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Detection Of Hidden Insects in Museum Objects by Carbon Dioxide Measurement Using FTIR

A quantitative method using FTIR spectroscopy was proven successful as a mean to detect the presence of insect in art objects by measuring the CO_2 respired by insect. CO_2 measurements from individual insects and selected infested art objects are presented. This technique allowed an unambiguous detection of insect infestation within 3 hours.

Introduction

Infestation is major threat to the preservation of organic materials due to the irrevocable damage caused by the insect feeding on the materials. Effort to minimize the damage as well as to prevent the spreading of infestation can be achieved through prompt action of isolating and performing insect eradication treatment on the infested objects.

The ability to recognize the presence of active infestation, however, requires trained eyes and experiences. In some cases, infested objects are easily identified due to the presence of live insects on and around the objects. In most cases, however, we can only find indirect evidences of insect remnants such as pupal casings, frass, or evidence of insect attack. Without being familiar with the regular condition of a particular objects, it is often difficult to assess whether these evidences comes from old or active infestations.

The most conservative measures to prevent a wide spread infestation is by treating every questionable objects. Despite this conservative measure, however, there is no accurate method to evaluate the effectiveness of the treatment itself.

One way would be to isolate the treated objects for a period of time deemed safe in order to observe if there is any new development of insect activity. Unfortunately this method restricts the accessibility of the objects for some time and therefore is not an option when the object is soon needed for exhibition. Another solution, which is proposed by this study, is to use a detection system as an objective mean to perceive the presence and absence of life insects.

There have been various studies investigating means of insect detection, particularly in the field of agriculture. Some of these means included sound waves, X-rays, chemical reagents, microwaves, nuclear magnetic resonance, and FTIR. Among these, the FTIR method has the most potential in its application for art objects because of its non-destructive quality.

LN_2-cooled-InSb FTIR sytem (the second system).

FTIR Respiration Systems

All living things, throughout their life cycles, respire and give off CO_2 When an infested object is placed in a closed environment, the CO_2 level will increase over a period of time. FTIR system allows the rise of the CO_2 level to be measured at interval periods. The study presents data from two models of

Bomen FTIR systems. Both models operate with a detector optimized in the mid- infrared region from 1700 cm^{-1} to 4000 cm^{-1}, covering the highest absorption peak of the CO_2 that falls around 2330 cm^{-1}. The two models are equipped with a computer for data reduction and analysis, and control of the valving system. A flexible chamber is created to enclose objects using Mylar coated aluminum sheets that are heat sealable. A pump with adjustable speed was used to circulate the air inside the bag into the IR analyzer.

The main differences of the two models lie in the temperature needed for the detector to function properly and the limit of the detector's sensitivity. The detector in the older model operates in ambient temperature and therefore has the advantage of being able to perform continuous reading of CO_2 for days.

The current model employed an InSb (Indium antimony) liquid Nitrogen -cooled detector. Each run of measurement was limited to four hour maximum due to the heating up of the cell. Every four hours, the cell required re-cooling. The sensitivity of the current model, however, is much greater than the old one. The older model of the FTIR is sensitive in the parts-per-million (ppm) range for CO_2 whereas the current system is able to detect CO_2 in the parts-per-billion (ppb) range. The higher sensitivity of the current system as a result, allows detection of changes in CO_2 level in shorter periods of time.

Experimental Standard Measurement

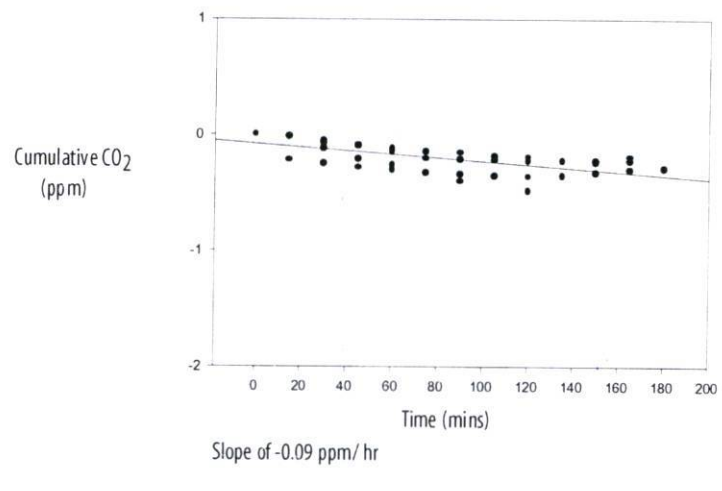
The first step in this study is to performed experimental standard measurement on the current system which will serve as the background data from which other data will be compared. The background study of the old model is not presented here because it has been covered in previous publication. Some data from the old models are selected to reinforce the result gathered from the new FTIR model. The following data, except for two which I will point out, are from the current model.

The behavior and sensitivity of the cell without pump were measured repeatedly. The cell was cooled with liquid nitrogen and then left to stabilize for the next 30 minutes. Measurements are taken 30 minutes after cooling and then at regular 15 minute intervals. The time 30 minutes after cooling was designated as time 0. The measurement taken at time 0 is also assigned as 0 ppm. The change of CO_2 reading over time is calculated and added as cumulative effect. Figure 1 presents the plotting of several set of data, each from a different day of the cumulative CO_2 versus time from 30 minutes to 180 minutes. This time period is chosen because it yielded the most consistent results. Linear regression line test was done and resulted in a decreasing slope of about –0.1 ppm / hour.

4 L and 3 L volume of empty aluminum sheet bag was used for standard measurement of the cell variability combined with the pump. The speed of the pump were adjusted depending on the size of the bag in order to ensure thorough mixing of the air circulating through the bag and the IR cell analyzer before each measurement. So far there seemed to be no difference in the behavior of the cell with pump when measuring 4 L bag or 3 L bag. Measurement is taken 30 minutes after the pump is turned on and every 15 minutes of pumping time intervals. For each measurement, the pump was first turned off, the valve isolating the environment in the IR cell analyzer from the tube connecting to the bags are closed, and measurement was taken after 2 minutes wait for the air current to stabilize. Figure 2 showed the plotting of cumulative readings of CO_2 over a period of two and a half hours from several sets of data that were done in different days. Linear regression line test of these data resulted in slope of about -0.4 ppm / hour. Comparison of the two slopes shows that the pump had a negative effect on the CO_2 detection. The negative effect of the pump could be the result of CO_2 absorption by the tygon tubing.

Figure 1

Cell Variability



Measurements From Life Insects

The measurement of the cell and the cell with pump variability are used as standards against which measurement from life insects were compared.

The respiration of one silverfish (Lepisma saccharina) was measured for two and a half hours. Silverfish are pest of paper and textiles. They are fond of starch and sizing on papers and fed on regenerated cellulose material and linen. The young and adult of silverfish are alike and only vary in proportion. The data plots and the regression line test that resulted from the measurement of an adult silverfish shows no positive increase in CO_2 (Figure 3). The slope

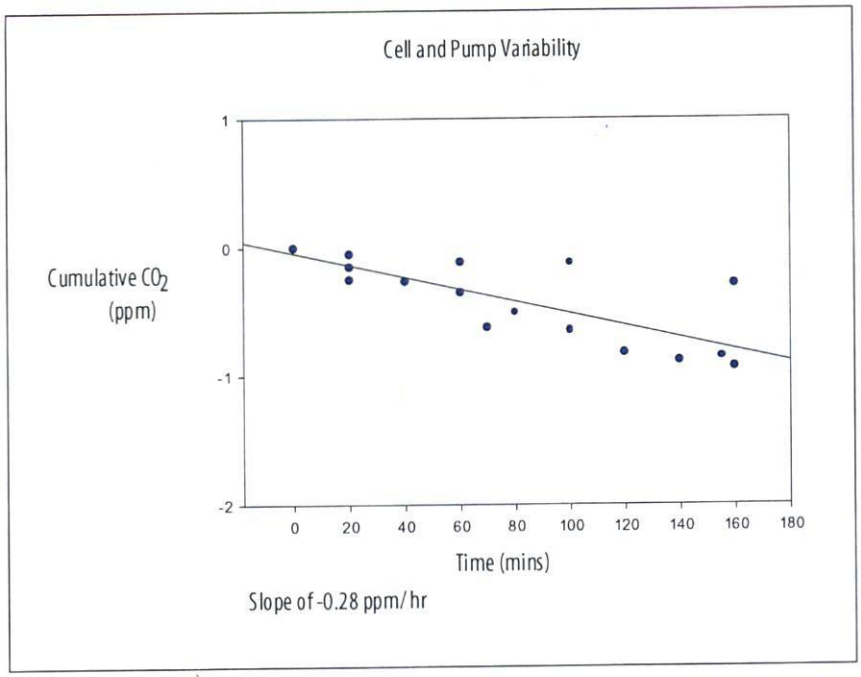
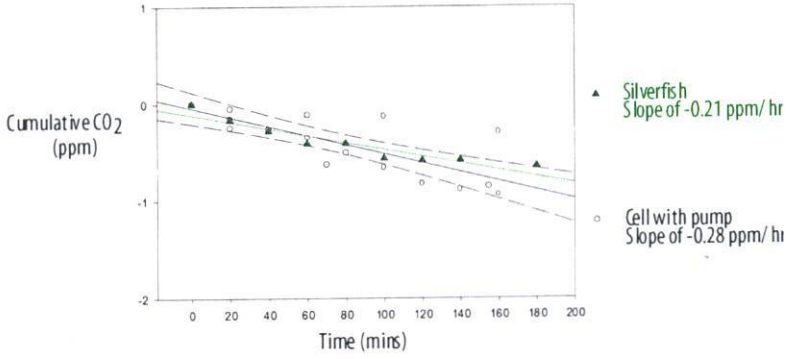


Figure 3

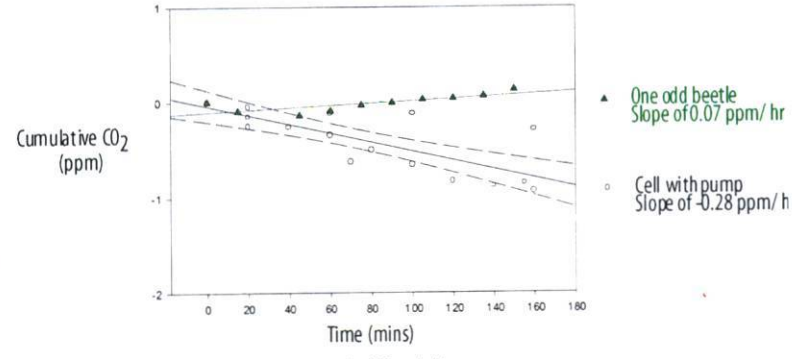
Respiration of one Silverfish



Respiration rate of 0.07 ppm/ silverfish/ hr

Figure 4

Respiration of one Odd Beetle Larva



Respiration of 0.35 ppm/ odd beetle/ hr

is about -0.3 ppm / hour. Although there seemed to be a slight increase in the positive direction when compared to the regression line of the cell with the pump, it still fell within the background noise of the cell and the cell with the pump. Therefore we concluded that the presence of one silverfish was not detectable.

When the respiration of one Odd Beetle larva (Thylodrias contractus) was measured (Figure 4), the behavior of the resulted line test was quite different from that of the silverfish. The data plots shows a decreasing tendency for the first 40 minutes but then reverses toward positive direction. The initial downward trend is probably the result of the mixing action of air inside the bag. The regression line test resulted in a positive slope of about 0.1 ppm / hour. After one and a half hour, the presence of this insect is detectable.

It is clear that the respirations measurement of the odd beetle larva is very different from that of the silverfish. This difference illustrates that different type of insects and probably at different stages of their lives respire at different rate. It may therefore be possible to roughly categorize the state of infestation by first measuring the slope of the CO^2 increase and then taking into account the respiration rate of that particular insect type. Based on these two factors, the state of infestation can be categorized into low, medium and high. Further respiration measurements from different types of insect would therefore be very valuable and informative.

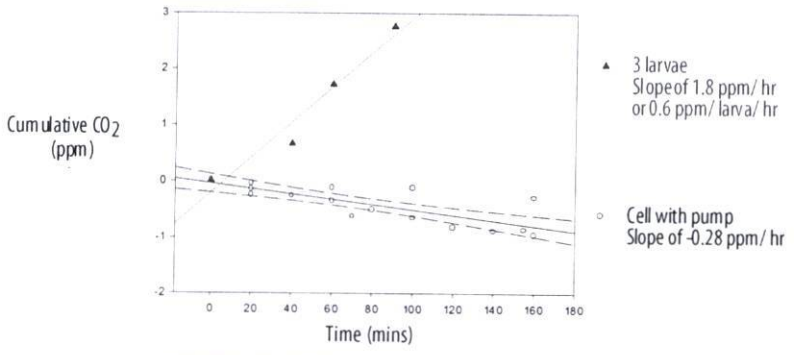
The data from the respirations measurement of the silverfish and the odd beetle larva shows that different type of insects, and probably at different stages of their lives, respire at different rate. When the respiration of 3 varied carpet beetle larvae (Anthrenus verbasci) was measured, the data showed a very pronounced positive slope of 1.8 ppm / hour (Figure 5). The respiration rate of one larva is therefore calculated to be 0.6 ppm / hour. The

presence of the three larvae was clearly detectable within an hour. This result is very encouraging because it tells us that we could expect a more dramatic CO_2 increase in infestation cases where there are usually more than three insects.

With the older FTIR model, we were able to measure CO_2 level continuously for days because the cell can operate in ambient temperature. Figure 6 shows the respiration activities of 20 termites over a period of 40 hours. Two runs are being showed. The first run clearly showed that termites the diurnal cycles of the termite – they seemed to be active in the morning and less active at night. This type of behavior is important to note because for our current system where now we are focusing in such a very narrow area it gives us clue as to whether we are measuring the high time or low time. The second run shows less of a slope with more even pace activity because at this time the termites were more dried out and they were probably more stressed. Based on this data, it was approximated that one termite produces 0.1 to 0.2 ppm / hour. It is interesting to note that the respiration of silverfish appear to be very similar to that of termite.

Figure 5

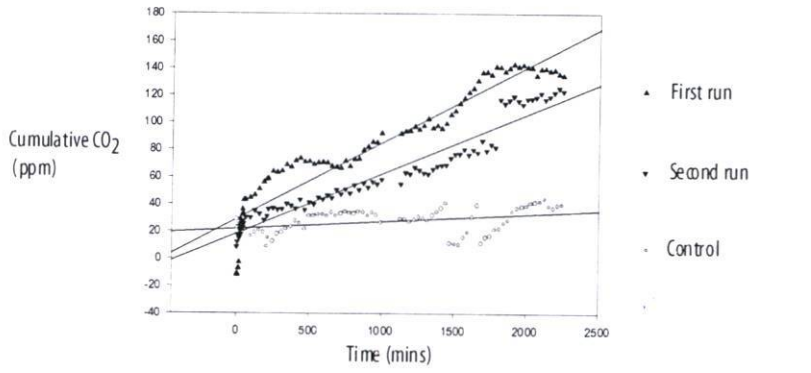
Respiration of Three Carpet Beetle Larvae



Respiration rate of 0.65 ppm/ larva/ hr

Figure 6

Respiration of 20 Termites (Reticulitermes sp.)



Detecting Infestation In Art Objects

We next proceeded to implement the FTIR system as an assessment measure on the state of infestation of art objects. Pieces from a 20th century frame with many insect holes and frass were measured (Figure 7). The frame pieces have been sitting in the lab for several years untreated. During those period there has not been any sign of new insect activity, therefore we felt that the holes and frass are the leftover from past infestation that now no longer active. The result of the measurement of the pieces showed that the cumulative CO_2 level over time is a negative slope of about –0.25 ppm / hour. We concluded that the pieces are not infested. This conclusion confirms our initial assessment based on visual monitoring of the regular condition of the pieces for the past several years.

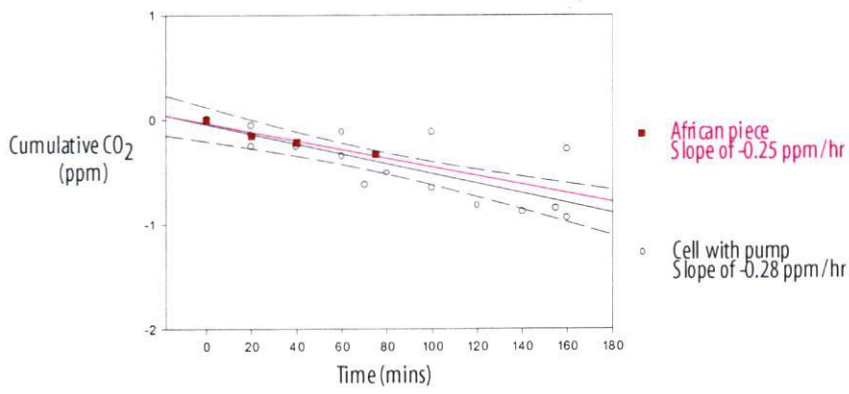
For some objects, however, we have no access to its past historical condition, as with the case of an African piece on loan from a museum in France. The object was a composite materials of metals, glass beads, bones, animal hairs, textile and elephant tails. There were holes on the textiles and some deterioration on the animal hairs that were suspected to be the result of insect activity. This is an example of a case where we have no access to the past history of the condition of the object. Neither frass, nor insect remnant are found on and around the object. As with the case of many ethnographic materials, however, there are many areas, for example in between the tufts of hair where we could not see what is going on. The result of measurement from this piece, shows no increase of the CO_2 readings (Figure 8) The regression line is about –0.32 ppm/hour, very similar slope to that of the frame pieces. We concluded that the pieces are not infested.

At present there is no data yet available from measurement of infested objects with the current FTIR system. Therefore a case study from the old FTIR system will be illustrated instead.

A framed painting by Andrea del Sarto was brought to the lab for infestation treatment. Concern for infestation was raised based on the tell tale signs of new insect holes on the frame and accumulation of frass over time. Measurement using FTIR confirmed that the painting was indeed infested. Anoxic treat-

Figure 8

Measurement of an African Piece



Measurement of 0.03 ppm/ hr

ment with nitrogen based on the guideline by the Getty was then performed on the painting.

A year later, it was discovered that the treatment had failed and the painting was still infested. It was treated again, this time, argon was used and the time period of suffocation was extended to four weeks. After treatment, the painting was measured with FTIR and this time the result showed no sign of increase in CO_2.

This treatment was done a few years ago and it has not shown any sign of new insect activity since.

Conclusion

FTIR provides a simple and fast way to determine the presence and absence of insect in art object. The system is useful to assist conservators and art caretaker in identifying infested objects. It also equips them for testing the effectiveness of different insect eradication treatments. The speediness of the process, requiring less than three hours, is also an advantage to circumvent the longer and unnecessary treatment for some questionable objects. Last but not least, they enabled testing the effectiveness of insect eradication treatments. Once objects have shown to be no longer infested, they can be safely put away in storage or exhibition without posing a danger to itself and others.

Acknowledgement

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References

Bruce, W.A., and M.W. Street, Jr. (1974). Infrared CO_2 detection of hidden insects. Journal of the Georgia Entomological Society 9(4):260-5.

Koestler, R.J. (1993). Insect eradication using controlled atmospheres, and FTIR measurement for insect activity. ICOM Committee for Conservation, 10th Triennial Meeting, Washington, D.C. Vol. II:882-886.