Geometric Feature Extraction of Wax Crystals in Oils Using Image Processing Algorithms

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Abstract

The geometric characterization of wax crystals is essential for understanding wax deposition in petroleum systems. This study analyzes optical microscopy images acquired under cross-polarized light, using Sobel edge detection combined with two aspect ratio measurement methods: the rotated bounding box and a radial centroid-based approach. Images were captured during a controlled cooling process from 70°C to 10°C at 1°C/min to induce crystallization. Image processing was performed in Python with OpenCV, enhancing crystal boundaries and extracting geometric features efficiently under high-contrast conditions[1]. Figure 1 shows the processed images and intensity histograms for samples at 64°C and 14°C.

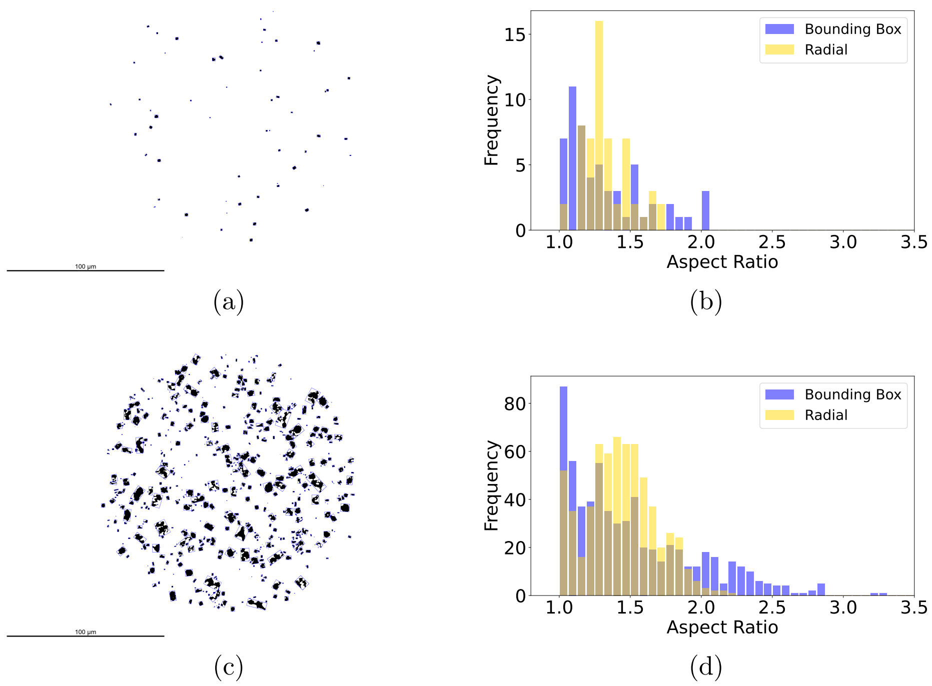

Figure 1: Processed images and their respective histograms. (a) After processing at 64°C. (b) Intensity histograms for 64ºC. (c) After processing at 14°C. (d) Intensity histograms for 14ºC.

Figure 2 shows that the average number of crystals is zero at 70°C, increases exponentially from 64°C to 44°C, and remains nearly constant, just under 300, from 42°C to 30°C due to aggregation. Below 30°C, the number rises linearly to over 12, likely due to secondary nucleation. [2] To explore this, data near the Wax Appearance Temperature (WAT) were examined, where the standard deviation remained acceptable. Both methods yield similar crystal counts because they share the same Sobel-based edge detection; the divergence lies in how aspect ratios are measured—bounding box versus radial centroid—affecting shape characterization, not object detection.

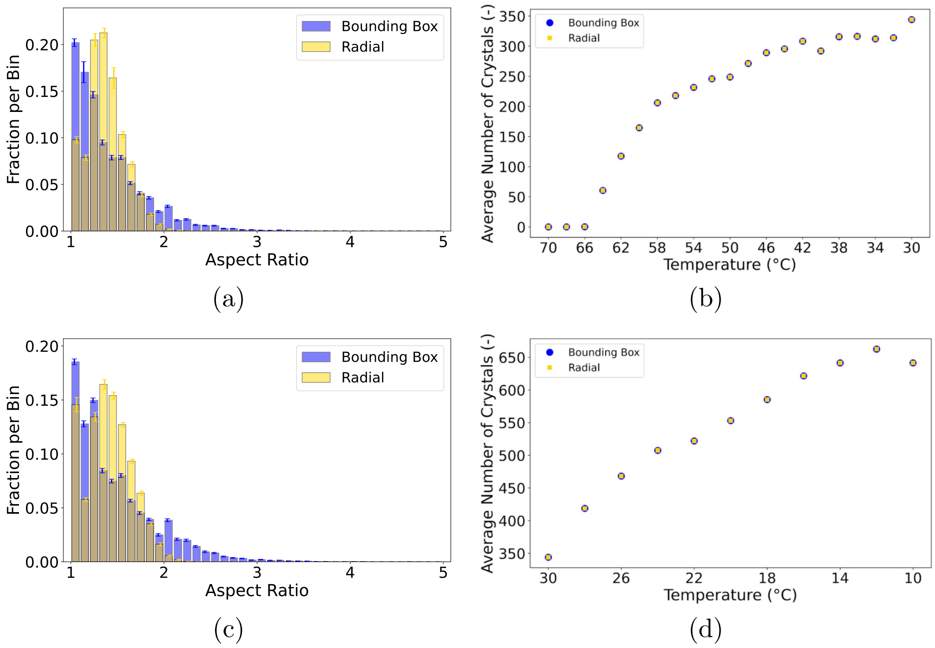

Figure 2: Aspect ratio and crystal counts: (a) Normalized mean histogram for 70–30°C; (b) Crystal counts for 70–30°C; (c) Normalized mean histogram for 30–10°C; (d) Crystal counts for 30–10°C.

Comparing the histograms above and below the critical temperature (Figures 2 (a) and (c)) reveals an apparently stable distribution with small standard error bars. However, this stability masks a critical limitation of Sobel edge detection, which—under increasing crystal density—begins to identify aggregated networks rather than discrete structures. The methods diverge in behavior: the radial approach is more sensitive to circular shapes, while the bounding box tends to overestimate elongation in tilted or asymmetric objects. Therefore, even when the results appear statistically robust, the observed monotonic morphological progression of the crystals reflects both a genuine secondary nucleation process and spurious detections, where structural aggregates are erroneously identified as individual particles. This duality underscores the limitations of the Sobel operator in accurately segmenting complex morphologies, an important limitation considering that many commercial tools in the oil industry still rely on this technique as a segmentation stage.

References

1. R. C. Gonzalez and R. E. Woods. *Digital image processing. 4th ed.*, Pearson, 2018.

2. B. Li, Z. Guo, L. Zheng, E. Shi and B. Qi. A comprehensive review of wax deposition in crude oil systems: mechanisms, influencing factors, prediction and inhibition techniques. *Fuel* **357**(Pt A), 2024.