Analysis of using brewery mash for energy

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Abstract

Konrád Z., Los J., Fryč J., Kudělka J., 2014. **Analysis of using brewery mash for energy**. Res. Agr. Eng., *60*: 10–16.

In contrast to waste in a full sense of the word, brewery mash is not considered as waste nowadays but rather as a material for various kinds of use. It can be fed to animals or processed to produce biogas. Various scientific and state institutions conduct experiments to find other possibilities of its use. Our experiment was focused on analysing the energy potential of this material.

Keywords: beer; by-product; combustion heat; brewery mash; stamping; pellets

Brewery mash is a by-product of beer brewing. For its very good nutritive characteristics, it is mainly used as a fodder for farm animals in the Czech Republic (http://www.agroweb.cz). However, the use of this by-product is considerably limited by its durability, i.e. by the time during which it can keep its nutritional value. This is why the brewery mash cannot be used efficiently at all times and the valuable material easily becomes a waste. It is appropriate to develop new methods for using this material, which is now often considered a waste. Regarding the stage of beer brewing in which the brewery mash is produced its use for energy calls for the removal of excessive moisture at first and subsequently for its treatment into a form suitable for its combustion. This experiment establishes methods for brewery mash dewatering, conditions for its material transformation and determination of its heating capacity.

MATERIAL AND METHODS

Brewery mash is understood as fuel in our experiment and this is why analyses were made as in other fuels in order to establish water content (W), combustibles (H) and ash (A) (http://vscht.cz):

$$W + A + H = 100 \qquad (\% \text{ wt}) \qquad (1)$$

The experiment was conducted with 3 brewery mash samples originating from:

Sample 1 – Mendel University in Brno laboratory, 12° beer, 17 kg light malt,

Sample 2 – Mendel University in Brno laboratory, 12° beer, 6 kg light malt and 12 kg Bavarian malt,

Sample 3 – Regional brewery Richard, 11° beer, 150 kg light malt and 15 kg wheat malt.

With respect to brewery mash characteristics, we decided upon mechanical dewatering by using the following technologies:

- Screw press for oil plants Model N-Farmet UNO-SE (Farmet, Česká Skalice, Czech Republic) (Fig. 1) – nozzle diameters 10, 8 and 6 mm
- Juicer Model Robamix II (WS International, Prague, Czech Republic)
- Manual mechanical press (Kovomat, Prague, Czech Republic)

Supported by the Internal Grant Agency of the Faculty of Agronomy Mendel University in Brno, Project No. TP 7/2012.

– Spin-drier – model Perla (Romo Fulnek, Fulnek, Czech Republic).

After dewatering, the relative moisture content in the material was established for each technology according to the following relation:

$$\varphi_r = \frac{m_{H_2O}}{m_v} \times 100 \qquad (\%) \qquad (2)$$

where:
φ_r – relative moisture content (%)
m_{H_2O} – water weight in the sample after pressing (g)
m_v – sample weight after pressing (g)

Dry matter was established in the laboratory drier at 105°C for 12 hours. The content of dry matter was calculated according to the following relation:

$$s = \frac{a}{b} \times 100 \qquad (\%) \qquad (3)$$

where:
s – content of dry matter (%)
a – sample weight after desiccation (g)
b – sample weight before desiccation (g)

Ash content was ascertained in the laboratory oven in which the sample was annealed for 6 h at a temperature of 595°C. The amount of ash was then calculated according to the following relation:

$$P_s = \frac{x}{a} \times 100 \qquad (\%) \qquad (4)$$

where:
P_s – amount of ash (%)
x – ash weight after annealing (g)
a – sample weight after desiccation (g)

Combustion heat value was determined on the Parr Calorimeter 6400 (Fig. 2) made by Parr Instrument Company, Moline, USA.

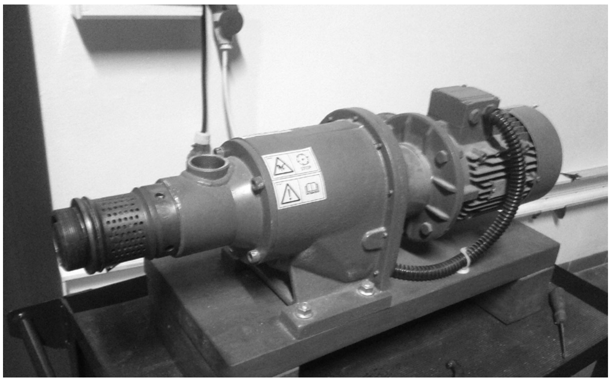

Fig. 1. Screw press for oil plants

Fig. 2. Parr Calorimeter Model 6400

The methodology of calculation is based on relations for the material and energy budget of waste combustion (http://biom.cz). The combustion heat of combustible matter was established according to the Eq. (5) and fuel combustion heat was established according to the relation Eq. (6). Other energy parameters are heating capacity of the combustible matter and heating capacity of the fuel; these were established according to the Eqs (7) and (8), respectively:

$$Q_{n,h} = 34{,}834x_c + 93{,}868x_H + 10{,}487x_s + 6{,}280x_N - 10{,}802x_O \qquad (\text{kJ/kg}) \qquad (5)$$

where:
$Q_{n,h}$ – combustion heat of the combustible matter (kJ/kg)
x_c, x_H, x_s, x_N, x_O – percentage share of individual fuel components

$$Q_{n,p} = Q_{n,h} \times (1 - x_{H2O} - x_{ash}) \qquad (\text{kJ/kg}) \qquad (6)$$

where:
$Q_{n,p}$ – combustion heat ot the fuel (kJ/kg)
$Q_{n,h}$ – combustion heat of the combustible matter (kJ/kg)
x_{H_2O}, x_{ash} – weight percent water and ash in combustible matter (%/100)

$$Q_{v,h} = \frac{\left(Q_{n,h} \times G_h - 2{,}500 \times G_{H_2O,h}\right)}{G_h} \qquad (\text{kJ/kg}) \qquad (7)$$

where:
$Q_{v,h}$ – calorific value of combustible matter (kJ/kg)
G_h – amount of combustible matter (kg/h)
$G_{H_2O,\,h}$ – amount of water generated from the combustible matter by burning hydrogen

(kg/h)

$$Q_{v,p} = \frac{\left(Q_{n,h} \times G_h - 2{,}500 \times G_{\mathrm{H_2O,\,total}}\right)}{G_p} \quad \text{(kJ/kg)} \qquad (8)$$

where:

$Q_{v,p}$ – fuel efficiency (kJ/kg)
$Q_{n,h}$ – combustion heat of the combustible (kJ/kg)
G_h – amount of combustible matter (kg/h)
$G_{\mathrm{H_2O,\,total}}$ – amount of water generated from the combustible matter by burning hydrogen and free water present in the fuel (kg/h)
G_p – amount of fuel (kg/h)

Actual calorific value of the material under constant pressure was established according to the Eq. (9) stipulated in the standard ČSN ISO 1928 (2001) as follows:

$$Q_{p,\,net,\,dry} = [q_{v,gr,d} - 212w_{H,d} - 0.8(w_{O,d} + w_{N,d})] \times \times (1 - 0.01M_T) - 24.43M_T \quad \text{(J/g)} \qquad (9)$$

where:

$Q_{p,net,dry}$ – combustion heat of dry matter (kJ/kg)
$q_{v,gr,d}$ – combustion heat at a constant volume (J/g of water-free fuel)
$w_{H,d}$ – hydrogen content in the water-free fuel, weight percent includes hydrogen from the hydrate water of ash substances as well as from the coal substance
$w_{O,d}$ – oxygen content in the water-free fuel, weight percent
$w_{N,d}$ – nitrogen content in the water-free fuel (% wt)
M_T – content of all water for which the calculation is required (% wt)

RESULTS AND DISCUSSION

Dry matter (DM) in the initial brewery mash samples ranged on average from 23.3 to 27% wt in the sample. Comprehensive results of dry matter determination are presented in Table 1. It can be stated that the DM content depended on the input raw material used in the beer brewing. In the first trial with pressing Sample 2 in the N-Farmet UNO-SE screw press, the machine was first heated as recommended by the manufacturer. How-

Table 1. Dry matter, ash and relative moisture contents in the brewery mash

	Initial sample DM (% wt)	Pressed sample DM (% wt)	Ash in DM (% wt)	Ash in brewery mash (% wt)	Initial moisture content before pressing (% wt)	Relative moisture content after pressing (% wt)	Mechanically removed water (%)
Sample 1							
	27.00						
Sample 2							
d = 10 mm	24.97	30.38					
d = 8 mm	24.97	34.12					
d = 6 mm	24.97	31.5					
Sample 3							
d = 10 mm	23.32	27.47	3.7	1.03			
d = 8 mm	23.32	28.42	3.7	1.05			
d = 6 mm	23.32	28.65	3.7	1.07			
Juicer model Robomix II					76.70	61.96	6.30
Manual mechanical press with a helix					76.70	48.76	8.86
Spin-drier Perla					76.70	56.16	15.00
Screw press – model N-Farmet UNO-SE				*d* = 10 mm	76.70	65.60	11.00
				d = 8 mm	76.70	62.60	14.10
				d = 6 mm	76.70	57.10	19.60

d – diameter of nozzle (mm); DM – dry matter

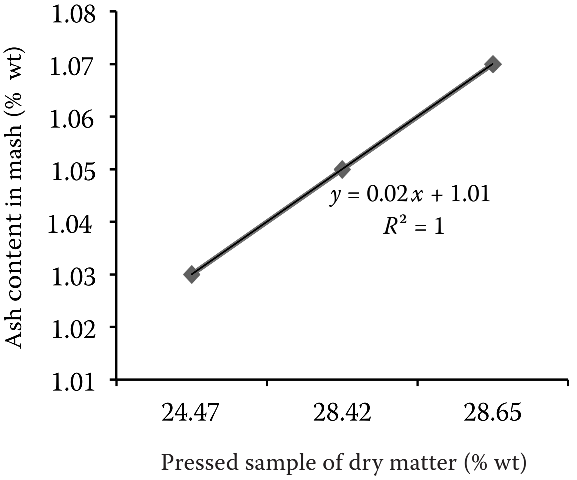

Fig. 3. Dependence of ash content in the original material on dry matter content in the sample

ever, heavy water evaporation occurred during the pressing, which was accompanied by steam generation. Therefore, the machine heating was stopped for safety purposes (scalding of the machine operator), and Sample 2 was pressed subsequently at a normal temperature with using the nozzle diameter of 6 mm. This is why the percent of pressed water is lower. Sample 3 was pressed without heating the machine for the whole time of operation. Attempting at an establishment of dry matter in dependence on the pressing rate in the N-Farmet UNO-SE screw press we found out that the content of dry matter in the sample was increasing with the decreasing nozzle diameter. The reason is that the smaller nozzle diameter could process the material into smaller particles, which increased the material density as well as the DM content in the sample.

The content of ash in the dry matter of Sample 3 was established by ignition loss to be on average 3.7% wt. The ash content in the initial mash was linearly depending on the content of DM in the sample and its value ranged around 1% wt (Fig. 3).

At an attempt to remove water from Sample 3 mechanically, the most efficient technology in terms of the highest share of mechanically eliminated water was the screw press designed for oil plants Model N-Farmet UNO-SE with a nozzle diameter of 6 mm. On the other hand, the least amount of mechanically eliminated water from the sample was recorded with the use of Robomix II juicer (Table 1).

The third trial with the manual mechanical press with a helix was conducted at a lower sample amount and a higher pressure, which increased the proportion of mechanically removed water. The efficiency of the manual mechanical pressure with a helix could have been enhanced if the material had been inserted in a fabric prior to the pressing. In our trial, however, the sample pressing was stopped at the moment when the partially pressed out mash started falling through the perforated bale chamber.

The average combustion heat of the combustible matter in Sample 3 was established from the dry matter by the Parr Calorimeter 6400 as 19.97 MJ/kg (Table 2).

Calculation of the combustion heat of combustible matter in the brewery mash:

$$Q_{n,h} = 34{,}834 \times 0.5129 + 93{,}868 \times 0.0713 + \\ + 10{,}487 \times 0.0035 + 6{,}280 \times 0.05 - \\ - 10{,}802 \times 0.3623 = 20{,}996.287 \text{ kJ/kg}$$

Calculation of the combustion heat of wet brewery mash:

$$Q_{n,p} = 20{,}996.287 \times (1 - 0.7670 - 0.0105) = \\ = 4{,}672.09376 \text{ kJ/kg}$$

Calculation of the heating capacity of combustible matter:

$$Q_{v,h} = (20{,}996.287 \times 1.475 - 2{,}500 \times 0.94)/1.475 = \\ = 19{,}403.37 \text{ kJ/kg}$$

Calculation of the heating capacity of wet brewery mash:

$$Q_{v,p} = (20{,}996.287 \times 1.475 - 2{,}500 \times 6.03)/ \\ /6.630 = 2400.14 \text{ kJ/kg}$$

For combustion to be economical, a min. heating value should be 10 MJ/kg. This is why we calculated the heating value for different water contents in the pressed out mash. The required minimum heating value corresponds to water content of up to max. 40% wt. As shown in Fig. 4, the fuel heating value decreases linearly with the increasing water content in the material while the heating value of the combustible matter and the combustion heat of the material do not depend on the material water content.

Table 2. Combustion heat of the combustible matter for Sample 3

Dry matter (% wt)	Combustion heat of combustible matter (MJ/kg)
23.575884	20.0407
23.394059	19.9538
22.992348	19.93
	Ø 19.97483

As indicated above, the calculation of the actual heating value of brewery mash under constant pressure is stipulated by the ČSN ISO 1928 (2001) standard. It is made for the water-free condition and for the initial condition. A basis for the calculation is the material budget (http://biom.cz) according to which the values are as follows (for symbols see Eq. (9):

$q_{v,gr,d}$ – 19,974.8 J/g
$w_{H,d}$ – 7.13%
$w_{O,d}$ – 36.23%
$w_{N,d}$ – 5%
M_T – 76.7%

For the water-free condition:

$$q_{p,net,dry} = [19{,}974.8 - (212 \times 7.13) - 0.8 \times (36.23 + 5)] \times [1 - (0.01 \times 0)] - 24.43 \times 0 = 18{,}430.256 \text{ kJ/kg}$$

For the initial condition:

$$q_{p,net,dry} = [19{,}974.8 - (212 \times 7.13) - 0.8 \times (36.23 + 5)] \times [1 - (0.01 \times 76.7)] - 24.43 \times 76.7 = 2{,}420.4686 \text{ kJ/kg}$$

The heating value calculation according to the ČSN ISO 1928 (2001) standard corresponds with the calculation for wastes. The conversion for the water-free condition corresponds to the heating value of the combustible matter (19,403.37 kJ/kg) and the conversion for the initial condition corresponds to the heating value of the wet brewery mash (2,400.14 kJ/kg).

An attempt to transform the material of dewatered brewery mash into pellets failed. In spite of the fact that the material was correctly crushed and its moisture content was optimal, when compressed it released heat energy without the pressing out and amalgamation of pellets. The experiment was conducted with other similar materials – hay and straw. However, the pellets could not be produced either. Thus, a possibility of unskilled adjustment comes into consideration or a defect of the device.

When the mash was dewatered in the Robomix II juicer, a great amount of material was stuck in the operating mechanism. The extracted juice remained in the dish under the sieve and did not flow into the groove. A large amount of solid matter stuck onto the internal parts of the device. Although the device was cleaned after each pressing, some losses might have occurred and hence a distortion of resulting values. In the mechanical removal of water, the technology is one of the least efficient ones.

Another technology was the manual press with a helix. There were three experimental pressing operations conducted on this device with the third one having a lower sample amount on which a higher pressure was applied than in the two other experiments. This was why the third experiment yielded a higher share of mechanically removed water. The efficiency of this technology could have been further increased if the brewery mash had been inserted in a fabric first and then pressed. However, the fabric was not used in our experiment and the pressing operation was terminated at the moment when the mash started to fall through the perforated bale chamber.

The simplest dewatering of the material occurred in the Perla spin-drier. The machine ranks with technologies with the highest percentage share of the removed water. During the third trial however a defect occurred on the machine and the measurement was brought to an end.

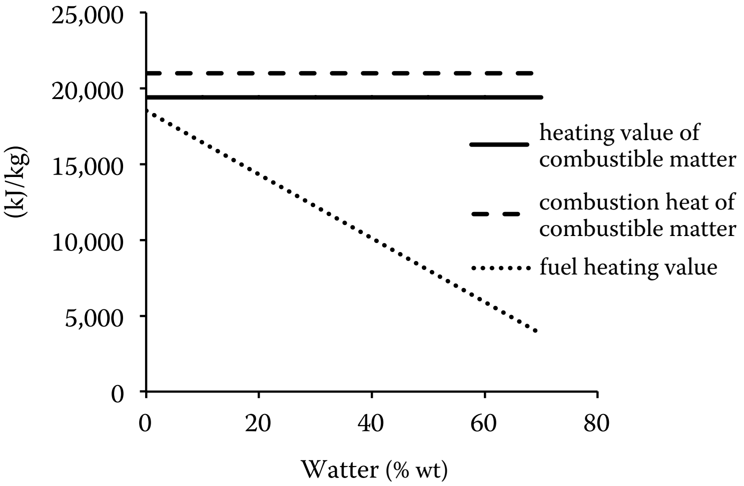

Fig. 4. Dependence of the fuel heating value on the material water content

The last machine was the N-Farmet UNO-SE screw press. This device is designed exclusively for pressing out oil plants. In our experiment, it was put into operation for a short time to compare it with other technologies and to establish its efficacy. Generally it holds however that the machine cannot be used for other purposes than designed for a longer time. This machine was the most effective in terms of water removal. Nevertheless, its cleaning after the operation was laborious because the material stuck onto all mechanical parts. This press should also serve for the material transformation. However, the material did not fall out through the nozzle in the form of granules as it happens in the oil plants but in a loose form. After the removal of excessive water from the material, another attempt was made to transform the material into pellets with the used technology being a pelleting press. However, the material transformation did not occur even after consulting experts and newly adjusting the machine.

In this part of the experiment, we established relative water content values of the material after the mechanical removal of water in all technologies and the magnitude of centrifugal force in the Perla spin-drier. An attempt was made to transform the brewery mash material.

Another part of the experiment was to determine properties of the dried material – dry matter, ash and combustion heat of combustible matter.

Dry matter was established in the laboratory of biogas transformations at Mendel University in Brno (MENDELU) for three different brewery mash samples. Dry matter contents in the samples differed in dependence on the used input raw material in the beer brewing. Sample 3 contained 23.32% wt of dry matter. Since a similar value (22.08% wt of dry matter) was reached in a study ordered by Plzeňská teplárenská a.s. (Pilsen Heat Company), this sample was further compared with other values. Dry matter was established also from the experiment with the mechanical removal of excessive water, namely in the N-Farmet UNO-SE screw press for oil plants.

Ash content was determined from dry matter in Sample 3, again in the laboratory of biogas transformations at MENDELU; it amounted on average to 3.7% wt. The content of ash in the brewery mash sample was linearly depending on the content of dry matter in the sample and ranged around 1.05% wt.

The theoretical value of ash in DM was ascertained according to the material budget of brewery mash combustion by recalculation to a value of 4.5 % wt. This value is comparable with the results from the study conducted for Plzeňská teplárenská a.s. (4.53% wt) and the theoretical calculations were therefore related to that value.

Heat of combustion was determined in the BAT MENDELU laboratory at the Parr Calorimeter Model 6400. Combustion heat of combustible matter was established in the dried out brewery mash Sample 3. The attempt at establishing also the combustion heat of fuel failed because the material did not ignite due to a high content of moisture. The mean value of combustion heat was established at 19.97 MJ/kg and differed only negligibly from the result of the study ordered by Plzeňská teplárenská a.s. (21.6 MJ/kg). The value of combustion heat obtained from the measurement was considerably affected by a higher content of mineral substances in the brewery mash (3.7% wt).

A theoretical calculation of the combustion heat of combustible matter (20.99 MJ/kg) from the material budget was made to determine characteristics of the dried material. The value obtained by the calculation did not differ much from the measured sample and from the sample used in the study ordered by Plzeňská teplárenská a.s. Another obtained value was heat of fuel combustion – 4,672.09 kJ/kg. The theoretically calculated values of material heating capacity were compared with the values obtained through the calculation according to the ČSN ISO 1928 (2001) standard. The theoretical heating value of combustible matter was calculated to be 19.40 MJ/kg and according to the ČSN ISO 1928 standard to be 18.43 MJ/kg. The heating value of the fuel in the initial condition was established to be 2.40 MJ/kg and according to the ČSN ISO 1928 standard to be 2.42 MJ/kg. The values established through the theoretical calculation did not differed much from those calculated according to the ČSN ISO 1928 standard.

The results of our research show that the heating capacity of combustible matter and the combustion heat of combustible matter do not change in dependence on the material moisture content by contrast to fuel heating capacity, which shows linear changes in dependence with water content. The economic stability of operation requires a heating capacity of fuel higher than 10 MJ/kg, which in this case corresponds to the material water content of 40% wt.

CONCLUSIONS

Comparing the energy parameters of brewery mash with other materials, we importantly have to know the fuel moisture content since the heating capacity of the fuel linearly depends on the content of water in the material. A material that can be compared with brewery mash is industrial wood waste (Filip, Oral 2003) (water content 10–20% wt and fuel heating value ranging from 14.32 to 16.42 MJ/kg). The two materials are very similar in their heating value.

The use of brewery mash for energy by combustion is possible under the given conditions. A basic prerequisite is to reduce the water content in the material by an economically acceptable method, e.g. on a belt press, which is capable of reducing the relative moisture content in the mash to 40–42% wt (Skoblia et al. 2010). Already at a reduction of moisture to 40% wt, the heating value of the material ranged around 10.1 MJ/kg, which was economically acceptable. The liquid product from dewatering can be further processed by anaerobic methods in biogas plants at a simultaneous gain of energy. In large incinerators, the brewery mash is usually burned directly on travelling grates. For small users (e.g. households), a transformation of the material is recommended (briquettes or pellets) for more convenient handling with the mash (as a fuel).

The ash generated after burning can be further used too. Its high content of phosphates makes it a useful additive in fertilizers. This way of using the brewery mash is environment-friendly. The burning of brewery mash considerably reduces the greenhouse emissions and thus helps to fulfil the objectives of sustainable development. Another possibility is trading with CO_2 emission permits and hence generating profit from their sales.

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Received for publication March 21, 2013
Accepted after corrections June 11, 2013

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