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Original scientific paper

Analysis of Tobacco Drying with Different Energy Sources

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Abstract: Excessive use of fossil fuels has an extremely negative impact on the environment and climate, as it results in the emission of harmful gases into the atmosphere. The goal of this research was to compare the use of solar energy and biomass as an energy source for drying tobacco in relation to natural gas. The research covered the drying of Virginia tobacco leaves with batch dryers, namely: thermogen models that use wood chips ("Model 1"), firewood ("Model 2") and pellets ("Model 3"), one model with natural gas thermogen combined with solar cells ("Model 4") and one thermogen with classic tobacco drying with ground gas ("Model 5"). In the first and third drying phase "Model 1" provides enough energy for drying the tobacco leaf but in the second phase it could not provide the required temperature, so it is necessary to increase the capacity of the combustion chamber. "Model 2" fully meets the requirements of tobacco leaf drying technology. Using pellets according to "Model 3" there were no difficulties and the tobacco was dried with good quality. Energy saving by using solar collectors according to "Model 4" is about 20%. Natural gas drying showed as the most expensive one.

Keywords: biomass, burners, solar energy, tobacco dryers

1 INTRODUCTION

The consequences of losing energy supplies are almost unimaginable today. Fossil fuels are the primary source of energy used in today's world. They are non-renewable, and in the not so distant future energy from fossil fuels will be less available and more expensive, so new energy sources must be used [1-3]. One of the underutilized sources of energy today is solar energy and energy from biomass. There are different ways to obtain energy from biomass. Direct production of electricity or thermal energy is possible, as well as conversion into solid, liquid or gaseous fuels. As biomass for energy production, plants can be grown directly or plant residues created in forestry and agricultural production can be used [4-8]. The use of biomass in Croatia has a long tradition. However, today Croatia uses biomass to cover only a small part of its energy needs. Croatia achieved the European goals of the required 20% share of production from renewable energy sources by 2020, but the analysis of the Croatian biomass market showed that the share of biomass in production from renewable sources is still too small. Therefore, there is still a lot of potential for further progress and greater use of biomass as an energy source. It is predicted that the available biomass (forest) in Croatia will be around 655566,000 m^3/ha by 2025, which represents a great potential [9, 10]. Research shows that solar energy can reduce the consumption of non-renewable sources by 27% to 80 % [11]. The annual insolation in the area around the town of Virovitica amounts to 1934.5 sunny hours. During the tobacco drying period, from July 15 to October 20, the total insolation amounts to 696.1 sunny hours; this is potentially a large amount of free energy that can be obtained from the sun. The Republic of Croatia encourages the use of biomass with financial support through the Energy Efficiency Fund and is a signatory to the KYOTO protocol, which obliges to implement measures to reduce emissions of harmful gases by 20%, replace fossil fuels by 20% and increase the use of renewable energy sources by 20%. All EU member states implement the KYOTO protocol through national programs based on the Energy Convention established in Copenhagen [12]. Croatian companies are introducing new agrotechnical measures in the production of tobacco in order to increase yields and reduce costs [13-15]. The agrotechnical measure of tobacco drying is carried out in chamber dryers and is divided into three phases: the leaf yellowing phase; leaf drying phase and rib drying phase. Tobacco leaves for drying are placed in metal frames. The moisture content of tobacco at harvest is around 82%. The process of tobacco leaves drying is carried out with a gradual increase in temperature from 25 °C to 74 °C and a gradual decrease in humidity from 95% to 10% at the end of a drying process. Tobacco producers have mastered the technology of production and drying so that the yields and quality of tobacco are at the level of the world's best tobacco. Tobacco producers mainly use liquefied and natural gas for drying but also recognize the problems of fossil fuels (quantity and price), and for the last few years, when drying tobacco leaves, they have been introducing new furnaces thermogens that use biofuels (in the form of firewood, pellets and wood chips) and solar energy to obtain the thermal energy needed for drying [16-19]. The goal of the research was to compare the use of solar energy and biomass as an energy source for drying tobacco in relation to natural gas as an energy source.

2 MATERIAL AND METHODS

The research included tobacco drying with three thermogen models that use biofuel (firewood, pellets and wood chips), one model with thermogen on natural gas in combination with solar cells, and one thermogen with classic drying of tobacco leaves with natural gas as an energy source. They are installed in tobacco dryers of different owners. Researched Virginia type tobacco leaves were harvested from the middle insertion in the period from August 1st to September 10th. The average length of the leaf was 52 cm and width 28 cm. Average initial humidity of the tobacco leaf was 82% and the average final humidity of the tobacco leaf was 10%.

Thermogen "Model 1" uses wood chips for drying. 250 kg of wood chips can be stored in a container with a capacity of 1 m^3. The wood chips are delivered into the combustion chamber through the dispenser, where they are burned while supplying the air required for combustion.

Tubular heat exchangers are located above the combustion chamber. An axial fan with a capacity of 18000 m^3/h is located in the upper part. Combustion in the chamber is regulated through the existing thermo regulator. The drying process is carried out using automatic regulation, which maintains the set temperature and air humidity in the dryer. Wood chips were bought at purchase price of €13.27/m^3. The mass of 1 m^3 of wood chips at 25% humidity is 200 kg. The energy value of 1 kg of wood chips at 25% humidity is 3.30 kWh. The thickness of the wood chips ranges up to 30 mm, which ensures smooth operation when dosing the wood chips through the auger dispenser into combustor. The price of 1 kg of wood chips is €0.08 including delivery costs.

Thermogen "Model 2" uses firewood as a fuel. Firewood is manually imported in the combustor. The burner with heat exchanger is located above the fan. Combustion of the wood mass is increased and decreased using the air current which is introduced from below. The drying process is controlled by a thermoregulator which maintains the set temperature in the range from 20 °C to 74 °C. The air humidity in the chamber is maintained manually using a latch. The amount of air required for drying tobacco is provided by a radial fan with a capacity of 15000 m^3/h. The firewood used in tobacco leaf drying is a sawed log of beech and hornbeam. The purchase price of 1 m^3 is €60, and it weighs 560 kg at a humidity of 25%. The energy value at 25% humidity is 3.50 kWh/kg, and at 10% humidity it is 4.40 kWh/kg. Wood logs were cut to a length of 50 cm. The price of 1 kg of firewood is €0.11.

Thermogen "Model 3" uses pellets for drying, which are stored in a tank with a volume of 0.5 m^3. It can hold about 300 kg of pellets. The pellets are placed into the combustion chamber using dispenser, where they burn with the support of air introduced under the combustion chamber. Through the heat exchanger, smoke gases transfer the heat to the air in the dryer. The air temperature is maintained manually by thermoregulator, and the air humidity is controlled by opening the flaps through which fresh air with a lower moisture content enters the dryer. A radial fan with a capacity of 18000 m^3/h is installed in the thermogen in the space above the combustion chamber and exchanger. The pellets are packed in PVC bags and weigh 15 kg. The dimensions of the pellets are 6 × 30 mm, with humidity of 8%. The mass of 1 m^3 is 650 kg. The energy value of a 1 kg of pellets is 5.0 kWh. The price of 1 kg of pellets is €0.40.

"Model 4" is a dryer that uses the energy of a gas-powered thermogen in combination with a solar collector to dry tobacco leaves. The dryer has four solar collectors (4.44 m^2 each) with total area of 17.76 m^2. "Model 4" is installed in the area around the town of Virovitica, where the annual insolation is 1934.5 of sunny hours.

"Model 5" represents standard tobacco drying. The dryer uses a natural gas thermogen. The data obtained from this model are used for comparison with dryers that use the energy from sun and biomass.

Weighing scales were used for measuring the mass of tobacco leaves before and after drying. Electronic thermometers were used during the drying process to measure the air temperature in the dryer, air humidity in the dryer and the temperature of smoke gases in the chimney. Through the sensor, the data were transmitted wirelessly to the computer. Data are stored in computers in numerical and graphic form so that the drying process can be continuously monitored from start to finish.

3 RESULTS AND DISCUSSION

Based on the conducted research the following results were obtained:

"Model 1"

The average filling of tobacco per frame was 47 kg. In total, there were 4984 kg of moist tobacco in the dryer. Pile of wood chips was located nearby and chips were inserted into a thermogen tank. The mixer in the tank ensured the operation of the dispenser with a two-shaft auger in order to protect against flames from the combustion chamber. Wood chips with 25% humidity have an energy value of about 3.30 kWh/kg. The drying temperature with wood chips in the second phase of color fixation and drying of the leaf blade, and the third phase of drying the middle rib, could not be achieved because the moisture content in the wood chips was high and the caloric value was not sufficient to achieve the required heat in that phase. Fig. 1 shows the movement of temperature and air humidity in the dryer during drying tobacco with wood chips. The curve with squares indicates the drying temperature that did not exceed 40 °C. In order to successfully dry tobacco leaves in the second (temperature 43-57 °C) and third phase (temperature 71-76 °C) with wood chips in the thermogen, it is necessary to increase the dosage and capacity of the combustion chamber. This requirement increases the capital cost of the available system, but the significant saving of energy costs of €0.13/kg of dried tobacco makes the investment economically attractive [20, 21]. The chimney temperature ranges from 65 °C to 130 °C, visible as a curve with triangles in Fig. 1.

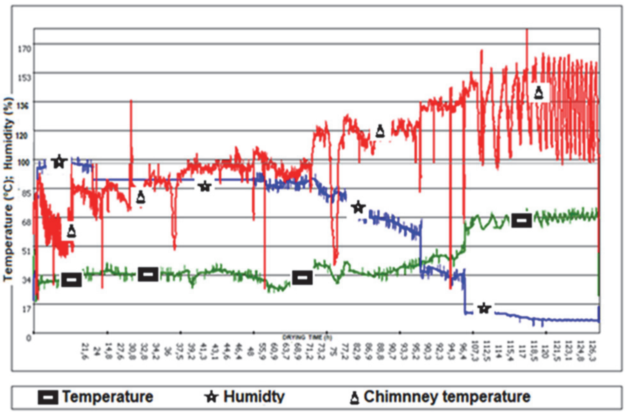

Figure 1 Temperature and air humidity movements in the drying of tobacco with wood chips

The curve with stars, which represents air humidity, has a gradual decrease, which is a necessary element during drying in the second phase of color fixation and drying of the leaf blade. Heat losses through the chimney are reduced to a minimum. The drying of tobacco with wood chips in the dryer was done on three occasions and an average of 872 kg of tobacco was dried and 1350 kg of wood chips were used.

"Model 2"

The average weight of tobacco in a frame was 58 kg, and a total of 4524 kg is placed in a drying room with 78 frames. The values of temperature and humidity when drying tobacco with firewood can be seen in Fig. 2. The curve with squares shows temperature values that were without major deviations from the default. In several shorter periods of time, there was a slight drop in the temperature at night when firewood was not put into the fireplace on time. The curve with stars shows the movement of the air humidity in the dryer, where the air humidity was decreased within the given limits. The process of drying tobacco using firewood meets the requirements of tobacco drying technology and there were no disturbances that would adversely affect drying. The curve with triangles in the figure shows the movement of the temperature of the exit gases through the chimney. The temperature during drying ranged from 75 °C to 105 °C, which indicates that the combustion chamber has good heat utilization. At the end of each drying, the dried tobacco was weighed in the same frames in which the tobacco was weighed before drying. The dried tobacco was of good quality.

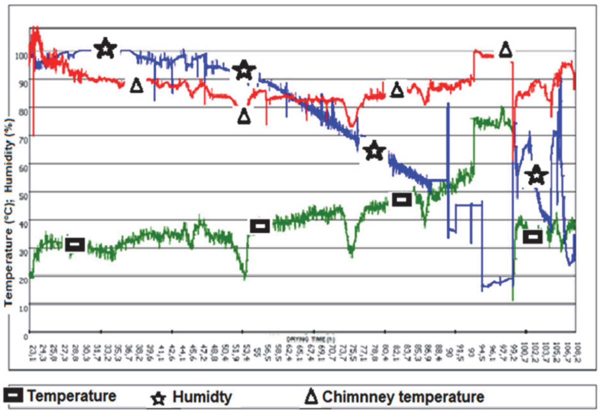

Figure 2 Temperature and air humidity movements in the drying of tobacco with firewood

The drying of tobacco in a dryer with firewood was carried out on nine occasions and a total of 7854 kg of tobacco was dried. On average, 872 kg of tobacco was dried per dryer and 1229 kg of firewood was used. Using this drying model, it is possible to use larger amounts of plant residues that are close by, thus reducing drying costs even more.

"Model 3"

A dryer with 105 frames contains an average of 5294 kg of tobacco, and the average filling per frame is 50.42 kg. A thermogen that uses pellets for drying was installed in the same place and in the same dimensions as the gas thermogen. The tank has a volume of 0.5 m^3 and can hold 300 kg of pellets. The pellets are in PVC bags weighing 15 kg and are manually transferred into the container. The drying process is managed by manual temperature regulation using thermoregulator, and humidity is regulated by manual adjustment of the inlet air flaps. Fig. 3 shows the drying temperature, which has a regular rise and air humidity has a regular drop (air humidity in the dryer is regular from the beginning to the end of drying). The smoke gas temperature ranges from 55 °C at the beginning to 180 °C at the end of drying process. Drying was done in four cycles and an average of 994 kg of tobacco was dried in the dryer and 1269 kg of pellets were used. The increased cost of drying with pellets compared to firewood and wood chips is compensated by a significant reduction in CO_2 emissions [22, 23]. With this drying method, the dried tobacco had a good quality.

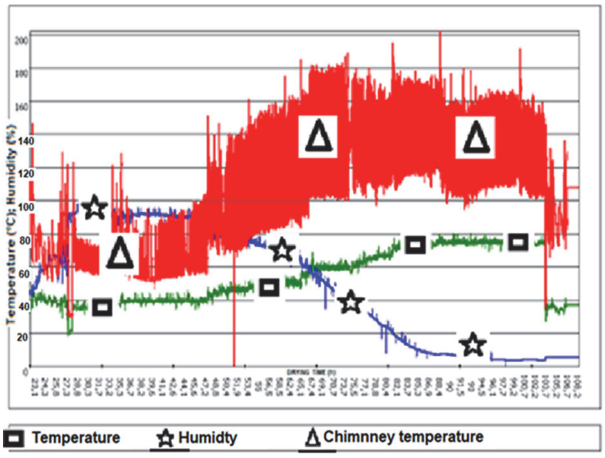

Figure 3 Temperature and humidity movements in tobacco drying with pellets only

"Model 4"

The installed "Model 4" is in the area around the town of Virovitica, and during the tobacco leaf drying from August 1st to September 15th, total insolation was 328.5 sunny hours. Installed solar collectors with vacuum tubes have an efficiency of up to 94%, and can provide 0.75 kW/m^2 of installed solar collector. During the research period, the vacuum collectors produced a total of 4375 kWh, or if this is converted into m^3 of natural gas of standard quality, that is 459.5 m^3 of natural gas. The "Model 4" dried tobacco was of good quality. In order to achieve the greatest possible savings, it is necessary to install a minimum of equipment for two dryers, and to dry the tobacco so that at least one dryer is always working during the above-mentioned period. With such a combination, the investment of installing solar collectors is profitable in four years, and if the installed system were to be used throughout the year, they would achieve additional savings by using the solar hot water for sanitary needs and heating residential spaces, thus shortening the repayment period.

"Model 5 - natural gas"

Tobacco drying with natural gas as an energy source was carried out in existing dryers and the obtained results are used for comparison with dryers that use biomass and solar energy for drying.

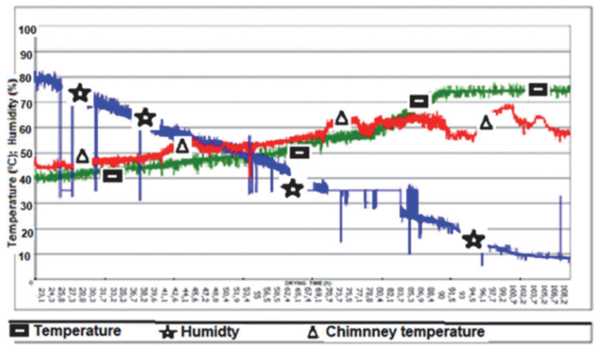

Figure 4 Temperature and air humidity movements in the drying of tobacco with natural gas

Fig. 4 shows the values of temperature and air humidity when drying tobacco with natural gas. Air humidity has a regular downward path, and the value of air temperature has a uniform upward flow from the beginning of the drying to the end. Regulation of temperature and air humidity is performed by automatic regulation named "Tobacco 4". The temperature of the exhaust gases in the chimney ranges from 45 °C at the beginning of drying to 70 °C at the end of drying, which indicates that the temperature of the smoke gases is very low. By drying tobacco with natural gas, an average of 873 kg was dried in the dryer. The average consumption of natural gas was 406 m^3 and the drying costs were €446.60. The obtained results are approximately equal to the results obtained by Budimir et al. (2013) [24]. The price of 1 m^3 of natural gas was €1.10 and the energy value of natural gas is 33120 kJ/m^3.

Further processing of all data resulted in the values of quantities and prices of different fuels used as energy sources for drying tobacco, which are shown in Tab. 1. The costs of drying tobacco are the highest with the use of natural gas and amount to €2300/ha (with a yield of 2300 kg/ha) and the lowest with the use of firewood, with a note that a person is needed who will dose the wood logs into the combustor. The obtained drying costs for firewood are 20% lower than those obtained by Welter et al. 2019, [25]. Drying costs for pellets and wood chips are approximately equal to the results of Welter et al. 2019, [25]. The combination of using natural gas and solar collectors (17.76 m^2) showed good results because solar energy is free. The optimal power of installed solar collectors for a drying room with 78 frames should be 19.98kW, and they should produce a total of 13908 kWh (or 1464 m^3 natural gas of standard quality) in the period from July 15th to October 20th (when drying tobacco). The installation of solar collectors requires additional costs, and in order to achieve the greatest possible savings, it is necessary to install a minimum of equipment for two dryers, and to dry the tobacco in a way that at least one dryer is always working (during the above mentioned period), because when one dryer is not working, then the solar system switches from inactive dryer to the active one. In short, it means that two solar systems produce energy for one active dryer. With such a combination, the investment of installing solar collectors is profitable in four years. If the installed system were to be used throughout the year, they would achieve additional savings with very small additional investments by using solar hot water for sanitary needs and heating of residential spaces, thus significantly shortening the investment payback time.

Table 1 Values of quantities and prices of different fuels used as energy sources for drying tobacco

Energent		€/kg €/m³	Spenditure kg/kg of tobacco (Average)	Dried tobacco / €/kg	+, – €/kg	INDEX	2300 kg/ha €/ha
A	Natural gas	1.10	0.90	0.99	–	100	2300
B	Wood logs	0.11	1.40	0.16	–0.83	16	368
C	Iver chips	0.08	1.54	0.13	–0.95	13	300
D	PELLETES	0.40	1.27	0.51	–0.48	51	1150
E	Natural gas + solarenergy	1.10	0.72	0.79	–0.20	80	1817

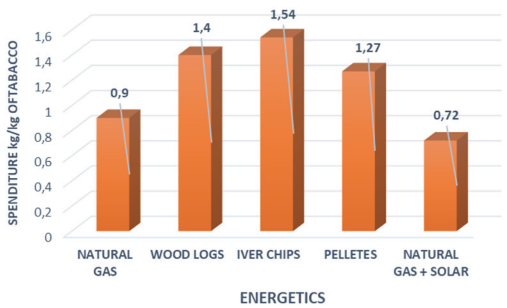

Figure 5 The amount of energy used in tobacco drying per kilogram of dried tobacco

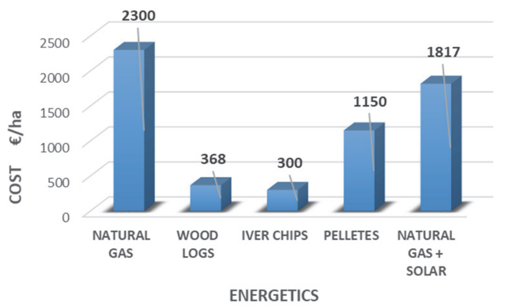

Figure 6 The cost of tobacco drying with different energy sources with an average yield of 2300 kg/ha

Fig. 5 shows the amount of energents used in tobacco drying per kilogram of dried tobacco. Fig. 6 shows the costs of drying tobacco with different energy sources with an average yield of 2300 kg/ha. The lowest costs are obtained when using wood chips and firewood (0.13-0.16 €/kg), then pellets (0.51 €/kg), then combination of ground gas and solar energy (€0.79/kg) and the highest price of €0.99/kg was obtained when using natural gas which is similar to the results of Budimir et al. 2013, [24]. The above data are relevant economic indicators in the production of dried tobacco leaves.

4 CONCLUSION

After conducting a research on tobacco drying with a thermogen that uses biofuels (in the form of firewood, pellets and wood chips) and solar energy to obtain the thermal energy needed for drying, the following conclusions were obtained:

1. By using only wood chips in the thermogen "Model 1" in the second and third phase of drying the necessary temperature could not be achieved, so it is necessary to increase the capacity of the combustion chamber with the installation of a radial fan which enables higher pressure and better air circulation. For drying tobacco leaves using wood chips, 1.54 kg of wood chips are needed for a kg of dried tobacco, or €300/ha.

2. The process of drying tobacco leaves using firewood as a fuel for the thermogen "Model 2" fully meets the requirements of tobacco drying technology and there were no disturbances that would adversely affect the drying and the tobacco was dried with good quality. To dry 1 kg of tobacco, 1.4 kg of firewood is needed, or €368/ha.

3. In "Model 3", which uses only pellets as a fuel, 1.27 kg of pellets were used to dry 1 kg of tobacco, or €1150/ha.

4. A tobacco dryer, which uses a combination of natural gas + solar energy ("Model 4") requires 0.72 m^3 of gas to dry 1 kg of tobacco, or €1817/ha.

5. Classic tobacco drying, "Model 5", with natural gas used in all stages of drying ensured the necessary

temperature for tobacco drying. To dry 1 kg of tobacco 0.9 m^3 of natural gas is needed, or €2300/ha.

6. Installation of a fireplace that uses wood chips and pellets for drying tobacco is profitable in four years. If a fireplace uses firewood for drying tobacco, it is profitable in two years. The installation of solar collectors of 17.76 m^2 is profitable in six years, and in order to achieve the greatest possible savings, it is necessary to install a minimum of equipment for two dryers. With such a combination, the investment of installing solar collectors is profitable in four years.

7. The biggest saving during tobacco drying was achieved by using firewood.

8. Global energy crisis and instability in the world affects the business of all stakeholders in the economy. The amount and distribution of natural gas as an energy source for business entities is uncertain, so apart from the ecological aspect, the use of biofuels in tobacco drying in relation to natural gas is also economically justified.

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