

Tadeáš OCHODEK\*, Jan NAJSER\*\*, Rafal CHŁOND\*\*\*

TECHNICAL ASPECTS IN HEAT AND ELECTRIC ENERGY PRODUCTION BY  
WASTE BIOMASS GASIFICATION IN SOUTH MORAVIA SAWMILL

TECHNICKÉ ASPEKTY VÝROBY ELEKTŘINY A TEPLA ZE ZPLYNĚNÍ ODPADNÍ  
BIOMASY Z JIHOMORAVSKÉ PILY

**Abstract**

The paper presents results of tests on a pilot plant using waste from the process timber. Experiments presented were obtained from the gasification of different biomass fuels, as well as various types of reactors. Presented biomass gasification technology shows the optimization process of converting fuel to its energy use in cogeneration unit. Installation requires few refinements of various gas purification components and the preparation of a long work to obtain the best possible economic effects.

**Abstrakt**

Príspevek prezentuje výsledky testů na pilotním zařízení určeném pro využití odpadního dřeva z pilařského průmyslu. Prezentovány experimenty byly získány ze zplyňování různých paliv, v různých typech reaktorů. Prezentovaná technologie zplyňování biomasy ukazuje optimalizaci procesu přeměny pevného paliva na plyn a jeho energetické využití v kogenerační jednotce. Instalace vyžaduje vylepšení systému čištění plynu a přípravu dlouhodobého provozu pro **získání co nejlepších ekonomických výsledků**.

**1 INTRODUCTION**

World energy consumption trend is rising and surely it will not be limited by more efficient activities and technologies. The reason for this state of affairs is population growth but also the needs of industry and households. This is another reason of huge interests of new and cheaper sources of energy, alternative fuels, energy recovery and finally renewable energy sources which include biomass.

Current efforts to reduce CO<sub>2</sub> emissions and the amounts used of fossil fuels are the cause of wider use of renewable fuels as well as waste. This leads to the arising of new installation using local fuel sources as well as with various types of process waste. Wastes are increasingly being used to produce electricity and heat. A high level of pollution in waste requires applying more efficient and resistant to different substances devices.

The current situation in the energy industry emphasize the desirability of implementation the small cogeneration systems to national grid. The interests in renewable energy sources as well as the use of waste generated in various processes are increasing. The cogeneration units must meet the both criteria – economic ones as well as demand for high reliability and low environmental impact [9].

The last decade has shown that the European Union is moving towards the use of fuels with high purity as well as renewable fuels. The table below (Tab. 1) was presented information about fuel

---

\* Doc. Dr. Ing. Tadeáš OCHODEK, VŠB - Technical University of Ostrava, Energy Research Center, 17. listopadu 15, Ostrava-Poruba, 708 33, Czech Republic, tel. (+420) 59 732 4265, e-mail tadeas.ochodek@vsb.cz

\*\* Ing. Jan NAJSER, Ph.D., VŠB - Technical University of Ostrava, Energy Research Center, 17. listopadu 15, Ostrava-Poruba, 708 33, Czech Republic, tel. (+420) 59 732 3855, e-mail jan.najser@vsb.cz

\*\*\* Ing. Rafał CHŁOND, VŠB - Technical University of Ostrava, Energy Research Center, 17. listopadu 15, Ostrava-Poruba, 708 33, Czech Republic, tel. (+420) 59 732 3855, e-mail rafal.chlond@vsb.cz

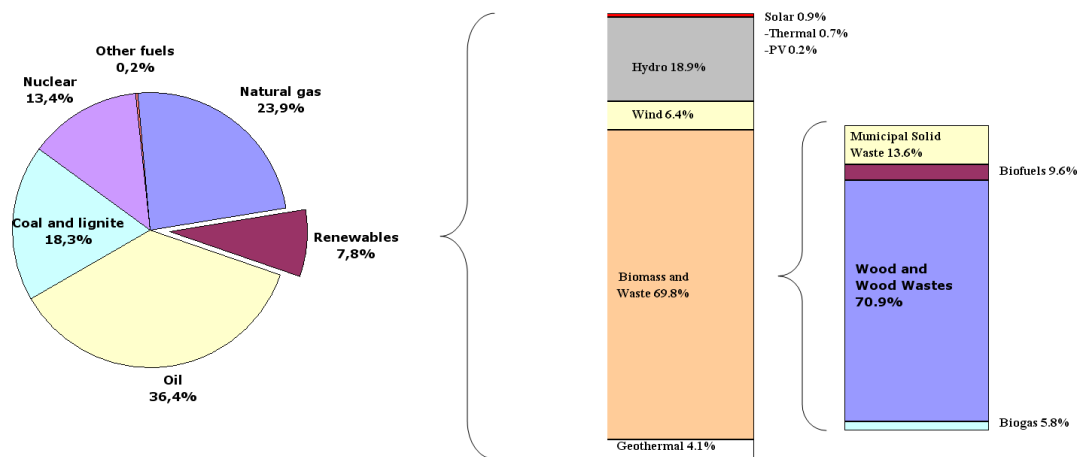
consumption and waste in the toe. Numbers of fossil fuels like coals, oil or fissile fuels are kept constant. However, clear tendency of increased demand for gases fuels about 10% and 41% of renewable fuels.

**Tab. 1** Total fuel consumption in EU27 in toe. [5]

| EU27 million toe                                  | 2000          | 2001          | 2002          | 2003          | 2004          | 2005          | 2006          | 2007          |
|---|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Coal and lignite                                  | 321.1         | 321.9         | 320.9         | 331.9         | 330.0         | 319.5         | 325.1         | 331.2         |
| Oil   | 659.9         | 675.0         | 667.9         | 674.0         | 676.4         | 676.5         | 673.1         | 656.9         |
| Gas   | 393.4         | 404.1         | 406.0         | 425.9         | 435.7         | 446.0         | 438.0         | 432.4         |
| Nuclear   | 243.8         | 252.5         | 255.4         | 256.9         | 260.1         | 257.4         | 255.3         | 241.3         |
| Renewable   | 99.6          | 102.4         | 100.9         | 109.0         | 117.4         | 121.6         | 129.9         | 141.0         |
| Other (industrial waste, net electricity imports) | 6.6           | 7.0           | 6.7           | 5.3           | 4.3           | 4.6           | 4.1           | 3.5           |
| <b>Total (as reported)</b>                        | <b>1724.3</b> | <b>1762.9</b> | <b>1757.8</b> | <b>1803.0</b> | <b>1823.9</b> | <b>1825.6</b> | <b>1825.5</b> | <b>1806.3</b> |

Calculating the percentage of those two types of fuels in the total balance is obtained about 1/3 share in the overall market. Gases fuels, by virtue of their nature, are also burdened with the political influence. Long-planned investments based on gas may prove to be unviable as a consequence. It leads to conclusion that is necessary to use locally available raw materials.

Renewable fuels such as biomass can for the local market fully satisfy the needs of its residents. Using energy crops, we can in a controlled way schedule delivery of raw materials, which is beneficial for the manufacturing process, the economics of investments as well as social peace. In wooded areas responsible forest management also brings tangible benefits. Presented on the chart below (Fig. 1) was shifted percentage of used fossil fuels, renewable and waste in the EU 27. Analyzing the share of biomass in the used renewable energy can be seen both significant and lasting impact on energy production. The potential lying on the side of renewable fuels has not been yet fully exploited but it requires reasonable management. A similar situation applies to waste and those in the near future will become a big part in energy production.



**Fig. 1** Total primary energy consumption by energy source in 2007, EU-27. [5]

The article presents state of art and gained experience in Energy Research Centre in Ostrava. The second part of the paper is focus on the characteristics of the plant used to produce electricity and heat using air biomass gasification process. A presented sheet date shows the results of measurements

gas composition and efficiency of purification devices. Presented installation based on waste biomass gasification located in south Moravia sawmills.

## 2 REQUIREMENTS OF GASIFICATION PROCESS

### 2.1 Fuels in gasification process

The shape of the installation is determined of the fuel composition. The composition of fuel used in installation significantly affects the way of gasification and purification methods resulting gas. A main factor influencing the type of used reactor is moisture content. At low water content in the fuel in a simple way without pre-drying can be provide such fuel to reactor. For a downdraft reactor is the value to 20% War [6]. For higher values of moisture should be used to fuel the drying process, however, replacing the classic updraft reactor [6], it can avoid additional investments. Reactors of this type can be operated with fuel at a water concentration of up to 50% (Tab. 2). That high water content often found in fresh biomass or pre-processed sludge. However, attention should be paid to the concentration of tars in the gas caused by high moisture may be significant and occur up to several  $\text{g}\cdot\text{m}^{-3}_{\text{N}}$ .

The second factor that affects the way of gasification is granulation of fuel. It influences at the way of transportation as well as the type of reactor. Otherwise, gasification technology will look like for chips and for rice hulls. The classic Imbert type reactor is able to work on fuel by only a lower limit of size. Below this value, the fuel will pour through the throat of reactor. Therefore, this type of device is optimal for fuels with high grain and also will not require the preparation of fuel. Fine coal plants are often highly energy intensive. Looking at renewable fuels, which are already available to small grain size like rise hulls, require updrafts reactors with low-speed gas flow or fluidized bed reactors. This type of fuel is a quality product that does not require either drying or grinding for appropriate granulation.

**Tab. 2** Technical and elementary analysis of biomass and other substances used for energy production.

| Parameters      | Wood         |             |             | Waste   |               |         |
|-----------------|--------------|-------------|-------------|---------|---------------|---------|
|                 | Hardwood     | Softwood    | Tree bark   | MSW     | Sewage sludge | RDF     |
| Moisture War[%] | 11.3 - 66.1  | 41.6 - 55.8 | 0 - 71.2    | 25 - 40 | 0.2 - 83.9    | 5 - 35  |
| Volatiles Va[%] | -            | -           | 76          | 22.4    | 47.8          | -       |
| Ash Aa[%]       | 0.35 - 15.21 | 0.17 - 1.77 | 0.34 - 9.53 | 5 - 25  | 14.25 - 42.66 | 1 - 10  |
| Carbon %        | 43.7 - 45.2  | 42.8 - 53.4 | 47.8 - 56.9 | under 8 | 39.2 - 58     | -       |
| Hydrogen %      | 4.35 - 6.2   | 5.42 - 5.86 | 4.8 - 6.4   | 5.37    | 5 - 9.2       | -       |
| Oxygen %        | 43.1 - 45.4  | 41.5 - 44.2 | 40          | 39.37   | 30.2          | -       |
| Nitrogen %      |              |             | 0.02 - 0.81 | 1 - 5   | 2.25 - 12.21  | -       |
| Sulfur %        | 0.03 - 0.15  | 0 - 0.02    | 0.02 - 0.12 | 0.1 - 1 | 1.02 - 5.33   | 0 - 0.4 |
| Chlorine %      | -            | -           | -           | 0.3     | 0.017 - 0.1   | 0 - 1   |
| LHV MJ.kg-1     | 4.6 - 14.7   | 6.8 - 18    | 16 - 21     | 4 - 11  | 12 - 25       | - 19    |

### 2.2 Gasification agent

Gasification agent is an important factor and significantly affects the low heating value LHV generated gases. Effect of medium on the gas composition was shown in the following table (Tab. 3). In small installations is always used as a gasification agent air which does not require the preparation and is safe way to convert the fuel but 50% of content of nitrogen in generated gas lower the LHV.

When it is using water steam as a agent, gasification process converts from autothermal to allothermal. Process required providing the necessary amount of processes heat. It may seem the best solution will be to apply oxygen, but it significantly affects the unit costs of installation as well as the process of gasification of the fuel. During the process there comes a phenomenon of melt slag. Currently, such facilities are not built based on biomass. The solution to this problem would be to use a mixture of  $O_2+H_2O$ . In the solution installation does not require such a large installation for the production of oxygen. At the same time steam which is in the agent acts as a shield and stabilize the gasification process, reducing the probability of ash slagging. Currently available are cheap plants for the production of sufficient oxygen purity of 92% and low rate of energy consumption.

**Tab. 3** Effect of gasification agent on the gas composition.

| Gas composition,<br>% vol.                | Types of medium gasification |       |            |        |       |
|---|------------------------------|-------|------------|--------|-------|
|   | $O_2+N_2$<br>(air)           | $O_2$ | $O_2+H_2O$ | $H_2O$ | $H_2$ |
| <b>H2</b>                                 | 8-16                         | 10-25 | 28-40      | 35-40  | 34.8  |
| <b>CO</b>                                 | 10-18                        | 40-60 | 15-25      | 25-30  | 4.3   |
| <b>CO2</b>                                | 12-16                        | 15-30 | 20-40      | 20-25  | 10.1  |
| <b>CH4</b>                                | 2-6                          | <3    | 5-8        | 9-11   | 50.2  |
| <b>N2</b>                                 | 45-60                        | <1    | <1         | <1     | <1    |
| <b>&gt;C2</b>                             | 0.5-2                        | <0.5  | <2         | <5     | -     |
| <b>Dust <math>g \cdot m^{-3}</math></b>   | 1-1000                       | <20   | <0.5       | <20    | -     |
| <b>LHV <math>MJ \cdot m^{-3}_N</math></b> | 4-7                          | 9-18  | 10-14      | 10-16  | >22   |

### 2.3 Experience of gasification of different fuels in different technologies

Energy Research Centre (ERC) in its work deals with the process gasification of biomass, contaminated biomass and as well as various kinds of wastes. Table 4 below shows the results of many experiments carried out both on small laboratory installation as well as on the bigger pilot. In the table are presented the results of experiments of energy crops, wood biomass as well as waste biomass from agriculture. Each type of fuel will behave a little different and gave different final composition of the gas. In addition, in the table are presented the results from gasification in two different types of reactors (downdraft and fluid) [10]. Variation of the composition and finally LHV may be due to the longer response time of fuel in the process with agent in the fluid bed reactor.

### 2.4 Comparison of gas composition in different technologies in Czech Republic and the world

Gasification process begins to return to its old glory and more institutions begin to deal with these issues on a larger or smaller scale. ERC operates a number of studies related to both the gasification of different fuels as well as using different technologies. The following table (Tab. 5) was presented the average ranges of concentrations of individual gas components of the technologies developed in the Czech Republic (DSK, Skoblia, ERC VT1 and VTP) and other works in the world. These are plants with efficiency to several hundred of kW, operating on the air. This is also due to a low calorific value LHV of gases. However, the considerable interest of small installations leads to the building of new units that use the fuel in place of its creation (sawmills, waste separation factor, etc.). ERC has a laboratory installation VT1 130 kWt for biomass gasification, which is used to study properties of fuels and conditions of gasification process. Technology VTP is a pilot installation based on laboratory plants but on a larger scale. The installation was designed for a 100 kWt working on contaminated wood after the initial separation. This installation is at the stage of performance tests.

**Tab. 4** Gas parameters from gasification of different plants and in different types of reactors

| Biomass                                 | Amaranth | Birch | Beech | Corn  | Spruce | Willow |
|---|----------|-------|-------|-------|--------|--------|
| Parameters                              |          |       |       |       |        |        |
| <b>Fluid reactor</b>                    |          |       |       |       |        |        |
| <b>Gas comp. %</b>                      |          |       |       |       |        |        |
| CO                                      | 12.7     | 11.6  | 15.1  | 9.83  | 13.1   | 15.5   |
| CO <sub>2</sub>                         | 15.8     | 12.6  | 15.5  | 18.3  | 15.6   | 12.8   |
| N <sub>2</sub>                          | 48.9     | 53.2  | 55.5  | 52.3  | 58.2   | 48.4   |
| O <sub>2</sub>                          | 0.72     | 0.62  | 0.82  | 0.29  | 1.63   | 0.19   |
| H <sub>2</sub>                          | 18.9     | 18.7  | 8.29  | 15.6  | 10.0   | 13.5   |
| CH <sub>4</sub>                         | 1.42     | 1.96  | 3.06  | 1.83  | 0.80   | 0.84   |
| C <sub>2</sub> -C <sub>6</sub>          | 1.41     | 0.98  | 1.47  | 1.48  | 0.21   | 0.24   |
| H <sub>2</sub> S                        | 0.01     | 0.01  | n. d. | 0.01  | 0.01   | 0.01   |
| benzene                                 | 0.07     | 0.07  | 0.14  | 0.11  | 0.07   | 0.07   |
| toluene                                 | 0.023    | 0.014 | 0.12  | 0.028 | 0.009  | 8.025  |
| <b>LHV MJ/m<sup>3</sup><sub>N</sub></b> | 5.62     | 5.23  | 5.03  | 5.18  | 3.34   | 4.08   |
| <b>Downdraft reactor</b>                |          |       |       |       |        |        |
| <b>Gas comp. %</b>                      |          |       |       |       |        |        |
| CO                                      | 13.4     | 20.3  | 18.4  | 11.2  | 17.9   | 19.5   |
| CO <sub>2</sub>                         | 16.2     | 18.4  | 12.7  | 12.9  | 14.1   | 10.5   |
| N <sub>2</sub>                          | 51.8     | 49.4  | 48.6  | 58.4  | 50.3   | 59.7   |
| O <sub>2</sub>                          | 1.15     | 0.9   | 1.30  | 2.4   | 1.5    | 2.2    |
| H <sub>2</sub>                          | 16.0     | 9.59  | 17.3  | 9.93  | 14.2   | 5.23   |
| CH <sub>4</sub>                         | 1.09     | 0.98  | 1.40  | 3.15  | 1.083  | 1.33   |
| C <sub>2</sub> -C <sub>6</sub>          | 0.16     | 0.21  | 0.23  | 1.22  | 0.31   | 0.44   |
| H <sub>2</sub> S                        | 0.01     | 0.01  | n. d. | 0.01  | 0.01   | 0.01   |
| benzene                                 | 0.04     | 0.14  | 0.02  | 0.04  | 0.05   | 0.1    |
| toluene                                 | 0.008    | 0.004 | 0.007 | 0.14  | 0.007  | 0.009  |
| <b>LHV MJ/m<sup>3</sup><sub>N</sub></b> | 4.03     | 4.37  | 4.72  | 4.83  | 4.53   | 4.01   |

**Tab. 5** Comparison of different technology in Czech Republic and the World

| Installation      | Gas composition, % vol. |                 |                |                 |                | LHV<br>MJ·m <sup>-3</sup> <sub>N</sub> |
|-------------------|-------------------------|-----------------|----------------|-----------------|----------------|--|
|                   | CO                      | CO <sub>2</sub> | H <sub>2</sub> | CH <sub>4</sub> | N <sub>2</sub> |  |
| <b>DSK</b>        | 15.5-21.7               | 10.4-14.4       | 13.1-15.9      | 1.0-2.8         | 48-55          | 4.3-6.0                                |
| <b>Skoblia</b>    | 24.0-28.0               | 7.8-10          | 13.9-16.5      | 1.7-2.0         | 46-49          | 5.6-5.7                                |
| <b>Bario</b>      | 23.2-26.6               | 8.6-11.3        | 14.3-16.7      | 1.3-1.8         | 46.2-49.4      | 5.3-5.7                                |
| <b>Mukunda</b>    | 15.5-19.6               | 12.4-14.9       | 18.6-20.6      | 1.1-1.5         | 47.4-49.5      | 4.8-5.2                                |
| <b>Reed, Gaur</b> | 22.1                    | 9.7             | 15.2           | 1.7             | 50.8           | 5.8                                    |
| <b>Schenk</b>     | 17.0-18.1               | 15.3-16.7       | 18.2-20        | 2.4             | 44-46          | 5.7-5.8                                |
| <b>ERC VT1</b>    | 16.0-19.0               | 11.0-14.0       | 13.0-18.0      | 1.0-3.5         | 49.0-52.0      | 5.2                                    |
| <b>ERC VTP</b>    | 6.1-9.1                 | 10.6-12.1       | n.d            | 1.0-1.8         | n.d.           | 4.3                                    |

### 3 INTERUPPTS IN THE PRODUCED GAS

The main obstacle preventing the extension of gasification technologies is to meet the requirements for quality and purity of the produced gas. Impurities in the gas (TSP, tar, nitrogenous compounds, alkaline compounds, sulphur, chlorine) cause operational problems for the individual apparatus gasification technologies, clogging of pipes and fittings, and tar covering of work surfaces of engines and turbines, which can lead to serious disruption of operated facility [1].

Solid particles contained in the gas from the gasification reactor are defined as solid phase comprising unreacted fuel particles (semi coke), inorganic substances (ash), or fluidized bed material [1].

The main source of TSP is ash material. Wood contains 1-2% of inorganic material, straw of various cereals about 10% [7]. Inorganic base of fuel remains in the bed and is discharged through the grid, or it is carry off from the reactor during biomass gasification. The concentration of solid particles in the gas depends on the generator design (type of reactor and gas speed in generator) and the ash content in fuel. Other major sources of solid pollutants are contaminants in the fuel (inert material incorporated into the fuel during its processing - such as soil, etc.) and incompletely reacted fuel – unreacted rest of carbon. Fuel particles during the gasification process in the reactor reduce its volume and subsequently there are drift by gas. Soot is also part of solid particles.

### 3.1 The quality requirements for gas

Gas quality requirements vary by type of device using the produced gas and also by the specific manufacturer of the device. Finishing of the gas depends on its use and various types of equipments need the specific gas quality and purity, viz. Tab. 6.

**Tab. 6** List of allowable gas pollution for various devices.

| Parameters and interrupts in gas | Fuel Cells SOFC                               | F-T Synthesis   | Gas turbine                                       | Piston engine                                    |
|----------------------------------|---|---|---|--|
| Temperature                      | 400 - 600°C                                   | 200 - 350°C   | < 100°C (for compressor)                          | < 50°C   |
| Pressure                         | Atmospheric or higher                         | 2,5 – 6 MPa   | <2.5MPa   | Atmospheric                                      |
| Dust concentration               | < 1 mg·m <sup>-3</sup><br>d <sub>p</sub> <1µm | ~0,1 ppm (mass)   | < 1-5 mg·m <sup>-3</sup><br>d <sub>p</sub> <3-5µm | < 50 mg·m <sup>-3</sup><br>d <sub>p</sub> < 10µm |
| Alkali                           | < 1 ppm (vol.)                                | < 10 ppb (vol.)   | < 0.2 mg/m <sup>3</sup>                           | *-   |
| Heavy metals                     | < 1 ppm (mass)                                | < 1 ppb (vol.)  | *-  | *-   |
| H <sub>2</sub> S                 | < 1 ppm (vol.)                                | < 1 ppm (vol.)  | < 50 ppm (vol.)                                   | *-   |
| HCL + HF                         | < 1 ppm (vol.)                                | < 10 ppb (vol.)   | < 5 ppm (vol.)                                    | *-   |
| NH <sub>3</sub> + HCN            | -   | < 1 ppm (vol.)  | < 50 ppm (vol.)                                   | *-   |
| Tars                             | < 10 mg·m <sup>-3</sup> *                     | * -   | < 5 mg·m <sup>-3</sup> *                          | < 100 mg·m <sup>-3</sup> **                      |
| Purifications methods            | High temperature ceramic filters              | Low temperature and pressure or high temperature and pressure | High or low temperature filters                   | Low temperature filtration                       |

\* no fully specify – depending on the conditions

\*\* only higher parts of tars (regardless on BTX)

Cogeneration units with internal combustion piston engines are the most common device used to produce electricity from gas produced by gasification of biomass [3]. The main advantage of this system is its simplicity, high efficiency and the possibility of using commercially produced both petrol and diesel engines. The gas must be free of dust and tars before its entering to the combustion engine. Solid particles cause accelerated wear of moving engine parts. Tar is prone to condensation on cold parts of the engine and forming of stable aerosols in cold gas. Requirements of internal combustion engines manufacturers are inconsistent and often incomplete because they manufacturers they have very few practical or negative experiences with the engines operated on the wood gas [11].

### 3.2 Removing of TSP from the gas

In Fig. 2 shows the scope of work and the efficiency which work's most popular on the market separators. Type of technology used is usually dictated by the requirements of the terminal equipment, the volume of gas, the concentration of particles in the raw gas, the properties of particles. The complexity of the purification process depends on the type of technology. Capital costs,

operating and maintenance costs may be substantially different for different methods and are a determining factor in the final stage of selecting the appropriate device.

Technology of removal of solid particles from the gas, we can distinguish [3]:

- inertial separators (for example cyclones),
- filters,
- electrostatic precipitators,
- scrubbers.

The chart below shows the fractional separation efficiency of various devices for removing solid particles from the gas [3].

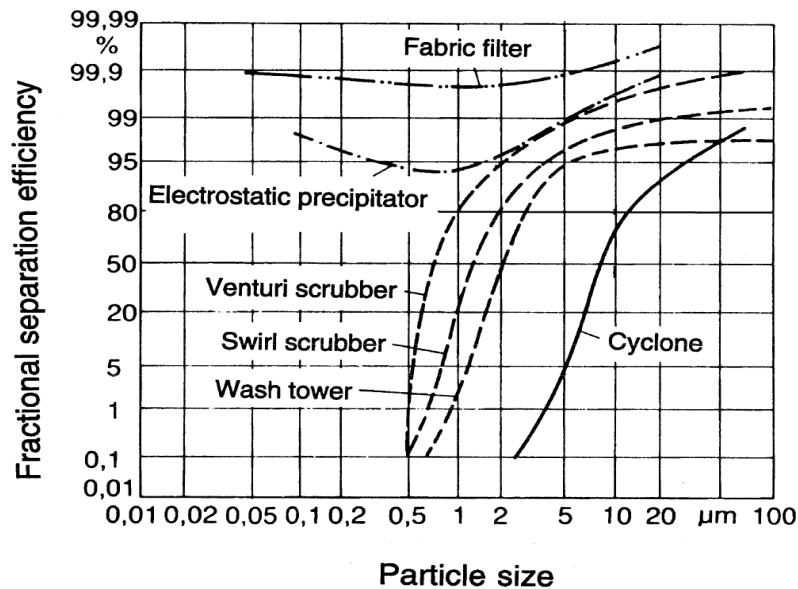


Fig. 2 The fractional separation efficiency of various gas purification devices

## 4 MEASUREMENT PART

### 4.1 Description of fuel used in gasification process

In the plant is used fuel, which is waste from the production process of sawmills. The fuel is collected from several processes and stored in open containers for better drying. The resulting waste has a different size. Pieces of wood are from 2 to 10 cm thick, 5 cm wide and 5 to 20 cm in length. Such a particle size of fuel is appropriate for the reactor and allows it to contact the gasification agent throughout the reactor. The following table (Tab. 1) present the physical and chemical composition of the fuel used in the installation. Moisture content (16.7 %) in the fuel is at a low level, within the limits of tolerance for a reactor. The high calorific value of 17.6 MJ.kg<sup>-1</sup> positive effect on the stability of the gasification process.

**Tab. 7** Fuel used in gasification installation.

| Parameters      | % mass              | Softwood |
|-----------------|---------------------|----------|
| Humidity Wa     | % mass              | 16.73    |
| Volatiles Vd    | % mass              | 82.99    |
| Fixed carbon Fd | % mass              | 16.71    |
| Ash Ad          | % mass              | 0.30     |
| C               | % mass              | 49.86    |
| H               | % mass              | 6.14     |
| O               | % mass              | 43.38    |
| N               | % mass              | 0.31     |
| S               | % mass              | 0.01     |
| LHV             | MJ/kg <sup>-1</sup> | 17.59    |
| HHV             | MJ/kg <sup>-1</sup> | 20.52    |

#### 4.2 Description of the installation

The basis of the installation is modified Imbert reactor for biomass gasification. Developed unit generates over 660 kW with efficiency 87.4 %. Fuel is supplied to the top of the reactor [Fig. 3] by trolley and poured through the hole.



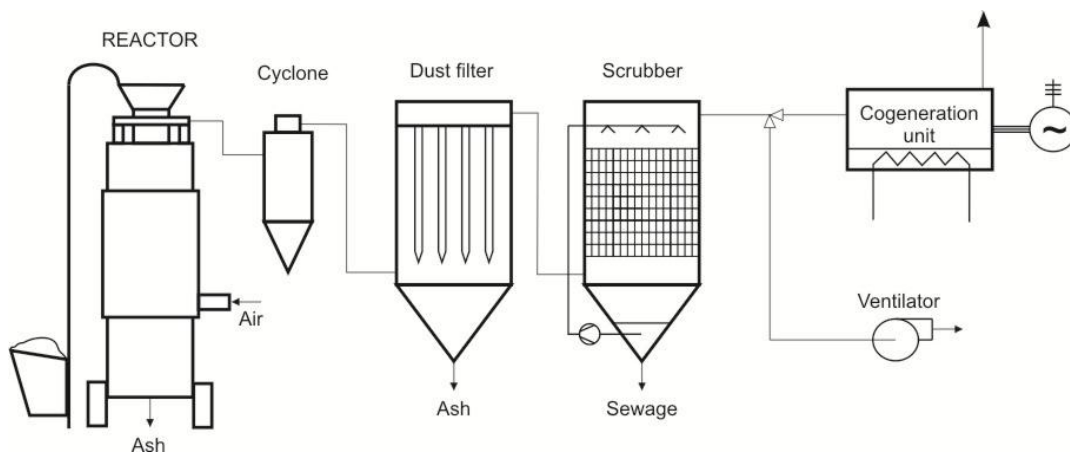
**Fig. 3** Photo of modified Imbert reactor.

Whole process is full automatist beginning from the main container. Filling level of the generator is controlled by ultrasonic range-finder placed above the inlet of the reactor. The



measurement of the height fuel column is conducted at the time of opening the hatch for about 10 seconds. The amount of fuel measurement is made every 5 minutes. If it is low, trolley pure the reactor, if it is high, flap is closing in anticipation of further opening period.

Agent used in biomass gasification is air which is heated in a heat exchanger located on the outer coat of reactor to temperatures of 200-240°C. Localization of nozzles distributing agent in the reactor on two levels allow reducing levels of field temperature in neighborhood of nozzles. The reason of nozzles level division was fuel slagging often occurring in earlier version of gasifier. The good results obtained in modeling process of the vertical agent supplying pipe implementation will help further reduce the risk of clogging the reactor. The biomass gasification process in each type of fixed bed reactors looks different. In presented solution setting of zones sequence looks as following: first and the highest one is drying zone, second and lower is pyrolysis zone, next one is oxidation zone and the lowest in whole gasification process is reduction zone. The gasification process in Imbert reactor is autothermal and does not need the external sources of energy. The drying zone, pyrolysis zone and reduction zone are endothermic and consume heat energy from exothermic process. To reactor has been implemented an innovative method of recycling heat from hot gas from reduction zone flowing through the drying zone and giving back thermal energy. The gas is leaving the reduction zone with a high temperature around 850°C. It seems to be natural to turn such large quantity and high quality heat back to the gasification process. Gas passing through the fuel bed is initially cleared of dust and charcoal. 50% of dust flowed in the produced gas is a chemical energy that could be used back in gasification process. Even small part of chemical energy returning to process helps to improve the mass balance. In additional phenomenon effecting the process of gas flowing through the fuel is decreasing the tars concentration. The biggest problem that may occur in the properly operating is tars condensation in purification and utilization devices. In conjunction with the dust contained in the gas, it reduces the pipe clearance and cause accumulation of gas in installation [Fig. 4].



**Fig. 4** Schema of a gasification installation during measurement.

The gas at the reactor outlet still has a high temperature of 400°C. This condition helps to protect against the tars and water vapour condensation but require the implementation of advanced technology. In the first step gas is being purified form the dust by the cyclone and secondly by the material filters which removes remainder concentration.

A pulse-jet system was implemented in the dry filter to regenerate the working elements. In addition at working element is being created a layer of dust cake which helps both: to filter the dust and to protect the elements from erosion. Gas purification installation gains efficiency of the level of 99.3 %.

In next step, gas was been cooled to temperature near 70 °C and introduced to scrubber. Water was an agent used in scrubber. It purified gas from tars and water vapour. It helped to remove

residues in gas and reduced temperature to required 30°C. Demister used in scrubber helped to remove all droplets contained in gas. The temperature of the produced gas is an important parameter required by the piston engine. Compressor was implemented to increase the engine power in the flow system. Gas prepared in that way was utilized in a cogeneration unit. In tested installation there was implemented modified piston engine form Tedom company, with the efficiency  $\eta = 0.35$ . Presented plant is able to produce from the gas, exhaust cooling and engine cooling block 350 kW of heat. Gas utilization allows producing 200 kW of electricity.

#### 4.3 Measurement result

On the installation there were carried out a series of measurements which were taken to confirm the reasonableness of the modernizations, changes and installation settings. Ultimately, this allowed achieving optimal working conditions and maintenance-free. Measurements were made on partially modified plant that replaced the two cogeneration units with one but achieving the same gas producing capacity. The rest of the gas, which was not utilized in engine, was drained and burned in a fan flare. To maintain high efficiency of the reactor included in the installation of a fan.

##### 4.3.1 Gas measurement methodology

The installation was conducted on two types of measurements: energetic parameters (gas and water flows, temperatures, pressures, electric power) and parameters of the gas (composition of gas, dust and tar content). Some of parameters were recorded by main computer, rest was measured and all were balanced. Measurement of the composition of the gas and tars were taken in two places but concentrations of dust were measured on individual elements of the gas purification system for determining the efficiency of individual devices. Measurement of gases was carried out in two methods, ON-Line and Off-Line. Samples received from gas to tedlars allow conducting later detailed analysis of the gas. The results of the ON-Line measurement of basic components (CO, CH<sub>4</sub>, CO<sub>2</sub>) and OFF-Line were presented on the work achieved in the following figure Fig. 5 [8].

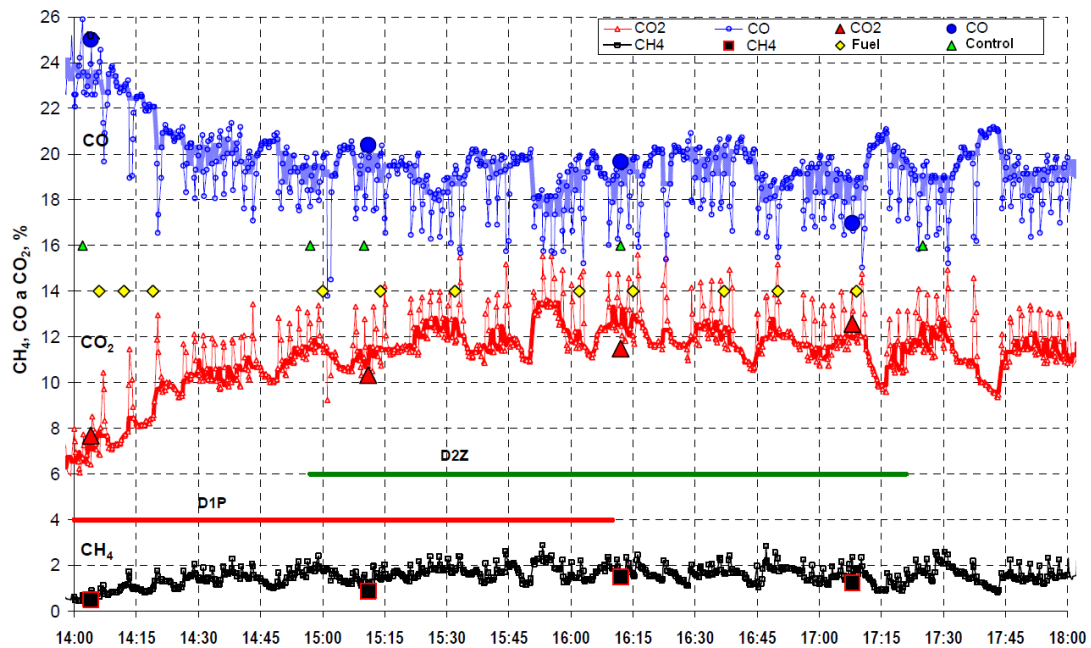


Fig. 5 Timing variability of CO, CO<sub>2</sub> and CH<sub>4</sub> concentrations produced gas.

The above diagram presents the time course of methane, carbon monoxide, carbon dioxide concentrations which were measured after turn off the piston engine. Using huge triangles, circles and squares signs were shown places of OFF-Line analysis. The rhombuses indicate the time when fuel

was delivered to the gasifier. Visible changes in the concentration of individual components are caused by changes in the size of deposits and individual reaction zones occurring through bridging. However, 2 percent change in concentration of gaseous components (CO, CO<sub>2</sub>) is acceptable for this type of reactor and it has little effect on the stability of the cogeneration unit, wider ranges of changes are caused by changing temperatures in bed. These changes are the results of delivery colder fuel to process and dislocation heat flows. Two shortcuts D1P and D2Z are showing the range time in which the samples of tars were taken.

A detailed analysis of the gas generator measuring in ON-Line and OFF-Line method helped to verify the values component obtained in biomass gasification. Table 1 presents the results of the analysis made on gas samples taken to tedlars. In presented summary of the main components occurs oxygen which is the result of a leak in the system for gasification or sampling installation. Its content is so small and does not cause danger to the whole devices. More than 50 percentage nitrogen is caused by using air as an agent in the gasification process. This is the simplest form of fuel gasification in which we obtain a gas with low calorific value 5.2 MJ·m<sup>-3</sup>. Percentage part of flammable substances in gas is about 40% and depends on the temperature of the gasification process, equitable access medium, time of reaction, calorific value and fuel humidity.

**Tab. 8** The composition of the generated gas sampled to tedlars.

| Substances                              | Samples               |       |       |       |
|---|-----------------------|-------|-------|-------|
|   | 14:04                 | 15:11 | 16:12 | 17:08 |
|   | <b>Content % vol.</b> |       |       |       |
| <b>O<sub>2</sub> in sample</b>          | 2.31                  | 0.62  | 0.22  | 1.23  |
| <b>CO<sub>2</sub></b>                   | 7.68                  | 10.33 | 11.49 | 12.57 |
| <b>H<sub>2</sub></b>                    | 16.91                 | 15.66 | 17.76 | 15.36 |
| <b>CO</b>                               | 25.01                 | 20.4  | 19.68 | 16.98 |
| <b>CH<sub>4</sub></b>                   | 0.52                  | 0.88  | 1.49  | 1.23  |
| <b>N<sub>2</sub></b>                    | 49.21                 | 51.94 | 48.72 | 52.97 |
| <b>Ar</b>                               | 0.58                  | 0.64  | 0.58  | 0.68  |
| <b>ethane</b>                           | 0.001                 | 0.001 | 0.004 | 0.003 |
| <b>ethylene</b>                         | 0.033                 | 0.06  | 0.152 | 0.112 |
| <b>acetylene</b>                        | 0.043                 | 0.068 | 0.105 | 0.079 |
| <b>benzene</b>                          | 0.009                 | 0.015 | 0.017 | 0.016 |
| <b>toluene</b>                          | 0.001                 | 0.001 | 0.001 | 0.001 |
| <b>Q<sub>s</sub>, MJ·m<sup>-3</sup></b> | 5.59                  | 5.03  | 5,54  | 4.74  |

#### 4.3.2 TSP measurement methodology

The principle of measuring method is based on the isokinetic suction of the gas sample from the pipeline according to EN ISO 9096 which was placed in the output pipeline of tested device.

Gas temperature at the measurement point was measured with a thermocouple type "K" connected to the measuring unit. Differential and static gas pressure was measured using the Pitot tube connected to pressure sensors.

Sampling of the gas was carried out with probe that was connected to an electrically heated trap, where the filter from the glass micro-fiber captured most solid particles from exhaust gas sample. After the capture of solid particles the gas was introduced into the condenser where the water vapor condensed. The cooled gas saturated of water vapour in the measured temperature was introduced into the volume measuring equipment and then into the air pump. The proper flow rate of the gas sample was adjusted by changing of pump speed and monitored using pressure sensors and temperature sensors.

The total amount of solid particles captured on the filter was determined gravimetrically as the weight difference of filter before and after the sampling. Mass concentration of solid particles was determined by dividing the amount of captured solid particles and exhausted volume of wet gas converted to normal conditions (0°C, 101325 Pa) and it is expressed in  $\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ .

Measurements of solid particles concentrations were carried out on the gasification technology in two stages at different locations of technological complex.

In each measuring site two samplings (about 20 minutes long) were carried out for determining the concentration of TSP and the result is their average.

The main results are presented in tables. During the hole measurement campaign were researched the best conditions for gas purifying and good exploitation of installation. Scheme of installation shown in Fig. 5 is the last version of applied devices cogeneration installation based on biomass gasification.

**Tab. 9** Datasheet of measurements of TSP made on different settings of installation.

| Device                          | First combination                                | Second combination                               | Third combination                                | Fourth combination                               | Fifth combination                                |
|---------------------------------|--|--|--|--|--|
| Reactor                         | 1252<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ | 1252<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ | 1207<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ | 1207<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ | 1207<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ |
| Rotary separator version 1      | 1047<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ | 1047<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ | -  | -  | -  |
| Rotary separator version 2      | -  | -  | 174<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  | 174<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  | 174<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  |
| Dust filter                     | 7.6<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  | -  | 4.2<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  | -  | applied in installation                          |
| Scrubber                        | -  | 270<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  | -  | -  | -  |
| Scrubber with rotator equipment | -  | -  | -  | 6.8<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  | 0.44<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$ |
| Dry cooler                      | -  | -  | 2.3<br>$\text{mg}\cdot\text{m}^{-3}_{\text{N}}$  | -  | -  |

The average concentration of dust in the gas was on the level  $1222 \text{ mg}/\text{m}^3_{\text{N}}$ . The quantity of dust was half lower than before the purification. At the exit from the dry filter the average concentration was at the level of dust at  $4.2 \text{ mg}\cdot\text{m}^{-3}_{\text{N}}$ . The device achieved efficiency at the level of 99.3%. Cogeneration unit manufacturers reduce the maximum level of dust in utilized gas to provide longer service of device. Currently, the permitted level of solid particles is at  $5 \text{ mg}/\text{m}^3_{\text{N}}$ .

## 5 CONCLUSIONS

The results of the modeling are seems to be an interesting solutions, allowing thinking that conducted modification will increase the efficiency of the gasification process. Unfortunately, the gasification process is still an unrecognized phenomenon so that carrying out more complex operations may yield results varied from real conditions of working reactor.

The result of many hours of operation managed to set all relevant parameters is the installation working in a fully unmanned running. Automated process control system of biomass gasification, fuel supply, gas purification system is able to react with/on different parameters of fuel by changing the constants of characteristics. In addition, there was developed a technology for gas purifying from the dust which reaches more than 99.3% of efficiency. The increasing requirements of devices such as internal combustion engines, gas turbines and fuel cells requires lower dust limits in developing technologies with higher efficiency.

Experience gained in the operation of the presented technology of biomass gasification will help to create a fully commercial installation, permitting to supply the needs of heat and electricity from local sources.

## ACKNOWLEDGEMENTS

The author Energy Research Centre at the VSB – Technical University of Ostrava thank the Ministry of Industry and trade of the Czech Republic, which supported this research in terms of the grant projects MPO TIP FR-TI1/219, FR-TI1/344 and The Ministry of Education, Youth and Sports and Research and Development for Innovations Operational Program project nr. CZ.1.05/2.1.00/01.0036 - “Innovation for efficiency and environment (INEF)”

## REFERENCES

- [1] NAJSER J., OCHODEK T., CHŁOND R., „Wysokotemperaturowa technologia oczyszczania gazu” – Conference „Rynek Gazu“ 24-26.06.2009, ISBN 978-83-927680-4-31
- [2] NAJSER J., OCHODEK T., CHŁOND R. „Functioning of installation for biomass gasification and economic aspects of electricity generation” – Rynek Energii p. 68, december 2009 ISSN 1425-5960,
- [3] CHŁOND R., NAJSER J., „Analysis of gas purification technology from biomass gasification based on work of ceramic filter”. Journal Rynek Energii 3/2010, Poland, p. 107-112. ISSN 1425-5960.
- [4] CHŁOND R., „Technologiczne i energetyczne aspekty wykorzystania różnego rodzajów odpadów w procesie generacji energii elektrycznej i ciepła opartego na technologii zgazowania” – Conference „Innowacyjne technologie w gospodarce odpadami“ 23 april 2010, ISBN: 978-80-214-4027-2,
- [5] <http://www.eea.europa.eu/data-and-maps/figures/total-primary-energy-consumption-by>
- [6] CHŁOND R., „Process investigation of wood gasification”, unpublished material, Silesian University of Technology, 2008
- [7] NAJSER J., „Biomass gasification in cogeneration”, 2008 VSB TU Ostrava,
- [8] Skoblja S., Beňo Z., Buryan P., Vlastnosti plynu produkovaného souproudým generátorem v extrémních podmínkách, VŠCHT Praha, March 2010,
- [9] KOLAT, P. Biomass Gasification in EU. In Politechnika Wroclawska. Wroclaw: Faculty of Mechanical and Power Engineering, 2008. pp. 33-36. ISBN 978-83-7493-427-5.
- [10] POHOŘELÝ M., JEREMIAŠ M., SKOBLJA S., VOSECKÝ M., KAMENÍKOVÁ P., ŠYC M., TOŠNAROVÁ M., PUNČOCHÁŘ M., SVOBODA K.: Alotermní fluidní zplyňování biomasy. Paliva 1 (2009),
- [11] KOHOUT, P.; OCHRANA, L.; BALÁŠ, M.; LISÝ, M.; PAVLŮ, J. Úpravy energoplynu pro použití v kogenerační jednotce. Acta Metallurgica Slovaca, 2007, p. 166-172. ISSN:1335 – 1532.

