Research into Modifications to the CooKit-New Materials for the Bag and Panels

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Overview-What was Studied

This informal report covers some research that was done primarily in the late summer and early fall 2006 in Columbus Ohio. The work was done by Dale Andreatta, a mechanical engineer, and Stephen Yen, a graduate student in electrical engineering at Ohio State. The goals of the research were two-fold, to see if a material was available to replace the oven bag on the CooKit, and to see if a material was available to replace the cardboard. We did not intend to do any extensive redesign of the CooKit.

A bag material, PFA, was found that appears promising, however we started late in the season and could not perform longevity tests until 2007.

A panel material, corrugated plastic, was found that appears promising. In the first half of 2007 a group of Ohio State University mechanical engineering seniors performed a number of tests with this material, including tests of the material itself and tests of cookers made from this material. Their work has been reported on separately.

Bag Materials

It was reported to us that the oven roasting bags worked well but did not last long, not more than 20-30 days. A new bag material was sought. It should be noted that the standard bag is designed to be used in a 350 °F oven, which should be well above what it sees in a solar situation. It is possible that the degradation of the bag is more due to UV exposure than heat, especially since the CooKit panel concentrates the sunlight in some areas.

Two new bag materials were identified as potential candidates, Teflon and perfluoroalkoxy fluorocarbon (PFA). These were selected because they have high melting temperatures, in the range of 500° F (260° C) and are UV stabilized. The Teflon was white but translucent, while the PFA was very clear. A 2-ft by 2-ft sample of each was obtained from McMaster Carr. I have done successful water pasteurization tests in the past with white translucent bags, so the fact that Teflon is not transparent doesn't necessarily mean it won't work.

Transmissivity Test

On a clear day the transmissivity of the materials to solar radiation was tested directly using a pyranometer which measures the strength of solar radiation. It measures the light coming from all directions of the hemisphere.

The ordinary oven roasting bags with came with the CooKits was tested using a single layer of each material. The test was conducted in two ways, once with the material perpendicular to the rays of the sun, and once with the material at about a 45° angle. In all cases the pyranometer itself was pointed directly at the sun. The largest uncertainty in the measurements is the angle at which the materials were held. The results are as follows:

Material	Transmissivity at 90°	Transmissivity at 45°
Oven roasting bag (single layer)	0.97	0.87
PFA	0.95	0.87
Teflon	0.85	0.81

The PFA is essentially as transmissive as the oven bag, but the Teflon is somewhat less transmissive.

Cooker Tests

A series of side-by-side tests of cookers were done. Two CooKits with identical amounts of water were tested side by side, under identical solar conditions. The purpose of such tests is to determine which of the two Cookers is better. One cannot compare results over different days since the solar conditions will be different. Unfortunately, time permitted only two tests with the Teflon and one test with the PFA.

In comparing the oven bag with the new materials, it should be noted that the shape of the bag and the shape of the new material were very different. The bag is a good bit larger than the pot, hence the bag forms a large air gap between the pot and the bag. The Teflon or PFA layer wraps more tightly around the pot, forming smaller air gaps. See the photographs below.

Figure 1: The CooKit with oven roasting bag. Note how the bag forms large air gaps around the pot.

Figure 2: CooKit with 2-ft square sheet of PFA. The sheet is wrapped tightly around the pot, which forms smaller air gaps around the pot.

One might think that a larger air gap would always reduce heat loss because the insulating air gap is thicker, however the situation is more complex than this. Larger air gaps allow the air to circulate more, hence much of the insulating power of the air is lost and the convective heat loss could actually be greater with a larger gap. The radiative heat loss will be greater as the bag area increases. Further, some of the resistance to heat transfer is because the bag's outer surface has limited capacity to transmit heat to the environment. A larger bag will tend to transfer more heat due to the larger surface area. A theoretical study is included later in this report to examine this situation further.

The minimum size of the sheet is 2 feet by 2 feet. To fold the sheet around the pot, center the sheet on the top of the pot and wrap the sheet around and under the pot. The weight of the pot holds the bottom of the sheet. Most of the gaps in the sheet are under the pot or near the bottom of the pot where little warm air will escape. The bulk of the heat loss will be by radiation anyway, regardless of how the sheet is arranged.

Comparing the Teflon system to the bag system, the bag was substantially better. The peak temperature with the bag was 86.5 °C while that with the Teflon was 75.0 °C. Most likely the difference is a result of the lower transmissivity of the Teflon. As stated above, we would expect the tight-fitting Teflon sheet to have lower heat losses and perform better if the transmissivities were equal.

Testing the PFA system against the bag system showed that the PFA clearly outperformed the bag. The graph of temperatures below shows that the PFA system rose to a higher temperature faster, and held that temperature for a long time.

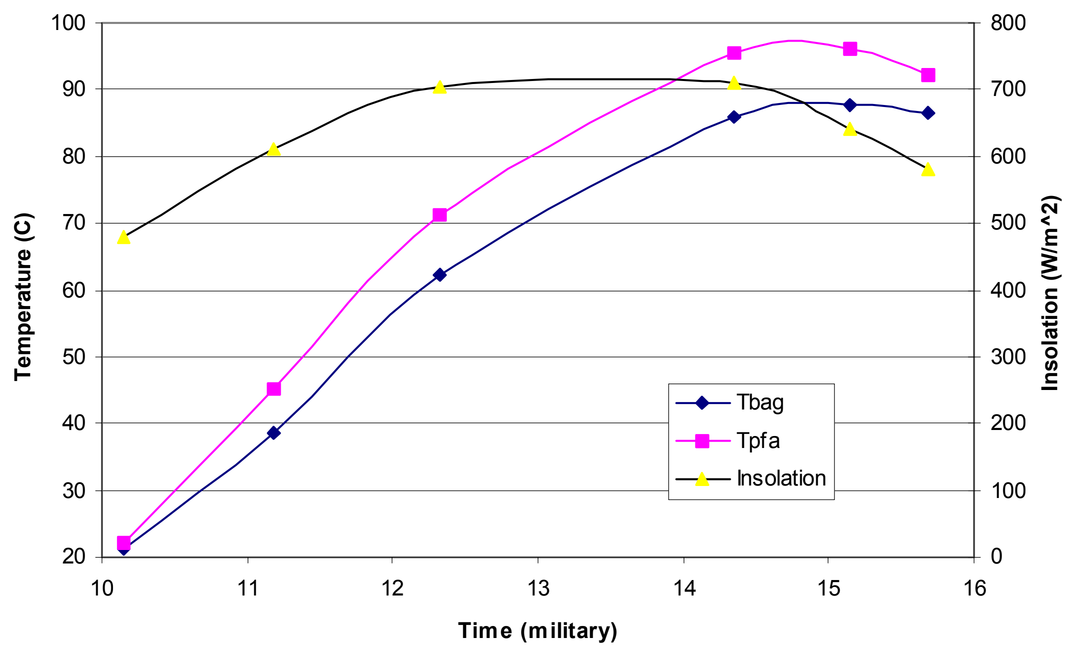

Figure 3: Temperatures for standard CooKit and CooKit with PFA cover.

Since this test was very successful, as few more details are in order. In each test 1897 g of water were used in the pot, and this generally filled the pot. The weather was very sunny all day with light to moderate wind. The insolation measured was perpendicular to the ground, that is, with the pyranometer pointed straight up. The test date was Oct. 6, 2006, and the latitude was 40.1° North. Solar noon was at about 13:20 on the 24-hour clock. The CooKits were rotated twice during the day to track the sun. Temperatures were measured with a thermocouple held about 1 inch above the bottom of the pot, at roughly the pot center. While two thermocouples were used to measure the temperatures, one in each pot, the same measuring instrument was used to read the thermocouple output. Thus, there should be no instrument bias in the results.

Since the PFA and the oven bag have similar transmissivities, I would conclude that the superior performance of the PFA system is due to the reduced heat losses, which is in turn caused by keeping the plastic material close to the pot with a ½ to 1 inch air gap rather than the 1-2 inch air gap seen with the bag.

This leads to an interesting aside. Since the PFA and the oven bag have similar transmissivities, it would seem that one could take a sheet of any clear plastic, wrap it tightly around the pot as in Fig. 2, and improve the performance of the CooKit greatly beyond what it has with the bag. The plastic sheet may or may not last very long, but it should give superior performance.

It appears that the PFA's performance is very good, what about the cost? The 4 square foot sample sheet that was tested cost about $16 from McMaster Carr. A source of less expensive PFA was sought, but could not be found.

A Theoretical Study of Heat Loss

An analysis of the effects of the gap between the pot and the bag was performed. The analysis should be reasonable, but of course contained a number of assumptions. One primary assumption was that the pot was at its likely maximum temperature. The pot was assumed to be 111 °C, with the assumption that the lid of the pot could be above boiling while the body of the pot would be near boiling. Another assumption was that evaporative heat transfer was neglected, which should be good until nearly boiling temperatures are reached. The results are summarized in the following table, which covers the case with no wind. The results with wind were similar.

In the left column of the table is the gap, in meters, given by the symbol L. The next column contains the total heat loss in Watts. The next 2 columns contain the radiative and convective components of the heat transfer, both in Watts, from the pot to the inside of the bag. We see that the bulk of the heat transfer is by radiation, which is usually the case with nominally stagnant air. We see that the convective component first decreases with increasing L, then increases. The total heat loss increases with increasing L.

The next two columns give the radiative and convective components of the heat transfer from the bag to the environment, again in Watts. Again, radiation is the bulk of the heat transfer. The right column gives the bag temperature.

L (m)	Total Heat Loss (W)	Q pot to bag Rad.	Q pot to bag Conv.	Q bag to env. Rad.	Q bag to env. Conv.	T bag (°C)
0.01	83.71	61.04	22.67	48.28	35.43	65.2
0.02	84.51	65.77	18.74	49.12	35.39	61.7
0.03	88.92	68.49	20.43	52.04	36.87	60.0
0.04	93.13	71.02	22.11	54.88	38.25	58.3
0.05	97.14	73.37	23.77	57.62	39.52	56.7
0.06	101	75.56	25.41	60.27	40.7	55.2
0.07	104.6	77.6	27.01	62.83	41.79	53.8
0.08	108.1	79.51	28.59	65.3	42.79	52.5
0.09	111.4	81.28	30.12	67.69	43.72	51.2
0.1	114.6	82.94	31.62	70	44.57	50.0

We see that the bag temperatures are fairly cool. In the real situation there may be hot spots in the bag where it touches the lid of the pot, which could be above the boiling point. If it were the case that the bag degrades only at a few spots and these spots correlate to hot spots on the bag, then it is likely that heat is the primary cause of bag degradation. If it were the case that the bag degrades all over, then it is likely that UV is the primary contributor. (See the later section on plastic longevity testing.)

Longevity Tests on the Plastic Materials

Longevity tests were conducted in Ohio from September 2006 through October 2007. Three situations were tested. A piece of ordinary bag material was exposed to sunlight but kept cool. An ordinary bag was placed around an empty pot and was thus exposed to both light and heat simultaneously. A sheet of PFA was placed around a pot and exposed to light and heat. Early tests were done without any light concentrator, and later tests were done with a concentrator somewhat like a CooKit.

The non-heated bag was outdoors from about the beginning of September 2006 through the end of March 2007. Much of this is in the Ohio winter when there is little sunlight. It appeared to be in good condition and was then placed outdoors again in the concentrator throughout approximately 2/3 of May 2007. By the end of May the bag was shredded and unusable. It was generally shredded all over.

The bag exposed to heat and light was also put outside from the beginning of September 2006 through the end of October 2006. It appeared OK, and was then put in the concentrator in May 2007. By early June it was also shredded all over and unusable.

The PFA sheet was outdoors with a pot and no concentrator through September and October of 2006, then again with a concentrator from early May 2007 through the end of October 2007. The PFA seemed to be unaffected by this usage. While it is expensive it is extremely durable.

While these tests were not well controlled in terms of comparing the materials under identical conditions, one can conclude that light alone is enough to destroy the bag, but that heat and light together are more damaging than just light itself. The bag exposed to light saw slightly less time in the concentrator, but saw 4 more months of total exposure without the concentrator (although much of this was during the winter months).

This raises the possibility of using a close-fitting sheet of some type of inexpensive but UV stabilized plastic instead of the bag. This would hopefully last much longer than the bag, while decreasing the heat loss due to the tighter fit, and at the same time keeping the cost reasonable. The material would need to be somewhat heat-resistant, but would not need the super-high melting point that Teflon and PFA possess. The UV stabilized 3-ply polyethylene/nylon/polyethylene used to make the Aquapak might be a candidate. It is very tough and inexpensive, but has been shown to get tacky at 250 °F.

Conclusions

Materials are available that resist heat and light very well, but the materials tested appear to be expensive.

Light alone will destroy the oven roasting bag, but light and heat together will destroy it faster.

A tight fitting sheet holds heat to the pot better than a loose fitting bag.

Work to be Done

The tight-fitting sheet should be tested under actual cooking conditions. An effort should be made to find materials with better heat and light resistance than the oven bag but at a lower price than the PFA. UV stabilized materials might be good candidates, even if they could not withstand heat as well as the bag. Such materials might last longer that the bag, but probably not as long as the PFA. These materials should be tested for longevity, and also performance.