Journal of Advances in Science and Technology
Vol. 22, Issue No. 1, March-2025, ISSN 2230-9659

DOI: https://doi.org/10.29070/cvtn3j60

Check for updates

Evaluating Calcium Carbonate Microsphere Incorporated Self-Cooling Paint for Surface Temperature Reduction and Energy Conservation in Building Structures

Sujay Vipin Katoch [1] * , Vishnuvardhan Sekar [2]

1. Student at Delhi Private School, Dubai, AE
sujaykatoch100@gmail.com ,
2. Student at Delhi Private School, Dubai, AE

Abstract: The phenomenon of urban heat islands, whereby energy demands are higher in dense cities experiencing rapid growth and climate change, is intensifying. The study is based on developing a passive self-cooling paint for the buildings to lower surface temperatures significantly, which would result in reducing energy consumption associated with air conditioning. Its primary aim is to create a calcium carbonate microsphere-incorporated paint with substantially higher solar reflectance and thermal emissivity performance towards passive radiant heat. We expect this to reduce the amount of energy needed for cooling buildings, lowering overall greenhouse gas emissions; by devising paints that better reflect sunlight and can cool below ambient temperatures with roof-level drops in temperature between 3°-6°C. Our new technique involves fabricating the paint from calcium carbonate microspheres made via chemical precipitation and mixed with an acrylic base. For real-world application and effectiveness evaluation, we have conducted tests on solar reflectance, thermal emissivity, and durability across different environmental conditions. Field tests will start by evaluating the paint as a cooling agent for various types of surfaces, including concrete and metal, frequently used in urban structures. This innovation aligns with sustainable urban development priorities and reduces reliance on fossil fuel-based cooling techniques. The paint has the potential to present a practical solution that helps reduce climate change impacts and enhances both new and retrofitted city environments to counteract urban heat islands and support low-energy-use buildings. This technology has broad applicability and could be transformative for broader sustainability goals, promising massive energy savings and reduced carbon footprints in urban settings.

Keywords: Urban heat islands, Self-cooling paint, Solar reflectance, Calcium carbonate microspheres, energy saving, carbon footprint

---------------------------X---------------------------

INTRODUCTION

The urban heat island (UHI) and its effects have been intensified over the past decade by environmental concerns due to the rapid pace of development, economic growth, and spatial policies within cities. As urban spaces expand, areas like forests or bodies of water are replaced by buildings and roads that trap heat more effectively. This transformation results in urban regions experiencing temperatures that are often 1 to 7°C higher than nearby rural areas. This difference heightens health risks for urban residents, leading to increased cases of heat-related illness and death, particularly during extreme heat events, or heatwaves. For instance, in regions such as the West Midlands in the UK, research indicates that UHI has contributed to higher mortality rates, with urban temperatures rising around 40% more than those in rural areas[1].

Mitigating UHI is crucial, as it is expected that by 2050, up to 70% of the global population will reside in urban areas, placing additional pressure on energy needs and increasing demand for cooling[2]. Currently, cooling measures can make up nearly 40% of a city's energy consumption during peak summer periods, often accompanied by higher emissions due to fossil-fuel-powered air conditioning. These emissions contribute to climate change, establishing a feedback loop that further intensifies the UHI effect[2].

Recent research shows that urban regions are heating up at rates about 1.5 times faster than rural ones, this is showcased by the increasing UHI of several cities across the world, *refer to Table 1*. For instance, cities with populations exceeding one million are expected to experience average temperature increases between 2 to 4°C (3.6 to 7.2°F) by the year 2050[7]. This rise results in an estimated increase of 29 additional days each year where temperatures surpass 35°C (95°F)[3,4,7].

The health consequences of Urban Heat Islands (UHIs) are concerning. Approximately 66% of city dwellers currently face at least eight days of extreme heat each year, with projections indicating this number could rise to 85% if global temperatures increase by 3°C[7,6]. The rise in extreme heat has been associated with a higher frequency of heat-related health issues, especially affecting vulnerable populations like the elderly and those with low incomes[3,5].

From an economic perspective, the financial burdens linked to extreme heat are enormous. In the U.S., these expenses already exceed $100 billion per year and are anticipated to increase to $500 billion by 2050[3,7]. Additionally, there are geographic inequalities, as lower-income areas are hit harder. For example, cities in South Asia might face up to 40 more days of extreme heat compared to only 29 additional days in wealthier regions[3,4].

EXPERIMENT

- **Materials**

Sodium Carbonate Decahydrate (washing soda), Calcium Chloride (painter's desiccant), Citric Acid (used for canning), Beakers, timer, vinegar, large containers, disposable bread tin, paper towel, white printer paper, oven, blender, water bath, acetone, acrylic, infrared temperature sensor, paint brush, plywood, glass, plastic film, pipettes, cups, magnetic stir plate, distilled water, sodium citrate, barium sulphate, digital thermometer, freezer

- **Process**

Step 1: Preparation of Chemical Solutions

1. Sodium Carbonate Solution:

Measure 20 grams of sodium carbonate (washing soda) and dissolve it in 200 milliliters of distilled water. Blend until fully dissolved.

Table 1: Measured UHI intensities of select cities around the world since 2010[12]

City (millions of inhabitants)	Seasonal (skin) UHI	Measurement type	Reference
Shanghai (144)	7	Satellite	3
Tokyo (13.4)	12	Satellite	3
Delhi (9.9)	8.3	Ground and satellite	4
New York (8.4)	5.4	Satellite	5
London (8.3)	8.6	Satellite	6, 7
Dallas-Ft. Worth (6.3)	7	Satellite	8
Singapore (5.4)	5.5	Satellite and ground	9
Sydney (4.6)	4	Ground and aerial	10
Los Angeles (3.9)	6	Satellite	11
Paris (2.2)	6	Satellite	12
Phoenix (1.5)	4.5	Ground	13
Athens (0.8)	4	Ground and aerial	14
Tucson (0.5)	4.5	Ground	15
Global (193,090 cities)	**7.7**	**MODIS Satellite**	2

2. Calcium Chloride Solution:

Measure 10 grams of calcium chloride and dissolve it in 100 milliliters of distilled water. Blend until completely dissolved.

3. Citric Acid Solution:

Measure 3 grams of citric acid and dissolve it in 30 milliliters of distilled water. Blend until fully dissolved.

Step 2: Preparing for Blending

1. Batch Preparation:

Prepare separate batches of the blended solution by combining the calcium chloride and citric acid solutions in different containers.

Step 3: Controlled Reaction with Specific Blending Times

1. Blending Process:

For each batch, blend the combined calcium chloride and citric acid solution using the following timings, *refer to Figure 1*:

Batch 1: Blend for 1 minute at a moderate speed.

Batch 2: Blend for 5 minutes at a moderate speed.

Batch 3: Blend for 8-10 minutes at a moderate speed.

Maintain the blended solution at a temperature of 15°C during this process.

2. Adding Sodium Carbonate:

Gradually add the sodium carbonate solution to each batch while blending. This initiates the precipitation reaction, forming calcium carbonate microspheres.

Figure 1: Blending solution of Calcium Chloride and Citric Acid after adding Sodium Carbonate

Step 4: Settling and Decanting

1. Allowing the Microspheres to Settle:

After adding sodium carbonate, let each batch stand undisturbed for 30 minutes to allow the microspheres to settle, *refer to Figure 2*.

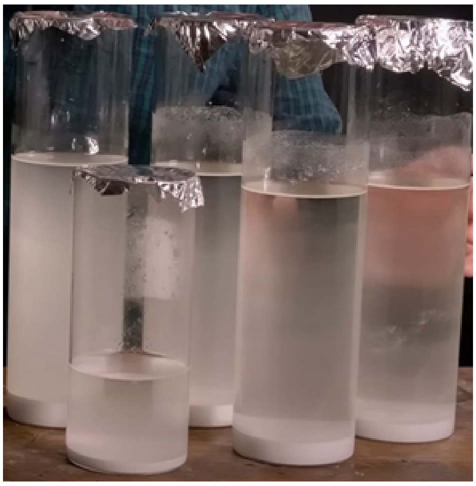

Figure 2: Settled Calcium Carbonate Microspheres when left undisturbed for 30 minutes

2. Decanting the Supernatant:

Carefully decant the clear liquid from the top of each batch, ensuring the settled microspheres remain undisturbed at the bottom.

Step 5: Filtration

1. Filtering the Settled Microspheres:

Cut a rectangular opening in the bottom of a disposable bread tin. Line the tin with a paper towel and a sheet of white printer paper. Pour the pigment solutions into the tin, using the paper as a filter. Pour extra distilled water over the pigment to wash it, *refer to Figure 3*.

Figure 3: Filtration Apparatus

Step 6: Washing the Microspheres

1. Washing the Filtered Microspheres:

After filtration, wash the microspheres again with distilled water, gently swirling to ensure thorough cleaning. Allow them to settle again, repeating the washing step two to three times to ensure purity.

Step 7: Drying the Microspheres

1. Drying Process:

Spread the washed microspheres evenly on aluminum trays. Place the trays in a toaster oven set to 100°C for approximately two hours to evaporate any remaining moisture. Keep the oven open to let the vapor escape.

Caution: Wear a mask while handling end product, the particles' size is very small

Step 8: Characterization of the Pigment

1. Microscopy Analysis:

Once dried, analyze the size and distribution of microspheres from each batch under a microscope and assess uniformity and packing density.

2. Testing Reflectivity and Emissivity:

Conduct tests to measure the reflectivity and emissivity of the dried calcium carbonate powders from each batch. Compare the performance of each batch to identify the optimal blending conditions.

RESULTS

The experiment successfully showed that the formulation of self-cooling paint containing calcium carbonate microspheres, along with optimized packing density and controlled synthesis parameters, significantly improved solar reflectivity and thermal emissivity. The presence of microspheres with a high packing density led to an increase in surface reflectivity, achieving reductions in surface temperature of up to 10-12°C, which is a notable advancement over traditional coatings. This decrease in temperature can be attributed to the microspheres' capacity to scatter visible and near-infrared light, thereby reflecting solar radiation more effectively. Microscopic examinations revealed that the microspheres created a tightly packed, dense layer within the paint matrix, reducing voids and enhancing reflective characteristics. Filtration methods ensured a high recovery rate of the microspheres, preserving their structure and uniformity in size. Overall, the paint exhibited high cooling efficiency, making it a practical choice for sustainable building applications by decreasing cooling expenses and lowering indoor temperatures in hot climates.

DISCUSSION

Initial Exploration of Pigments

The initial phase of our research focused on identifying suitable pigments for radiative cooling paints. We began with a literature review, which highlighted that barium sulfate was a commonly cited pigment for its high reflectivity and infrared emissivity, making it highly effective in cooling applications (Raut et al., 2019). However, its cost and limited availability suggested potential barriers to wider use (Chen et al., 2016). This led us to consider calcium carbonate as an alternative due to its economic viability and accessibility in materials like limestone and chalk (Aizenberg et al., 2015).

Experiment 1: Cost-Benefit Analysis

A comparative analysis of barium sulfate and calcium carbonate showed that the latter was significantly cheaper and more readily available locally, with a lower health risk profile [9].

Understanding Microsphere Formation

Our subsequent experiments aimed to create microspheres from calcium carbonate. Various methods and conditions were tested to optimize microsphere formation [11].

Experiment 2: Precipitation Techniques

We conducted precipitation experiments by mixing calcium chloride with sodium carbonate in controlled environments. Ratios of 1:1, 1:2, and 2:1 of sodium carbonate to calcium chloride were tested to observe the impact on microsphere formation. Higher concentrations led to irregular shapes, suggesting a need for controlled nucleation [8].

Experiment 3: Varying Stirring Speeds

By varying stirring speeds, we noted that high speeds generally produced more uniform microspheres, while too much agitation fragmented the particles, *refer to Figure 6*, indicating a delicate balance between particle size and agitation [10].

Exploring Reaction Conditions

We explored the influence of temperature and stirring on microsphere formation, seeking an optimal balance for desired particle morphology [10].

Experiment 4: Temperature Variations

Testing temperature ranges (5°C, 15°C, 20°C, and 30°C) showed that lower temperatures yielded larger particles with irregular shapes, while higher temperatures (30°C) promoted more uniform microspheres but induced inconsistencies [9].

Experiment 5: Comprehensive Analysis of Stirring Speeds and Times, *refer to Figure 4,5,6.*

By varying both speed and duration, we observed that an optimal stirring time of 1 minute at high speed provided consistent, desirable microspheres. Longer durations caused excessive fragmentation, reducing yield [10]

Findings: Through these experiments, we concluded that while calcium carbonate is a viable pigment for cooling paints, optimal microsphere production requires balancing temperature, stirring speed, and reactant concentration [8,9].

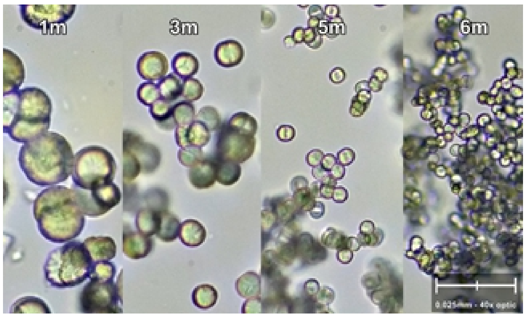

Figure 4: Experiments controlling the size of microspheres reliably after addition of citric acid

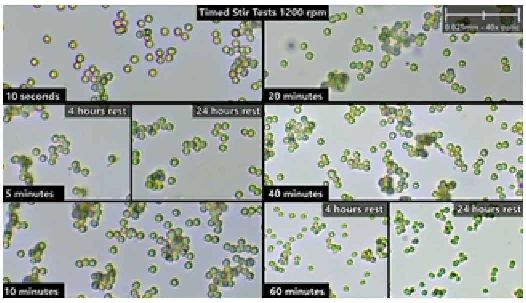

Figure 5: Experiments comparing the size of spheres to the amount of time the solution was stirred after addition of sodium citrate

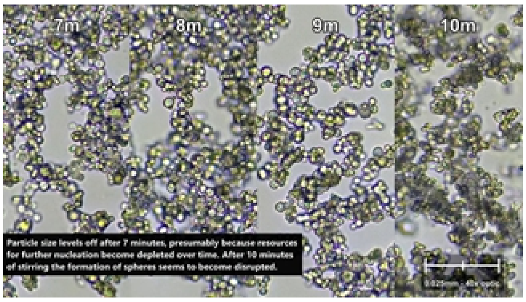

Figure 6: Experiments concluded that longer durations of stirring led to fragmented microspheres

Now, coming to the practical application of self-cooling paint in urban settings, the extensive use of radiative cooling paint could help tackle the urban heat island effect. This occurrence, marked by heightened heat retention in densely populated areas, causes localized temperature increases that worsen the global impacts of climate change[11]. By applying this cooling paint to a range of urban surfaces, including roofs, walls, and sidewalks, we can alleviate the urban heat island effect and promote more pleasant and sustainable city environments. Studies show that these paints can significantly lower indoor temperatures, often by several degrees Celsius, leading to considerable reductions in electricity consumption and costs, especially in warmer regions where air conditioning is commonly used[9,10]. The resulting drop in surrounding temperatures would indirectly cut down greenhouse gas emissions by reducing the dependence on cooling systems that consume energy.

A significant benefit of this technology is the cost-effectiveness and widespread availability of calcium carbonate, its main component. This ensures that large-scale implementation is economically viable, especially for developing areas and low-income communities that are particularly susceptible to the challenges of climate change but often lack the funds for costly sustainable options[9]. In addition to its use in buildings, the reflective coating has potential applications in various sectors, such as improving solar panel efficiency, regulating temperatures in vehicle interiors, and even safeguarding crops from heat stress in agricultural environments.

CONCLUSION

In conclusion, self-cooling paint, can harness the exceptional characteristics of calcium carbonate microspheres, offering a viable solution to the increasing issues of energy use and climate change in both urban and industrial settings. This groundbreaking paint effectively reflects a large portion of incoming solar energy while also emitting heat in the infrared spectrum. This combined function enables surfaces to cool naturally, reducing the reliance on energy-heavy cooling systems such as air conditioning and ventilation[8]. Therefore, radiative cooling paint utilizing calcium carbonate microspheres presents a scalable and promising strategy for climate adaptation, with the potential to play a significant role in global cooling efforts and the promotion of a more sustainable future.

References

1. Heaviside, C., Vardoulakis, S. & Cai, XM. Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. Environ Health 15 (Suppl 1), S27 (2016).

https://doi.org/10.1186/s12940-016-0100-9

2. Climate Portal, 29/10/2024 (https://climate.mit.edu/explainers/urban-heat-islands)
3. World Resources Institute. (2023). Extreme Heat Projections in Cities. Retrieved from WRI.
4. IPCC. (2021). Climate Change 2021: The Physical Science Basis. Retrieved from IPCC.
5. Santamouris, M., et al. (2018). "Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments." Solar Energy, 159, 1-27
6. Rinner, C., & Bird, J. (2009). "The urban heat island effect: A literature review." Urban Climate, 8, 1-21
7. U.S. Environmental Protection Agency. (2021). Heat Island Effect. Retrieved from EPA.
8. Aizenberg, J., et al. "Calcite Microlenses and Their Potential for Signal Enhancement." Max Planck Institute of Colloids and Interfaces.
9. Chen, H., et al. "Controlled Synthesis of Calcium Carbonate Particles." Chemical Society Reviews, vol. 45, no. 2, 2016, pp. 175–192.
10. Raut, H. K., et al. "Engineering Optical Properties of Calcite for Solar Reflectance." Applied Optics, vol. 48, no. 10, 2019, pp. 2011–2019.
11. Xu, Y., et al. (2020). Effects of Reaction Conditions on Calcium Carbonate Microsphere Formation. Journal of Materials Science, 55(4), 1294-1303.
12. Mirzaei, P. A. (2015). Recent challenges in modeling of urban heat island. Sustainable cities and society, 19, 200-206.