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Hanwell Anoxibug ®: Testing a Static Reduced Oxygen Environment System for Treatment at the Bodleian Library

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ABSTRACT
Some library and archive collections in the Bodleian Library, due to their composition, conservation history or fragility present a problem in terms of available insect infestation treatment methods. In addition to preservation requirements, reduced resources require methods that are easily affordable and sustainable by various library staff with little or no training in laboratory procedures. The use of Anoxibug® a new commercial oxygen absorber from the IMC Group Ltd's Hanwell range is discussed. The initial trial investigates the effectiveness of the system in killing larval and nymph stages of the insects as well as maintaining suitable environmental control inside the bag. We also discuss the practicality of the set-up and maintenance of the system during the treatment. Finally, the paper will look at how the initial tests are shaping future anoxia control strategies for the Bodleian Libraries.

KEYWORDS: library, pest, anoxia, scavenger

INTRODUCTION

The Bodleian Libraries have been dealing with library and archive pests for over 400 years. During this time, the Libraries have used a relatively small variety of methods for mitigation. To summarise, housekeeping and basic cleaning gave way to various chemicals and fumigation methods until the 1990s when freezing was introduced. We currently use fumigation for building fixtures and fittings and freezing for infested collections. An entire history of our changing approaches to pest management can be seen in our poster, *A History of Pest Management at the Bodleian Libraries*. In 2013, the Library started to research anoxia treatments as an additional method of control due to the fragility and composition of a few illuminated manuscripts and the composition of an early 19th century game board that were found to have insect activity.

ANOXIC TREATMENT BACKGROUND

Anoxia, as a conservation treatment, has been used since the late 1980s and methods and materials have been covered thoroughly in the literature, so the description of the methods and equipment here will be brief. The key idea behind anoxia as a treatment is that the infested object is placed into a bag or enclosure where the oxygen is reduced to levels sufficient to kill all stages of the life cycle for that particular insect. Many studies over the years have looked at insect mortality data and carried out tests to determine effective levels of oxygen and duration of treatment etc. Most studies agree that levels of oxygen below 1% are required for various durations to kill most insects in most situations (Selwitz and Maekawa 1998). Low oxygen levels are achieved using one of 2

ways, dynamic or static methods. A dynamic system uses an inert gas, continually pumped into the enclosure to help displace oxygen. It may or may not include an oxygen monitor which records levels of oxygen to indicate when the gas should be increased or decreased. A static system may also use an inert gas to help maintain low oxygen levels but tends to use periodic or one off purges rather than a continual stream of gas. The most basic static system is one that only uses an oxygen scavenger or absorber to maintain low oxygen levels.

Problems with anoxia

To date, there have been 3 key areas for improvement concerning anoxic treatments. The first is the oxygen permeability rate of the materials used for the container. Historically, plastic films have a wide range of permeability, with PVDC and EVOH polymers exhibiting the lowest rate of permeability and polyethylene exhibiting a higher rate (Yam, 2009). An additional problem is that there has been no simple and accurate way to monitor the oxygen levels inside the enclosure. Electronic oxygen monitors have been expensive and for passive oxygen indicator tablets, the nature and quality of the chemicals that make up the indicator have produced varied results over the years with some of them sensitive to light (Daniel and Lambert 1993). The third reason is the cost of the scavenger. Scavengers used for oxygen reduction have been produced in small amounts and were very expensive. This is why static anoxia systems using scavengers only have mainly been used for very small treatment volumes of 100 L or less (Daniel, Hanlon and Maekawa 1993).

Anoxibug ® system

In looking for an anoxia system that could address these issues, we decided to investigate a completely static system called Anoxibug®. This system was originally designed and sold as ZerO2®. With the addition of additional components in 2013, it was rebranded Anoxibug®. The system is comprised of a readymade enclosure, oxygen scavenger pack, humidity stabiliser and an electronic oxygen indicator. The enclosures are available in bags, tubes or box containers, ranging in size from $1m^2$ up to $3m^3$. The flexible bags used are comprised of polyethylene and aluminium and have an oxygen permeability rate of < 0.006 ($cc/m^2/24hr$). The oxygen absorber is iron based and includes sodium chloride as the catalyst. It comes in 1 kg packets which is capable of removing the oxygen from 1,000 L of air under standard conditions. The manufacturer suggests that one scavenger per m^3 is sufficient to reduce the oxygen level to less than 0.2%, with sufficient spare capacity to cope with small leaks (Smith, 2014). The desiccant sachets are comprised of 36 g of aluminosilicate clay enclosed in Dupont Tyvek® (polyethylene). One unit of desiccant is able to absorb 6 grams of moisture vapour at 40% relative humidity at 25°C. The electronic oxygen monitor can either be ordered as an indicator or a monitor. The indicator version flashes red when oxygen levels exceed 0.2% and green when levels are below 0.2%. The monitor version records oxygen level percentage during the treatment and the information can be shown in graph form. RH and temperature monitoring devices are optional but can also be added inside the enclosure as each one is fitted with a clear inspection window for the oxygen indicator.

Anoxibug® tests

Having researched the system components and literature thoroughly, we decided to test its application before using it on priceless library collections. We designed simple practical tests to investigate the system's efficacy in terms of operation, mortality rate, bag stability, environment and effect on library and archive materials.

Test 1 Experimental design and method

The larvae of two separate pest species were used in our tests: *Dermestes maculatus* (leather and hide beetle) and *Anthrenus verbasc*i (varied carpet beetle). Leather beetles have been found to

attack leather bound volumes as well as parchment such as our limp vellum bindings. Carpet beetles have been found to attack wool felts used in conservation treatments and box linings as well as leather, fur and hair in archive materials. The insects used in our tests were reared at the Food and Environment Research Agency, a research department of DEFRA (Department for Environment, Food and Rural Affairs). They provided 20 leather and hide beetle and 20 carpet beetle larvae.

Materials chosen for use in the tests included representative library and archive materials including paper, parchment, vellum, leather (both tanned and untanned), silk, cotton, wool felt and book cloth (Table 1). The materials were acclimatised in the lab for a period of two weeks at 45% RH and 20°C with a total final weight of 152.50 g (Table 2).

The larvae were placed inside a 1 m^2 bag along with our representative materials, the 1 kg package of oxygen scavenger, 4 RH stabiliser pouches totaling 144 g, 1 electronic oxygen indicator sensor and 1 RH and temperature data logger. The experiment was carried out for the suggested 30 day duration according to manufacturer instructions. The scavenger was placed directly on the floor of the bag with the electronic oxygen indicator and temperature and RH data logger placed on the opposite side of the bag. The treatment was carried out for the suggested 30 days duration.

The bag was left on a flat surface in the lab and the ambient RH and temperature recorded using a data logger.

Test 1 Result and discussions

Several members of library conservation staff and staff representatives from a nearby museum were present for the preparation of test 1. The preparation was found to be simple, fast and the instruction was coherent. Creation of the bag for test 1 took one person 15 minutes to complete. Checking the oxygen levels during the test was also simple, as the oxygen monitor was placed in the inspection window of the bag and one merely had to glance at the window in passing every day to check the indicator was flashing green.

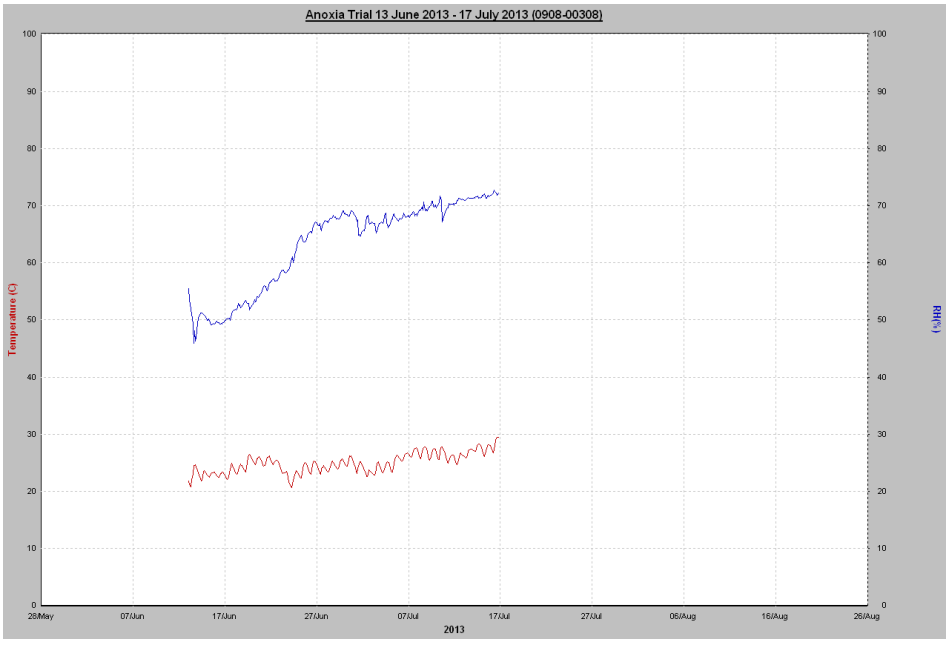


Figure1*: Test 1 RH / T anoxic package*

Effect on materials and insect mortality

At the end of the test, the bag was cut open and the materials were removed and examined. The larvae were separated from the material samples and the samples weighed and found to have gained 7.5 g in moisture (Table 2). Several scraps of the wool felt, leather and silk had signs of being nibbled but otherwise the materials retained their original visual appearance and flexibility.

100% of the larvae were recovered from the materials and 100% mortality was observed for all insects. One carpet beetle larvae had developed into an adult beetle at some point during the 30 day treatment, not surprising as the pupal stage is 10 - 17 days. For the leather and hide beetle samples, all were regained in the larval stage, not surprising as this stage is longer (60 to 70 days). The materials, larvae (and beetle) were kept and studied for signs of life for 2 months after the treatment with no reanimation occurring. Mortality in the insects was confirmed periodically by viewing under a stereo microscope.

Environment

The oxygen monitor was checked on a daily basis during the experiment and the indicator showed that the concentration was reduced to < 0.2% and maintained for the duration of the test. The ambient RH and temperature logger was downloaded (figure 1) and showed no diurnal effects. According to manufacturer instructions, after about two hours, the internal temperature of the scavenger will start to rise as the reaction progresses and should last for 24 hours. We confirmed this by placing our hands on the plastic bag on top of the scavenger and could feel the heat from the reaction on the first day but could no longer feel any heat by the third day of the test. After the test, the scavenger resumed its reaction once the bag was cut open and it came into contact with oxygen in the open air of the lab. Using a Rotronic probe, we measured a maximum surface temperature of the scavenger, in open air, at 53°C. Figure 2 shows the RH and temperature recorded in the Anoxibug® package over the duration of the 30 day treatment. We recorded an initial temperature of 21° C (same as the ambient lab environment) followed by a quick spike to 25° C in the temperature which then ranged between 24 - 29°C during the remainder of the test.

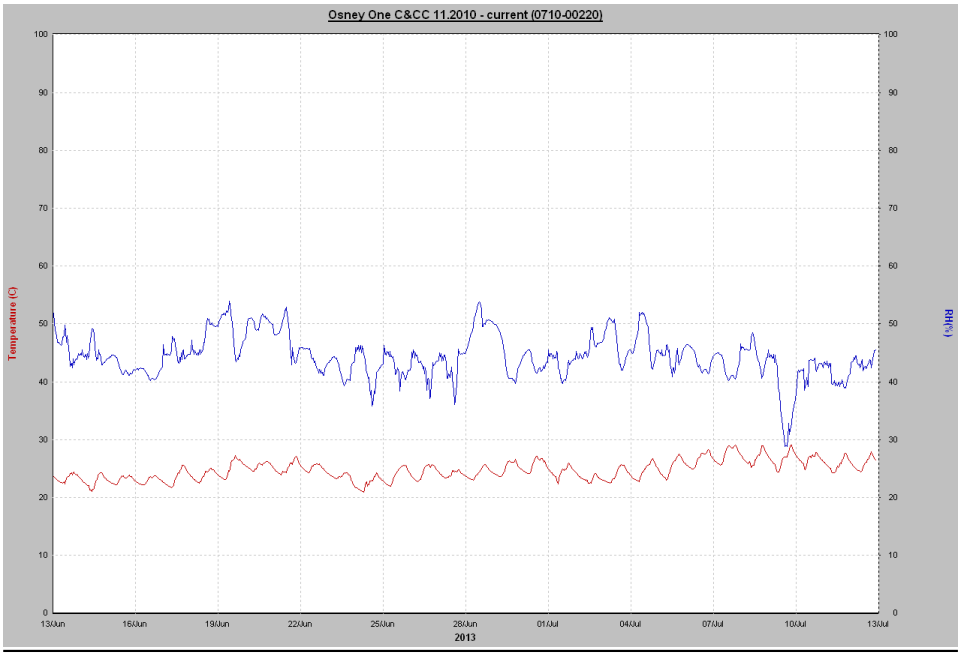


Figure 2: *Test 1 Ambient RH/T in conservation workshop*

The RH inside the enclosure shows an initial RH of 45% that matches our ambient lab RH. The RH then shows a small jump to 50% and then a gradual rise over the duration of the test period to a maximum 72%. The RH results were a bit surprising as we had expected from product literature to obtain an average RH of 68% or lower. We also expected the environment to reach equilibrium and the RH to settle based on the water content of the objects inside the enclosure so our continued rise in RH was curious. Elevated RH inside the bag could only be coming from a limited number of sources. The oxygen indicator showed throughout the test period that the bag was sealed so there was no ingress of ambient room RH or temperature. Even so, the relatively dry ambient RH in our lab and modest temperatures could not be contributing and there were no appreciable diurnal changes that would account for the results inside the bag. Either the library skins and textile materials were releasing moisture into the enclosure or the oxygen scavenger and / or desiccant

were contributing to elevated RH. The fact that the library materials gained in weight suggests that they were not the source.

Test 2 Experimental design and method

As the first test confirmed the basic ability of the test to maintain a low oxygen environment using scavengers only which resulted in a 100% mortality rate, we turned our attention to the elevated RH results inside the enclosure. We designed a second test to isolate the variable of the library and archive materials. The same materials were chosen as used in test 1 except this time we tested two identical groups of material, a control group 2a and a test group 2b. Both groups were allowed to acclimatize at room temp and RH for 2 weeks at 40-42 % RH and 20-21°C.

Immediately preceding the anoxic test, both groups were weighed. Group 2a materials weighed 152.72 g and group 2b materials weighed 152.83 g. Group 2b materials were then dried in an oven at 100°C for 10 minutes to drive off excess moisture. Both groups were then reweighed; with group 2b losing 7.3 g (Table 2). The desiccant packs were weighed prior to the test and each weighed 36-38 g. Both groups were placed into 2 separate but equal 1 m^2 Anoxibug® systems containing a 1 kg oxygen scavenger, 4 desiccant sachets, the electronic oxygen level indicator and an RH / temperature monitor.

Table 1: Materials used in tests	
Test 1 and Test 2 Group A Material	Weight (g)
Wool felt	37.0
Silk	5.0
Goat tanned leather	9.0
Harmatan Sokoto Nigerian	8.5
Calf- alum tawed	45.0
Sheep Parchment	4.0
Calf Parchment	4.5
Paper lined silk	10
Grey Book cloth	9
Cotton	6

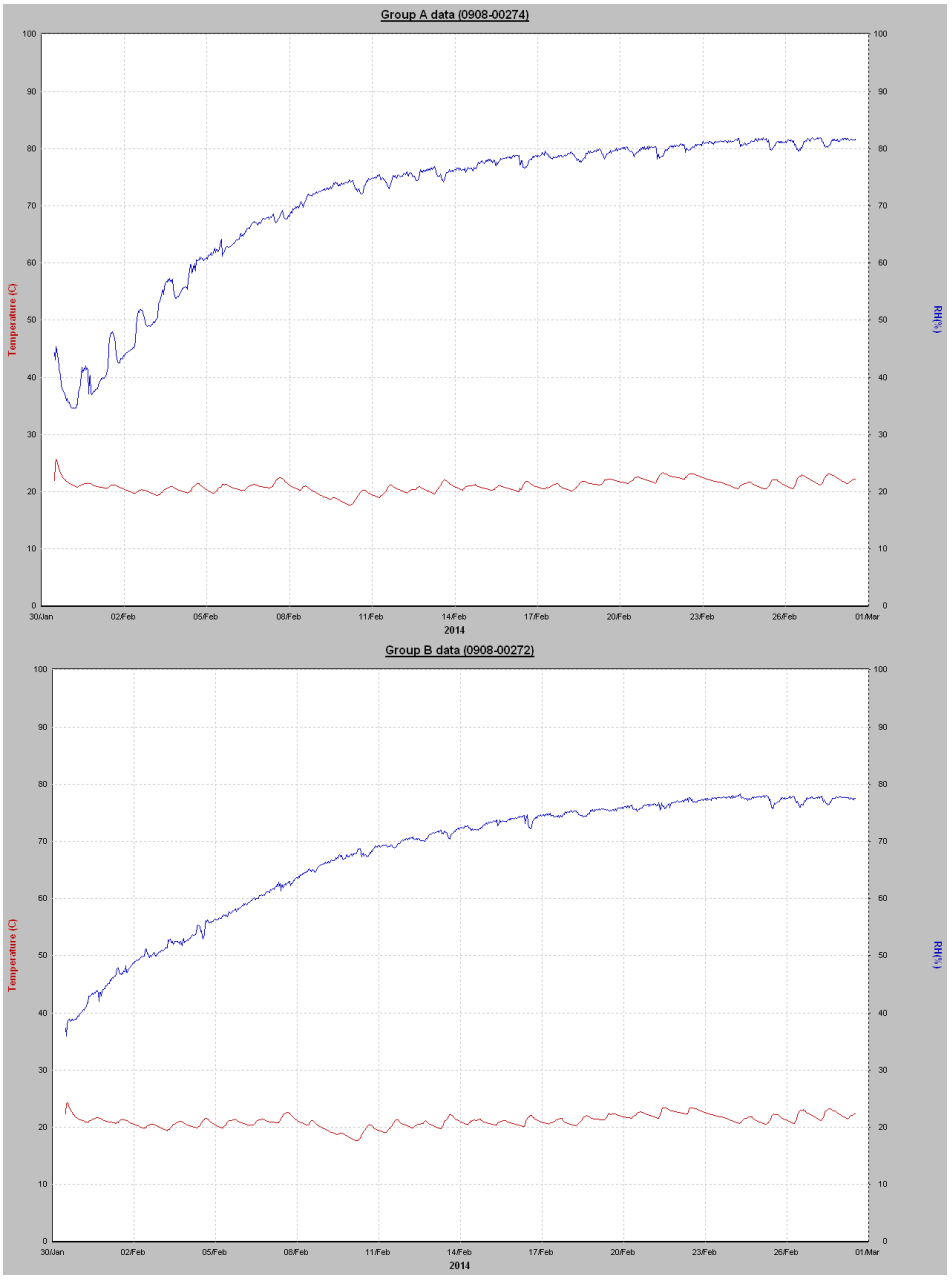
Table 2 : Total weights of library materials before and after tests			
	Test 1	Test 2a	Test 2b
Weight prior	152.50 g	152.72 g	152.83 g
Weight after drying in oven	n/a	n/a	145.51 g
Weight after test	160 g	162.71 g	207.76 g

Test 2 results

Effect on materials

After 30 days, group 2a materials were removed from the anoxia package to be weighed. It was immediately apparent that the materials were slightly damp to the touch. The new total weight for the group 2a materials was 162.71 g, which equates to a gain of 9.99 g. Furthermore, group 2b materials dried in the oven were very damp to the touch and had gained 62.25 g in moisture (Table 2). The significant increase in weight of group 2b materials was surprising as we would have expected them to gain approximately 17-18 g of weight, the sum of the initial loss of 7.32 g plus the same gain as group 2a (9.99 g). Again the weight gain in materials suggests that they were not the source of the increased RH. Also, if the materials were releasing moisture then we would have expected to see a greater increase in RH inside the group 2a package as 2b had been dried off in the oven.

The desiccant was reweighed and showed a slight increase in weight from 36 g to40 g which indicated that, they too, could not account for the release of moisture inside the package. Considering that 1 unit should absorb 6 g of weight, this also indicated that the desiccant was not working as expected.



As with test 1, both packages were kept in same room and in the same location throughout the test. Ambient room monitors showed no marked diurnal temperature or RH changes (Figure 3). The electronic oxygen level indicators were checked every day of the test and indicated an oxygen environment of <0.2% and that there was no leakage over the test period.

***Figure3**: Test 2 RH and temperature monitoring results for Group A (top) and B (bottom) anoxic packages*

The data logger graphs for test 2 show

that RH and temperature measurements inside the enclosure (figure 4). There was a slight temperature increase as the reaction starts but then levels settle to a stable 20-22°C. At the beginning of the test, the RH inside the enclosure was 43%, with an initial drop in first 24 hours to 34% followed by a gradual rise over the next 20 days where it levels off at 82%. An overlay of the graphs shows the exact same trends between the group 2a and 2b packages. Group 2b is slightly lower but after 21 days it levels off at 77-78%.

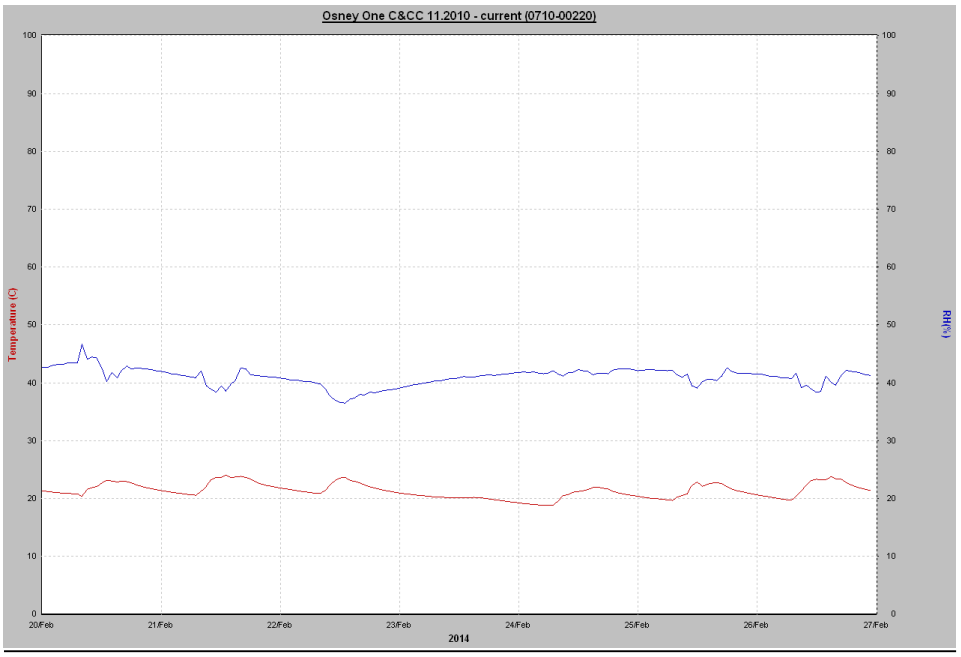


***Figure 4**: Test 2 ambient RH/T. (final week recorded data, first 3 weeks visual guide from sensor)*

Test 3 Experimental design and method

As test 2 confirmed that the materials could not be contributing to an increase in RH, we considered the fact that the oxygen scavenger could be releasing excess moisture. The desiccant provided was either supplied in insufficient amounts or could also be releasing moisture back into the package. In order to test this, we decided to remove another variable and carry out a control test on an empty bag. For Test 3, the bag contained only the scavenger, an oxygen sensor and the RH / temperature logger. By isolating the scavenger as the only variable, we hoped to clearly see if the scavenger reaction was releasing excess moisture into the enclosure. At this point, we consulted the designer of the system and asked if elevated RH had been reported by any other users of the system, and it was confirmed that this problem had not been reported (Smith, 2014).

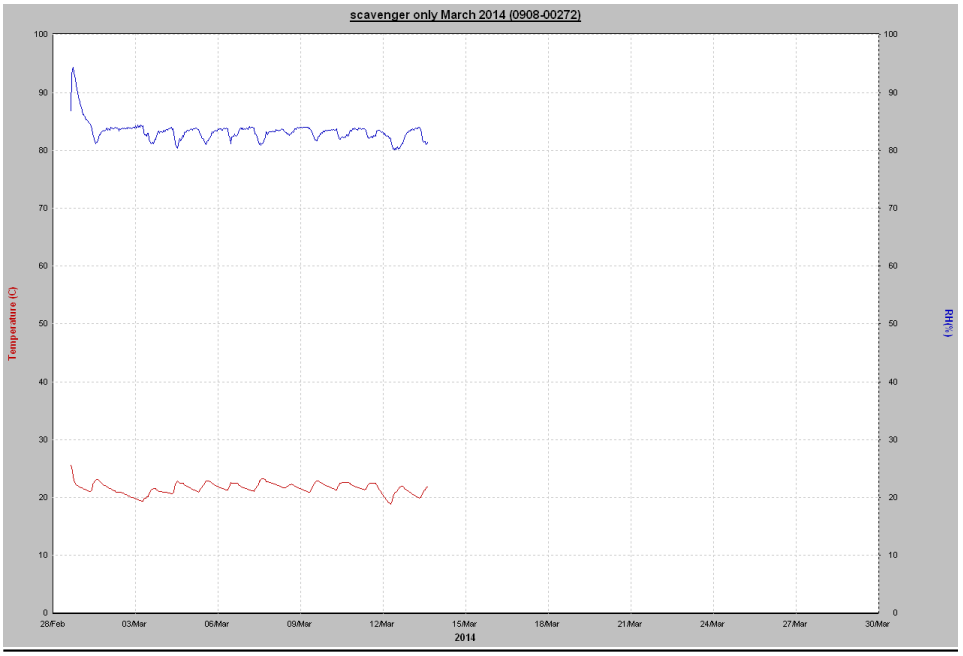


***Figure 5**: Test 3 RH and temperature monitoring results anoxic package*

Test 3 Results and discussion

As with previous tests, the electronic oxygen level indicators were checked every day and indicated an oxygen environment of <0.2% and that there was no leakage over the test period. The ambient logger showed that there were no appreciable diurnal effects in the room to affect the results inside the enclosure.

Figure 5 shows the logger graph results for test 3. The temperature at the start of the reaction is 26 and fluctuates between 23°C and 19°C for the duration of the test period. At the start of the reaction the RH inside the enclosure is 86% and drops to 83% in the first 24 hours where it remains constant for the remainder of the test period. This confirmed that the reaction itself was responsible for the high RH.

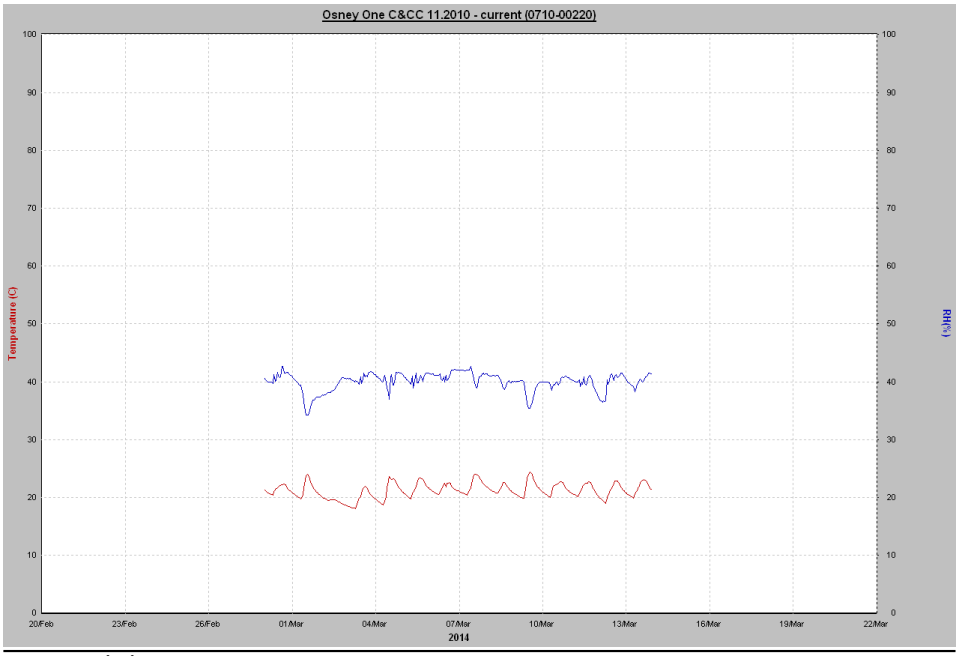


***Figure 6**: Test 3 Ambient RH/T Conservation Workshop*

Colin Smith confirmed that the RH results for test 3 were high and that he had only found these results in the developmental stage of the products before the correct scavenger was found but had not experienced this in field trials or later use.

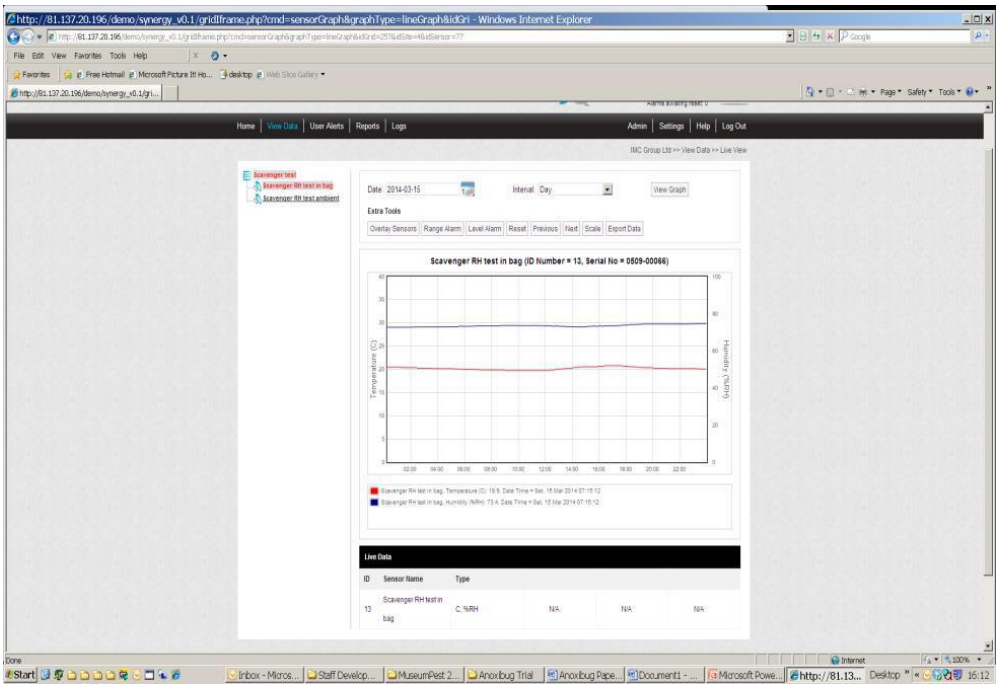


***Figure 7**: IMC Group RH test results*

He also confirmed the average of 68% RH from his testing procedures when developing the system (Smith, 2014). This prompted Hanwell to run their own control test using the same set up as in our Test 3. The results of their test show a similar result (Figure 7). The RH inside the enclosure starts at 84% and drops to 80% where it remains constant.

CONCLUSIONS AND FURTHER RESEARCH

It has already been documented in the literature that scavenger surface temperatures can reach temperatures as high as 46°C. During our experiments, we measured a higher scavenger surface temperature of 53°C and Smith (2014) confirmed temperatures in excess of 60° C in open air. This confirms that care should be taken to avoid direct contact with sensitive library and archive materials (e.g. wax seals, acrylic paints, encaustic paints and some adhesives). The rise in temperature inside the bag, although inconsistent from test 1 to tests 2 and 3, is of less concern. This initial short spike and following slight elevation in temperature for the duration of 30 days is acceptable to the libraries.

Our initial tests suggest that the system releases moisture and affects RH above the average suggested by the designer, and other users of the system. They also suggest that the scavenger is responsible for the release in moisture and that the desiccant may not be working at full capacity. The weight increase in materials and desiccant show that they cannot be contributing to the moisture levels. All three tests showed a gradual and sustained rise in RH inside the enclosure to levels that present a risk for library and archive materials. Sustained RH above 65% could be a concern for mould growth as some moulds can grow in extremely low oxygen levels of 0.5 % and any defects in the packaging could cause oxygen levels to rise to this amount. Probably of more relevant concern is the fact that high RH levels can cause RH induced damage in some constrained composite materials or materials that have been previously conditioned at lower relative humidities. Anoxibug® is used by 7 museum, galleries and trusts across the UK and high humidity has not been reported to the manufacturer as an issue. For this reason, it is thought that, at worst, our experiences are an anomaly, due to an inconsistent batch of scavengers, a failure of the desiccant, or both.

NEXT STEPS

Despite these initial concerns highlighted by our tests, the Anoxibug® system still combines a number of advantages to make it a cost effective anoxia treatment. To start with, it the oxygen absorber supplied is on a much larger scale than other systems, allowing for treatment inside a larger space. The need for cylinders of nitrogen and humidification systems is avoided with this static system which reduces the health and safety risks and also makes training non laboratory staff easier. The pre-made bag of suitable oxygen permeability in modular sizes can be reused for additional treatments. The system comes with a low cost electronic oxygen monitor.

The disadvantages of moisture production resulting in high RH, appear to be easily solvable by increasing the amount of desiccant or simply designing in a different desiccant altogether. What is clear for the Bodleian however is that further research is required before we can wholly adopt this system as part of our treatment program. Freezing continues to be our primary treatment method. We will continue to test Anoxibug using additional batches of scavengers and desiccant in addition to testing alternative desiccants. The system was originally designed using activated clay as the cost is so much less than other desiccants per kg. One could replace it with even the most expensive silica gels and still retain the overall low cost system. Finally, and probably most importantly what our test show is that when thinking about using a new methodology, to test the products thoroughly before use. Our trial shows some possible supplier inconsistencies which reminds us all that batch testing is beneficial.

REFERENCES

Braga, L.R.; C.I.G.L. Sarantopoulos; L. Peres and J.W.B. Braga. 2010. Evaluation of absorption kinetics of oxygen scavenger sachets using response surface methodology. Packing Technology and Science 23 (6):351.

Daniel, V.; G. Hanlon and S. Maekawa. September 1993. Eradication of Insect Pests in Museums Using Nitrogen. WAAC Newsletter 15 (3):15-19

Daniel, V. and F.L. Lambert. May 1993. Ageless oxygen scavenger: practical applications. WAAC Newsletter 15 (2):12-14.

National Parks Service. 1999. Anoxic Microenvironments: A treatment for pest control, Conservogram Number 3/9.

Selwitz, C. and S. Maekawa. 1998. Inert Gases in the Control of Museum Insect Pests. Los Angeles: The Getty Conservation Institute.

Rust, M.K.; V.Daniel; J.R. Druzik and F.D. Preusser. 1996. The feasibility of using modified atmospheres to control insect pests in museums. Restaurator 17: 43–60.

Smith, Colin. Director of Colin Smith Conservation Ltd. (retired), personal communications, March 2014.

Smith and Newton 1991

Yam, K.L, ed. 2009. Encyclopedia of Packaging Technology. New York: John Wiley and Sons.

MATERIALS AND EQUIPMENT

Anoxibug® system (inclusive of bag, oxygen scavenger, desiccant, electronic oxygen indicator, RH and temperature logger)

IMC group/Hanwell
Ltd.
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688070

Larvae (Athrenus *verbasci* and *Dermestes maculatus)*

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