Far Eastern Mathematical Journal. 2022. V. 22. No 2. P. 164–166

UDC 532.5
MSC2020 35Q79 + 76D07

© V. M. Chudnovskiy[1], M. A. Guzev[2]

Evaluation of the boiled water mass fraction during its heating by a laser heating element

In the paper the mass fraction of water boiled during its laser heating near the working tip of an optical fiber coated with a thin layer of iron oxide that absorbs radiation is estimated. This information is necessary for calculations of the dynamic and thermal effects of laser cavitation, which are of great practical importance.

Key words: *lasers, cavitation, boiling.*

DOI: https://doi.org/10.47910/FEMJ202218

Laser heating is widely used in technical applications and medicine, especially when laser radiation can propagate through an optical fiber. In this case, the conversion of laser radiation into heat occurs in the vicinity or at the end of the quartz distal tip of the optical fiber. Due to the small diameters of the fibers (tenths of a millimeter), even at low radiation powers the heat sources of record heat flux values (of the order of 1–10 MW/m^2) can be created [1]. When optical fiber is used to heat liquids, in particular water, which is the basis of any biological fluid, the fiber end face becomes a concentrated laser heating element. This heat source being placed into water, can quickly locally heat it to a saturation temperature ($100°C$). When the saturation temperature is reached, the water in the vicinity of the end face of the fiber locally boils. However, not all of the heated liquid boils, but only some of it. The estimate the mass fraction of boiled water is the aim of this paper. Fig. 1 shows an elementary act of water boiling up at the end face of a cylindrical optical fiber with a diameter of $d = 600$ μm, coated with a thin layer of iron oxide, which completely absorbs laser radiation with a wavelength of $\lambda = 0.97$ μm. As follows from frame 1 of Fig. 1, a cylindrical layer of heated liquid with a thickness of $H = 170$ μm and a diameter of 600 μm was formed at the end face of the optical

[1] V. I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences, Russia, 690041, Vladivostok, Baltiyskaya st., 43.
[2] Institute for Applied Mathematics, Far Eastern Branch, Russian Academy of Sciences, Russia, 690041, Vladivostok, Radio st., 7.
E-mail: vm53@mail.ru (V. M. Chudnovskiy), guzev@iam.dvo.ru (M. A. Guzev).

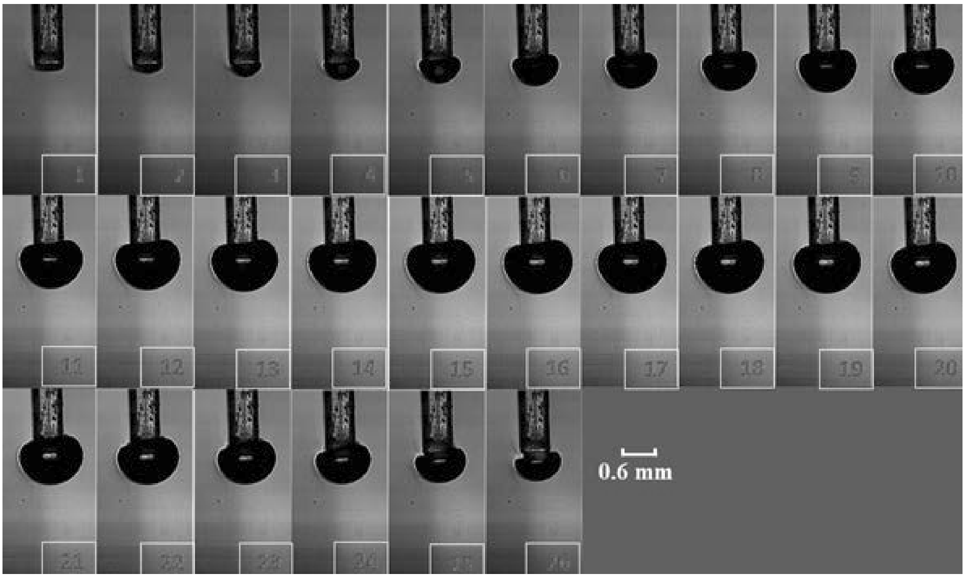

Fig. 1: An elementary act of water boiling at the tip end face of an optical fiber coated with a layer of iron oxide that absorbs laser radiation with a wavelength of $\lambda = 0.97\mu m$. Radiation power $7W$. The time between frames is $4.2\mu s$. Fiber diameter $600\mu m$.

fiber. Further, the liquid boils with the formation of a vapor bubble, which grows to the maximum size and then collapses, since it meets the surrounding liquid subcooled to the saturation temperature (Fig. 1, frames 2 - 26). Only a part of the heated liquid boils, and completely turns into steam (frame 16 of Fig. 1, where the vapor bubble reaches the maximum size$R_1 = 686\ \mu m$). The rest of the heated liquid is located in a layer of thickness $h = R_2 – R_1$ around the bubble, where R_2 is the radius of the sphere that bounds the entire heated and evaporated liquid.

The condition of equality of the masses of water heated at the end face of the optical fiber and the mass of water concentrated in a sphere bounded by a radius R_2 gives: $M_1 = M_2$, where $M_1 = \rho_1 H d^2 \pi/4$ and $M_2 = \frac{4}{3}\pi\left[R_2^3\rho_1 + R_1^3(\rho_2 - \rho_1)\right]$. From this condition one can find $R_2 = \left[\frac{3}{16}d^2 H + R_1^3\left(1 - \frac{\rho_2}{\rho_1}\right)\right]^{1/3} = 694\ \mu m$, where ρ_1, ρ_2 are density of water and steam, respectively , $h = R_2 - R_1 = 8\ \mu m$, and the ratio of the masses of heated water to the mass of steam $\frac{M_1}{M_2} \approx 36$.

Conclusion

The experiment shows that only 36 % of the water heated by laser heating near the fiber tip boiled up and turned into steam.

References

[1] R. V. Fursenko, V. M. Chudnovskiy, S. S. Minaev, J. Okajima, "Mechanism of high velocity jet formation after a gas bubble collapse near the micro fiber immersed in a liquid", *International Journal of Heat and Mass Transfer*, 2020, 120420.

Received by the editors
June 24, 2022

The work was supported by the Ministry of Science and Higher Education of the Russian Federation as part of the work under the State order of the V. I. Il'ichev Pacific Oceanological Institute FEBRAS No. AAA-A20-120031890011-8.

Чудновский В. М., Гузев М.А. Оценка массовой доли вскипевшей воды при её нагреве на лазероном нагревательном элементе. *Дальневосточный математический журнал.* 2022. Т. 22. № 2. С. 164–166.

АННОТАЦИЯ

В работе приводится оценка массовой доли вскипевшей воды при её лазерном нагреве вблизи рабочего кончика оптоволокна, покрытого тонким слоем оксида железа, поглощающего излучение. Эти сведения необходимы для расчёта динамических и тепловых эффектов лазерной кавитации, имеющих большое практическое значение.

Ключевые слова: *лазеры, кавитация, кипение.*