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Shadow Sizing as a hot trub particles identification method

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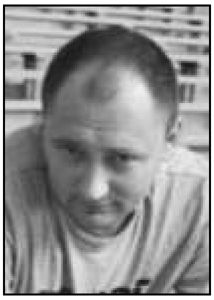

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Abstract

This article presents the application of the Shadow Sizing method for the analysis of fundamental morphometric parameters of the hot trub particles resulting from the beer wort manufacturing process. Research material was provided by a whirlpool separator, working in an industrial environment. The analyses were performed using a test rig assembled in the Department of Food Industry Devices and Processes at Koszalin University of Technology. The measurements were performed with the use of computer-aided image analysis, which incorporated a Shadow processor implemented in the DynamicStudio platform.

Keywords: Shadow Sizing, whirlpool, hot trub.

Zastosowanie Shadow Sizing do identyfikacji cząstek osadu gorącego

Streszczenie

Artykuł prezentuje możliwość zastosowania metody Shadow Sizing do analizy wielkości oraz prędkości cząstek osadu gorącego oddzielonych od brzeczki piwnej. Wytrącanie osadu gorącego następuje podczas procesu gotowania brzeczki piwnej. Do jego usuwania wykorzystuje się separator z zawirowaniem zwanym whirlpoolem. Znajomość rozkładu wielkości cząstek osadu gorącego pozwala na wprowadzenie wybranych danych morfometrycznych do opracowywanego modelu CFD (Computational Fluid Dynamics) przepływu w kadzi wirowej. Materiał do badań stanowiła brzeczka produkowana na warzelni browaru przemysłowego średniej wielkości. Pomiary prowadzono na próbkach brzeczki z osadem gorącym pobranych po klarowaniu w whirlpoolu. Analizę Shadow Sizing wykonano na stanowisku badawczym zbudowanym w Katedrze Procesów i Urządzeń Przemysłu Spożywczego Politechniki Koszalińskiej. Stanowisko składało się z kamery FlowSence 2M wyposażonej w obiektyw z zestawem pierścieni pośrednich, stolika z uchwytem z kuwetą pomiarową o grubości 2,5 mm i źródła światła oświetlającego próbkę z kuwetą umiejscowioną naprzeciw obiektywu kamery. Do obróbki obrazów wykorzystano oprogramowanie Dantec DynamicStudio w wersji v3.41. Przedstawiono przykładową obróbkę wstępną obrazu, konieczną do przeprowadzenia analizy obrazu osadu o wysokim stopniu koncentracji cząstek. Zaprezentowano również przykładowe wyniki pomiaru rozmiarów i przemieszczenia zidentyfikowanych cząstek oraz przygotowanie materiału do tego typu analiz.

Słowa kluczowe: Shadow Sizing, kadź wirowa, osad gorący.

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1. Introduction

The advancements in the food industry's processing technology have necessitated the identification and research of its component processes. The currently applied standards of processing techniques and technologies are constantly a subject to modifications due to keen market competition.

Non-contact, optical methods find increasingly more applications in identification of morphometric parameters of solid phase's particles dispersed in a continuous phase. It is true both in the case of suspended particles, and the ones carried by the flow. The identification of the dispersed phase parameters allows to learn more about the changes taking place during processing. This is applicable to atomization of liquids and solid bodies, their sedimentation, floatation, and also to saturation of gases in liquids. All of those phenomena occur as a part of the technological operations and processes in the food industry. The benefit of using imaging methods, i. e. Shadow Sizing, is the ability of simultaneous analysis of granulometric composition, and the velocity and morphologic characteristics of the particles within the analyzed working area. It is a non-contact measurement method, based on the analysis of the particles' shadows image, which allows to determine all characteristics without the necessity of preliminary homogenization. The obtained data may serve as a basis for optimization of processing and operations involving precipitation of a solid phase in a mixture. An example of identification of such an operation is the separation of hot trub particles from beer wort while it is being clarified in the whirlpool cycling vat. The topic of this processing operation and its phenomena was presented in more detail in [4]. The formation process, the shape and size of the particles depends primarily on the composition of raw materials, and the correct manner of precipitation of those particles is an indication that the previous brewing operations (e. g. mashing and boiling) were performed properly.

The aim of this paper is to determine the possible range of applications of the Shadow Sizing method for hot trub particles analysis. The subject of this study is the ability to identify a suspension using a sample characterized by high particle concentration.

2. Performing the measurement using the Shadow Sizing method

Throughout the years, measurement techniques based on image analysis have been advancing. There are new object-detection algorithms constantly under way, which allow to perform non-invasive measurements in almost every domain of scientific research and processing operations. Lack of intrusion into the process enables examination without any disruptions, which could be caused by e. g. introduction of a measuring sensor. Image analysis applied in industrial environments allows to make realtime decisions regarding e.g. rejection of defective pieces of raw materials without the necessity to segregate the whole consignment. The non-contact methods of flow measurement and particles imaging have found their application as a scientific aid in many disciplines related to fluid mechanics, e.g. hydro- and aerodynamics, mixing, combustion and biomedical processes.

Velocity values and their distribution is one of the crucial of the measured parameters, critical to better understanding flows in heterogeneous mixtures. One of the many available on the market ready-made solutions for imaging and analysis of particles is the Shadow Sizing module implemented in the DynamicStudio platform. At its core lays capturing images - with a camera - of objects within a certain exposure area (open or closed). Because the light source (used for illuminating the researched area) is situated opposite the camera lens, the sensor (e.g. CCD) captures merely the light traveling through the particle-free, clear regions. The areas occupied by particles, on the other hand, correspond to dark - shadow - parts of the image, hence the name Shadow Sizing. Figure 1 presents Shadow Sizer in a simplified diagram.

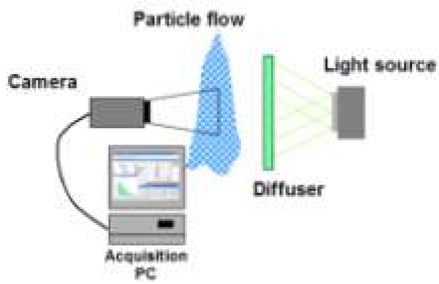

Fig. 1. Shadow Sizer System [3]
Rys. 1. Schemat pomiaru Shadow Sizer [3]

A quick impulse of light synchronized with the camera's time of exposition freezes the particles' motion in a single image frame. For instance, for a laser impulse of 10 ns it is possible to achieve a sharp image of flow at virtually any velocity value. Obviously, too short exposition time may result in an underexposed image. This can be compensated for by adjusting the aperture.

The analysis of the output image is based on using an advanced edge-detection algorithm, which detects closed (or not) particles' contours and performs gradience comparison with an 8-bit, grayscale, user-defined sample. This algorithm is not limited to recognition of particles of regular shapes, which is crucial for the analysis of organic materials, the shapes of which are often characterized by dissimilarity, and also, they are able to form conglomerates.

The Shadow Sizer's processor enables the analysis of particles in terms of their:
- position;
- orientation;
- equivalent diameter;
- velocity vectors;
- eccentricity;
- shape factor;
- perimeter;
- spatial moments;
- central moments.

Image analysis using the Shadow Sizing method is carried out in accordance with the common procedure: image registration, identification and differentiation of single particles, their segregation, and the final data collection. Arcichowski [2006] describes this topic in more detail.

Measurement range is strictly constrained by hardware limitations in terms of the camera's sensor's resolution. Each particle being identified, for obvious reasons, shall not be smaller than the size of a single pixel. The maximal size is limited only by the exposed area. Before beginning the analysis, a calibration of the exposed area is required [2].

Originally, the Shadow Sizing method was devised for the analysis of atomized liquid droplets (sprays), and also, small particles of solid bodies and gas bubbles dispersed in a liquid. Later on it turned out, this detection algorithm can be successfully applied onto particles of irregular shapes. However, it is a requirement for the analyzed images to present particles with pronounced contours.

3. The research material and the test rig

In the research, samples of beer wort (Fig. 2a) were used, the extract content of which corresponded to the ones used in a mid-size brewery (12,5; 14,1; 16,1 i 18,1% vol.). The samples were taken before the whirlpool clarification. Additionally, samples of hot trub (Fig. 2c) filtrate (Fig. 2b) were analyzed. The hot trub was taken from the cone formed in the separator's tank directly after spinning. The measurement was performed within an hour after taking the samples.

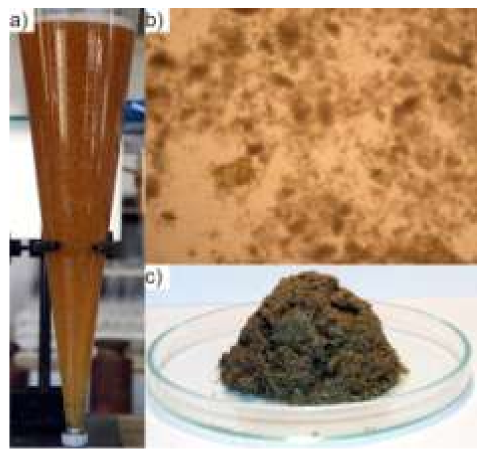

Fig. 2. The hot trub: a) sedimentation in the Imhoff cone, b) under the microscope (magnified 60x), c) the sample taken from an industrial tank
Rys. 2. Osad gorący: a) sedymentracja w leju Imhoffa, b) pod mikroskopem (powiększenie 60×), c) próbka pobrana ze zbiornika przemysłowego

Measurements were performed using a test rig assembled by the Chair of Food Industry Processes and Device at Koszalin University of Technology. It incorporated a FlowSense 2M PIV camera, equipped with a 1600 x 1200 resolution sensor. The camera had a Nikkor 50 mm f/1.8 macro lens attached, along with a set of three adapter rings. They allowed to achieve a considerable image magnification. The lens were placed in front the cuvette (Fig. 3), made of optical glass. Its gap was 2 mm wide. The setup was synchronized with a timerbox.

Behind the cuvette there was a low-power laser light source, the wavelength of which was 532 nm, equipped with beam-scattering optics. As a result, the light was uniformly distributed throughout the whole working area. An alternative for this type of lighting solution can be an optical system equipped with a high-power LED. This type of system is currently under development with the use of the described rig.

The measurement of particles was performed in a sample the total volume of which was 1,5 ml. The area of exposure was 0,1875 cm^2. The volume of measurement was 0,05 ml. In a single measurement 30 images were captured for each of the wort samples, and the measurements were repeated 10 to 30 times, depending on the expected level of particle concentration.

The image of the analyzed area was captured in the camera's full resolution and saved as a 8-bit, grayscale map. Next, the initial post-processing was performed, in order to achieve an image possibly most suitable for the Shadow-processor analysis.

4. The initial post-processing and sample results

The obtained images present particles' shadows of different intensity of grey. With relatively high level of particle concentration, it is necessary to perform the initial image post-processing. In such a case, various IPL (Image Processing Library) filters can be applied - they are available in the image post-processor's library. They process the image, so that it becomes suitable for the target numerical methods. Currently, the initial image post-processing library is very diverse, however, before the Shadow Sizing analysis, it makes sense to apply only selected filters.

Fig. 3. The Shadow Sizing rig - the measurement stage, where: 1 - camera's lens' ring, 2 - the cuvette on the table, 3 - diffusion filter with the laser's optical system

Rys. 3. Stanowisko pomiarowe do Shadow Sizer - widok części pomiarowej, gdzie: 1 - pierścień obiektywu kamery, 2 - kuweta pomiarowa na stoliku, 3 - pierścień dyfuzyjny z układem optycznym lasera

In the case of images the analysis is of which is more difficult - the image is not clear (underexposed, or the focus plane is not 'on the spot'), the particles have formed considerable agglomerates, or their contours are poorly-defined (e. g. as shown in the Figure 4), one of those filters can be applied:

- *High-pass* in edge detection (Fig. 4a);
- *Low-pass* combined with *Morphology* in order to increase the image's contrast (Fig. 4b);
- *Utilities*, to alter the shape, dimension, orientation or to invert the colors (Fig. 4c);
- *Threshold*, to initially block the background levels (Fig. 4d).

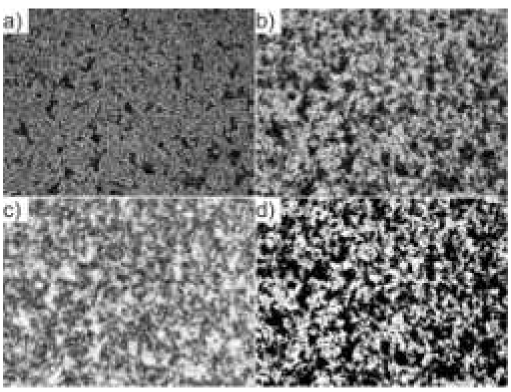

Fig. 4. An image of hot trub particles in a sample filtered with: a) High-pass, b) Low-pass with Morphology, c) Utilities, d) Threshold

Rys. 4. Obraz cząstek osadu gorącego w próbce po zastosowaniu filtru: a) high-pass, b) low-pass wraz z morphology, c) utilities, d) threshold

Correctly combined filters will allow to achieve an image, which, in certain aspects, will correspond to the original and at the same time will be more suitable for the shadow-processor analysis (Fig. 5a). However, it ought to be borne in mind to - when using the filters - avoid image distortion (as presented in the Figure 5b), which would render the output results misleading.

The actual analysis is the phase, when the data is processed using the tool called the Shadow Sizing method „processor". It allows to map sediment particles by manually selecting an average-size particle in the image. It amplifies the algorithm's exposure area scouring, (Fig. 6) making the analysis carried out more thoughtfully by the software operator. This tool also provides additional features, allowing to incorporate more advanced settings.

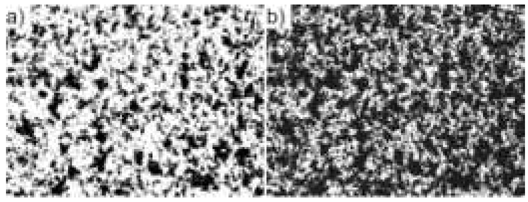

Fig. 5. An image of hot trub particles in a sample after using filters: a) proper for particles mapping, b) causing image distortion

Rys. 5. Obraz cząstek osadu gorącego w próbce po filtrach: a) właściwych do mapowania cząstek, b) zniekształcony obraz

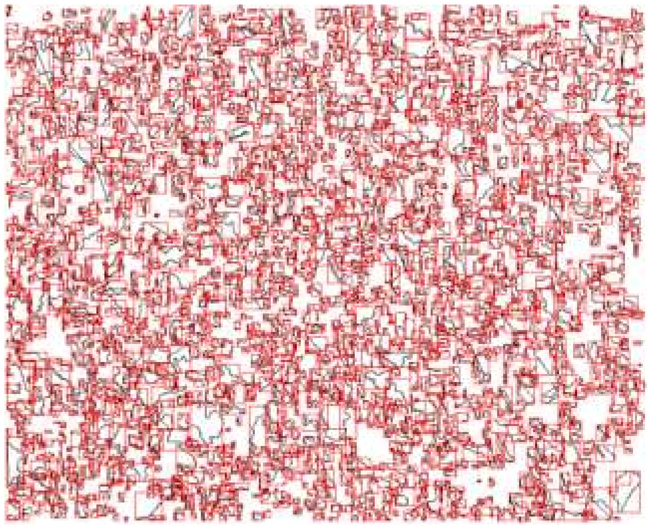

Fig. 6. Shadow Sizing analysis of the image presented in Fig. 5a - the particles and their contours have been identified in the analyzed image

Rys. 6. Analiza Shadow Sizer obrazu przedstawionego na rys. 5a - zidentyfikowane cząstki i ich krawędzie na analizowanym obrazie

After inputting the search criteria the algorithm analyzes the whole area, and highlights the identified sediment particles. The exposure area is defined using calibration cells and images of shadows. The calibration can be performed on the input image and then assigned to each of the future measurements. Grey saturation is the key to the beginning of the analysis.

Depending on how well-defined the shadows' contours are it is possible to adapt the particles' identification and manually input the settings. The software program's module offers the ability to export the obtained data in a numeric form, which can be implemented in the flow's CFD model, such as the one presented in [5]. Threshold algorithms allow to distinguish the particles pixels from the ones representing the background. It is done by comparing the selected pixels to the grayscale level, and their correlation to the surrounding pixels. Another algorithm contributes to the processing of the obtained images and also qualifies them in terms of presence of separate particles (as in a spray) or combined in to structures, e.g. hot trub agglomerates [1].

The output results can be reported back as a statistical distribution. Figure 7 presents (in the form of histograms) examples of hot trub particles size distribution for worts of 12,5 and 18,1 extract content.

The obtained distributions are depict the particles' equivalent diameters divided by theirs size into 30 groups. Just by a rough analysis one may conclude that hot trub comprises of particles of different diameters (between 34 and 400 µm) the quantity of which is variable. This state is in conflict with the literature statement, that the hot trub particles' size falls between 30 and 80 µm [6]. However, it is difficult to argue about this fact in the context of the obtained data, as the literature doesn't provided any reference to the presented data. It is generally true for all publications replicating the aforementioned data regarding the particles' range of size. In favor of the presented Shadow Sizing analysis results is the fact, that hot trub particles are visible to the naked eye, which proves the falseness of at least the particles' maximal size value suggested by the literature.

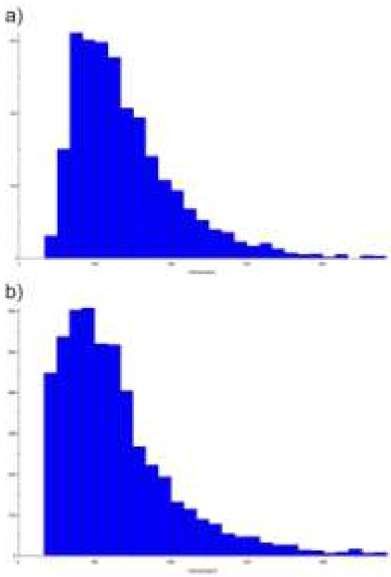

Fig. 7. Examples of equivalent diameters distribution of hot trub particles in malted worts: a) 12,5%, b) 18,1% (average results of 12 measurements from the measurement volume)

Rys. 7. Przykładowe rozkłady średnic ekwiwalentnych cząstek osadu gorącego w brzeczkach słodowych: a) 12,5%, b) 18,1% (wyniki średnie z 12 pomiarów dla objętości kontrolnej próbki)

5. Hot trub particle motion

The Shadow processor facilitates the ability to analyze the particles' vector velocity, regardless of the direction of their motion. It is a very useful feature of the module, and it is based on PTV (Particle Tracking Velocity), which seems worth of further discussion.

When it comes to preparing for this type of analysis, it is necessary to perform initial post-processing in order to obtain dual-frame images. It is an analogous form of data to the one required by the PIV (Particle Image Velocimetry). DynamicStudio's Image Processing library offers a tool for converting single images into double frames. There is a certain number of images required in order to perform the analysis. The minimum is 20 consecutive images registered with a frequency matching the particles' velocity. After the conversion, the rest of the processing is performed (depending on the needs) the same way it is done when determining the size distribution of the hot trub particles.

Figure 8 is an example of a contour map with marked velocity vectors of hot trub particles. It was the analysis of the image presented earlier in Fig. 6 and the image following after, which it was paired with in that particular run. In order to improve the comprehensibility of the map, the particles are presented only as contour shapes.

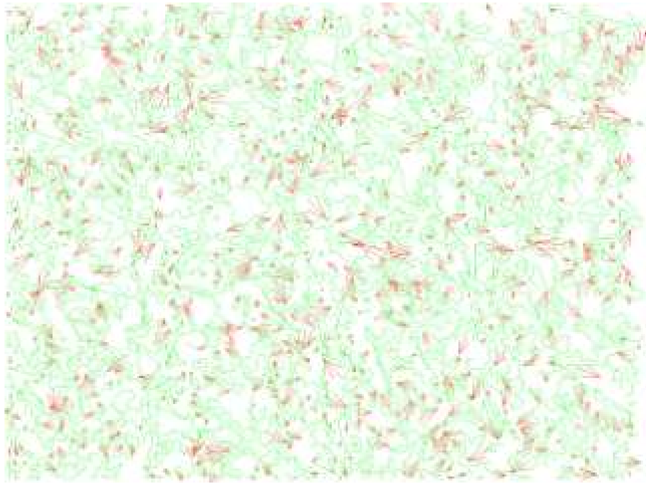

Fig. 8. An example of a map of hot trub particles' velocity (marked in green are the particles' contour shapes, and in red - their velocity vectors)

Rys. 8 Przykładowa mapa prędkości cząstek osadu gorącego (na zielono kontury cząstek, na czerwono wektor prędkości cząstek)

In the analyzed case the multidirectional motion of the hot trub particles is - inter alia - a result of the thickness of the analyzed mixture layer (2 mm) and the hot trub particles' considerable presence. However, the opportunity to perform a Shadow Sizing analysis of moving particles' velocity presents a compelling alternative to the PIV measurement method, particularly in the case of considerable magnifications and without the requirement of introducing seeding particles.

6. Conclusions

This article presents a possible application of the Shadow Sizing processor for the analysis of hot trub particles' selected morphometric parameters. Regardless of the considerable presence of the dispersed phase in the sample it is possible to correctly discern particles in an image. This allows to obtain numerical data, which can be then successfully applied as an initial condition for filling the whirlpool CFD model.

The adaptation possibilities for the presented tool in the scope of image processing combined with a highly-effective edge detection processor would allow to analyze other mixtures with high concentration level of dispersed phase.

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