# COMBUSTION OF SOYA OIL AND DIESEL OIL MIXTURES FOR USE IN THERMAL ENERGY PRODUCTION

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## ABSTRACT

In August 2005, Spain approved the *Plan for Renewable Energy Sources for the period 2005-2010* (P.E.R.), including co-combustion installations. Co-combustion in the P.E.R. aims to increase power output by 12,185.3 GWh in five years and shows great interest in studies of the combustion of mixtures of fossil and bio-combustible fuels.

This paper presents studies of the co-combustion of soya oil and diesel for thermal heating. The paper begins with a characterization of soya oil as well as mixtures of this oil, with diesel, as fuels. The combustion of the soya oil mixtures and diesel is made in an installation, where the pressure of injection as well as the air volume of the burner can be changed. The obtained results inside to be the environmental average legislation and a greater efficiency of combustion is found. The conclusions show that the use of mixtures of soya oil and Diesel for producing thermal energy in conventional equipment is feasible.

**Keywords:** Soya oil, Vegetable oils-Diesel mixtures, Thermal energy.

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**1 – SOYA OIL**

The soya belongs to the leguminous family. It is known by several names but, since 1948, the correct denomination is *Glicine max* (L.) [4] Merrill. It is a spring – summer annual plant, with a height in between, 50 and 180 cm. Both the intrinsic genetic factors and the external environmental effects, such as the hours of daylight, spacing and soil fertility, affect the ramification.

Analyses of soya oil as fuel, as well as those of its mixtures with diesel, were carried out at the Regional Fuel Laboratory (LARECOM), located in León, according with norms set out in table 1:

Chemical and physical characteristics of soya oil are shown below Tables 2 and 3.

**2 - CHARACTERISTICS OF THE MIXTURES TESTED**

The mixtures used as fuels were made in a volumetric percentages. Thus, and to facilitate understanding, from now on, we shall speak of an S-10 mixture, meaning that it is a mixture of 90 % Diesel and 10 % refined soya oil, and so on for S-20, S-30, etc. S-0 indicates pure diesel.

This section studies the different characteristics of the refined soya oil and its mixtures with diesel, to predict their optimum behaviour as fuels. Characteristics of mixtures were determined from either: i) theoretically, from the knowledge of the proper properties of the pure components that make up the mixture or ii) experimentally, by laboratory measurements.

Table 4 shows the density at 15º and 35º as well as the L.H.V. of the mixtures of soya oil and Diesel, obtained experimentally and theoretically.

Sulphur concentration of the mixtures decresas as percentage of soya oil increases. However, the tendency of the experimental and theoretical data are not so similar as in the other elements. The fact that such deviations occur in the sulphur analyses is due to a lack of accuracy in the analytical method used in the laboratory, Table 5.

Viscosity of the mixtures is shown below, in Table 6.

## 3 - EXPERIMENTAL INSTALLATION AND MEASURING APPARATUS.

The energy generating group is a conventional house-heating boiler, whose characteristics are shown in Table 7.

Characteristics of the drills used to measure the combustion conditions are shown in Table 8.

## 4 - EXPERIMENTAL AND RESULTS

Experiments were carried out with different mixtures of soya oil and diesel, as well as with pure vegetable oil. Different fuel injection pressures and different positions for the air intake grid of the burner were used. All of the parameters shown in Table 9 show none variation during the experimental (input and return temperatures of boiler, fuel and air, and impulse and return pressures of both water and fuel are all constant). The number of experiments carried out are shown in Table 9.

## 5 - RESULTS

Results which were not according with the Spanish legislation requirements, have been eliminated, table 10 [8].

Characteristic parameters of the combustion of the mixtures of soya oil and diesel obtained in the 45 tests carried out in the previously described installation are shown in table 11.

Those analysis of the results, alloading with Spanish legislation, are shown in Figure 1, where: (a) represents the percentage of $CO_2$ emitted in the fumes (average of the five mixtures used), (b) represents the ppm of CO emitted in the fumes (average of the five mixtures used), c) represents the ppm of $NO_x$ emitted in the fumes (average of the five mixtures used) and d) represents the average combustion performance of the five mixtures used.

## 6 - CONCLUSIONS

The combustion of oil mixtures of soya and diesel, in conventional diesel installation, is possible, being necessary a simple adjustment of the pressure of injection and regulation of air in the burner.

The percentage of $CO_2$ in the fumes increases, because soya oil, according to their molecular structure, contain less hydrogen than diesel, although the amount of $CO_2$ from fossil sources, in all the mixtures, is smaller than that of diesel.

The percentage of CO and NO in the smoke are parameters that depend on more factors of those than it controls the installation, among them the temperature of flame. When increasing the flame temperature ppm of CO in smoke is reduced, but ppm of NO increase.

The performance of the combustion increases along with the percentage of oil. This is a consequence of the fact that the mixtures have a lower L.H.V. and the combustion conditions are maintained.

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**Table 1**. Norms used in the characterization of the fuels.

**Table 2**. Composition of different oils in  % of mass [6]

**Table 3**. Physical propertiess of  oils and diesel[7]

**Table 4**. Density (kg/$m^3$) and L.H.V. of mixtures of Diesel and soya oil.

**Table 5**.  Elemental composition by percentage in experiments and theoretical f the mixtures used.

**Table 6**. Experimental viscosity of the mixtures used at 40, 50 and 100 ºC cStk.

**Table 7**. Characteristics of the generating group used in the combustion tests.

**Table 8**. Measuring equipment used in the experimental, with their range of measurement.

**Table 9**. Test plan with respect to control parameters.

**Table 10**. Summary of the specified limitations.

**Table 11**.  Mean values of the combustion of the mixtures.

**Figure 1**: Analysis of the fumes emitted for the five mixtures used.

*Table 1. Norms used in the characterization of the fuels.*

| Property | Test Norms |
|---|---|
| Upper and Lower Calorific Power | UNE 51 123 |
| Density at 15 ºC and 35 ºC | UNE 51 116 |
| Kinematic Viscosity at 40 ºC and 100 ºC | UNE 51 108 |
| Cloudiness point | UNE 51 129 |
| Sulphur % | ASTM D-1552 |
| Carbon % | LECO CHN-600 |
| Hydrogen % | LECO CHN-600 |

*Table 2. Composition of different oils in % of mass [6]*

| Type | Refined Soya | Crude Soya |
|---|---|---|
| Peroxides | 0.05 | 0.85 |
| Humidity ( %) | --- | 0.21 |
| Phosphates | Imperceptible | --- |
| C 14:0 | 0.07 | 0.07 |
| C 16:0 | 10.63 | 10.9 |
| C 16:1 | 0.06 | 0.07 |
| C 18:1 | 52.47 | 54.43 |
| C 18:2 | 52.47 | 54.43 |
| C 18:3 | 6.77 | 6.81 |
| C 20:0 | 0.5 | 0.46 |
| C 20:1 | 0.34 | 0.22 |
| C 22:0 | 0.52 | 0.54 |
| C 22:1 | 0 | 0 |
| C 24:0 | 0.18 | 0.18 |

*Table 3. Physical propertiess of  oils and diesel[7]*

| Oil | Soya | Diesel |
|---|---|---|
| Density at 15 ºC | 923 | 848 |
| Density at 35 ºC | 911 | 635 |
| Kinematic Viscosity at 40 ºC | 32.9 | 2.7 |
| Kinematic Viscosity at 100 ºC | 7.6 | 1.2 |
| % S of mass | 0.06 | 0.11 |
| % C of mass | 79 | 86.6 |
| % H of mass | 11.2 | 12.3 |
| % O of mass | 9.74 | 0,99 |
| H.H.V. (kcal/kg) | 9376 | 10735 |
| L.H.V. (kcal/kg) | 8808 | 10112 |

*Table 4. Density (kg/m$^3$) and L.H.V. of mixtures of Diesel and soya oil.*

| **Name** | **Experimental Density 15 ºC** | **Experimental Density 35 ºC** | **Theoretical Density 15 ºC** | **Theoretical Density 35 ºC** | **Experimental L.H.V. kcal/kg** | **Theoretical L.H.V. kcal/kg** |
|---|---|---|---|---|---|---|
| **S-0** | 848 | 835 | 848.00 | 835.00 | 10112 | 10112 |
| **S-10** | 858 | 843 | 856.07 | 843.18 | 10009 | 9972 |
| **S-20** | 865 | 850 | 864.01 | 851.22 | 9898 | 9834 |
| **S-30** | 872 | 857 | 871.82 | 859.13 | 9768 | 9698 |
| **S-40** | 880 | 865 | 879.47 | 866.89 | 9674 | 9565 |
| **S-50** | 887 | 873 | 887.02 | 874.54 | 9432 | 9434 |
| **S-60** | 894 | 881 | 894.46 | 882.08 | 9321 | 9304 |
| **S-70** | 901 | 888 | 901.78 | 889.50 | 9196 | 9177 |
| **S-80** | 908 | 896 | 908.99 | 896.80 | 9095 | 9052 |
| **S-90** | 916 | 904 | 916.02 | 903.92 | 8978 | 8929 |
| **S-100** | 923 | 911 | 923.00 | 911.00 | 8808 | 8808 |

*Table 5. Elemental composition by percentage in experiments and theoretical f the mixtures used.*

| Name | Experimental analysis | | | | Theoretical analysis | | | |
|---|---|---|---|---|---|---|---|---|
| | %C | %H | %O | %S(*) | %C | %H | %O | %S |
| **S-0** | 86.6 | 12.3 | 0.99 | 0.11 | 86.60 | 12.30 | 0.99 | 0.11 |
| **S-10** | 84.6 | 12.3 | 2.91 | 0.15 | 85.78 | 12.18 | 1.93 | 0.10 |
| **S-20** | 84.7 | 12.3 | 2.82 | 0.14 | 84.98 | 12.07 | 2.86 | 0.10 |
| **S-30** | 83.8 | 12.1 | 3.97 | 0.13 | 84.19 | 11.95 | 3.77 | 0.09 |
| **S-40** | 83.0 | 11.9 | 5.00 | 0.1 | 83.41 | 11.84 | 4.66 | 0.09 |
| **S-50** | 82.2 | 12.0 | 5.74 | 0.06 | 82.65 | 11.73 | 5.54 | 0.08 |
| **S-60** | 80.4 | 11.8 | 7.75 | 0.05 | 81.89 | 11.62 | 6.41 | 0.08 |
| **S-70** | 80.5 | 11.7 | 7.75 | 0.05 | 81.15 | 11.51 | 7.26 | 0.07 |
| **S-80** | 79.8 | 11.5 | 8.64 | 0.06 | 80.42 | 11.41 | 8.11 | 0.07 |
| **S-90** | 79.9 | 11.3 | 8.75 | 0.05 | 79.71 | 11.30 | 8.93 | 0.06 |
| **S-100** | 79.0 | 11.2 | 9.74 | 0.06 | 79.00 | 11.20 | 9.74 | 0.06 |

*(*) The equipment does not have sufficient rank for its determination.*

*Table 6. Experimental viscosity of the mixtures used at 40, 50 and 100 ºC cStk.*

| Name | Viscosity (40 ºC) | Viscosity (50 ºC) | Viscosity (100ºC) |
|---|---|---|---|
| **S-0** | 2.7 | 2.3 | 1.2 |
| **S-10** | 3.1 | 2.9 | 1.4 |
| **S-20** | 4 | 3.8 | 1.6 |
| **S-30** | 5.1 | 4.6 | 2 |
| **S-40** | 6.72 | 6 | 2.5 |
| **S-50** | 9.5 | 8 | 3.1 |
| **S-60** | 12.1 | 10.3 | 3.4 |
| **S-70** | 15.4 | 13 | 4.7 |
| **S-80** | 19.7 | 14.1 | 5.3 |
| **S-90** | 25.3 | 21.2 | 6.4 |
| **S-100** | 32.9 | 27.8 | 7.6 |

*Table 7. Characteristics of the generating group used in the combustion tests.*

| **Boiler model AR/25GT by ROCA** | | | | |
|---|---|---|---|---|
| Boiler type | | Cast iron | | |
| Calorific power | | 26.7 kW | | |
| Water capacity | | 26 litres | | |
| Approximate weight | | 210 kg | | |
| Max. working temperature | | 110ºC | | |
| **Burner model KADET-TRONIC by ROCA** | | | | |
| GPH Nozzle | Angle | Pump pressure (bar) | Flow (l/h) | Regulation of air |
| 0.6 | 60º | 8-16 | 2.3 | |

*Table 8 .Measuring equipment used in the experimental, with their range of measurement.*

| | |
|---|---|
| **Fumes analyser (one piece)** | |
| Make and model | TESTO model 342-3 |
| K type thermometer | Range -40 to 1,200ºC ± 0.1 ºC |
| Electrochemical $O_2$ drill | Range 0 % to 21 % |
| CO drill (with H compensation) | Range 0 to 4,000 ppm. |
| NO electrolytic cell drill | Range 0 to 3,000 ppm |
| **Temperature drill (Five drills)** | |
| Thermopar type | K |
| Measurement range | -40º to 1,000ºC ± 0.5 ºC |
| **Pressure drill (Four drills)** | |
| Manometer type | Spiral |
| Impulse pressure range | 1 to 40 bar accuracy to 1 % |
| Aspiration pressure range | 0.2 to 1 bar accuracy to 1 % |

*Table 9. Test plan with respect to control parameters.*

| Fuel type | Combustion pressure (bar) | Position of air grid ( %) |
|---|---|---|
| C-0 | 10 | 1.5 |
| C-10 | 12 | 2.5 |
| C-20 | 14 | 3.5 |
| C-30 | | |
| C-40 | | |
| Total number of tests: 5x3x3=45 | | |

*Table 10. Summary of the specified limitations.*

| | |
|---|---|
| **CO** | 500 ppm |
| **NO** | 300 ppm |
| **$CO_2$** | 10-13 % |
| **Power below 60 KW** | 75 % |

*Table 11. Mean values of the combustion of the mixtures.*

| Mixture | Fuel pressure | Grid position | $CO_2$ (%) | CO (ppm) | NO (ppm) | Performan of combustion |
|---|---|---|---|---|---|---|
| **S-0** | **10** | **1.5** | 4,57 | 74,67 | 25,33 | 83,27 |
| ~~S-0~~ | ~~10~~ | ~~2.5~~ | ~~3,90~~ | ~~574,67~~ | ~~15,00~~ | ~~74,88~~ |
| ~~S-0~~ | ~~10~~ | ~~3.5~~ | ~~3,77~~ | ~~1311,33~~ | ~~14,67~~ | ~~66,83~~ |
| **S-0** | **12** | **1.5** | 4,70 | 49,33 | 31,67 | 83,36 |
| **S-0** | **12** | **2.5** | 4,17 | 200,67 | 27,33 | 76,45 |
| ~~S-0~~ | ~~12~~ | ~~3.5~~ | ~~3,83~~ | ~~981,00~~ | ~~16,33~~ | ~~68,38~~ |
| **S-0** | **14** | **1.5** | 4,83 | 91,00 | 33,67 | 82,44 |
| **S-0** | **14** | **2.5** | 4,30 | 80,67 | 36,67 | 77,64 |
| **S-0** | **14** | **3.5** | 4,10 | 475,67 | 24,67 | 71,79 |
| **S-10** | **10** | **1.5** | 4,27 | 253,33 | 17,67 | 81,47 |
| ~~S-10~~ | ~~10~~ | ~~2.5~~ | ~~3,47~~ | ~~597,33~~ | ~~10,00~~ | ~~73,36~~ |
| ~~S-10~~ | ~~10~~ | ~~3.5~~ | ~~2,90~~ | ~~1313,67~~ | ~~11,00~~ | ~~61,54~~ |
| **S-10** | **12** | **1.5** | 4,73 | 96,67 | 28,33 | 82,85 |
| ~~S-10~~ | ~~12~~ | ~~2.5~~ | ~~3,60~~ | ~~350,33~~ | ~~17,33~~ | ~~74,56~~ |
| ~~S-10~~ | ~~12~~ | ~~3.5~~ | ~~3,33~~ | ~~1047,67~~ | ~~11,00~~ | ~~66,55~~ |
| **S-10** | **14** | **1.5** | 5,23 | 79,67 | 33,00 | 83,51 |
| **S-10** | **14** | **2.5** | 4,00 | 102,00 | 27,67 | 76,88 |
| ~~S-10~~ | ~~14~~ | ~~3.5~~ | ~~3,70~~ | ~~512,00~~ | ~~16,67~~ | ~~71,24~~ |
| **S-20** | **10** | **1.5** | 4,53 | 200,33 | 22,00 | 82,41 |
| ~~S-20~~ | ~~10~~ | ~~2.5~~ | ~~3,27~~ | ~~1019,33~~ | ~~8,67~~ | ~~69,12~~ |
| ~~S-20~~ | ~~10~~ | ~~3.5~~ | ~~2,73~~ | ~~1689,67~~ | ~~10,67~~ | ~~57,93~~ |
| **S-20** | **12** | **1.5** | 4,90 | 85,67 | 25,33 | 83,82 |
| **S-20** | **12** | **2.5** | 3,60 | 262,00 | 15,67 | 75,84 |
| ~~S-20~~ | ~~12~~ | ~~3.5~~ | ~~3,50~~ | ~~1155,00~~ | ~~9,33~~ | ~~66,37~~ |
| **S-20** | **14** | **1.5** | 5,30 | 105,33 | 31,00 | 83,99 |
| **S-20** | **14** | **2.5** | 4,13 | 53,00 | 26,33 | 78,38 |
| ~~S-20~~ | ~~14~~ | ~~3.5~~ | ~~3,87~~ | ~~231,00~~ | ~~18,67~~ | ~~73,15~~ |
| ~~S-30~~ | ~~10~~ | ~~1.5~~ | ~~5,80~~ | ~~2045,67~~ | ~~1,67~~ | ~~77,12~~ |
| **S-30** | **10** | **2.5** | 4,87 | 16,67 | 0,00 | 76,04 |
| ~~S-30~~ | ~~10~~ | ~~3.5~~ | ~~4,60~~ | ~~205,00~~ | ~~25,33~~ | ~~70,64~~ |
| ~~S-30~~ | ~~12~~ | ~~1.5~~ | ~~5,93~~ | ~~5703,33~~ | ~~18,33~~ | ~~65,49~~ |
| **S-30** | **12** | **2.5** | 5,13 | 8,33 | 29,33 | 80,40 |
| **S-30** | **12** | **3.5** | 5,00 | 24,00 | 30,00 | 73,97 |
| **S-30** | **14** | **1.5** | - | - | - | - |
| **S-30** | **14** | **2.5** | 5,73 | 14,00 | 36,00 | 79,22 |
| ~~S-30~~ | ~~14~~ | ~~3.5~~ | ~~5,50~~ | ~~12,67~~ | ~~38,33~~ | ~~74,93~~ |
| ~~S-40~~ | ~~10~~ | ~~1.5~~ | ~~5,90~~ | ~~2994,67~~ | ~~0,00~~ | ~~74,55~~ |
| **S-40** | **10** | **2.5** | 5,10 | 4,33 | 30,67 | 76,73 |
| ~~S-40~~ | ~~10~~ | ~~3.5~~ | ~~4,70~~ | ~~175,00~~ | ~~27,67~~ | ~~70,16~~ |
| **S-40** | **12** | **1.5** | - | - | - | - |
| **S-40** | **12** | **2.5** | 5,53 | 3,33 | 36,67 | 77,57 |
| ~~S-40~~ | ~~12~~ | ~~3.5~~ | ~~5,27~~ | ~~11,33~~ | ~~37,67~~ | ~~73,53~~ |
| **S-40** | **14** | **1.5** | - | - | - | - |
| **S-40** | **14** | **2.5** | 6,03 | 0.00 | 40.33 | 79,14 |
| ~~S-40~~ | ~~14~~ | ~~3.5~~ | ~~5,40~~ | ~~0.00~~ | ~~40.67~~ | ~~73,72~~ |

(~~0000~~ Results which were not according with the Spanish legislation requirements)

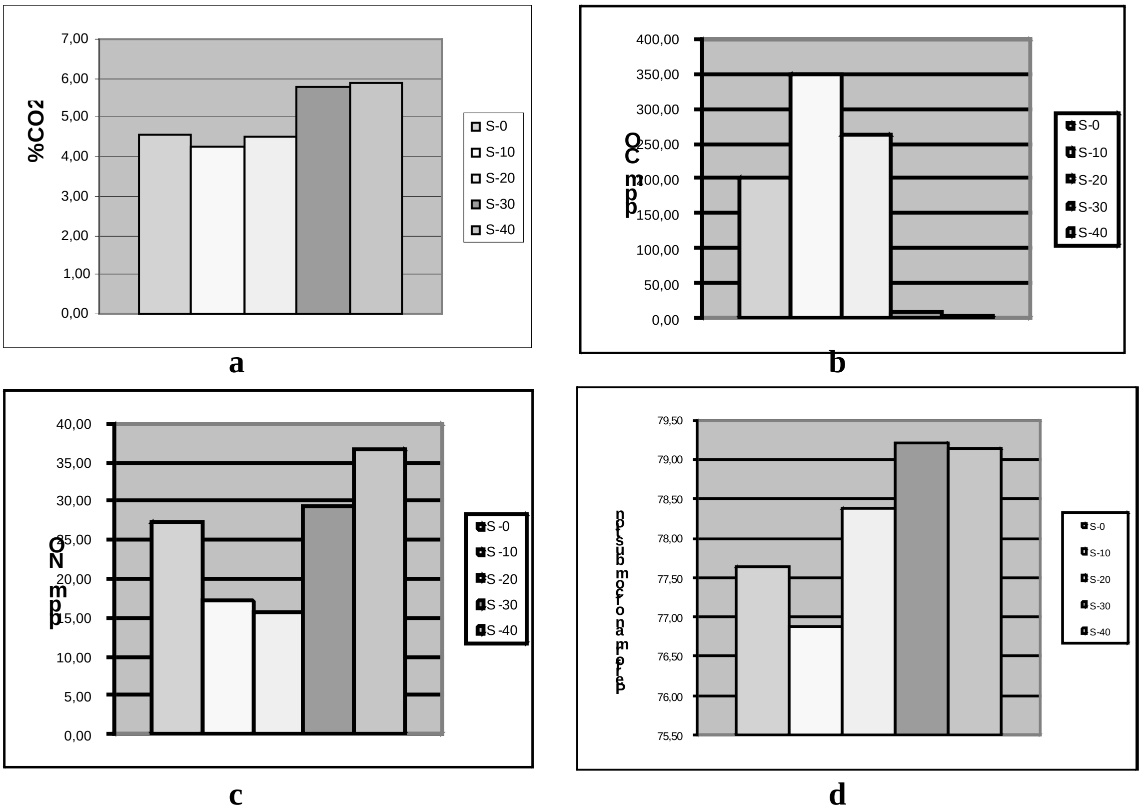


*Figure 1: Analysis of the fumes emitted for the five mixtures used.*