Coffee-based colloids for direct solar absorption

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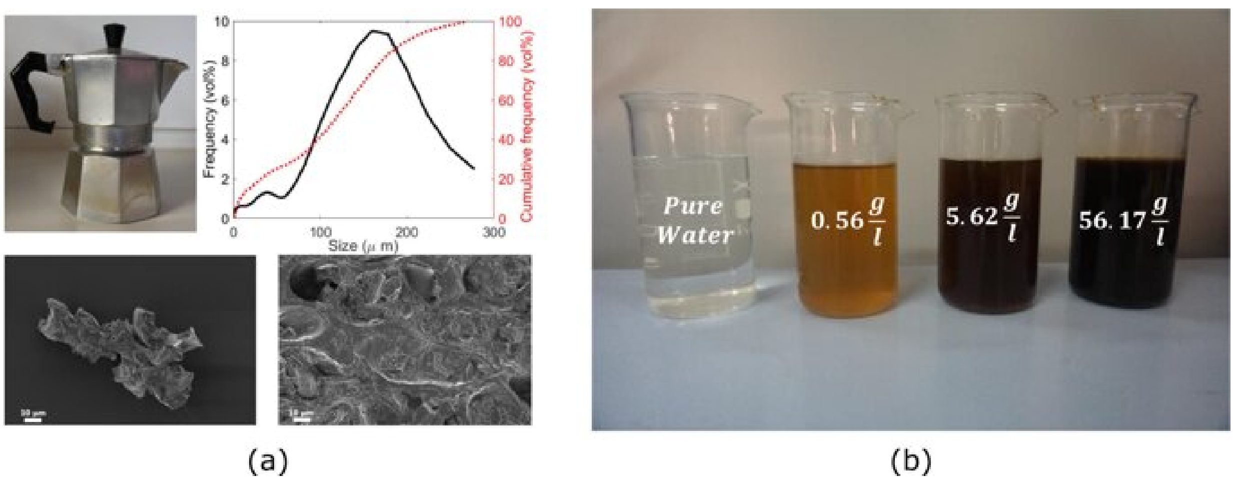
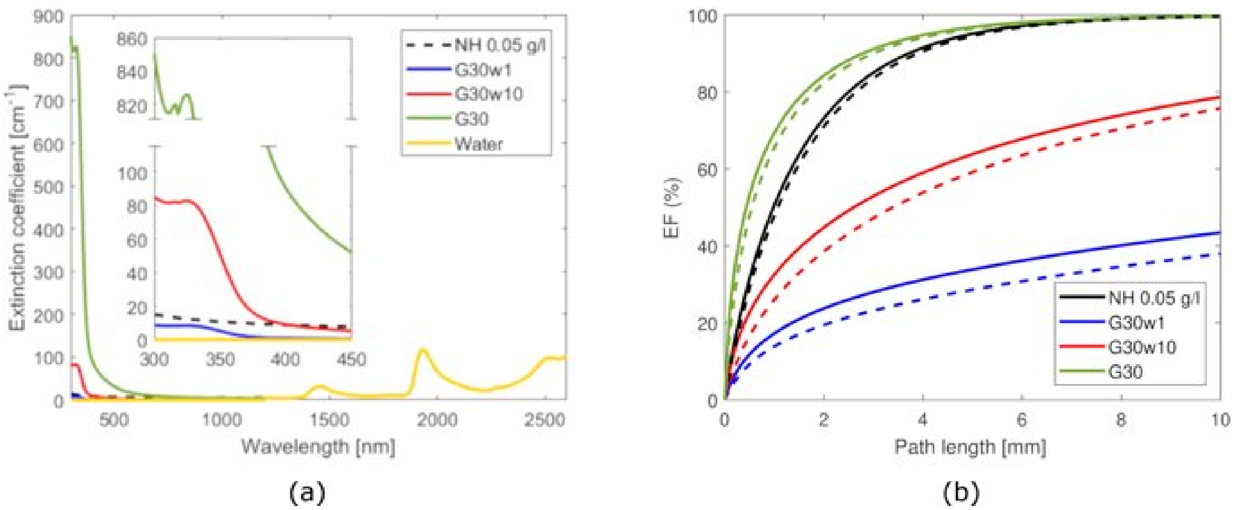


Synthesis of coffee-based colloids. (a) Coffee pot moka used for coffee preparation (top-left); size distributions of the suspended coffee particles (top-right); Scanning Electron Microscopy (SEM) images of the coffee particles (bottom). (b) Colloids with different G30 concentration (from right to left): pure G30 fluid (56.17 g/l of suspended particles); G30w10 fluid (10% dilution); G30w1 fluid (1% dilution in water); pure water. Credit: *Scientific Reports*, doi: 10.1038/s41598-019-39032-5

Solar energy is one of the most promising resources to help reduce fossil fuel consumption and mitigate greenhouse gas emissions to power a sustainable future. Devices presently in use to convert solar energy into thermal energy mostly rely on the indirect absorption of sunlight, where the efficiency is generally limited as a result of major convective heat losses into the surrounding environment. A promising alternative is the direct absorption of sunlight, where a fluid can serve as both solar energy absorber and heat carrier. The advantage of the technique is based on reduced convective and radiative heat losses, since temperature peak shifts from the absorbent surface (indirect absorption) to the bulk region of the carrier fluid (direct absorption). In a recent study, Matteo Alberghini and co-workers at the Departments of Energy, Applied Science and Technology, and the National Institute of Optics in Italy, investigated a sustainable, stable and inexpensive colloid based on coffee solutions to implement direct solar absorption. Results of their work are now published on *Scientific Reports*.

In the work proposed by Alberghini et al. the colloid consisted of distilled water, Arabica coffee, glycerol and copper sulphate to optimize the properties and biocompatibility of the fluid. The scientists analyzed the photothermal performance of the proposed fluid for direct solar absorption and compared its performance with traditional flat-plate collectors. They showed that the collectors could be precisely tailored and realized with 3-D printing for the experimental tests.

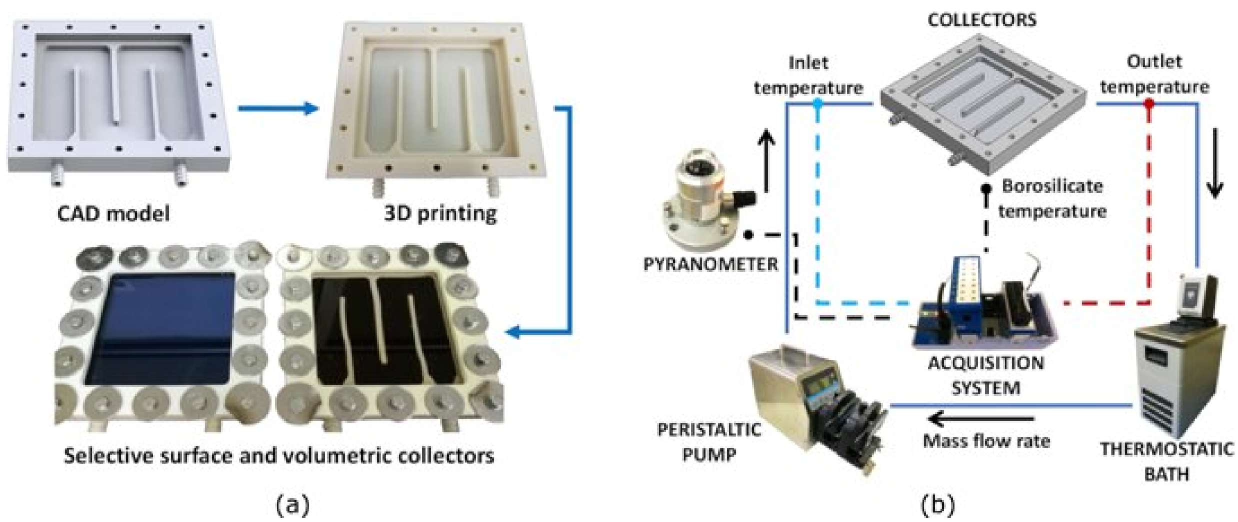
Existing carbon-based nanocolloids have presented drawbacks, despite promising thermo-physical properties suited for direct solar absorption, as a result of cytotoxicity and harmful impacts on the environment. In pioneering experimental work, researchers have therefore used a black fluid containing India ink in water (3.0 g/l) for direct solar thermal energy absorbance. They observed an encouraging performance, which lead to the use of nanocolloids also known as nanofluids to allow direct solar absorption. The fluids are typically characterized by a suspended phase that is able to confer enhanced photo-thermal properties to the base of the fluid. If opportunely designed, these nanocolloids will have promising potential for solar-to-thermal conversion.



Optical properties of the coffee-based colloids (1%, 10% and 100% dilutions in water). (a) Comparison of the spectral extinction coefficient of the coffee-based colloids at different dilutions and a 0.05 g/l suspension of carbon nanohorns in water27. The G30 preparation (100% dilution) is coffee with 2 ppm of copper sulphate and 30% wt. glycerol; G30w1, G30w10 are respectively 1% and 10% volume fractions of G30 in distilled water. (b) Stored energy fraction (EF) as a function of the path length for the three considered coffee-based colloids. Solid lines correspond to the energy fraction obtained with Planck's black body distribution, while dashed lines that obtained with the AM1.5 standard spectrum. For comparison, the curves for a 0.05 g/l suspension of carbon nanohorns in water are also reported. Credit: *Scientific Reports*, doi: 10.1038/s41598-019-39032-5

In the present work, Alberghini et al. first conducted optical characterization of the proposed coffee-based colloids. Since coffee is a complex substance, the scientists used Arabica coffee prepared in an aluminum coffee maker known as 'moka' for stovetops, for consistency. They followed a protocol to prepare 'student's coffee' allowing increased caffeine particle suspension in water and conducted scanning electron microscopy (SEM) to assess particle size distribution in the resulting solution. Then they introduced glycerol to the preparation to lower its freezing temperature for use outdoors in cold or freezing climates. Finally, the scientists added copper sulphate ($CuSO_4$) to reduce risks of alga or mold formation in the liquid. They considered five variants of the proposed colloid for the experiments that were stable during the entire time-frame spanning six months. The five variants were the primary colloid solution containing glycerol (30 % w/v) and $CuSO_4$ (2 ppm), which the scientists named as G30, followed by 1 percent, 10 percent, 20 percent and 50 percent volume fractions of G30 in distilled water named as; G30w1, G30w10, G30w20 and G30w50 in the study.

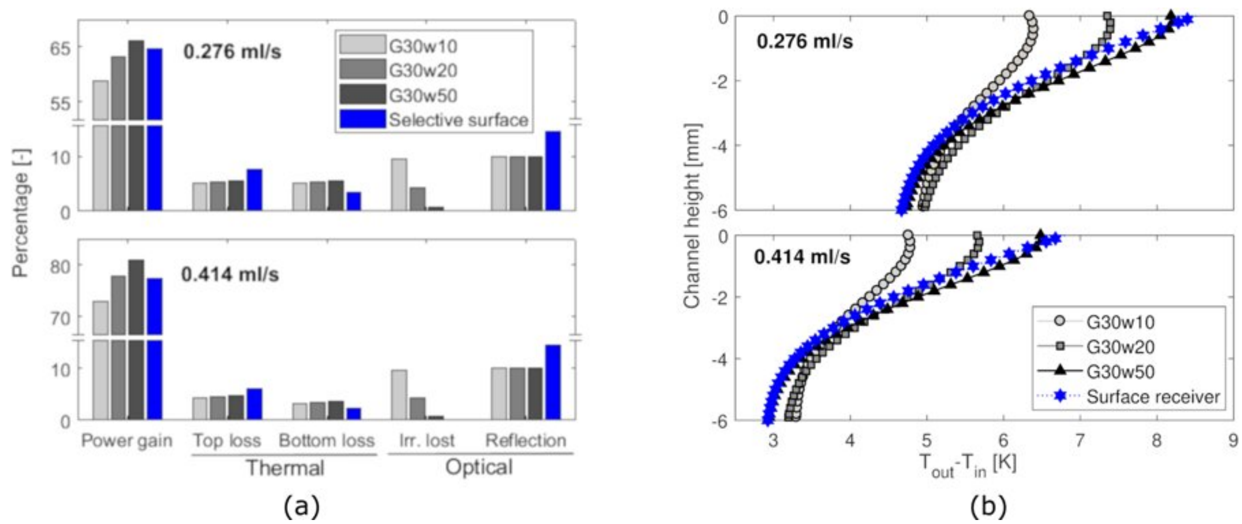
The scientists conducted characterization studies of the optical properties of the proposed colloids relative to the extinction coefficient and calculated the stored energy fraction of the fluids. They derived the extinction coefficient in the study as the sum of absorption and scattering coefficients for a given wavelength. The scientists recorded an extremely intense optical coefficient for the G30 fluid, which they credited to the coffee content. The height of recorded peaks decreased with increased water dilution. Thereafter, Alberghini et al. calculated the stored energy fraction of the solutions based on the incident solar radiance and the penetration distance into the fluid, known as the path length. The G30 fluid had the highest stored energy, which gradually decreased with the increased dilution of water.



Set-up for the solar absorption tests. (a) Flow chart of the solar collectors design and manufacturing: from CAD model, to 3D-printed collector, to final assembly. During field tests, the performance of the direct solar absorber is compared with that of the traditional flat-plate collector. (b) Scheme of the experimental set-up used for testing the efficiency of the coffee-based colloids for the direct solar thermal energy absorption. Solid lines represent hydraulic pipes for the colloidal flow; dashed lines electric wires for data acquisition. Credit: *Scientific Reports*, doi: 10.1038/s41598-019-39032-5.

The scientists then experimentally investigated the photothermal performance of the coffee-based colloids compared to a selective absorber with specifically designed solar collectors. They used similar geometries in the experiments to study both direct and indirect absorption of sunlight. The scientists first designed the solar thermal collectors using computer aided design (CAD) software prior to their manufacture.

During direct absorption, colloids flowing in the channel directly absorbed sunlight. For indirect absorption, Alberghini et al. mounted a selective surface absorber on the collector for water to flow through the underlying channels. Using a peristaltic pump, they provided constant fluid flow through the channels and controlled the inlet temperature of the fluid using a thermostatic bath. To compare the efficiency between the two collectors, they calculated thermal losses and optical efficiency through energy conservation in the system. They also tested the colloids at three different flow rates and reported the corresponding mean optical efficiency of the fluids to the flow rates.



Modeling of thermal performances. (a) Decomposition and analysis of the power components (1D model) for the different configurations (direct and selective surface absorption) at 0.276 ml/s (top histogram) and 0.414 ml/s (bottom histogram) flow rates. Higher fluid speed reduce the thermal losses towards the environment due to lower operating temperatures. The irradiance absorption is not influenced by different mass flow rates hence the design favors the fluid able to capture as high irradiance as possible, namely the G30w50 fluid. (b) Fluid temperature profiles at the outlet section (inlet temperature is constant) obtained with the 2D model. The colloids have lower surface temperature than that of the surface receiver, and top thermal losses are lower. Lower fluid concentrations lead to reduced surface temperature and less sharp profiles. Credit: *Scientific Reports*, doi: 10.1038/s41598-019-39032-5.

In addition, Alberghini et al. developed and validated numerical models against the experimental data. For this, they used two models; 1) a one-dimensional model based on an electrical analogy and 2) a two-dimensional computation fluid dynamics (CFD) model. They reported that optical losses did not depend on the flow rate, but on the optical properties of the flowing fluids and the material composition of the collectors. The scientists maintained the efficiency of the collector by striking a balance between heat absorption and reflection for optimal thermal performance.

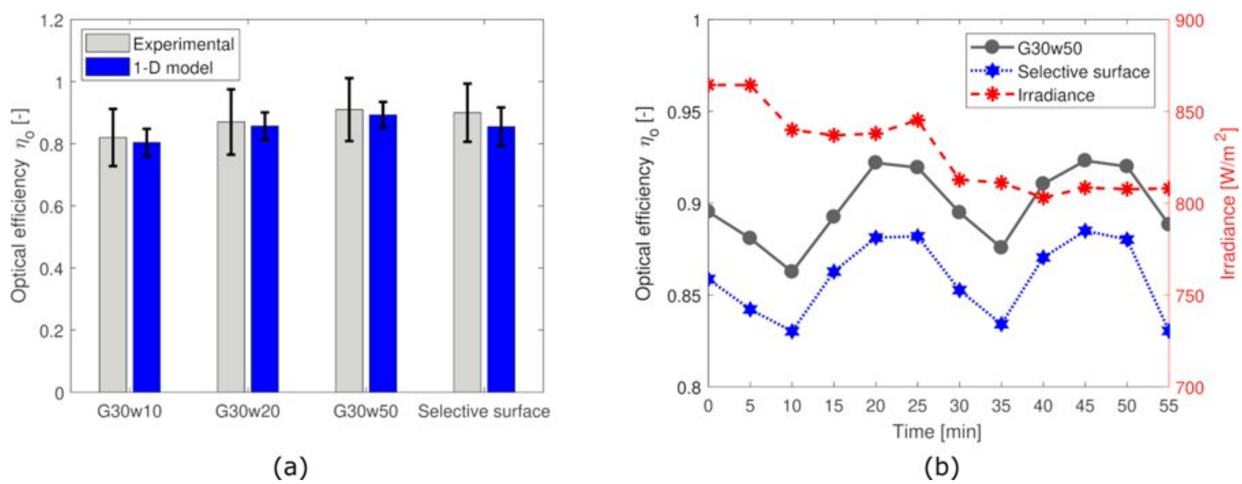


Photo-thermal performance. (a) Results obtained for the optical efficiency of the proposed coffee-based colloids at different dilutions (10%, 20% and 50% G30 volume fraction in water) and of the selective surface absorber. The average value obtained at steady state (5 minutes sampling frequency) for three different flow rates (0.138, 0.276 and 0.414 ml/s) is reported. The error bars have been obtained via uncertainty quantification on the experimental data and on the model parameters. (b) Time evolution of the experimental optical efficiency of the G30w50 fluid (black), of the selective surface (blue) and of the irradiance (red) for the experimental test at 0.138 ml/s flow rate. Credit: *Scientific Reports*, doi: 10.1038/s41598-019-39032-5.

In this way, Alberghini et al. showed that the proposed coffee-based colloids showed competitive optical and thermal properties for direct solar absorption. The experimental results agreed with the numerical models, validating these fluids to perform similarly to the traditional indirect absorption technique. The scientists found that during operation, the optimal dilution guaranteed the best energy storage capacity. The results will pave the way towards developing an unconventional family of biocompatible, environmentally sustainable and inexpensive colloids for solar applications. The scientists propose using the technique in additional solar-based applications such as:

1. Solar-driven evaporation
2. Seawater desalination
3. Domestic water heating, and
4. Sustainable solar cooling.

More information: Boyle, G. Renewable Energy: Power for a Sustainable Future. (OUP Oxford, 2012).
global.oup.com/academic/produc … 59751?cc=us&lang=en&

Matteo Alberghini et al. Coffee-based colloids for direct solar absorption, *Scientific Reports* (2019). DOI: 10.1038/s41598-019-39032-5

Peng Tao et al. Solar-driven interfacial evaporation, *Nature Energy* (2018). DOI: 10.1038/s41560-018-0260-7

Andrej Lenert et al. Optimization of nanofluid volumetric receivers for solar thermal energy conversion, *Solar Energy* (2011). DOI: 10.1016/j.solener.2011.09.029