



# **Examination of hemp oil with regard to its suitability as fuel for engines adapted to pure plant oil use**

## **Motivation, Summary and Outlook**

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August 2007

# 1 Motivation

Since the rediscovery of the agricultural crop hemp and its high-grade raw materials fibres, shives and seeds/oil, it has often been discussed if hemp oil could also be used as fuel.

At present, high-grade hemp seeds and the hemp oil produced from these, having an unusually high share of polyunsaturated fatty acids (75-80%), are mainly used in the food and skin care sector and additionally as animal feed for birds and fish. Hemp oil, produced in comparatively small amounts, has difficulties establishing in other sectors (hemp oil in food-grade quality costs about 7 €/l).

Nevertheless, the question raised by the study “Examination of hemp oil with regard to its suitability as fuel for engines adapted to pure plant oil use” does make sense, namely for the following reasons:

- The quality requirements towards oils for food and skin care products are very high and cannot be met by all batches. Therefore the use as fuel could be an interesting option for inferior batches.
- At present, there are plans to cultivate hemp on large areas, e.g. 15.000 ha for the chipboard industry. If seeds were also produced here by means of coupled use, the amounts accumulated would be difficult to place in current market segments, and alternative applications would be desirable.
- The behaviour of the prevailing rapeseed oil fuel at low temperatures might be improved by hemp oil admixtures.
- So far, there isn't any scientific study worldwide that has examined hemp oil with regard to its technical and economic applicability as pure plant oil fuel.

The study on hand intends to close this gap and answer the mentioned questions in a comprehensive way.

In Germany, the use of pure plant oils as fuel is particularly well advanced. This development was motivated by the fact that the use of pure plant oils as fuel can contribute to climate, soil and water protection. Furthermore, an increase of the added value in agriculture and the regions can come about by means of refining the products and selling them.

Research and development in Germany has intentionally focused on rapeseed oil as the most important domestic plant oil. Here a lot of positive experience, especially in South Germany, could be gathered in recent years. Meanwhile, a DIN pre-standard (DIN V 51605) for pure plant oil fuel based on rapeseed oil has been elaborated and passed. Companies that convert diesel engines to operate on rapeseed oil are geared to this norm. For the operation of combined heat and power plants (CHP), comprehensive experiences with palm oil and soy oil is have been made.

In contrast, only limited experience is available for other pure plant oils such as hemp oil. Their applicability will have to be judged in analogy to rapeseed oil. They will need to prove their suitability as fuels for combustion engines that were converted to operate on rapeseed oil according to DIN pre-standard (DIN V 51605). Therefore, the potential of those plant oils certainly won't be fully used. However, it is very unrealistic to assume that manufacturers will develop motors especially for e.g hemp oil in the foreseeable future.

In addition, considering its high nutritional value thanks to its fatty acid spectrum, burning hemp oil would really be a shame. It is furthermore susceptible to oxidation and thus certainly

not the fuel of desire for engine developers. It is all the more important to carry out a disinterested analysis of its applicability as a fuel from a technical and economic point of view.

In the following chapter you will first find a summary of the technical analysis and then one of the economic analysis. The former was conducted by the Technology and Support Centre (TFZ) in Straubing (Bavaria), an acknowledged institution that has been active in this field for many years, also significantly contributing to the development of the DIN prestandard (DIN V 51605). The economic analysis comes from the nova-Institut GmbH in Hürth (North-Rhine Westphalia) that has conducted a multitude of economic analysis' in the field of renewable resources over the past ten years.

## 2 Technical suitability of hemp oil as fuel for engines adapted to the use of pure plant oil

In the technical analysis, three different hemp oil samples from varying production and processing methods (cold pressed, hot pressed, refined) were investigated for the properties relevant fuels and tested for meeting the requirements according to the DIN prestandard for rapeseed oil fuel. **All analysed hemp oil samples met the threshold values for rapeseed oil fuel regarding density, kinematic viscosity, cetane number, calorific value, sulphur content and water content.** The deviations from these parameters to the characteristic values of a rapeseed oil fuel were small and are no obstacle to using hemp oil as a fuel.

**The requirements of the DIN V 51605 on coke residue, iodine number and oxidation stability could not be fulfilled.** Especially the coke residue of hemp oil is twice as high as that of rapeseed oil. This will negatively affect the operation of the engine.

The high coke residue indicates a high tendency to building deposits in the combustion chamber, on the injection nozzles and on the valves, which will lead to increased maintenance requirements, deterioration of the emission characteristics and disturbance of the engine operation.

The lower oxidation stability of hemp oil in comparison with rapeseed oil results from the high content of polyunsaturated fatty acids. Hemp oil is thermally less stable and more susceptible to oxidation processes than rapeseed oil. Lower oxidation stability leads to decreased storage stability and quicker deterioration, which will lead to gummings in the fuel and injection system and to faster depletion of the lubricating oil. For the storage of hemp oil, cool and dark storage conditions are very important to reduce the deterioration processes.

The disadvantages of hemp oil concerning coke residue and oxidation stability could possibly be improved by fuel additives. However, it has to be considered that there is almost no experience on using fuel additives for plant oils and that additional costs will arise.

Hemp oil showed a **better low-temperature behaviour and thus a better flowability** compared to rapeseed oil (20% less kinematic viscosity at 40°C), which results from the differing composition of fatty acids.

The three hemp oil samples showed differences in the fuel properties, some of them quite considerable. The sample "hemp oil refined" could comply with 12, the sample "hemp oil cold-pressed" with 8 and the sample "hemp oil hot-pressed" with 6 of the 15 parameters set by the DIN V 51605. **"Hemp oil refined" showed the best properties of the samples tested.**

### *Conclusion*

**The research indicates a high risk of operational disturbances and changes in the emission behaviour if hemp oil is used as a fuel in current engines adapted to plant oil use.**

However, there are possibilities to improve the fuel properties by optimizing the processing process or by usage of additives. Furthermore, the use of hemp oil in engines specifically constructed or adapted to the properties of hemp oil might make it possible to use hemp oil as an alternative fuel in the future. This would require further and extensive investigations concerning the effect on operating behaviour and emissions when using hemp oil as fuel in engines adapted to plant oil use.

However, it has to be considered that the plant oil compatible engines currently available are only optimised for the use of rapeseed oil in mobile applications and some for palm and soybean oil in stationary applications. If hemp oil would be used in those engines not only technical problems would occur but a loss of warranty would also be very likely.

### **Mixtures of hemp oil and rapeseed oil**

In order to check the possibility of improving the aging stability of hemp oil by adding rapeseed oil, defined amounts of rapeseed oil fuel were added to the hemp oil and analysed in further studies.

By adding 80% of rapeseed oil to refined hemp oil, the demands on oxidation stability according to DN V 51605 could be fulfilled. As a positive effect the viscosity compared to pure rapeseed oil was improved by adding hemp oil. But it has to be noted that high quality hemp oil is needed for making those mixtures. More research in the field of fuel quality for hemp and rapeseed oil mixtures and engine test runs with those mixtures have to be done to evaluate the feasibility of those fuel mixtures.

### *Conclusion*

**A mixture of rapeseed oil with up to 20% hemp oil may turn out to be feasible as a fuel in plant oil compatible engines, but more research has to be done first.**

## **3 Economic suitability of hemp oil as fuel**

The economic analysis shows that even the cheapest type of hemp oil is considerably more expensive than rapeseed oil, even in the case of high rapeseed prices.

The pressing technique for hemp oil is not different from the one for rapeseed oil. The optimum valorisation of the coupled product press cake constitutes an essential factor for the cost valuation of both oils, but does not make much of a difference for hemp and rape. The price for hemp oil from local oil mills is significantly higher than the one for rapeseed oil – partly due to lower oil yields, but mainly due to the higher seed costs and the lower oil content of the seeds. Even if the hemp oil was hot-pressed, resulting in a higher yield, it remains more expensive than rapeseed oil.

Coming from small-scale production that is common today, hemp oil costs at least 2.34 €/l (in case of good valorisation of the press cake), totally ruling out the use as fuel. Under large-area cultivation and with hot pressing, the minimum price of hemp oil could decrease to 0.91 €/l.

The minimum prices of rapeseed oil as calculated in the three scenarios range between 0.58 and 0.78 €/l, thus being considerably cheaper.

The mentioned figures mainly depend on the seed price (considerable fluctuations exist particularly in the rapeseed sector), the oil content (primarily depending on the strain) and the valorisation of the press cake (heavy regional fluctuations). Particularly the latter can have a strong regional influence on the minimum price for hemp and rapeseed oil.

**All in all, it becomes clear that the hemp strains available today for the production of pure plant oil fuels do not constitute an economic alternative to rapeseed at all.** Only if, by means of modern breeding methods, considerably higher seed yields per hectare (from today about 1 t/ha to 3 to 4 t/ha) with a simultaneously increased oil content (more than 40%) were achieved, this analysis could change. So far, the breeding potential of hemp as an oil plant can't be estimated.

Apart from first activities in Canada, however, no relevant breeding activities in the field of hemp oil yields are recorded worldwide. With regard to the use as pure plant oil fuel, this means for hemp that in the foreseeable future **only low-quality charges that cannot be marketed at a high price in the food, skin care or animal feed sector come into consideration for fuel production from an economic point of view.**

There is another possibility if hemp was cultivated on large areas for fibres and shives (e.g. 15,000 ha for the chipboard industry) and the seeds accumulating in coupled use cannot be fully sold on the existing markets. **If in this case the additional expenses of coupled use should turn out to be profitable also at lower seed prices (on the level of rape), from an economic point of view this would be another possibility of using hemp seed for the production of hemp oil fuel.** It has to be investigated, however, in further studies whether this is the case.

## 4 Outlook

In the future, hemp oil will not play a relevant role as a pure plant oil fuel before engines are well developed or modified for the use of hemp oil and hemp strains are developed that grow considerably larger seed yields with improved oil content. Both things won't be the case in the foreseeable future.

From today's point of view, the use of hemp oil as pure plant oil fuel will be restricted to niches and special cases. From an economic point of view, such special cases would be inferior qualities or large amounts of seeds from coupled production with hemp fibres that cannot be sold in the high-quality sectors food, skin care and animal feed.

From a technical point of view, it could be an interesting option at the moment to use hemp oil as an additive to rapeseed oil. If a maximum of 20% refined hemp oil is added to high quality rapeseed oil, the problematic oxidation stability can meet the requirements of DIN V 51605. The low-temperature behaviour and viscosity compared to pure rapeseed oil can improved by adding hemp oil. But more research in the field of fuel quality for hemp and rapeseed oil mixtures and engine test runs with those mixtures will have to be done to evaluate the feasibility of those fuel mixtures.

**References:**

- Emberger, P, Thuneke, K., Haas, R., Remmele, E. (TFZ) (2007): Prüfung von Hanföl hinsichtlich seiner Eignung als Kraftstoff für pflanzentaugliche Motoren (Technical Analysis). Straubing, April 2007.
- Carus, M., Breuer, T., Ortmann, S. (nova-Institut) (2007): Untersuchung von Hanföl auf seine Eignung als Pflanzenöl-Kraftstoff (Economic Analysis). Hürth, August 2007.

The studies ma be downloaded without charge at:

- European Industrial Hemp Association (EIHA): [www.eiha.org](http://www.eiha.org) --> Studies
- nova-Institut GmbH: [www.nova-institut.de/nr](http://www.nova-institut.de/nr) --> nova-Publications & Shop



# **Examination of hemp oil with regard to its suitability as fuel for engines adapted to pure plant oil use**

## **Figures**

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August 2007

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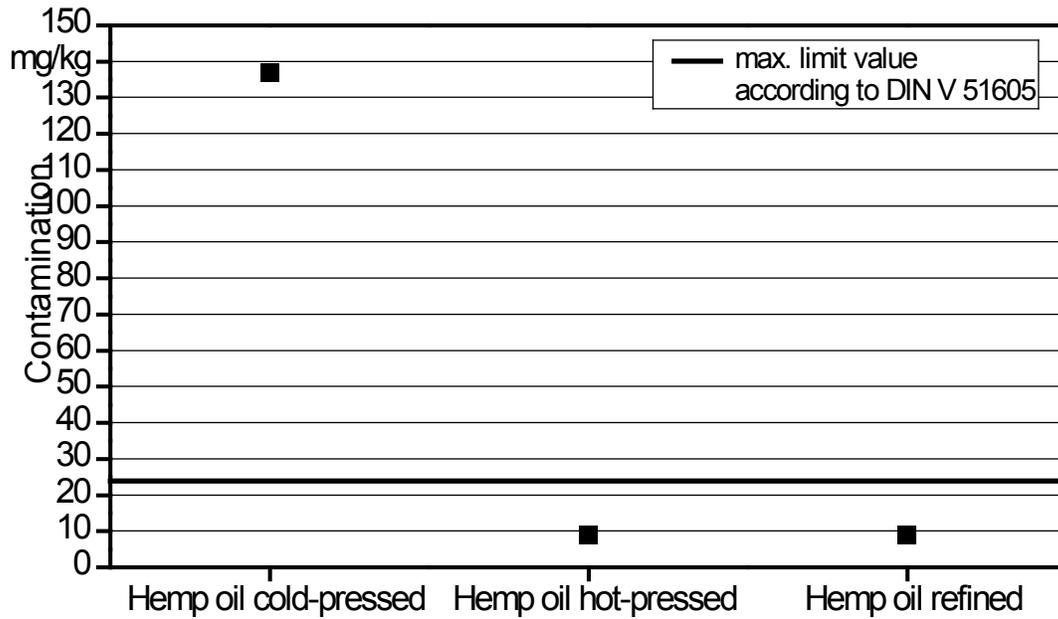


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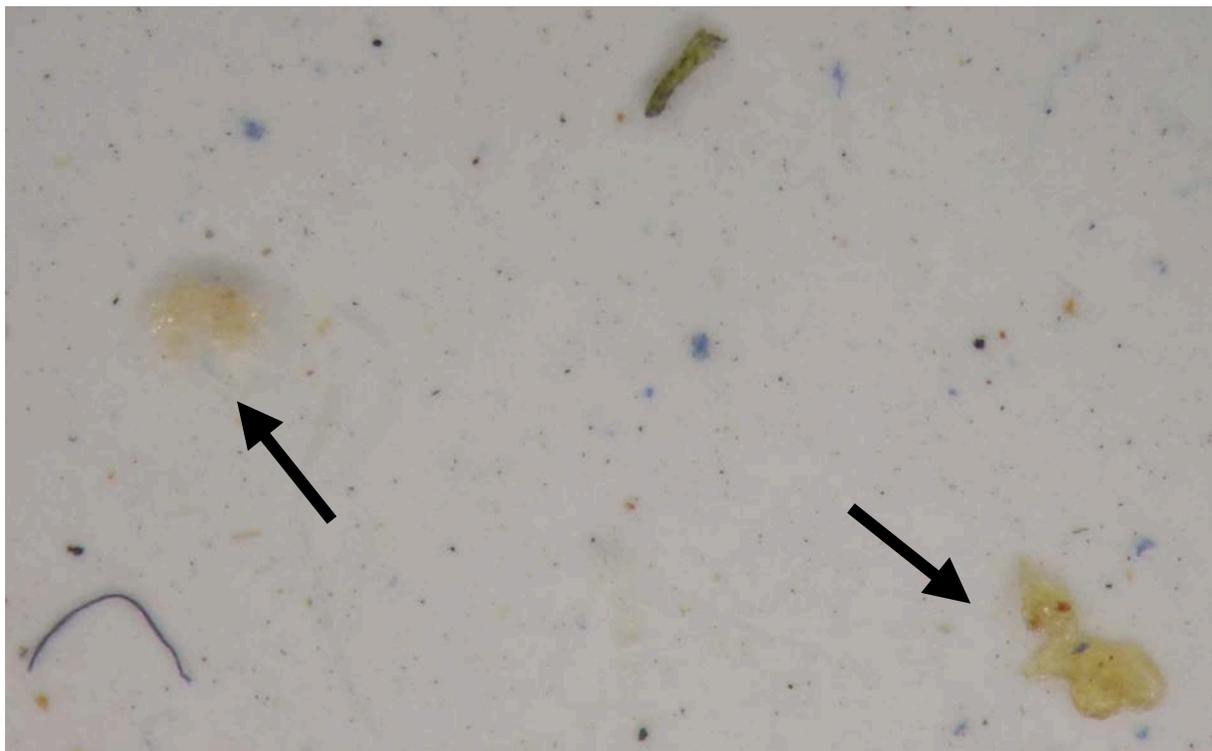


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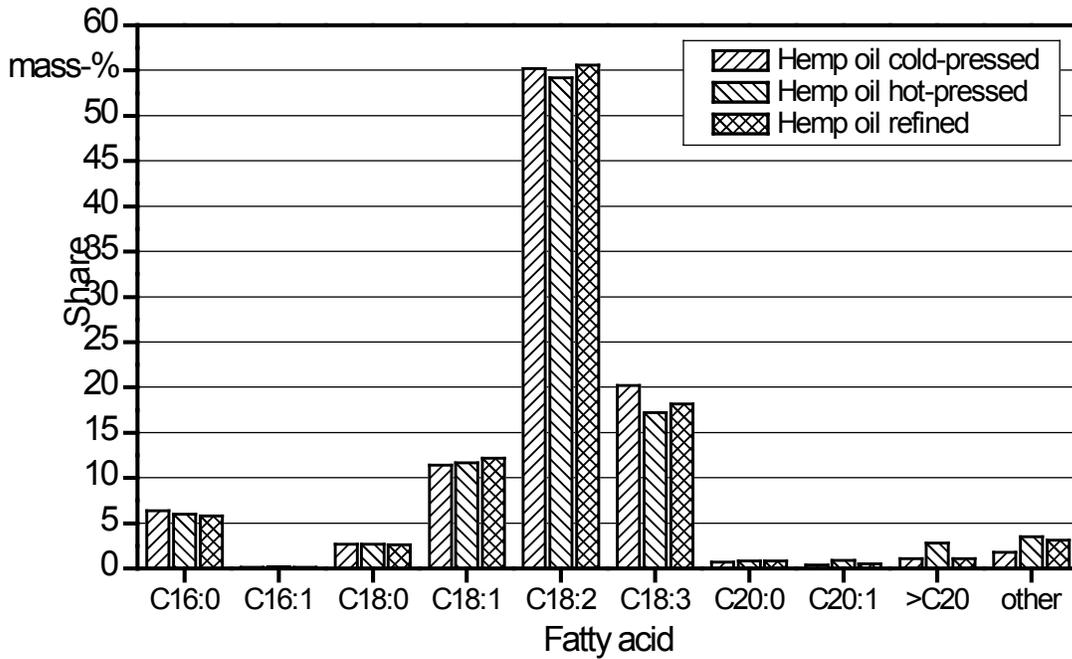


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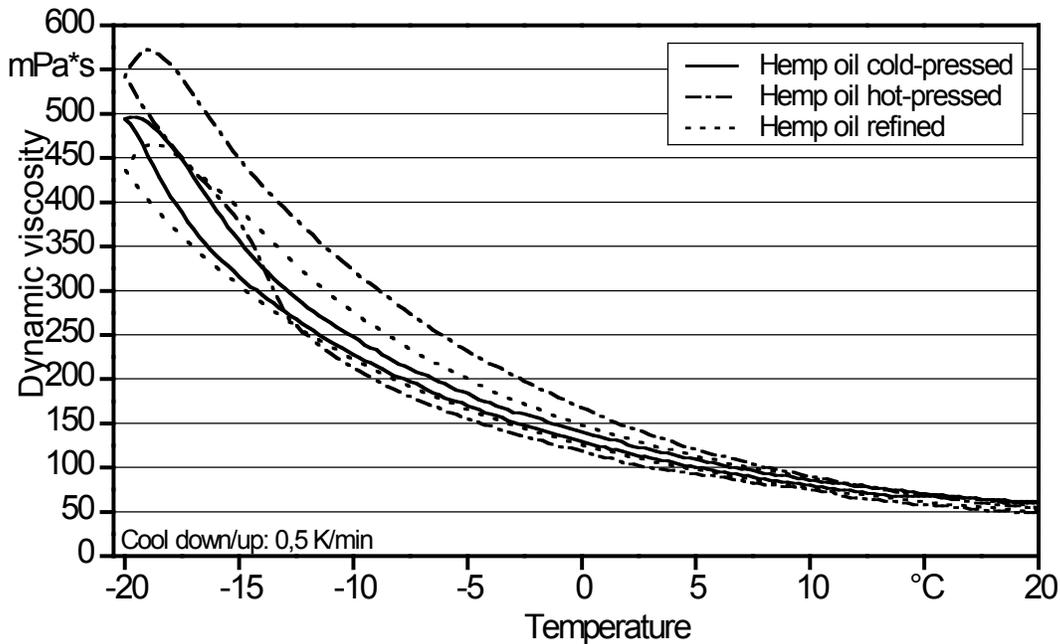


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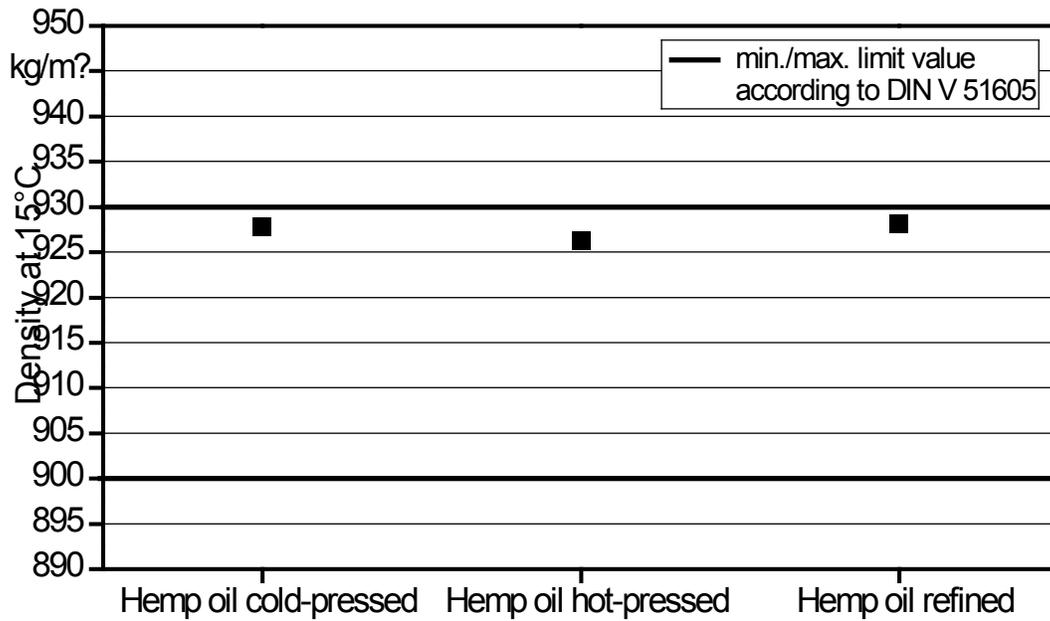


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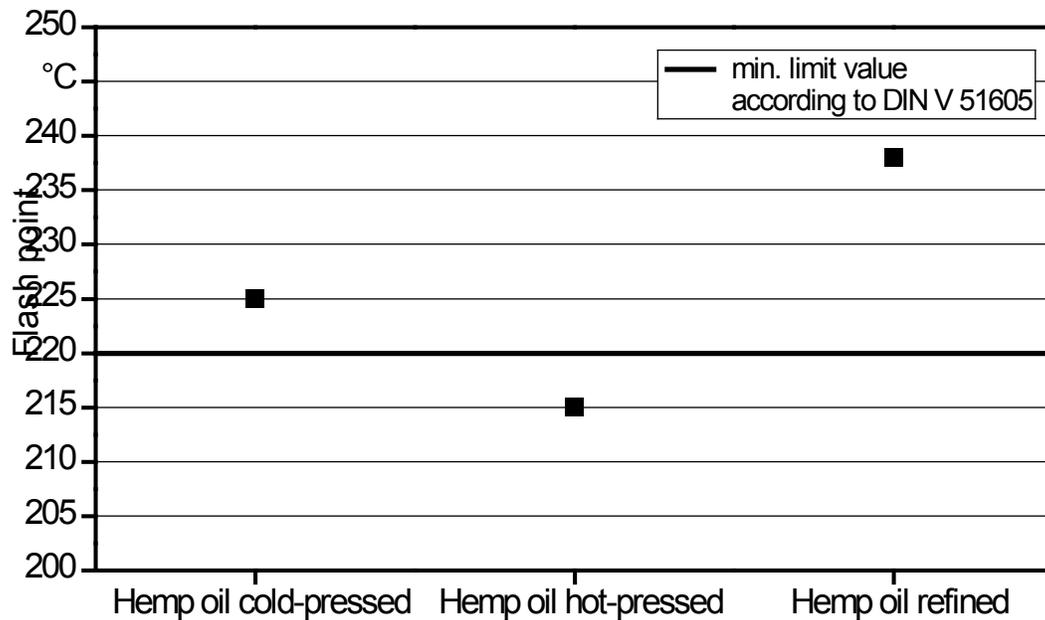


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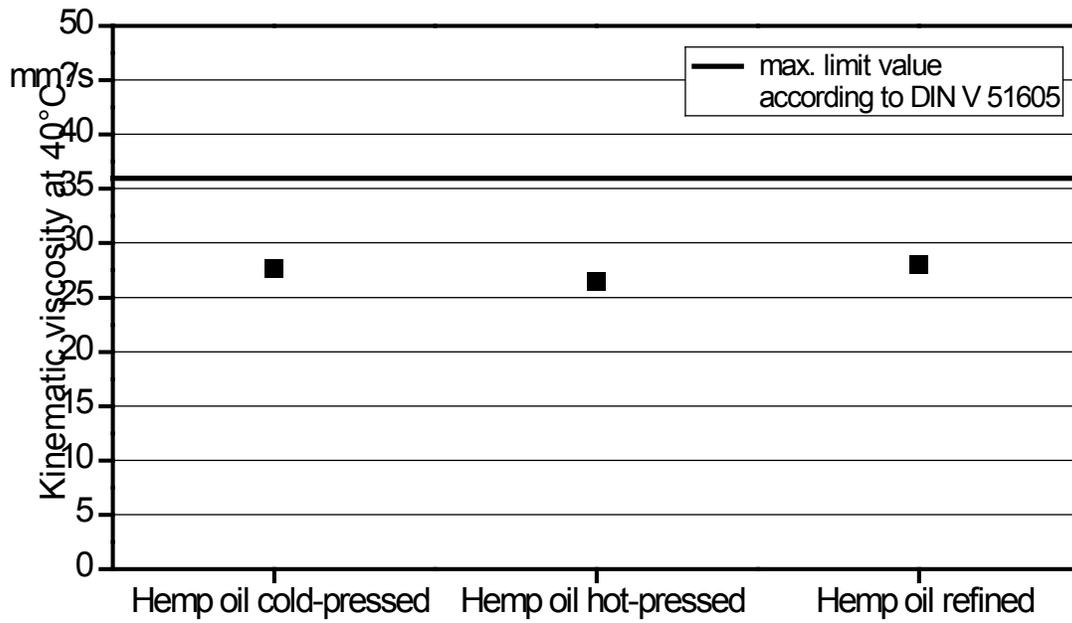


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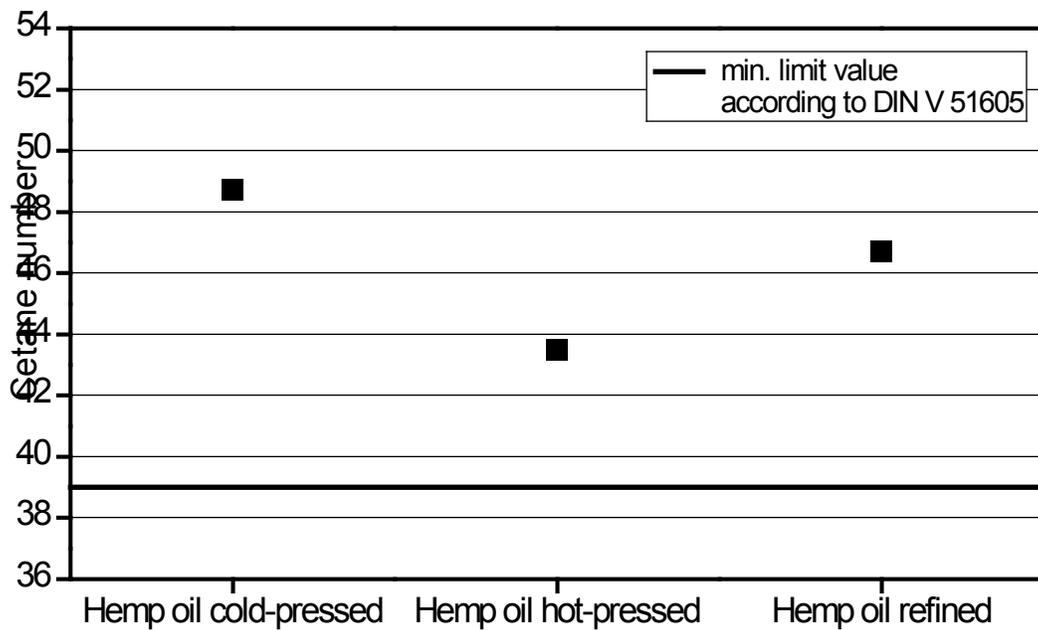


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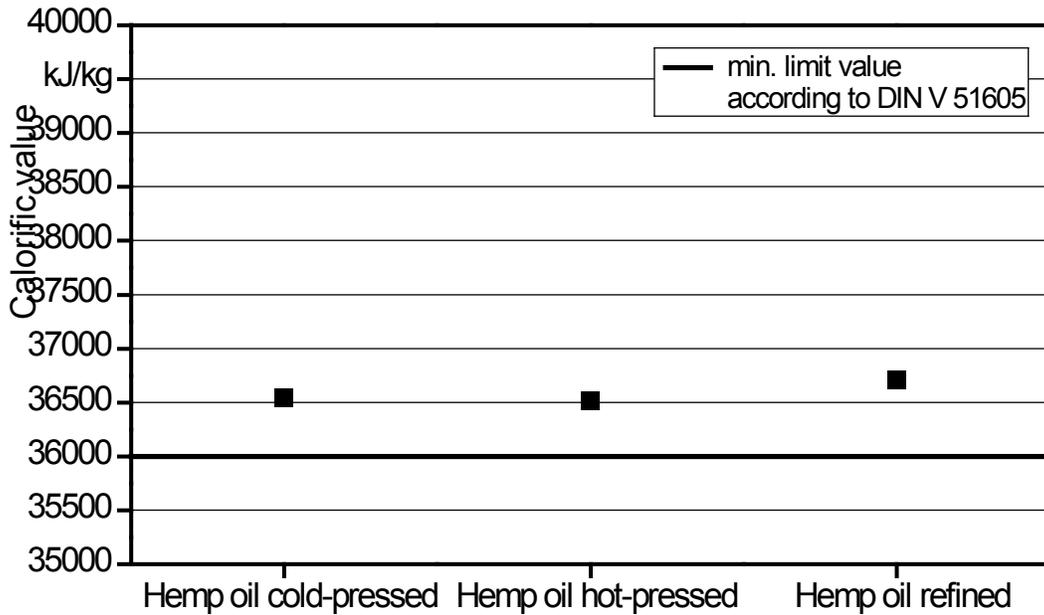


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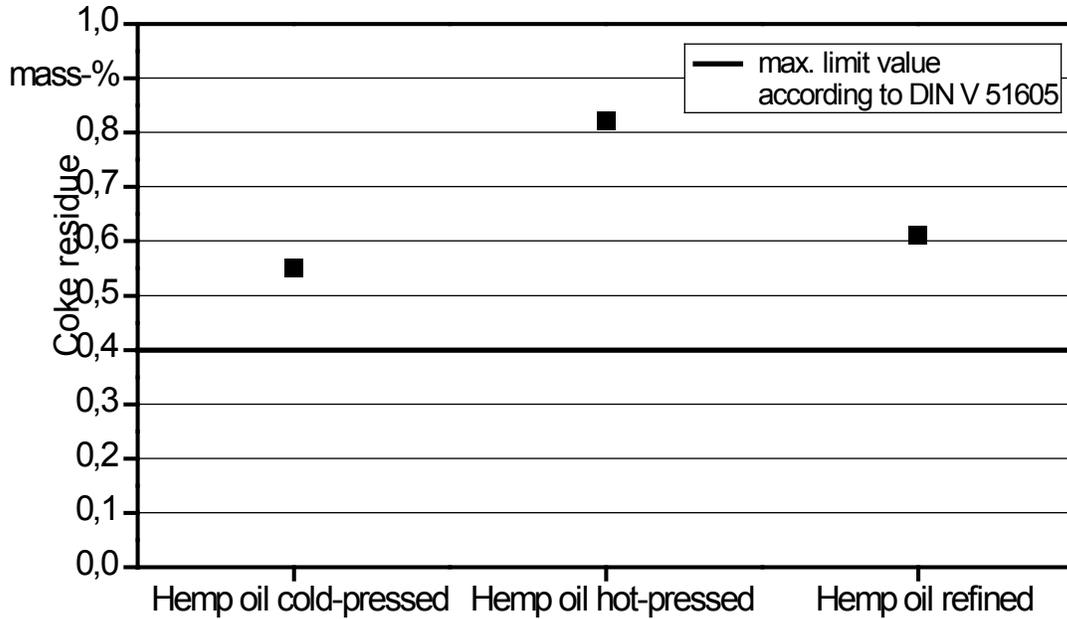


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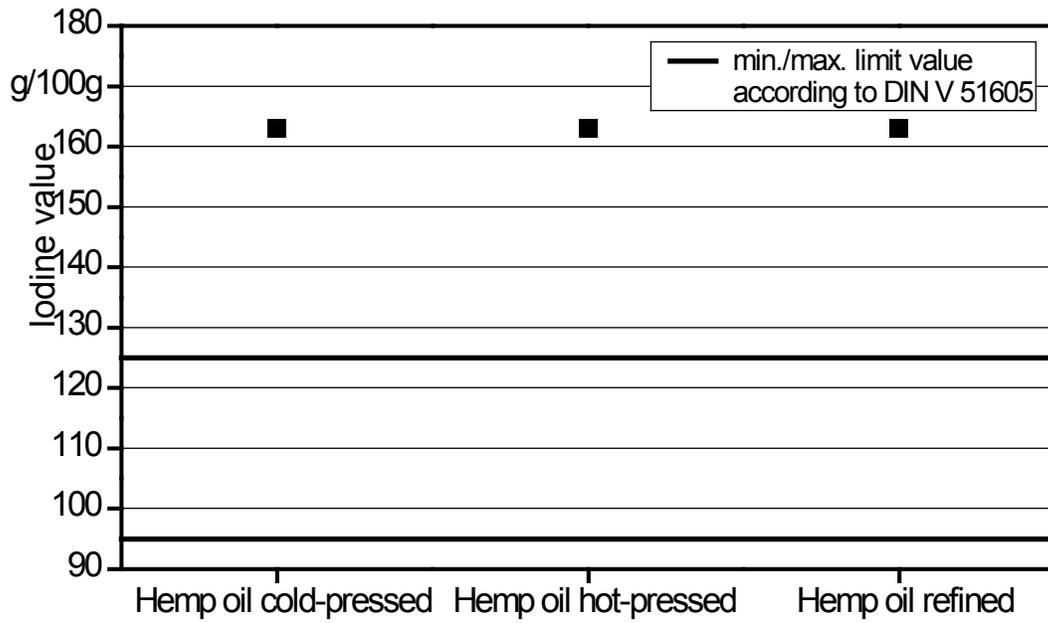


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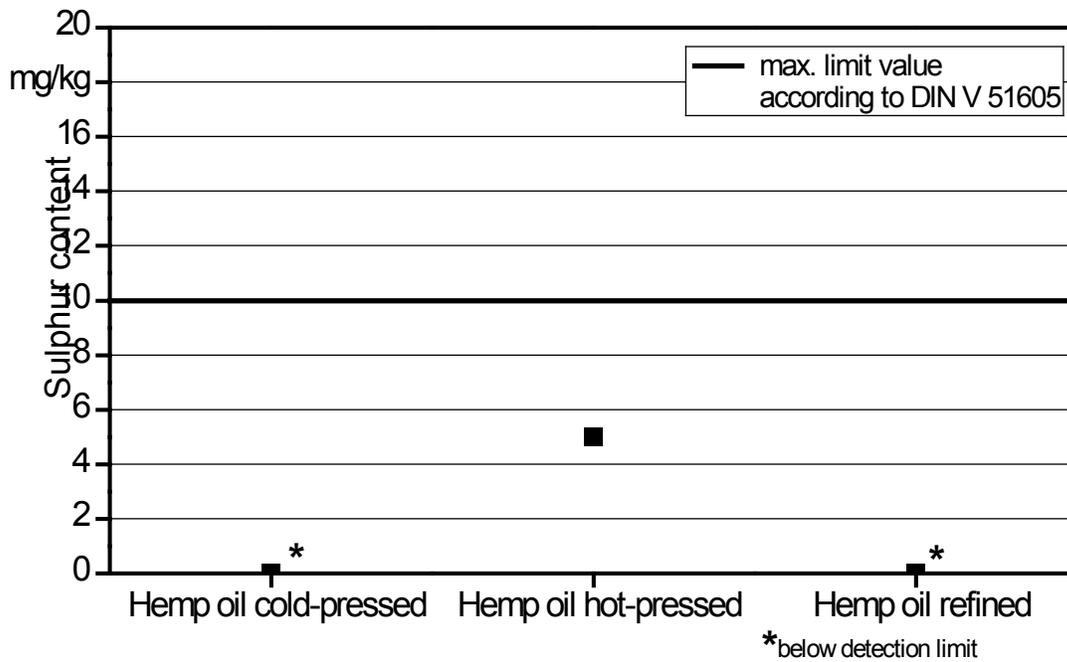


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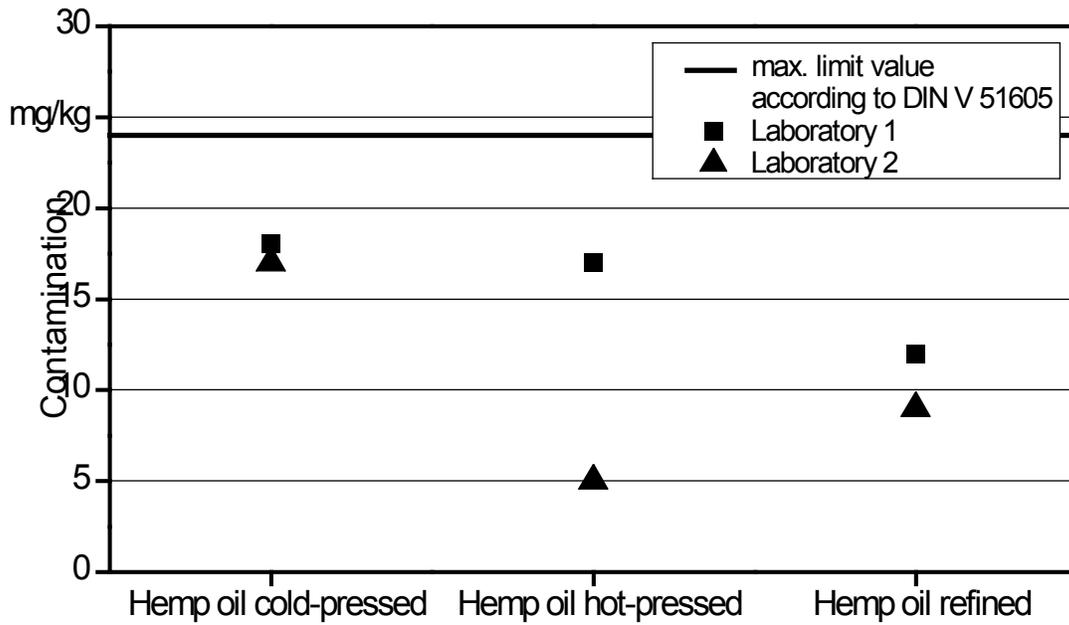


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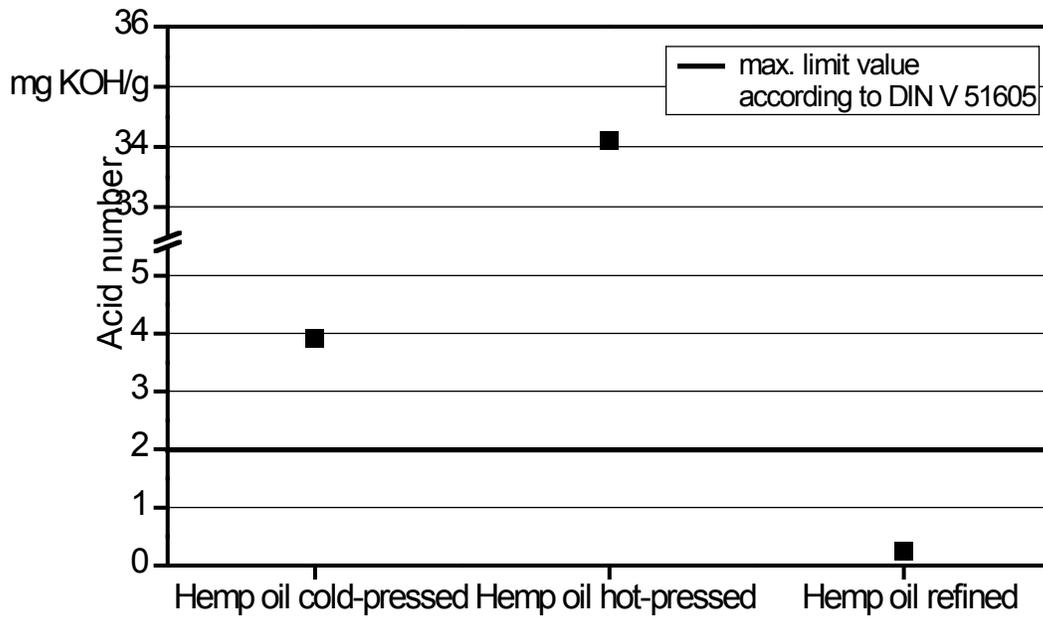


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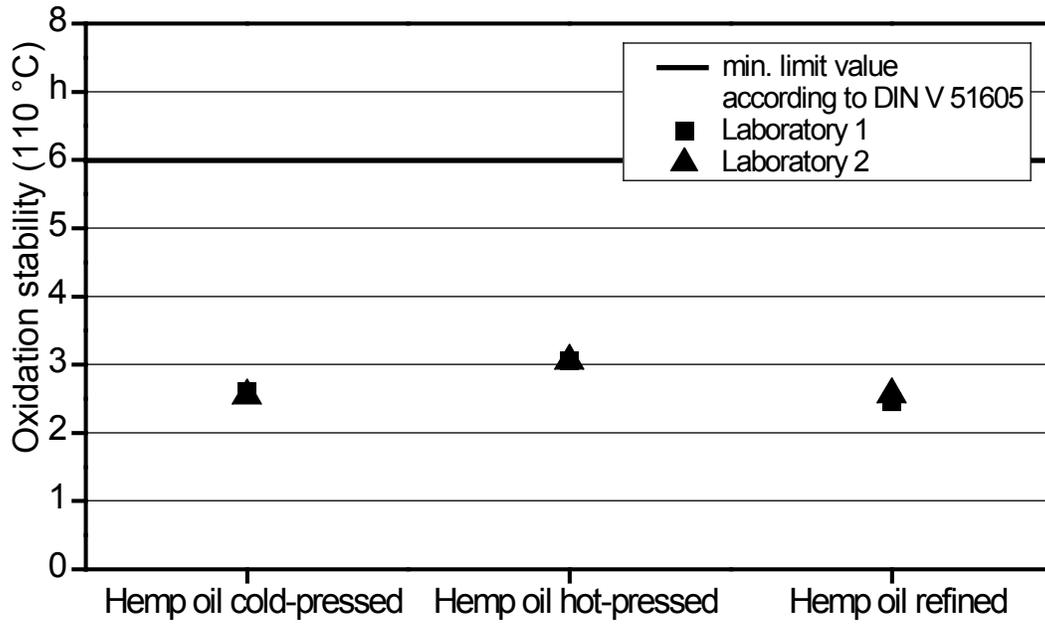


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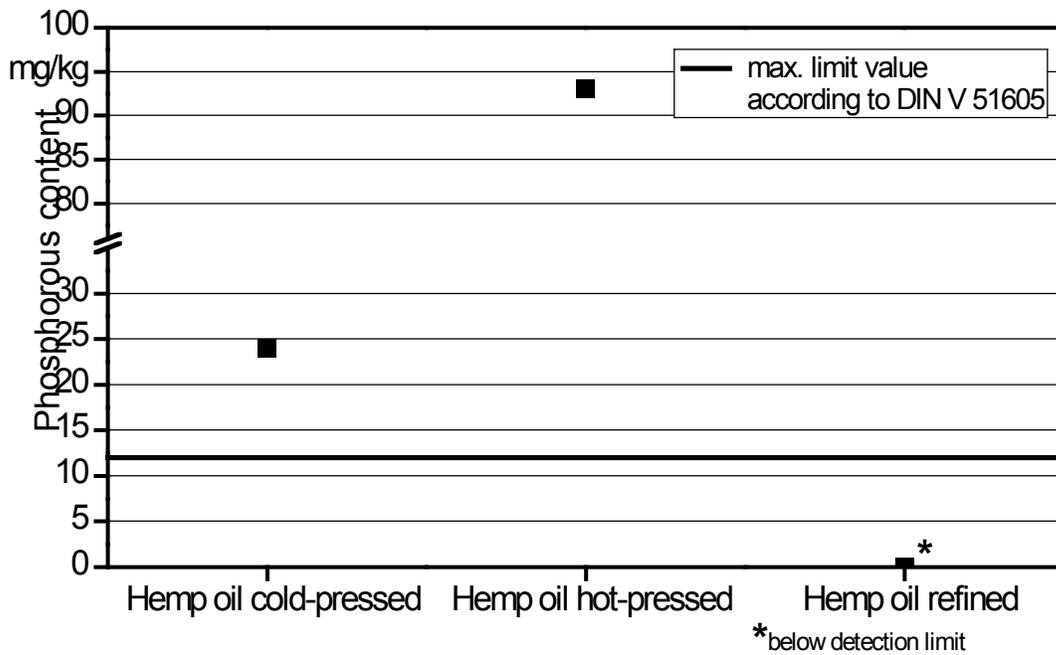


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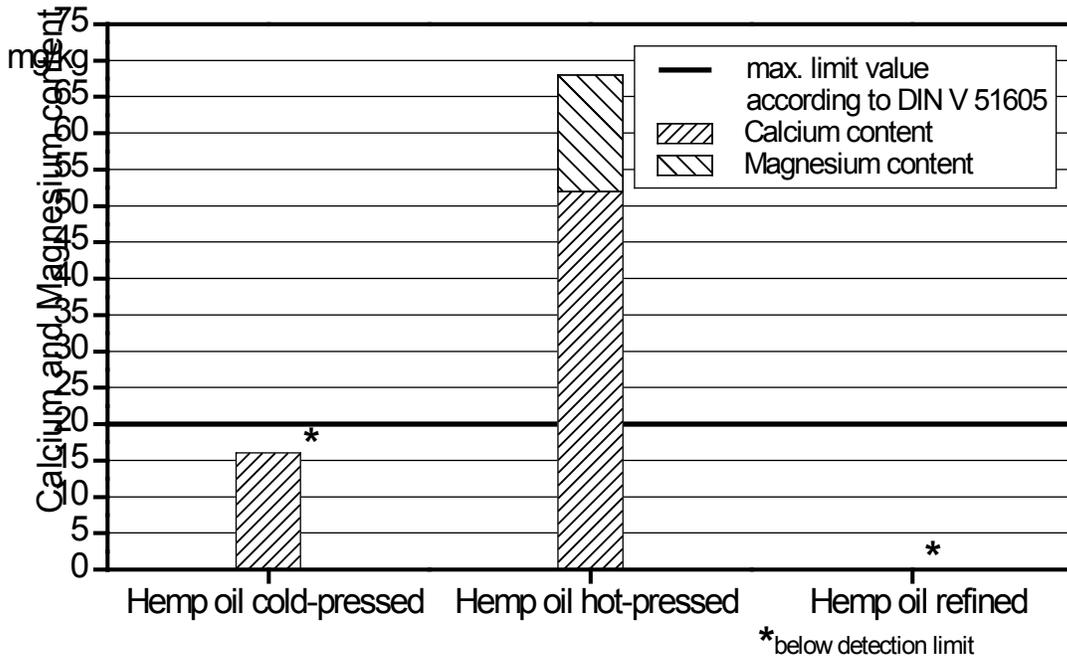


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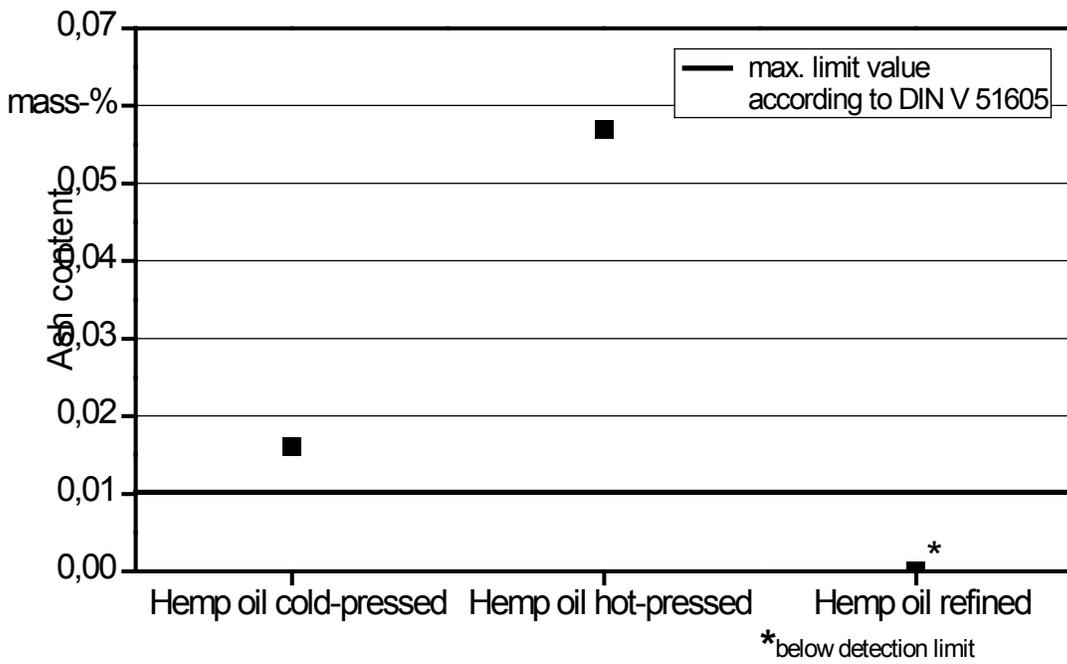


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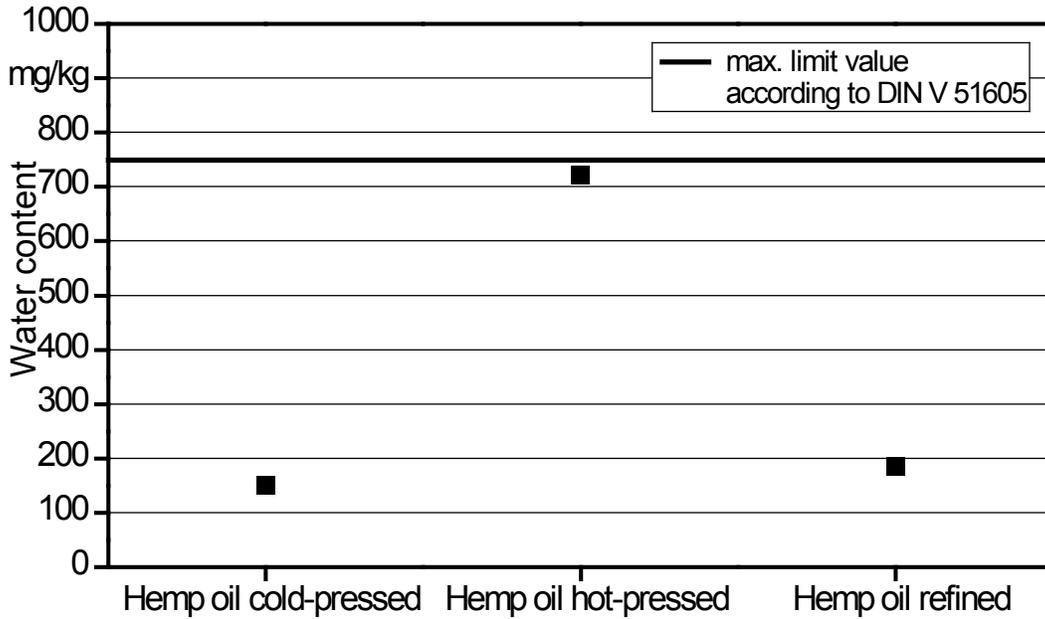


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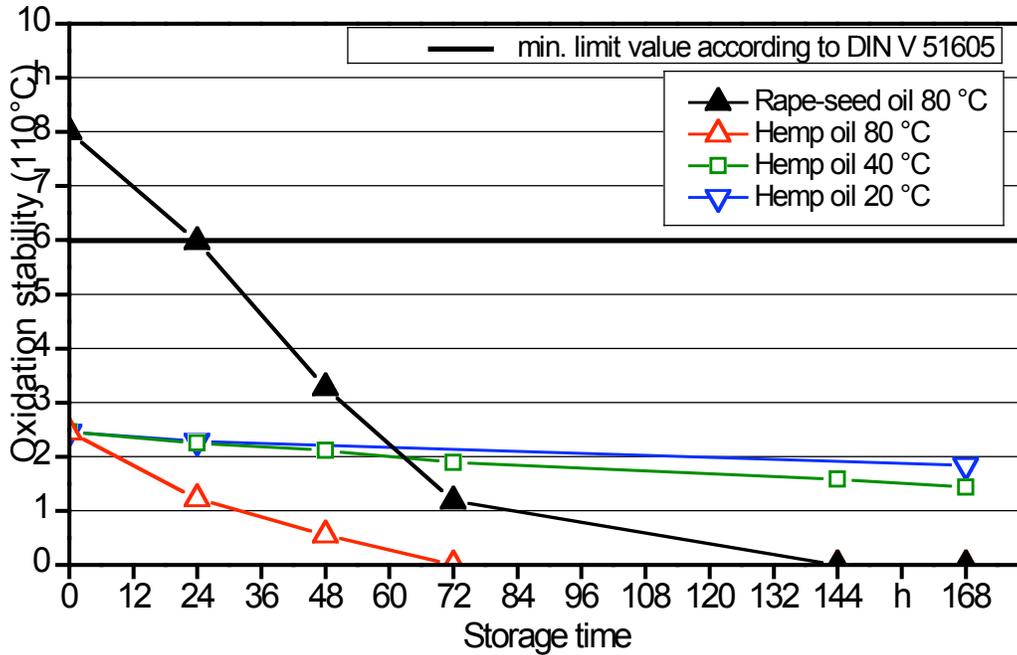


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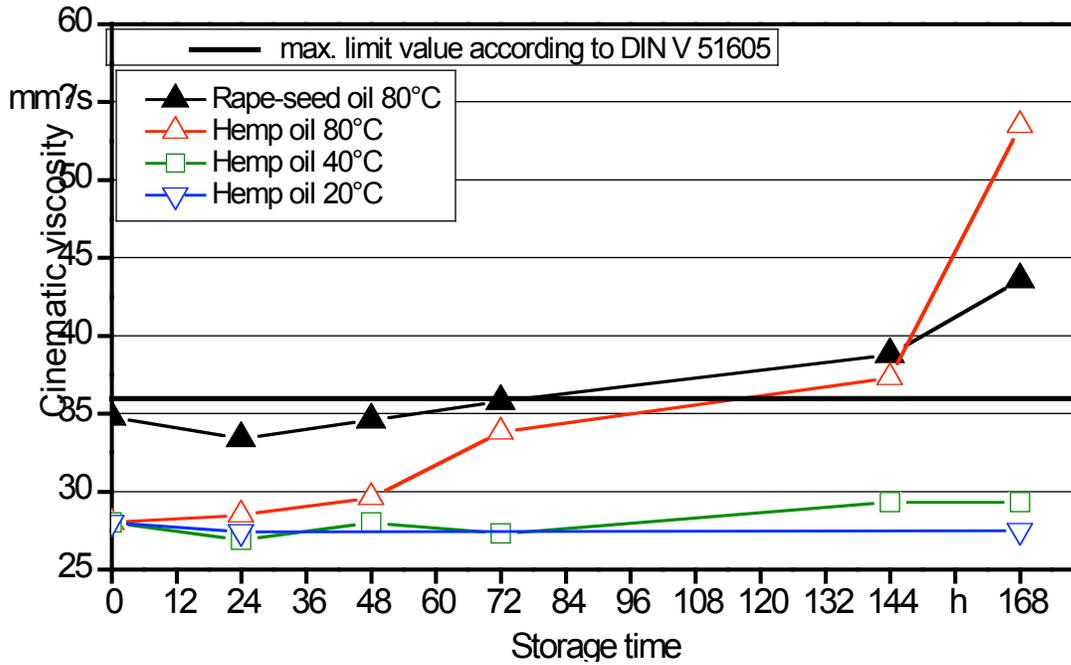


Figure 21: Change of kinematic viscosity (40 °C) (ISO 3104) of hemp oil and rape-seed oil stored at different temperatures

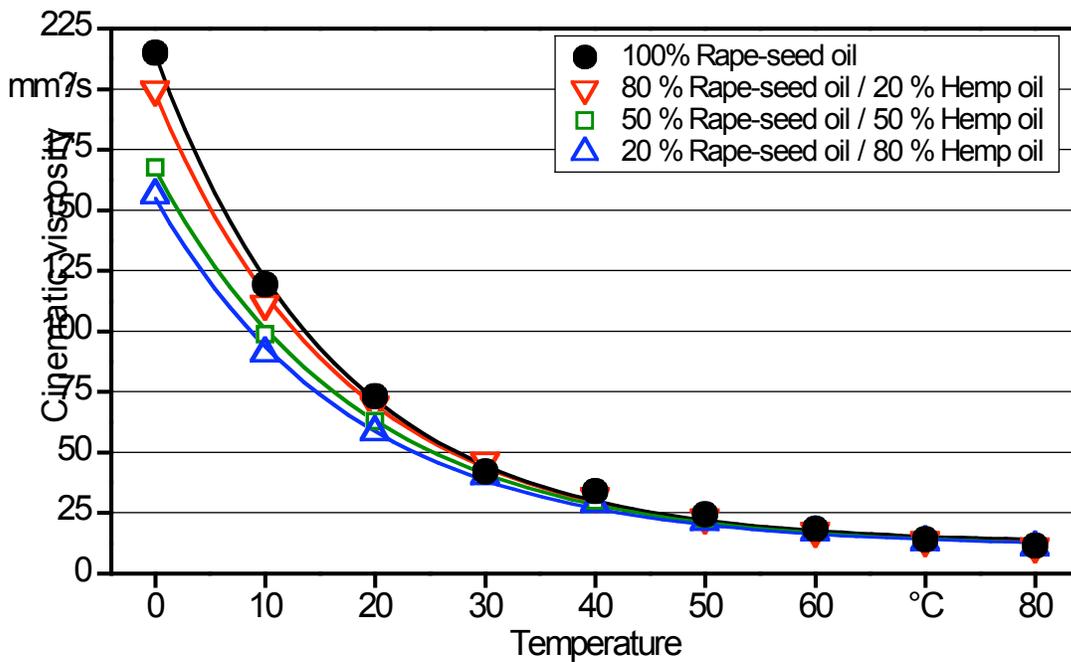
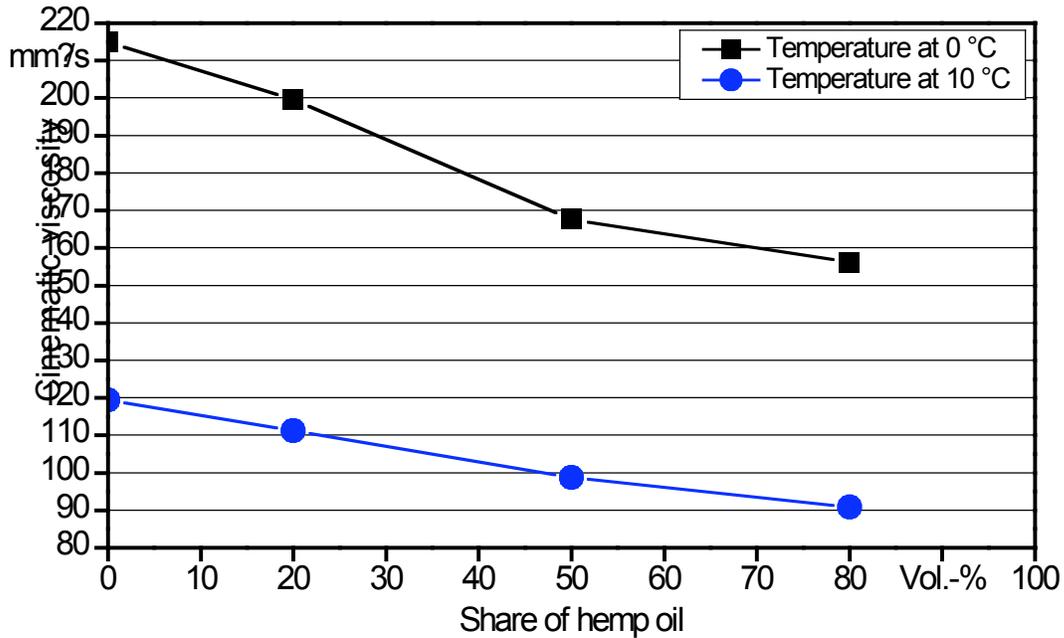
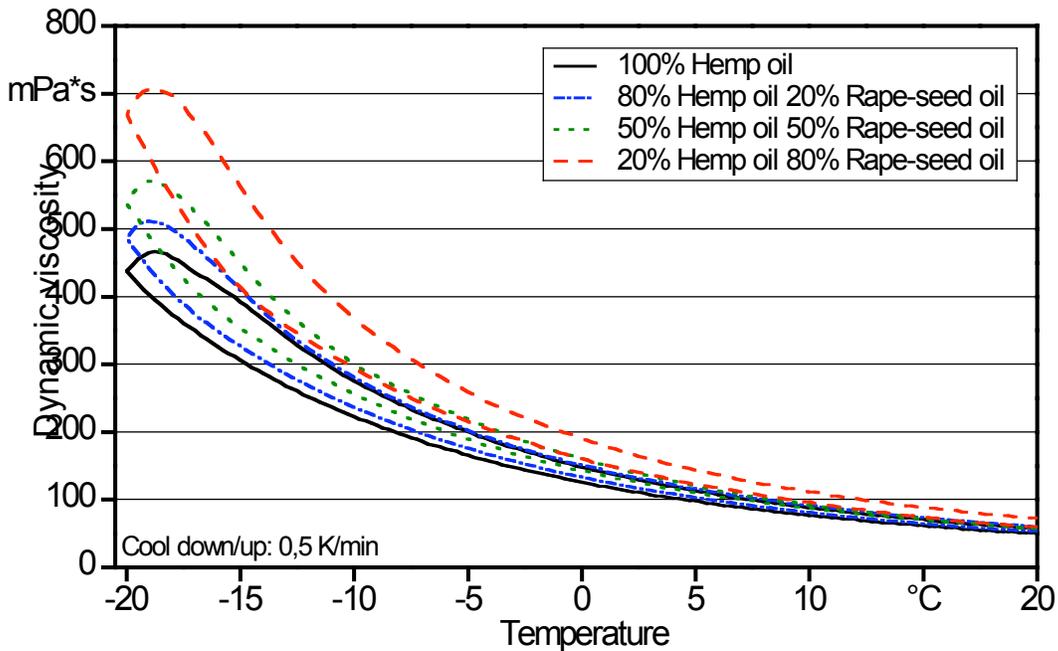


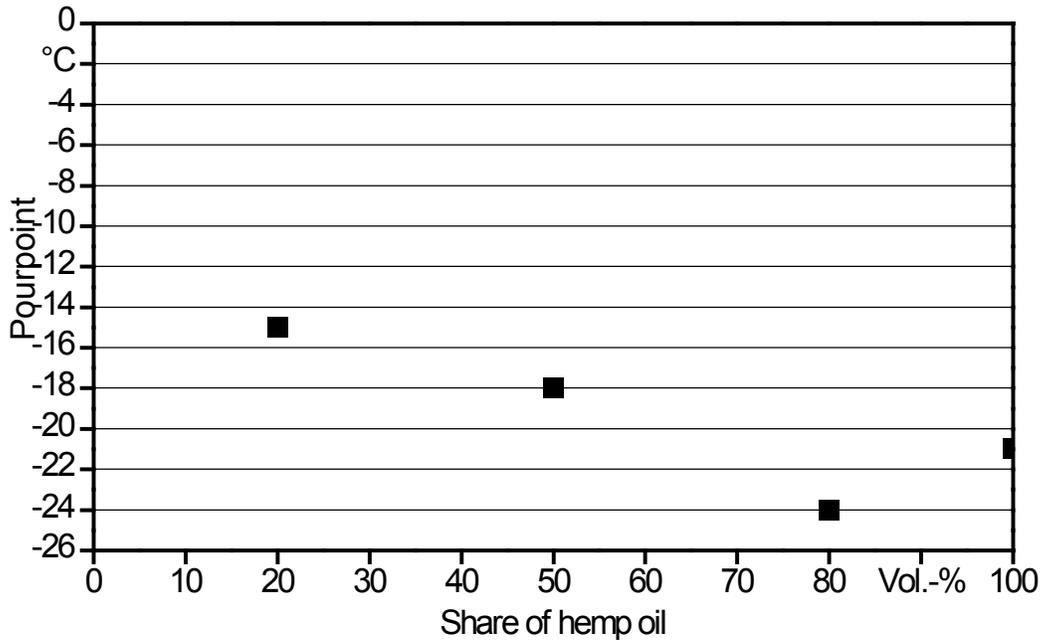
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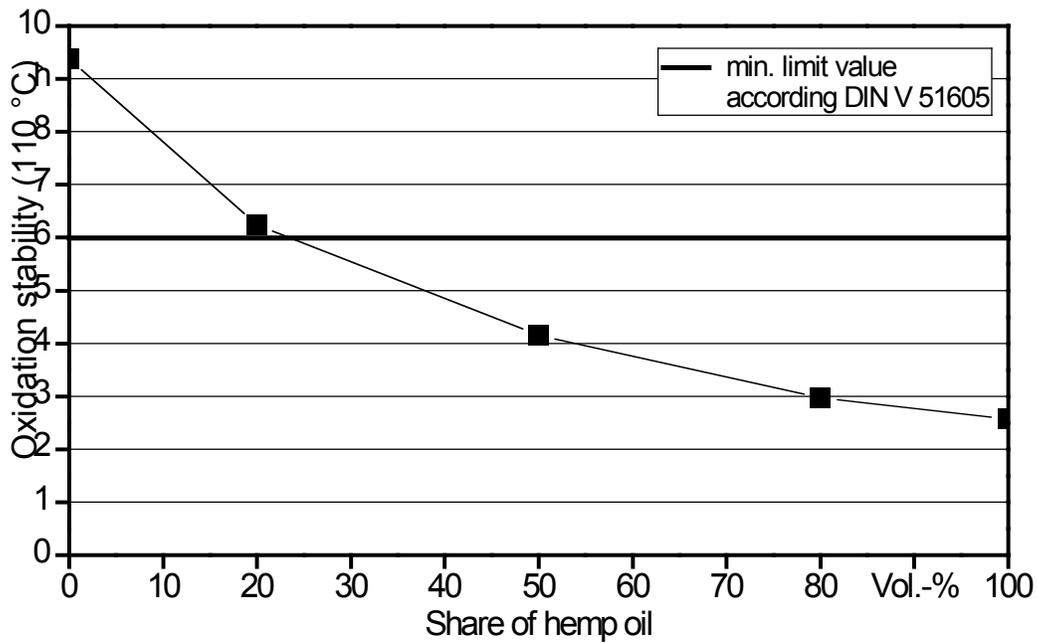
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**Figure 24: Dynamic viscosity of mixtures of hemp oil and rape-seed oil, measured by a rotation viscosimeter, with a cool down/up speed of 0.5 K/min**



**Figure 25: Influence of the share of hemp oil on the pour point (ISO 3016) of a mixture of hemp oil and rape-seed oil**



**Figure 26: Influence of the share of hemp oil on the oxidation stability (110 °C) (EN 14112) of a mixture of hemp oil and rape-seed oil**