SUBSTITUTION OF NATURAL GAS BY BIOMASS

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Abstract. The task of investigation was development of main approaches for biomass preparing and processing for use it in industrial furnaces and boilers instead of natural gas. The direct combustion of sawdust and sunflower husks and gasification of different kinds of biomass were studied. The burn-out time of sawdust and sunflower husks particles was defined and demands for fuel preparing for use it in rotary kilns were elaborated. Special burners and heat regimes for sunflower husks combustion in rotary kilns were developed and implemented. Original technology of biomass air gasification was proposed and studied. It was shown, that producer gas has low calorific value sufficient for use it in boilers and engines. Industrial gas generator of 1,8 MW capacity and dual fuel burners for joint or separate combustion of producer and natural gas were developed and implemented at steam boiler. Technical solutions piloted in industrial scale could be efficiently applied in manufacturing sectors and energy sector.

Keywords: natural gas, biomass, gas substitution, biomass processing, technology of biomass air gasification.

Introduction
A considerable share of natural gas is one of the key problems of Ukraine’s energy balance. The biggest part of it is imported on high prices. So, development of technologies and equipment for natural gas substitution by alternative fuels is very actual. Among fuels for natural gas substitution special place possesses biomass. In Ukraine the cost of natural gas is two or three times higher than the cost of biofuel in a volume equivalent to the natural gas in terms of its energy potential. The resources of biomass in Ukraine are estimated in more than twenty billions of equivalent quantity of natural gas (Davyi, 2012). It must be also mentioned, that biomass has unquestionable advantages in comparison with coal from the point of view of negative influence on environment and greenhouse effect. Creating reliable and cost-efficient industrial objects, which use biomass for the substitution of natural gas, with the minimum payoff periods, was instrumental in defining the work program of biofuel use. Two types of technologies of biofuel use in thermal technological processes exist, which are based on two different principles – direct combustion and gasification. Each of them has its advantages and areas of application. The comparison of advantages and disadvantages of these two technologies is given in (Karpi, et. al., 2009). The highest effect is reached in case of direct combustion of pre-treated biomass in boiler furnaces or kilns. Biomass pre-gasification technology competes with direct combustion in a number of applications. Any energy transformation causes irreversible thermodynamic losses, which makes the fuel’s primary energy utilization somewhat less efficient than direct combustion. However, gasification has an indisputable advantage over direct combustion when the project is specifically intended to generate electric energy directly, process steam, in cogeneration technologies and combined processes of producer gas combustion simultaneously with natural gas and in the same burner. The study of technological chains using natural gas as a fuel enabled to develop the criteria to assess applicability of the specific technology for the natural gas substitution. The additional advantage of biomass direct combustion is equipment simplicity, the advantages of preliminary gasification are a big variety of initial raw materials, less charging of environment. In (Karpi, et. al., 2009) are also given numerous examples of wood wastes use for heat and electricity production in European countries. Mainly there are power station in a range of capacity 3,5-20MW. It is interesting to mention, that for suppression of nitric oxide formation in all examples the ammonia injection is used. For successful decision of problem the scientific-technical basis of technologies creation must be developed, but in literature information needed for technologies of biomass preparing and use in heat apparatus is insufficient. So, the task was raised to study some peculiarities of biomass direct combustion and gasification.
The process of burn-out of biomass solid particles was studied on the basis of applied theory of combustion principles. Knowledge of biomass particles combustion peculiarities is needed for development of natural gas substitution technology in furnaces, in particular in rotary kilns. The key parameter is time of burn-out of particle depending on its dimensions and humidity. This parameter determines possibility of use of definite kind biomass in heat apparatus. In process of development of furnace heating systems it must be also taken into consideration biofuel calorific value, conditions of ignition, ash melting temperature, flame position in furnace, formation of hazard wastes in a combustion process.

The most complete survey of many hundred publications in CIS and foreign countries on gasification and adjacent processes and technologies since year 1811 to this time is given in monograph (Kopytov, 2012). The novelty of our investigations consisted in thermodynamic calculations of producer gas content, experimental study of big variety of biomass gasification, perfection of gasification process and equipment.

**Methods**

The burn-out of sawdust particles was investigated theoretically by mathematic simulating (Karpi, et. al., 2010). The main stages of process were considered in sequence – free and bounded moisture removing, release and combustion of volatile matters at particle surface, burn-out of coke residue. Model permitted to solve combined task of outer and internal heat exchange. The physical parameters of wood particle were taken into account – free volume of pores, its filling by free water, content of mineral and combustible parts of solid phase, part of volatile and bounded moisture. It was supposed, that motionless particle is blown by oxygen content stream of constant temperature.

The time of the particles’ combustion was experimentally determined by the installation of the fluidized bed with inert heat carrier during the combustion in the air at 900°C temperature. The installation is intended for dynamic of burn-out of solid particles study in air in fluidized bed in a range of pressures 0,1-2,5 MPa and temperatures since 500°C to 1250°C [5]. The process of study is clear from fig. 1.

![Experimental plant for biomass particles burn-out time study](image)

**Fig.1** Experimental plant for biomass particles burn-out time study: 1 - electrical furnace; 2 – reactor; 3 – gas distribution rate; 4 – MgO filling; 5 – specimen suspension; 6 – cooler; 7 – cyclone; 8 – throttle; 9 – gas analyzer Ultramat-23; 10 – computer; 11 – rotameter; 12 – air vessels; 13 – argon vessels; 14 – valves; 15 – manometer; 16 – reservoir; 17 – sluice; 18 – thermometer; 19 – thermocouples; voltage control.
The experimental and theoretic study of biomass gasification process was provided. A pilot batch-oriented gas generator for gasification of different biomass types was developed and tested (fig. 2).

![Fig.2 The view of experimental gasification installation](image)

The main task was to determine the heat characteristics of producer gas and to estimate possibilities of use it for natural gas substitution. The fundamentals used for the generator development were based upon technology by Sibtermo Company (Krasnoyarsk) applied for Kansk-Achinsk brown coal gasification for semi-coke production purposes (Stepanov, 2002). This technology uses inverse gasification process of very low productivity, so the approaching to chemical equilibrium must be maximal. Calculations of thermochemical equilibrium of reacting systems were used as an instrument for assessment of thermodynamic perfection of processes. For calculations standard program “Terra” (Trusov, 2012) was used.

**Results**

The results of calculations of sawdust burn-out time are shown at fig. 3 (Karpi et. al., 2010). The sunflower husk burnout process was not modelled, because not sufficient source data on this fuel’s physical properties was available.

![Fig.3 The temperature of center and surface of sawdust particle in burn-out process](image)

The curve at fig.3 shows that burning of coke residue defines particle burn-out time. Typical curve of burn-out of biomass particle is shown at fig. 4; The generalized results of experimental study of burn-out time of sawdust and sunflower husks particles in a range of humidity 0,5-2,5 % and particles dimensions 1,0 -3,0 mm are shown at fig. 5.
Fig. 4 An example of curve of burn-out sawdust particle (d=2.5-3.0 mm, W=12.5%). Temperature/time.

Fig. 5 The dependence of sunflower husks and sawdust burn-out time on its diameter and humidity:
■ – 1.3 m; ▲ – 2.05 m; ● – 2.75 m: husks – solid line, sawdust – dashed line.

It is shown that minimal burn-out time and maximal combustion temperature are reached if fuel is of naturally-air drying (W_r = 10 – 12%). Both increased and decreased humidity leads to burn-out time increasing. Particles dimensions increasing leads to burn-out time increasing only on account of coke remainder combustion time. It follows from this experiment that wood waste burns out about two times quicker than the particles of sunflower husk. The deviation in the level of particles' moisture from the natural moisture results in the increase of their burnout time. The experimental data regarding the wood sawdust have coincided with the results of mathematical process modelling completely.

For the implementation in industry results of researches, technical requirements were defined, which the fuel had to meet to ensure complete combustion of particles in the combustion space. The type of fuel was to be taken into account. The parameters that determine the combustion speed are fraction composition and moisture of solid particles. It was installed, that the diameter of sawdust particles must be no more 3.0mm, sunflower husks – 2.0 mm or less, both of naturally-air drying. The solution of using biofuel direct combustion technology was implemented on the rotary kiln of refractory clay firing at one Refractories in Ukraine. Technical re-equipment of the system was targeted at the maximum reduction of natural gas’ usage through its substitution with pre-treated biofuel. The furnace specifications (fig. 6): 75 m length, 3.5 m diameter, 15 ton/hour output of final product.

The automated complex of biomass use as fuel includes a fuel depot, biomass pneumatic conveying line, a burner device, as well as a control and automation system. Average gas consumption before the project was 2200 m^3/hour. Based upon the evaluation of the local biomass resources by the factory’s experts, sunflower husk was selected as the principal biofuel, with the possibility to use waste wood (sawdust) as well. During the burning of mid-temperature fire-proof compounds the degree of natural gas substitution reached 70%, while in the process of burning of high-temperature fire-proof compounds - it was up to 50%.
Fig. 6 Rotary kiln fuelled by biomass in Ukraine

The complex has been successfully operated since 2010. Annual volume of natural gas substitution with biofuel is over 10 million m$^3$. The funds invested in the project had been repaid in less than 1 year.

The testing results of biomass gasification at experimental installation are presented in Table 1.

Table 1
Gasification of solid fuels. Gas composition, substitution rates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Solid fuels for gasification</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wood chips (humidity 15%)</td>
<td>Rise husk</td>
<td>Pellets</td>
<td>Lignite husk</td>
<td>Brown coal</td>
</tr>
<tr>
<td>H$_2$</td>
<td>13.35</td>
<td>11.36</td>
<td>16.86</td>
<td>11.3</td>
<td>12.24</td>
</tr>
<tr>
<td>N$_2$</td>
<td>48.83</td>
<td>54.8</td>
<td>44.92</td>
<td>49.45</td>
<td>55.24</td>
</tr>
<tr>
<td>CO</td>
<td>16.03</td>
<td>15.69</td>
<td>19.51</td>
<td>12.59</td>
<td>11.88</td>
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<tr>
<td>CH$_4$</td>
<td>5.57</td>
<td>4.72</td>
<td>5.81</td>
<td>6.71</td>
<td>4.24</td>
</tr>
<tr>
<td>CO2</td>
<td>12.49</td>
<td>10.55</td>
<td>9.15</td>
<td>15.84</td>
<td>12.87</td>
</tr>
<tr>
<td>C$_2$H$_4$</td>
<td>0.77</td>
<td>0.55</td>
<td>0.71</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>C$_2$H$_2$</td>
<td>0.16</td>
<td>0.02</td>
<td>0.0</td>
<td>0.34</td>
<td>0.0</td>
</tr>
<tr>
<td>C$_2$H$_6$</td>
<td>0.11</td>
<td>0.07</td>
<td>0.18</td>
<td>0.21</td>
<td>0.0</td>
</tr>
<tr>
<td>C$_3$H$_8$</td>
<td>0.07</td>
<td>0.03</td>
<td>0.1</td>
<td>0.13</td>
<td>0.0</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>2.62</td>
<td>2.21</td>
<td>2.69</td>
<td>2.49</td>
<td>2.34</td>
</tr>
<tr>
<td>$\sum$</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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</tbody>
</table>

The composition of the generator gas, % vol

Indicators of substitution and energy data

| Low calorific value, MJ/m$^3$ (cal/cm$^3$) | 6.13 (1464) | 5.24 (1251) | 6.97 (1664) | 6.77 (1617) | 4.92 (1175) | 5.32 (1270) |
| Solid fuels to replace 1 m$^3$ of natural gas, kg | 3.7 | 3.3 | 2.5 | 2.6 | 3.2 | 2.8 |
In parallels calculations of equilibrium content of producer gas, received by wood pellets gasification were provided. The results of its comparison with experimental content are given in Table 2.

<table>
<thead>
<tr>
<th>Gas content</th>
<th>H₂</th>
<th>CO</th>
<th>CH₄</th>
<th>CₘHₙ</th>
<th>N₂</th>
<th>CO₂</th>
<th>Residue*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated</td>
<td>24,61</td>
<td>21,55</td>
<td>1,22</td>
<td>0,00</td>
<td>41,31</td>
<td>11,32</td>
<td>0,08</td>
</tr>
<tr>
<td>Experimental (1)</td>
<td>20,70</td>
<td>21,17</td>
<td>3,63</td>
<td>0,28</td>
<td>42,45</td>
<td>11,78</td>
<td>0,08</td>
</tr>
<tr>
<td>Experimental (2)</td>
<td>20,42</td>
<td>20,52</td>
<td>3,60</td>
<td>0,31</td>
<td>41,79</td>
<td>13,37</td>
<td>0,08</td>
</tr>
</tbody>
</table>

* Csolid+ash

It is seen, that low calorific value of producer gas is at 1,7-1,8 times more than LCV of blast furnace gas and can be successfully used for natural gas substitution in low and middle temperature furnaces, boilers and gas engines. In high temperature processes both gas and air must be heated.

About 20% of energy is spent on the cooling of the gas generator body. This energy can be used for heating of the boiler feed water or for technical needs.

The difference between calculated and experimental results is not considerable. At the same time it shows imperfection of real process and points out the necessity and way of technology improvement.

Setting up of a complex with 1.8 MW installed capacity for wood pellets gasification is an example of the development and implementation of biomass gasification technology and equipment. The complex is designed for partial substitution of natural gas in the steam boiler heating system. It includes gas generator (fig. 7); gas purification and transportation system; dual fuel burner for simultaneous combustion of natural and producer gas; system of boiler operation automatic support and the steam boiler. The complex has been operated at Paper Mill at Zhytomir region, Ukraine, since January 2011.

Average producer gas output, taking into account the power change, was 120 m³/hour in natural gas equivalent. The substitution of natural gas with producer gas did not result in the boiler productivity reduction. The development of an effective system for producer gas purification from resins and resin-containing items was an important result of this effort. The use of wood pellets for natural gas substitution enabled reduction of the costs for natural gas purchase by over 30%.
Discussion

The substitution of natural gas with biofuel is commercially viable and attractive for many countries. Two technologies of biomass use are considered in article: direct combustion and gasification. For realizing of this technologies in industrial scale it was provided preliminary theoretical and experimental study of biomass combustion and gasification. Mathematical simulation of wood particle combustion was provided by specially developed model. The physical parameters of wood particles were taken into account. The experimental data regarding the wood sawdust have coincided with the results of mathematical process modelling completely. The results of researches has enabled to formulate the requirements to biofuel for efficient burning in the rotary kilns, to develop original burners and control system, to elaborate special combustion regime with minimal hazard wastes issue.

The same steps were done in biomass gasification research and implementing: calculation of producer gas content on the basis of thermochemical equilibrium approach, pilot scale experimental study of different kinds of biomass gasification, design on this basis of industrial gas generator, duel fuel burners, control system, heat regime elaboration.

Technical solutions piloted in industrial scale is the best confirmation of rightness of main approaches and investigation results and could be efficiently applied in manufacturing sectors and energy sector.

References


