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Clarification of *Jatropha curcas L.* oil for direct use in plant oil stoves

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Introduction

J. curcas seeds contain about 30 to 40 % oil (Francis & Becker, 2006) and is considered as a primary energy source for households in tropical and subtropical developing countries, such as India, Mali, Madagascar, Tanzania among others (Stumpf & Mühlbauer, 2002; Henning, 2004) *J. curcas* is also found as an option to reduce deforestation and dependence on fossil fuels and to promote agricultural activities (Fairless, 2007; Kratzeisen *et al.*, 2007). Furthermore, this plant is known for its contribution to economic growth and welfare of poor rural farmers, (Saverys & Haveskercke, 2008). For instance, rural producers of *J. curcas* oil in India have become independent with respect to the production of fuel for cooking, lighting and heating (Openshaw, 2000; Augustus *et al.*, 2002).

In remote rural areas the oil used for plant oil stoves should not be highly processed, in order to increase its approachability and reduce its production costs. However, more impurities are found in less processed oils (Stumpf & Mühlbauer, 2002). The oil quality of *J. curcas* is highly influenced by the clarification process. The eligibility of plant oil for cooking stoves depends on its chemical characteristics and physical properties. Between the most relevant chemical properties that influence combustion are found: calorific value, boiling point, ignition point, density, iodine value, and saponification value (Stumpf & Mühlbauer, 2002).

The mechanical extraction of *J.curcas* oil contains up to 35 % of fines, small impurities or sediments, which should be removed in order to increase the combustion properties (Jongschaap, 2007). In fact, the presence of these contaminants in oil can lead to an accumulation of residues and thus damage of the injection nozzles used in combustion systems (Jongschaap, 2007). For every kind of technical use, these solids must be removed from the oil to avoid blockage of technical components and to hold off the acceleration of the oxidation (Widmann, 1994; Remmele & Widmann, 2002). Likewise, impurities influence burning characteristics and lessen storage stability (Stumpf & Mühlbauer, 2002).

The aim of this research was to investigate the influence of two different clarification systems on the final quality of the *J. curcas* raw oil to be used for direct combustion in plant oil stoves. Thus, the efficiency of continuous and discontinuous clarification methods is analyzed using parameters such as particle size, sedimentation time and total contamination.

Materials and Methods

Oil extraction

The *J. curcas* seeds were grown in India. The selected seeds were pressed with the mechanical cold press oil machine, type OEKO 85D – 1G. *J. curcas* oil yield obtained during extraction was about 30 % by weight. The extracted oil was collected in plastic containers and stored at room temperature. Before the clarification process took place the oil was stirred with a stirring device, type Heidolph – RZR 2020 for achieving homogeneous oil.

Particle size distribution, density and viscosity

The particle size distribution (PSD) of a fluid defines the relative amounts of particles present, sorted according size. Analyses were performed by the laboratory of Technologie und

Förderzentrum (TFZ) für Nachwachsende Rohstoffe in Straubing, Germany on particle size distribution for raw oil, semi- cleaned and filtered oil. This analysis comply with the specifications of ISO 13320-1 "Particle size analysis - laser diffraction methods". The density for vegetable oils is usually about 0.910 - 0.920 at 25°C (Lawson, 1985). Density of *J. curcas* oil was analyzed at different temperatures, ranging from 0 to 90°C. Kinematic viscosity is the ratio between the dynamic viscosity and the density of the fluid. A rheometer was used to measure the dynamic viscosity (Pa s) in a temperature range from 0 to 90°C with constant shearing stress for 300 seconds of time (DIN EN ISO 3104, 1999). Kinematic viscosity (mm²/s) was calculated as the ratio between the dynamic viscosity and the density of the fluid.

Discontinuous sedimentation system

The discontinuous sedimentation system consisted of a single container oriented either in vertical or horizontal direction. The tanks are presented in Figure 1. The containers had the same capacity, approximately of 32 l, and the following size dimensions: 270 x 200 x 600 mm.

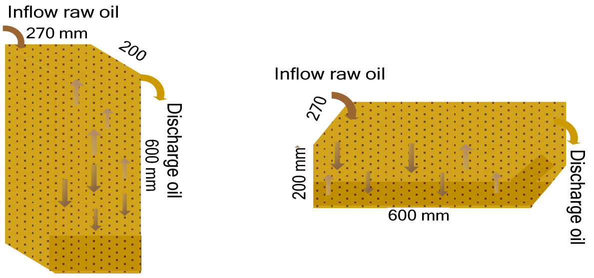

Figure 1: Discontinuous sedimentation system vertical (left) and horizontal (right) orientation

The settling rate was monitored through measurements of the height of interface over a period of time. The sedimentation time was extended until the oil exhibited a clear appearance having an amber color.

Continuous sedimentation system „Weihenstephan Standard"

The design of this sedimentation method followed the protocol known as Weihenstephan standard Figure 2, designed by 'Technologie und Förderzentrum (TFZ) für Nachwachsende Rohstoffe' in Straubing, Germany.

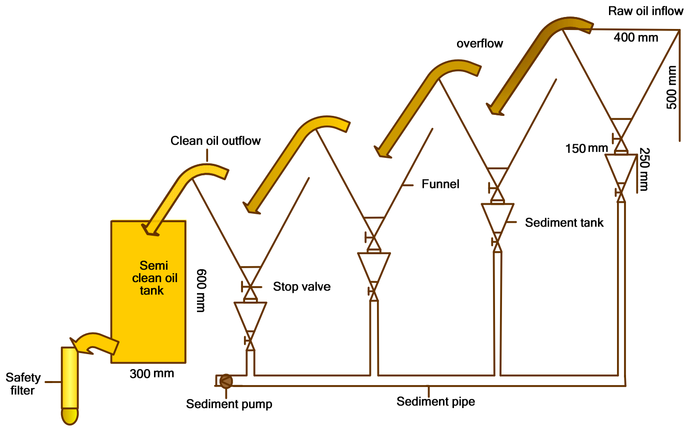

Figure 2: Weihenstephan standard for a continuous sedimentation system

The sediments that settle in the bottom of the tanks are transfer to separated sub-funnels located below each of the main four funnels. To avoid the loss of the oil from the transfer of the mud to the sediment tanks a valve between the main funnels and the sub-funnels was installed. Bag and cartridge filters were used for the safety filtration.

The bag filter used was manufactured in polyester, with dimensions 178 mm of diameter x 432 mm hight, and retention of 1 µm. The cartridge filter was characterized by a tubular filter contained in a matching vessel constructed of plastic (Dickenson, 1997). The material of the cartridge filter used was cotton with dimensions 64 mm diameter and 254 mm length, and retention of 1 µm.

Statistical analysis

The results of continuous and discontinuous sedimentation systems were plotted using OriginPro-8 software. Furthermore, the fitting of the data to determine the best function describing the behaviour was performed using the same software.

Results and discussion

Characterization of *J. curcas* oil

The particle size distribution (PSD) of *J. curcas* raw oil (immediately after it was cold pressed) is shown in Figure 3.

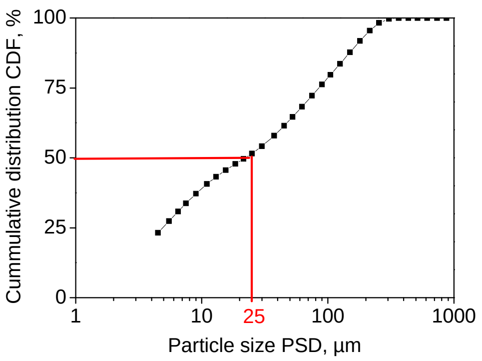

Figure 3: Particle size distribution *PSD* of *J. curcas* raw oil

The PSD varied in a wide range, from 4 µm to 1000 µm with an average of about 175 µm. Figure 3 shows that 50 % of the particles were smaller than 25 µm.

Density and viscosity of *J. curcas* raw and sediment oil at different temperatures are depicted in Figure 4. The increase of the temperature produces a decrease of the density and viscosity for both raw and sediment oil.

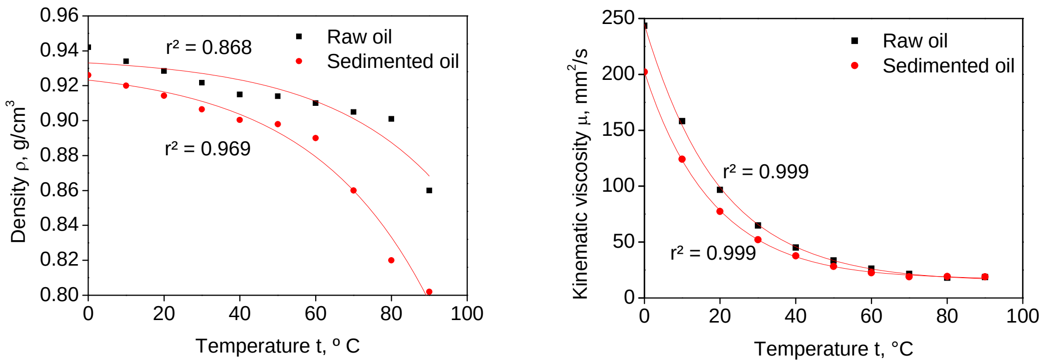

Figure 4: Density ρ and kinematic viscosity μ for raw and sedimented *J. curcas* oil

Statistical analysis for raw oil density ρ_r, reveals a good correlation to temperature that can be expressed as exponential function ($r^2 = 0.868$).

$$\rho_r = -0.003 \cdot e^{\left(\frac{x}{30.49}\right)} + 0.936 \qquad (1)$$

Statistical analysis for sediment oil density ρ_s, reveals a high correlation to temperature that can be expressed as exponential function ($r^2 = 0.969$).

$$\rho_s = -0.007 \cdot e^{\left(\frac{x}{31.25}\right)} + 0.930 \qquad (2)$$

Statistical analysis of kinematic viscosity of raw oil μ_r and sedimented oil μ_s, reveal a high correlation to temperature that can be expressed as exponential functions ($r^2 = 0.999$).

$$\mu_r = 230.18 \cdot e^{\left(\frac{-x}{19.94}\right)} + 14.59 \qquad (3)$$

$$\mu_s = 185.79 \cdot e^{\left(\frac{-x}{18.12}\right)} + 16.46 \qquad (4)$$

There is also a distinguished decrease of density and viscosity values of the sedimented oil in comparison to the raw oil. This is due to lower concentration of solids in sediment oil and larger thermal conductivity of the raw oil compared to the sediment in this way the oil absorbs more energy from the applied heat yielding lower viscosity (Quear, 2001).

Sedimentation settling curve of discontinuous system

Figure 5 show the correlation of the height of interface and the settling time for the horizontal and the vertical tank, respectively. Statistical analysis for horizontal sedimentation settling curve $H_{c.h}$, reveals a high correlation to time that can be expressed as exponential function ($r^2 = 0.991$).

$$H_{c.h} = 11.94 \cdot e^{\left(\frac{-x}{3.54}\right)} + 2.91 \qquad (5)$$

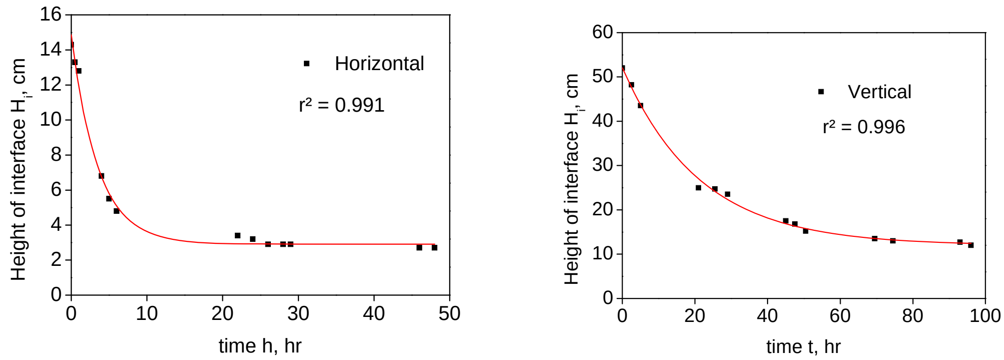

Figure 5: Sedimentation settling curve H_c for horizontal (left) and vertical (right) tank

Statistical analysis for vertical sedimentation settling curve $H_{c.v}$, reveals a high correlation to time that can be expressed as exponential function ($r^2 = 0.996$).

$$H_{c.v} = 40.11 \cdot e^{\left(\frac{-x}{21.38}\right)} + 11.98 \qquad (6)$$

The sedimentation time needed to obtain a clear *J. curcas* oil, namely amber color in horizontal tank was about half the time needed for the vertical tank. The required times were 48 and 96 hours, respectively.

Total contamination of the discontinuous system for horizontal and vertical orientation is depicted in Figure 6. Statistical analysis for horizontal total contamination $T_{c.h}$, reveals a high correlation to time that can be expressed as exponential function ($r^2 = 0.984$).

$$T_{c.h} = 64.09 \cdot e^{\left(\frac{-x}{28.25}\right)} + 35.62 \qquad (7)$$

Statistical analysis for vertical total contamination $T_{c.v}$, reveals a high correlation to time that can be expressed as exponential function ($r^2 = 0.909$).

$$T_{c.v} = 54.18 \cdot e^{\left(\frac{-x}{101.52}\right)} + 42.91 \qquad (8)$$

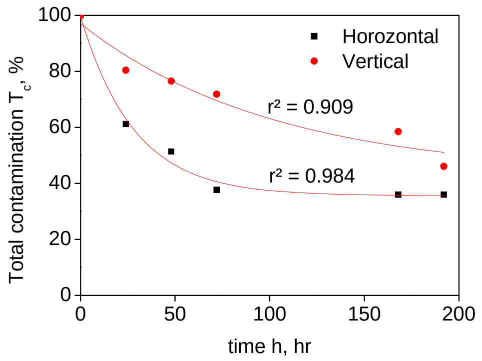

Figure 6: Total contamination T_c for horizontal and vertical clarification systems

After 190 hr the efficiency of vertical sedimentation system was about 54 % and that of horizontal sedimentation system was about 65 %.

Weihenstephan standard clarification system

Figure 7 show total contamination reduction for the Weihenstephan system in percentage, where 100 % stands for the raw non clarified oil.

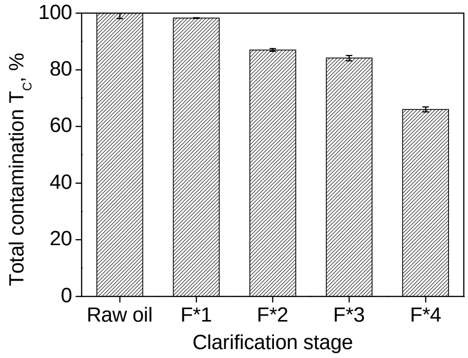

Figure 7: Total contamination T_C of Weihenstephan system

The standard deviation was around 13 % and the reduction of the total contamination reduction reached at the end was about the 34 % in 5 hours.

Particle size distribution PSD

Figure 8 shows the particle size distribution for the *J. curcas* raw oil and oil clarified by three different methods.

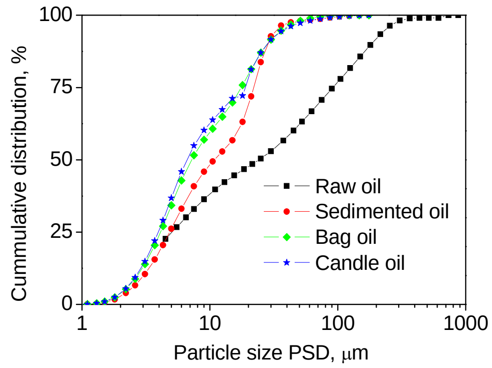

Figure 8: Particle size distribution PSD of *J. curcas* raw oil and oil clarified by three clarification methods

After the sedimentation, the largest size of particles present in the oil was equal to 175 µm. For the raw oil, the 50 % of the accumulated particle distribution corresponds to particle size equal or smaller than 25 µm. For the semi-clarified oil and the filtered oil, the 50 % of the accumulated volume corresponded to particle size equal or smaller than 12 and 7.5 µm, respectively. This is a clear reduction of the amount of bigger particles within the oil after each clarification stage. However, there was no difference between oil filtered by the bag and cartridge filter systems.

Conclusions

The main objective of this study was to investigate the efficiency of continuous and discontinuous clarification methods by analyzing parameters such as particle size, sedimentation time and total contamination. Following conclusions were drawn:

1. Horizontal discontinuous sedimentation system was more efficient than vertical sedimentation system for the same retention time.
2. Increasing the retention time of the oil in the funnels would maximize the efficiency of the system.
3. Particle sizes ≤ 5.5 µm were still present in the oil at the end of the clarification process. In case that the presence of these particles would decrease the performance of plant oil stoves, improvements on the filtration system should be implemented.

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