

Article

# Co-Gasification of Crude Glycerol/Animal Fat Mixtures <sup>†</sup>

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<sup>†</sup> This paper is an extended version of our paper published in Energy Reports, 6th International Conference on Energy and Environment Research ICEER 2019, Aveiro, Portugal, 22–25 July 2019; pp 460–465.

Received: 19 February 2020; Accepted: 2 April 2020; Published: 3 April 2020



**Abstract:** The aim of this work was to assess the technical viability of glycerol/fat co-gasification. The gasification performance was studied in a downflow fixed bed reactor using activated alumina particles as bed material and steam as oxidizing agent. The effect of gasification temperature, from 800 to 950 °C was studied with a feed mixture with 10% (*w/w*) of animal fat. The influence of fat incorporation on the feedstock in the overall gasification process was also performed, using 3% (*w/w*) and 5% (*w/w*) of fat in feed mixtures. Samples of dry gas from the gasifier were collected and analyzed by gas chromatography in order to determine the CO, CO<sub>2</sub>, CH<sub>4</sub>, and H<sub>2</sub> content. The best results were obtained using the highest tested temperature, 950 °C, and using 3% (*w/w*) of animal fat in the feed mixture. The overall results revealed that the co-gasification of glycerol/animal fat mixtures seems to be a feasible technical option.

**Keywords:** animal fat; co-gasification; crude glycerol; steam reforming; fixed-bed

## 1. Introduction

The management and valorization of crude glycerol and animal fat residues have become an important issue in the last decade. The growth of biodiesel industry in Portugal has generated large quantities of crude glycerol. Crude glycerol is characterized by containing up to 80% (*w/w*) of glycerol (C<sub>3</sub>H<sub>8</sub>O<sub>3</sub>) with the remaining 20% composed of methanol, water, non-glycerol organic matter (MONG), and salts. In 2019, the Portuguese biodiesel industry generated 39,279 t of crude glycerol, a by-product that represents 10% (*w/w*) of the conventional process. The incorporation of 55% (*w/w*) of waste materials in the raw material causes several fluctuations in the conventional process of biodiesel production and results in a real decrease of crude glycerol commercial value due to the reduction of its purity. For this reason, the chemical and physical characteristics of crude glycerol are no longer attractive for crude glycerol purification, due to its high economic and energetic costs. The sale of this low purity by-product is not an economically interesting solution. At this moment, the biodiesel industry faces several adversities in order to find alternatives of crude glycerol valorization [1].

In Portugal, the leather industry has also a remarkable impact in the national market. In this sector, one of the wastes with significant impact results from the mechanical operation is called hide fleshing and it is estimated that 30–35 t/day of these wastes were produced in 2019. The thermal hydrolysis of fleshing results into two phases, a protein hydrolysate and animal fat. The fat phase represents 30%–40% (*w/w*) of the hide fleshing production, with an estimated fat production between 2178 and

3388 t/year. Regarding animal fat, the usual valorization solutions for this kind of waste could be its transesterification for biodiesel or green diesel production. However, the process is limited, since it might cause a final product with high CFPP (cold filter plugging point) value, or its direct burning, which is not a feasible option due to the restrictions in the national law. Therefore, there is no viable alternative for its valorization.

Gasification is a thermochemical process of partial oxidation, which allows the conversion of high content carbon and hydrogen feedstock into value-added products, such as producer gas (mainly composed by H<sub>2</sub>, CO, CO<sub>2</sub>, and CH<sub>4</sub>) and residual fractions of char and tars [2].

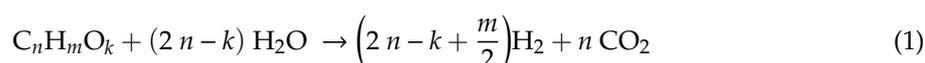
Although there are some studies, either simulation or experimental, on technical glycerol gasification, crude glycerol gasification is not yet sufficiently studied, especially regarding non-catalyzed fixed bed gasification using steam as a gasification agent.

The influence of bed temperature, water/glycerol ratio, and feed flow rate, on the performance of non-catalyzed crude glycerol steam gasification has been studied by Sabio et al. [3] and Suero et al. [4]. Dou et al. compared the effect of temperature on crude and technical glycerol steam gasification, using a fixed-bed reactor with and without dolomite as catalyst [5].

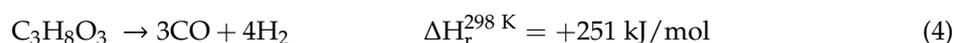
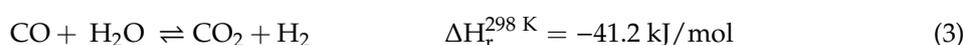
Regarding the catalytic glycerol gasification approach there are many other studies. In such studies [6–10] the authors synthesized nickel-based catalysts in order to study glycerol steam reforming, with a special emphasis on the effect of temperature on the overall process, H<sub>2</sub> selectivity, and glycerol conversion yields. Yus et al. [11] provided a different perspective to this field, since they used a two-zone fluidized bed reactor for the glycerol steam reforming, in order to prevent catalyst deactivation by coke. Rémon et al. [12] carried out a detailed study of crude glycerol steam reforming, covering the entire process from glycerol purification to catalytic gasification by itself.

Concerning animal fat gasification, it is not easy to find published works. There are some studies on gasification of oils [13–15] and about animal fat pyrolysis such as Zhang et al. [16] or Ben Hassen-Trabelsi et al. [17], but studies involving the co-gasification of both crude glycerol and animal fat were not found.

A typical gasification process involves several complex and sequential steps, from drying, devolatilization to homogeneous and heterogeneous reactions. After the devolatilization step, the released products will participate in the homogeneous and heterogeneous gasification reactions. Equation (1) represents a typical hydrocarbon steam reforming global reaction [2,18].

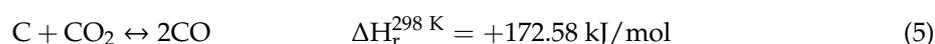


The global steam reforming reaction for glycerol (Equation (2)) results from the combination of water-gas shift reaction (Equation (3)) and glycerol decomposition (Equation (4)) [2,19,20].

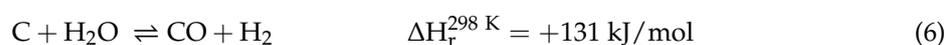


The gasification process follows a complex reaction mechanism. Some of the reactions that can occur in this type of thermochemical process are listed below [2,19,20]:

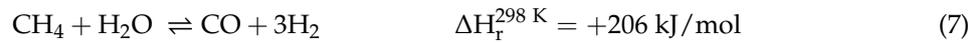
Boudouard reaction:



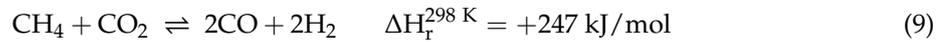
Steam char reaction or H<sub>2</sub>O gasification:



Methane steam reforming:



Methane dry reforming:



Tar reactions:  $\Delta H_r^{298 \text{ K}} = +[200 - 300] \text{ kJ/mol}$

Thermal cracking:



Tar steam reforming:



Tar dry reforming:



Tar carbon formation:



Based on product fractions and producer gas composition, the following gasification parameters were defined in order to assess the co-gasification performance [2]:

Carbon conversion efficiency (%):

$$\eta_c = \frac{MM_c \times A}{\left(x_{\text{C}_{Mat.Org}} \times \dot{m}_{\text{Mat.Org}}\right) + \left(x_{\text{C}_{Fat}} \times \dot{m}_{\text{Fat}}\right)} \quad (14)$$

where  $A$  is the total molar flow (kmol/s) of carbon-bearing components ( $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{CH}_4$ ) present in the producer gas,  $MM_c$  is the molar mass of carbon (kg/mol),  $x_{\text{C}_{Mat.Org}}$  and  $x_{\text{C}_{Fat}}$  are the carbon mass fraction (kg/kg) of organic matter in crude glycerol (glycerol and MONG) and the carbon mass fraction (kg/kg) in animal fat, respectively.  $\dot{m}_{\text{Mat.Org}}$  is the mass feed flow rate of crude glycerol (kg/s) and  $\dot{m}_{\text{Fat}}$  is the mass feed flow rate of animal fat (kg/s).

Hydrogen conversion efficiency (%):

$$\eta_H = \frac{MM_H \times B}{\left(x_{\text{H}_{Mat.Org}} \times \dot{m}_{\text{Mat.Org}}\right) + \left(x_{\text{H}_{Fat}} \times \dot{m}_{\text{Fat}}\right)} \quad (15)$$

where  $B$  is the total molar flow (kmol/s) of hydrogen-bearing components ( $\text{H}_2$ ,  $\text{CH}_4$ ) present in the producer gas,  $MM_H$  is the hydrogen molar mass (kmol/kg), and  $x_{\text{H}_i}$  is the hydrogen mass fraction (kg/kg) of glycerol and animal fat.

Dry gas yield ( $\text{m}^3/\text{kg}$ ):

$$Y = \frac{\dot{V}_g}{\dot{m}_{\text{Mat.Org}} + \dot{m}_{\text{Fat}}} \quad (16)$$

where  $\dot{V}_g$  is the volumetric flow rate ( $\text{m}^3/\text{s}$ ) of producer gas ( $0^\circ\text{C}$ , 1 atm).

Cold gas efficiency (%):

$$\eta_g = \frac{\dot{V}_g \times HHV_g}{\left(\dot{m}_{\text{Mat.Org}} \times HHV_{\text{Mat.Org}}\right) + \left(\dot{m}_{\text{Fat}} \times HHV_{\text{Fat}}\right)} \quad (17)$$

The  $HHV_g$  is the higher heating value of the producer gas ( $\text{kJ}/\text{m}^3$ ) and  $HHV_i$  is the higher heating value ( $\text{kJ}/\text{kg}$ ) of glycerol and animal fat. The efficiency of cold gas (Equation (16)) should not be understood as an indicator of the overall thermal efficiency of the process, since the way it was defined does not include the energy needed to produce steam and heat the reactor. This indicator is a measure of the chemical energy conversion of the raw material.

Higher heating value of producer gas:

$$HHV_g = y_{H_2} \times HHV_{H_2} + y_{CO} \times HHV_{CO} + y_{CH_4} \times HHV_{CH_4} \quad (18)$$

where  $y_i$  is the volumetric fraction of component  $i$  present in the producer gas and  $HHV_i$  is its higher heating value ( $\text{kJ}/\text{kg}$ ).

In order to solve real problems of national industries and to find a solution that enables the management and treatment of these by-products/wastes, the present work aims to study glycerol/animal fat co-gasification using a fixed bed reactor and steam as gasification agent. The effect of temperature and fat content on the feed was evaluated. The gasification process was quantified in terms of producer gas composition and its higher heating value, carbon and hydrogen conversion efficiency, dry gas yield, and cold gas efficiency. The main purpose of this type of thermochemical procedure is the optimization of the overall process in order to produce a value-added gaseous fuel.

## 2. Materials and Methods

### 2.1. Preparation and Characterization of Raw Materials

Crude glycerol was acquired from a Portuguese biodiesel producer. The salt content of the feed may contribute to several operation problems during the gasification process. Therefore, if the salt content of the feedstock is high it should be reduced or eliminated. In order to reduce the salt content a two-stage ion exchange process was used to pretreat the crude glycerol [21]. During the work, two packs of treated crude glycerol were produced and their final characterization is presented in Table 1. Pack 2 of crude glycerol after salt removal had a lower final content of water (35.8 %  $w/w$ ) since technical glycerol was used in the displacement rinse after the resin's regeneration. The first pack of treated crude glycerol had higher water content than expected (57.6%  $w/w$ ) because water was used in the displacement rinse of the ion exchange process.

Animal fat was supplied by a technological center for the Portuguese leather industry and its characterization is presented in Table 1.

**Table 1.** Crude glycerol and animal fat characterization.

Total Basis (%) ( $w/w$ )	Crude Glycerol after Salt Removal—Pack 1	Crude Glycerol after Salt Removal—Pack 2	Animal Fat
Carbon	17.08	27.07	74.76
Hydrogen	9.7	9.12	11.93
Water	57.6	35.8	1.0
Ash	0.13	0.07	1.01
Sulphur	0.12	<0.01	< 0.01
Sodium	0.05	0.03	0.2
Potassium	0.01	<0.01	<0.01
Calcium	-	-	0.3
Chloride	0.09	0.04	-
HHV ( $\text{kJ}/\text{g}$ )	5.7	9.3	39.1

### 2.2. Methodology

The co-gasification process was studied using steam as gasification agent, in a down flow fixed bed reactor, with 54 mm of internal diameter and 500 mm of length. Activated alumina particles were

used as bed material. A 4-kW external electrical resistance provided the heating. The fat/glycerol/water mixture was heated (57 °C) and stirred before being fed up to the upper chamber of the reactor, 100 mm above the bed, through a peristaltic pump. After the gasification process, the product gas followed towards a condensing system composed of a heat exchanger, a condensable tank with 500 mL of water and plastic Raschig rings, and two glass flasks, all immersed in an ice bath. After removing the condensable fraction, the producer gas flowed through two filters, the first with activated carbon and glass wool and the second with silica gel and glass wool. Then, the producer gas mass flow was measured in an Alicat flow meter (FIT) calibrated for syngas (M-5SLPM-D/5M) and samples were collected (S) for GC-TCD analysis (Dani 1000 DPC). The GC is equipped with a thermal conductivity detector (TCD OPT266) and an OPT333 injector suitable for compacted columns (60/80 Carboxen 1000). Argon was used as the carrier gas. Figure 1 shows the experimental apparatus.

The effect of gasification temperature and the influence of fat content on the feed were studied. The study of the co-gasification of fat/glycerol mixtures began with the evaluation of the influence of temperature on the gasification process. Tests were performed from 800 to 950 °C using a mixture with 10% (*w/w* d.b.) of animal fat, 38% (*w/w* d.b.) of treated crude glycerol (pack 1), and 52% (*w/w*) of water. This mixture has a C/H<sub>2</sub>O mass ratio of 0.45. After this study, the pack 2 of treated crude glycerol was used to study the effect of animal fat content in the feed. The influence of fat content on the feed was studied using two mixtures with 3% and 5% (*w/w* d.b.) of fat and with a 0.72 C/H<sub>2</sub>O mass ratio, 0.13 H/H<sub>2</sub>O mass ratio, and 38% (*w/w*) of water. To prepare the mixtures with the desired composition, the amounts of fat and water necessary to achieve this composition were added to the treated crude glycerol (pack 2). For each tested condition, three to five trials were performed at mass feeding flow rates between 2.37 and 2.59 g/min.

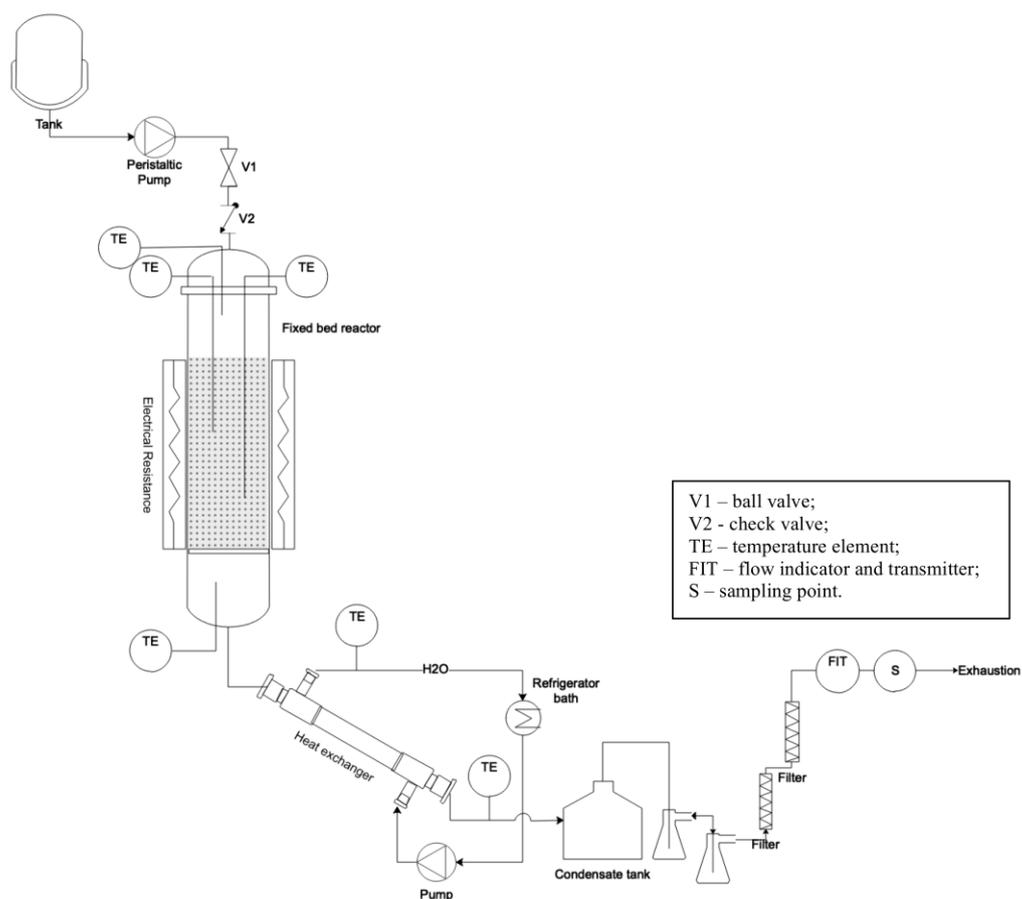


Figure 1. Schematic diagram of the gasification experimental apparatus.

### 3. Results and Discussion

#### 3.1. Effect of Gasification Temperature

The effect of temperature on the average volumetric composition of producer gas is shown in Figure 2. The increase of bed temperature resulted in an increase of H<sub>2</sub> and CO<sub>2</sub>, and a decrease of CO and CH<sub>4</sub> volumetric concentrations in producer gas composition. Along the tested temperatures, H<sub>2</sub> concentration increased from 37% to 53% (v/v), CO<sub>2</sub> increased from 9% to 13% (v/v), CO decreased from 39% to 27% (v/v), and CH<sub>4</sub> decreased from 15% to 11% (v/v). As a consequence of composition evolution, an increase of H<sub>2</sub>/CO ratio from 0.94 to 1.96 was observed, with the temperature rise. This behavior may be explained through a typical gasification mechanism. In the first step of the gasification process, devolatilization seems to be crucial for thermal decomposition of large hydrocarbons molecules into lower molecular weight compounds, which will participate, on both, gasification reactions and tar reactions (Equations (10)–(13)). Water-gas shift (Equation (3)) has also a well-known role in the process up to 850 °C, and from this temperature on, methane steam reforming (Equations (7) and (8)) and methane dry reforming (Equation (9)) become more significant.

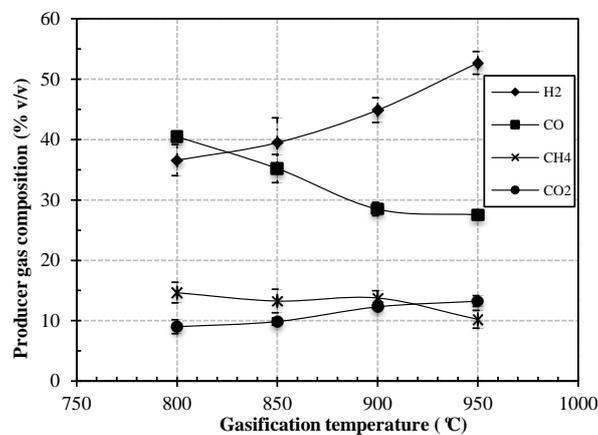


Figure 2. Effect of gasification temperature on producer gas composition.

The effect of temperature on the gasification parameters was assessed. In the range of tested temperatures, a rise of carbon and hydrogen conversion efficiencies were observed with the increase of temperature (Figure 3). The evolution of hydrogen conversion efficiency with the gasification temperature presented a higher slope than the carbon conversion efficiency. The carbon conversion efficiency increased from 59.5% to 75.8% and the hydrogen conversion efficiency increased from 42.5% to 76.6%.

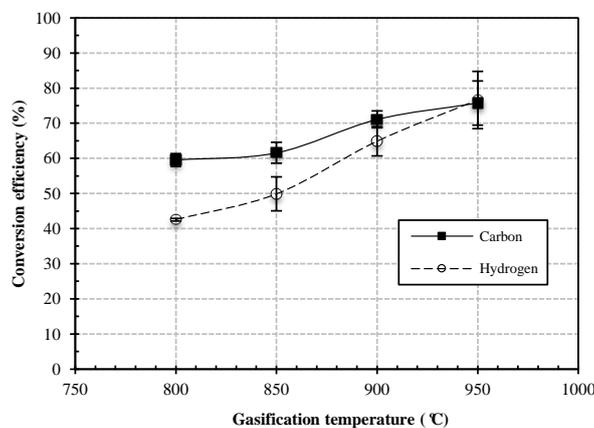


Figure 3. Effect of gasification temperature on carbon and hydrogen conversion efficiencies.

The increase of temperature from 800 to 950 °C also caused an increase of both the cold gas efficiency and the dry gas yield (Figure 4). The cold gas efficiency increased from 72.2% to 105.2% and the dry gas yield increased from 0.9 to 1.4 m<sup>3</sup>/kg. Values higher than 100% for cold gas efficiency can be expected when steam is used as gasification agent, because steam dissociation can also contribute to the increase of hydrogen concentration on the producer gas [21]. The increase of those parameters is related with the increase of gas phase production, with the rise of temperature. The high content of water in the feed (52%) also contributes to this behavior as it potentiates the tar and methane reforming reactions at higher temperatures.

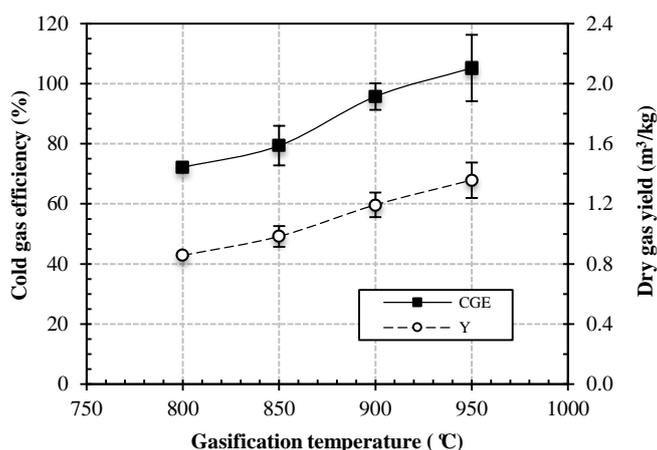


Figure 4. Effect of gasification temperature on cold gas efficiency and dry gas yield.

The producer gas higher heating value decreased with the temperature rise, from 15.8 to 14.5 MJ/m<sup>3</sup> (Figure 5), as a consequence of the behavior observed in the composition of the producer gas (Figure 2). As the temperature increases a decrease in the concentration of CH<sub>4</sub> and CO was observed, and an increase in the concentration of H<sub>2</sub> in the producer gas. As the individual HHVs of CO and H<sub>2</sub> are of the same order of magnitude, the reduction seen in the HHV of the producer gas is essentially related to the decrease in the concentration of CH<sub>4</sub>, the component with the highest individual HHV.

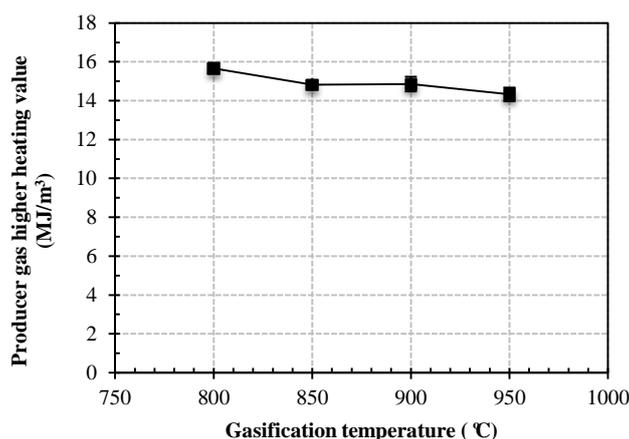


Figure 5. Effect of gasification temperature on producer gas higher heating value.

With this preliminary study, good results were obtained for the co-gasification parameters of crude glycerol/fat mixtures. However, in the following tests, it was decided to reduce the incorporation of fat in the fat/glycerol mixtures to reduce the experimental difficulties found in obtaining a homogeneous feed flow with the existing experimental set up. Furthermore, it is known that the ratio between the amount of this fat residue and the amount of crude glycerol produced, per year, in Portugal, is around 3%.

### 3.2. Effect of Fat Content in the Feed

Two fat/glycerol mixtures were tested with 3% and 5% (*w/w* d.b.) of fat and with the same organic matter/H<sub>2</sub>O ratio of 1.65% and 38% (*w/w*) of water. Considering the annual production of animal fat and glycerol, it appears that a fat incorporation rate in the crude glycerol varying between 5.2% and 8.0% (*w/w* d.b.) would allow to exhaust all the produced fat and solve the problem of the management and treatment of this waste. As, in practice, it is not expected that this scenario will be possible to implement, it was decided to study two incorporation rates up to 5% (*w/w*).

The obtained results were compared with those obtained in the steam reforming of treated crude glycerol using a mixture with the same ratios of C/H<sub>2</sub>O and H/H<sub>2</sub>O but with an organic matter/H<sub>2</sub>O ratio of 1.89% and 35% (*w/w*) of water

During the experimental tests the dry gas phase mass flow rate was measured, and at the end of each test the final mass of liquid phase produced was weighed. The liquid phase mass flow rate was estimated using the mass of liquid and the time of the test. The solid phase was estimated by mass difference. The results obtained for the phase yields are presented in Figure 6. Although these results are largely affected by experimental uncertainty (error bars represent the standard deviation which varied between 0.4% and 5.3%), they reflect the behavior of the gasification process.

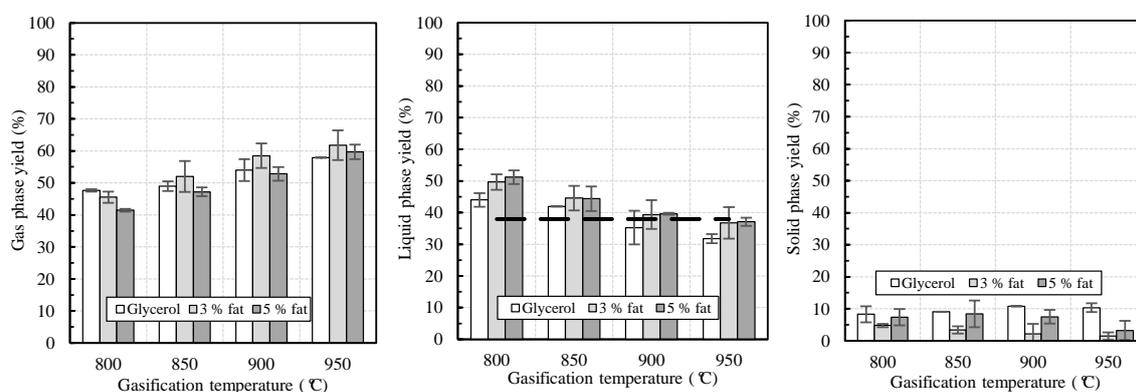


Figure 6. Effect of the addition of fat on phase yields.

Increasing fat content in the mixture, from 3% (*w/w*) to 5% (*w/w*), results in a reduction of gas phase yield and an increase in the solid phase yield. On average, the gas phase yield was between 50% and 60%, the liquid phase yield between 30% and 50%, and the solid phase yield was below 10%.

In Figure 7, for all the tested conditions, the results obtained for the evolution of producer gas composition in the co-gasification tests are presented. The increase of fat content in the feed from 3% to 5% (*w/w*) results in a decrease of H<sub>2</sub> and CO<sub>2</sub> concentrations and an increase of CO and CH<sub>4</sub> concentrations in the producer gas. For the highest temperature tested and for the mixture with 3% (*w/w*) of fat, mean concentration (*v/v*) values of 51% for H<sub>2</sub>, 31% for CO, 9% for CH<sub>4</sub>, and 12% for CO<sub>2</sub> were obtained in the producer gas.

Concerning the gasification parameters, the results have shown a reduction of mean values of carbon and hydrogen conversion efficiencies and dry gas yield with the increase of fat content in the feed (Figures 8 and 9). Considering that all the tests were performed with fat/glycerol mixtures with the same C/H<sub>2</sub>O mass ratio, it seems that mixtures with higher carbon content from heavier chain hydrocarbons present more difficulties in the gasification process. A reduction in all the previous mentioned gasification parameters were observed with the increase of fat content in the feed from 3% to 5% (*w/w*). However, this difficulty seems to be minimized with the increase of temperature and a reduction of this effect was observed at the highest tested temperature (950 °C). The best results were obtained with the 3% (*w/w*) fat mixture and maximum values of 85.5%, 102.5%, and 1.35 m<sup>3</sup>/kg were obtained for carbon and hydrogen conversion efficiencies and dry gas yield, respectively.

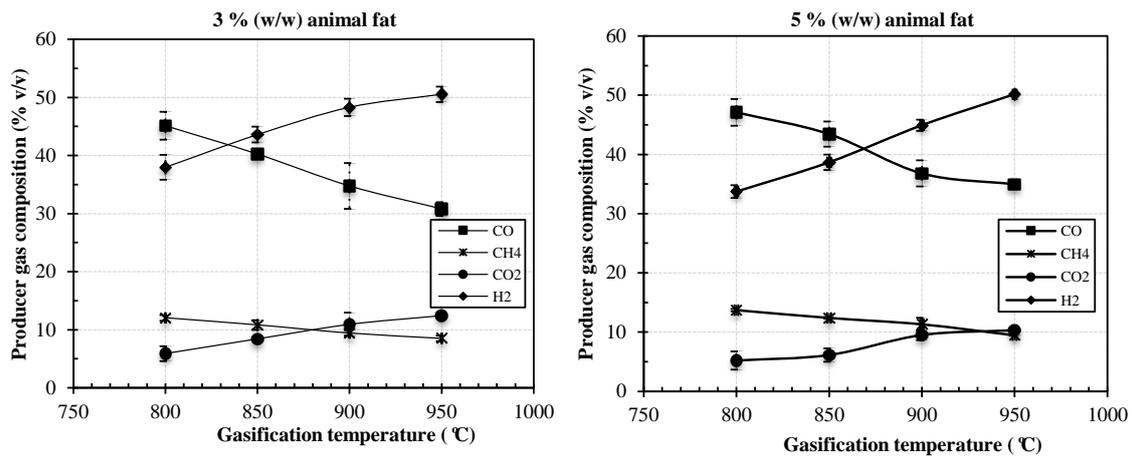


Figure 7. Effect of gasification temperature and fat content in the producer gas composition.

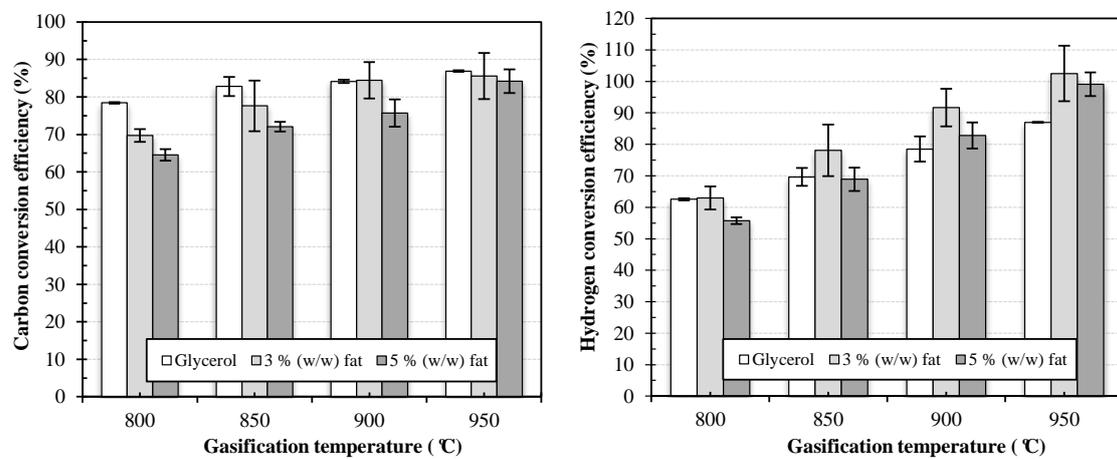


Figure 8. Effect of the addition of fat on carbon and hydrogen conversion efficiencies.

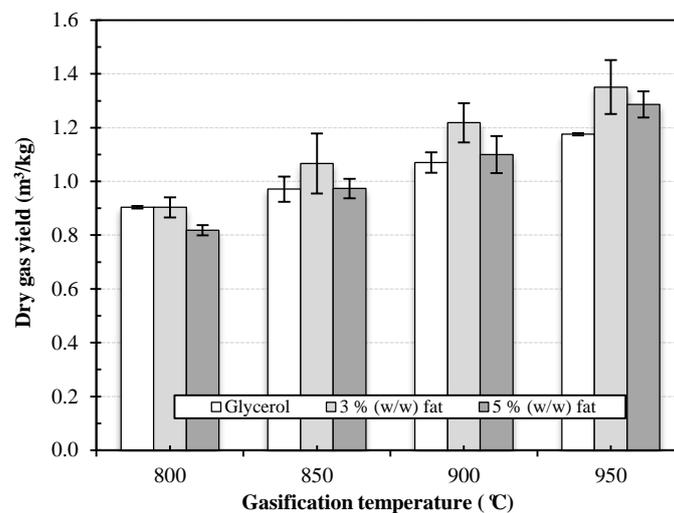


Figure 9. Effect of the addition of fat on dry gas yield.

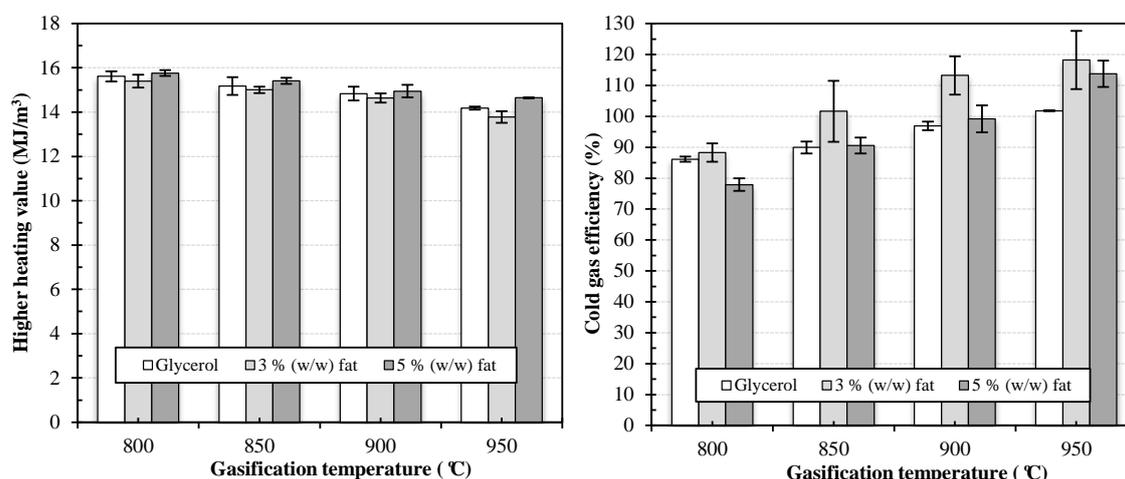
The decrease of carbon and hydrogen conversion efficiencies, with the increase of fat content from 3% to 5% (w/w), may be related to the increase of solid phase yield observed when increasing fat content in the feed. When steam is used as the gasification agent the gasification efficiency can reach values above 100% because, in these circumstances, the dissociation of steam can contribute to the increase of the hydrogen concentration in the production gas. The reduction of dry gas yield

seems to be associated with the reduction of gas phase yield, measured when the fat content in the feed was increased.

The results also show that incorporating small amounts of animal fat to the feed causes a slight reduction in carbon conversion efficiency (Figure 8), when compared with the values obtained in the gasification of treated glycerol/water mixtures. However, this effect was attenuated with the increase of bed temperature and for the tests performed at 950 °C carbon conversion efficiency values of the same order of magnitude (85%) were obtained.

Regarding the remaining two gasification parameters, it was found that, in general, low rates of incorporation of fat in the feed contribute to the increase of the overall obtained values. These values are on average about 10%–15% higher than those obtained in the treated crude glycerol steam reforming.

Regarding higher heating value of the producer gas (Figure 10), an increase of its value was observed with the increase of fat content in the feed mixture from 3% to 5% (*w/w*). This behavior is correlated with the rise in the CO and CH<sub>4</sub> volumetric concentrations and the decrease in the H<sub>2</sub> concentration in the producer gas, detected with the increase of fat content in the mixture. The individual HHV value of CO is similar to that of H<sub>2</sub> and the individual HHV value of CH<sub>4</sub> is much higher than these. Thus, the behavior observed in the evolution of concentrations tends to raise the producer gas HHV.



**Figure 10.** Effect of the addition of fat on producer gas higher heating value and cold gas efficiency.

The efficiency of cold gas is a parameter that measures the chemical energy conversion of the raw material and it was observed that the increase in the fat content in the feed from 3% to 5% (*w/w*) promotes the reduction of its value (Figure 10). The decrease in the produced gas flow rate also seems to be the explanation for this reduction. However, at temperatures above 900 °C, the reduction in the difference of results observed for this gasification parameter can be explained by the increase of HHV difference of the producer gas obtained between mixtures with 3% and 5% (*w/w*) of fat. The highest values (118%) were obtained at tests performed at 950 °C. Taking into account how cold gas efficiency was defined, given by Equation (17), it is possible to obtain values higher than 100% if steam is used as a gasification agent. Additionally, at higher temperatures, the liquid phase yields were lower than the feed water percentage (38% *w/w*), showing that vapor dissociation may contribute to hydrogen production. Under these conditions, the increase in energy of producer gas due to the contribution of hydrogen from water may outweigh the energy losses through the produced tars and char.

The difference in the observed results between the steam reforming of glycerol and the co-gasification of fat/glycerol mixtures was unexpected and may partly be due to experimental uncertainty. However, as the differences in behavior are systematic, this can also result from the different initial composition of the gas phase resulting from the pyrolysis process of raw materials

with different chemical compositions. This fact can affect the chemical kinetics during the gasification process. Further testing is needed to confirm this trend.

#### 4. Conclusions

The study of crude glycerol/animal fat co-gasification using a fixed bed reactor and steam as gasification agent was performed in order to understand the effect of gasification temperature and fat content in feedstock on overall gasification performance.

For all the tested gasification temperatures and using a mixture of 10% (*w/w*) of fat with a C/H<sub>2</sub>O mass ratio of 0.45, there was a decrease in the concentration of CO and CH<sub>4</sub> and an increase in concentration of H<sub>2</sub> and CO<sub>2</sub> in the producer gas, with increasing gasification temperature. The increase of bed temperature also contributed to the increase of both carbon and hydrogen conversion efficiencies, cold gas efficiency, and dry gas yield. As expected, the higher heating value of the gas decreased with the increase of bed temperature. Regarding the gasification parameters, maximum values of 76% and 77% were obtained for carbon and hydrogen conversion efficiencies, respectively, and values of 105%, 1.4 m<sup>3</sup>/kg, and 15 MJ/m<sup>3</sup> were obtained for cold gas efficiency, dry gas yield, and producer gas higher heating value.

Regarding the study of the two fat/glycerol mixtures with the same C/H<sub>2</sub>O mass ratio of 0.72, the increase of fat content from 3% to 5% (*w/w*) in the feed mixture results in a decrease of H<sub>2</sub> and CO<sub>2</sub> concentrations and an increase of CO and CH<sub>4</sub> concentrations in the producer gas. With the increase of fat content in the feed, the results have shown a reduction of mean values of carbon and hydrogen conversion efficiencies and dry gas yield, and an increase of HHV of producer gas. Although tests were not carried out with the necessary conditions to identify the optimal fat incorporation rate, better results were obtained with a fat incorporation rate of 3% (*w/w*) than with an incorporation rate of 5% (*w/w*). Best results were obtained at a bed temperature of 950 °C and 3% (*w/w*) of fat, with values 86% and 103%, for carbon and hydrogen conversion efficiencies, and 118%, 1.35 m<sup>3</sup>/kg, and 14 MJ/m<sup>3</sup> for cold gas efficiency, dry gas yield, and producer gas higher heating value, respectively.

It was found that, at low rates of fat incorporation in the treated glycerol, there was a small increase of carbon and hydrogen conversion efficiencies, cold gas efficiency, and dry gas yield, when compared to the values obtained for the steam gasification of treated crude glycerol with the same order of magnitude of the raw material/H<sub>2</sub>O ratio and water content. Slightly lower values were obtained for the producer gas HHV.

The results revealed that the co-gasification of treated crude glycerol and animal fat mixtures seems to be a feasible technical option for the disposal of these two by-products.

As future work we intend to study the co-gasification of glycerol/fat mixtures using dolomite as a catalyst.

**Author Contributions:** A.A. carried out the experimental works and prepared the original draft of the paper. R.P. and E.R. were responsible for the guidance of experimental work, results analysis, and revised the article. C.P. defined the structure and content of this article and participated in the revision process. A.R. was responsible for the raw material characterization and participated in the revision of the article. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by Portugal 2020—POCI-01-0145-FEDER-024067 and Fundação para a Ciência e Tecnologia, research grant No. SFRH/BD/137913/2018.

**Conflicts of Interest:** The authors declare no conflict of interest.

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