THE KNOWLEDGE OF WOOD GAS PURIFICATION BY ADSORPTION CARTRIDGE FILTERS FOLLOW UP WITH ITS APPLICATION IN COMBUSTION ENGINES.

POZNATKY Z ČISTENIA DREVNÉHO PLYNU ADSORPČNÝMI NÁPLŇOVÝMI FILTRAMI V NÁVÄZNOSTI NA JEHO VYUŽITIE V SPAĽOVACÍCH MOTOROCH

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Abstract

The article deals with a highly actual theme of wood biomass exploitation for energy purposes, specifically problems of wood gas production and purification systems in relation to the requirements of combustion engines. Wood matter gasification represents one of the ways of alternative exploitation of wood matter in power engineering. The paper deals with filter efficiency and effectiveness evaluation by means of adsorption cartridge filters. The evaluation was carried out on a basis of determination of the ingoing and outgoing change of solid particles concentration in wood gas during a continuous 4 – hours loading. The evaluating criterion was an acceptable value of contaminants in wood gas for its utilization in combustion engines.

Abstrakt

Článok sa venuje vysoko aktuálnej téme využívania drevnej biomasy pre energetické účely, konkrétne problematike produkcie drevného plynu a systémom jeho čistenia vzhľadom na požiadavky spaľovacích motorov. Splynovanie drevnej hmoty predstavuje jednu z ciest alternatívneho využívania drevnej hmoty v energetike. Príspevok sa zaoberá hodnotením filtračnej účinnosti a efektívnosti čistenia drevného plynu pomocou adsorpčných náplňových filtrov. Hodnotenie prebiehalo na základe zisťovania zmien vstupnej a výstupnej koncentrácie tuhých častíc obsiahnutých v drevnom plyne počas 4-hodinového zaťaženia. Hodnotiacim kritériom bol prípustný obsah kontaminantov v drevnom plyne pre jeho použitie v spaľovacom motore.

Key words: wood gas, contaminants, adsorption cartridge filter, filter efficiency, effectiveness of filtration

1 INTRODUCTION

The present civilized society has continuous increasing demands on energy consumption, which is in essence the basic condition of the human existence. One of the possibilities of solution of the increasing deficit of classic fossil fuels is searching for alternative energy sources and also improving the existing energy sources. From the future outlook biomass is considered as a key recoverable energy source on levels of small as well as large technological units. Today it already participates in worldwide consumption of primary energy sources with a share of 14 %. Replacement of fossil fuels by biomass has apart from a relatively easy availability also a positive environmental impact. Significant amount of suplhur as well as CO_2 is released into the air by burning of fossil fuels. On the contrary burning biomass has a so called "zero balance of CO_2", because in this process only such amount of carbon dioxide is released, which was accumulated by the plant by photosynthesis during the period of its growth. Other important aspects of Slovakia's orientation on energy from wood is the insufficiency of its own fossil fuels, tendency for energy independence on import of fossil energy resources and fuels, lowering of transport costs and the above mentioned positive environmental influence of biomass burning. The foremost is however the lower price of wood as a fuel in comparison with other types of fuels. Forests cover up to 40 % of the area of Slovakia, whereby they represent a huge potential also from the viewpoint of accumulated energy. Currently gasifiers of outputs starting from a few tens of kW up to a few hundred MW units [1] start to appear in developed countries in experimental as well as commercial operations.

2 THE CURRENT PROBLEMS OF WOOD GASIFICATION AND PURIFICATION OF WOOD GAS

Gasification is a process during which the combustible share of solid fuel is transformed to gas fuel. This process takes place by the influence of high temperature and by limited access of oxygen. The result of wood gasification is gas fuel – wood (generator) gas with thermal value of 4,5–6,9 $MJ.m^{-3}$ and 1,6–1,9 m_n^3 of generator gas is extracted from 1 kg of dry wood. The forming mix of gases has a high energy value and may be used as other gas fuels, for production of heat and electricity and also in motor vehicles. However this gas leads to a lower engine output in vehicles by about 40 %.

The composition of wood gas significantly fluctuates and depends on several factors. The share of combustible gases in wood gas represents roughly 40 %, it is mainly carbon monoxide CO (17 – 22 %), hydrogen H_2 (12 – 20 %) and methane CH_4 (2- 3%). The share of noncombustible gases is 60 % in total, from which the nitrogen N_2 (50 – 54 %) is predominant, furthermore carbon dioxide CO_2 (9 – 15%). Apart from the mentioned components the raw wood gas contains also other – undesirable admixtures, such as water vapour, higher hydrocarbons – tars, acetic acid and also solid contaminating substances.

The main obstacle which prevents expansion of gasification technologies is the necessity to comply with requirements on pureness of the produced gas. The produced wood gas contains large amount of dust particles and tars, therefore contaminants which it is necessary to remove from gas. The experience has shown that these contaminants are the main causes of engine damage as well as extreme maintenance costs of engines powered by wood gas. Contaminants content in wood gas is dependent on gasification technology (on type of gasification generator as well as gasification media) and on fuel characteristics. A comparison of parameters of various types of gasification generators with specified concentration of tars is shown in tab. [2].

Tab.1 Comparison of tar concentration and other parameters of gasification generators

Generator / Parameter		with movable bed		*fluid bed*
		co-current	counter-currents	
Tar concentration	$g.m_n^{-3}$	0,1 – 2	5 – 150	1,0 – 50
Thermal output	kW	5,0 – 3000	< 10 000	5000–100000
Fuel size	mm	5,0 – 50	15 - 100	< 20
Fuel moisture	%	< 20	< 50	< 50
Technology	-	simple	simple	complex
Conversion efficiency	%	75 – 90	80 - 90	60
Output gas temperature	^oC	300 - 700	75 - 150	650 - 850

There are several open systems of wood gas purification. In principle it is possible to divide purification into removal of solid contaminating substances – fly ash from burning of wood and tar – heavy carbohydrates forming in the burning process. Purification of the mentioned undesirable components proceeds at the same time, it cannot be separated. There are many purification methods of wood gas and their employment depends on parameters of generator operation, its size, economic possibilities of the operator and on the final use of the gas. Currently for the purposes of wood gas purification use of barrier filters with different cartridges is preferred. Problem during filtration of wood gas is choking of filters with soot, which is being formed during thermal decomposition of tars in the gas phase on the filter's surface. This problem may be restrained by cooling down the gas before filtration to under the temperature of 500 ^oC and by lowering the speed of gas passing through the filter [3].

3 PROCEDURE. EXPERIMENTAL EQUIPMENT AND MATERIAL

Measuring of mass concentration of solid particles in wood gas and verification of the efficiency of proposed wood gas purification system took place in the experimental laboratory of the company VIMAR, s.r.o., Slovenská Ľupča. A gravimetric method was chosen for measuring the mass concentration of solid particles in wood gas. The standard STN ISO 9096 specifies a gravimetric method for procedure of single measuring of

emissions (TZL-solid polluting substances) from a stationary source of air pollutant to demonstrate the emission limit. The measures took place in two variants of measuring line connection:

- Detection of concentration of contaminants in raw wood gas – a heating filter was connected in the measuring apparatus (120°C heating temperature) for gas extraction before its cooling and condensation, there was no equipment connected to the line for purification of wood gas - cyclone and cartridge filter
- Detection of concentration of contaminants in purified wood gas, after going through the complete measuring line (Fig. 1).

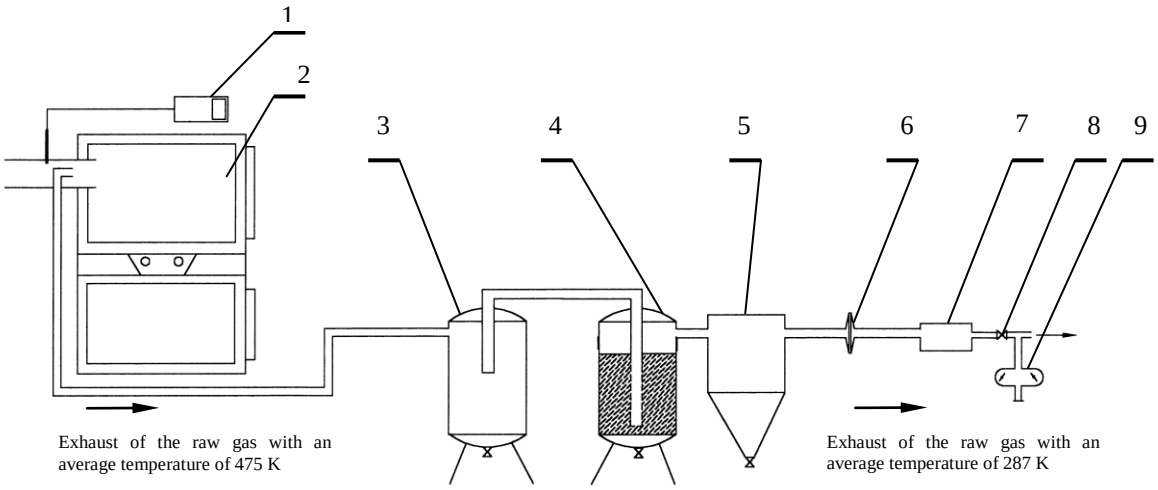

Fig.1 Experimental measuring line scheme.

1 - Testo 300 XL, 2 - gasification boiler VIGAS 25, 3 – cyclone separator of solid particles, 4 – cartridge filter, 5 – tube cooler, 6 – separator of solid particles with a paper filter, 7 – gasometer, 8 – pressure control valve 9 – the vacuum air pump

After the measuring was finished calculations of the whole volume of exhausted gas under operating and normal conditions were carried out and the resulting calculation was a calculation of concentration c_n of contaminating substances in wood gas under normal conditions (p_0, T_0) :

$$c_n = \frac{m_{TZL}}{V_n} \text{ [mg.m}_n^{-3}\text{]} \quad (1)$$

m_{TZL} is the mass of contaminating substances in gas determined by differential weighing of the filter before and after the extraction:

$$m_{TZL} = m_2 - m_1 \text{ [mg]} \quad (2)$$

V_n is the volume of gas mixture under normal conditions (p_0, T_0) *:*

$$V_n = V_o \cdot \frac{p_{ep}}{T_g} \cdot \frac{T_0}{p_0} \text{ [m}_n^{\,3}\text{]} \quad (3)$$

Filtration efficiency on the basis of measuring of particles concentration before and after the filter is expressed by the formula:

$$\eta_{pf} = \left(1 - \frac{c_{n2}}{c_{n1}}\right) \cdot 100 \quad [\%] \tag{4}$$

c_{n1} – concentration of particles measured before the filter [mg.m_n^{-3}]

c_{n2} – concentration of particles measured after the filter [mg.m_n^{-3}]

Detailed procedures, calculations and results of measuring of concentration of contaminating substances in raw wood gas and in purified wood gas are specified in the doctoral thesis of the author [4].

4 RESULTS AND EVALUATION

Three filter cartridges were compared – wood coal, active coal and zeolite. Measuring of efficiency of cartridge filters for purification of wood gas was divided into two parts. In the first measuring stage concentration of contaminating substances in raw (unmodified) wood gas was measured, which was actually the entry concentration of contaminants into the cartridge filter c_{n1}. Three extracts of raw wood gas took place, for further calculations an average concentration of solid admixtures in gas under normal conditions were considered. The average gas temperature at the entry point of the measuring apparatus was 475 K, at the output the temperature was 287 K on average. Particular measuring results are specified in Tab.2.

Tab. 2 Measuring results of average contaminants concentration in raw wood gas

Date of measuring			28.4.2005		
Measuring No.			1	2	3
Volume of sieved gas under normal conditions	V_n	m_n^3	0,9886	0,9981	1,0900
Mass of dust captured by paper filter	m_{TZL}	kg	0,0013857	0,0013111	0,0017746
Concentration of solid admixtures in gas under normal conditions	c_{n1}	mg.m_n^{-3}	1402	1314	1628
Average concentration of solid admixtures in gas under normal conditions	c_{np1}	mg.m_n^{-3}	1448		

In the next measuring stage concentration of contaminants after going through the purification column was determined and filtration efficiency of the filter cartridge during the 4-hours loading was evaluated. Three filter cartridges were compared – wood coal, active coal and zeolite.

Specifications of filter cartridges:

- Wood coal – producer SLZ Chémia, a.s. Hnúšťa, granularity: under 10 mm – 5 %; 12 – 20 mm – 25 %; above 20 mm – the rest up to 100 %
- Active coal – NORIT RB 3W, apparent density 500 kg. m^{-3}
- Zeolite Ysit V 15, effective surface of pores 0,9 nm, apparent density 580 kg. m^{-3}

The measuring results are listed in Tab. 3, 4, 5 and graphically in Fig. 2, 3, 4.

Tab. 3 Evaluation of the wood-coal filter efficiency during 4 – hours loading

Date of measuring			12.5.2005			
Measuring / hour			1.	2.	3.	4.
Volume of gas under normal conditions	V_n	m_n^3	3,66	3,41	3,49	3,40
Mass of dust captured by paper filter	m_{TZL}	kg	0,0002104	0,0006259	0,0022747	0,0034077
Concentration of solid admixtures in gas under normal conditions	c_n	$mg.m_n^{-3}$	58	184	651	1002
Filter efficiency	η_{pf}	%	96,0	87,3	55,0	30,8

Tab. 4 Evaluation of the active coal filter efficiency during 4 – hours loading

Date of measuring			25.5.2005			
Measuring / hour			1.	2.	3.	4.
Volume of gas under normal conditions	V_n	m_n^3	4,30	3,18	2,77	4,25
Mass of dust captured by paper filter	m_{TZL}	kg	0,0001684	0,0004384	0,0014274	0,0030375
Concentration of solid admixtures in gas under normal conditions.	c_n	$mg.m_n^{-3}$	39	138	515	715
Filter efficiency	η_{pf}	%	97,3	90,5	64,5	50,6

Tab. 5 Evaluation of the zeolite filter efficiency during 4 – hours loading

Date of measuring			31.5.2005			
Measuring / hour			1.	2.	3.	4.
Volume of gas under normal conditions	V_n	m_n^3	1,70	1,78	4,46	4,44
Mass of dust captured by paper filter	m_{TZL}	kg	0,0000771	0,0002199	0,0013733	0,0026838
Concentration of solid admixtures in gas under normal conditions	c_n	$mg.m_n^{-3}$	45	123	308	605
Filter efficiency	η_{pf}	%	96,87	91,47	78,71	58,21

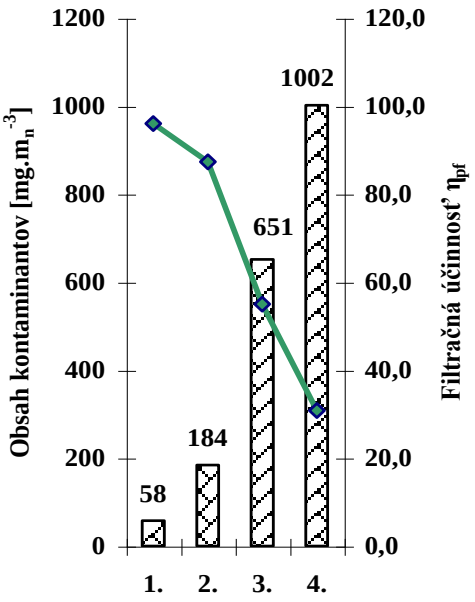

Fig. 2 Evaluation of the wood-coal filter efficiency during 4 – hours loading

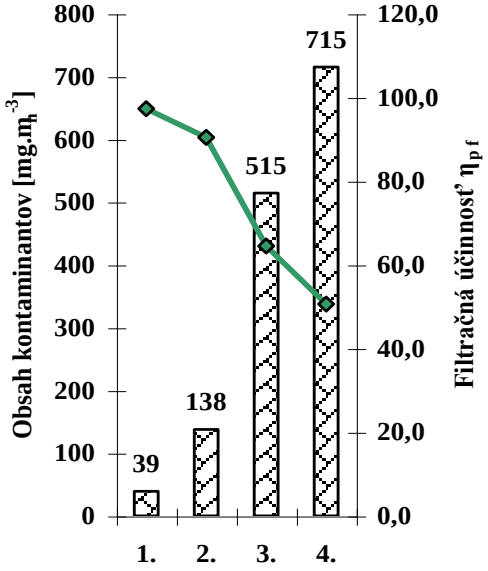

Fig. 3 Evaluation of the active coal filter efficiency during 4 – hours loading

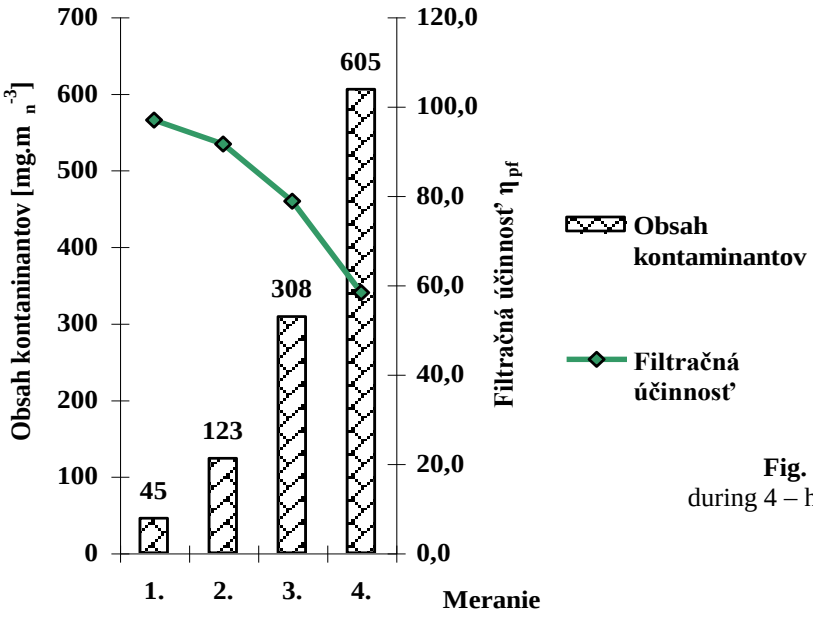

Fig. 4 Evaluation of the zeolite filter efficiency during 4 – hours loading

The change of output concentration of solid admixtures during filtration of wood gas was being determined during a continuous 4 – hours loading of filter cartridges and on its basis a change of filter efficiency

of used cartridge filters was evaluated. The assumed decline of filter efficiency by the influence of lowered filter capability caused by choking of its porous surface by solid admixtures contained in wood gas was confirmed. In Fig. 5 is a comparison of decline of filter efficiency of individual evaluated filter cartridges depending on time of filter operation. The figure implies that the lowest decline of efficiency was recorded with cartridge of zeolite, where the efficiency declined from 100% to 58 %, the biggest decline of efficiency was measured with wood coal – to 31 %. A conclusion can be made from the results that all evaluated filter cartridges fulfill the requirement of satisfactory purification of wood gas from undesirable admixtures during the first 120 min. of operation. After this period of time the filtration ability of cartridges visibly declines and the wood gas does not meet the allowed value of pollution. The least favorable results were achieved with the wood coal cartridge, where the pollution overpassed the allowed limit of 150 $mg.m_n^{-3}$ already during the second hour of filter operation.

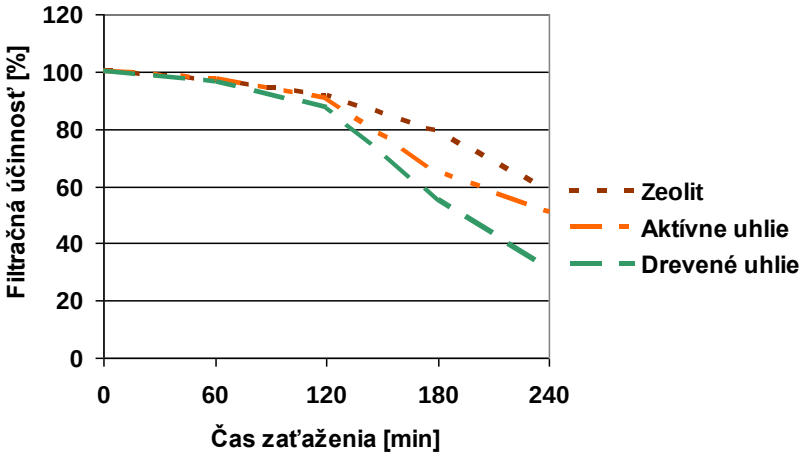

Fig. 5 Comparison of cartridge filter efficiency decline

The allowed pollution of wood gas for combustion engines was a decisive standard during the evaluation of filter effectiveness. The literature [5] specifies the total admissible content of 150 $mg.m_n^{-3}$ of solid contaminants in wood gas for usage in combustion engines. Based on the realized measuring the total volume of wood gas purified by the tested filter cartridge was expressed, which complies with the allowed value of pollution. This value basically sets the durability for the filter cartridge, because when the filtration continues above a set value of gas volume this gas does not comply with the criteria of pureness anymore – the content of contaminants for usage in combustion engine. A comparison of filter effectiveness for filter cartridges used for purification of wood gas with dependence on time of filter operation is displayed in Fig. 6. After exceeding the effective period of time the purification of wood gas is insufficient for usage in combustion engine, then it is necessary to replace the filter cartridge, appropr. regenerate. The time of effective filtration was 106 minutes for the wood coal cartridge which corresponds to a volume of purified wood gas of 6,17 m_n^3 . For active coal the time of effective filtration was 125 min which corresponds to a volume of purified wood gas of 7,6 m_n^3 and 131 min for zeolite which corresponds to a volume of purified wood gas of 8,08 m_n^3. The best result was determined during the filtration of wood gas through the zeolite cartridge where the time of effective filtration was by 19 % longer than for the wood coal. The difference between zeolite and the second in order – active coal is 6 min., which represents 4,6 %.

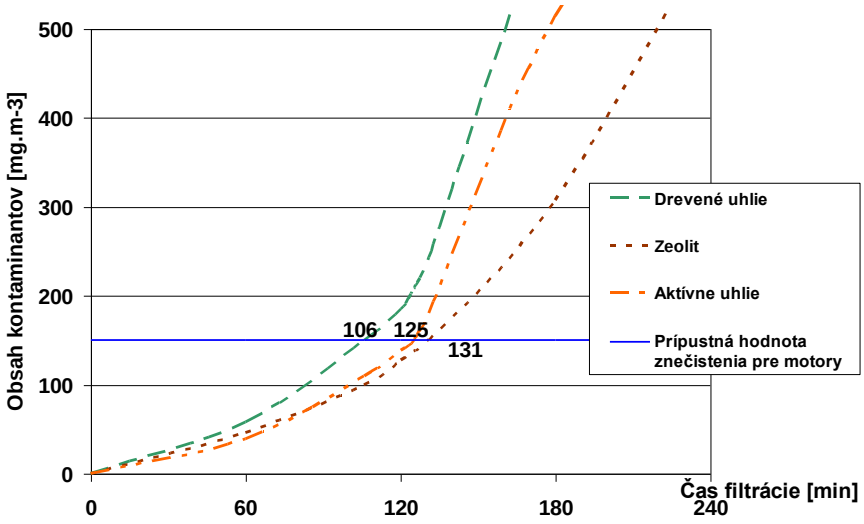

Fig. 6 Comparison of filtration effectiveness of selected filter cartridges

Generally it is possible to say that the time of ca 120 min. for reaching the optimal results of cartridge filter is little, and virtually useless in practice. In practical use of cartridge filters for purification of wood gas from contaminants the problem of choking of cartridges is solved by means of increased filter surface, where it is possible to increase the filter operation time multiple times [6]. Filters for purification of wood gas in energy systems utilizing wood gas represent a high volume container with the need of filter replacement roughly once per 2 – 4 weeks. In the presented experimental measurings the used filter cartridge with the volume of 0,0032 m^3 i.e. 3,2 l was used, which was given by the volume of the cartridge filter container. The gas flow rate volume during measuring was moving within the range of 2,77 to 4,46 m_n^3, the average flow rate was 3,74 m_n^3. During practical utilization of the researched filter cartridges it is necessary to increase the volume of cartridges, and by this also the size of the filter surface, by which the optimal time of filter operation is increased. Another instrument for increasing the effectiveness of cartridge filters is to lower the speed of gas filtering. During measuring the effectiveness of filter cartridges the speed of filtration was moving within the interval of 0,03 – 0,05 $m.s^{-1}$, which falls within the interval of values recommended by literature.

5 CONCLUSIONS

As an alternative to the classic heat production technology by burning wood is a technology utilizing its gasification, that is to say production of gas fuel with limited access of air. It is then possible to burn wood gas formed by gasification directly, or utilize it in other systems, e.g. in production of electricity. This possibility was the idea of the realized research, where the composition of wood gas was adjusted for the requirements of combustion engines from the viewpoint of content of solid contaminants. The designed system of purification of wood gas was functional and the filtration was effective for a certain time interval. From the experiment results recommendations may be given to designers of filter units designated for purification of wood gas as well as to the filters‘ operators.

The experimental work was aimed at measuring the effectiveness of cartridge filters for purification of wood gas from undesirable admixtures. The procedure was based on observing the change of filtration effectiveness of cartridge filters used for purification of wood gas on a basis of change of output concentration of solid admixtures in gas during a continuous 4 – hours loading. Wood coal, active coal and zeolite were used as filtration cartridges, which are used normally in practice for purification of gases. The measuring results imply, that the filters were reaching admissible values of gas pollution during the first 120 min. of operation, then its effectiveness declined under acceptable level. In practical utilization of evaluated filter cartridges it will be necessary to increase the filtration surface of the filters by increasing the volume of the filters depending on the amount of gas being purified and the reached flow rate.

REFERENCES

[1] BTG, s.r.o., 2000: *Technologie pro energetické využití biomasy.* Splynování biomasy.[Technology for energy exploitation of biomass. Biomass gasificaion.]

[2] *Slavičín, máj*, 2000. s. 20 – 26. Zdroj FAO (1986).

[3] KRŽIN, I., 2005: *Čištění plynu ze zplyňování biomasy*. In. Energetika a životní prostředí [Purification of gas from biomass gasification. In: Power engineering and environment] 2005. Ostrava, VŠB – TU Ostrava, 2004. str. 53 - 56. ISBN 80 – 248 – 0909 – 5.

[4] SUJOVÁ, E., 2002 : *Systémy čistenia drevného plynu*. In. Zborník referátov z kolokvia Environmentálna technika a energetika. [Wood gas purification systems. In: Collection of reports from colloquium of Environmental Technology and Power Engineering] Zvolen, október 2002. str. 29 – 34.

[5] SUJOVÁ, E., 2006: *Technické zariadenia úpravy drevného plynu pre jeho aplikáciu v spaľovacích motoroch.*[Technical equipment for wood gas processing for its application in combustion engines] Doctoral thesis. FEVT, 2006.

[6] STASSEN, H.E. – HARRIE, K., 2004: *Theoretical and practical aspects on the use of LCV – gas from biomass gasifier in internal combustion engines.* BTG biomass technology group, The Netherlands. www.gasnet.uk net, 2004.

[7] HINDSGAUL, C., 2000: *Low Temperature Particle Filtration of Producer Gas with Low Tar Content.* Technological University of Denmark, Dept. Of Energy Engineering, ET-ES 2000-05, ISBN 87-7475-237-5. 30 s.