THE APPLICATION OF GRAPE POMACE AS A SOLID BIOFUEL IN COMBUSTION TECHNOLOGIES

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ABSTRACT

The winemaking sector generates considerable quantity of biodegradable waste, that
may be used as a solid fuels in several combustion technologies. Importantly, the
specificity of both material physicochemical properties and production periodicity
of grape marc imposes some limitations in its utilization within power units. In the
article issues concerning combustion and co-combustion with lignite and
bituminous coals of grape residues from wine industry were presented and
discussed. The grape pomace was identified and compared to other solid fuels on
the basis of proximate and ultimate analysis. The physicochemical parameters
proved, that winemaking residues are similar to more conventional types of solid
biomass (wood, straw), however, they contain more nitrogen. That fact may lead to
increased emissions of NOₓ, particularly unfavourable in the case of small heating
systems. Moreover, grape pomace differed significantly from coals, therefore, when
utilised in existing single coal-fired power station, it seems to be vital to limit its
presence in fuel mixture to 5-10%. In subsequent parts of the paper, in order to
assess the yield of winemaking residues, production ratios (per unit of manufactured
wine) of this type of biomass were proposed (0.18-0.35 kg per 1 litre of wine) as
well as the influence of the moisture content on their technical potential in heat
generation. Finally, cogeneration unit supplied by grape pomace in two ways were
identified and calculated in terms of the identification of both electricity and heat
capacities per wine production unit.

INTRODUCTION

The current pro-environmental transformation of the European industry has
influenced significantly on the structure of fuel used by power sector. In order to
reduce the emissions of several pollutants and preserve natural resources, new
power technologies and clean substrates for electricity, heat and cold generation are
being rapidly investigated. A number of studies over recent years focused notably
on both renewable and waste energy sources, furthermore, many projects have been
conducted to discover most favourable energy storage systems. The primary

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objective of all conducted endeavours is to create clean, cheap, high efficient, easily adjustable, independent power system that may continuously covers all energy demands of both municipal and industrial activities.

Unfortunately, many of new low-emissions power technologies are highly susceptible to weather conditions, at an early stage of development or require high financial outlays. For this reasons, in order to ensure high availability and precise adjustability within eco-friendly power sector at current stage of reorganisation, it seems to be justified to focus on the locally-generated biomass first. If properly managed, biomass may constitute an essential element of national pro-environmental power sector, less influenced by the environmental limitations. Therefore, when technical potential of biomass is sufficient to cover - in an economically feasible way - at least part of the energy demand, the replacement of coal, oils, gasoline and natural gas into biofuels should be examined. Importantly, energy market is still seeking new source of biofuels. Rapidly growing demand for heat, electricity and cold results in the shortage of both agro and forest biomass resources. Fortunately, these deficiencies may be supplemented by biodegradable waste fuels from agro-food sector.

![Fig. 1.](image)

Wine growing zone in the Lower Silesia region (Poland) (A), the formation of red grape must (B) and the post-production red grape residues (pomace) (C) sources: own elaboration (A); Bogdan (B) and Adrian J. Hunter (C) - wikimedia.org, GNU FDL licence

One of the potential waste biomass source is wine industry. During the manufacturing process (after the stage of grape must preparation – maceration) in wineries, considerable amounts of fruit residues are discharged (Fig. 1.). Treated as waste, until quite recently they were mainly used as a compost, fertiliser or an additive in animal nutrition. However, due to new environmental standards concerning both power and agricultural sectors, past experience were notably limited and new solutions of its utilisation are vital to be introduced. Importantly, the implementation of grape pomace within several power units (as a biofuel) is possible - both with small and large capacities – however, some crucial issues (associated with its quality and quantity) need to be covered. While winemaking residues have sufficient quality to be regarded as a valuable substrate in:

- combustion technologies – to produce heat or electricity (as a primary or secondary fuel, i.e. in the form of pellets) [1],
- low- and high temperature pyrolysis – to convert grape pomace into char, bio-oils or combustible mixture of gases [2, 3],
• anaerobic fermentation – to produce biogas (composed mainly of CO₂ and CH₄) and relatively homogenous pulp, used as a fertiliser [4],
• alcoholic fermentation – to generate bioethanol, oleanolic acid and solid residues (that may be used as a thermal insulation material) [5],
• gasification – to generate syngas, chars and liquid residues [6],

In this article selected issues concerning the combustion of grape pomace were emphasised and discussed. The implementation of grape pomace within combustion technologies seems to be favourable in particular in power sector dominated so far by coal-fired units (like in Poland) by fostering positive financial feedback (existing boilers may be easily adopted). It has been previously reported that this type of grape marc utilisation within power sector is financially reasonable and technically justified in both small and large wineries [6, 19]. Moreover, in this case it may be easier to introduce wine pomace in power sector through one general technical solution. By the formation of biopellets, made by the dried grape pomace and additional materials (i.e. sawdust), we can obtain universal biofuel dedicated to different power capacities – individual heating systems, local only-heat units and professional power plants [1, 10].

WINE POMACE YIELD ASSESSMENTS

Importantly, the technical potential of grape marc in all highlighted power technologies differs significantly in various countries and regions – mainly due to spatial distribution of wineries. While the European Union is the largest producer of wine worldwide - it supplies about 65% of its production by volume and covers almost 50% of vineyard area in the world - in 2014/15 estimated 16.3 billion litres of wine were manufactured mainly in France, Italy and Spain (4,600-4,100 million litres each). These 3 countries represented 81% of European total output and seemed to have the greatest opportunities to introduce grape marc to professional power sector. However, there is still many countries with extensive experience in wine production, that may cover at least local energy demand from winemaking residues – among others Hungary. Wine making has been developing here for hundreds of years. The vast experience in growing of grape are promoted among other by favourable weather conditions, unique microclimates and rich soils in over 22 Hungarian wine regions (i.e. the area around Lake Balaton). In 2014, 260 million litres of wine (1.6% of EU-29 market) were produced in Hungary – about 70% of total production was covered by white wines, 28% - by red and less 2% - by rose ones. Hungarian vineyard area in 2013 was assessed at more than 82,000 ha [8]. At the other end of the wine production is Poland. In 2016, 103 licensed vineyards used for cultivation of grape only about 194 ha and produced 2301,09 hl of red wine and 2716,26 hl of white one. Polish winemaking sector consumed for this about 800 tonnes of fruits [9].

To identify the quantity of grape pomace and offer most favourable direction of its utilisation, national assessment concerning winemaking industry need to be introduced. However, when it is hard to evaluate precisely by the direct measurement, some waste generation rates may be harnessed. According to [1, 7] and own elaborations of Authors, generation of 1 litre of wine leads to the creation of 0.18-0.35 kg (depending on manufacturing process) of raw pomace. As a result,
wet, semi-solid residues from winemaking processes represent approximately 13-25% mass of fruits consumed in the production of grape must. On this basis, using provided generation rates, up to 176 tonnes of Polish grape marc could have been utilised in power sector annually (in Hungary – 47,000-91,00 tonnes). In comparison to Spanish, Italian or French winemaking sector, it is about 10,000 times less when it comes to the national potential of this type of biomass fuel. Notably, it is even less than in some Italian or Spanish regions alone - in Trentino (Italy), according to [6], up to 20,000 tonnes of wet pomace in 2010 was investigated to be used in centralised power unit (with gasification system or biomass-fired steam boiler).

Following these calculation we can easily deduce, that in case of Poland utilisation of grape marc should take place mainly in individual heating systems, whereas in Hungary, Italy or Spain – in professional units as well. Importantly, in all these countries combustion of grape pomace may be introduced in different scales of both wineries and power plants.

PHYSICOCHEMICAL ANALYSIS OF GRAPE POMACE

In order to specify general conditions relating to pollution emissions and combustion parameters of winemaking residues, proximate and ultimate analysis of grape pomace must be executed. Moreover, to assess the possibilities to create multi-fuel blends (i.e. biomass - coal), obtained results need to be compared to other solid fuels. Importantly, several energy materials have been already examined at the Chair of Energy Technologies, Turbines and Modelling of Thermal and Fluid Flow Processes (Wrocław University of Science and Technology). Standardised both Polish and European procedures were implemented in order to determine the physicochemical composition of every energy carrier. Physicochemical properties of each fuel are shown in Tab. 1.

As illustrated, when winemaking residues are dried, their HHV is similar to lignites, but approximately 25% smaller than bituminous coals (mainly due to higher oxygen and lower carbon presence in fuel). The contents of ash and sulphur in most cases is lower than in coals. Grape pomace has a similar quality as other solid types of biomass, however, nitrogen content in this case is higher than in more popular agro and forest biofuels (resulting in potential problem of increased NOx emission) [17, 18]. Importantly, biomass has about twice more violate matter and 30% more hydrogen than coals, therefore, to assure safe co-combustion enterprise of winemaking residues and coals, strict composition limits need to be met (i.e. 5-10% of biomass in the mixture) [10]. Importantly, that fact may be advantageous when grape pomace generation is too low to create single fuel unit (or when it is impossible).

Beyond the ones above, there is many other aspects to be concerned. Apart from the issues concerning grinding, homogenisation and composition with other fuels, the problem of high moisture content in pomace need to be resolved. In raw state, up to 70-80% mass of grape residues is water. It is necessary to dry it first to guarantee effective utilisation within most of power technologies, i.e. no-condensing boilers. According to [19], to reduce a moisture content of grape pomace from 60% to 8%, approximately 1.5 GJ of heat need to be utilised. However, that value may be covered by renewable energy streams (solar,
geothermal) or waste heat (from fumes) in integrated dryers. Comprehensive drying of grape pomace is essential to be introduced also for reasons of the periodicity of the grape pomace generation (harvesting takes place between September and October) \[9\]. When having a lot of water, aerobic biodegradation during storage contributes would deteriorate quality as a fuel. Furthermore, when grape pomace is used as a peak load fuel during winter and spring, the level of drying may be lower.

Tab. 1.
Physicochemical properties (proximate and ultimate analysis) of winemaking residues and solid fuels used in power generation sector (in dry state) \[11-16\]

<table>
<thead>
<tr>
<th>fuel</th>
<th>A</th>
<th>V</th>
<th>FC</th>
<th>FR</th>
<th>HHV</th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>S</th>
<th>O</th>
</tr>
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<td>WINEMAKING RESIDUES</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grape pomace</td>
<td>4.3</td>
<td>78.2</td>
<td>17.4</td>
<td>0.22</td>
<td>21.3</td>
<td>54.3</td>
<td>6.35</td>
<td>2.25</td>
<td>0.10</td>
<td>32.7</td>
</tr>
<tr>
<td>grape seeds</td>
<td>4.3</td>
<td>66.7</td>
<td>29.2</td>
<td>0.44</td>
<td>20.0</td>
<td>53.1</td>
<td>6.23</td>
<td>2.28</td>
<td>0.31</td>
<td>33.9</td>
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<tr>
<td>CONVENTIONAL SOLID BIOMASS</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>wheat straw</td>
<td>9.4</td>
<td>73.0</td>
<td>17.6</td>
<td>0.24</td>
<td>17.9</td>
<td>45.3</td>
<td>5.77</td>
<td>0.64</td>
<td>0.08</td>
<td>38.8</td>
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<td>rapseeds</td>
<td>7.4</td>
<td>73.5</td>
<td>19.1</td>
<td>0.26</td>
<td>19.6</td>
<td>47.1</td>
<td>6.13</td>
<td>0.52</td>
<td>0.71</td>
<td>32.2</td>
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<tr>
<td>oak wood</td>
<td>0.6</td>
<td>83.4</td>
<td>16.0</td>
<td>0.19</td>
<td>19.5</td>
<td>50.1</td>
<td>6.10</td>
<td>0.17</td>
<td>0.02</td>
<td>43.1</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>3.3</td>
<td>80.3</td>
<td>16.4</td>
<td>0.20</td>
<td>19.1</td>
<td>47.4</td>
<td>6.63</td>
<td>0.21</td>
<td>0.01</td>
<td>42.5</td>
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<tr>
<td>pumpkin husks</td>
<td>2.9</td>
<td>77.7</td>
<td>19.4</td>
<td>0.25</td>
<td>23.4</td>
<td>53.8</td>
<td>6.43</td>
<td>3.22</td>
<td>0.25</td>
<td>33.4</td>
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<td>POLISH COALS DEDICATED TO POWER PLANTS</td>
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<tr>
<td>bituminous coal 1</td>
<td>10.8</td>
<td>34.3</td>
<td>54.9</td>
<td>1.60</td>
<td>26.8</td>
<td>78.9</td>
<td>4.26</td>
<td>1.25</td>
<td>1.66</td>
<td>3.0</td>
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<tr>
<td>bituminous coal 2</td>
<td>7.9</td>
<td>35.8</td>
<td>56.3</td>
<td>1.57</td>
<td>27.0</td>
<td>79.0</td>
<td>4.71</td>
<td>1.23</td>
<td>1.13</td>
<td>5.8</td>
</tr>
<tr>
<td>lignite 1</td>
<td>17.9</td>
<td>47.6</td>
<td>34.5</td>
<td>0.73</td>
<td>21.7</td>
<td>60.2</td>
<td>4.90</td>
<td>0.51</td>
<td>1.33</td>
<td>15.1</td>
</tr>
<tr>
<td>lignite 2</td>
<td>16.8</td>
<td>46.4</td>
<td>36.6</td>
<td>0.79</td>
<td>18.9</td>
<td>57.7</td>
<td>4.71</td>
<td>0.63</td>
<td>1.88</td>
<td>18.2</td>
</tr>
<tr>
<td>ALTERNATIVE FUELS</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sewage sludge</td>
<td>36.0</td>
<td>52.9</td>
<td>11.2</td>
<td>0.21</td>
<td>13.8</td>
<td>56.8</td>
<td>4.62</td>
<td>0.67</td>
<td>1.28</td>
<td>0.7</td>
</tr>
<tr>
<td>RDF</td>
<td>17.6</td>
<td>70.8</td>
<td>11.6</td>
<td>0.16</td>
<td>26.8</td>
<td>53.3</td>
<td>7.36</td>
<td>0.10</td>
<td>0.21</td>
<td>24.9</td>
</tr>
</tbody>
</table>


ENERGY GENERATION POTENTIAL OF GRAPE POMACE

In order to calculate the technical potential of grape pomace in power generation, two calculations models were introduced and dealt with separately. First of them concerns the heat generation in heat-only units with average annual efficiency 85%, second – the idea of combustion and co-combustion with black coal in cogeneration plant.

Firstly, in order to calculate lower heating value of a grape pomace (on the basis of the results of proximate and ultimate analysis – Tab. 1.), formulae (1) is used:

$$Q_l^w = Q_a^{100-W^w} - r\left(W^w + 8.94 \cdot H_a^{100-W^a}\right),$$  \[(1)\]
where: $Q_i^w$ – lower heating value in a operation conditions, $Q^a$ – higher heating value in a air-dried state (determined in a standardised lab tests), $W^w$ – moisture content in a operation conditions, $W^a$ – moisture content in a air-dried state, $r$ – heat of vaporisation of water per every 1% mass of moisture in the fuel (24.43kJ/kg).

Moreover, when transient moisture content in grape residues is determined, to evaluate total moisture content $W^w$ in a material equation (2) may be introduced:

$$W^w = W^a + W^w \frac{100 - W^a}{100}$$

(2)

Finally, to assess total heat generation from combustion process of grape pomace, formulae (3) can be utilised. However, when the yield of winemaking residues is unknown, the equation (4) is added:

$$Q = \eta \cdot B \cdot Q_i^w$$

(3)

$$B = P_{\text{wine}} \cdot b_{gp}$$

(4)

For the case of the thermal efficiency of a combustor $\eta = 0.85$ and unit generation of grape pomace (per 1 litre of wine) - $b_{gp} = 0.18$ kg/l, the contour graph representing influence of moisture content was created and presented in Fig. 2. Significant impact of moisture content on heat generation has been proven – for example, by drying raw waste material (70% of water), derived from the production of 70 mln litres of wine, to the moisture content of 10%, potential heat generation from no-condensing boiler can be enhanced four times. In Tab. 2., selected indicators concerning grape pomace utilisation in cogeneration unit were presented. Total net efficiencies - 30% for electricity and 50% for heat generation - of CHP unit was used. To calculate nominal power, 150 day of operation (from November to March) was adopted as well as 10% of moisture content in dried grape pomace.
Tab. 2.
Unit heat and electrical capacities (per 1 million litres of wine) of CHP unit supplied with grape pomace as a primary and secondary fuel (5% of mass in a mixture with black coal)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>95% coal + 5% grape pomace</th>
<th>100% grape pomace</th>
</tr>
</thead>
<tbody>
<tr>
<td>tonnes of grape marc</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>tonnes of black coal</td>
<td>3.420</td>
<td>-</td>
</tr>
<tr>
<td>electricity production</td>
<td>7.112</td>
<td>0.272</td>
</tr>
<tr>
<td>heat generation</td>
<td>42.672</td>
<td>1.632</td>
</tr>
<tr>
<td>average electric capacity</td>
<td>1.976</td>
<td>0.076</td>
</tr>
<tr>
<td>average heat capacity</td>
<td>3.293</td>
<td>0.126</td>
</tr>
</tbody>
</table>

SUMMARY

Grape pomace seems to have favourable quality to be regarded as a valuable solid biofuel in combustion units. Having the same or similar physicochemical properties of other biomass, the implementation within power units may be easier and faster. Importantly, due to higher content of nitrogen, the problem of increased NO\textsubscript{x} emission need to be solved in small units i.e. by the reorganisation of combustion zone. Furthermore, drying of grape pomace seems to be crucial to improve the technical potential of its utilisation.

In summary - when weather conditions do not promote obtaining high power capacities of wind turbines and photovoltaic units, frequent fluctuations of their instantaneous output are inadmissible or energy storage potential is insufficient, the implementation of renewable energy sources within power generation sector may be introduce by the firing or co-firing of different solid biomass, including grape pomace, in boilers with different power capacities. The energy use of winemaking residues responds to the growing interests in sustainable development and new energy policies, encouraging the application of waste biomass and clean sources of electricity, heat and cool within both municipal and industrial power units.

REFERENCES


