ANALYSIS AND SIMULATION BY ANSYS CFX OF THE AERODYNAMICS FLAME FOR BURNING ANIMAL FATS WITH LIQUID HYDROCARBONS

Dana Andreya BONDREA[1], Gheorghe LAZAROIU[2]

The paper presents an alternative of integrating animal waste in the combustion process of the fuel. The object of the case study is to obtain biofuels by making an emulsion between animal fat and diesel fuel. The animal fat is obtained from the several processes and chemical operations to which the animal skin is subjected. Processing of animal fats mandatory includes its recovery and release into the environment. The recovery of animal fats from tanning can be an important factor in protecting the environment. The article presents results obtained experimental. This paper also presents the results obtained by numerical simulation using the software ANSYS CFX software.

Keywords: leather industry, animal fat, ANSYS CFX, waste, environment.

1. Introduction

The leather industry in Romania has strongly developed until 1980 and, therefore the next 9 years were productive. Since 1989 this industry is in competition with a competitive market opened by other countries [1]. We can say that despite the progress made by the leather industry in relation with the environment this is still a pollution factor due to protein waste. The leather is a unique material and cannot be replaced with synthetic materials. The leather production is about 4.8 billion sq meters in the world. About 6.5 million tons of wet salted hides and skins are processed each year in the world and 3.5 million tons of different chemicals substances are used in their processing [2].

The process of restructuring and reorganizing of the tanning plant was necessary after the accession of Romania to the European Union and it had to include regulations related to environmental protection, waste management and waste treatment [3]. Currently the most economical waste disposal is throwing them in the field. Waste like ash or animal fat can be sold and used in other industries. The ash from this experiment or from manure treated by gasification can be considered as an opportunity to use it in agriculture [4]. Usually, the leather industry uses skins as raw materials. This industry generates a large

---

[1] PhD Student, Dept. of Hydraulics, Hydraulic Equipment and Environmental Engineering University POLITEHNICA of Bucharest, Romania, e-mail: andreya.dana@yahoo.com
[2] Prof. PhD, Dept. of Energy Production and Use, University POLITEHNICA of Bucharest, Romania, e-mail: glazaroiu@yahoo.com

amount of solid and liquid waste [5]. The main processes made in tanning have been seriously changed and directed to what it means ecological and cleaning production. We can say that progress has been made to a less polluting production but the leather sector still has technical problems to solve.

The potential of biofuels to reduce pollution is high and this can be a positive element in the relationship with the environment. Theoretical studies suggest complex technological processes which have the risk of triggering undesired oxidation reactions, transforming Cr (III) into Cr (VI) so this can means that the chemical processes have the risk of converting material from normal waste to dangerous waste [6]. More than 210 million m2 of leather are produced every year in over 2800 tanneries in the European Union. To produce this amount, about 7 million tons of skins are needed [7]. The pigs and sheep skins have a higher fat content than cattle, so it can be recovered. Animal skin from European countries has a fat content between 5% and 15%, while those from Australia have a fat content between 20% and 40% [8]. The European tanneries produce about 2.14 kilograms of waste per square meter of leather produced [9].

Biodiesel can be blended with petro-diesel fuel in various proportions to provide similarity in terms of energy density and kinematic viscosity for direct use in the existing engines without modifications [10]. In the last years, many researches were done regarding strategies of waste management toward less environmental impact considering e different reduction emission systems [11].

2. General aspects about main tanning operations

The whole process to which the animal skin is subjected contains a series of complex operations, chemical reactions and mechanical processes. Tanning operations consist of the transformation of strong putrescible leather in a fine and stable material. Finished leather can later be used in a large number of products such as shoes, clothing, cars, and furniture and so on. The leather is a biological material that is treated in a watery medium.

The first operation to which the leather is subjected after it comes into tanning is washing. By washing, the salt is removed and the animal skin is cleaned. The following two operations are those that reduce excess animal fat and remove hair from the skin surface. The tanning is the most important operation of the whole process. This operation transforms putrescible leather in a non-putrescible material.

The leather tanning is made with chemicals: for instance with Cr_2O_3, it has a complex structure and reacts with leather proteins [12]. The next operation is squeezing which means to eliminate water excess from the leather. The last process is painting and has the role of giving the leather a nice aspect.

3. The case study – Methodology

The object of this case study is to determine the combustion characteristics of animal fats in combination with diesel fuel. The main differences from diesel appear in the value of viscosity and oxygen content, which influences spraying and burning. Due to the high viscosity, the use of animal fats in diesel engines is only possible if mixing it with diesel fuel, obtaining a low viscosity of the mixture. This mixture can be used in conventional diesel engines [13]. The animal fats and liquid hydrocarbons have a similar calorific value between 35000 kJ/kg and 35500 kJ/kg [14].

The animal fat is taken from tanning, then is weighed using an analytical balance and is divided into different amount so that the fat concentration of the mixture is 10%, 20%, and 30%. The quantity of diesel was 5 liters. The mixture of animal fat with diesel fuel was heated in a vessel with electrical heating element which had attached a thermocouple to measure the temperature.

Effective burning has occurred in a pilot boiler of 50kW for hot water production; the model is Multiplex CL 50 and is presented in Fig.1 and Fig.2 [15].

The boiler has 4 components: the evacuation of combustion gases is 1, room of the boiler is 2, the pipes of heat exchanger are 3 and 4 is the burner [16].

Fig. 1. The experimental boiler Multiplex CL50

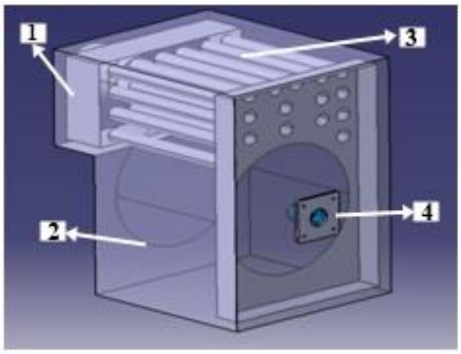

Fig. 2. The geometry of the boiler made in CATIA V5R21

The boiler has a mechanical spraying burner with pump. The injection of the mixture was performed with burner GB-Ganz type ANYO-12R-2-1-0, presented in the Fig.3, the aerodynamic stabilizer presented in Fig.4 and the CATIA model in Fig.5.

The burner used has its own preheater that achieves a 70-75°C fuel temperature before spraying. The burner was equipped with an injector spray nozzle with 0.5 mm diameter.

The aerodynamic stabilizer for the flame is composed from a peripheral channel for inlet air 1, 2 is central channel for inlet air, 3 are tangential channels for air and 4 is spray nozzle.

Fig. 3. The burner GB GANZ

Fig. 4. The aerodynamic stabilizer for the flame

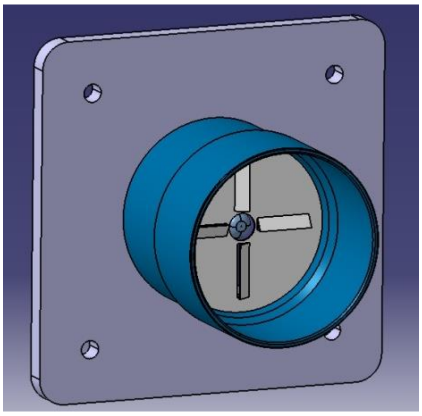

Fig. 5. The construction of aerodynamic stabilizer in the CATIA program

The mixture of light liquid fuel with animal fat for our proportions was homogenized by heating between 45°C and 50°C in the heater attached to the burner.

The comparison from elemental analysis for diesel and the mixture used in the experiment are in table 1 [17]:

Table 1

The elemental analysis

Fuel	C [%]	H[%]	O[%]
The diesel	86.67	12.96	0.33
The mixture used	68-75	14-15	14-19

The burner used consists of the following:
- the external diameter of the swirl channel is d=80 [mm];
- the center zone diameter is d_0=20[mm];
- the angle of geometrical elements for swirl is α=60°.

The axial air flow velocity is u_x=20 [m/s].
The tangential velocity is determined by:

$$u_\beta = u_x \frac{d^2}{d^2 - d_0^2} tg\alpha \left[\frac{m}{s}\right] \quad (1)$$

By calculation, the result is:

$$u_\beta = 37.6 \left[\frac{m}{s}\right] \quad (2)$$

The average swirl rating is determined by the relationship:

$$n = \frac{\sum n_i \rho_i F_i u_{xi}^2 D_f}{D \sum \rho_i F_i u_{xi}^2} \quad (3)$$

where, ρ [kg/m^3] is fluid density, F [m] is the flow section, u_{xi} [m/s] is axial velocity, D_f [m] is flow channel diameter, D [m] is embrasure diameter. After the interaction of the three concentric jets through the flow sections results the equivalent degree of swirling: n_{ech}=2.7.
The mass of the swirl jet is calculated with the relationship [18]:

$$\frac{D_m}{m_{imass}} = (0.32 + 0.4n) \frac{x_{ad}}{D} \left[\frac{kg}{s}\right] \quad (4)$$

where, x_{ad} [m] is the axial distance, m_{imass}[kg/s] is initial mass, n is degree of swirl, D [m] is embrasure diameter.
At an average flame temperature of 1100K the mass of the swirl jet increases and reaches [19]:

$$D_m = m_{imass} 1.4 \rho \frac{x}{D} = 0.26 \left[\frac{kg}{s}\right] \quad (5)$$

During the experiment the burner worked for 10 minutes with diesel, then it continued with the first mixture of 10% concentration animal fat. Before performing the experiment with sample 2, the burner operated with diesel another 10 minutes then the mixture was introduced. The sample number 3 was done under the same conditions as the other two. The amount of animal fat introduced in our fuel is presented in Fig.6.

The sample 1 The sample 2 The sample 3

Fig. 6. The aspect of animal fat dissolution in diesel fuel for each sample

The gas emissions were measured with the MAXILYZER NG from Fig.7 for each sample [20].

Fig. 7. The gas analyzer MAXILYZER NG

The flame lengh for the combustion of liquid fuel is calculated according to the formula:

$$L_{flame} = \frac{ut}{(1+A)^2} \text{ [m]} \tag{6}$$

where, u [m/s] is the flow velocity at the outlet of the burner, t [s] is time and A is the coefficient characterizing the interaction between the energy characteristics of the fuel and the geometry of the burner. The coefficient A is calculated with the formula:

$$A = 1 + \frac{2.4}{\tau_c}\left(\frac{\rho_c}{\rho_c} \cdot \frac{v_a}{v_c}\right)^{0.5} \left(\frac{d_j}{d_0}\right)^{1.5} \tag{7}$$

where, τ_c [N/m] is the surface tension of the fuel, ρ_a[kg/m^3] is air density, ρ_c[kg/m^3] is fuel density, ν_a, ν_c [m^2/s] viscosity of air and fuel, d_j, d_o [m] are diameter of the output section.

The length of the flame on the burner was L_{flame} = 0.46 [m].

4. The results of experiment

The results obtained are indexed in the tables to make it easier to analyze.

Table 2

The results of experiment for sample 1

Sample 1		O_2 [%]	CO [ppm]	CO_2 [%]	Efficiency [%]
Animal fat 10[%]	10[min]	13	1536	6.3	72.3
	15[min]	13.7	1683	6	70,1
	20[min]	14	1801	5.8	70
	Average	13.56	1673	6.03	70.8

Table 3

The results of experiment for sample 2

Sample 2		O_2 [%]	CO [ppm]	CO_2 [%]	Efficiency [%]
Animal fat 20[%]	10[min]	13.2	1314	5.1	73.2
	15[min]	13.5	1023	5.8	74.1
	20[min]	13.4	1625	6.1	70.1
	Average	13.3	1321	5.67	72.5

Table 4

The results of experiment for sample 3

Sample 3		O_2 [%]	CO [ppm]	CO_2 [%]	Efficiency [%]
Animal fat 30[%]	10[min]	10	1160	8.7	77.1
	15[min]	10.1	1156	8.1	76.2
	20[min]	9.7	1151	8.7	76.2
	Average	9.93	1155	8.5	76.5

5. CFD simulation and results

The modeling is done in CATIA V5R21 software (Computer Aided Three Dimensional Interactive Application) and the simulation is done in ANSYS WORKBENCH 14.0 CFX. The role of simulation is to confirm the experimental results. The purpose of this simulation was to view the swirling currents of the flame. The speed of air and particles were introduced according to burner calculation values.

The simulation consists of two directions:

1. To see the flame aerodynamics;
2. To observe the dynamic of the combustion process.

Fig. 8. The experimental aspect of the flame outside the boiler

The simulation of the flame was done in 2D in Fig.9 in order to be able to compare with the experimental aspect, Fig.8.

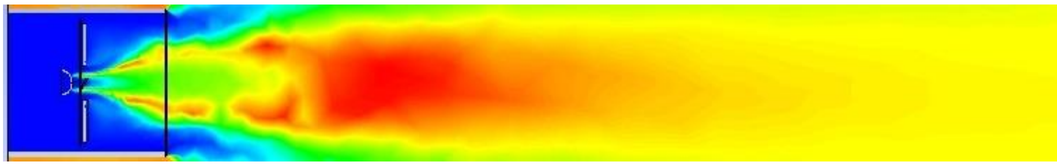

Fig. 9. To observe the simulation aspect of the flame

The simulation was done also to see the general flame aerodynamics which is composed from multiple jets including a swirling one; they are represented in Fig.10 and Fig.11.

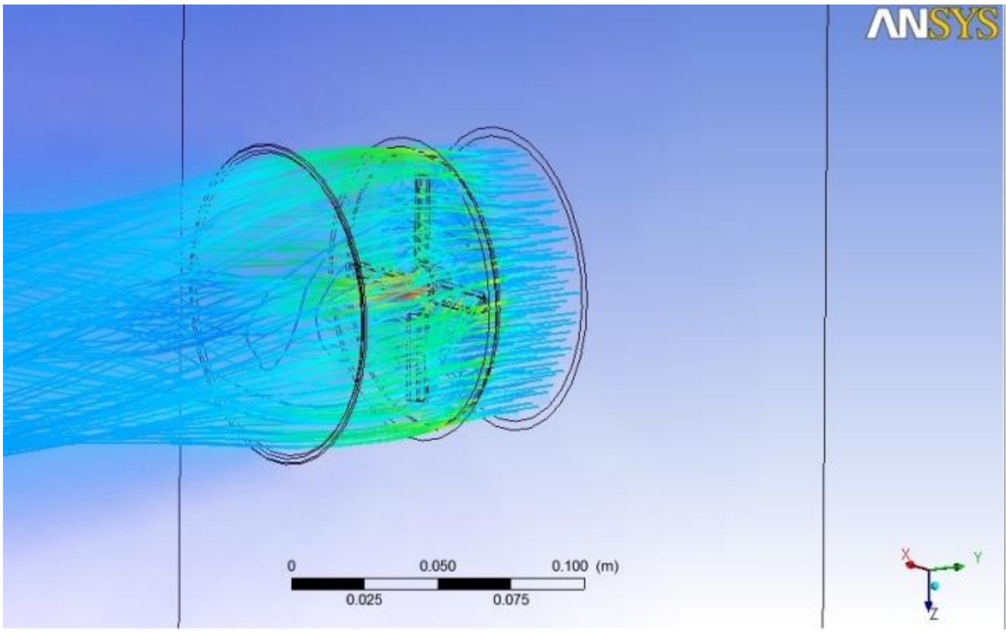

Fig. 10. The lateral view of the swirl flow

The simulated model consists in an air flow inlet through the three sections, including the tangential channels that generate swirling. The flow lines from Fig. 11 show the swirling flow.

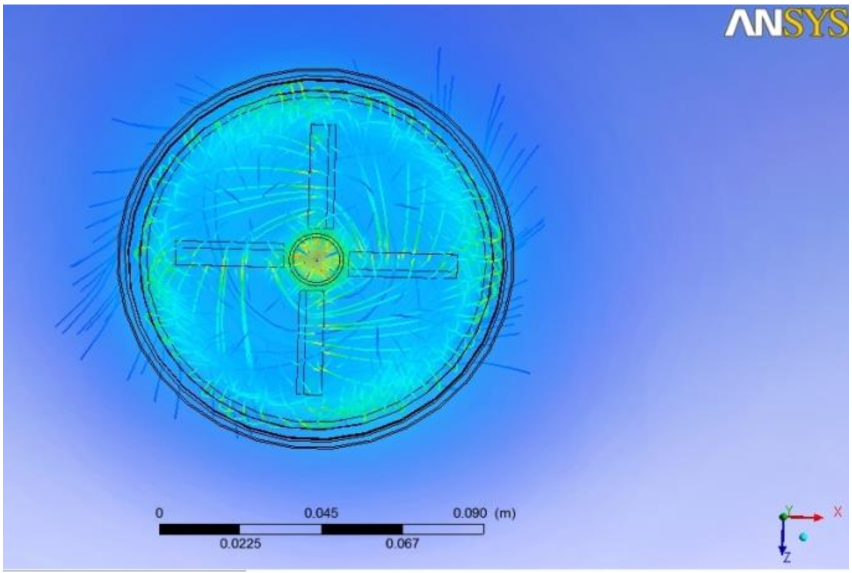

Fig. 11. The frontal view of the aerodynamic stabilizer and swirl currents

From the simulation program we can see the axial flow velocity determined by the burner aerodynamics and flame temperature. The brightness from the end of the flame is difficult to see using experiments, but it can observed in simulation.

The simulation presented in Fig.12 shows that the length of ideal flame is 0.48[m] and the axial flow velocity are similar to the parameters of the experiment. The air velocity is 20 [m/s] but due to the reduction of the air section through the air deflector, the velocity reached about 50[m/s].

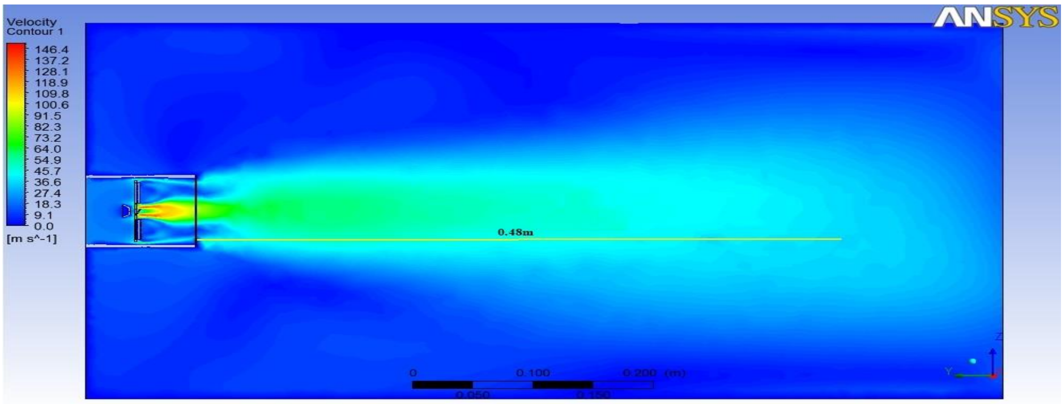

Fig. 12. The length of the flame

The maximum velocity is in the area where the fuel mixture is injected because the ignition starts there.

In Fig.13 are explained the most important 4 areas of the simulated flame:

1. The area where the swirling effect directs the flame ignition to the periphery;
2. The flame ignition area;
3. The nucleus of the flame;
4. The area of unlighted flame.

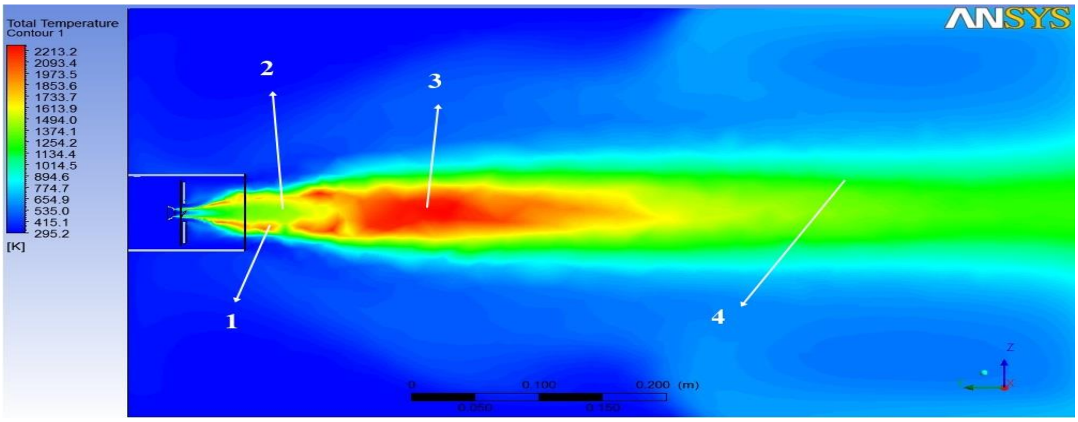

Fig. 13. The temperature of flame

To exemplify the flow process in real tridimensional conditions, it was introduced Fig.14 and Fig.15 with the combustion isometric, which demonstrated a correct location of the flame in the boiler.

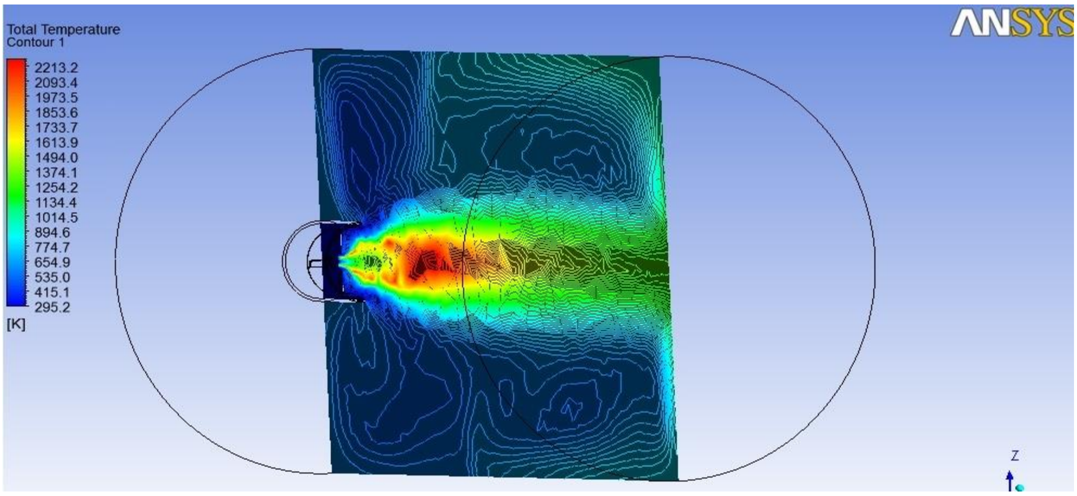

Fig. 14. The isometric view for temperature of the flame

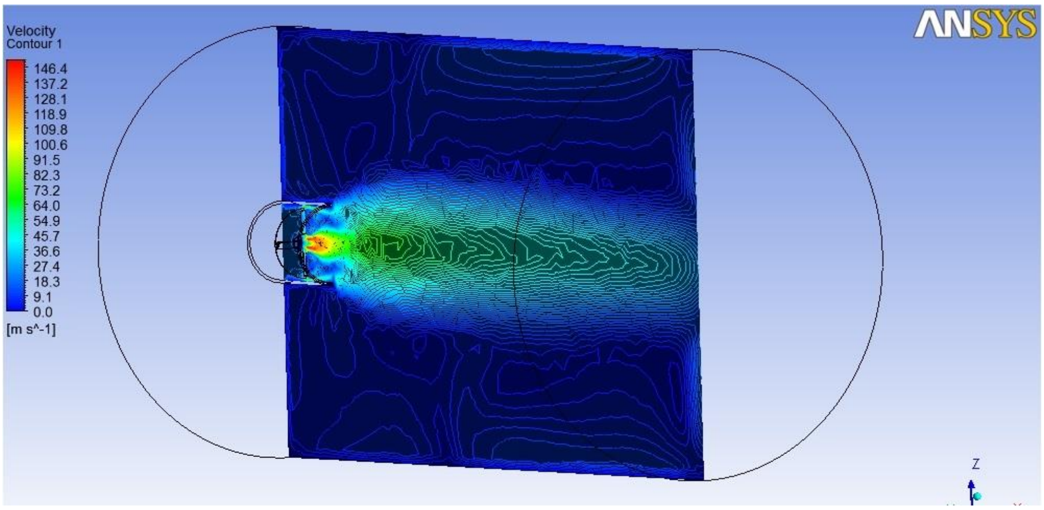

Fig. 15. The isometric view for velocity of the flame

6. Conclusions

This paper has proposed to follow the ecological process of destroying animal fat waste using combustion. The article proposes a technological possibility to burn animal fat waste in certain proportions without the change of burner. The research was done on an experimental stand with the boiler Multiplex CL50 and the burner GB-Ganz type ANYO-12R-2-1-0 for flame aerodynamics. The simulation was done in ANSYS WORKBENCH 14.0 CFX and confirmed the yield values, the flame length and the nucleus of the flame.

The flame obtained in the experiment has a length of 0.46 [m] and the one released in the simulation program under the same condition has a length of 0.48 [m]. The difference of 0.02 [m] can only be seen in simulation and is called the unlighted flame. In order to reduce the environmental and atmospheric pollution, it can be considered that the use of biofuels from animal waste for diesel engines is a reliable method. The combustion gases from this biofuel have a low content CO and CO_2. According to the results of the present paper, the characteristics of this mixture are environmentally friendly and can be used in the future as an alternative to conventional fuels. This biofuel does not contain sulfur, nitrogen and heavy metals. In the experiment was intended to determine the smoke but it did not exist.

The future research will be based on the simulations of this process, but at different concentrations of animal fat. The burner will also be equipped with various nozzles to study the ignition temperature, the ignition point and the length of the flame.

Acknowledgment

„This work was supported by a grant of the Romanian Ministery of Research and Innovation, CCCDI – UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0404 / 31PCCDI/2018, within PNCDI III".

R E F E R E N C E S

[1]. *V. Mirciu*, "Industria de pielarie incaltaminte romaneasca in contextul national si international" (The romanian leather and footwear industry in the national and international context), feb-mar 2005, Perfectlink.

[2]. *J. Kanagaraj , T. Senthilvelan , R.C. Panda , S. Kavitha*, "Eco-Friendly Waste Management Strategies For Greener Environment Towards Sustainable Development In Leather Industry: A Comprehensive Review", 2015, Journal of Cleaner Production 89(2015) pages 1-17, http://dx.doi.org/10.1016/j.jclepro.2014.11.013, Elsevier.

[3]. ***Legea nr. 211/2011 privind regimul deşeurilor – modificări (o.u.g. nr. 68/2016)

[4]. *Torretta V., Rada, E.C., Istrate, I.A., Ragazzi M.*, 2013. Poultry manure gasification and its energy yield, UPB U.P.B. Sci. Bull., Series D, 75(1), 231-238.

[5]. *A. İşler , S. Sundu, M. Tüter, F. Karaosmanoğlu*, "Transesterification Reaction Of The Fat Originated From Solid Waste Of The Leather Industry", Waste Management 30 (2010) pages 2631–2635, Elsevier.

[6]. *Bufalo G., Florio C., Cinelli G., Lopez F., Cuomo F.,Ambrosone L.*, 2018.Principles of minimal wrecking and maximum separation of solid waste to innovate tanning industries and reduce their environmental impact: The case of paperboard manufacture, Journal of Cleaner Production, 174,324-332.

[7]. *Onem E., Gulumser G., Renner M., Yesil-Celiktas O.*, 2015. High pressure vegetable tanning of sheepskins using supercritical carbon dioxide, The Journal of Supercritical Fluids, 104, 259-264.

[8]. *F.Vitan* "Instalatii Pentru Tratarea Apelor Din Industria De Prelucrare A Pieilor" (Equipments For Water Treatment From The Leather Processing Industry).

[9]. *F. Brugnoli, G. Gonzalez-Quijano, Luminita Albu*, "The First Social & Environmental Report Of The European Leather Industry", pages 21-48, Leather and Footwear Journal 13 (2013)1.

[10]. *Onga L.K., Kurniawana A., Suwandia A.C., Linb C.X., Zhao X.S., Ismadjia S.*, 2013. Transesterification of leather tanning waste to biodiesel at supercritical condition: Kinetics and thermodynamics studies, The Journal of Supercritical Fluids, 75, 11-20.

[11]. *Antognoni, S., Ragazzi, M., Ionescu, G., Passamani G., Zanoni S., Rada E.C., Torretta V.*, 2016. Respirometric index as a tool for biogas generation production from poultry manure, Management Of Environmental Quality, 27(3), 269-280.

[12]. *Andrew P. Abbott, Omaymah Alaysuy, A. Paula M. Antunes, Andrew C. Douglas, Jeffry Guthrie-Strachan, William R. Wiseb*, Processing of Leather Using Deep Eutectic Solvents, ACS Sustainable Chem. Eng., DOI: 10.1021/acssuschemeng.5b00226 , 2015, 3 (6), pp 1241–1247.

[13]. *Gh. Lăzăroiu, L. Mihăescu, I. Pîşă, G. Negreanu, E. Pop, V. Berbece, A. Bondrea,* "Analysis Of Flame Aerodynamics For Burning Tests Of Animal Fat Mixed With Liquid Hydrocarbons", 6th International Conference on Thermal Equipment, Renewable Energy and Rural Development, TE-RE-RD 2017, Proceeding, ISSN:2457-3302, ISSN-L:2457-3302, Moieciu de Sus, 8-10 June 2017, Romania, pages 73-47.

[14]. *L. Mihăescu, Gh. Lăzăroiu, I. Pîşă, E. Pop, G. Negreanu, V. Berbece, A. Bondrea*, "Analysis Of The Possibilities Of Combustion Of Animal Fat Mixed With Liquid Hydrocarbons In Boilers With Small Furnaces", 6th International Conference on Thermal Equipment, Renewable Energy and Rural Development, TE-RE-RD 2017, Proceeding, ISSN:2457-3302, ISSN-L:2457-3302, Moieciu de Sus, 8-10 June 2017, Romania, pages 83-86.

[15]. *G. Lăzăroiu, L. Mihăescu, I. Pîşă, E. Pop, C.R. Mocanu*, Animal Fats Mixed With Liquid Hydrocarbons Combustion Efficiency, Proceedings of university of ruse - 2016, Volume 55, book 1.2., pages 12-16, Ruse, Bulgaria.

[16]. ***http://www.ganz.ro/arztoare-monobloc-pe-lichid/anyo-12.

[17]. *Lazaroiu G., Pana C., Mihaescu L., Cernat A., Negurescu N., Mocanu R., Negreanu G.,* Solutions For Energy Recovery Of Animal Waste From Leather Industry, energy conversion and management, issn: 0196-8904, eissn: 1879-2227, 2017, volume 149, pages: 1085-1095,doi:10.1016/j.enconman.2017.06.042,accession number: wos:000411537200088

[18]. *L. Mihăescu, N. Pănoiu, Cr. Totolo*, Arzătoare turbionare"(The swirling burners), Ed. Tehnică, Bucureşti, 1986.

[19]. *L. Mihăescu* „Arzătoare pentru hidrocarburi cu NO_x scăzut"(Burners for hydrocarbons with low NO_x), Ed. Printech, Bucureşti 2004, ISBN 973-718-039-9.

[20]. *** http://analizoaredegaze.ro/wp-content/uploads/2015/01/Maxilyzer-NG_prez.pdf.