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Small-Size Nanoparticles and Nanofluids Fabrication via Plasma Arc

David Gelenidze
E. Andronikashvili Institute of Physics

Gela Gelashvili
E. Andronikashvili Institute of Physics

Abstract: The main issue with nanotechnology is the rapidly expanding fields of application, which necessitate heavy investment in research and development, and complicated devices to produce (<10nm) nanoparticles. The article describes the method of plasma arc technology designed for the production of metal nanoparticles, which is related to "Vapor phase techniques" when the material is heated to its boiling point. It is common knowledge that the homogeneity of the plasma heating zone is affected by the varying amperage of electric current in the thermal plasma column caused by fluctuations in plasma column resistance. For the manufacture of small-size nanoparticles, it's also essential to create a sizable heating zone and give the feed materials plenty of time to vaporize completely. The suggested technique uses an electric arc, powered by a constant current power source, to produce a lengthy high-temperature plasma zone.

Keywords: Thermal plasma, Nanoparticles, Plasma reactor, Dispersion, Synthesis.

Introduction

Using their special qualities of high temperatures, thermal plasma has been employed as a heat source for a variety of material transformation processes such as melting, vaporization, Synthesis, and pyrolysis (Murphy et al., 2018). Using plasma can achieve high temperatures (4000^0C and above) so the production of nanoparticles in the gas phase has gained widespread acceptance. High-temperature plasma synthesis can produce particles with unique properties and morphology that are not possible with other methods. Currently, plasma technology is gaining great attention as a prominent "green" synthesis method for nanomaterials, due to its distinguishing properties when compared to solid, liquid, and gas phase synthesis approaches (Kaushik et al., 2019). Thermal plasma is an excellent way to prepare spherical metal powders with a stable composition, high sphericity, and good dispersion due to its advantages of high temperature, concentrated energy distribution, no electrode pollution, and flexible control (Yuming et al., 2013). Various types of plasma technology are used in the production of nanopowders of metals. The paper (Baskoro et al., 2019) examines a number of plasma processes for the production of metal powders.

Many assessments and tests found that the processing capabilities of current plasma technologies have some limitations and couldn't satisfy the following critical requirement for low-cost nanoparticle production it's a long residence time for full vaporization of low-vapor-pressure materials. The Idaho National Laboratory developed two advanced hybrid plasma reactor concepts that produce a large uniform heating zone and a long residence time for the feed materials to achieve full vaporization. The concepts are modular AC/AC hybrid plasma and modular DC/DC hybrid plasma systems. The modular hybrid plasma concept means stacking plasma torches in sequence to form a long plasma system that produces a large uniform high-temperature heating zone and a very long residence time for feed materials vaporization (Kong, 2011). A three-stage AC/AC modular hybrid plasma reactor concept uses three arc discharges that form the cascading energy loading effect in the plasma reactor, which shows the overall increase in the plasma volume. The net plasma energy content cascading from the

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modular unit above will increase by the superimposition of an arc discharge in the plasma gas and raise the total energy content.

We propose a technique for producing a long zone of high-temperature plasma with a single electric arc powered by a constant current power source when any variation in the resistance of the plasma column is compensated for by “just” changing the voltage. Thus, the stability of the current in the arc column ensures the homogeneity of the plasma zone as well as the ability to lengthen or shorten the length of the plasma arc during operation.

Method

The most essential component of plasma arc reactors for nanoparticle gaseous synthesis is a stable, uniform, high-temperature plasma arc column. Maintaining a stable current strength is critical to ensure uniformity of the heating zone when the material is fed into the plasma zone, as the plasma resistance begins to change dramatically. Non-uniformity has a negative impact on the efficiency of nanoparticle synthesis as well as their physicochemical properties.

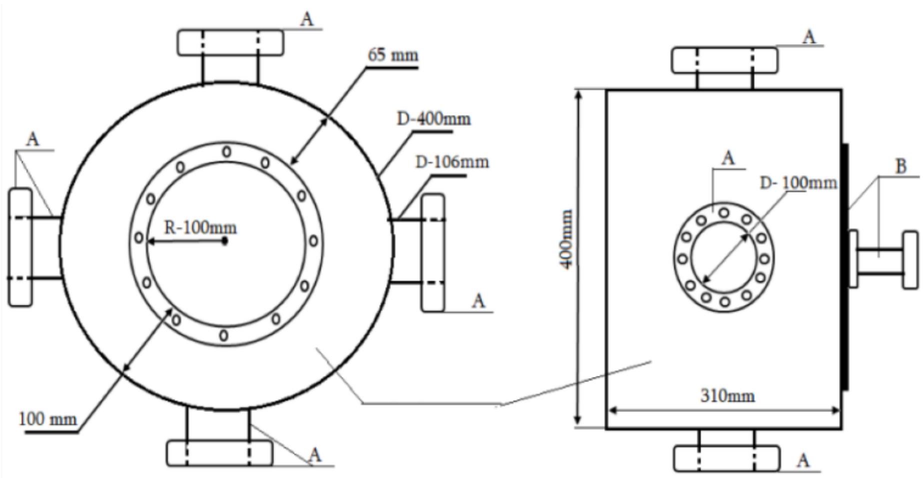

Figure 1. The reactor chamber's common scheme

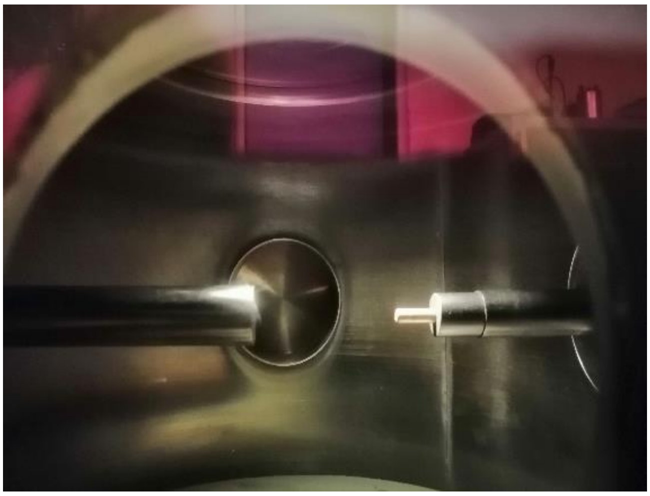

Figure 2. Inside view of the chamber of the reactor

From 2012 to 2016, E. Andronikashvili Institute of Physics in partnership with the Brookhaven National Laboratory led the US Department of Energy project “Gasification of Municipal Waste” (GIPP DOE, BNL-T2-0393). In order to ensure stable operation of the arc in the reactor, a plasma-arc reactor powered by a constant current power source with specific current-voltage characteristics was designed as part of this project. The power source with an almost rectangular volt-ampere characteristic was applied to ignite and continuously generate the plasma arc, ensuring the plasma zone's stability and homogeneity during operation. Experiments have shown that the plasma arc operates stably and its length can be adjusted (1–15 cm). The results of the project allowed us to apply this approach to some applications. for example, we conducted research on burning low-quality coal (Gelashvili G. et al. 2018). Our team received a grant for applied research from the National Science Foundation of Georgia (AR-19-719. 2019-2024). The goal is to develop a plasma arc reactor in which the evaporated material passes through a long plasma heating zone. A laboratory prototype of a plasma-arc reactor with a power source of 30 kW has been developed (see Figures 1, and 2).

In the reactor chamber, a rod and one tubular graphite electrode are installed vertically. Step by step, a current conductive wire with an outer diameter equal to the inner diameter of the electrode is passed through the tubular electrode until it reaches the end of the graphite electrode rod, at which point the plasma arc ignites and vaporizes all the wire located between the electrodes. The distance between the two electrodes ranges from 1 to 12 cm. To ignite the plasma arc, a constant current power source with an almost rectangular volt-ampere characteristic is used, which ensures the stability and uniformity of the plasma zone during operation. Experiments were carried out to obtain copper and aluminum oxide nanoparticles (< 5nm). The materials used were wires with a cross-section of 0.8, 09, 1, ..., 5 mm. The voltage varied from 150 to 450V, and the amperage of the initial current from 120 to 250A depended on the wire's cross-section.

Results and Discussion

A high-resolution X-ray diffraction system (XRD), a transmission electron microscope (TEM), and a scanning electron microscope (SEM) were used to make measurements. The materials were copper and aluminum. The results of measurements including the Whole Powder Pattern Fitting (WPPF) analysis of obtained copper oxide and aluminum nanoparticles are shown in Figures 3,5, …,9.

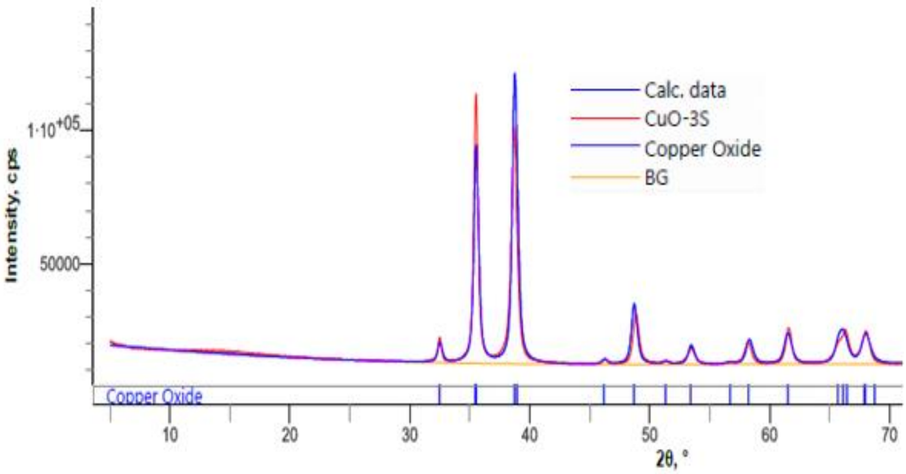

Figure 3. WWPF profile view of CuO nanoparticles. (XRD)

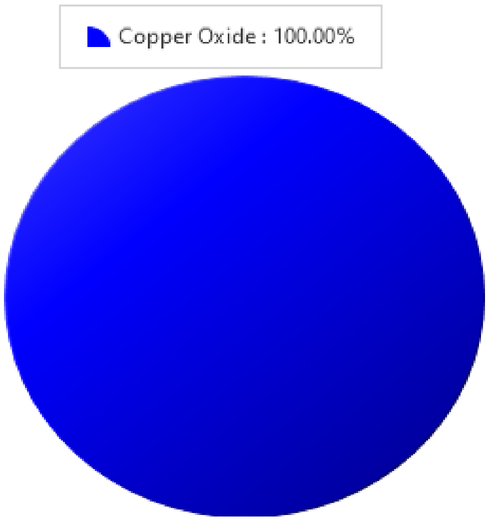

Figure 4. WPPF weight fraction of CuO nanoparticles. (XRD)

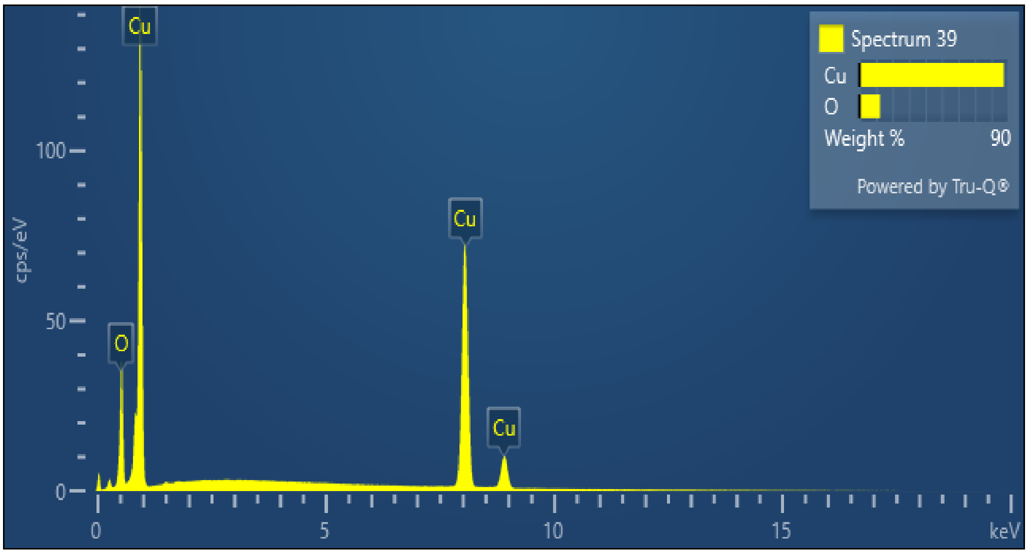

Figure 5. Spectrum of copper oxide nanoparticles. (SEM)

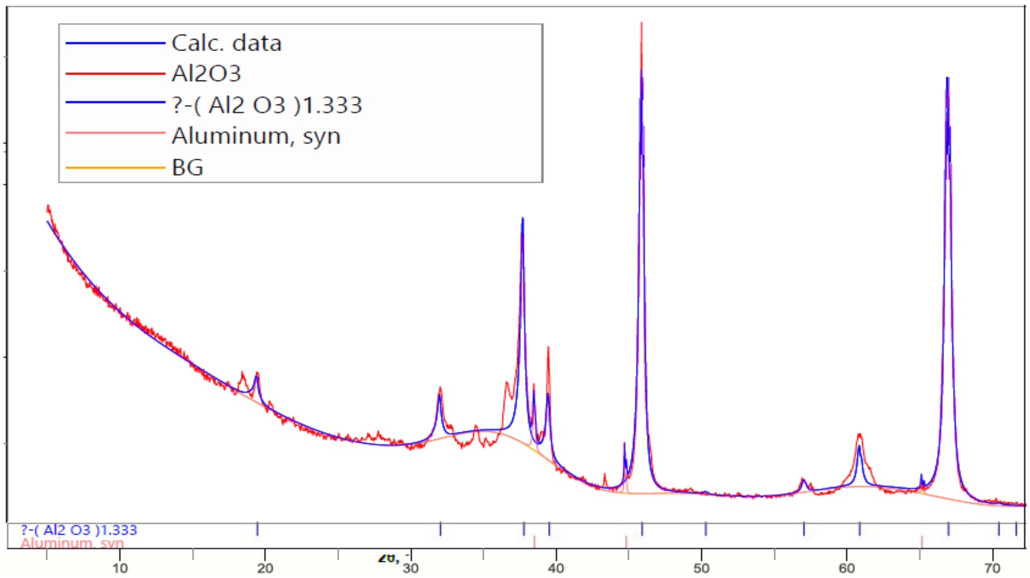

Figure 6. WWPF profile view of Al_2O_3 nanoparticles. (XRD)

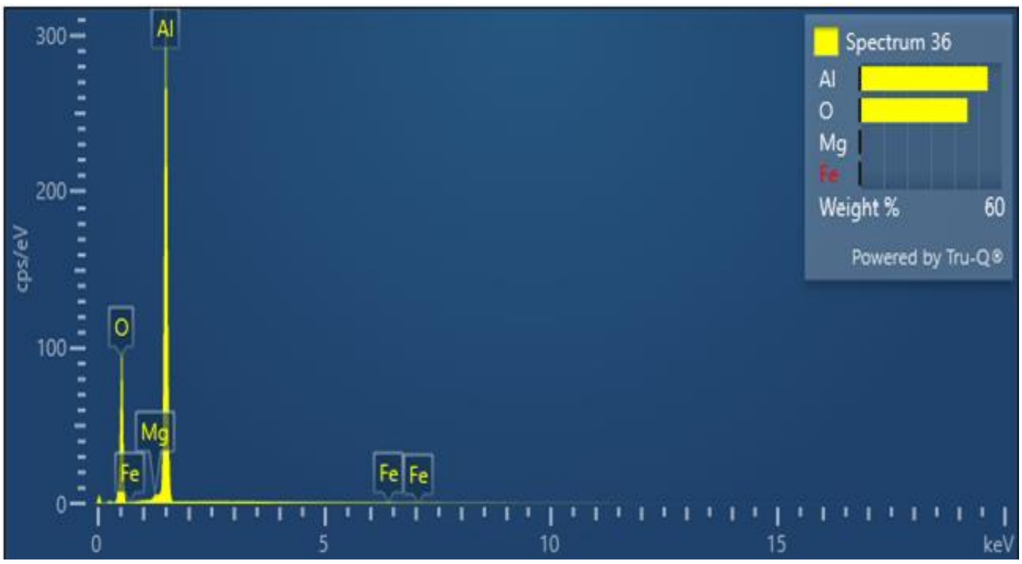

Figure 7. Spectrum of Al_2O_3 nanoparticles (SEM).

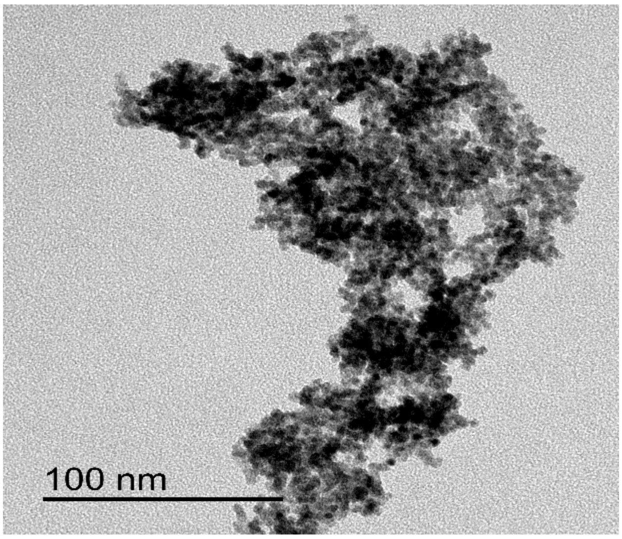

Figure 8. Al_2O_3 nanoparticles size (TEM).

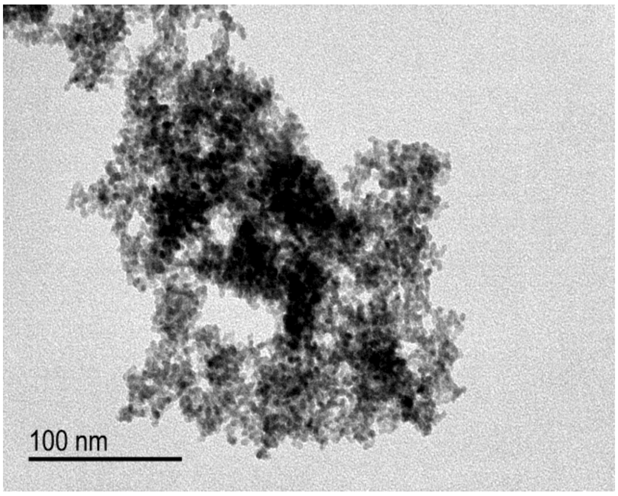

Figure 9. CuO nanoparticles size (TEM).

Nanofluids are used in many areas of industry: solar energy, heat transfer, microelectronics, fuel cells, pharmaceutical processes, hybrid engines, engine/vehicle cooling systems, nuclear reactor coolants, grinding, machining, space technology, defense, and shipbuilding, as well as in biomedical approaches in different fields.

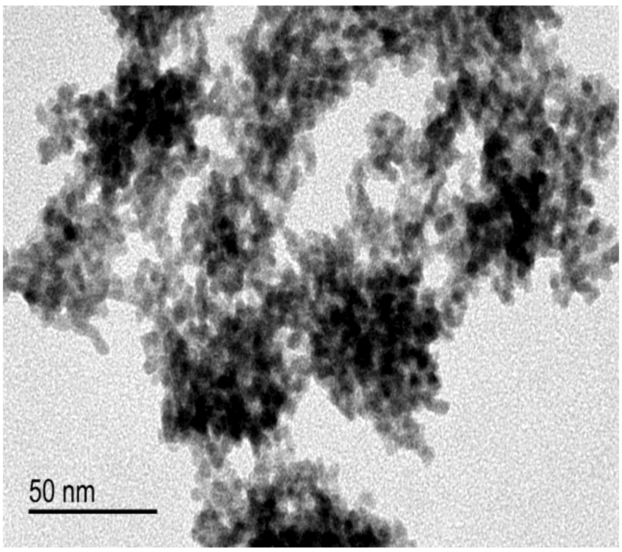

Figure 10. CuO nanoparticles dispersed in H_2O. (TEM)

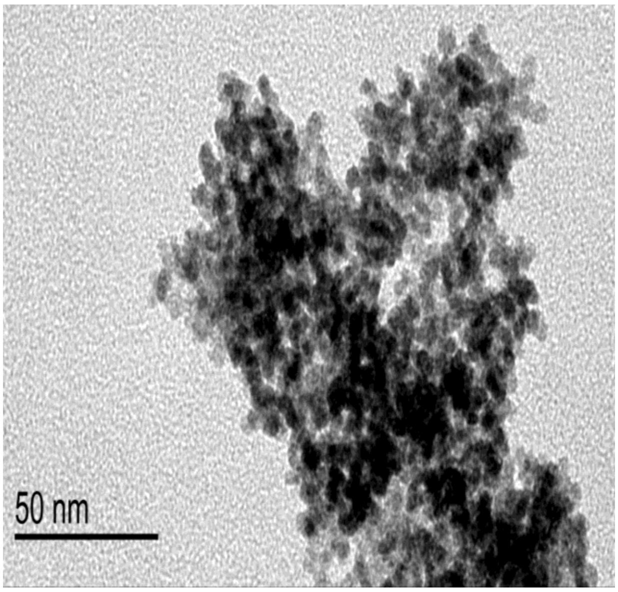

Figure 11. CuO nanoparticles dispersed in H_2O. (TEM)

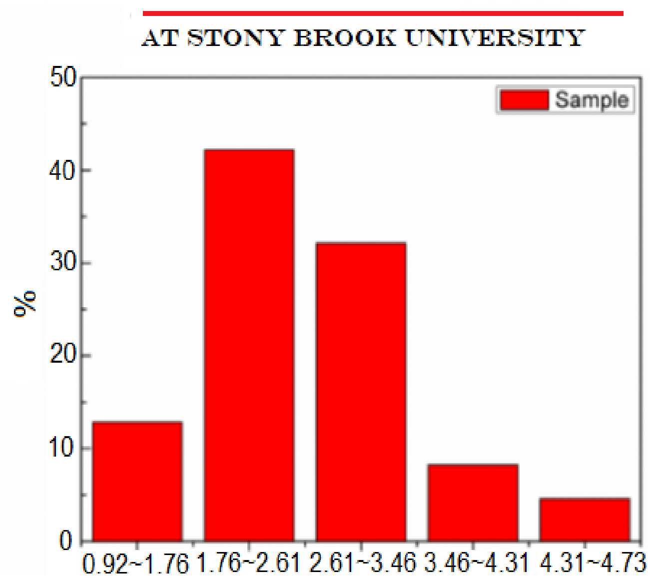

Figure 12. Size distribution of CuO nanoparticles dispersed in H_2O (TEM).

The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations (preferably < 1% by volume) by uniform dispersion and stable suspension of nanoparticles (preferably < 10 nm) in host fluids(Sawant et al., 2021). Using our approach, we also conducted some preliminary experiments to receive small-sized nanoparticles (<10nm) dispersed in deionized water. To obtain a dispersion of copper oxide in the liquid, plasma arcs were ignited in water using copper wire with various cross-sections. The results of the tests (shown in Figures 10, 11 and 12) are optimistic

Conclusion

When there are frequent sudden changes in the resistance of the plasma arc, its power is regulated solely by automatically changing the voltage. Consequently, a constant current passes through the arc column, which ensures homogeneity of the plasma medium, as well as precise adjustment of the length of the plasma arc during operation, and so complete evaporation of the loaded material. Nanofluids of various concentrations were obtained by a one-step method. There is no need to prepare dry nanoparticles in advance and then disperse them in water; both occur in a single discharge, simplifying the production of nanofluids. The sizes of the nanoparticles were almost uniform and ranged from 1 to 10 nm, with most of them being less than 3 nm.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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Author Information

David Gelenidze
E. Andronikashvili Institute of Physics
6, Tamarashvili St. 0186, Tbilisi, Georgia.
Contact e-mail: *david.gelenidze@tsu.ge*

Gela Gelashvili
E. Andronikashvili Institute of Physics
6, Tamarashvili St. 0186, Tbilisi, Georgia.

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