

Removal of Unpleasant Odorous Substances from Smoke Produced by Smoke Curing Houses

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Abstract: Problem statement: For purification of smoke in PPHU Duda-Bis Plant water washers, placed in the outlet channel of smoke chamber, have been applied, but the amount of the substances remaining in the air after passing through the washer were not acceptable by the standards and caused repulsive odor emitted into the atmosphere. **Approach:** To eliminate discomfort, caused by smoke emission unto the environment, PPHU Duda-Bis has been introduced a simple and effective method of thermal utilization of post-curing smoke by using heated with natural gas boiler. Before the smoke enters the boiler, water vapors undergo condensation and the water drops obtained are separated in steam drier. The smoke introduced into the boiler brings some excess of air. **Results:** After the new method of curing smoke after-burning had been put into practice in PPHU Duda-Bis, the unpleasant odorous and harmful to the environment compounds were eliminated. The content of the emitted components per year, after thermal utilization of the smoke, was 100 times lower in comparison to the wet-method. **Conclusion:** The thermal methods belong to the most efficient BAT techniques enabling removal of the unpleasant odorous substances from the gases generated by meat industry.

Key words: Meat industry, odorous, thermal decomposition

INTRODUCTION

Food products belong to the goods bio-chemically unstable. Changes in food quality caused by microbiological activity make it useless for the people or the animal consumption. It is important to work out such technological procedures that eliminate or limit the rate of micro-organisms propagation in food products and extend their storage life (Kowalski and Prycz, 2003; Toth and Potthast, 1984).

Smoke curing is one of the oldest methods of food conservation. Using that specific method, the food is simultaneously subjected to a heat and chemicals, present in the smoke obtained by wood combustion (Toth and Potthast, 1984; Gullien and Manzanos, 1996). Some properties of smoke-cured product depend on a technology of smoke manufacturing. Characteristic aroma and taste of smoked products are attributed to a variety of components, present in the smoke obtained by slow combustion of sawdust, derived from special sort of wood (beech, alder, cherry). Moreover, some other effects that increase quality and storage life of the product caused by the smoke are as below (Toth and Potthast, 1984; Gullien and Manzanos, 1996):

- The product, especially its surface, is partly dried
- The product is impregnated by various, present in the smoke, bactericidal components
- Hardening of polypeptide chains adjacent to casing (secondary skin)
- Coloring and aromatization of the food

Two basic phenomena can be distinguished in the smoke curing process:

- Saturation of the surface with the smoke components
- Physic-chemical processes, taking place in the bulk of the product and on its surface, resulting in changes of mechanical properties, color and gloss of the surface. The processes are affected by the smoke curing parameters and the composition of the smoke

Intensity of the smoking can be differentiated according to the expected final properties of the product. Smoke curing parameters, in details, are selected for each assortment of the product individually. Those depend mainly on the initial composition,

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expected final composition, shape of the product (diameter, length) and its weight. Intensity of the smoke precipitation on the product depends on a concentration of the smoke in a smoke chamber, temperature and humidity of the air, curing time, a ratio of the surface/volume, properties of casing (artificial or natural gut), size of the boundary between the surface of the product and the stream of circulated air.

In general, three methods of meat product saturation with smoke components are in application: Aerosol-blowing, electrostatic and smoke-containing agent method (Kowalski and Prycz, 2003; Toth and Potthast, 1984; Gullien and Manzanos, 1996).

In aerosol-blowing method smoke in aerosol is applied. With respect to temperature of the smoking, cold, warm or hot smoke curing is known. Cold smoke-curing is carried out within the temperature range of 12-25°C for 6 h up to a few days. The method has been applied for raw sausages, bacon and also for some poultry smoking. Cold smoke curing consists in a gradual temperature increase, while full saturation of the air with steam ($J = 100\%$) is maintained constant. The air circulation in the smoke chamber is realizing only by gravity. Concentration of the smoke in chamber, initially low, is gradually increasing. The long lasting process results in a high impregnation of the meat with aromatic and conserving components and also in a considerable drying of the product.

Warm smoke curing is carried out at a temperature at which fat is already melting; however, significant protein denaturing changes are still not on. The temperature of the process is 25-45°C, the relative humidity is 70-90%, the rate of air circulation is 7-15 m min⁻¹, while the density of the smoke can differ from low to high value. Warm method is applied for smoking baked and steamed sausages.

In hot curing method smoke of different density at temperature within the range of 35-90°C, depending on the stage of smoking, has been applied. Diffusion of the smoke components is limited to the surface layers. Hot method is used for baked sausages, pork, beef and poultry smoking.

Electrostatic smoke curing is carried out mostly in corona discharge field. Voltage of 20 kV, applied to a corona discharge electrode, generates "crown-effect"-ionization of gaseous particles. "Electric wind" generated by the discharged electric field drives the smoke to the direction of the smoked object. Electrostatic smoking reduces time of smoke precipitation on the surface of the product to 2-3 min. That enables to carry out the process in a continuous mode. However, to increase penetration of the smoke components into the bulk of the product other

technological operations, after the short in time smoke curing process is completed, have to be implemented.

One of the essential ecological problems is utilization of post-curing smoke. In the present work effects of post-curing smoke utilization, by thermal method, using heated with natural gas boiler has been presented. The thermal methods belong to the most efficient BAT techniques enabling removal of the unpleasant odorous substances from the gases generated by meat industry (European Commission, 2005; Cardinal *et al.*, 2006).

MATERIALS AND METHODS

Methods of smoke manufacturing for curing purposes: Smoke for food curing is obtained by pyrolysis of wood (Kowalski and Prycz, 2003; Toth and Potthast, 1984; Gullien and Manzanos, 1996; European Commission, 2005; Cardinal *et al.*, 2006; Olsen, 1977). Some organic compounds, formed in this process, produce aroma, color and are responsible for preservation of the cured meat products. Depending on the method applied, the smoke obtained has different properties and different technological applicability. For smoke manufacturing the following methods have been developed:

- Glowing combustion
- Steam driven method
- Frictional method
- Fluidized-bed generator

The glowing combustion method is an exothermic method. Energy for wood pyrolysis is obtained by charcoal combustion. In this method wooden chips undergo glowing combustion under low supply with oxygen. At present, the glowing combustion method is one of the widespread methods. In general, it is applied for smoke curing of raw, steamed and boiled products. Traditionally, smoke-generators are supplied with a container of wood chips, combustion chamber, chips feeder into the glowing zone and into a quenching system, acting against excessive flame or explosion. The smoke produced by that method is dry, dense and contains admixture of oxygen. Its temperature is 20°C. Humidity of the smoke can be controlled by controlling the humidity of the wood chips.

In steam driven method the smoke is obtained by treating the wood chips with superheated steam of low pressure (temperature 130-140°C) mixed with compressed air. Pyrolysis, with low access of oxygen, occurs without the glow. The steam driven is one of the modern methods applied at present. The smoke

obtained is very dense and humid. Its application results in achieving food of satisfactory taste and color, while good preservation prevents losses in production. As the temperature of the smoke is ~80°C it can be used for steamed salami smoking. It is also free of smoke soot. That enables cleaning of smoke chambers simply by rinsing them with water. The advantage of the smoke-generator used is the possibility to reach its full capacity within a few seconds, computer-controlled automatic work, easy cleaning, safe in service, fire precautions.

The product obtained by this method contains about 50% less of carcinogenic compound such as 3, 4-benzopyrene in comparison to traditional glowing combustion method.

Frictional method consists in exploiting a friction force that appears between the surface of a block of wood and a surface of a shifting metal. The friction force is converting into heat. The block of wood is loaded with weight or pressed using pneumatic device against grooved metallic surface of rotating roller. The temperature of the surface is increasing up to 350-450°C and the smoke is forming. By controlling the pressing parameters the smoke of different quality can be obtained. It can be either light, a little colored for a short time curing, dense, medium colored for long lasting curing, or very dense. The disadvantage of the frictional method is high noise (exceeding 80 dB) of working smoke-generators. Those require specially constructed sound-absorbing buildings.

Fluidized-bed generator is sort of modified glowing-combustion generator. The process consists in thermal decomposition with simultaneous oxidation of sawdust in fluidized bed. The air, before entering the chamber, is heated using electric heater up to 150-300°C. The advantage of this smoke-generator is its high efficiency, the disadvantage, on the other hand, is low coefficient of the air excess. The smoke, generated by that method is dense, dry and contains significant amount of oxygen. The important for curing process parameters such as density, temperature and manufacturing time of the smoke can be regulated.

Chemical composition of the smoke depends on several factors, among them are sort of wood and temperature of smoke manufacturing (Toth and Potthast, 1984). Curing smoke is a colloidal system. It is forming, while air with gaseous, liquid and very fine solid particles of partly burned wood are mixing. The air and gaseous components make dispersion (continuous) phase in which about 10% of smoke components can be found. The rest of the smoke components are dispersed (suspended) in the gaseous phase. A state of equilibrium, depending on

temperature and concentration of the components, exists between the two phases. Some organic compounds evaporate from liquid to gaseous phase when temperature is increasing. On the contrary, when temperature is decreasing condensation of some gaseous components takes place. Smoke particles, affected by Brown forces, gravity forces, heat, electrostatic attraction, are in a continuous motion. The most important role is attributed to the Brown movements. Those are the driving force for coagulation and smoke precipitation on the product. There are about 10,000 of various substances in the smoke. Among them about 600 are identified. They can be distributed in three groups: Carboxylic acids and compounds, phenols and their derivatives, alcohols, esters and hydrocarbons. Typical composition of the curing smoke is presented in Table 1.

For smoke manufacturing deciduous hard tree has been applied the most (Toth and Potthast, 1984; Olsen, 1977). In order to obtain desired organoleptic effects, for example in some sort of raw-maturing hard salami, smoke from juniper or coniferous tree has been used. The smoke of deciduous tree contains more furfural and di-aldehyde. In the smoke of coniferous tree, on the other hand, more carbonyl-containing compounds can be found. The phenol content is comparable in either of them. When soft wood (fir, pine, alder) is paralyzed the amount of carcinogenic benzopyrene in the smoke is from 1.5-4.5 times higher, than in that obtained from hard wood. Differences in sensory properties between the smokes, obtained from different sort of wood, are likely to arise from different chemical composition of lignin. The smoke obtained from humid wood is characterized by a smell of conflagration. It is dark, heavy, contains much soot, ashes and acids. As a result, the color of the surface of the smoked product is not uniform and the taste is not good.

Table 1: Typical composition of curing smoke formed in one of the smoke chambers (Kandefér *et al.*, 2006)

Component	Amount (g h ⁻¹)
Acetic acid	0.57
4-Methylpentane-2-on	0.69
2-Methylpentane-1-ol	0.14
Methanol	2.33
Mesitylene	0.08
Butyl acetate	0.09
Ethyl acetate	0.34
Methyl acetate	0.50
Vinyl acetate	7.32
Propyl benzene	0.28
Styrene	2.75
Wood tar	28.20
Toluene	8.88
Elemental carbon	11.36
Aliphatic hydrocarbons	43.23
Aromatic hydrocarbons	1.46
Amount of smoke (from one chamber) 250 m ³ h ⁻¹	
Temperature of the smoke at the chamber outlet 50-60°C	

Temperature of the smoke manufacturing is the most important parameter affecting the curing process. Several reactions, including thermal decomposition of carbon and oxidation of volatile products evolved, are proceeding in the process of smoke manufacturing. The temperature in smoke manufacturing cannot exceed 425°C in the carbon decomposition zone and 325°C in the oxidation zone. Higher temperatures act in favor of carcinogenic hydrocarbons, especially benzopyrene and di-benzoanthracene, formation. Depending on the temperature of wood decomposition the following phases can be distinguished:

- About 170°C evaporation of water
- 270°C-280°C intensive decomposition of cellulose and hemi-cellulose
- 350°C-450°C intensive decomposition of lignin

The amount of volatile substances, evolved from wood at temperatures higher than 500°C is not significant. However, the amount of polycyclic aromatic hydrocarbons is increasing significantly. Some of them are carcinogenic. Cellulose is treated as acetic acid source, while lignin as phenol source. The rate of the phenol formation depends on glowing-temperature and the velocity of air flow through the glow-zone. Before the smoke is used for curing the volatile components-products of thermal decomposition of wood-must undergo an oxidation process in the diffusion layer.

The smoked products are more resistant to the rancid process. Anti-oxidizing properties of the smoke are attributed more to the components dispersed than to the dispersing phase. Phenols, less carboxylic acids, are characterized as strong antioxidants. Among the phenol group, the strongest antioxidants are 3-methyl-pyrocatechol and pyrogallol, then, in decreasing rate: Hydroquinone and its homologues, guaiac resins and their homologues, mono-hydroxyl phenols. Anti-oxidizing properties display also formic acid, benzoate acid, salicylic acid, vanilla. The anti-oxidizing properties of smoke retards auto-oxidation of fats.

Smoke curing effects observed as a decrease in number of micro-organisms, or a suppression of their development consists in micro-biocytic or micro-biostatic activity of numerous smoke components. Additional effects are drying and heating when warm or hot curing is applied. The strongest antibacterial effect gives formaldehyde, while anti-mold effect-phenol, guaiac resins and their derivatives. Organic acids acidify the cured product, resulting this way in synergistic with other smoke components effect upon meat conservation. Characteristic for the micro-

organisms is different susceptibility to the smoke effect. They can be ranged according to susceptibility decrease in the following row:

Enterobacteriaceae > pseudomonas > micro-and streptococci > yeast > mould bacteria

Hazardous components in smoke: The most undesirable chemical compounds in the smoke are Polycyclic Aromatic Hydrocarbons (PAH). Some of them (1, 2, 5, 6,-dibenzoanthracene and 3, 4-benzopyren) are carcinogenic. They can be found also in the smoked products. Concentration of these compounds in the smoke depends on the temperature and increases significantly when temperature in the wood thermal decomposition zone exceeds 425°C. The smoke contains also methyl alcohol, acetone, formic acid and of high toxicity dioxin, among them the most toxic 2,3,7,8 tetrachlor-dibenzo-p-dioxin. Harmful are also nitrosamines. Their formation is associated with the presence of nitrates, nitrites and nitro phenols. Toxic are also phenols, cresols and furfural, although they are not carcinogenic. The carcinogenic benzene in smoke and also in smoke-condensates is present in small quantities. Formaldehyde, on the other hand, is likely to be carcinogenic and also allergenic. Formic and acetic acid irritate respiratory system and can synergistically increase toxicity of other, present in the smoke, compounds. In these terms particularly harmful is acrolein (Toth and Potthast, 1984; Sikorski, 2002).

More and more objections against traditional methods of smoke curing food are raised, mostly by hygienists, because of carcinogenic PAH compounds possible presence in the smoke. Modern smoking consists in application of specially prepared, condensed smoke-containing agents. They are obtained from condensed smoke or from the wood distillates after removing carcinogenic and odor-unpleasant compounds. The preparation can be liquid, fatty or integrated with a solid such as NaCl, malt or other materials (Toth and Potthast, 1984; Olsen, 1977).

Measurement methods: Temperature, static, dynamic and barometric pressure were measured and chemical composition, relative humidity and dust content in the exhaust gas were determined in order to investigate emission of the dust and gaseous components into the air.

Temperature was measured by means of thermocouple installed at the head of the probe of mobile digital thermometer. The probe was placed in the outlet channel.

Dynamic pressure of the exhaust gases was measured using Prandl tube coupled with digital micro-manometer DML2L. Static pressure was determined similarly to the dynamic one. Atmospheric pressure was recorded by barometer. The gas components CO₂, O₂, CO, NO₂, SO₂ were measured using electronic gas analyzer.

Determination of aliphatic, aromatic hydrocarbons and acetone: Sample was collected with the help of aspirators for 20 min into a tube, filled with activated coal. The gas flow was 30 dm³ h⁻¹. The sample analyzed was extracted from the activated coal with carbon disulphide for 15 min in ultrasonic washer. The extract was analyzed using gas chromatograph equipped with FID detector, column of 60 cm in length, internal diameter 0.53 mm, film thickness 1.0 μm. Concentration of the analyzed sample was determined by calibration with external standard, taking into account desorption coefficient.

Determination of alcohol content: Sample was collected, with the help of aspirators for 40 min into a tube, filled with silica gel. The gas flow was 30 dm³ h⁻¹. The sample analyzed was extracted for 20 min from the sorbent in ultrasonic washer, using water/iso-butanol (95/5) system. The extract was analyzed by gas chromatography with the use of analytical column filled with chromosorb of granulation 80/100 mesh, 4 m in length, 1/8 inch in diameter. The concentration was determined by calibration with external standard, taking into account desorption coefficient.

Determination of aldehyde content: Sample was collected with the help of aspirators for 30 min into a tube filled with XAD2 (2-HMP). The gas flow was 40 dm³ h⁻¹. The sample analyzed was extracted from the sorbent according to (NIOSH, 2007). The extract was analyzed by gas chromatography using glass column (chromosorb + 10% Carbowax 1500+2% KOH) 3 m in length, 4 mm in diameter. The concentration was determined by calibration with external standard, taking into account desorption coefficient.

Determination of phenols and cresols content: Sample was collected with the help of aspirators for 40 min into a tube filled with XAD 7. The gas flow was 30 dm³ h⁻¹. The sample analyzed was extracted from the sorbent. The extract was analyzed by gas chromatography method equipped with detector FID, glass analytical column of 3 m in length, 4 mm in

diameter filled with chromosorb +10% of Carbowax 1500+2% KOH. The concentration of the compound was determined by calibration with external standard, taking into account desorption coefficient.

Determination of acetic acid content: Sample was collected by gas aspiration through washers for 30 min. The gas flow was 1 dm³ min⁻¹. The collected samples were analyzed.

Determination of tar substances and soot: Sample was collected for 60 min in a tube filled with activated coal with the help of aspirators. The gas flow was 55 dm³ h⁻¹. The sample was extracted under pressure with methyl chloride using ASE 200 equipment. The solvent was evaporated from the extract using nitrogen and the Turbo Vap apparatus. The tar residue was determined gravimetrically. The soot was extracted from the filter with bromophor, using ultrasonic washer. Its amount, after drying, was determined by weighing.

Absolute humidity of the gas was calculated. The parameters, needed for calculation, were determined by water condensation in condensing vessel, temperature and pressure measurement.

Gas density was calculated taking into account exhaust gas composition, temperature and static pressure. Having dynamic pressure and density of the gas linear velocity of the gas was also determined.

Concentration of dust in the gas was calculated taking into account the amount of recorded gas flow and the amount of collected dust. Collection of the dust was achieved by means of gravimetric dust recorder EMIOTEST 2598. The length of stub pipe used enables to insert easily impact pressure tube, thermometer, dust separator and anemometer inside the channel of the aspiration probe.

RESULTS AND DISCUSSION

Former method of smoke purification applied in PPHU Duda-Bis Plant: For purification of smoke in PPHU Duda-Bis Plant water washers, placed in the outlet channel of smoke chamber, have been applied. To determine the effectiveness of the method used for reduction of the emission into the atmosphere the measurements were carried out in front and behind the washer in the outlet channel.

To assess the efficiency of the method required measurements were done in front and behind the washer. The results are presented in Table 2 and 3.

Table 2: Intensity of the exhaust gases flow and temperature (Dittmann and Zak, 2003)

Emission source	Intensity of exhaust gas flow (Nm ³ h ⁻¹)	Temperature of the gas (°C)
In front of the washer	261.3	49.7
Behind the washer	239.8	41.3

Table 3: Effects of purification of curing smoke by washer application (Dittmann and Zak, 2003)

Substance	Before the washer (g h ⁻¹)	After the washer (emission) (g h ⁻¹)	Efficiency (%)	δ _x E ±(%)
Dust	-	92.99000	-	15.4
Nitrogen dioxide	2.82	2.04000	27.7	3.7
Sulphur dioxide	34.43	27.90000	19.0	3.6
Carbon dioxide	463.97	373.60000	19.5	3.6
Acetaldehyde	0.83	0.76000	8.2	4.6
Acetone	1.37	1.00000	19.8	4.7
Acryl aldehyde (acrolein)	0.67	0.61000	8.2	4.6
Butan-1-ol	0.04	0.04000	4.7	5.4
Butan-2-on	0.76	0.53000	29.9	6.7
Cyclohexanon	0.09	0.02000	77.9	5.2
Ethyl benzene	0.73	0.11000	85.4	5.2
Phenol	0.08	0.01000	84.9	7.3
Formaldehyde	0.88	0.80000	8.2	4.6
Isopropyl benzene	0.13	0.06000	54.8	4.8
Cresol	0.03	0.01400	52.1	7.3
Xylene	0.32	0.22000	30.6	5.2
Acetic acid	0.52	0.48000	8.2	16.4
4-methyl pentan-2-on	0.05	0.02400	51.5	5.4
Methanol	0.97	0.89000	8.2	5.4
Mesitylene	0.25	0.13000	56.9	6.2
Butyl Acetate	0.03	0.02000	34.5	6.0
Ethyl acetate	1.46	1.19000	18.8	5.0
Methyl acetate	0.33	0.13000	60.0	5.0
Vinyl acetate	1.43	1.01000	29.5	5.4
Propyl benzene	0.09	0.02000	74.2	5.1
Styrene	0.20	0.10000	48.5	6.5
Wood tar	26.00	17.56000	32.4	6.5
Toluene	1.20	0.76000	26.0	5.5
Elemental carbon (soot)	-	10.34000	-	6.5
Alyphatic hydrocarbons	12.27	0.00667	45.6	5.4
Aromatic hydrocarbons	0.68	0.00006	90.5	5.4

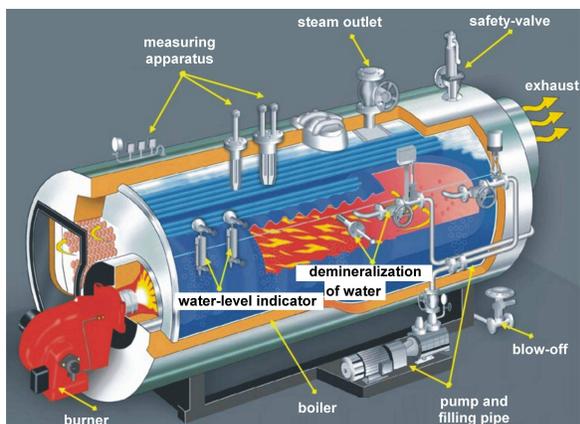


Fig. 1: Boiler EDs 6 made by Sefako, Sędziszow, Poland

Data in Table 2 demonstrate rather low reduction in the intensity of the exhaust gas flow after passing

through the washer. The recorded content of the components in the smoke displayed low efficiency of the method (Table 3). Chemical nature and the amount of the substances remaining in the air after passing through the washer were not acceptable by the standards and caused repulsive odor emitted into the atmosphere.

Thermal method of curing smoke oxidation: To eliminate discomfort, caused by smoke emission into the environment, PPHU Duda-Bis has been introduced a simple and effective method of thermal utilization of post-curing smoke by using boiler of type EDs 6 (Fig. 1) (Sefako, 2004a; 2004b; 2004c). The aim of the method was neutralization of odorous components in curing smoke, emitted into the atmosphere. The amount of considered smoke is ~1800 m³ h⁻¹ at 35°C. Before the smoke enters the boiler, water vapors undergo condensation and the water drops obtained are separated in steam drier.

Table 4: Results of analysis of the substances emitted into the air (PPHU Duda-Bis Ltd, 2006)

Component		Result of analysis	Unit of measure	
Concentration in dry gas (in relative conditions)	Dust (total)	3.57	mg m ⁻³	
	Carbon oxide	3.0	mg m ⁻³	
	Nitrogen dioxide	110.0	mg m ⁻³	
	Sulfur dioxide	2.6	mg m ⁻³	
	Carbon dioxide	179683.0	mg m ⁻³	
	Elemental carbon	0.274	mg m ⁻³	
	Acrylaldehyde (acrolein)	<0.100	mg m ⁻³	
	Acetaldehyde	<0.250	mg m ⁻³	
	Methyl alcohol	<0.050	mg m ⁻³	
	Phenol	<0.100	mg m ⁻³	
	Formaldehyde	<0.060	mg m ⁻³	
	Cresol	<0.020	mg m ⁻³	
	Xylene	0.403	mg m ⁻³	
	Toluene	0.598	mg m ⁻³	
	Acetone	0.144	mg m ⁻³	
	Cyclohexanon	<0.010	mg m ⁻³	
	Ethyl benzene	<0.060	mg m ⁻³	
	Cumene	<0.100	mg m ⁻³	
	4-methyl pentan-2-on	<0.030	mg m ⁻³	
	Mesitylene	<0.250	mg m ⁻³	
	Butyl acetate	0.192	mg m ⁻³	
	Ethyl acetate	<0.160	mg m ⁻³	
	Aliphatic hydrocarbons	2.533	mg m ⁻³	
	Aromatic hydrocarbons	2.123	mg m ⁻³	
	Wood tar	<0.100	mgm ⁻³	
	Emission	Dust (total)	0.0226	kg h ⁻¹
		Carbon oxide	0.0190	kg h ⁻¹
		Nitrogen dioxide	0.6976	kg h ⁻¹
		Sulfur dioxide	0.0165	kg h ⁻¹
		Carbon dioxide	1138.96	kg h ⁻¹
		Elemental carbon	0.00173	kg h ⁻¹
		Acrylaldehyde (acrolein)	<0.00064	kg h ⁻¹
Acetaldehyde		<0.00159	kg h ⁻¹	
Methyl alcohol		<0.00032	kg h ⁻¹	
Phenol		<0.00064	kg h ⁻¹	
Formaldehyde		<0.00038	kg h ⁻¹	
Cresol		<0.00013	kg h ⁻¹	
Xylen		0.00255	kg h ⁻¹	
Toluene		0.00379	kg h ⁻¹	
Acetone		0.00091	kg h ⁻¹	
Cyclohexanone		<0.00006	kg h ⁻¹	
Ethyl benzene		<0.00038	kg h ⁻¹	
Cumene		<0.00064	kg h ⁻¹	
4-metyl pentan-2-on (MEK)		<0.00019	kg h ⁻¹	
Mesitylene		<0.00159	kg h ⁻¹	
Butyl acetate		0.00121	kg h ⁻¹	
Ethyl acetate		<0.00101	kg h ⁻¹	
Aliphatic hydrocarbons		0.01604	kg h ⁻¹	
Aromatic hydrocarbons		0.01347	kg h ⁻¹	
Wood tar		<0.00064	kg h ⁻¹	
Meteorological conditions		Atmospheric pressure	981.0	hPa
		Temperature	295	K
Gas parameters in the pipe	Temperature	405.5	K	
	Static pressure	980	hPa	
	Dynamic pressure	18.9	Pa	
	Rate of gas humidity	2.9	%	
	Mean velocity	5.63	m sec ⁻¹	
	Chemical composition	O ₂	8.2%	
		CO ₂	9.7%	
	Density of dry gas (relative conditions)	1.335	kg m ⁻³	
	Density of wet gas (relative conditions)	1.311	kg m ⁻³	
Density of wet gas (measurement conditions)	0.855	kg m ⁻³		

Part of the organic compounds is caught by the forming drops, the rest is subjected to combustion in the, specially adapted to this purpose, boiler EDS 6. Oxygen demand for combustion of organic compounds is not high in comparison to the amount of oxygen present in the smoke. The smoke introduced into the boiler brings some excess of air. For the after-burning, the smoke is directed to a flamer through a specially shaped inlet. The inlet hole, to keep the proper temperature, is isolated using additional lining. The flamer is fixed over the burner.

Technical description of the typical boiler EDS 6 (Sefako, 2004a): ED symbol describes type of the boiler for steam manufacturing for technological and heating purposes. The boiler has furnace tube and smoke tube. It has been adopted to be fed with natural gas. The exhaust gas flows horizontally through furnace and smoke tube (Sefako, 2004b). The ED boilers are compact in their construction, highly efficient, characterized by high water capacity and low demand for the area space. The gas burner G60/2-A (Weishaupt Company) is fixed at the inlet of furnace tube. At the outlet of the exhaust gases heater ECO is shell-lined in order to increase heat capacity of the boiler.

Working parameters of the EDS 6 boiler according to (Sefako, 2004c) are:

- Nominal working pressure of the boiler = 1.0 MPa
- The highest working pressure = 1.1 MPa
- Temperature of the saturated steam = 188°C
- Nominal temperature of feeding water = 105°C
- Nominal heating output = 6 t/h
- Heat power = 3.9 MW
- Heating area-total (without ECO) = 228 m²; total (with ECO) = 319 m²
- Fuel-natural gas GZ50 of heating value = 35000 kJ Nm⁻³
- Fuel consumption (for 100% power) = 441 Nm³ h⁻¹
- Air demand ~ 7020 Nm³ h⁻¹
- Exhaust gas at the outlet = 5076 Nm³ h⁻¹
- Amount of utilized curing smoke = 1800 Nm³ h⁻¹
- Temperature of the outlet gas = 150°C
- Flow resistance of the exhaust = 1100 Pa

Service load of the boiler is in the range of 30-100% of the nominal, while burner is continuously working.

Technology of thermal utilization of curing smokes using boiler EDS 6: The boiler EDS 6 has been adapted to smoke after-burning. The smoke is directed to the furnace tube through four pipe lines of Ø = 180 mm with total cross-section of 0.1017 m². Maximal gas stream (including air and smoke) is 1800 m_n³ h⁻¹ (related to

normal conditions). That gives the velocity rate ~3 m sec⁻¹ of the gas entering the furnace tube. Such small velocity cannot disturb the combustion process of the burner. In practice, the amount of air and smoke utilized can be regulated by flap valve. An improvement in gas combustion, in comparison to standard boiler EDS 6, is achieved by introduction some additional elements, such as the plate at the front of furnace tube, the furnace tube of ~2500 mm, resulting in heat accumulation. Only a small (~3%) decrease in efficiency of the described boiler, in comparison to typical ones, has been observed. That effect is resulted from some heat losses caused by temperature (150°C) of leaving the boiler after-burnt gas. Composition of the gas, emitted from the boiler, is measured alternately by two emitters fixed at the roof of the plant. The measurement is carried out by independent laboratories twice a year. The results are presented in Table 4.

CONCLUSION

After the new method of curing smoke after-burning had been put into practice in PPHU Duda-Bis, the unpleasant odorous and harmful to the environment compounds were eliminated. The content of the emitted components per year, after thermal utilization of the smoke, was 100 times lower in comparison to the wet-method (Table 5).

Table 5: Acceptable emission/year when thermal method (PPHU Duda-Bis Ltd, 2006) or wet method (PPHU Duda-Bis Inc, 2002) is used

Compound	Emission (t/year)	
	Thermal method	Wet method
Dust	0.6950	
Sulfur dioxide	5.2903	
Nitrogen dioxide	33.0554	
Carbon dioxide	2.8945	1.630
Acetaldehyde	0.0177	
Acetone	0.0117	0.3741
Acryal adehyde	0.0078	
Cyclohexanon	0.0009	
Ethyl benzene	0.0048	
Phenol	0.0095	
Formaldehyde	0.0043	0.554
Isopropyl benzene	0.0082	
Cresol	0.0017	
Xylene	0.0251	
4-methyl pentan-2-on	0.0026	
Methanol	0.0566	1.832
Mesitylene	0.0043	
Acetic acid		0.137
Buthyl acetate	0.0112	
Ethyl acetate	0.0112	
Wood tar	0.4838	2.2798
Toluene	0.0613	
Elemental carbon (soot)	0.0341	
Alyphatic hydrocarbons	0.8640	
Aromatic hydrocarbons	0.8640	
Hydrocarbons aliphatic/aromatic*	0.0002	

*: Vapors of fuel oil

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