RESULTS ON THE USE OF LIQUID FUELS MIXTURES IN LIQUID FUELS FURNACES

Florentina CĂLUGĂRU[1]

Articolul tratează o alternativă la combustibilii lichizi tradiționali şi avantajele folosirii sale în domeniul energetic. Impactul redus asupra mediului al mixturilor de combustibili pe lanțul de la producție până la consumator şi emisiile reduse rezultate în urma arderii lor pot fi validate prin calculul emisiilor. Durabilitatea producției de mixturi de combustibili lichizi poate crea cadrul corespunzător pentru o dezvoltare durabilă în domeniul energetic în urmatoarea perioadă de timp, cu costuri şi consumuri de energie pentru producere mai mici ca alte surse de energie regenerabilă, ca biomasa, energia eoliană, energia geotermală şi, de asemenea, poate oferi oportunități pentru dezvoltarea rurală durabilă.

The article is developing an alternative at conventional liquid fuels and the advantages of its use in the energetic field. The low impact on the climate of the liquid fuel oil mixtures from production to the consumer and the low combustion emissions can be validated by emissions calculations. The sustainability of liquid fuel mixtures production can define the appropriate frame for the sustainable development in energetic field in the next stage, with costs and energy consumption for production lower than other renewable sources like biomass, wind, geothermal, and can also offer opportunities for sustainable rural development.

Keywords: numerical calculations, emissions values, mixture structure, fuel oil mixture, dimethylether, viable alternative , sustainable energy development

1. Introduction

1.1 Developing renewable energy sources as a means of reducing pollution from combustion of liquid fuels.

At the beginning of the third millennium, as alternatives to conventional fuels there aren't too many solutions, and from the ecological-economic point of view remains accessible: plants that store large amounts of energy in growth and development, solar energy, wind, soil and thermal water. The first group means plants with energy potential, that can be used for energy production.

[1] PhD student, Electrocentrale Bucharest Branch, Bucharest, e-mail: flore_calugaru@yahoo.com

The distribution of these plants from which oil is extracted worldwide is the following: 28% soybean, palm oil 22%, 14% canola, sunflower 10.5%, 5.2% ground peanuts, cotton and 4.7% is illustrated in fig. 1.

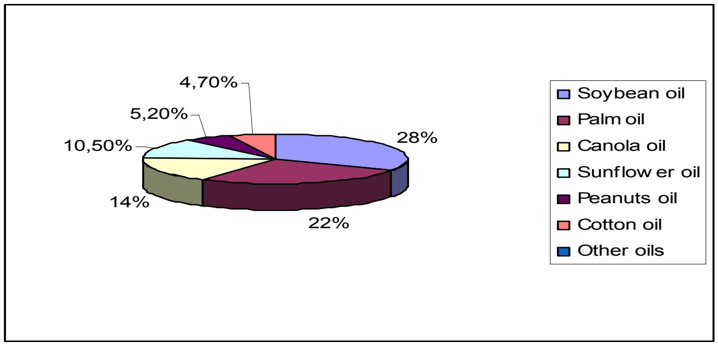

Fig.1 Main types of oil extracted worldwide

1.2. Possibility of using mixtures of biofuels and liquid fuels in the energy field

• Use mixtures of biofuels as an alternative at conventional sources

From the economic point of view, mixtures of fuel energy is a viable alternative to conventional sources, taking into account the diminishing oil reserves and increasing its price, and contributing to rural development (by improving work conditions and increased arable options products) .

• Use vegetable oils and DME for engines in projects in the transport industry in Europe

In the early 70s, Elsbett company has created the first engines to run on vegetable oil. They were more expensive on the market, engines being assembled and manually adjusted. To reduce emissions, Elsbett engines with larger displacement, used two injectors, symmetrical; they have reduced the time of injection of approximately 50%. Also in the transport industry, with the potential of biofuels for the future, it was remarked DME (dimethylether). Engine product manager at Volvo Trucks (Sweden) said, related to DME, "DME is viable due to the fact that the burning process is so clean. ". Volvo Truck wants alternative fuels commercially viable, without negative effects on the ecological cycle of production.

2. Calculation of NOx emissions, SO2, CO2 to liquid fuel mixtures and vegetable oils

The calculation shows the formation of nitrogen oxides from combustion of fuel oil and vegetable oil mixture containing oil in 90%, 80%, 70%, 60%, the remainder being vegetable oil. Emissions calculations were carried out according to the procedure set out in 2.1, for a mixture of oil and sunflower oil. Categories surveyed in oil composition sulfur = 0.49%, sulfur = 1.4% and sulfur = 2.8%. Then we made the synthesis of results and calculations, were compared variations represented NOx, SO_2, CO_2 for the three categories of oil.

2.1 Calculation of nitrogen oxide mixtures: oil 90%, oil 80%, oil 70% and 60% and the remaining oil sunflower oil (= 0.49% Sulphur)

A. Calculation of NOx when 100% oil

Baseline data: Qi = 38937kJ/Kg V_a =10,52Nm3
Vga =12.14 Nm3 α = 1.08

The heat exhausted from combustion area:

$$Q_f = 38937 \text{ kJ/kg} + 3128,9 \text{ kJ/kg} = 42065,9 \text{ kJ/kg} \quad (1)$$

$$Q_{aa} = \alpha \cdot V_a \cdot c_a \cdot t_{ap} = 1,08 \cdot 10,52 \cdot 1,53 \cdot 180 = 3128,9 \text{ kJ/kg} \quad (2)$$

where t_{ap} is the temperature for the air preheating
c_a is the specific heat of the air

The value of Tm (the maximum temperature in the flame area) depends, in adiabatic conditions, on the combustion temperature in the flame area, given by (7)

The adiabatic temperature for the specific heats can be calculated as follows:

$$t_a = \frac{1950}{\alpha_a}(1+0,36 \text{ x}10^{-5} Q_f) = \frac{1950}{1,08}(1+0,36 \text{ x}10^{-5}\, 42065,9) = 2078\ °C. \quad (3)$$

The specific heat of combustion and air in the burning process of the mixture consisted of the fuel oil and vegetable oil can be determined as follows:

$$c_{ga} = 1,57+0,134\, k_t \quad (4)$$

$$c_a = 1,46+0,092\, k_t, \quad \text{where} \quad (5)$$

$$k_t = (t_a-1200)/1000 \quad (6)$$

where k_t is the coeficient of variation of specific heat with temperature

Therefore k_t = (2080 -1200)/1000 = 0,88 and c_a = 1,46+0,092·0,88 = 1,54

The adiabatic temperature in the combustion area can be calculated as follows:

$$T_a = \frac{Q_f}{V_{ga}c_{ga} + 1{,}016(\alpha_a - 1)V_a c_a} + 273 = \tag{7}$$

$$\frac{42065{,}9}{12{,}14 \cdot 1{,}65 + 1{,}016(1{,}08 - 1)10{,}52 \cdot 1{,}54} + 273 = 2243\text{K}, \qquad \text{where:}$$

$$Q_f = Q_i + Q_{aa} \text{ , given by (1)}$$

The maximum temperature in the flame area can be calculated as follows:

$$T_m = \beta \cdot T_a\,(1-\psi)^{0.25} \cdot m_a = 0{,}98 \cdot 2243 \cdot (1 - 0{,}3)^{0{,}25} = 2009 \text{ K}. \tag{8}$$

Consider β=0,98, ψ=0,3 , ma = 1

(β rate of fuel burn up to the maximum flame temperature area;

β=0,97-0,99 for liquid and gaseous fuels

ψ coefficient of walls thermal efficiency in the core of flame, considered at 1.5 m above the last row of burners, ma =1, for swirl burners)

Theoretical time to achieve equilibrium concentration of NO at temperature Tm:

$$\pi_0 = 0{,}024 \cdot e^{54290/2009-23} = 0{,}024 \cdot e^{4{,}28} = 1,3 \text{ s}. \tag{9}$$

Reaction time for the formation of oxides of nitrogen, K, in furnace is determined by the relationship:

$$\pi_r = \frac{\Delta T_r}{T_a - T_f}\left(\frac{q_s \Pi}{300}\right)^{0{,}5} \pi_{st} = \frac{64{,}06}{2243 - 1749}\left(\frac{3{,}47 \cdot 40}{300}\right)^{0{,}5} 2{,}1 = 0{,}18 \text{ s}. \tag{10}$$

The temperature difference of the NOx formation reaction:

$$\Delta T_r = \frac{T^2_m \cdot 10^{-5}}{0{,}614 + T_m \cdot 10^{-5}}\ {-5} = \frac{2009^2 \cdot 10^{-5}}{0{,}614 + 2009 \cdot 10^{-5}} = 62{,}47 \text{ K} \tag{11}$$

τ_{st} , the stationary time of combustion gases in the furnace, s, given by:

$$\tau_{st} = \frac{273\xi}{q_v \cdot T_f \cdot v_{ga} \cdot \alpha \cdot (1 + r)} \tag{12}$$

where: $q_v = \frac{BQ_i}{v_f}$ thermal volume apparent loading of furnace,

MW/m3 (13)

$$T_f = 0{,}84\,\left[(T_m) + (T_f'')\right]^{0{,}25} \quad \text{average temperature} \tag{14}$$

of the combustion gases in furnace, K.

v_{ga}, average reported theoretical volume of combustion gases from α = 1, m^3/MJ

for mixture of fuel oil and vegetable oil , $v_{ga} = 0.30 m^3$/MJ

ξ , coefficient of filling section furnace by the combustion gases stream

Replacing in the above relationship:

$T_m = 2043$ K si $T_{f'} = 1273$, we have $T_f = 1749$ K.

q_v = 0,18 MW/m3, ξ=0,8

α = 1,08

The result, with (12), will be $\tau_{st} = 2{,}1$s

The concentration of nitrogen oxides which are formed as a result of the reaction with the flame kernel area and expression as nitrogen dioxide NO_2^t, g/m3 is determined as follows:

$$NO_2^t = 7{,}03 \cdot 10^3 \cdot CO_2^{0,5} \exp(-10860/T_m) \frac{\tau_r}{\tau_0} \quad (15)$$

where CO_2, mass concentration of oxygen existing in the reaction zone (in excess), kg/m3 and is determined by the relationship:

$$CO_2 = \frac{0{,}21 \cdot V_a \cdot (\alpha - 1) \cdot \rho_{O2}}{V_{ga} + (\alpha - 1) \cdot V_a} \cdot = \frac{0{,}21 \cdot 10{,}52 \cdot (1{,}08 - 1) \cdot 1{,}428}{12{,}14 + (1{,}08 - 1) \cdot 10{,}52} = 0{,}019 \text{ kg/Nm}^3 \quad (16)$$

Replacing CO_2 in the (8.15) , the result of NO_2^t concentration is :

$$NO_2^t = 7{,}03 \cdot 10^3 \cdot (0{,}019)^{0,5} \exp(-10860/2009) \frac{0{,}1}{1{,}3} = 0{,}280 \text{ g/Nm3} = \mathbf{280} \text{ mg/Nm}^3 \quad (17)$$

The calculation of NO_2^p , in order to take into account the increased speed of the combustion reaction , introduces in the maximum temperature calculation, the T_m' temperature, given by :

$$T_m' = 1{,}01 \text{ Tm}, \quad (18)$$

where T_m is given by (8) . Therefore $T_m' = 2029$ K.

The concentration of prompt nitrogen oxides is determined as follows:

$$NO_2^p = 0{,}1\ \alpha \left(\frac{T_{m'} - 800}{1000}\right)^{0,33} = 0{,}1 \cdot 1{,}08 \cdot \left(\frac{2029 - 800}{1000}\right)^{0,33} = 0{,}115 \text{ mg/Nm3} = \mathbf{115} \text{ mg/Nm3} \quad (19)$$

The total concentration of nitrogen oxides is, therefore:

$$NOx = NO_2^t + NO_2^p \quad (20)$$

NOx = 280 mg + 115 mg = **395** mg.

B. Results of numerical calculations referring to the production of NOx from combustion of fuel oil mixture (0.49% sulfur) 90%, oil 80%, oil 70% and 60% and the remaining oil sunflower oil

The results of numerical calculations referring to the production of NOx from burning oil and oil mixtures, using the same calculation methodology are given in table. 1

Calculations were performed with the following initial conditions:

1. In the calculation presented, it was adopted equivalent elemental analysis of the mixture of fuel oil and vegetable oil.
2. It was not taken into account the degree of flue gas recirculation.
3. It was taken into account the excess coefficient of 1.08, it was operating (in Bucharest South CET) with this value, the case of fuel oil 100%.

Table 1

Results of NOx calculation for mixtures of fuel oil (0.49% sulfur) and sunflower oil

Symbol size (mathematical expressions)	Mixture structure of liquid fuels				
	Fuel oil 100% Oil 0%	**Fuel oil 90% Oil 10%**	**Fuel oil 80% Oil 20%**	**Fuel oil 70% Oil 30%**	**Fuel oil 60% Oil 40%**
1	2	3	4	5	6
Q_i, kJ/Nm^3	38937	39067	39198	39328	39458
V_a, Nm^3/Nm^3	10,52	10,45	10,40	10,35	10,30
V_{ga}, Nm^3/Nm^3	12,14	12,06	12,04	11,99	11,97
α , -	1,08	1,08	1,08	1,08	1,08
c_{ga},kJ/Nm^3 (8.4)	1,654	1,654	1,654	1,654	1,654
c_a, kJ/Nm$_3$ (8.5)	1,540	1,540	1,540	1,540	1,540
k_t (8.6)	0,88	0,87	0,87	0,87	0,87
t_a, °C (8.3)	2078	2076	2077	2077	2078
T_a, K (8.7)	2243	2239	2247	2261	2270
T_m,K (8.8)	2009	2007	2012	2025	2033
τ_o, s (8.9)	1,3	1,4	1,3	1,1	1,0
τ_r, s (8.10)	0,18	0,18	0,18	0,18	0,18
ΔT_r, K (8.11)	64,06	63,93	64,25	65,07	65,60
τ_{st}, s (8.12)	2,1	2,1	2,1	2,1	2, 1
$C_{O2,}$ g/m3 (8.16)	0,019	0,019	0,019	0,019	0,019
NO_2^t, mg/Nm^3 (8.17)	280	200	216	255	281
NO_2^p, mg/Nm^3 (8.19)	115	115	115	116	116
NOx, mg/Nm^3 (8.20)	**395**	**315**	**331**	**371**	**397**

The analysis of results allows the followings remarks:

• calorific value is slight increasing from 39 067 kJ / kg oil 90% to 39 458 kJ / kg for combustion with 40% vegetable oil mixture.

• thermal NOx is slight increasing, from 315 mg 10% oil mixture up to 397 mg in the largest percent of the vegetable oil in mixture and prompt NOx, is maintaining approximately constant
• In all four cases, the NOx value is below the limit imposed by environmental standards for power plants (NOx 450mg, according to GD 541/2003 on measures to limit emissions from large combustion plants).
• In the case of 10% vegetable oil, is was found a reduction of NOx by about 20%, and slight increase in NOx as increasing the share of vegetable oil from mixtures with 20%, 30% and 40% vegetable oil, taken into account.

In fig.2 it was shown the NOx variation at mixtures of fuel oil (0.49% S) and sunflower oil.

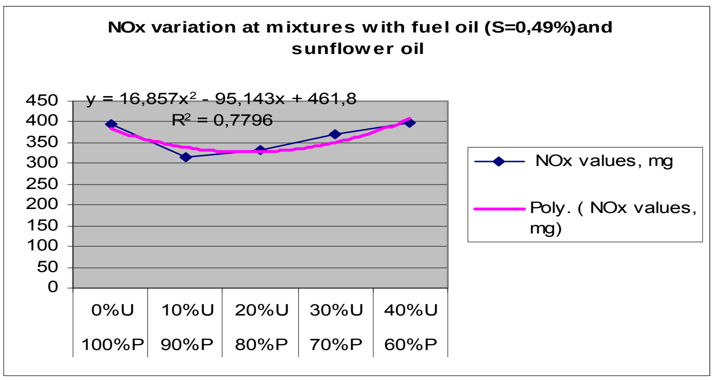

Fig. 2 NOx variation at mixtures with fuel oil (S=0,49%) and sunflower oil

C. Results of numerical calculations referring to the production of NOx from combustion of fuel oil mixture (1.4% sulfur) 90%, up to 60% and the remaining sunflower oil

Table 2

Results of numerical calculations referring to the production of NOx from burning mixtures (1,4%sulphur)

Symbol size (mathematical expressions)	Mixture structure of liquid fuels				
	Fuel oil 100% Oil 0%	**Fuel oil 90% Oil 10%**	**Fuel oil 80% Oil 20%**	**Fuel oil 70% Oil 30%**	**Fuel oil 60% Oil 40%**
1	2	3	4	5	6
NO_2^t, mg/Nm^3 (17)	332	234	255	281	312
NO_2^p, mg/Nm^3 (19)	116	115	115	116	116
NOx, mg/Nm^3 (20)	**448**	**349**	**370**	**397**	**428**

The four options presented above enable us to found out the following:

● thermal NOx is slight increasing from 234mg if oil mixture 90%, reaching up to 312mg for a 60% oil mixture and prompt NOx is maintaining approximately constant, the value of 112 mg

● In all four cases, the NOx value is below the limit imposed by environmental standards for power plants (NOx 450mg, according to GD 541/2003 on measures to limit emissions from large combustion plants) .

● in the case of 10% vegetable oil, it was found a reduction of approximately 22%, reaching 12% in the mixture with 30% sunflower oil

NOx variation at mixtures with fuel oil (S=1,40%) and sunflower oil is illustrated in fig.3 .

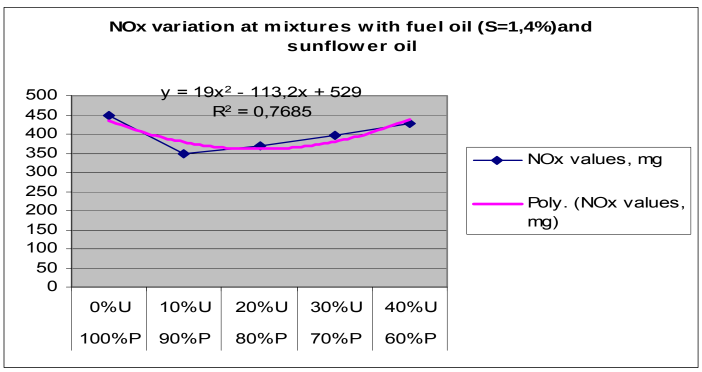

Fig. 3. NOx variation at mixtures with fuel oil (S=1,4%) and sunflower oil

The values analyzed in the cases presented enable to be found that *fuel oil with 0.49% sulfur and 1.4% sulfur fuel oil, <u>for mixtures with 10% sunflower oil</u>, reducing NOx* is about <u>*20%*</u> , *compared the case with 100% oil.*

D. Results of numerical calculations referring to the production of NOx from combustion of fuel oil mixture (2,8% sulfur) 90%, up to 60% and the remaining sunflower oil

Table 3

Results of numerical calculations referring to the production of NOx from burning mixtures (2,8%sulphur)

Symbol size (mathematical expressions)	Mixture structure of liquid fuels				
	Fuel oil 100% Oil 0%	Fuel oil 90% Oil 10%	Fuel oil 80% Oil 20%	Fuel oil 70% Oil 30%	Fuel oil 60% Oil 40%
1	2	3	4	5	6
NO_2^t, mg/Nm^3 (17)	352	243	293	282	320
NO_2^p, mg/Nm^3 (19)	116	116	115	116	116
NOx, mg/Nm^3 (20)	468	359	378	398	436

The four options presented above enable us to found out the following:

• thermal NOx is slight increasing from 243 mg at mixture with10% oil, up to 320 mg for 60% oil mixture and prompt NOx is maintaining approximately constant, the value of 116mg

• In all four cases the NOx value is below the limit imposed by environmental standards for power plants (NOx 450mg, according to GD 541/2003 on measures to limit emissions from large combustion plants).

• in the case of 10% vegetable oil, (NOx value of 359 mg) shows a reduction of about 24% of the NOx value , in comaprison of the value obtained at 100% fuel oil reducing is lowering with the oil sharing increasing in the mixture, reaching of about 20% to 20% oil, and of about 15% to 30% oil in the mixture

In fig. 4 it was given a graphic illustration of the NOx variation for mixtures with fuel oil (S=2,8%) and sunflower oil.

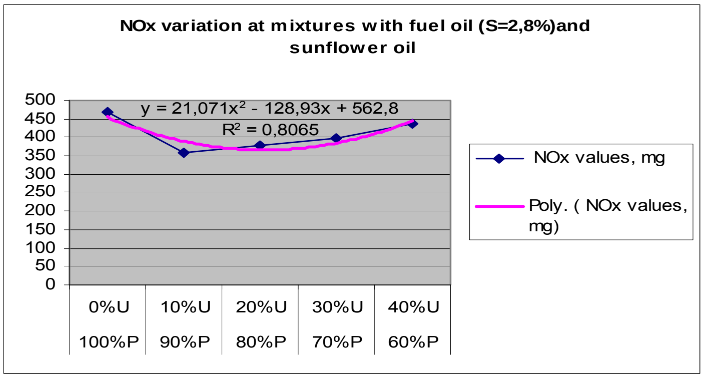

Fig. 4. NOx variation at mixtures with fuel oil (S=2,8%) and sunflower oil

The NOx calculations at oil mixtures (S = 2.8%) enable the result that the mixtures of sunflower oil can be used by up to 40% oil, without exceeding the maximum allowable NOx emissions.

Analyzing the NOx values in the cases presented, it is found that *all fuel oils types (0.49% sulfur ,1.4% sulfur, and also 2.8% sulfur) at mixtures with 10% sunflower oil, NOx reduction is between 18-24% in comparison with 100% fuel oil.*

At mixtures with higher percentages of oil, *all fuel oils taken into account can form functional mixtures of sunflower oil*, the values of 397 mg (S = 0.49%), 428 mg (S = 1.4%) and 436 mg (S = 2.8%) falling in the allowable range.

2.2. NOx numerical calculations referring to the production of NOx from combustion of fuel oil and dimethylether

Results of NOx numerical calculation for mixtures of fuel oil (0,49% sulfur) 90% up to 60% and dimethylether are shown in table 4.

Table 4

Results of NOx calculations at mixtures of fuel oil(0,49% sulfur) and dimetylether

Symbol size , MU	Mixture structure of liquid fuels				
	Fuel oil 100% DME 0%	**Fuel oil 90% DME 10%**	**Fuel oil 80% DME 20%**	**Fuel oil 70% DME 30%**	**Fuel oil 60% DME 40%**
1	2	3	4	5	6
NO_2^t, mg/Nm3 (17)	280	179	131	152	178
NO_2^p, mg/Nm3 (19)	115	115	113	115	114
NOx, mg/Nm3 (20)	**395**	**294**	**244**	**267**	**292**

Therefore, the four options presented in the table enable us to found out the following:

- in operation with 10% DME, it is found a reduction of about 26% of NOx emissions in comparison with the operating case of 100% fuel oil, in which total NOx emission is 395 mg/Nm3; further increasing of DME proportion leads, in any of the cases, in NOx reductions of over 26%; it is reaching a Nox reduction of 33% at mixture of 30% DME
- in all four variants, the NOx value is below the limit imposed by environmental standards for power plants.

For fuel oil (S=0,49%) and dimetylether mixtures, the variation is shown in fig. 5:

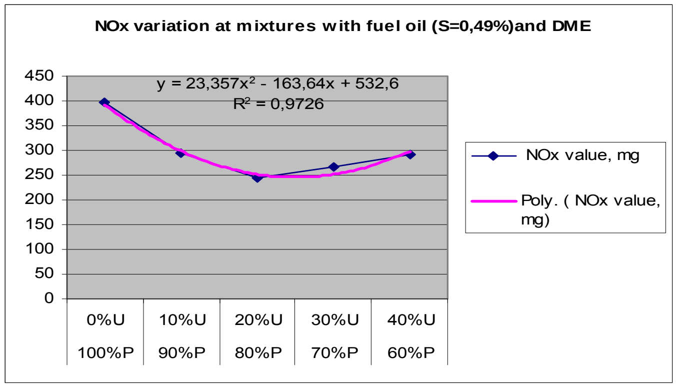

Fig. 5. NOx variation at mixtures of fuel oil (S=0,49%) and DME

By introducting 10% DME in the mixture, it can be achieved a NOx reduction of 24% in comparison with 100% fuel oil, a large reduction reported to all fuel oil mixtures; it was recorded the same reduction in the case of fuel oil mixtures (S = 2.8%) and sunflower oil.

2.3 Calculation of SO_2 and CO_2 emissions from combustion of liquid fuel oil (sulfur at a rate of 0.49%, 1.4%, 2.8%) and sunflower oil mixtures)

Calculation of SO_2 and CO_2 from burning oil treated in the calculation of NOx (sulfur at a rate of 0.49%, 1.4%, 2.8%) was performed using relations (21) - (24).

B. Calculation of SO_2 for mixtures of fuel oil and sunflower oil

In order to calculate SO_2 emissions we can use the mathematical relationship:

$$C\ (mg/m_N^3) = 5000\ \frac{Sc}{Vg}(1-\beta_{fSO_2}) \quad (21),$$

where the meanings are:

Sc (%) - percentage of fuel oil sulfur

$Vg\left[\frac{m^3{}_N}{kg}\right]$ - actual volume of dry flue gas

β_{SO2} - degree of sulfur retention in the furnace, which is considered null in the case of operating with 100% fuel oil

In the case fuel oil 100%, the result will be:

$$C_{SO2} = 5000\ \frac{0,49}{9,79}\ (1 - 0) = 250,25\ \ mg/m^3_N \quad (22)$$

C. Calculation of CO_2 for mixtures of fuel oil and oil mixtures

In order to calculate CO_2 emissions, we can use the mathematical relations (23) and (24).

$$e_{CO_2} = \frac{\frac{m_{CO_2}}{m_C} C_i\%}{Q_i} \cdot 10^6 = \frac{\frac{44}{12} \cdot 85{,}90}{38937} 10^6 = 8089{,}13 \left[\frac{g}{GJ}\right] \quad (23)$$

$$c_{CO_2} = \frac{e_{CO_2}}{F_v} = \frac{8089{,}13}{290} 10^3 \left[\frac{mg}{m_N^{\ 3}}\right] = 27893{,}5 \left[\frac{mg}{m_N^{\ 3}}\right], \quad (24)$$

where the results are available in the case of fuel oil 100%.

In relations (23) and (24),

e_{CO_2} - emission factor for CO_2, in $\left[\frac{mg}{GJ}\right]$

m_{CO_2} - molecular weight of CO_2, equal to 44

m_C - molecular weight of carbon , equal to 12

Q_i - lower calorific value of fuel , $\left[\frac{kJ}{kg}\right]$

Fv - the volume factor, defined as the ratio of combustion gas volume and amount of heat related to the fuel introduced in the boiler; the values are given in the methodology for calculating emissions: lignite/480, oil / 290, natural gas /320

The results of SO_2 calculation are recorded in the table 5:

Table 5

Results of SO_2 calculation at mixtures of fuel oil and sunflower oil

Mixture type/fuel oil type	**Fuel oil 100% Oil 0%**	**Fuel oil 90% Oil 10%**	**Fuel oil 80% Oil 20%**	**Fuel oil 70% Oil 30%**	**Fuel oil 60% Oil 40%**
Fuel oil (S=0,49%)	250	232	207	188	168
Fuel oil (S=1,4%)	712	651	588	524	453
Fuel oil (S=2,8%)	1454	1324	1183	1041	904

Following the analysis of table 5, we can remark :

- The lowest SO_2 values are recorded for oil with S = 0.49% (the values are decreasing from 232 mg up to 168 mg in the case of mixtures with sunflower oil). Minimum value, the 168 mg represents a 33% reduction in SO_2 in comparison with the value in the case of 100% fuel oil.

From the presented cases , it is found that, at the three types of oil, by introducting a10% oil mixture in the composition, reductions are between 2% and

10% in comparison with 100% fuel oil ; when mixtures with 40% vegetable oil, reductions range is between 33 and 38% depending on the fuel oil type..

The variation of SO_2 for fuel oil mixtures (S = 0.49%) (S = 1.4%) and (S = 2.8%) and sunflower oil is illustrated in fig.6, 7 and 8 .

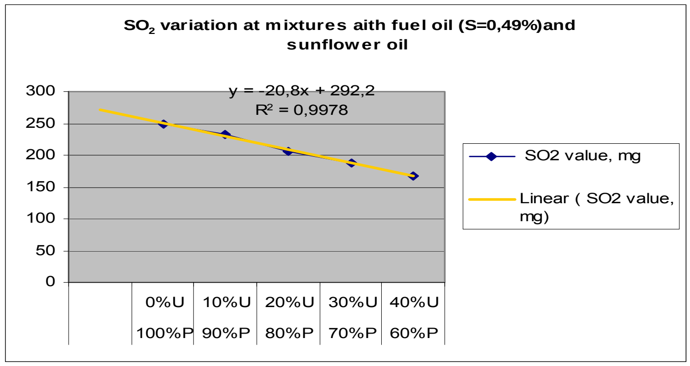

Fig.6. SO_2 variation at mixtures of fuel oil (S=0,49%) and sunflower oil

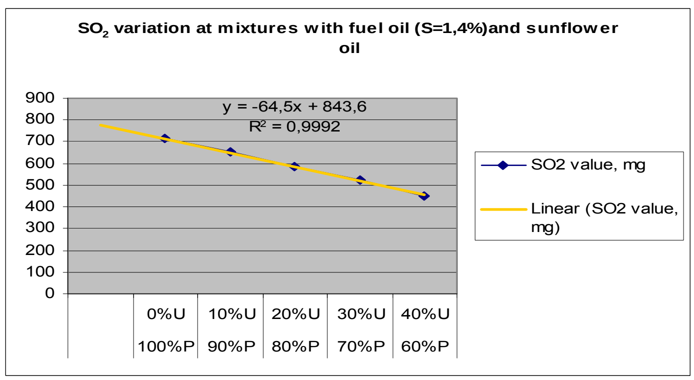

Fig.7. SO_2 variation at mixtures of fuel oil (S=1,4%) and sunflower oil

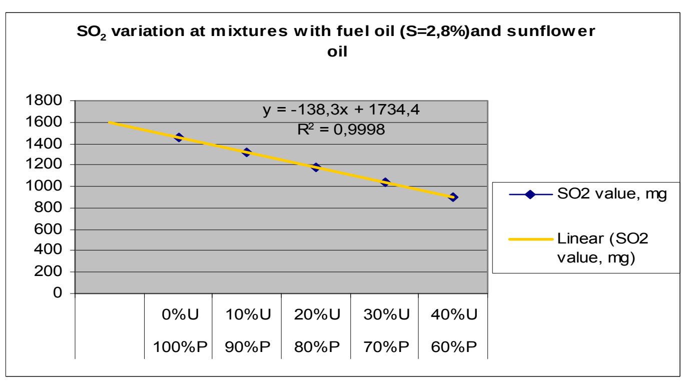

Fig.8. SO_2 variation at mixtures of fuel oil (S=2,8%) and sunflower oil

The results of CO_2 calculation at mixtures of fuel oil and sunflower oil are recorded in the table 6.

Table 6

Results of CO_2 calculation at mixtures of fuel oil and sunflower oil

Mixture type/fuel oil type	**Fuel oil 100% Oil 0%**	**Fuel oil 90% Oil 10%**	**Fuel oil 80% Oil 20%**	**Fuel oil 70% Oil 30%**	**Fuel oil 60% Oil 40%**
Fuel oil (S=0,49%)	27,8	27,5	27,1	26,7	26,3
Fuel oil (S=1,4%)	26,6	26,4	26,1	25,8	25,6
Fuel oil (S=2,8%)	27,0	26,9	26,4	26,1	25,8

Minimum values are those corresponding to the mixtures of *1.4% sulfur* with *sunflower oil* at a rate of 40%. All minimum values are obtained by using of minimum 60% fuel oil in the mixture, the remaining oil. *Maximum values* are obtained when using fuel oil of 0.49% sulfur and 10% oil.

By proper control of the burning process and continuous emissions monitoring , CO_2 emissions could reach minimum values.

Finally, a table shows the final results, and charts show the results of operation with different structures of mixtures, in comparison with the results of operation with 100% fuel oil. In the charts, we used for all structures of mixtures the average value of the respective emission.

2.4 Synthesizing the results of numerical calculations

The results of numerical calculations of NOx, SO_2, CO_2 emissions, which were presented and analyzed in section 2.1 – 2.4 are collected in table7. In version 1 there are presented **the results of numerical calculations of NOx, SO_2, CO_2 emissions when burning fuel oil and oil mixtures**, and in version 2 are shown **the results of numerical calculations of NOx, SO_2, CO_2 emissions when burning fuel oil mixtures and DME.**

Table 7

The results of numerical calculations of NOx, SO_2, CO_2 emissions in the case of liquid fuel mixtures

1. The results of numerical calculations of NOx, SO_2, CO_2 emissions in the case of fuel oil and vegetable oil mixtures , in comparison of the results at fuel oil 100%					
Mixture type /fuel oil type	Fuel oil 100% Sunflow.oil 0%	Fuel oil 90% Sunflow.oil 10%	Fuel oil 80% Sunflow.oil 20%	Fuel oil 70% Sunflow.oil 30%	Fuel oil 60% Sunflow.oil 40%
NOx calculation					
S=0,49%	395	315	331	371	397
S=1,4%	448	349	370	397	428
S=2,8%	468	359	378	398	436
SO_2 calculation					
S=0,49%	250	232	207	188	168
S=1,4%	712	651	588	524	453

S=2,8%	1454	1324	1183	1041	904
CO_2,*10^3					
S=0,49%	27,8	27,5	27,1	26,7	26,3
S=1,4%	26,6	26,4	26,1	25,8	25,6
S=2,8%	27,0	26,9	26,4	26,1	25,8
2. The results of numerical calculations of NOx, SO_2, CO_2 emissions in the case of fuel oil and DME mixture, in comparison of the results at fuel oil 100%					
Mixture type /fuel oil type	Fuel oil 100% DME 0%	Fuel oil 90% DME 10%	Fuel oil 80% DME 20%	Fuel oil 70% DME 30%	Fuel oil 60% DME 40%
NOx calculation					
S=0,49%	395	294	244	267	292
SO_2 calculation					
S=0,49%	250	234	214	195	173
CO_2 calculation					
S=0,49%	27,9	27,5	27,1	26,6	26,2

Using data from table 7, NOx, SO_2, CO_2 values at mixture of fuel oil and sunflower oil in comparison with fuel oil 100% can be graphic illustrated, for the three types of oils taken into account, and also NOx, SO_2, CO_2 values at mixture of fuel oil and dimethylether.

In figures 9, 10, 11 are presented the values of NOx, SO_2, CO_2 at fuel oil mixtures (S = 0.49%,S = 1.4%,S = 2.8%) and sunflower oil, in comparison with fuel oil 100% . In fig.12, in the same way, the emissions values at fuel oil (S = 0.49%) and dimethylether mixture.

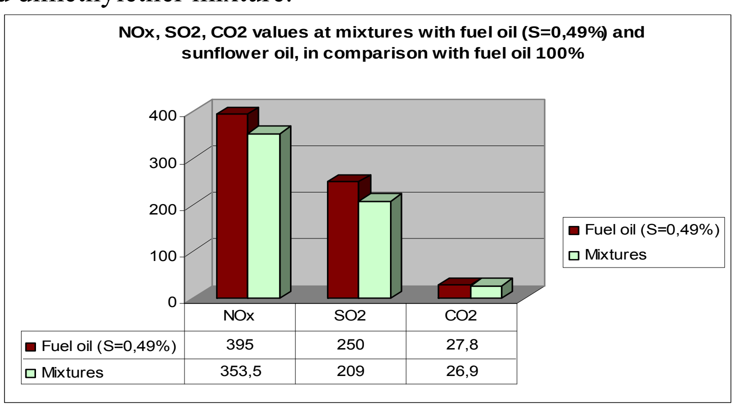

Fig. 9. Emissions values at fuel oil (S=0,49%) and sunflower oil mixtures

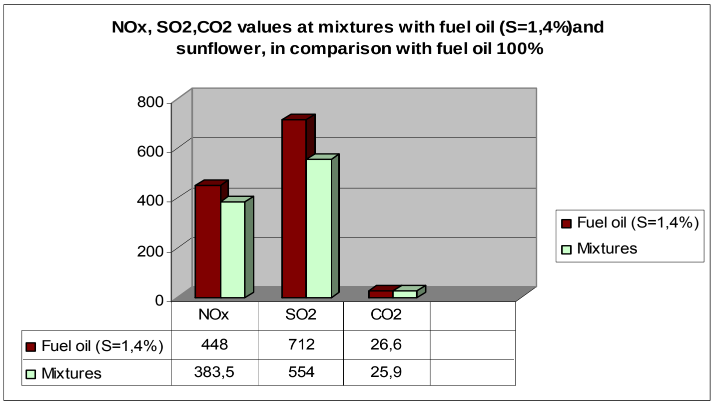

Fig. 10. Emissions values at fuel oil (S=1,4%) and sunflower oil mixtures

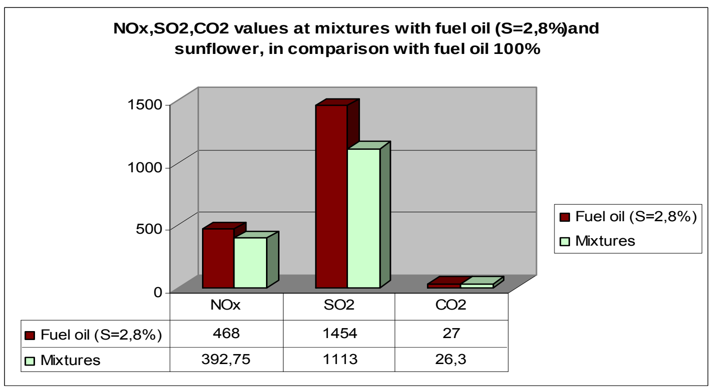

Fig.11 Emissions values at fuel oil (S=2,8%) and sunflower oil mixtures

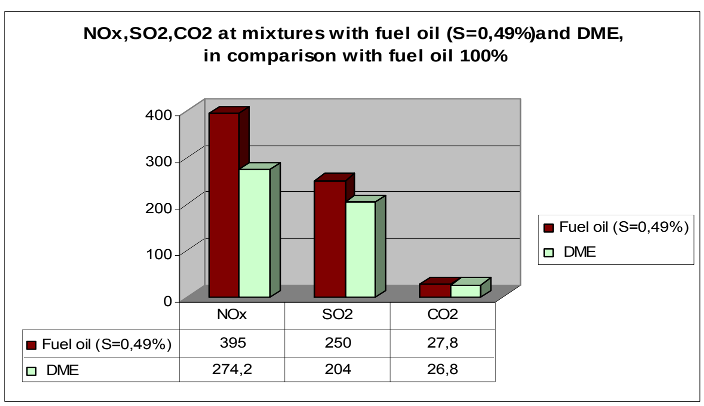

Fig.12 Emissions values at fuel oil (S = 0.49%) and dimethylether mixture

3. Conclusions

The results of emissions numerical calculations demonstrate that:
- emissions values are decreasing, in operation of mixtures
- NOx emissions are decreasing with the introduction of vegetable oil, then are slightly increasing , depending on the share of the oil in the mixture; emission values are maintained within limits of environmental regulations;
- SO_2 emissions are decreasing, depending on the proportion of vegetable oil in the mix – remarcable is the proportion of sulfur in the elemental analysis of the vegetable oil , which is very low, of approximately 0.07%
- CO_2 emissions are decreasing with the proportion of vegetable oil in the mixture, reducing acceptable if we are considering that the oils are obtained from plants (which consumed CO_2 in the process of growth and development)
- calorific value of the mixtures taken into account is compatible with that of conventional liquid fuels
- the great oxygen content of vegetable oils (9-11% oxygen in the chemical composition of sunflower oil) helps to burn almost completely of the liquid hydrocarbons, with the result in a decrease emissions and increase energy efficiency
- by exploiting a variety of mixtures, it is possible to ensure the sustainability of biofuels production
- crude vegetable oils, notably those of rapeseed and sunflower, offers advantages of cost and energy consumption for production lower than other renewable sources like biomass, wind, geothermal, and also opportunities for sustainable rural development .

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