Evaluation of materials for suitability in the construction of solar-powered unmanned hot-air balloons

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Abstract:

Solar-powered unmanned hot-air balloons have proven themselves useful for some aspects of high-altitude balloon work. The lower-cost of construction materials (compared to latex weather balloons) and launch supplies make them accessible to a greater spectrum of potential users. Part of the cost-saving measures enjoyed when constructing these balloons includes the use of easily-available and inexpensive materials to build the balloon envelope. However, some of these materials are more labor-intensive to utilize than others. For example, when using black plastic garbage bags to make an envelope, the bags must be cut to form sheets, and these sheets joined into larger constructs using adhesive tape or heat-sealing. This can be contrasted to using rolls of high-density "painters plastic" which require far less cutting and joining, but the plastic is transparent and requires treatment with a pigment to augment its ability to absorb sunlight. This pigment-treated plastic may be less effective in generating heat from incident sunlight. To characterize the trade-offs involved, experiments were conducted to test the heat-generating capabilities of various materials, including black plastic trash bags and transparent high-density polyethylene sheeting coated with pigment or left clear. Based on these results, a comparison of the materials was made, and the suitability of each material is discussed.

Introduction:

The use of lighter-than-air vehicles such as balloons in scientific research and other experimentation has a long history. Typically these balloons would be filled with a lift gas having a density lower than air, to provide the lift needed for flight. Some early balloons used hydrogen, either compressed in cylinders for transport, or generated on-site during the filling of the envelope by chemical reaction. While hydrogen provides excellent lift and is relatively inexpensive, its flammability when mixed with air presents some significant safety concerns, especially with relatively inexperienced flight crews, such as students. Helium, being completely nonflammable, is an excellent alternative. A draw-back to helium, especially in recent times, is that the supply has diminished causing a rise in price and lower availability from suppliers. There are also the safety concerns of dealing with high-pressure gas with heavy tanks and associated plumbing.

To avoid these risks and the high cost of helium, a different lift gas can be employed: hot air. To heat air trapped inside an envelope to a sufficiently high temperature that its density is low enough to provide adequate lift, a number of methods can be employed. The safest and simplest is probably to use incident solar radiation, absorbed by the balloon envelope itself, to heat the internal air via conduction and convection. Balloons using this method of heating to achieve lift for flight are typically referred to as "Solar Balloons" [1] (or sometimes "Solar Montgolfier Balloons" after the famous French brothers who pioneered hot air ballooning).

The performance of a solar balloon is dependent on a number of factors. The strength of the material used to construct the envelope is very important. It must be strong enough to survive the stress created by the lift of the hot air, the weight of the payload/gondola, and to resist damage from handing during inflation and launch. The weight of the envelope material will also directly affect flight performance, since the lift generated by the hot air is a fixed value. That lift must be split between the weight of the payload and the weight of everything else, including the envelope. Finally the envelope material's efficiency as a collector of solar energy is also critical, since the balloon's ability to sustain flight is directly dependent upon the envelope's ability to maintain a sufficiently high temperature of the inside air. If the material is not an effective solar collector, the balloon may not perform adequately or perhaps not be able to take off at all.

While it is possible to obtain custom materials that exhibit all of these characteristics, this paper will explore only materials that are easily available as candidates for solar balloon envelope construction. The rationale behind this is to provide an avenue to groups, such as schools and amateur experimenters, to construct and fly solar balloons with a very limited budget and little or no access to specialized tools and equipment.

Method:

Previous successful flights were made by the authors and other groups using solar balloons constructed from black plastic garbage bags [1, 2, 3]. The bags were of 30 gallon capacity, with a thickness of 0.5 mil, and were ordered online [7]. These bags were cut open to form sheets, then these sheets were assembled into tetrahedral balloon envelopes using adhesive masking tape. Figure 1 shows one such balloon.

Figure 1. 5 meter tetrahedral solar balloon

Two proof-of-concept flights were made in 2013 with envelopes of approximately 3 m (10 foot) and 5 m (16 foot) diameters, one of which was tracked by radar to an altitude of 11.5 Km (38,000 feet) and landed 415 Km (258 miles) from the launch site [5, 6]. Other groups have also made successful flights with envelopes constructed from high-density polyethylene plastic sheeting ("Painter's Plastic") 0.31 mil thick, which had been treated with a pigment to decrease its albedo [4]. The authors decided to test these two materials, as well as untreated polyethylene sheeting, to gauge their efficiency as solar collectors.

A set of test chambers was constructed using foam rubber sheeting and an adhesive silicone caulk. The foam rubber was 2.5 cm (1") thick, and each chamber measured 7 cm (2.75") wide by 10 cm (4") deep by 25.5 cm (10") tall. Each chamber was slotted at the top to receive an alcohol-type thermometer, allowing the measurement of internal temperature. The thermometer bulb was located inside the chamber, while the scale was left outside to allow reading of the temperature during the experiment. The open face of each chamber was covered with a sample of the balloon envelope material under test, which was secured to the chamber with adhesive tape to make an air-tight seal. A light shield was constructed from four layers of ordinary printer paper and fitted to the chamber to prevent direct sunlight from falling on the thermometer bulbs (figure 2).

Figure 2. Solar-heating test chambers

The image shows the chamber during the experimental run. The right-most chamber is covered with black garbage bag material, the central chamber with clear polyethylene sheeting, and the left-most sheeting that has been darkened with the addition of laser printer toner powder. The powder was dusted onto the surface of the sheeting and smeared by hand to produce a fairly uniform covering.

To minimize problems with wind, the experiment was conducted indoors. The use of sunlight filtered through a window may have introduced unwanted factors such as the filtering of UV light, but the wind problem the day of the experiment made it necessary. The chamber set was propped such that the incident sun from a south-facing window struck the test materials at an angle close to 90 degrees. The light shield and the frame of the window prevented sunlight from striking any of the thermometers directly. Temperatures were recorded at 5 minute intervals, and the experiment was concluded when all three chambers reached a steady state. The chambers were then moved to an office were no sunlight was present, and allowed to cool to close to ambient temperature. Temperatures were also recorded at five minute intervals.

Results:

Figure 3 shows the result of the experiment.

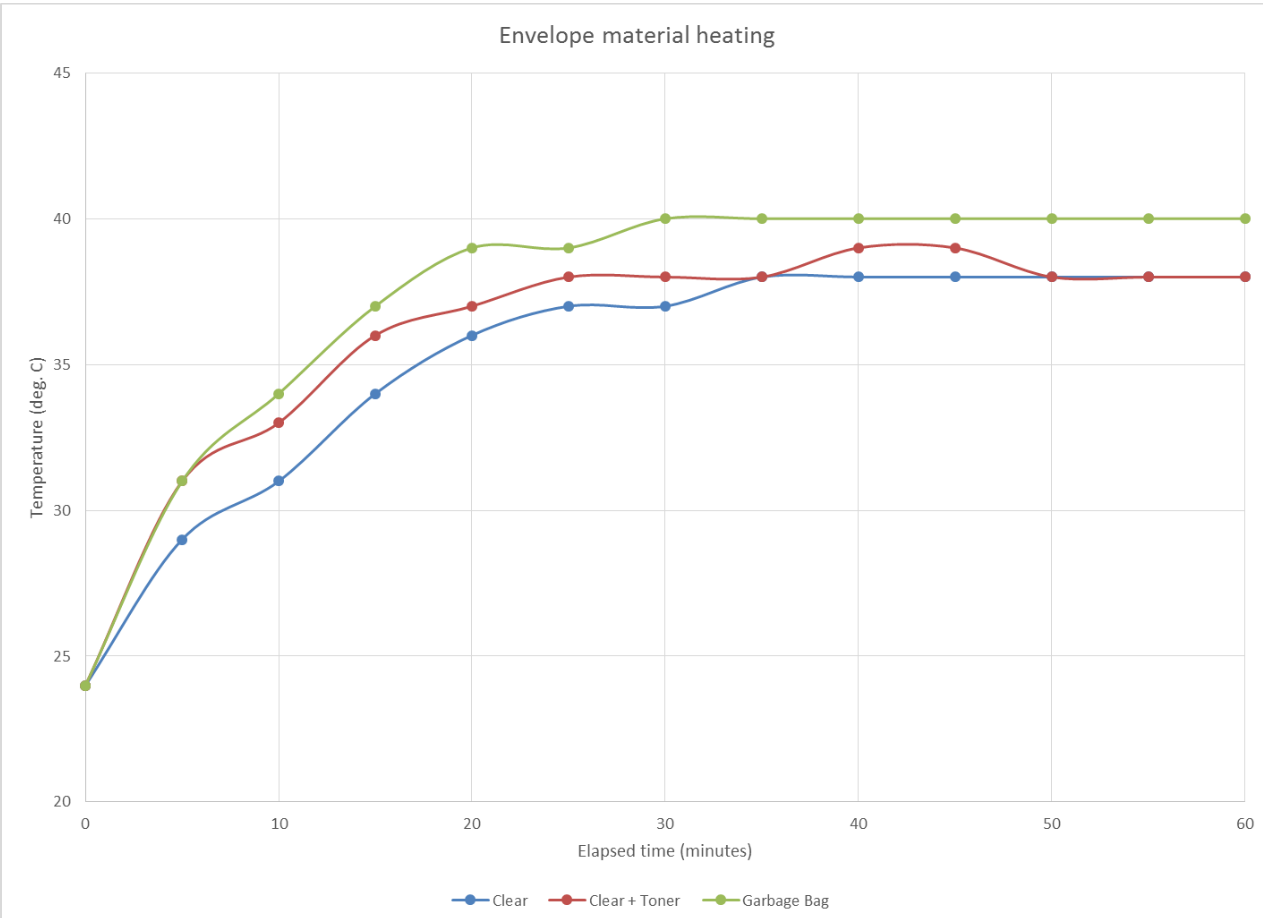

Figure 3. Chamber temperature vs. elapsed time (heating)

Figure 4 shows the results of allowing the chambers to cool back to room temperature. The higher initial temperature of the "clear" plastic is due to an earlier run of the experiment without the light shield in place, which allowed the thermometer to heat directly from sunlight to a higher temperature.

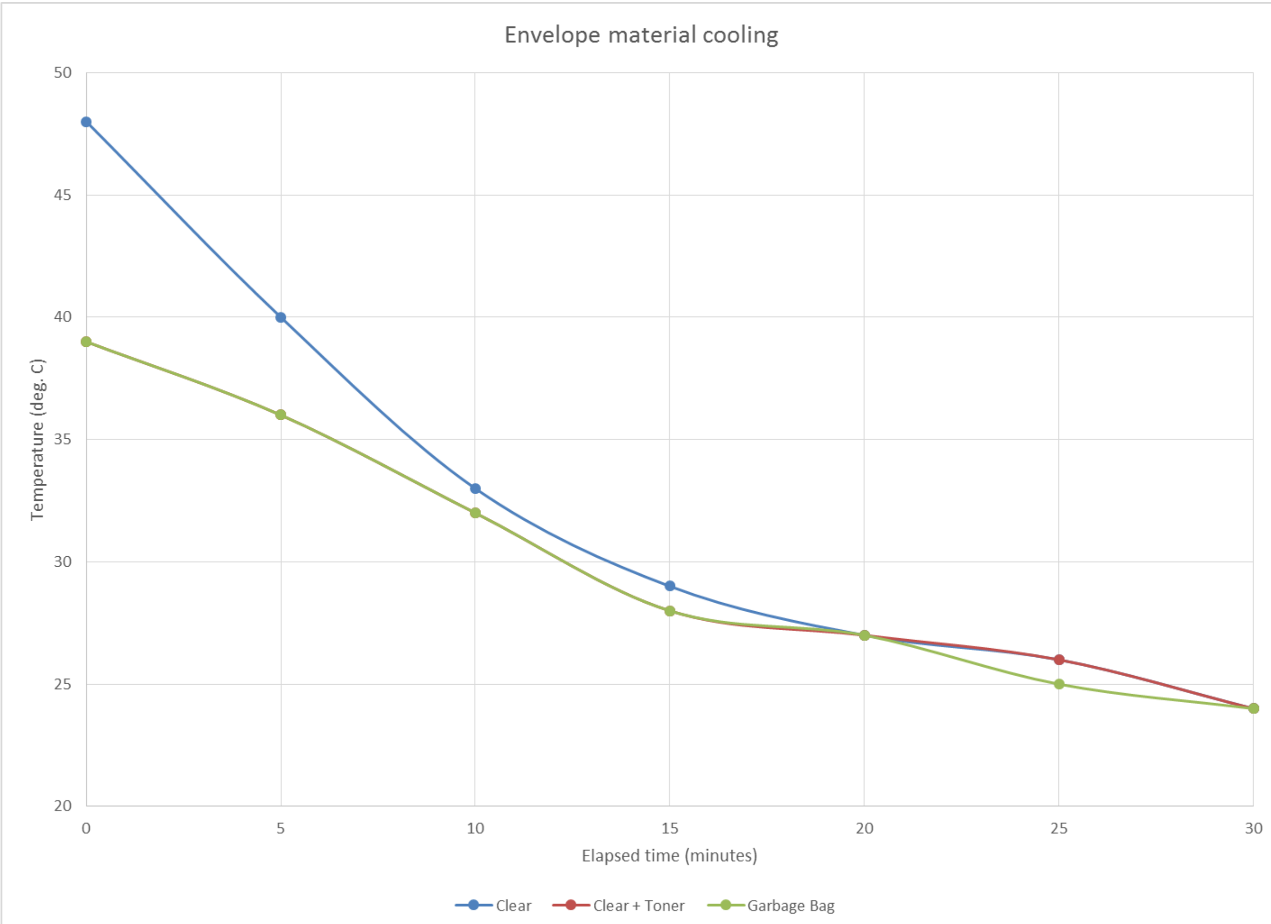

Figure 4. Chamber temperature vs. elapsed time (cooling)

Discussion:

The heating data from figure 3 suggests that the black garbage bag material not only heats more quickly than the other two test materials, but also maintains a higher equilibrium temperature. This would suggest that the bag material is the most efficient solar energy collector tested. The authors were also surprised to see that the uncoated ("clear") plastic sheeting reached the same equilibrium temperature as the sheeting coated with toner powder, though the coated sheeting did heat more quickly in the early part of the experiment.

The cooling experiment, though contaminated due to the higher initial temperature of the clear sample, did tend to suggest that all of the materials allow air inside the envelope to cool to ambient temperature at about the same rate. The clear plastic cooled faster initially, but also started at a higher temperature. More tests are needed to verify this observation.

Conclusion:

The experiment suggests that black plastic garbage bags seem to be the best low-cost, easily-available material to construct solar balloon envelopes from a solar-heating point of view. This must be balanced with some drawbacks to the material, such as the time and effort required to cut the bags open, and the additional weight incurred by the extra masking tape needed to reform the cut bags into larger sheets. Other groups have also reported that the bag material is mechanically weaker than the polyethylene sheeting, and thus requires more careful handling when constructing, transporting, filling, and launching the balloon [8]. Using the coated sheeting may have some advantages in the initial construction, but the difficulty and mess associated with coating the inside of an envelope with toner powder must also be taken into consideration. That and the lower thermal performance observed in this experiment lead the authors to continue to use the black plastic bags as their main construction material.

Future work:

This is only the first step in the continuing work to identify the most practical material with which to construct solar balloon envelopes. The surprising heating of the clear sheeting material suggests that the material may be useful in some solar balloon applications [8]. The next logical step would be to construct actual balloon envelopes of equal size from all three materials and test them to see how much lift each one generates under identical conditions. Ultimately the suitability of each material must be gauged in terms of cost, availability, and ease of assembly.

References:

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