 3.3. Force-distance diagram

I fitted a polynomial curve on the data points (Graph v4.3). The area under the curve is the work (W) needed for briquetting.

$W = \int F \cdot ds = A \int p\, ds$, where:
- W work,
- F force,
- s distance,
- A surface of the tablet (normal to the force).

The specific work:

$w = W / m_t$ [J/g], where
- w specific work,
- W work necessary for one tablet
- m_t mass of the tablet.

Determination of the density of tablets

The quality of tablets can be described easy with the density. The diameters and heights of the tablets were measured by vernier caliper. The barrel diameter is 25 mm, but there can be differences between barrel diameter and tablet diameter because of the extension of the tablets after briquetting. I determined the exact mass of each tablets.

$\rho_t = m / V = 4\, m / (D^2\, \pi\, h)$, where:
- ρ_t density of tablet,
- m mass of tablet,
- V volume of tablet,
- D diameter of tablet,
- h height of tablet.

Determination of tensile strength

For the determination of the strength of tablets, I used the indirect tensile strength. The tablets were placed between two plates set on edges during the measurement. The test was carried out with hydraulic equipment produced by MTS Systems Corporation at the Department of Mechanical Technology at University of Miskolc. The equipment saves during the test the displacement of the breaker jaw and the actual force, so the force-displacement function can be determined. I calculated the tensile strength from the maximal force value with the following form:

$\sigma_h = 2\, F_{max} / (\pi\, h\, D)$, where:
- σ_h: tensile strength of tablet,
- F_{max}: maximal force during the test.

Evaluation of the results

The measured data were processed in tables and diagrams, the evaluation was fulfilled by density – briquetting pressure, tensile strength – briquetting pressure, and density or tensile strength – specific briquetting work diagrams. Furthermore the well-known methods of process engineering (Johanson function), mathematical statistics and correlation counting were used for evaluating. For description of the processes different functions were fit into the measured points and the value of correlation coefficient, absolute or relative error were given.

IV. Scientific achievements, theses

The new scientific results of my dissertation can be summarized as follows:

1. By briquetting of brittle materials with binder I established that the ρ=f(p) correlation can be described by the Johanson function. This relation is actually independent from the binder content:

$$\boldsymbol{\rho = \frac{\rho_0}{p_0^{1/\kappa}}\, p^{1/\kappa} = c\, p^{1/\kappa}}, \text{ where } \kappa \neq f(c_k),$$

in the case of SiC κ=23,24≈konst.. The relation of density – briquetting work is also independent from the binder content:

ρ=f(w).

2. Contrary to density – briquetting work correlation the strength of briquette depends on binder content (c_k) and specific briquetting work (w):

$$\boldsymbol{\sigma_h = f(w, c_k)}.$$

The following correlations are valid for silicon carbide:

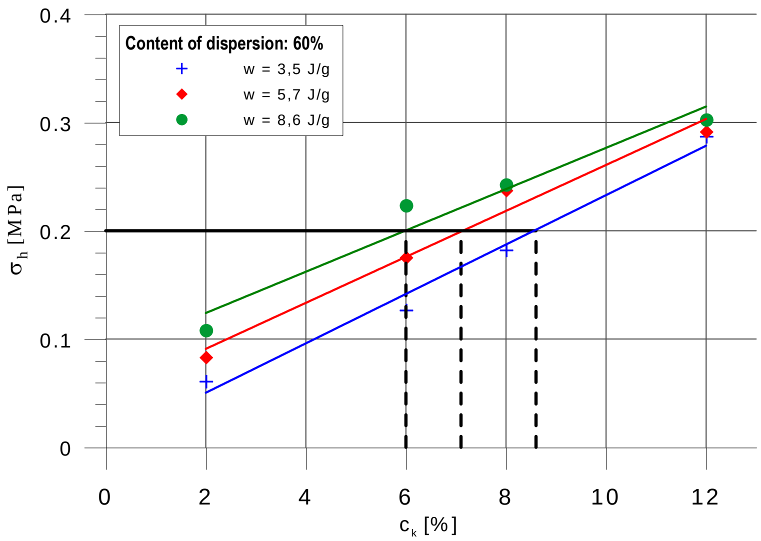

Figure 4.1. Tensile strength as function of binder content

$$\boldsymbol{\sigma_h = f(c_k, a, b) = a\, c_k + b},$$

where

$a=f(w)=\alpha_1 w+\beta_1$,
$b=f(w)=\alpha_2 w+\beta_2$,

where:

$\alpha_1 = -7{,}3504\ 10^{-4}$,
$\beta_1 = 2{,}5401\ 10^{-2}$,
$\alpha_2 = 1{,}5751\ 10^{-2}$,
$\beta_2 = -4{,}7082\ 10^{-2}$.

3. A method was developed for the calculated planning of briquette quality using the correlations of thesis 2. According to the above mentioned correlations the tensile strength of the briquettes can be achieved in two different ways: with higher work and less binder or with more binder and less work. The minimum cost (so the optimal conditions for the desirable briquette quality) can be determined by a simulation with above mentioned correlations, if the cost of work (K_W) and cost of binder (K_c) and the sum of them ($K_t=K_c+K_w$, Figure 4.2) are determined.

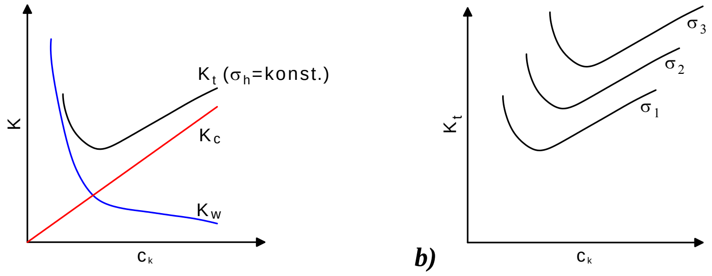

Figure 4.2. Cost functions as a function of binder content (c_k), briquetting work (w) and σ_h desirable briquette strength

K cost,
K_C cost of binder,
K_W cost of briquetting work,
K_t total cost.

4. Correlations for describing of briquetting process were introduced for generally any kind of materials. These are **ρ*** relative density - **w** work, furthermore $\boldsymbol{\sigma_h}$ briquette strength - work relations:

- **$\rho^*=f(w)$,**

  $\rho^*=\rho/\rho_0$, where ρ_0 is the initial density (at p_{min});

- **$\sigma_h=f(w)$.**

Due to the correlations the objective evaluation and comparison of briquetteability of different materials are possible.

5. It was established, that the Johanson function and the relative density - briquetting work relationship are appropriate for describing the binderless briquetting process of wood, paper and the mixture of them. The briquetting phenomena (volume reduction) is similar: κ=5,14…5,87 konst., average $\kappa_{átl}$=5,54. Related to briquette strength it was established, that the strength of paper is higher than the strength of the mixture.

6. It was established, that in the case of binderless briquetting of the extremly inhomogeneous refuse derived fuel originated from municipal solid waste, the functions **$\rho^*=f(w)$** and **$\sigma_h=f(w)$** shows high deviation (with temperature range: 100…140 ˚C; with briquetting pressure: 100…250 MPa). This relation can be described only with a tendency or function interval. The following tendencies were established:
- the basic phenomena (volume reduction) corresponds to Johanson function;
- for the briquetting of this material minimum 120 ˚C and 100 MPa are necessary;
- the strength of briquetting increases significantly as function of briquetting pressure (work).

7. The composted waste water sludge was briquetted binderless at 20 ˚C with different moisture contents ($c_{víz}$=2,3…29 %) at 100…250 MPa pressure. It was considered, that the Johanson formula is also valid for this raw material, but the compressibility coefficient depends on the moisture content: ρ=f($c_{víz}$) and κ=f($c_{víz}$), κ=5,61…31,99. The strength of the briquette is also change with the moisture content:

$$\boldsymbol{\sigma_h = f(c_{víz}),}$$

The optimal moisture content within the examined range is 8,7 %, over 29 % the material is not briquettable.

8. It was established that for briquettability of all examined wastes the Johanson formula, and the introduced relative briquette density – briquetting work and the tensile strength – work relations are appropriate to compare the briquettability of different materials.

8.1. The plotted **ρ/ρ_0 – w** values of the examined different wastes build well describable regions.

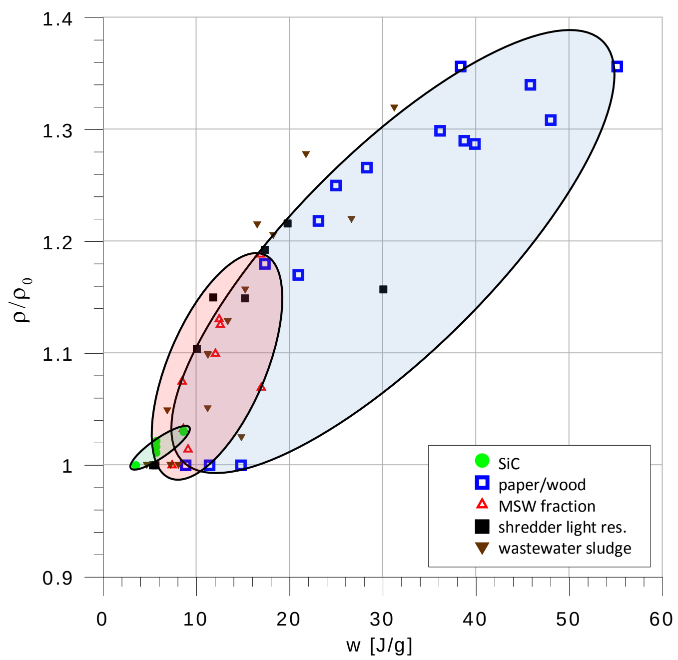

Figure 4.3. Relative density as function of briquetting work

8.2. The σ_h **– w** values plotted as point distribution can be grouped well with lines starting from origin (Figure 4.4). The ratio of tensile strength and briquetting work was introduced:

$$\zeta=(\sigma_h/w),$$

which is the angular coefficient of the lines, and characteristic for different material types. This ratio shows the tensile strength per unit briquetting work. The higher ζ is, the higher will be the tensile strength of the briquette with the same briquetting work (other parameters are constant).

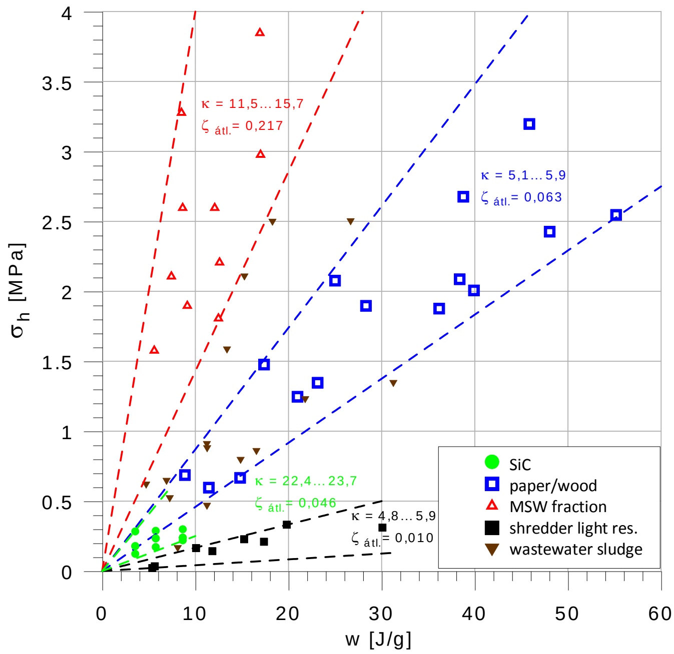

Figure 4.4. Tensile strength as function of briquetting work, and the κ and average ζ values of the different regions

V. Opportunities for application

Regarding the opportunities of application the experimental equipment and the evaluation method of tablets are able to determine the optimal briquetting parameters of different wastes, namely numerous experiments can be carried out with different parameters, and the necessary amount of sample is low. The industrial experiments can be made so already with optimal parameters, so the costs and amount of sample material are low.

The introduced method for economical evaluation, allows the reduction of briquette production costs, so the briquettes can be produced with the lowest running cost.

The results of experiments with municipal solid waste and composted wastewater sludge can be used directly at the design of industrial briquetting processes.

The introduced correlations:

$\boldsymbol{\rho^*=f(w)}$,
$\boldsymbol{\sigma_h=f(w)}$,
$\boldsymbol{\zeta=(\sigma_h/w)}$,

allows by the same or by different materials the comparison of briquettability at different circumstances. Due to these correlations the evaluation and comparison of briquetting results are reliable.

VI. Literature

[1] H. Schubert: Aufbereitung fester mineralischer Rohstoffe, VEB Deutscher Verlag für Grundstoffindustrie, Leipzig 1984

[2] Csőke B.: Előkészítéstechnika, Intézeti jegyzet

[3] N. Chevanan: Bulk density and compaction behavior of knife mill chopped switchgrass, wheat straw, and corn stover. Bioresource Technology 101 (2010) 207–214

[4] Phani Adapaa, Lope Tabila, Greg Schoenau: Compaction characteristics of barley, canola, oat and wheat straw. Biosystems Engineering 104 (2009) p335-344.

[5] Jorn M. Sonnergaard: Quantification of the compactibility of pharmaceutical powders. European Journal of Pharmaceutics and Biopharmaceutics 63 (2006) p270-227.

[6] S. Mani: Evaluation of compaction equations applied to four biomass species. Canadian Biosystems Engineering Volume 46 (2004) p3.55-3.61.

[7] Sudhagar Mani: Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. Biomass and Bioenergy 30 (2006) p648-654.

[8] J. T. Fell: Determination of Tablet Strength by the Diametral-Compression Test. Journal of Pharmaceutical Sciences, Vl.. 59, No. 5, May 1970, p.688-691.

[9] Somosvári Zsolt: Geomechanika, ISSN: J 14-1625, Tankönyvkiadó, Budapest 1989.

VII. Publications in the topic of the PhD dissertation

1. Faitli, J., Csőke, B., Nagy, S.: Dry agglomeration of hazardous waste incineration plant fly ash, MicroCAD 2005, International Scientific Conference Miskolc, 10-11 March 2005. (Publ.: University of Miskolc, ISBN 963 661 646 9ö , ISBN 946 661 647 7), p25-30

2. Nagy, S.: Hulladék biomassza aprítása/Comminution of waste biomass material, BIOhulladék/BIOwaste 3-4/2008, p37-44

3. Nagy, S.: Biomassza agglomerálási lehetőségei/Agglomeration opportunities of biomass, BIOhulladék/BIOwaste 1-2/2009, p15-20

4. Nagy, S.: Agglomeration processes of fine powders used in metallurgy. ESCC 2009, 12th European Symposium on Comminution and Classification, Espoo (Finland), 15-18 September 2009 (Publ.: CD Proceeding 7B-2)

5. Faitli J., Gombkötő I., Mucsi G., Nagy S.: Mechanikai Eljárástechnikai Kutatások az Intézetünkben. A Miskolci Egyetem Közleménye, A sorozat, Bányászat, 79. kötet (2010) Miskolc, Egyetemi Kiadó, HU ISSN 1417-5398

6. Bokányi L., Takács J., Varga T., Mádainé Üveges V., Nagy S., Paulovics J.: Kutató-fejlesztő munka a bioeljárástechnika és reakciótechnika területén. A Miskolci Egyetem Közleménye, A sorozat, Bányászat, 79. kötet (2010) Miskolc, Egyetemi Kiadó, HU ISSN 1417-5398

7. Nagy, S.: Agglomeration of biomass and other wastes. Proceeding of the 1st Knowbridge Conference on Renewables, Miskolc September 27-28, 2010 (Publ.: University of Miskolc, ISBN: 978-963-661-944-2)

8. Nagy, S., Ferencz, K.: Tüzelőanyag előállítása a polgárdi pelletáló üzemben/Fuel production in the pellet plant located in Polgárdi, BIOhulladék/BIOwaste 2-3/2010, p18-22

9. Nagy, S., Agatics, R., Csőke, B.: MBH technológia és másodtüzelőanyag előkészítő rendszer a Felső-Bácskai Hulladékgazdálkodási Kft-nél/MBT technology and secondary fuel preparation system at the Felső-Bácska Waste Management Ltd., BIOhulladék/BIOwaste 1/2011, p 9-12

10. Nagy S., Mádainé Üveges V., Ladányi R., Gulyás Á.: MBH technológiával kapcsolatos vizsgálatok az AVE Miskolc Kft. Hejőpapi I. telepén / Experiments with MBT technology at the Hejőpapi I. Plant of AVE Miskolc Ltd., BIOhulladék/BIOwaste 2/2011, p 25-30

11. Szűcs I., Nagy G., Palotás Á., Csőke B., Nagy S., Boros É.: Biomassza és szilárd települési hulladék alapú másod tüzelőanyag kifejlesztésének időszerűsége / Timeliness of developing a biomass and solid residential waste based additionak fuel. Anyagmérnöki Tudományok, Miskolc, 36/1 kötet, (2011)