Reproducibility of radiant energy measurements inside light scattering liquids

Reprodutibilidade de medidas de energia radiante dentro de líquidos espalhadores de luz

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Abstract

The aim of this project is to evaluate the uncertainty associated with measurements performed with laser beams in scattering liquids with optical fibers. Two lasers with different wavelengths were used, 632.8 nm and 820 nm, to illuminate a cuvette with Lipovenos PLR, the scattering liquid. A mask at the top of the cuvette was used to control the positioning of 250 µm optical fiber and the laser entrance point. The light energy was measured with an optical power meter, and the integration time was 60 s, measured with a chronometer. There were no systematic errors associated with the integration time. Two tests were done to evaluate the uncertainty associated with the positioning of the components of the experimental arrangement. To evaluate the uncertainty of the positioning of the cuvette, seven series of measurements with the optical fiber 5 mm far from the beam were performed. Between two series, the cuvette was removed from the holder, the liquid was mixed and the cuvette was put back in the same position. A second test was done to evaluate the reproducibility of fiber positioning and the relative positioning of mask and cuvette. Three distances between the beam and the fiber were used: 4 mm, 5 mm and 6 mm, through the positioning of the fiber at three different holes in the mask. Six series of measurements were performed. Between two series, the cuvette was removed from the holder, the liquid was mixed and the cuvette was put back in the same position. Each series was done in a different order, permuting the three positions. The uncertainty associated with the positioning of the experimental elements was of the order of 7%. The variation of incident laser energy was also evaluated, resulting in 6.5% and 4.0% for the red and infrared lasers respectively.

Keywords: laser, scattering liquids, light energy.

Resumo

O objetivo deste projeto é avaliar a incerteza associada às medidas realizadas com feixes de *laser* em líquidos espalhadores com fibras ópticas. Dois *lasers* com diferentes comprimentos de onda foram utilizados, 632,8 e 820 nm, para iluminar uma cubeta com Lipovenos PLR, o líquido espalhador. Uma máscara no topo da cubeta foi utilizada para controlar o posicionamento da fibra óptica de 250 µm e o ponto de entrada do *laser*. A energia da luz foi medida com um medidor de potência óptica (Optical Meter), o tempo de integração foi de 60 segundos, medido com um cronômetro. Não houve erros sistemáticos associados com o tempo de integração. Dois testes foram realizados para avaliar a incerteza associada com o posicionamento dos componentes do arranjo experimental. Para avaliar a incerteza do posicionamento da cubeta, foram realizadas sete séries de medidas com fibra óptica a 5 mm de distância do feixe. Entre duas séries, a cubeta foi removida do recipiente, o líquido foi misturado e a cubeta foi colocada na mesma posição novamente. Um segundo teste foi realizado para avaliar a reprodutibilidade do posicionamento da fibra e o relativo posicionamento da máscara e da cubeta. Três distâncias entre o feixe e a fibra foram utilizadas: 4, 5 e 6 mm, por meio do posicionamento da fibra em três diferentes orifícios na máscara. Seis séries de medidas foram realizadas. Entre duas séries, a cubeta foi removida do recipiente, o líquido foi misturado e a cubeta foi posta novamente na mesma posição. Cada série foi realizada em uma ordem diferente, mudando as três posições. A incerteza associada com o posicionamento dos elementos experimentais foi da ordem de 7%. A variação da energia de *laser* incidente também foi avaliada, resultando em 6,5 e 4,0% para os *lasers* vermelho e infravermelho, respectivamente.

Palavras-chave: *laser*, líquidos espalhadores, energia da luz.

Introduction

The determination of the uncertainty associated with an experimental arrangement is very important. It determines the reliability of the experiment. In our experiment, with the uncertainty, is possible to distinguish measurements and to investigate variations of light energy inside an illuminated volume.

The aim of this project was to evaluate the reproducibility of light energy measurements on scattering liquids with the use of an optical fiber coupled in an optical meter, in order to determine the uncertainty associated to the positioning of the experimental components and analyze the main uncertainty components.

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Materials and methods

A cylindrical cuvette was used, with 25 mm diameter, with a plane window with 10 mm of width, parallel to the cylinder axis, as it is possible to see at Figure 1-A and 1-B.

Lipovenos PLR, which is a lipid emulsion for intravenous use and has scattering behavior[1], was used as scattering liquid.

An optical fiber with a diameter of 250 μm was used to collect the scattered light. The fiber was guided by a metallic tube (internal diameter of 0.85 mm, external diameter of 1.5 mm and 47.65 mm length) in order to make sure that the fiber was vertical and that its entering position in the liquid could be measured. The fiber depth in the liquid was 5 mm and this portion of fiber was without protective cover.

A mask, detailed in Figure 1-C, was used in order to allow the controlled positioning of the optical fiber in relation to the laser beam. The central hole, for the laser beam, has a diameter of 3 mm, and each one of the other holes, for the optical fiber, has a diameter of 1.5 mm. The first hole is at a distance of 4 mm of the center, the second is at 5 mm and so on, until the last one that is at 11 mm of the center.

The final experimental arrangement is represented at Figure 2.

Lasers with two different wavelengths were used, one in red range (He-Ne, 632.8 nm) and the other in infrared range, 820 nm. The circular beams reached the center of the cuvette, passing through the mask central hole. In the case of infrared laser, an aperture was used to ensure that the laser beam reaching the liquid was circular.

An optical meter (Newport Hand-Held Optical meter, model 1918-C) with a connector to optical fibers was used in integration mode, and the signal was integrated in 60 s. This measurement was taken with a chronometer, as the optical meter doesn't have this function.

In order to determine the uncertainty associated with the positioning of the cuvette and the optical fiber, two reproducibility tests were carried out. The objective of the first one (R1) was to evaluate the reproducibility of the positioning of the cuvette in the holder for illumination. Seven series of seven measurements with the optical fiber 5 mm far from the beam were performed. Between two series, the cuvette was removed from the holder, the liquid was mixed and the cuvette was put back in the same position.

The objective of the second test (R2) was to evaluate the reproducibility of the optical fiber positioning and the relative positioning of mask and cuvette. Three distances between the beam and the fiber were used: 4 mm, 5 mm and 6 mm, through the positioning of the fiber at three different holes in the mask. Six series of seven measurements with the fiber at each of the three positions were performed. Between two series, the cuvette was removed from the holder, the liquid was mixed and the cuvette was put back in the same position. Each series was composed by a different permutation of the three positions.

Data of the incident energy from the lasers were collected in order to determine the stability of this value. These measurements were done with the same optical meter, but without the optical fiber attachment, in order to determine how the lasers, the mask and the aperture affect the results obtained. For red laser, measurements were taken at two different positions: position 1 - before the mask; and position 2 - behind the mask. For infrared laser, measurements at three different positions were taken: position 0 - before the aperture; position 1 - between the aperture and the mask; and position 2 - behind the mask. The positions 1 and 2 are the same for both lasers.

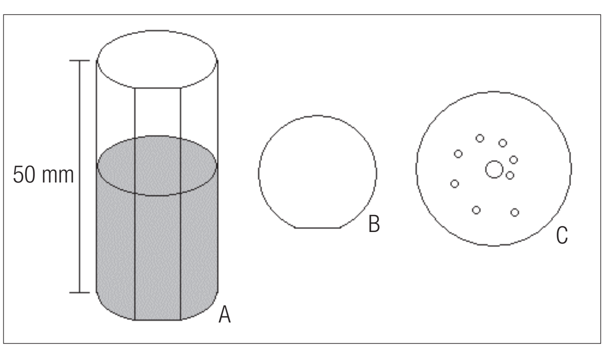

Figure 1. Figure of the cuvette used at the experiment. A) Three-dimensional view; and B) cross-section view. At C, is shown the mask used at the experiment to position the optical fiber and the laser beam.

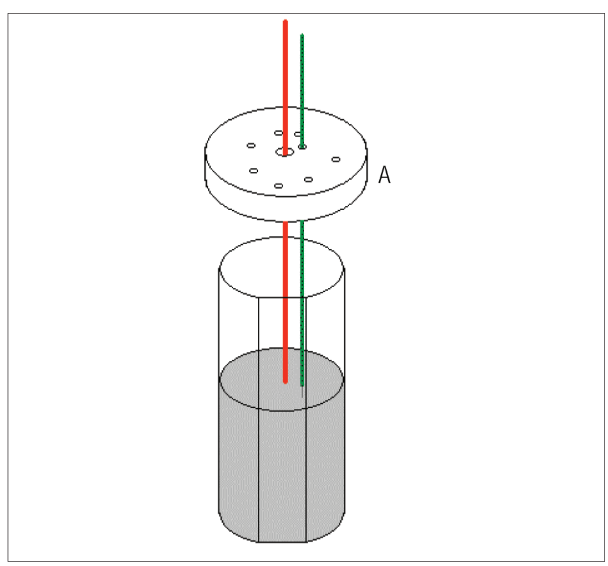

Figure 2. Figure of the experimental arrangement used. The laser is represented by the red line. The optical fiber is represented by the green line, the fiber depth in the liquid is 5 mm. The mask used is represented in A, it has a central hole for the laser beam and eight radial holes for the fiber.

Results

He-Ne laser

The results obtained for the wavelength 632.8 nm for the test R1 are represented at the graphs of Figures 3 and 4.

The data sequence for test R2 is shown at the graph of Figure 5, in which it is possible to see a change at the data for all distances, because of the same reasons of test R1.

At Table 1 are the values for average, standard deviation and coefficient of variation for each test.

The results for the measurements of laser incident energy are shown at Figure 6. The energy is relative to the average of the measurements of each position (position 1 and 2). There are no irregularities at the data, showing that the laser output is stable. Results for average, standard deviation, coefficient of variation and sample size are shown at Table 1.

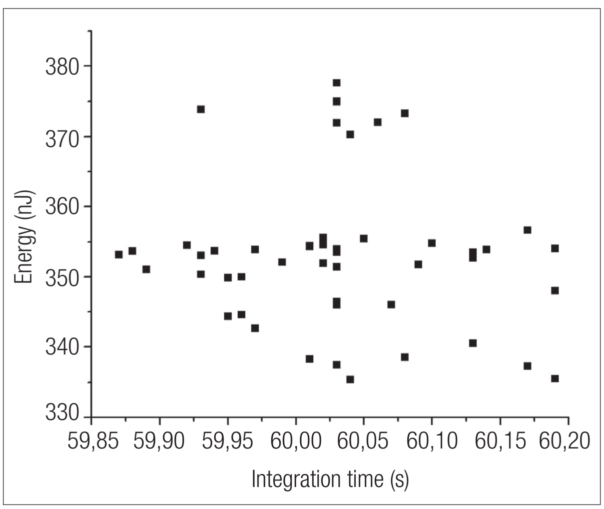

Figure 3. Graph with data for test R1, red laser. The graph shows integration time dispersion data, measured with manual chronometer.

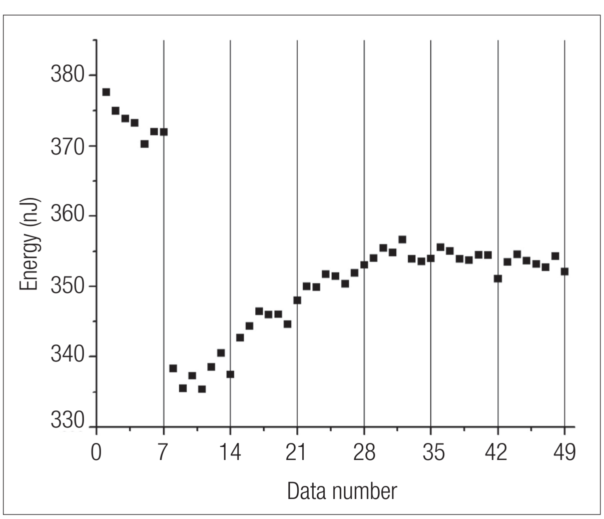

Figure 4. Graph with data for test R1, red laser. The graph shows data in chronological order. The arrows correspond to the change of measure series.

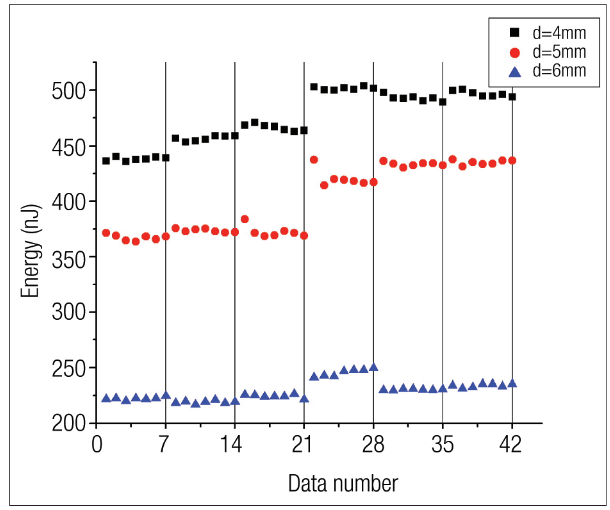

Figure 5. Graph with data for test R2, red laser. The graph shows data in chronological order for each distance from the fiber to the center of the cuvette.

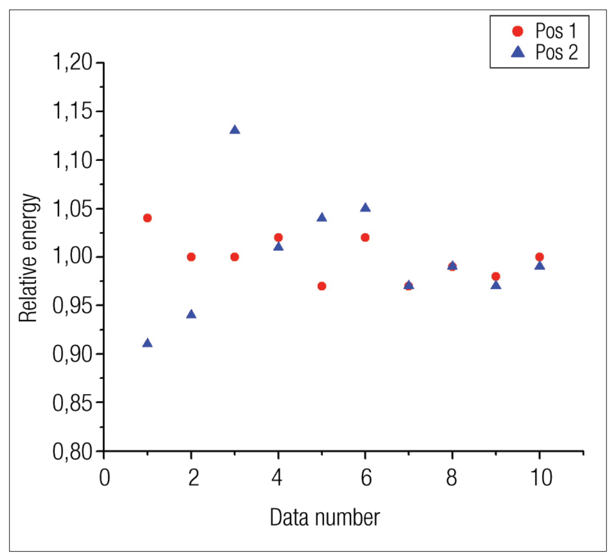

Figure 6. Graph with data for laser incident energy, red laser. The energy is relative to the average of the measurements of each position.

Table 1. Average, standard deviation and coefficient of variation of the radiant energy for each test (R1 and R2) realized with red laser and data for laser incident energy at positions 1 and 2 (lines Pos 1 and Pos 2, respectively).

Test/ distance	Average (nJ)	Standard deviation (nJ)	Coefficient of variation (%)	Sample size
R1	353	10	2.9	49
R2/4 mm	475	24	5.0	42
R2/5 mm	400	30	7.6	42
R2/6 mm	229	9	3.9	42
Pos 1	333×10^{6}	7×10^{6}	2.2	11
Pos 2	362×10^{6}	23×10^{6}	6.5	10

Infrared laser

The data obtained for test R1, in chronological order, are shown at the graph of Figure 7.

It is possible to note, at graph of Figure 7, that data oscillate a lot, without any clear change, neither tendencies.

For test R2, the results are shown at the graph of Figure 8, in which is possible to note that there is a big change at energy for all distances after the seventh measurement. The reason for this alteration is a variation of the incident laser energy, which is changed by a factor of 2.6. After this big change, other variations with this magnitude did not occur.

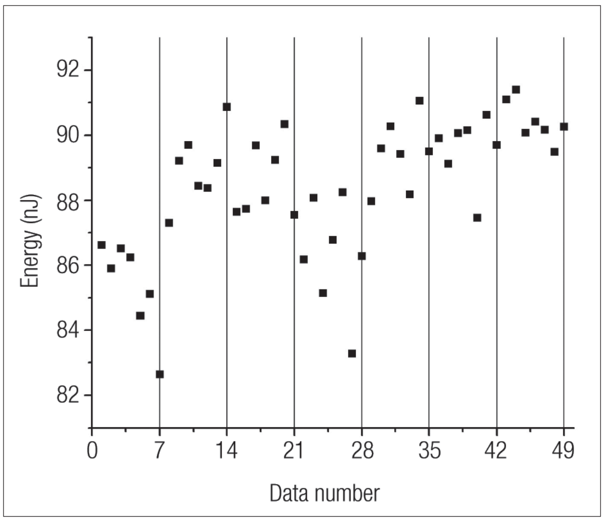

Figure 7. Graph with data for test R1, infrared laser. The graph shows data in chronological order.

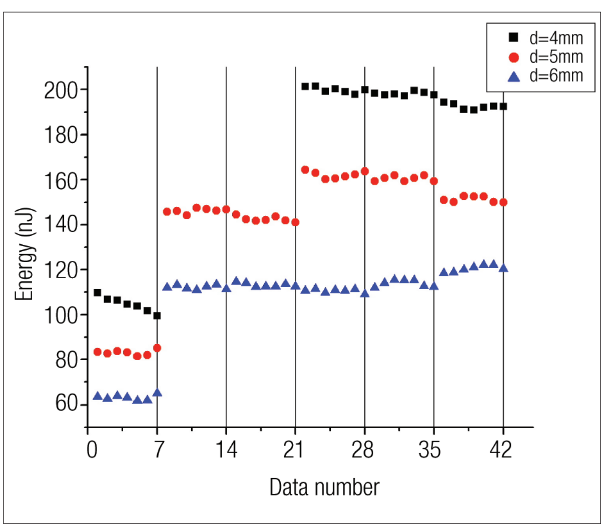

Figure 8. Graph with data for test R2, infrared laser. The graph shows data in chronological order for each distance measured.

At Table 2 are the values for average, standard deviation and coefficient of variation for each test. Probably, the low standard deviation obtained for test R2, at distance of 4 mm, occurred because three series of measurements at this position were lost.

Table 2. Average, standard deviation and coefficient of variation of the radiant energy for each test (R1 and R2) realized with infrared laser and data for laser incident energy at positions 0, 1 and 2 (lines Pos 0, Pos 1 and Pos 2, respectively).

Test/ distance	Average (nJ)	Standard deviation (nJ)	Coefficient of variation (%)	Sample Size
R1	88.4	2.1	2.3	49
R2/4 mm	196.8	3.4	1.8	21
R2/5 mm	152.5	8.0	5.2	35
R2/6 mm	113.9	3.6	3.2	35
Pos 0	262.2×10^6	6.1×10^6	2.3	11
Pos 1	89.3×10^6	3.4×10^6	4.0	11
Pos 2	81.3×10^6	0.61×10^6	0.75	11

The results for the measurements of laser incident energy are shown at Figure 9. The energy is relative to the average of the measurements of each position (position 0, 1 and 2). There are no irregularities at the data, what means that there are not big variations of incident energy and there is not any important effect of the aperture and the mask. Results for average, standard deviation, coefficient of variation and sample size are shown at Table 2.

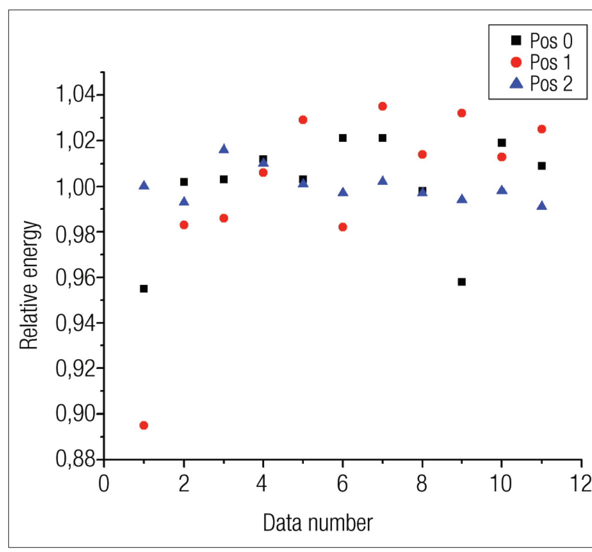

Figure 9. Graph with data for laser incident energy, infrared laser. The energy is relative to the average of the measurements of each position.

Conclusions

Through the analysis of the data, it was concluded that there are no tendencies related to the integration time, what is seen at integration time dispersion graphs. Therefore, it is possible to say that this source of error is considered when the energy analysis is done.

There is an uncertainty associated to the optical fiber and cuvette positioning, shown by the standard deviation obtained for each group. As they have similar magnitudes, varying roughly between 2 and 8%, we will adopt 7% as a value of the uncertainty associated with the data collection. It is equivalent to the largest standard deviation found for the series data. A large portion of the radiant energy data variation is due to the laser stability, as the coefficients of variation of the incident energy are similar to the standard deviation of the reproducibility experiments.

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References

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