Flexible thermal blanket and low pressure envelope system in the structural treatment of paintings on canvas

2 authors:

Tomas Markevicius
University of Amsterdam

Nina Olsson
IMAT Project

The AIC Painting Specialty Group

POSTPRINTS

VOLUME TWENTY-THREE 2010

The American Institute for Conservation of Historic and Artistic Works

AMERICAN INSTITUTE FOR CONSERVATION OF HISTORIC AND ARTISTIC WORKS

NINA OLSSON AND TOMAS MARKEVICIUS

Flexible Thermal Blanket and Low Pressure Envelope System in the Structural Treatment of Large Scale and Traditional Paintings on Canvas

ABSTRACT

Thermal applications are some of the most common treatments in the conservation of paintings. Increased area of treatment makes even heating problematic and since the 1950s metal heating tables have been used. In most cases, they constitute a heavy duty device, which is limited in its application size, can be used almost exclusively in a fixed location, and is relatively expensive. The often slow response, temperature fluctuation, and uneven heat distribution do not comply with the current treatment methodology, which demands increasingly accurate and selective heat application along with mobility and versatility. The proposed experimental method, using a mobile and fast responding thermal silicone rubber blanket, offers versatility and precision and could be successfully used as an alternative to heating tables. The paper examines the method in use and the results of diverse case studies.

INTRODUCTION

Throughout the history of conservation various methods have been employed in an attempt to gain the desired control over the heat distribution during treatments, achieving variable degrees of success: from the heated sand poured by Pietro Edwards in 18th-century Venice, to hand-held irons and various electrical and digitally controlled sources.

During the 20th century, the search for an efficient heating device seems to have been driven initially by the diffuse practice of impregnating paintings with wax resin, and later, from the 1950s onwards, this search was sustained by the introduction and the growing use of thermoplastic resins. In particular during the period between the 1970s and the 1990s the technologies developed rapidly to serve the increasingly common practice of lining.

Yet more recently, the key issues in conservation practice have become minimal intervention, retreatability and preservation of the multifaceted aspects of an object's authenticity and integrity. Extensive treatments such as the lining and relining of paintings have been replaced by more selective approaches, and a focus on preventive measures. While the methodology and philosophy of treatment has evolved dramatically, the heating devices themselves have not. Many of the treatment techniques applied today involve the application of sealed systems, such as an envelope, and application of heat and pressure in a combined form using a vacuum or low pressure heating table. The heating tables come in various models and sizes, but basically have not changed much since the 1980s. In most cases, the table is a relatively expensive piece of studio equipment, which is limited in its application size and can be used only in a fixed location.

What if you could roll up your heating device like a mat and store it when not in use, or take it to your work site when treating a large format painting?

An experimental method using a flexible silicone rubber thermal blanket offers versatility and precision when treating both large scale and conventional paintings and could be successfully used as an alternative to the heating table. In 2003, upon the advice of Al Albano (Intermuseum Conservation Association), a silicon thermal blanket was custom designed by Instrumentor's Supply for use in the onsite treatment of two large-scale New Deal murals in Portland, Oregon. Since then this method has been applied in the treatment of other paintings by the authors and other art conservators. From the preliminary results it is apparent that along with the impressive versatility and unlimited size, the thermal blanket also offers considerably shorter heating and cooling times and a more uniform heat distribution over the surface, free of "hot" and "cold" spots, often so problematic in conventional heating tables.

APPARATUS

Background

The precursor of our device–an electrically heated blanket–was patented by Frank R. Whittelesey in 1913. [1] In the 1920s, the Thermega Underblanket was manufactured in Britain. Electric overblankets were introduced in the United States in 1937, and first thermostats were attached. [2] The early blankets were rather unsafe; the wiring would degrade and easily break, causing disruption in heating, and worse. Yet other new devices appeared on the market in 1940, when conductive rubber was used for electric heated USKON mats by US Electrical Company, first for military and later for civil applications. [3] The boost in development of high precision thermal blankets and of flexible heaters in general was originally linked to aerospace and military research as part of the active thermal protection system for the spacecraft and satellite controls. The great advantage of flexible heaters is their capacity to transfer heat to an object of almost any shape or configuration. Such heaters with attached high precision thermostats are currently applied as freeze protection for instrumentation and hydraulic equipment in the aerospace and military industry, in medical equipment, for battery heating, to keep traffic lights and the ATM machines going in cold climates, and even inside laser printers or any other application requiring a flexible shape or design.

It must be noted that electrically heated mats are not entirely new to art conservation, but they've had rather marginal use. Heat blankets were employed in early heating tables, and Helmut Ruhemann suggested an application similar to ours in 1959 using the Electrothermal Rubber Sheet. [4] In the same year, Alain Boissonnas described the USKON mat and its use in an early heating table [5] and perhaps even used by other conservators, but not documented. More recently, a silicone rubber heated mat, mounted on a solid support and controlled manually with a dimmer and external thermometer in combination with a low pressure ring, was used by Jos van Och (Stichting Restauratie Atelier Limburg) in Maastricht for the lining of the colossal Mesdag Panorama mural in The Hague (1990-1996). [6]

Technical

The design of flexible heaters employs a grid of wound wire or etched foil elements vulcanized between two layers of silicone rubber, Kapton, or neoprene and the size could vary from miniature mats to virtually unlimited size blankets.

The wound wire silicone rubber heater combines the excellent dielectric properties of silicone rubber and the strength of fiberglass. The heating element is manufactured by twisting fine nickel-chromium alloy wire over a center core of fiberglass, producing a fine, strong, flexible cord. The cord is then patterned in a dense grid, with elements no farther apart than 1/4" (now available also in 1/8") to provide uniform heat distribution. Once the heating element is positioned, a second layer of silicone rubber is laid over the wire. The layers are then vulcanized to permanently position the elements. The heating elements are connected to wire leads for power. The total thickness of the heating pad with the wire wound element is .055" (1.4 mm).

This type of heating pad was developed for applications where repeated flexibility is necessary, and to accommodate small radius bends (such as for heating drums and pipes). Because of the strength and flexibility of the wire element, this type of heater is most indicated if rolled storage of the blanket is desirable. The resistant nature of silicone to moisture, compression and solvents also adds to the durability of the heating pad as a studio tool. The pads may be bought in standard stock sizes up to 3' x 10', but may also be custom produced in smaller or wider dimensions, or in custom shapes with cutouts, perforations, etc. [7]

Etched foil heaters present a new development, and can be fabricated in an unlimited range of shapes and sizes as well. Their thin, lightweight design (0.007" thick) provides an even greater extension of the heated element surface within the external skin. The etched foil may be vulcanized to silicone rubber, or attached to Kapton®, a lightweight flexible polyimide film that has a proven performance record of maintaining outstanding mechanical, chemical and electrical properties over extreme temperature ranges. [8]

Electrical, performance and controls

To run the heater, the system includes a series of external controls neatly assembled within a box that also serves as a power outlet for the heater. The control box contains a precision digital temperature controller that drives a solid state relay to run the heating unit and a thermocouple to detect a single local temperature. (The relay is an electronic switch that opens and closes the circuit and provides current to the heater.) The relay that was installed in the 2003 system has a 1/4-1 second time cycle for temperature correction, while the newer solid state relays, known as variable time base relays, have time cycles that number 20-40 times per second to maintain an extremely precise and continuous target heat, with an accuracy of +/- .1% C. [9] (The newest phase angle fired relays have even greater accuracy, but with negligible difference for our application.) Once the desired temperature is reached, it will stay steady for the duration of the treatment.

The entire system may be designed for either a 120V current or 240V, which will be determined by the watt density requirement (watts/square centimeter) of the heating element type (foil or wire) and the heating pad dimensions. For pads over 20" x 30" (50 x 70 cms), the 240V support is necessary. The control box also contains a fuse for the temperature controller, fuses for the "hot lines", and one GFI outlet for safety purposes (although the 2003 was not designed with a GFI outlet). The engineers have also designed the temperature parameters of the system to not exceed 160º F/70º C, both within the setting of the temp controller and in the wiring of the heating pad itself. [10]

The temperature in smaller blankets, like any other electrical device could be controlled also using the solid state dimmer, though with only approximate results.

The temperature is detected with a single external thermocouple that may be positioned as appropriate to the treatment. Of course, auxiliary use of an IR thermometer and thermopapers is useful to monitor the entire surface of the work during treatment.

Testing

Three critical parameters: the temperature fluctuations, heat distributions and heating and cooling time of three heat sources were comparatively tested during their operation. The fluctuation of the temperature of the surface of a multipurpose low pressure table with a grill type heating element, constructed in the 1990s (similar models like this are found in many museums worldwide) indicated as much as 10 times greater fluctuations when compared to the thermal blanket. Unexpectedly, the heating table of 1950 (with 13 internally fixed heating blankets) performed rather well in this respect, showing a stable curve, comparable to that of the thermal blanket. This testing also indicated the striking difference in heating and cooling times between the compared devices. While the heating blanket reached the set temperature in approximately 12 minutes, the multipurpose table and the heating table reached it in 20 and 22 minutes respectively. The differences were more dramatic, when comparing the cooling time: the thermal blanket reached the ambient temperature in approximately 14-18 minutes, the hot table in 180 minutes, and the multi-purpose table in 90 minutes. (This may be caused by the heat sink properties of the table surfaces and different mass of tested heating devices.)

The distribution of heat patterns in all three devices was also explored with FLIR 025 thermographic camera and the results, as suspected, indicated the most even heat pattern in the thermal blanket, showing less even distribution in the hot and the low pressure tables. Certainly, the results may differ from one model to the other, and since similar devices are present in most museums and larger conservation laboratories, we would encourage performing similar tests. Even heat distribution, minimal temperature fluctuation and considerably shorter heating and cooling times are critical factors, making any heat involved in treatment safer and less invasive.

Thermographic imaging was also used to investigate the heat distribution of the 2003 blanket during the initial heating up phase. The dense patterning of the wound wire elements resulted in an immediate and fairly uniform dispersal of current to all areas of the heating pad. Engineers at Instrumentor's Supply suggested that the uniformity of the heat distribution could be improved considerably by laminating a copper wire mesh within the silicone heater. This would not only provide a perfect distribution of the heat all the way to the edges, but would also allow the blanket to be grounded for safety purposes. For fixed locations such as in heat tables, an aluminum foil backing may be adhered onto one side of the silicone rubber heater. Since the foil is prone to wrinkling if rolled and unrolled, it is not advisable if rolled storage is desirable.

APPLICATION AND TREATMENTS

The thermal blanket presents a universal and versatile device that may be applied in variety of treatments: from flattening surface deformations, both overall and locally, to various consolidation treatments. However, most effectively, it may be implemented in lining treatments in combination with a low pressure or vacuum envelope systems. The great advantage of the blanket over the table is in the possibility of placing the heat source in various locations, under, or over the treated artwork, and also in vertical and applying in sections. It could be combined with mini Mitka type or with standard low pressure table and envelope system – loose, fixed to the surface or loomed. While most of commonly fabricated vacuum pumps could be used, we have used the GAST 0523 rotary vain non lubricated pump, fitted with pressure gauge, vacuum relief valve and multiple suction cups. The vacuum or low pressure envelope could be assembled in variety of ways, depending on the need of each project. While the Nylon 6.6 Dartek membrane is most common in North America, PVC membrane, that is softer at operational temperatures, has been also successfully used. Polyethylene, though traditionally used for the cold "mist lining" technique developed by Jos van Och at Stichting Restauratie Atelier Limburg (SRAL), it may also be used in thermal treatments if the appropriate grade is selected. Polyethylene has the added advantage of being produced in much wider rolls than Dartek,

Howard S. Sewell *The Coming of the White Man Immigration*, 1937, oil on cotton, 153 cm x 690 cm each, Oregon City High School, Oregon City, Oregon, USA.

The prototype heater was created in 2003 by Instrumentor's Supply of Oregon City, Oregon and was manufactured for use in the treatment of two New Deal murals by painter Howard S. Sewell in Oregon City, Oregon. The silicone rubber heating pad has wound wire elements and was made to measure 36" x 66" (91 x 168 cms) in order to accommodate the height of the murals. The two murals were each composed of three separate pieces, originally marouflaged to the wall as a single image measuring 61 inches high by about 23 feet long. The works were lined onto a single continuous backing with a Reemay interleaf loaded with Beva-371. A vacuum envelope was created with Dartek with two out flowing points connected to the GAST pump. The works were then bonded to the backing by heating in sections, positioning the thermocouple between the heater and the backing surface. The heating pad allowed all of the work to be conducted on site at the school, with the simple installation of a 240V circuit for the heater.

Louis Bunce *Alice in Wonderland, 1001 Nights' Entertainment*, 1938, tempera on cotton, 183 cm x 274 cm each, North Salem High School, Salem, Oregon, USA

The silicone rubber heating pad was also used to bond two New Deal murals by painter Louis Bunce to aluminum honeycomb panels. The works had been, again, marouflaged to the library walls of an elementary school that, in this case, was destroyed soon after the removal of the murals. The works were positioned over the interleaf pre-tacked to the aluminum honeycomb panel in a vacuum enclosure, and in this case, the heater was positioned on the face of the work. The works were bonded to the panels in sections. The conductive properties of the aluminum facing skin of the panel no doubt aided in the diffusion of the heat.

This same method was more recently applied in 2009 to a series of six newly produced large works painted in acrylic on cotton canvas that were destined for the embellishment of the ceiling of a church in Portland.

Willem Van Aelst *Still Life with Peaches and other Fruits* 1650 Oil on canvas, 98, 5 cm X 112 cm, private collection Amsterdam

A second thermal blanket was designed and manufactured for T. Markevicius in 2005 (110 x 120 cm), again connected to a solid state relay with digital temperature control. This system was applied in the structural treatment of a 17th century painting by Willem van Aelst. This particular painting had been broken (horizontally) in two pieces right the middle and was wax resin lined in 1989, after having removed the marouflaged wood composite support from earlier restoration. The lining was carried out within the sealed envelope and fixed loose to the working surface.

Paolo Veronese: *Dead Christ Held by Angels* superior fragment of Petrobelli altarpiece, oil on canvas, 285 cm x 198 cm, Ottawa, National Gallery of Canada

The same thermal blanket was used in treating the fragment of the Petrobelli Altarpiece by Paolo Veronese by Stephen Gritt. While reconstructing the original format of the Ottawa fragment, lining was required. The loomed lining support and painting were enclosed in a Dartek envelope during the first phase of lining, which involved the painting without the cast lateral additions and was accomplished using the conventional heating table. During the second phase, the lateral pieces were attached using the thermal blanket, which enabled the National Galleries' conservators to perform a localized treatment, and eliminated the need to expose the whole painting to prolonged heating and cooling cycles.

Since the debut in 2003, several other thermal blankets were constructed for conservators in Europe and North America and we would be curious to hear about their experiences and results (See figures of San Diego blanket).

CONCLUSIONS AND DISCUSSION

Current conservation practices are moving towards ever more minimal and less invasive treatments. This thermal blanket may provide not only improved temperature control in terms of even heat distribution with minimal temperature fluctuations, but it may also be designed in a variety of sizes and configurations that allow it to be modified for specific needs. The heat blanket is easily transportable, storable and quite economically accessible. This versatility makes it a useful device for the museum laboratory and for those of us in private practice.

While it has been successfully used in its first imperfect iteration of 2003, later models have already improved the design, and naturally, new designs could be further improved. For example, the density of the wound wire grid was increased to 1/8' and the integration of the thermosensor into the heat blanket has already been incorporated into newer designs for recent requests, as has an upper-limit security setting. Other improvements, such as incorporating USB datalogger or IR non contact thermal sensor were also suggested and are possible, depending on individual needs.

From the "big picture" perspective, the future of heating devices in art conservation is clearly with highly mobile, versatile, accurate and cost effective devices. Our further research working on a concept of the new IMAT (Intelligent Materials for Accurate Thermoelectrics) [11] heating device is focused into the radically new design solutions, such as eliminating the internal resistance wiring, for example, which will open the doors to completely new class of heaters. While the first attempt at constructing film heaters without wires may be traced to the USKON conductive rubber heaters that were mentioned earlier, looking forward to the not so distant future IMATs may become available in ultra thin, stretchable, and even transparent forms. Our research and direct contacts with the inventors of relevant technologies, indicates, that these "smart" heaters could be designed using the most recent conductive rubber-like or even woven materials made with newly developed nanomaterials, such as carbon nanotubes (CNT) or silver nanowires (AgNW) and may represent one of the more exciting developments in this field and collaboration between art conservator, thermoelectrical engineer and scientist. While waiting for these innovations to reach the market, the flexible thermal blankets presented in this paper could find their place in current conservation practice, contributing to better results and more flexibility in treatment choices.

ENDNOTES

1. F.R. Whittlesey *Electric Heating Blanket, Pad, Robe and the Like* Brevetto no 1058825; Deposition of Request: 1 April 1912; Patent release: 15 April 1913; United States Patent Office; Google Patent Search
2. Rodney P. Carliste *Scientific American Inventions and Discoveries* John Wiley and Sons, Hobeken (NJ), USA 2004 p. 345
3. Anon. *Serving through science* Life 1944 p. 15
4. Helmut Ruhemann *Some Notes on Vacuum Hot Tables; Vacuum Relining Using a Heated Mat*, Studies in Conservation, Vol 5, No 1 (Feb 1960) pp. 17-18
5. Alain G. Boissonas *Some Notes on Vacuum Hot Tables; Fine Art Conservation Laboratories*, New York, Studies in Conservation, Vol 5, No 1 (Feb 1960) p. 18
6. Direct communication with Jos Van Och, Head of Conservation, Kate Seymour, Head of Education; Stichting Restauratie Atelier Limburg, Maastricht, The Netherlands.
7. See catalogues of Watlow Electric Manufacturing Company, USA.
8. See catalogues of Watlow Electric Manufacturing Company, USA.
9. See catalogues of Watlow Electric Manufacturing Company, USA.
10. Manufactured by Instrumentor's Supply, Inc., Oregon City, OR, USA.
11. IMAT acronym is suggested by the authors for the first time defining the new class of "smart" mobile thermoelectrical devices for art conservation

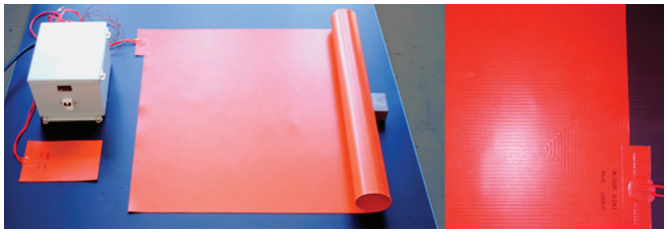


Figure 1. Thermal blanket and temperature control unit with thermocouple. Next to the control unit: mini thermal blanket. Right and below: details of thermal blanket.

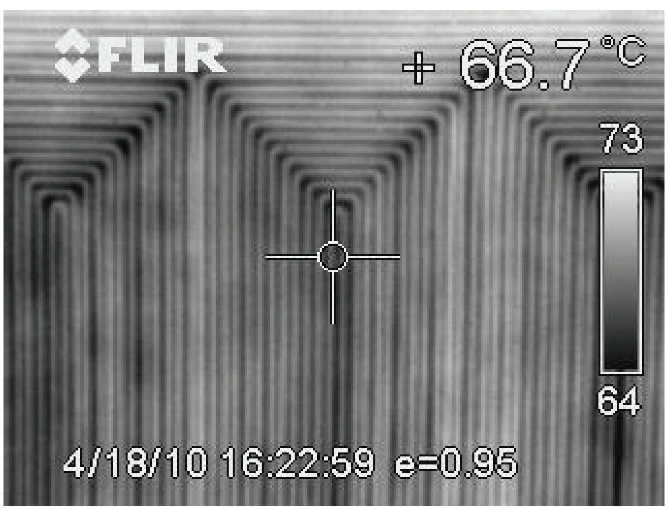


Figure 2. Thermographic image of wound wire element inside the thermal blanket

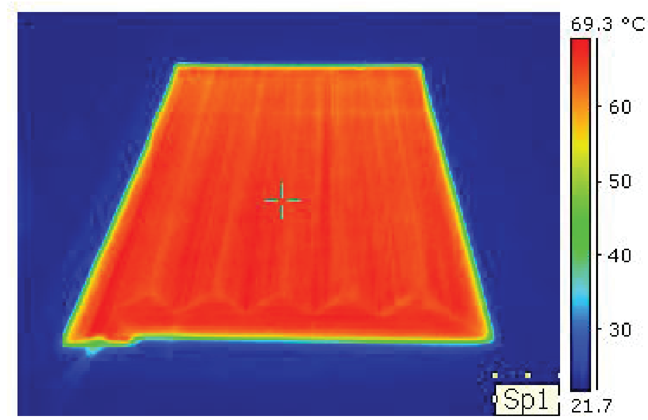


Figure 3. Thermographic image of thermal blanket showing even heat distribution

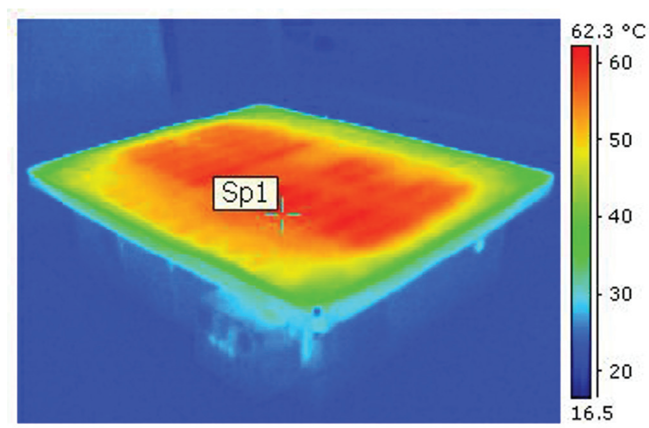


Figure 4. Thermographic image of 1990s multipurpose low pressure heating table showing uneven heat distribution

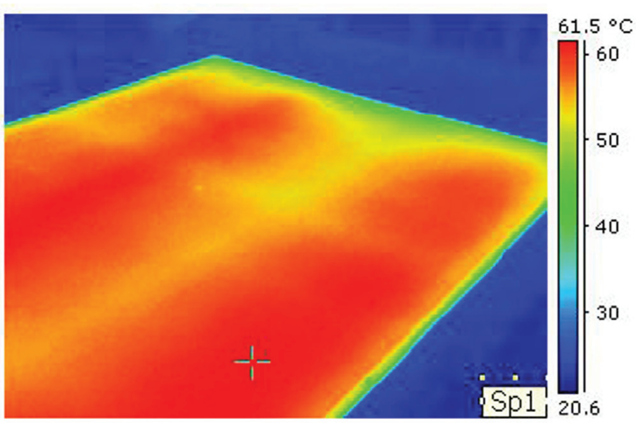


Figure 5. Thermographic image of 1960s vacuum heating table (detail) showing uneven heat distribution

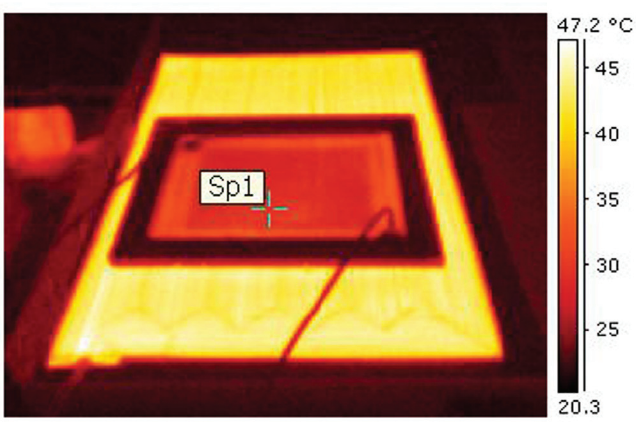


Figure 6. Thermographic image of a thermal blanket and of a test lining, showing even heat distribution. The pre-stretched lining fabric is enclosed in Dartek envelope and placed loose over the thermoblanket.

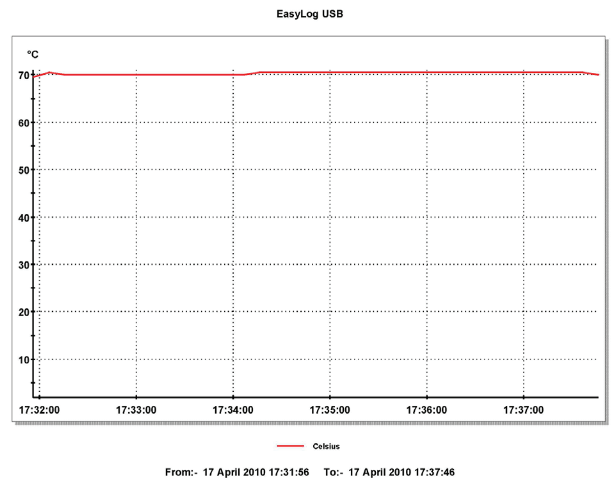


Figure 7. Graphic of surface temperature fluctuation: thermal blanket

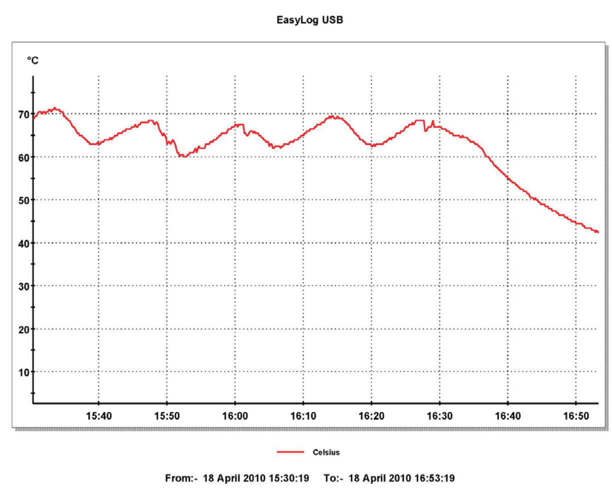


Figure 8. Graphic of surface temperature fluctuation: 1990s multipurpose low pressure heating table

Figure 9. Howard Stoyell Sewell (1899 – 1975) *Integration of Races: White Man's Settling of America* 1939 mural painting on canvas, 162 x 914 cm. Oregon City Senior High School, Oregon City (OR) USA. Above: after the treatment and installation in the Oregon City in 2003; below: lining one of the murals using vacuum envelope and flexible thermal blanket. Portland (OR) 2003.

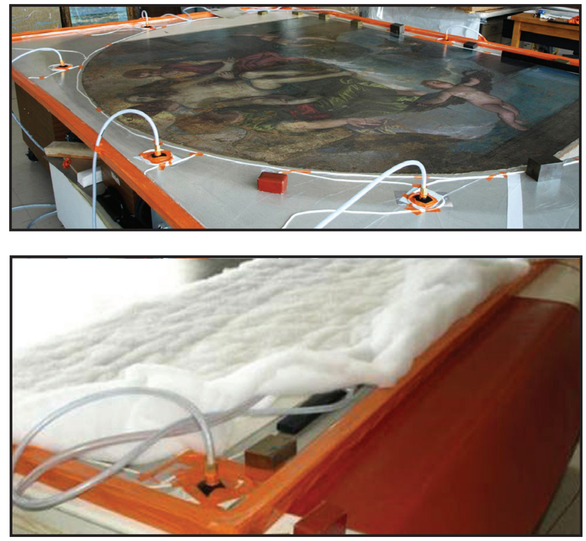


Figure 11. Paolo Veronese (1528-1588) *Dead Christ Held by Angels* 1563, oil on canvas, 295 x 398 cm during treatment at the National Gallery of Canada. Above: Overall view of lining in progress; below: local lining using silicone thermal blanket. Ottawa 2008-09.

Figure 10. Willem van Aelst (1626-1683) *Still Life with Peaches, Grapes and Other Fruits* oil on canvas, 98 X 112 cm, private collection, Amsterdam. Above: overall view after treatment; below: lining process using flexible thermal blanket. Amsterdam 2005.

Figure 12. Paolo Veronese (1528-1588) *Dead Christ Held by Angels* 1563, oil on canvas, 295 x 398 cm National Gallery of Canada. Above: after treatment. Below left: before treatment. Below right: detail during treatment. Ottawa 2008-09.

AUTHORS' INFORMATION

Nina Olsson
Paintings Conservator
Nina Olsson Art Conservation
2359 SW Park Place
Portland, OR, 97205, USA
Tel. 503.236.0789
E-mail: ninaolsson@earthlink.net

Tomas Markevicius
Paintings Conservator
National Gallery of Canada
380 Sussex Drive
Ottawa, ON, K1N9N4
Tel: 613.990.1946
E-mail: tmarkevicius@gmail.com

VERONICA ROMERO, KELLY O'NEILL, AND RUSTIN LEVENSON

Up in Smoke: New Solutions for Treating Soot Damaged Paintings

ABSTRACT

After a fire destroyed the Harold Golen Gallery in Miami in 2007, 108 paintings were transported to the Rustin Levenson Art Conservation Associates Miami studio. After traditional methods of soot removal were exhausted, with only 40 paintings successfully treated, the conservators tested different solutions to remove the soot on the remaining works. The results of the tests, and observations made during the treatment of the paintings are reported in this article.

I. The Emergency Phase of the Project
Veronica Romero

On December 13th, 2007 in the early hours of the morning, firefighters arrived and tried to fight a fire from inside the building of the Harold Golen Gallery in Miami, but quickly abandoned the interior when the roof began to collapse. The fire was believed to have started when an advertising balloon attached to the building, specifically put up to promote the gallery during Art Basel week, came into contact with electrical wires due to heavy winds and sparked the blaze.

On December 14th, Harold Golen contacted the Rustin Levenson studio in hopes that conservation would bring some optimism to his hapless situation.

Inside the Harold Golen Gallery was over half a million dollars worth of Pop Surrealism art pieces. Pop Surrealism is also often known by the name Lowbrow Art. Lowbrow describes an underground visual art movement that arose on the west coast in the late 1970s. Its origins were conceived from the underground comic world, punk music, hot-rod street culture, and other subcultures. Lowbrow art often has a sense of humor: sometimes the humor is gleeful, sometimes impish or deviant, and sometimes it's a sarcastic comment. Most lowbrow artworks are paintings, but there are also toys, digital art, and sculpture.

The Harold Golen Gallery was located in a concrete building. The ceiling caused the main damage; after being engulfed in flames, the ceiling caved-in and collapsed on the artwork. Out of 178 rescued pieces, Rustin Levenson Conservation Associates assumed 108 potentially salvageable painted surfaces for possible treatment.

Thus began the battle against time and soot residue.
Soot is a general term that refers to impure carbon particles resulting from the incomplete combustion of a hydrocarbon. It is more properly restricted to the product of the gas-phase combustion process, but is commonly extended to include the residual pyrolyzed fuel particles such as charred wood that may become airborne during decomposition brought about by high temperatures (i.e. pyrolysis).

Soot, as an airborne contaminant in the environment has many different sources, but they are all the result of some form of pyrolysis. Soot can be formed outdoors from sources such as internal combustion engines, central steam heat boilers, waste incineration, local field burning, house fires, or forest fires. Interior sources can include smoking of cigarettes, fireplaces or furnaces, cooking, oil lamps and candles, and even quartz halogen bulbs with settled dust. It is not necessary to have a fire to have soot. In very low concentrations soot is capable of darkening surfaces or making particle agglomerates, such as those from ventilation systems, with a black appearance. Soot is also the primary cause of "ghosting," the discoloration of intersecting walls and ceilings or walls and flooring where they meet. Soot normally forms at about 140°C (284°F). The composition of soot depends strongly on the fuel composition (the materials burned by the fire) and the substances used to extinguish the fire.

It was quickly realized that any handling or pressure that disturbed these soot particles could cause infiltration into the surface of a painting, making the soot nearly impossible to clean. It was also understood that efforts to remove the soot would become increasingly difficult over time, so the conservators had to move as quickly and as efficiently as humanly possible.

Before the arrival of the fire damaged pieces, the studio had to procure an adequate storage and work space to carry out the salvage operation. In addition to carbon from soot, surface deposits on the artwork contained potentially toxic and corrosive by-products, and could not cross the threshold of the conservation lab. It was an advantage that a few yards from the doors to the studio, Rustin's cottage would soon host some of the filthiest houseguests ever. The floors were lined with tarps and safety equipment was implemented, including the use of HEPA air filters. Harold Golen offered a rudimentary inventory and the conservators prioritized, documented, and organized the paintings. December in Florida has its benefits and the advantage of being able to work outside during the dry season was significant.

Throughout the salvage operation the studio was in constant contact with Harold Golen and the artists, gathering crucial information, entertaining visits, and even at times occupying the role of a therapist. There were encouraging recoveries coupled with discouraging moments. In some cases after countless hours and various cleanings, Harold would insist that the colors in a painting were not as vibrant as he remembered. Scot Olsen, who was preparing for a forthcoming retrospective, had most, if not all of his recent work up in the gallery during the Art Basel showing. Out of thirteen of his pieces that came to the studio, the conservators were able to salvage only one. In a recent conversation, he reported that he burns one painting every year, to "*appease the fire gods*."

II. Traditional Methods of Cleaning Smoke Damaged Paintings
Kelly O'Neil

Of the 108 paintings that were brought into the studio, the conservators were able to successfully treat 85; 61 of these were acrylic-based works (including silkscreen and enamel) and 24 were oil paintings. Their supports included canvas, Masonite, and wood panel. The many tested and established conservation treatments provided a broad foundation for soot removal from works carried out in oil medium. The complications of treating the acrylic paintings were more daunting. As a newer medium, there is still much research to be done on the long-term effects of surface cleaning applications. [1] The conservators were aware from research and personal experience of the sensitivities of acrylics to solvents regularly used for cleaning oil paintings. [2] Their susceptibility to accumulating surface dirt and of adhering to other surfaces made soot removal challenging. With their added exposure to heat and water in the fire, the conservators expected them to be even more complicated. They did not disappoint.

The first phase of soot removal began with the aid of a HEPA-filtration vacuum cleaner. The front and back of the paintings were vacuumed, holding the hose a safe distance from the painting's surface, allowing the loose soot particles to be removed without touching the painting.

The second step involved using dry cleaning: materials such as Groomstick and vulcanized rubber sponges were tested. Although the Groomstick removed some soot, it required too much pressure on the painting's surface, even with gentle rolling, so its use was discontinued. There was success with vulcanized rubber sponges on the reverse of the supports, stretchers, and tacking margins; there was also success with heavily varnished paintings, but the conservators abandoned its use for all other purposes. The painted surfaces, especially those that had visible interstices, such as thinly painted works on canvas, proved the sponges to be detrimental as the pressure from the sponges further lodged the soot between canvas threads and into the paint surface. Two years ago at the 2008 AIC Conference in Denver, Buffalo State's Dr. Aaron Shugar and graduate student Cynthia Albertson had a poster session on research on dry cleaning materials such as the vulcanized rubber sponge that revealed potential problems with scratching damage. This certainly would have been a possibility when rubbing against the heavy soot on these Pop Surrealist artworks.

The next step, cleaning, involved solutions recommended by conservators Chris Stavroudis and Dean Yoder; aqueous solutions with chelating agents and VM&P Naphtha emulsions. With both of these solutions, rinsing was an important step. Most solutions were rinsed several times. Unfortunately it was found that even after rinsing, residue was left on the paint surface. This led the conservators to carry out the final rinses with a PVOH sponge or to blot them dry with a paper towel.

In the next section, Rustin Levenson will discuss in more detail tests that were performed related to aqueous rinsing. As recommended, the use of chelating agents, such as dibasic ammonium citrate was successful with some of the paintings. The suggestion of VM&P Naphtha emulsion also proved very fruitful. It cleaned both oils and acrylics, and was especially successful with the oil paintings. In general, it was found that clearing the VM&P Naphtha emulsion with VM&P Naphtha seemed to remove the emulsion residue from the surface more effectively than water. As possible, the conservators, worked along design lines during the cleaning process. It was often found that a second application of solvent worked differently on a cleaned surface and the conservators wanted to prevent visible tide lines or overlapping cleaning.

Sometimes a combination or sequence of solvents proved successful. A good example of this is the cleaning of Niagara's *Snap Out of It*, an unvarnished acrylic on canvas. This work was treated first with ammonium citrate, followed by an application of VM&P Naphtha emulsion, and then rinsed with VM&P Naphtha.

Another success realized with VM&P Naphtha emulsions and sequences of solvents was Skot Olson's *Black Water Harvest*. An acrylic on canvas, *Black Water Harvest* was one of only a handfull of paintings in the warehouse that were varnished. After having the opportunity to talk with the artist, it was learned that the painting was 4-6 years old before the fire and had been varnished twice. In addition, this painting had an added and rather unconventional layer of protection, the floor. The work was discovered face down on the concrete floor in the Harold Golen Gallery. Having the painting face down on the concrete provided for 'some' relative safety from the elements, allowing debris from the caved-in ceiling to accumulate on its reverse rather than of the face of the painting. Despite the painting's orientation, the surface suffered smoke damage. For the treatment of this painting, a solution of mineral spirits and tri-methlypentane was applied to the surface, followed by an application of VM&P Naphtha emulsion, and then rinsed with VM&P Naphtha. The steps and series of solutions that facilitated the cleaning of this painting is an example of the tailored recipes required to clean most paintings.

Stronger solvents, such as xylene, were also employed in emulsions. An example of this was Tim Biskup's *I Love You Table*. An unvarnished, acrylic painted, 3-dimensional wood object, each of the six sides was cleaned with a 10:7 xylene emulsion: tri-methlypentane solution, and then rinsed with distilled water. It was noted that the paint became sensitive with a second application of solvent. During the cleaning treatments, the conservators often found each area had to be cleaned completely in the first application. Once an area dried, the residual material was sometimes difficult to remove. It was also discovered that some solutions would work better if the conservators covered a larger area of surface with a larger volume of solvent. This helped loosen and push out the soot, while saturating the area. In the case of the *I Love You Table*, as much soot as possible was removed and the work was returned to the artist to retouch.

In summary, it was discovered that traditional solutions worked best on oil paintings and only a few of the acrylic paintings. This still left the conservators with many acrylics and a few oil paintings that could not be cleaned with established methods.

III. Testing Phase: New Approaches for Soot Removal: Rustin Levenson

The remaining paintings, which could not be cleaned with conventional conservation solvents, were scheduled to be discarded by the insurance company. This offered a unique opportunity for research. Working with Harold Golen and the artists, the conservators received permission to do further testing for soot removal with non-traditional solutions. Starting with the familiar, the solvent cabinet was exhausted, testing everything from resin soaps to complex emulsions in various sequences.

Solutions with stronger chelating agents were successful on some of the paintings. A mixture of 10% Versenol, an EDTA chelating agent, 10% VM&P Naphtha and 80% distilled water, rinsed with distilled water, successfully cleaned several works.

Tests with stronger detergent agents were next. Concentrated mixtures up to 50% of the anionic detergent Vulpex with distilled water and/or naphtha showed some success. For example, on an oil on canvas by Ron English, *Raising the Brow*, a 30% solution of Vulpex in distilled water, rinsed with distilled water, began to unlock the soot layer. On other works, good results were also realized with 3-10% solutions of Vulpex in VM&P Naphtha. However, difficulties in clearing Vulpex and the high concentrations of the solutions that were successful kept the conservators searching for other alternatives.

The next tests were done with commercial solutions. From the aisles of Whole Foods, Home Depot, and Bed Bath and Beyond, and the depths of the kitchen cabinets a range of cleaning products was assembled. Promising results were realized with two products JC-100 and Gonzo Stain Remover. The Gonzo Stain Remover, described as "a water based surfactant solution," satisfactorily removed soot from the acrylic painting on panel, *Mamie* by Mitch O'Connell. The JC-100 partially removed soot from an acrylic on panel by Ryan Heshka, *Avia*. Frustratingly, there was little information about the formulation of these solutions. The JC-100 was no longer available and the MSDS pages on Gonzo Stain Remover listed the ingredients as "proprietary."

The investigation of these products led to a conversation with Dick Anderson, a cleaning chemist at Sentinel Products who suggested that a key to effective removal of carbon deposits with the JC-100 might lie with ethylene glycol monobutyl ether, a carbon solvent. Samples were acquired of ethylene glycol monobutyl ether EB from Lyondell Chemical and experimentation began. Various mixtures were tested with this solvent, some with positive results. The best solutions combined ethylene glycol monobutyl ether EB with Vulpex in mixtures of 3-10%. An example of success was an acrylic and vinyl painting on panel by Shag, *The Best Party in Palm Springs* where a solution of 5% Vulpex in the ethylene glycol monobutyl ether EB rinsed several times with distilled water removed the soot on the face of the painting. The surface of *Tiki Cat,* an acrylic on canvas adhered to board by Thorsten Hassikan, was cleaned with ethylene glycol monobutyl ether EB, rinsed several times with distilled water. Soot was removed from the acrylic painting, *Electric Eye* by Ryan Heshka using ethylene glycol monobutyl ether EB followed by a VM&P Naphtha emulsion, then rinses of distilled water.

There were still some paintings where soot had not responded to testing. A search for other products that contained ethylene glycol monobutyl ether led to Formula 88 Cleaner and Degreaser produced by Petruj Chemical Corporation. Formula 88, available in Home Depot, is sold to "Get Rid of the Mess with the Best." Despite this hopeful motto, it was with some trepidation that the studio tested it on a painting, but Formula 88 on swabs immediately lifted the soot off some of the remaining artworks, leaving the paint surface intact.

The MSD sheets and container list the ingredients in water as ethylene glycol monobutyl ether and sodium metasilicate. Sodium metasilicate, a common component of household cleaners, forms alkaline solutions when dissolved in water. The pH of Formula 88 is listed as 8.7-9.5pH. This was confirmed by measurements in the studio.

After further testing, several of the otherwise untreatable paintings were cleaned with Formula 88, rinsed several times with distilled water and/or VM&P Naphtha. Successful results were realized with a number of the paintings; one example is an oil on panel, *The Happy Idiot*, by Gary Baseman. This was cleaned with a 50:50 mixture of Formula 88 and distilled water, rinsed with distilled water. Adding 5% of Vulpex to Formula 88 and rinsing with VM&P Naphtha removed the carbon deposits on the acrylic on canvas *Or Are You Happy To See Me* by Niagra. Working with this solvent under a microscope resulted in a cleaned and intact surface.

Naturally, the studio had concerns about using materials unvetted by the conservation community. In anticipation of this presentation several empirical tests were carried out. Commercially primed canvas was treated with the various products, and then rinsed with distilled water once, twice, and three times. Only the pure Versenol solution left any evident residue on the primed surface. The same materials were tested on clear Mylar. These tests showed residues with all the solutions, even after three rinses. Although this is partially attributable to the Mylar as a test substrate, it gives rise for concern. Noting the residues in this test affirmed our routine of carrying out the final aqueous rinses with a PVOH sponge or with solvents and blotting the rinses with paper towels.

Ultimately, there were still paintings that could not be treated. Several of these works were donated to the Getty Research Institute for further testing by Tom Learner. Others were returned to Harold Golen.

It was with some surprise that one of these works, *Elvis, Elvis Pink Lace* by Ron English appeared, shining pristinely in Harold's new gallery at a recent opening. The medium of the painting on canvas was described by the artist as acrylic/enamel with silkscreen. The painting had been treated with ethylene glycol monobutyl ether with 5 % Vulpex and had been considered much improved. But when Harold viewed it, he felt the colors were still muted. Nonetheless, he had taken *Elvis* back to his gallery. At the opening, he proudly revealed that he had cleaned it himself with a new Clorox Greenworks product. Although it is hard to know without seeing the cleaning swabs, the paint surface appeared to have tolerated the cleaning well offering another solvent possibility to test in the future.

In a recent conversation, Dick Anderson discussed another new cleaning solution, which is part of the Sentinel Products Restoration line. These products, formulated from naturally derived esters, offer another possibility for testing.

In summary, each work had a unique solution for unlocking the soot on the surface. If a conservator is confronted with soot damaged paintings, the following advice is offered. Vacuum the reverse and clean it with a vulcanized rubber sponge. Vacuum, without pressure, near the paint surface. Forego the vulcanized rubber sponge on the paint surface except in cases of very light soot or heavily varnished paintings. Try the traditional solutions of chelating agents such as ammonium citrate in distilled water and naphtha emulsions. Other solutions to test could include other petroleum distillates, alone or in emulsions, xylene emulsions, ethanol, or mixtures of Versenol, VM&P Naphtha, and distilled water. Detergent mixtures such as Vulpex in distilled water or VM&P Naphtha could also be tested. Finally, there is the possibility of carbon solvents/degreasers such as ethylene glycol monobutyl ether, diluted, alone, or combined with detergents such as Vulpex. Careful rinsing of all solutions is also recommended and blotting, or using a PVOH sponge for the final rinse, so that no residue is left on the surface.

This information is shared in the hope that other conservators and conservation scientists will undertake further testing and research into these materials.

ACKNOWLEDGEMENTS

Tom Learner, Senior Scientist and Head of Modern and Contemporary Art Research, Getty Conservation Institute

Chris Stavroudis, Private Conservator

Dean Yoder, Conservator, Cleveland Museum of Art

Carol Young Verheyen, Conservator, Huntington Art Gallery

Dick Anderson, Chemist, Sentinel Cleaning Products

Harold Golen, Gallery Owner

Skot Olson, Artist

The LowBrow Artists

ENDNOTES

1. AIC *Reviews in Conservation*, Number 10 2009, "The effects of wet surface cleaning treatments on acrylic emulsion artist's paints–a review of recent scientific research," Bronwyn Ormsby and Tom Learner. pp. 29-30, 38.
2. AIC *Reviews in Conservation*, Number 10 2009, "The effects of wet surface cleaning treatments on acrylic emulsion artist's paints–a review of recent scientific research," Bronwyn Ormsby and Tom Learner; Tate Papers 2004 (Tate's Online Research Journal) "Conservation Concerns for Acrylic Emulsion Paints: A literature review," Elizabeth Jablonski, Tom Learner, James Hayes and Mark Golden; Tate Papers 2006 (Tate's Online Research Journal) "The Effects of Surface Cleaning on Acrylic Emulsion Paintings: A Preliminary Investigation," Bronwyn Ormsby, Tom Learner, Michael Schilling, Jim Druzik, Herant Khanjian, Dave Carson, Gary Foster and Mike Sloan; Modern Paints Uncovered: A Symposium organized by the Getty Conservation Institute, Tate and the National Gallery of Art, Tate Modern, London May 16-19, 2006, "From formulation to finished product: Causes and Potential Cures for Conservation Concerns in Acrylic Emulsion Paints," James Hayes, Mark Golden, and Gregory D. Smith

AUTHORS' INFORMATION

Veronica Romero
Kelly O'Neill
Rustin Levenson
Rustin Levenson Art Conservation Associates
13291 Old Cutler Road
Miami, FL 33156
E-mail: rustinfl@aol.com
Web: artcarenyc.com

BRONWYN A. ORMSBY, ALEXIA SOLDANO, MELINDA H. KEEFE,
ALAN PHENIX, AND TOM LEARNER

An Empirical Evaluation of a Range of Cleaning Agents for Removing Dirt from Artists' Acrylic Emulsion Paints

ABSTRACT

This study reports on a visual and empirical evaluation of wet cleaning systems for the effective removal of artificial dirt from artists' acrylic emulsion (dispersion) paints. Several wet-cleaning systems currently used by conservators were assessed by researchers at Tate, London, alongside a number of new systems/products identified via The Dow Chemical Company's high-throughput (HTP) automated analysis facilities, as reported in the general session of the 2009 AIC conference in Los Angeles. These new systems include Dow specialty ethoxylate surfactants, ethylene oxide/butylene oxide (EOBO) block copolymers and novel water-in-oil micro-emulsions. This report is part of an ongoing collaboration between Dow, Tate and the Getty Conservation Institute into the development of improved cleaning systems for acrylic emulsion paints.

INTRODUCTION

Much of the recent research into the cleaning of acrylic emulsion paints has focused on measuring ways in which commonly-used wet and dry cleaning systems might alter the surface (or bulk properties) of artists' acrylic emulsion paints (Ormsby and Learner, 2009). Once known, steps can be taken by conservators to minimize those risks in practice. However, an equally important aspect of this research is to develop cleaning systems that are more effective at removing dirt from the surface of these paints. A major part of an on-going research collaboration between The Dow Chemical Company, Tate and the Getty Conservation Institute has been to utilize Dow's high-throughput (HTP) capabilities to develop frameworks for the selection of liquid cleaning agents for the removal of surface dirt from artists' acrylic paints; specifically, to identify cleaning formulations which contribute to high efficacy of cleaning with low damage potential (i.e. risk) to paints. The HTP systems used included a range of automated instruments designed to deal with several tasks including product formulation and material testing; these systems have been previously used by Dow to dramatically increase the speed of developing cleaning products, designing paint systems and assessing the optical, physical and chemical properties of a range of different materials.

The first results and insights from this collaboration were presented at the General Session of the American Institute for Conservation conference, Los Angeles, May 2009 (Keefe et al. 2009). In that presentation, an HTP-based methodology was described that had been developed for comparing the cleaning efficacy of many wet cleaning systems for removing a standard soil from test acrylic paint surfaces. This system was applied to screen a wide range of pure liquids and formulated cleaning mixtures in order to identify systems or features that looked especially active for this purpose. The initial range of substances and cleaning formulations that were screened included both materials commonly used in conservation (e.g. water plus minor ingredients such as TRITON™ X-100 [nonionic surfactant], triammonium citrate (TAC) or EDTA [chelates], ethanol [co-solvent] and combinations of such ingredients; and mineral spirits, VM&P naphtha, etc.) and materials new to conservation that had been suggested by cleaning specialists at Dow. This latter group of substances included: alkylpolyglucoside nonionic surfactants (e.g. TRITON CG110, which is readily biodegradable); new biodegradable/ low aquatic toxicity alcohol alkoxylate nonionic surfactants (eg. ECOSURF™ EH9); novel surfactants (e.g. Satin™ FX) based on ethylene oxide/butylene oxide diblock copolymers [EOBO] (Harris, et al. 2002); linear alkylbenzene sulphonate (LAS) anionic surfactants; various oxygenated co-solvents (DOWANOL™, glycol ether-type) and INVERT™ 5000, a "water-in-oil" type of micro-emulsion. Initial screening of cleaning formulations for comparative efficacy considered both water-based and hydrocarbon solvent-based surfactant systems.

This paper aims to examine in more depth the cleaning performance of some of the more interesting and/or better-performing systems that emerged from the screenin tests. This involved the evaluation, via swab-rolling tests, of selected aqueous and non-polar cleaning systems that were highly rated in the Dow HTP tests alongside established and other novel cleaning systems. This empirical assessment aimed to compare the soiling removal efficacy of a relatively small group of systems using a methodology closer to conservation practice, and to evaluate other factors that might influence the final choice of cleaning system including: paint swelling, pigment loss or transfer during cleaning, handling properties of the cleaning solutions, clearance issues and detrimental changes to the paint surface. These factors cannot be assessed simultaneously using the HTP system but are clearly of concern to practicing conservators. The results of the empirical swab-rolling tests also help to inform subsequent HTP testing efforts, thus ensuring that ongoing experiments are optimized for the development of systems that rate highly in terms of soil removal efficacy, while being low risk in terms of damage potential.

EXPERIMENTAL

Paint samples

For this study, 2 colors of 4 brands of commercially available acrylic paints were cast onto a Fredrix 10 ounce double-acrylic dispersion primed cotton duck canvas (Fredrix) using a Sheen instruments adjustable film caster to a dry film thickness of ~110 μm (see Suppliers). In total a group of 23 soiled samples - 14 titanium white (PW6) and 9 azo yellow (PY3) - were chosen from a larger set. All paint media, extenders and pigments were characterized by using Pyrolysis Gas Chromatography – Mass Spectrometry (PyGCMS), μFTIR spectroscopy and Energy Dispersive X-ray analysis (EDX), as listed in Table 1. All samples were cast in 2003; some were thermally aged prior to soiling in a Fisons 185 HWC environmental oven (60° C; 55% RH) for 16 weeks; others were light aged at 15,000 lux for 16 weeks under Philips TLD 58W/840 daylight fluorescent tubes with the UV component filtered by acrylic sheet [Perspex p(MMA)]. Assuming reciprocity, this is equivalent to ~50 years exposure under normal museum conditions. All samples were soiled in 2006, after the initial period of natural/accelerated aging. Since soiling, all samples had a further 3 years natural aging in dark conditions prior to testing.

Artificial soil

An artificial soil mixture was prepared that was based on those proposed by Wolbers (1992) and Markopoulou (2003); the constituents (see Table 2) were blended together and sprayed onto the dried paint samples using a Badger Mini Spray Gun 250.4 (see Suppliers). The soil was applied in several layers to provide a medium-heavy coating with an area masked off as an unsoiled control.

Assessing surface characteristics of paint samples

The canvas samples were assessed before and after cleaning with methods aimed at documenting the nature of the film

Paint Brand	Pigment Type	Copolymer Type	Extender
Golden	Titanium white (PW6)	p(*n*BA/MMA)	-
W&N		p(*n*BA/MMA)	-
Talens		p(EA/MMA)	$CaCO_3$
Liquitex		p(*n*BA/MMA)	-
W&N	Azo yellow (PY3)	p(*n*BA/MMA)	-
Talens		p(EA/MMA)	$CaCO_3$
Liquitex		p(*n*BA/MMA)	-

Table 1: Description of test paints prepared for the swabbing study

Soil ingredient	Amount	% dry wt.	Supplier
Carbon black	2.0g	3.2	A.P. Fitzpatrick, UK
Iron oxide (ochre)	0.5g	0.7	
Silica	1.75g	2.8	
Kaolin	20.0g	32.4	
Gelatin powder	10.0g	16.2	VWR International, UK
Soluble starch	10.0g	16.2	
Cement (Type I)	17.5g	28.3	LaFarge Cement, UK
Olive oil (Berlotti)	10 ml	-	-
Mineral oil	20 ml	-	VWR International, UK
Petroleum spirit (80-100°C), 0% aromatic content [or VM&P Naphtha HT]	1L		

Table 2: Composition of complex artificial soil mixture

No	Cleaning system	pH	Conductivity (μS/cm)	Manufacturer/supplier
1	Deionized water (DI)	5	0	-
2	Tap water	7	650	-
3	Carbonated water (siphon)	5	1000	-
4	Acetic acid in DI water	4	72	VWR International, UK
5	1% v/v. ethanol in DI water	5	5	
6	1% w/v. triammonium citrate (TAC) in DI water	7	8100	
7	1% w/v. TAC + 1% v/v. TRITON® XL-80N in DI water	7	6700	Conservation Resources, UK
8	Petroleum Spirits (80-100°C bp.) ~ 0% aromatics	-	-	VWR International, UK
9	1% v/v. Surfynol 61 in petroleum spirits (80-100°C bp.) ~ 0% aromatics	-	-	Kremer Pigmente, Germany
10	Saliva	6-7	3100	-
11	INVERT™ 5000 (neat)	-	-	The Dow Chemical Company
12	INVERT™ 5000 (diluted 1:1 with mineral spirits (120-160°C bp.)	-	-	
13	2% v/v. SatinFX™ and 0.5% v/v. sodium lauryl sulphate (SLS) in petroleum spirits (80-100°C bp) ~ 0% aromatics	-	-	
14	1% v/v. SatinFX™ and 0.5% v/v. sodium lauryl sulphate (SLS) in petroleum spirits (80-100°C bp) ~ 0% aromatics	-	-	
15	1% v/v. ECOSURF™ EH9 and 1% w/v. TAC in deionized water	7	16800	
16	1% v/v. ECOSURF™ EH9 and 0.5% w/v. TAC in deionized water	6-7	500	

Table 3: Cleaning systems used for the swabbing study

surfaces. This assessment included measuring paint sample surface conductivity and the presence and relative amounts (see Table 5) of migrated surfactant, in order to explore whether these factors influence cleaning efficacy. Surface conductivity readings were taken to explore the relative ionic activity at the surface of each paint sample (unsoiled control areas), as this parameter that has been recently introduced as a tool to help tailor cleaning solutions to specific paint surfaces (Wolbers, 2000; Ormsby and Smithen, 2010). For this 100 µL of deionized water was pipetted and left on the paint film surface for 1min. The water was then drawn back up into the pipette and placed in a well-plate Horiba Conductivity Meter (B-173) (see Suppliers). The level of surface surfactant on each sample was assessed using Fourier Transform Infrared-Attenuated Total Reflectance (FTIR-ATR) spectroscopy. For this, a germanium ATR crystal was used with a Nicolet Avatar 360 spectrometer at 200 scans. At ~ 2000cm^{-1} the ATR system had a penetration depth of around 0.66 µm. Data was processed using Omnic 6.2 software and Table 5 contains data calculated as a ratio dividing the absorbance of the largest surfactant band at ~ 1110 cm^{-1} with that of the corresponding carbonyl band at ~1730 cm^{-1}. This provides a relative measure of surfactant abundance, with the highest figures indicating the greatest amounts of migrated surfactant.

Cleaning systems

Table 3 lists the systems chosen for this study, taken from a group of ten commonly used solutions (based on either deionized water or mineral/petroleum spirits), and supplemented by six systems that were highly rated by the HTP screening. Swab-roll cleaning tests were carried out with standardized Puritan® cotton-tipped applicators (see Suppliers).

RESULTS AND DISCUSSION

Table 4 contains the results from all swabbing study cleaning evaluations, which were defined as follows:

- Visual assessment of relative degree of cleaning after 8 x swab rolls.
- Number of swab rolls required to clean to a stopping point – determined as when: the sample was clean/pigment was removed/swelling was noted/damage was noted/100 swab rolls had been applied.
- Visual assessment of the final clean stage: compared with soiled and unsoiled control areas.
- Relative degree of 'damage' to the paint film: e.g. pigment removal, gloss change, swelling and/or abrasion of surface.
- Cleaning solution handling properties: consistency of swabbing action, control, wetting, clearance issues.

Visual Assessment

Each cleaning solution was applied to the 23 soiled test paint canvas samples and the results judged by eye and expressed in a scale ranging from 1 to 10; where 10 was the most effective system at removing soiling (Column A, Table 4). Interestingly, results were seen to approximate the soiling removal level achieved with the HTP system at ~8 swab rolls (consisting of 8 x 1 forward and back swab rolls).

As can be seen by the ratings and the example cleaned sample in Figure 1, eight swab rolls did not clean many of the samples to a significant degree, hence the maximum rating achieved for any of the solutions at this stage was 5/10. Nonetheless, the solutions rated highest in terms of cleaning efficacy were the neat and diluted INVERT™ 5000 water-in-oil microemulsion. The next most efficient included the surfactant and chelating agent combinations, followed by the various simple aqueous systems, with all of the mineral spirit-based solutions consistently rating poorly. This assessment provides an indication of the relative initial efficacy of each solution without accounting for any potentially complicating factors - such as pigment loss etc. The performance of the different cleaning solutions in this evaluation was in very good agreement with the results generated on the HTP equipment.

Number of swab rolls required to reach the final 'clean' point

Column B in Table 4 lists the number of swab rolls required to take the group of soiled samples to the final 'clean' state. This varied per sample, where swabbing was stopped at various

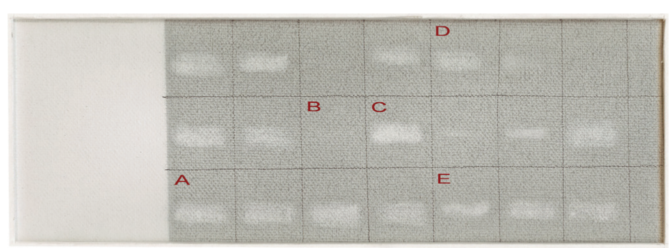


Figure 1: A soiled titanium white painted primed canvas sample cleaned to the 8x swab roll stage with the 16 swabbing-study cleaning systems. Marked tests are: water (A); Petroleum spirits (80-100°C bp.) (B); INVERT 5000 (C), 1% ECOSURF™ EH9 and 1% TAC in DI water (D); and 1% Satin™ FX in Petroleum spirits (80-100°C bp.) (E).

Evaluation criteria	A.		B.		C	D.		E.	
	Clean rating after 8 swab rolls (ave. 23 samples) 1-10; 10=clean	**SD : 8x swab rolls rating**	**No. swab rolls till fully clean (ave. 23 samples) <100x**	**SD for no. swab rolls**	**Rating for speed of cleaning: 1 = slowest; 10 = fastest (no. swab rolls)**	**Clean rating final clean (ave. 23 samples) 1-10; 10=clean**	**SD for final clean rating**	**Relative 'damage' rating; 10 = best; 1 = worst (ave. 23 samples)**	**Cleaning system type**
Material / solution (concentration)									
INVERT™ 5000 (neat)	5	2	15	12	10	8	1	1	ME
INVERT™ 5000 (diluted 1:1 with mineral spirits (MS) (120-160°C bp.))	5	2	23	14	9	8	1	3	ME
1% TAC + 1% TRITON® XL-80N in DI water	4	2	42	23	7	8	1	7	Aq + S + C
1% ECOSURF™ EH9+ 1% TAC in DI water	4	2	44	25	7	8	1	7	Aq + S + C
1% ECOSURF™ EH9 + 0.5% TAC in DI water	4	2	44	24	7	8	1	7	Aq. + S + C
1% TAC solution in DI water	3	2	57	27	6	7	1	8	Aq + C
Carbonated water (syphon)	3	2	58	29	6	7	1	8	Aq
Saliva	3	2	58	25	6	7	1	8	Aq
Deionised water (DI)	3	2	62	29	5	7	1	10	Aq
1% ethanol in DI water	3	2	66	25	5	6	1	10	Aq + solvent
Tap water	3	1	67	26	5	6	1	10	Aq
Acetic acid in DI water (pH 4.0)	3	2	69	27	5	6	1	10	Aq
2% SatinFX™ + 0.5% SLS in Pet. S (80-100 °C bp.)	1	1	82	26	3	5	2	10	Non-polar + S
1% SatinFX™ + 0.5% SLS in Pet. S (80-100°C bp.)	1	1	81	23	3	5	2	10	Non-polar + S
1% Surfynol 61 in Pet. S (80-100°C bp.)	1	1	87	21	3	3	3	5	Non-polar + S
Petroleum spirits (80-100°C bp.)	1	1	92	18	2	3	3	5	Non-polar

Table 4: Combined results for swab-roll tests on 23 different paint films on acrylic primed canvas. (Key: ME = microemulsion; S = surfactant; C = chelate)

points including: when the sample was clean; where 'damage' – such as pigment loss, abrasion or swelling - occurred; when 100 swab rolls had been reached. Not surprisingly, as shown in Figure 2, the required number of swab rolls varied with the cleaning system used: the least number of rolls were required when using the INVERT™ 5000 microemulsion and the largest number were achieved for all mineral spirits-based systems. The group of aqueous systems required moderate numbers of swab rolls, with marginally fewer for the surfactant-chelating agent combinations.

Although these tests were carried out by one person, the errors are notably large (see fig. 2). This is due to a number of factors including: the increased range of samples tested - i.e. 2 colors and 2 brands; differences in the heaviness of the applied soiling layer between samples; and the light and/or thermal ageing of some samples. It is also noted here that the number of swab rolls required was often far more than would be applied in typical conservation treatment situations; which is due to the tenacity of the applied soiling layer.

Solution efficacy at final clean point

When the final clean results were judged by eye (Column D, Table 4), it was clear that the mineral spirit based solutions were typically less successful at removing soiling compared to aqueous systems, apart from INVERT 5000, which was the most successful, alongside the aqueous surfactant and chelating agent combinations. The group of simple aqueous systems also cleaned moderately well. While still rating relatively poorly, the Satin™ FX/SLS mineral spirit combinations offered an improvement in cleaning efficacy over both the Surfynol 61 and pure mineral spirit solvent options. It was also noted during testing that cleaning efficacy appears to be at least in part dependent on the wetting power of each cleaning solution on each paint film. It was also observed, not surprisingly, that the paint film surface texture also affected the ease of cleaning. For example, samples with a limited number of air bubble holes as well as regular, flat surfaces tended to clean more easily; and films with more holes and rougher surface texture were often more difficult to clean.

Observations on relative damage: pigment transfer, handling, clearance and surface effects

During the complete clean stage, observations were also made on risks associated with each of the cleaning systems. This included assessing critical issues such as: pigment transfer during cleaning, surface abrasion, paint swelling, gloss alterations etc. A rating system was developed to assess the level of 'damage' caused by a particular solution (Column E, Table 4). The solutions with the lowest number posed the highest risk - where combined pigment loss, paint loss, gloss alteration and surface abrasion was noted. The highest ranking (10) was attributed to solutions where no visible change was noted either during or after cleaning. Differences were further refined according to the number of samples affected; hence if a particular solution caused damage to only one sample, the rating was lower than one that had repeatedly caused 'damage'.

These observations had a dramatic effect on the rating of some systems. For example, the INVERT 5000 microemulsion systems rated highest in terms of cleaning efficacy; however, the neat INVERT 5000 rated poorly with regard to risk due to frequent pigment transfer and surface abrasion noted during cleaning. With this product, pigment transfer was noted on 17 of 23 samples, which subsequently and reduced to 6 samples with the diluted system. The aqueous surfactant and chelating agent combinations also rated highly in terms of cleaning efficacy however they were sometimes affected by quantities of foaming at the paint surface, causing poor visibility and

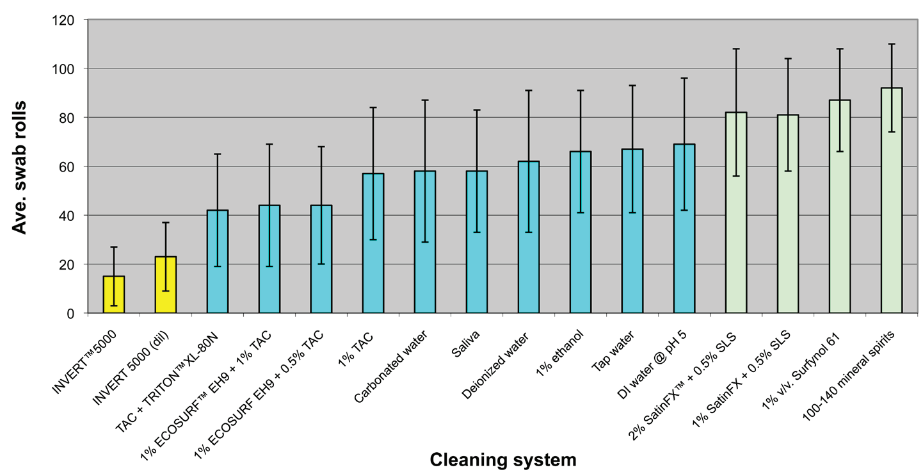


Figure 2: Number of swab rolls required for complete removal of soil (including stopping when clean/at damage or swelling point/after 100 swab rolls)

Pigment type	Paint Brand	Ageing regime	Surface conductivity – control unsoiled area. (1 x 1 min water extract) (µS/cm)	Surfactant level control unsoiled area (C=O/ 1110cm^{-1}) Ave. of 4 spots	Ave. swab rolls to final cleaning point across all solutions	Ave. of ave. swab rolls	SD. Ave. swab rolls
PW6	Talens	Natural	240	11.57	37	69	20
PW6	Golden		120	3.91	71		
PY3	W&N		151	2.20	52		
PY3	W&N		135	2.02	59		
PW6	Liquitex		39	0.51	82		
PW6	Liquitex		320	0.46	90		
PY3	Liquitex		250	0.94	90		
PW6	Golden	Light	97	0.74	61	71	13
PW6	Talens		102	0.72	72		
PW6	Liquitex		42	0.63	84		
PY3	Liquitex		250	1.03	85		
PW6	W&N		36	0.00	53		
PY3	Talens		93	0.00	70		
PY3	Liquitex	Thermal	227	12.16	50	42	10
PW6	Liquitex		195	10.19	27		
PY3	Liquitex		132	9.38	48		
PW6	Liquitex		143	3.88	25		
PW6	Talens		162	2.67	45		
PY3	Talens		147	2.62	42		
PW6	Talens		60	2.08	41		
PW6	Golden		20	1.06	53		
PY3	Talens		89	1.05	39		
PW6	W&N		19	0.00	52		

Table 5: Average swab rolls required for complete clean across all solutions compared to paint brand, pigment type, surface conductivity, and surfactant abundance

prompting concerns about adequate clearance. The simple aqueous systems - deionized water, tap water, water with added acetic acid and water with the addition of ethanol – did not caused any visible damage during or after treatment. Of the mineral spirits systems tested, the SatinFX™/SLS mixture rated highly in terms of its low damage potential, and therefore may be of some use in situations where aqueous systems and water-in-oil microemulsions are not suitable.

Repeated pigment transfer was noted with the INVERT™ 5000 systems across the range of samples. This did not appear to be brand dependent but was noted earlier with the PY3 samples. Those samples with higher initial gloss levels appeared to be more sensitive to surface abrasion and paint swelling, and the INVERT solutions were noted as occasionally causing paint surface swelling.

Influence of surface surfactant, paint brand, pigment type and aging on cleaning efficacy.

Several paint surface properties were also assessed in conjunction with the cleaning efficacy tests to ascertain whether the nature of the paint film surface plays a role. This included assessing levels of surface surfactant and surface conductivity; which have been discussed in detail elsewhere (Ormsby and Smithen, 2010; Ormsby et. al., 2009).

Table 5 compares the number of swab rolls required to clean each sample with pigment type, surface surfactant levels, surface conductivity values paint brand and ageing regime. The data indicates there was a slight reduction in average swab rolls required to fully clean the thermally aged samples. This may be due to the presence of substantial surfactant layers on many of these samples; or perhaps more feasibly, as the paint films had been thermally aged prior to soiling, they were probably a little harder, which may have prevented the applied soiling from becoming embedded.

Rearrangement of the data to reflect differences in pigment type (not shown) revealed little variation in the average number of swab rolls between the white and the yellow samples. Paints of the same brand – regardless of the pigment type - tended to require similar numbers of swab rolls to achieve a complete clean. For example, the Talens samples required an average of ~50 swab rolls; the Winsor and Newton (W&N) sample averages ranged from 53-56 rolls and the Liquitex samples ranged from 62-68 swab rolls. The data also suggested that there was no clear relationship between the surface conductivity of each paint film and either the surface surfactant levels present, paint brand, pigment type or the number of swab rolls required for complete cleaning. A marked increase in surface surfactant levels with thermal aging was noted for the Liquitex samples however this was not consistent across all samples.

Overview

Table 6 summarizes the results of this series of tests. For the aqueous systems, 1% ECOSURF™ EH9 + 1% TAC; 1% ECOSURF EH9 + 0.5% TAC; and 1% TAC + 1% TRITON® XL-80N were identified as the top-rated in terms of cleaning efficacy. These surfactant-chelating agent combinations showed a significant improvement in cleaning efficacy when compared to the simple aqueous systems, and the results generally concur with the HTP findings. That said, they also resulted in considerable foaming that occasionally obscured the paint surface during cleaning. The group of simple aque-

System	Swabbing study top rated systems	Comments from swab-roll study
Aqueous	ECOSURF™ EH9 / tri-ammonium citrate	Foams at surface; high cleaning efficacy; low risk to paint film.
	TRITON®XL-80N/ tri-ammonium citrate	Foams at surface; high cleaning efficacy; low risk to paint film.
	All other aqueous systems	Moderate cleaning efficacy; low risk to paint film.
Mineral spirits	Water-in-Oil Microemulsion (INVERT™5000)	Highest cleaning efficacy but can remove pigment. Requires reformulation to lower risk.
	LAS/ SatinFX™/VMP Naphtha	Generally poor cleaning efficacy; improvement on pure solvent; low risk to paint film.

Table 6: Top-ranked results from the swabbing study

ous systems also represented a low risk to each of the paint films, but up to 20 additional swab rolls were required to achieve the same degree of cleaning as the surfactant-chelating agent combinations.

Of the mineral spirits-based systems tested, the INVERT™ 5000 microemulsion achieved the greatest cleaning efficacy, representing an enormous improvement over the other systems tested, which all rated poorly. However, it also posed some risk to the paint films in this study, even when diluted with mineral spirits, and some further modification to its formulation may be needed before it can be fully recommended to the conservation profession (see Conclusion). The Satin™ FX and SLS mixtures offered a slight improvement over both the Surfynol 61 solution and pure mineral spirits which suggests that this approach may be worth pursuing to further increase the cleaning efficacy of mineral spirits-based systems.

CONCLUSIONS

This paper reports on tests into the relative efficacy of a range of different wet cleaning systems for the removal of dirt from the surfaces of artists' acrylic paint films, largely by practical tests carried out by conservators, and builds on previous work using Dow's HTP facilities to identify novel cleaning systems for this purpose. The results from the HTP and hand-swabbing assessments were in general agreement with respect to soiling removal efficacy.

When taking the associated risks into account; improved cleaning efficacy was consistently achieved using aqueous mixtures of tri-ammonium citrate and nonionic surfactants at low concentrations; with minimal associated risk to the paint film apart from some foaming noted at the paint surface. Many of the simple aqueous systems also produced moderate results with minimal risk to the paint films however longer mechanical action was often required. The least successful systems with respect to cleaning efficacy were the mineral spirits solutions. These had poor surface wetting and required extended mechanical action; and in many cases not removing much of the applied soiling. The addition of nonionic and anionic surfactant mixtures increased the cleaning efficacy of these systems however the most marked increase in soiling removal efficacy was noted when these solvents were formulated as part of an INVERT water-in-oil microemulsion.

Future work includes the assessment of these systems on case studies and the further refinement of the microemulsions, optimizing the surfactant-chelator content of aqueous systems and an investigation into the clearance of these materials from paint surfaces.

In particular, the good cleaning efficacy observed for the INVERT 5000 microemulsion has encouraged continued investigation of this class of formulation at Dow, with a view to preparing a microemulsion with properties more directly tailored to the particular application of cleaning acrylic paint, with lower inherent risk to the paint films. This work in progress will be achieved for example by lowering the overall concentration of surfactant and using faster evaporating co-solvents.

ACKNOWLEDGEMENTS

The authors would like to thank the following people and organizations: AXA Art for funding acrylic dispersion paint research at Tate (2006-2009); Patricia Smithen and Elina Kampasakali, Tate; Sarah Eckersley, The Dow Chemical Company.

SUPPLIERS

Golden Artist Colors, Inc.
188 Bell Road
New Berlin, NY 13411-9527 USA
607-847-6154
800-959-6543
Fax: 607-847-6767
E-mail: goldenart@goldenpaints.com
www.goldenpaints.com

ColArt International Holdings Ltd. (Winsor & Newton, Liquitex)
Whitefriars Avenue
Wealdstone, Harrow
Middlesex, HA3 5RH, UK
www.colart.com

Royal Talens
B.V., P.O. Box 4, 7300 AA Apeldoorn
The Netherlands
www.talens.com

Fredrix canvas
Russell & Chapple
68 Drury Lane,
London, WC2B 5SP, UK
Tel: +44 20 7836 7521
Fax: +44 20 7497 0554

Filmcaster
Sheen Instruments Ltd
2 Gatton Park Business Centre
Wells Place
Redhill
Surrey, RH1 3LG, UK
Tel: +44 1737 649300
Fax: +44 1737 649301
E-mail: info@sheeninstruments.com
http://www.sheeninstruments.com

Badger Mini Spray Gun 250.4
The Airbrush Company Ltd
Unit 7 Marlborough Road (East)
Lancing Business Park, Lancing
West Sussex, BN15 8UF, UK
+44 (0)1903 767800
www.Airbrushes.com

Puritan® Cotton Tipped Applicators
6" x 1/10", Wooden Shaft, Non Sterile
www.HealthProductsForYou.com
New Fairfield, CT, USA
Tel: +1 866-316-0162

Horiba B-173 well-plate conductivity meter
The Lab Warehouse
http://thelabwarehouse.com
11-12 The Oval
London, E2 9DU, UK
Tel: +44 (0) 207 729 7998
Fax: +44 (0) 207 729 2657

Dow alkyl polyglucoside surfactants, including TRITON™ CG110:
https://www.dow.com/surfactants/products/alkyl_po.htm
http://www.dow.com/PublishedLiterature/dh_00a4/0901b803800a425a.pdf?filepath=surfactants/pdfs/noreg/119-01873.pdf&fromPage=GetDoc

ECOSURF™ EH Surfactants
http://www.dow.com/PublishedLiterature/dh_0224/0901b80380224b12.pdf?filepath=surfactants/pdfs/noreg/119-02244.pdf&fromPage=GetDoc

SURFONIC™ JL-80X http://www.huntsman.com/performance_products/Media/SURFONIC%C2%AE_JL-80X.pdf
VWR International
Hunter Boulevard
Magna Park
Lutterworth,
Leicestershire, LE17 4XN, UK
P: +44 1455 558600
F: +44 1455 558586
E-mail: info@uk.vwr.com
http://www.vwr.com/

Conservation Resources (U.K.), Ltd.
Unit 2, Ashville Way
Off Watlington Road
Cowley, Oxford, OX4 6TU, UK
Phone: +44 (0) 1865 747755
Fax: +44 (0) 1865 747035
E-mail: ConservArts@aol.com
http://www.conservationresources.com/Main/S%20CATALOG/CoverPage.htm

Kremer Pigmente GmbH & Co. KG
Hauptstr. 41 – 47
DE 88317 Aichstetten
Germany
Phone 0049 75 65 911 20
Fax 0049 75 65 16 06
E-mail: info@kremer-pigmente.de

REFERENCES

Harris, J. K., Rose, G.D. and Bruening, M.L. 2002, Spontaneous generation of multilamellar vesicles from ethylene oxide/butylene oxide diblock copolymers. *Langmuir* 18: 5337-5342

Keefe, M.H., Harris, K.; Meyers, G. F.; Moore, L. A.; Reinhardt, C. W.; Zu, C.; Phenix, A.; Learner, T. J. S. and Ormsby, B. A. 2009. The use of high throughput testing for rapid screening of potentially useful cleaning formulations for the removal of surface dirt from acrylic emulsion paints. Presentation at the General Session of the meeting of the American Institute for Conservation, Los Angeles, (unpublished).

Markopoulou, E. 2003. *Cleaning surface dirt from unvarnished acrylic paintings.* MA dissertation, Northumbria University, Newcastle-upon-Tyne (unpublished).

Ormsby, B. and Phenix, A. 2009. Cleaning acrylic emulsion paintings. *Conservation Perspectives: The GCI Newsletter* 24.2 (Fall 2009), 13-15 http://www.getty.edu/conservation/publications/newsletters/24_2/cleaning.html

Ormsby, B., Kampasakali, E., Miliani, C., and Learner, T. 2009. An FTIR-based exploration of the effects of wet cleaning artists' acrylic emulsion paints. In *Infra-red and Raman Users' Group Meeting (IRUG), Vienna, 2008, e-Preservation Science* 6:186–195.

Ormsby, B., and Learner, T. 2009. The effects of wet surface cleaning treatments on acrylic emulsion artists' paints – A review of recent scientific research. *Reviews in Conservation,* 10: 29-41.

Ormsby, B., and Smithen, P. (2010). 'Surface Cleaning Acrylic Emulsion Paintings: Case Studies at Tate.' *The Picture Restorer*, No. 37, Autumn, The British Association for Picture Conservator-Restorers (BAPCR), London: 7-10, 24.

Wolbers, R. 1992. The use of a synthetic soiling mixture as a means for evaluating the efficacy of aqueous cleaning materials on painted surfaces. *Bulletin of the Association des Restaurateurs d'Art et d'Archéologie de Formation Universitaire (ARAAFU): Conservation-Restauration des Biens Culturels* 4 : 22-29.

Wolbers, R., 2000. Cleaning painted surfaces: aqueous methods. Archetype, London (2000).

AUTHORS' INFORMATION

Dr. Bronwyn Ormsby
Senior Conservation Scientist
Conservation Department
Tate Britain
Millbank, London, SW1P 4RG, UK
E-mail: bronwyn.ormsby@tate.org.uk

Alexia Soldano
Tate Conservation Science Intern
(January - March 2010)
c/o- Conservation Department
Tate Britain
Millbank, Pimlico, SW1P 4RG, UK
E-mail: alex_soldano@hotmail.com

Dr. Melinda H. Keefe
Research Scientist, Dow Coating Materials
The Dow Chemical Company
727 Norristown Rd., Building 2
Spring House, Pennsylvania, 19477, USA
E-mail: mhkeefe@dow.com

Alan Phenix
Scientist
Getty Conservation Institute
1200 Getty Center Drive, Suite 700
Los Angeles, California, CA 90049, USA
E-mail: aphenix@getty.edu

Dr. Thomas J. S. Learner
Senior Scientist / Head of Modern and Contemporary Art Research
Getty Conservation Institute
1200 Getty Center Drive, Suite 700
Los Angeles, California, CA 90049, USA
E-mail: tlearner@getty.edu

ANA ALBA, SUSAN LAKE, MEL WACHOWIAK, AND JENNIFER GIACCAI

A Question of Technique: Condition Issues Associated with Layering Structure in Richard Diebenkorn's Ocean Park Series

ABSTRACT

An examination of Richard Diebenkorn's *Ocean Park No. 111*, 1978, revealed a pattern of lifting cracks that correlated to design and/or color areas. To determine whether or not Diebenkorn's materials, his working methods or a combination of the two are responsible for the cracking, three additional Ocean Park paintings from the same time period were also examined. One exhibited similar cracking while the other two were in near perfect condition. Materials analysis was completed for all four paintings and the two paintings showing cracking were found to contain an acrylic preparatory layer. The affects of alkyd and oil paint binders on the stability of the paint films was also explored.

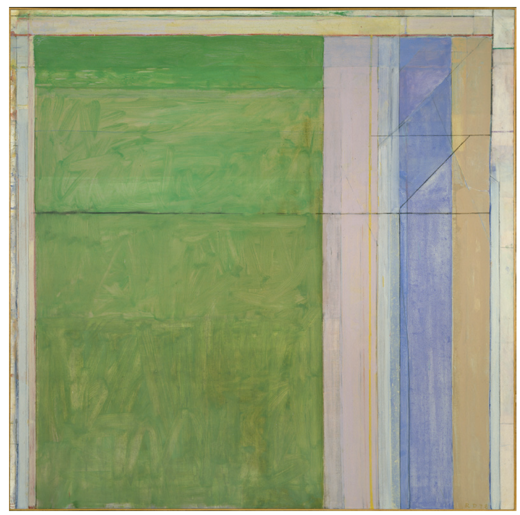


Figure 1. Richard Diebenkorn *Ocean Park No. 111*, 1978. Oil, alkyd, and charcoal on canvas, 236.5 cm x 236.9 cm, Hirshhorn Museum and Sculpture Garden.

INTRODUCTION

This paper presents the results of a two year study of the paint application methods, materials, and associated condition issues found on Richard Diebenkorn's paintings from the Ocean Park Series. The project began when a preliminary examination of *Ocean Park No. 111* (Hirshhorn Museum and Sculpture Garden, Washington, D.C.) revealed severe cracking patterns associated with specific areas of the painting (fig. 1). Subsequent examination and analysis of the painting revealed that the artist applied a clear synthetic resin directly to his canvas support before applying an acrylic ground and multiple oil-modified alkyd paint layers. Additional Ocean Park paintings from around the same time period were examined in order to determine whether or not Diebenkorn's materials and/or his application techniques are related to the extensive cracking seen in *Ocean Park No. 111* and the severe condition issues frequently associated with many of the paintings in the series.

Richard Diebenkorn (1922-1993) is recognized as one of the most important American artists in the abstract expressionist movement, as well as the leading artist of the Bay Area Figurative Movement. From 1947 to 1950 he taught at the California School of Fine Arts, San Francisco, where his fellow teachers included Elmer Bischoff and Clyfford Still. Under their influence he was drawn toward the Abstract Expressionist movement. [1] Richard Diebenkorn's Ocean Park series began late in 1967, while working in his studio in the Santa Monica Ocean Park district. The series includes about 150 paintings and was developed over the next 25 years. In the Ocean Park paintings, there is a shared emphasis on geometry and spatial relationships. The colors vary, but the paints he generally used were airy, translucent, and brightly colored, seemingly influenced by the light and color of his surroundings.

EXAMINATION AND GROUND WORK

When *Ocean Park No.111* was requested for loan, a preliminary examination revealed an extensive system of lifting cracks that appeared to have become more severe than when the painting was last examined. Examination also revealed drips of clear polymeric resin along the tacking margins. This resinous material which the artist applied directly to the raw canvas overall and beneath the ground and paint layers is soft and malleable. Samples removed from the tacking margins are noticeably porous, as evidenced by air bubbles. Under magnification, the resin is readily visible at the bottom of crack openings and is evident in paint cross sections (fig. 2). As seen in this cross section, the resin is as thick as the combined paint and ground layers above.

In an attempt to determine whether there is a correlation between the condition of *Ocean Park No. 111* and Diebenkorn's painting materials and methods of application, twelve additional Ocean Park paintings from other institutions were examined. Additionally, condition photos and treatment reports were reviewed for several other paintings of the series. Although samples were not taken from all the paintings examined, a general trend was noted. The paintings with a clear resin layer applied to the fabric support showed more severe cracking in the paint layers and were generally in poorer condition than those without it.

For the purpose of this study, the focus of the analysis was narrowed to four case studies: *Ocean Park No. 111*, 1978 (Hirshhorn Museum and Sculpture Garden), *Ocean Park No. 96*, 1977 (Solomon R. Guggenheim Museum), *Ocean Park No. 115*, 1979 (Museum of Modern Art), and *Ocean Park No. 125*, 1980 (Whitney Museum of Art). The four paintings chosen included two with severe cracking (*Ocean Park No. 111* and *Ocean Park No. 96*) and two that are in relatively good condition (*Ocean Park No. 115* and *Ocean Park No. 125*). These four paintings were also selected based on their closeness in date to remove concerns about making generalizations about condition issues of the whole series. Nonetheless, discussions and consultations with other conservators at additional institutions indicate that many of the Ocean Park paintings have varying degrees of cracking, some more distracting than others.

Case Study #1: Ocean Park No.111

Ocean Park No. 111 is executed on cream colored plain weave cotton duck canvas. The canvas is stapled and tensioned over an eight member wooden strainer. Wooden gussets are nailed into the strainer at each corner for additional support. The crossbars of the strainer, around the central square form, are smudged with paint, where the artist handled the strainer in order to turn the painting during execution. The artist applied his paints as diluted pastes, as evidenced by drying streaks and the matte, powdery surface appearance. In some areas, the paint is sufficiently thin that lower paint layers are readily visible. Also important to the design are charcoal lines drawn onto the paint surface and others that are half obscured by overlying layers of paint.

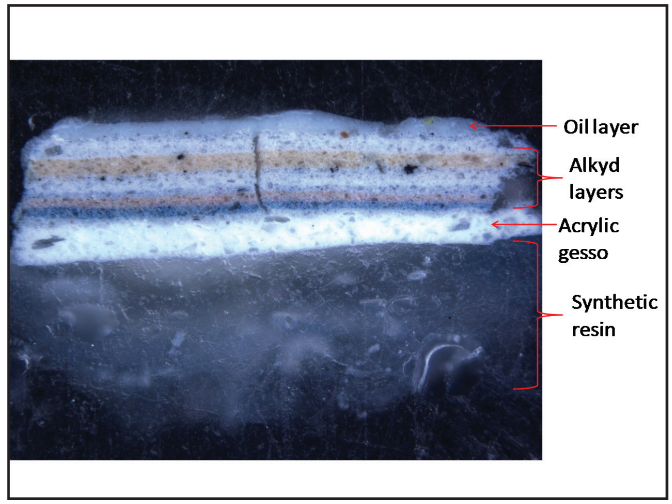


Figure 2. Cross section from *Ocean Park No. 111*. Darkfield 200x.

Cross sections from *Ocean Park No.111* indicate that the unpigmented resin layer described earlier was applied directly to the entire surface of the canvas, presumably as a size to protect the fabric support. Another possibility is that Diebenkorn wanted to create a smooth surface on which to work, as the resin completely masks the canvas texture. Fourier transform infrared (FTIR) analysis of a sample of the resin layer taken from a tacking margin identified it as an acrylic; specifically, a poly-ethyl acrylate-methyl methacrylate copolymer (pEA-MMA) such as Rhoplex. Rhoplex AC-33 is a likely candidate as the material was widely used by artists during the 1970s and 1980s. Figure 3 shows the spectra of a sample from *Ocean Park No. 111* compared to that of Neocryl BT-20, a bulk pEA-MMA resin. The shape of the C-H stretch region, around 2800-3100 cm^{-1}, is an indication of an acrylic resin, as is the location of the carbonyl peak at 1732 cm^{-1} and the shape of the fingerprint region. Pyrolysis-Gas-Chromatography–Mass

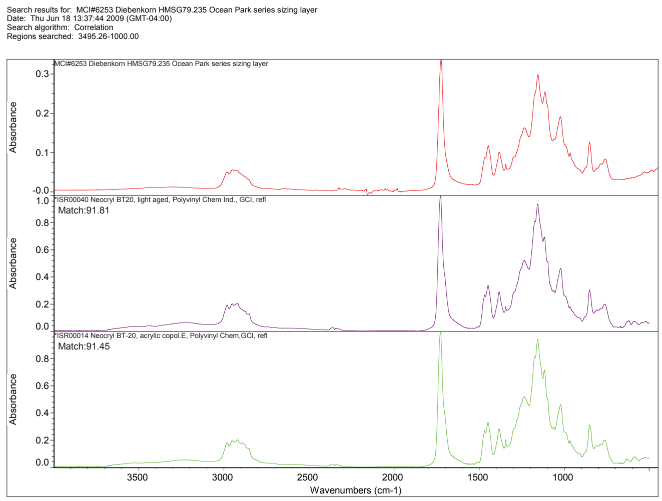


Figure 3. Comparison of the FTIR spectrum for the clear synthetic material in *Ocean Park No. 111* and two spectra for bulk ethyl acrylate methyl methacrylate acrylic emulsion (Neocryl BT-20 from DSM NeoResins).

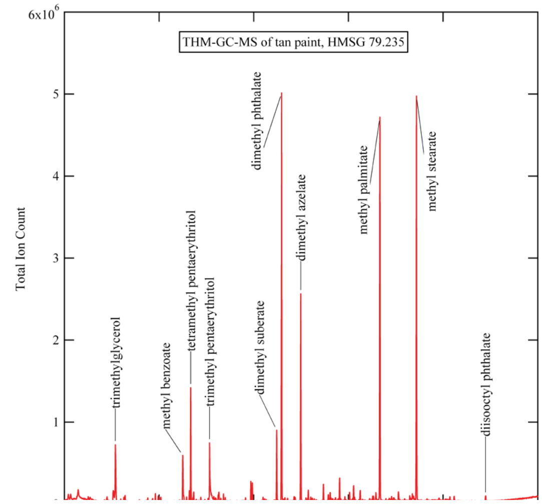


Figure 4. Pyrogram for a sample of tan paint taken from the surface of *Ocean Park No. 111* with the characteristic peaks noted.

Spectrometry (Py-GC-MS) verified the identification of the sample as a pEA-MMA resin.

Diebenkorn next applied a white ground directly to the synthetic resin layer. FTIR analysis and Py-GC-MS identified the ground medium as an acrylic resin (pEA-MMA). The homogenous dispersion of the pigments, the identification of the filler material (chalk and kaolin), and the fact that the ground does not extend onto the tacking edges suggest that this is a commercial priming that the artist applied himself.

FTIR and Py-GC-MS analysis identified the paints that Diebenkorn used as oil-modified alkyds. Peaks identifying the pentaerythritol backbone of an alkyd are clearly visible in the pyrogram from a sample of the tan paint taken from the surface of the painting (fig. 4). In several of the paint samples identified as alkyd paints, there also seems to be a peak at ~1160 cm^{-1} that suggests there is some free oil as part of the paint composition that may indicate an added artist's oil medium or paint. Additionally, the identification of pigments and the absence of filler materials characteristic of alkyds indicate that the artist occasionally alternated alkyd paint layers with artists' oil paints.

The surface of *Ocean Park No.111* is riddled with a complex network of cracking patterns (fig. 5). There are extensive linear cracks located at the corners of the painting. Additionally, isolated areas of branched crackle are associated with specific color areas and appear to correlate with changes that the artist made to his composition. For example, near the center of the left side of the painting there is an isolated rectangular area of cracking within the larger green area (fig.6). This seems to be associated with a design area that the artist scraped and subsequently reworked. Also visible is a system of distracting rounded cracks with cupped edges that extend along the left side of the painting. These cracks appear to coincide with vertical charcoal lines on the paint surface as well as charcoal lines that are concealed beneath the upper paint layers (fig. 7). Under magnification, additional smaller cracks and fissures can be seen in close proximity to these larger rounded cracks.

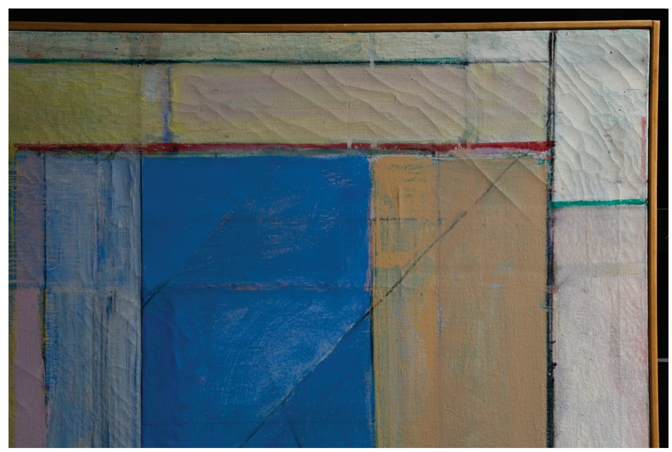


Figure 5. Detail of *Ocean Park No. 111*, raking light, upper right quadrant.

Figure 6. Detail of *Ocean Park No. 111*, raking light, left edge, center.

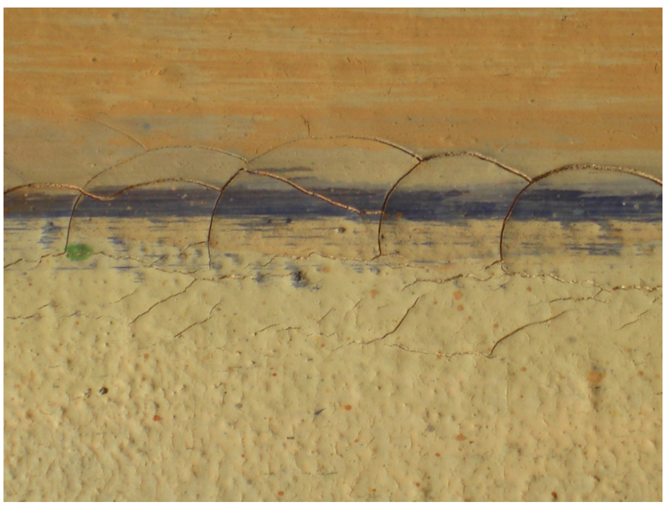


Figure 7. Cracking related to drawing on dry paint in *Ocean Park No. 111*, detail, along left edge.

Both cracking patterns appear to propagate from charcoal lines in the composition and were likely caused when the artist drew with charcoal into already dried paint layers. Diebenkorn was known to have worked on his paintings over long periods of time, sometimes repainting entire surfaces (Bernstein 2009).

Case Study #2: Ocean Park No. 96

Ocean Park No. 96, 1977, was painted a year before *Ocean Park No. 111* and exhibits many of the same condition issues. According to early examination reports, both paintings exhibited cracking less than two years following their completion. The cracking patterns in both *Ocean Park No. 96* and *Ocean Park*

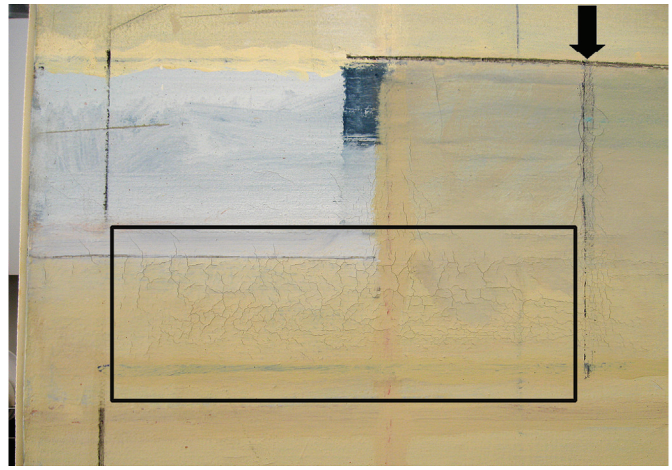
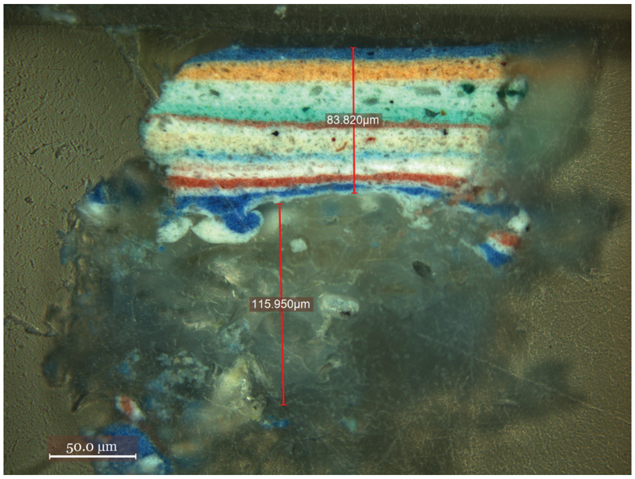


Figure 8. Detail of *Ocean Park No. 96* in an area exhibiting both widespread cracking and cracking following a drawn line as indicated by the square and arrow.

No. 111, show localized areas of dense cracking associated with reworked design areas and areas along drawn charcoal lines (fig.8).

As is the case in *Ocean Park No.111*, a clear resin material is visible as drips on the tacking margin and at the base of the cracks. A section of the composition left unpainted along the bottom edge also reveals this layer. The band retains the color of the raw canvas, a feature which Diebenkorn is known to have appreciated because of its neutral tonality (Larson 1977). FTIR analysis of the paint in *Ocean Park No. 96* revealed that they are oil-based alkyds similar to those found in *Ocean Park No. 111*. Rather than an acrylic gesso ground, *Ocean Park No. 96* has a preliminary white paint layer over the clear resin size, presumably an alkyd paint, although a sample was not available for analysis. The artist applied this white layer selectively to areas of the canvas that were painted.

Two cross sections were taken from the blue square located in the upper left quadrant of the design, half of which exhibited cracking and half of which did not. One sample was taken from each half. In both cross sections, the unpigmented acrylic resin layer is clearly visible and is as thick as, or thicker than, the combined thickness of the overlying paints layers. Significantly, the cross section taken from the half that exhibits cracking reveals a surprising buildup of paint layers measuring almost 83 μm thick (fig. 9a). The cross section from the non-cracking portion contains only 2-3 layers of paint and measures less than 50 μm in thickness (fig. 9b). Moreover, several of the individual paint layers in Figure 9a measure less than 10



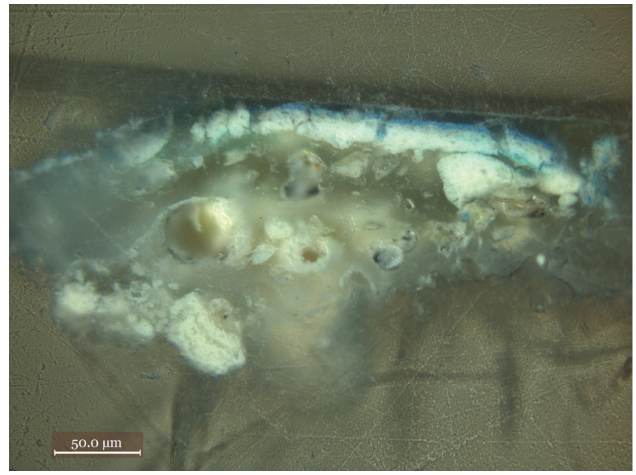


Figure 9. Comparison of two cross sections from *Ocean Park No. 96*, 200x, darkfield. The cross section on the left (a) was taken from an area that exhibited cracking while the section on the section on the right (b) was taken from an area that did not.

µm thick, which suggests that the artist diluted his paints to an almost wash-like consistency before applying them. As seen in *Ocean Park No. 111*, the filler content in both of these cross sections is consistent with a commercial paint, probably an oil-based alkyd. The difference between these two samples seems to indicate that artist layering and manipulation of his paint may play a large role in how much cracking occurs. Inconsistency of thickness in some of the thinner layers also suggests that the artist scraped down his paints once they were applied.

Case study #3: ocean park no. 115

Ocean Park No. 115, 1979, is in good condition and does not exhibit the widespread areas of cracking seen in the previous two case studies. The only cracking evident correlates with charcoal lines drawn into the surface along the top half of the painting. *Ocean Park No. 115* is executed on a commercially primed canvas, as the priming is evenly applied and extends to the ends of the tacking margins. It was again identified as an acrylic gesso ground. The paints were identified by FTIR as oil-based alkyds. Significantly, the painting does not have the synthetic resin preparatory layer identified in *Ocean Park No. 111* and *Ocean Park No. 96*. Otherwise, the painting materials in this work are similar to the previous case studies: oil-based alkyd and oil paints over acrylic grounds. Likewise, all three have similar exhibition histories.

Case Study #4: Ocean Park No. 125

Though painted only two years after *Ocean Park No. 111*, *Ocean Park No. 125* is in excellent condition. As with *Ocean Park No. 115*, cross sections revealed that there is no acrylic resin size present. The paint layers are exceptionally thin and alkyd use is very likely based on appearance and comparison of the paints to the cross sections of *Nos. 111, 115* and *96* where the medium was identified.

COMPARISON OF MATERIALS

The unpigmented acrylic resin size layers found in both *Ocean Park No. 111* and *Ocean Park No. 96* were compared using FTIR. Figure 10 shows their spectra compared to aged Rhoplex AC-33. As shown, the three materials share the same characteristic peaks. Furthermore, samples of the resin size material taken from two additional Ocean Park paintings were identified as poly(ethyl acrylate-methyl methacrylate).[2]

The grounds of *Ocean Park Nos. 111*, *115*, and *125* were all identified as acrylic gesso. Figure 11 shows their comparative spectra. Interestingly, the grounds of *Ocean Park No. 115* and *Ocean Park No. 125* were commercially primed while that of *Ocean Park No. 111* is an acrylic that the artist applied by hand based on the fact that the ground does not extend over the tacking margins. As mentioned previously, the preliminary white paint layer from *Ocean Park No. 96* is probably an oil-based alkyd based on pigment and filler composition.

FTIR analysis indicates that Diebenkorn's paints in all four works are predominantly oil-based alkyds, although isolated layers of drying oils were also identified. Figure 12 is a

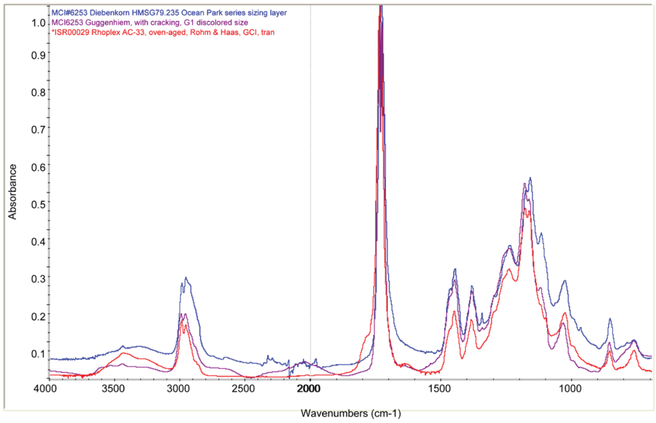


Figure 10. Comparison of FTIR spectra for the synthetic preparatory material from *Ocean Park No. 111* and *Ocean Park No. 96* to aged Rhoplex AC-33.

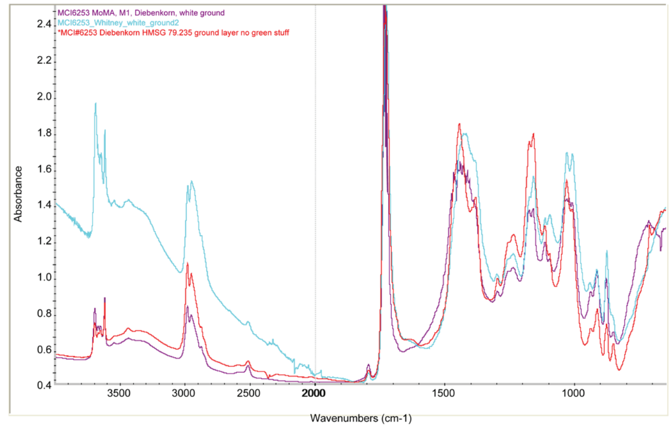


Figure 11. FTIR spectra for ground samples from *Ocean Park Nos. 111, 115,* and *125*. The comparison illustrates the similarities of the acrylic ground layer in the three paintings.

comparison of the FTIR spectra of paint samples from *Ocean Park Nos. 111, 115*, and *96*. All three show a broad peak from 1260-1280 cm^{-1}, typical of alkyd paint binder (Ploeger, Scalarone and Chiantore 2008). The alkyd peak at between 1260 through 1280 cm^{-1} in the spectrum of a paint sample from *Ocean Park No. 96* is partially obscured by the large calcite peak. Very small peaks or shoulders were visible in a number of the paint samples from the three paintings at 1600 and 1582 cm^{-1}, indicating the presence of phthalates, one of the components of an alkyd paint. The location of the carbonyl peak at 1732 cm^{-1} instead of 1740 cm^{-1} for oil based paint found in all of the spectra is also indicative of an alkyd binder. Py-GC-MS analysis of four samples from *Ocean Park No. 111* confirmed the presence of oil-based alkyd paint.

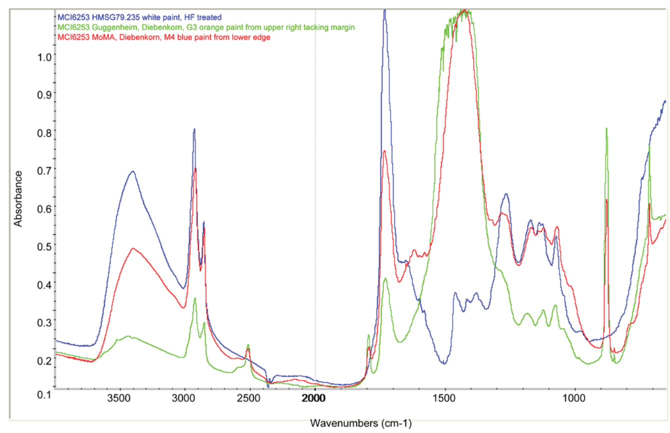


Figure 12. FTIR spectra of alkyd paint samples from *Ocean Park Nos. 111, 115,* and *96*.

PROBLEMS ASSOCIATED WITH ALKYD USE

Diebenkorn's use of oil-based alkyds and his methods of applying them may have contributed to the condition issues associated with many of the Ocean Park paintings. Oil-modified alkyds form stiffer and stronger paint films than do traditional drying oils due to the polyester backbone of the polymer. The molecular weight of an alkyd is much higher than that of traditional drying oils so fewer cross links are required for stable film formation, causing the binding medium to harden to the touch between 18 and 24 hours after application (Ploeger 2009). The artist may have found this quality appealing and selected these paints, in part, because they dry faster than artists' oils. Diebenkorn's use of fast-drying and relatively brittle paints combined with his practice of scraping down and drawing through them with charcoal at later stages in the painting process likely contributed to the cracking reported just two years after *Ocean Park No. 111* and *Ocean Park No. 96* were executed. Alkyd paints have also been found to become increasingly stiff with age (Ploeger 2009). Additionally, Ploeger found that the continuation of the oxidation processes in alkyd paint after film formation is complete might also lead to the deterioration of the film. With age, excessive cross linking may occur, causing the alkyd paint films to become still more stiff and brittle.

Diebenkorn's practice of heavily diluting his alkyd paints with solvents may also have had an effect on the overall stability of paint layers. Commercial alkyds are formulated for application to architectural structures and are meant to be applied directly from the can. Changing the formulation has the potential to adversely impact the integrity the paint. Evaporation of solvents from the alkyd paint creates a porous, under bound paint film that further contributes to the overall brittleness of the paint layer. With excessive dilution, a two phase structure forms instead of a cohesive layer, with the pigments favoring one phase over the other (Croll 2009). Additionally, much of the binder may have leached out of the uppermost layers, causing the powdery, matte surface characteristic of these paintings. Solvent loss during drying also has the potential to cause internal drying stresses (Whitmore et al. 1999). This results in paint layers under tension that are more prone to failure from additional stresses during handling, environmental responses, or further aging.

The cross section illustrated in Figure 2 may be indicative of what is happening structurally to the Ocean Park paintings that are in poorer condition. An internal vertical fissure is visible through the center of the sample. Significantly, the alkyd paint layers have cracked preferentially to the oil paint layer on the surface and the acrylic gesso layer beneath. Many of the cracks now visible on the surface of these paintings may have started in the alkyd paints and with time migrated to the softer artist's oil and ground layers. Moreover, it is likely that the inherent flexibility of the acrylic size layer would have magnified any stresses placed on the paint layers, causing smaller fissures and flaws in the brittle alkyds to propagate to the surface and into the ground. As previously noted, the paint layers in most of the cross sections from *Ocean Park No. 111* and *Ocean Park No. 96* measure about 100 microns on average, while the clear synthetic resin of both paintings is twice as thick. In these examples, brittle and excessively lean alkyd paints were applied to a heavy layer of flexible resin size that provides inadequate support. Moreover, Rhoplex has been found to maintain rubbery flow over many years (Michalski 1991). This potentially means a longer period of vulnerability these paintings might experience. With any cause of stress whether it be mechanical or environmental, and little resistance from the support, cracks form freely and propagate. A particularly interesting study by Young et al. (2006) found that alkyd paint layered over an acrylic gesso increased the overall stiffness of samples and caused premature failure of the acrylic during stress tests. These paintings illustrate this in a real, natural setting.

POSSIBLE PIGMENT EFFECT

Zinc was identified in *Ocean Park No. 111* within isolated layers of the white and green oil paints. It has been observed that the presence of zinc in paint layers has the potential to increase brittleness and cause structural failure (Mecklenburg, Tumosa, and Erhard 2005). In their study, paint layers over zinc grounds were found to crack preferentially compared to paint layers over lead grounds. A more recent study by Mecklenburg also suggests that zinc ions in an isolated paint layer can migrate to surrounding paint layers, increasing brittleness and changing mechanical properties (Mecklenburg, Tumosa, and Vicenzi 2010). As zinc was identified in isolated layers of drying oil across *Ocean Park No. 111*, it is possible that zinc may be affecting the stability of surrounding paint layers. As mentioned, the alkyd paints become progressively more rigid over time and the addition of zinc magnifies this effect.

CONCLUSION

A comparison of the materials and paint structures in two Ocean Park paintings by Richard Diebenkorn in good condition with two more extensively cracked paintings shows that those with alkyd paints applied over the synthetic resin show greater evidence of cracking than those that did not have the resin layer. While there may be other factors that have contributed to the condition issues evident in these paintings, this study indicates that the artist's practice of applying brittle paints over a rubbery, flexible support is a recipe for cracking. The relatively elastic nature of the synthetic size is poorly suited as a support for the extremely brittle alkyd paint and layering methods employed by Diebenkorn. Localized areas of dense cracking associated with specific design elements likely occurred when the artist scraped down and drew into already dried painting layers. While heavy paint build-up and scraping away of paints are techniques seen in Ocean Park paintings with no condition issues, the presence of the unpigmented resin size in combination with an inherently brittle paint magnifies the adverse effects.

Future work may include formulating a conservative treatment proposal and establishing preventative measures to protect against further cracking. At this time it is recommended that handling and traveling is limited. The effect of zinc ion migration on surrounding paint layers is currently being studied.

ACKNOWLEDGMENTS

The authors would like to thank: Judy Watson and Jeff Speakman for their assistance with acquiring SEM data. Many thanks to the following conservators for their expertise, assistance in examination, and access to research materials: Julie

Barten, Jim Coddington, Jay Krueger, Carol Mancusi-Ungaro, Matt Skopek, and Carol Stringari. Special thanks to Marion Mecklenburg and Dawn Rogala for discussions on mechanical failure of alkyd and oil paints. Thanks to the following organizations for their support in this project: Richard Diebenkorn Foundation, Leo & Karen Gutmann Foundation, Andrew W. Mellon Foundation, Bandrowski Art Conservation Fellowship, National Endowment for the Humanities, and to the faculty and staff of the Buffalo State Art Conservation Program.

ENDNOTES

1. http://www.diebenkorn.org/bio/bio.html. From the RD Biography. © 2010 The Estate of Richard Diebenkorn.
2. These were *Ocean Park No. 66.*, 1973, (Albright Knox Art Gallery in Buffalo, New York), and *Ocean Park No. 83,*1975, (Corcoran Gallery of Art in Washington, D.C.)

REFERENCES

Bernstein, J. 2009. Personal communication, Private Conservator.

Croll, S. (2009). Personal communication. Professor, Chair, Department of Coatings and Polymeric Materials, North Dakota State University.

Larson, S. 1977. *Oral history interview with Richard Diebenkorn, 1977 May 24 - June 2., Archives of American Art, Smithsonian Institution.*

Mecklenburg, M.F., C. S. Tumosa, and D.Erhardt. 2005. The Changing Mechanical Properties of Aging Oil Paints. *Materials Research Society Symposium Proceedings*, Vol. 852, 13-24.

Mecklenburg, M.F., C. S. Tumosa, and E. P. Vicenzi. 2010. The Influence of Pigments and Ion Migration on the Durability of Drying oil and Alkyd Paints" paper presented at the conference "Cleaning 2010, *New Insights in the Cleaning of Paintings*, Valencia, Spain, May 26th, 2010. The paper is being published by The Smithsonian Scholarly Press and currently in press.

Michalski, S. 1991. Paintings-Their Response to Temperature, Relative Humidity, Shock, and Vibration. *Art in Transit*. ed. Marion Mecklenburg. Washington D.C.: National Gallery of Art.

Ploeger, R. 2009. *The Characterization and Stability of Artists' Alkyd Paints*. PhD Thesis in Chemical Sciences, University of Torino, Department of I.P.M. Chemistry.

Ploeger, R, D. Scalarone, and O. Chiantore. 2008. The characterization of commercial artists' alkyd paints. J. Cultural Heritage 9, 412-419.

Whitmore, P. M., D. Moran, and C. Bailie, 1999. Shrinkage stress in art and conservation coatings based on synthetic polymers. *Journal of the American Institute for Conservation* Vol. 38 No. 3, p. 429-441

Young, C.R.T. 2006. Interfacial Interaction of Modern Paint Layers, In *Modern Paints Uncovered: Proceedings From the Modern Paints Uncovered Symposium,* ed. Thomas J. S. Learner, Patricia Smithen, Jay W. Krueger, and Michael R. Schilling, Los Angeles: Getty Conservation Institute. pp. 247-256.

http://www.diebenkorn.org/bio/bio.html

ADDITIONAL SOURCES CONSULTED

Chipp, H. 1957. Diebenkorn Paints a Picture. *ARTnews* 56(3): 44–47, 54.

Gottsegen, M. D. 1987. *A Manual of Painting Materials and Techniques*. Harper and Row, New York.

Hagan, E. C., T. Learner, T. Murray, and C. A. Young. Factors Affecting the Mechanical Properties of Modern Paints. In *Modern Paints Uncovered: Proceedings From the Modern Paints Uncovered Symposium,* ed. Thomas J. S. Learner, Patricia Smithen, Jay W. Krueger, and Michael R. Schilling, Los Angeles: Getty Conservation Institute. 227-35.

Keck, S. 1969. Mechanical Alteration of the Paint Film. *Studies in Conservation* Vol. 14 No. 1, p. 9-30.

Livingston, J. 1997. *The Art of Richard Diebenkorn*. University of California Press; 1 edition.

Standeven, H. 2006. The Development of Decorative Gloss Paints in Britain and the United States c. 1910-1960', *Journal of the American Institute for Conservation* Vol. 45, No. 1.

Standeven, H. 2003. Problems Associated With the Use of Gloss Paints by Twentieth-Century Artists. *V&A Conservation Journal*, No. 44.

Standeven, H. 2003. An Alternative Look at Gloss Housepaints: Problems Associated With Their Use by Twentieth-Century Artists, *Surface Coatings International: Technical Updates*, Vol. 86, Issue A01

Nordland, G. 2001. *Richard Diebenkorn: Revised and Expanded*. Rizzoli; Rev Exp Su edition.

AUTHORS' INFORMATION

Ana Alba
(Formerly Conservation Intern in Modern and Contemporary Paintings
Hirshhorn Museum and Sculpture Garden)
William R. Leisher Fellow in the Research and Treatment of Modern Paintings
The National Gallery of Art
Washington D.C.
2000B South Club Drive, Landover, MD 20785
E-mail: A-alba@nga.gov

Susan Lake
Director of Collection Management/Chief Conservator
Hirshhorn Museum and Sculpture Garden
PO Box 37012, MRC 354
Washington, D.C. 20013-7012
Tel: 202-633-2731
E-mail: lakes@si.edu

Mel Wachowiak
Senior Conservator
Museum Conservation Institute
Smithsonian Institution
4210 Silver Hill Road
Suitland, MD 20746-2863
301.238.1218
E-mail: WachowiakM@si.edu
www.si.edu/mci
Imaging Studio: www.si.edu/mci/ImagingStudio

Jennifer Giaccai
Conservation Scientist
Museum Conservation Institute
Smithsonian Institution
4210 Silver Hill Road
Suitland MD 20746
E-mail: GiaccaiJ@si.edu

DON H. JOHNSON, ELLA HENDRIKS, MURIEL GELDOF, AND
C. RICHARD JOHNSON, JR.

Do Weave Matches Imply Canvas Roll Matches?

ABSTRACT

Computational algorithms for measuring thread counts from scanned x-rays produce warp and weft thread count "maps" across entire paintings. Within the database of over 300 van Gogh paintings, we found a clique of 44 warp-weave-matched paintings. By reconstructing the smallest canvas section that could have produced this match, they must span the entire width of a commercial canvas roll (2+ meters) and more than 13 meters of length, much longer than a single roll (10 meters). Several grounds were found, further suggesting these matched paintings came from separate rolls. Investigation showed that commercial priming firms cut rolls from longer bolts.

INTRODUCTION

The recent introduction of computer-assisted and computer-automated thread count algorithms has not only greatly eased the tedium of measuring the vertical- and horizontal-thread densities from x-rays, but also provided more information about how thread densities vary across a painting (Johnson et al. 2009). The algorithms not only measure thread densities across an x-ray, but also thread angles: the departures of the horizontal and vertical threads from coordinate axes. These angle measurements provide immediate information about the presence and degree of cusping.

Thread densities are depicted as *weave maps* that use colors to illustrate how the thread densities vary across a painting (fig. 1). These maps reveal that thread density variations can typify the painting's canvas support. For example, a canvas's vertical thread counts persist across the height of the painting, but vary horizontally in a seemingly random fashion. The horizontal threads show a similar variation, but with persistent horizontal counts that vary vertically. In other words, thread packing varies across the painting's support. These variations in canvas thread densities are not specific to each painting, but characterize the larger canvas from which the painting's support was cut. Consequently, thread density variations serve as a fingerprint for the canvas, allowing painting weave maps to

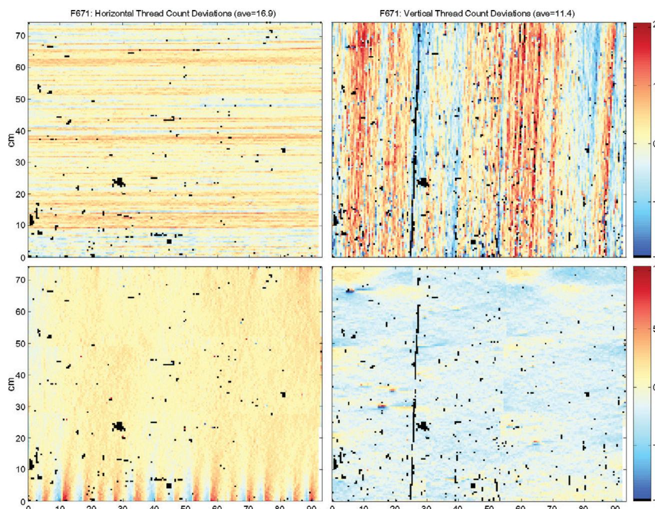


Figure 1. Example of weave maps (top row) and angle maps (bottom row) for the van Gogh painting *Blossoming Almond Tree* catalogued (de la Faille 1970) as F671. The colorbars on the right show how to convert colors into measured thread counts (as differences from painting average) and angles. For F671, the average horizontal thread count is 16.9 threads/cm and the vertical average is 11.4 threads/cm. Black indicates where no measurement was made because the algorithm could not extract a count due to poor legibility of the canvas weave in the x-ray. The warp direction corresponds to the horizontal threads and the horizontal thread angle map shows strong cusping along the bottom of the painting.

be compared in a search for matching weave patterns. We have also found that thread angle maps (fig. 1) help in determining painting position and, surprisingly, reveal aspects of the canvas weaving process. These interpretations result from understanding the commercial priming process: how canvas is delivered, how canvas rolls are cut from a longer length of canvas—known as a *bolt* of canvas—and then mounted on a priming frame, and how the primed canvas is stored and delivered to retail outlets.

This paper describes how weave matches are determined and illustrates how matching canvas support information can be used in art history. Angle maps coupled with knowledge of commercial priming operations supplement the weave matches, confirming painting support placement (for example, does cusping along a painting's edge confirm placing the support along an edge of a commercially primed strip of canvas).

We focus on the paintings of Vincent van Gogh for several reasons. First of all, a large fraction of his oeuvre is concentrated in a few museums. But more important are the detailed insights into his painting practices provided by the copious and well-preserved correspondence with his brother Theo, a Paris art dealer, and several artist friends (Jansen et al. 2009). Not only do the letters describe (in varying amounts of detail) what paintings were executed when, but also when he asked his brother for a new canvas roll and when shipments were received. Furthermore, the letters reveal that, particularly in his later periods, he was very specific about the kind of canvas he wanted. [1] On the one hand, we discovered that his preferred grade of canvas could be easily counted from x-rays, allowing accurate count estimates. On the other, this specificity could complicate the ability to localize weave-matched paintings to a specific roll. Could matching paintings come not from the same roll, but instead from different rolls cut from the same bolt?

Interpreting Weave and Angle Maps

Thread count (density) measurements are made with the algorithm described elsewhere (Johnson et al. 2009). The weave maps shown in Figure 1 represent the thread count measured every 0.5 cm for the surrounding 1 cm square as a color, which allows a ready visual representation of thread count variations across a painting. The horizontal- and vertical-thread weave maps look very different. Here, the horizontal-thread densities (counts) vary less (have a more consistent color), have a more persistent count along the thread direction, and vary more rapidly vertically than the corresponding features in the vertical-thread weave map. From this and many other examples, these features typify how weave maps allow quick determination of warp/weft direction: the horizontal threads in F671 correspond to the warp direction. [2] Because warp and weft threads are handled differently in the weaving process, they have different thread count characteristics. Van de Wetering (1997) noted that, for hand-woven seventeenth-century canvases, warp threads tend to vary less than weft threads. We have found this criterion to be reliable in 80-90% of van Gogh's paintings we have examined. By exploiting the features just described, we believe that weave maps can provide additional criteria that will improve warp/weft judgment.

Angle maps provide different information. If the canvas weave were perfect, with the horizontal and vertical threads crossing each other at right angles, the measured thread angles should be zero, which corresponds to a light golden color. The horizontal-thread angle map shows such consistency except near the bottom of the painting, where the color variation suggests the horizontal threads are waving up and down slightly. Such variations indicate cusping, in this case strong cusping. Because cusping occurs only along one side of the painting (none along the top and the vertical-thread angle map shows no cusping), the canvas support must have been primed (sizing or ground applied) not on the painting's strainer, but on a larger priming frame. If there had been cusping on four sides, then the interpretation would be that the primer was laid on unprimed canvas after it had been tacked to the strainer.

Weave Matching Procedure

The first step in the weave matching procedure is to determine whether the thread-count histograms agree sufficiently. We find the best agreement between the two pairs of measured thread counts (does the horizontal and vertical thread count from one painting agree most with horizontal and vertical from another painting or with vertical and horizontal?) and use a detection-theoretic technique to determine the degree of agreement (Johnson et al. 2010). Only if the histograms agree sufficiently—what we call a *count match*—do we consider determining if the two x-rays have a weave match. [3]

Once a count match has been found, we calculate deviation maps for a painting's x-rays and determine warp/weft directions. We then collapse the deviation maps along their count-persistent directions (horizontal direction for horizontal threads, vertical for vertical threads) to obtain what we term a *profile* that summarizes thread count variations. We then correlate the pairs of profiles to determine if they sufficiently agree to declare a match. In more detail, we take the vertical and horizontal profiles from two x-rays. We first correlate vertical-with-vertical, horizontal-with-horizontal, and retain the pairing that yields the largest correlation (Johnson et al. 2010). Just relying on this comparison does not take into account the various possibilities for how a canvas section cut from a larger sheet could have been oriented: it could be rotated arbitrarily and, if not pre-primed, flipped over. Letting v_i denote the vertical profile for painting i, h_i its horizontal profile, and rev(•) the operation of reversing a profile, the largest of the following eight pairs is selected to represent a possible weave match: $v_1 \leftrightarrow v_2$, $h_1 \leftrightarrow h_2$, $v_1 \leftrightarrow h_2$, $h_1 \leftrightarrow v_2$, $v_1 \leftrightarrow \mathrm{rev}(v_2)$, $h_1 \leftrightarrow \mathrm{rev}(h_2)$, $v_1 \leftrightarrow \mathrm{rev}(h_2)$, $h_1 \leftrightarrow \mathrm{rev}(v_2)$. The degree of correlation of the maximal pair must exceed a threshold to declare a calculated weave match. Because warp and weft threads have different characteristics, the threshold for weft matches is lower than for warp matches.

Once the x-rays for two paintings are calculated to have a weave match, we have found we must observe the match by constructing deviation maps for the entire paintings and comparing them in the suggested alignment. Warp thread matches suggested by single-x-ray calculations usually survive full-painting evaluation, but not weft matches. The wide-stripe characteristic of weft threads can produce a calculated match just because two wide stripes happen to match. Such potential matches may not persist across a larger segment of canvas, which can easily span more than one x-ray. In such cases, the matches are discarded. Figure 2 shows a typical warp-thread match. In several cases, warp-thread weave matches allowed us to align several paintings that do not all match each other. As Figure 2 shows, F659 and F617 do not have a warp-thread weave match. But, because F386 matches each, we indirectly have a weave match between the first two. In this case, the third painting straddles the other two and brings the paintings together. We term the paintings that share a weave match in this way a *match clique*.

Interpreting Weave Matches

A reason to determine weave matches is to locate the relative positions of two paintings on a canvas sheet. Once a warp- or weft-thread weave match is found, the two paintings are aligned in one direction but the distance between them in the opposite direction cannot be determined. For example, if the warp-thread deviation patterns match, as in Figure 2, their lateral alignment is known, but they could be close together or far apart in the warp direction. The opposite holds true for weft matches, but these are far more constraining because canvases are narrower in the weft direction.

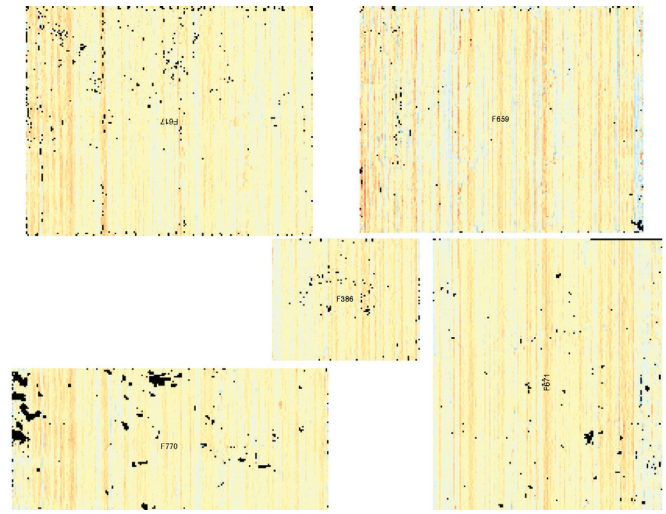


Figure 2. Aligned warp-thread weave maps for five of Vincent van Gogh's paintings F386 (*Still Life with Potatoes*), F617 (*Enclosed Wheat Field with Reaper and Sun*), F659 (*The Garden of Saint-Paul Hospital*), F671 and F770 (*Landscape with the Chateau of Auvers at Sunset*). The convention here has warp threads oriented vertically. To depict weave matches, paintings may need to be rotated to conform to this convention. The catalog labels on the weave maps indicates the "up" direction for the painting. These paintings were placed side-by-side to minimize vertical size of the graphic, *not* because they matched in weft. In fact, none of these paintings matched each other in the weft direction.

The location of warp-thread matches in the weft direction on the canvas sheet can be further detailed by considering the angle maps. Angle maps reveal the presence of cusping in a painting. Strong, so-called primary cusping occurs when the canvas sheet is stretched, sized and primed; the sizing and primer (ground) seal the thread deviations that occur at the fixture points on the priming frame. If primary cusping occurs on all four sides of a painting, the canvas was first cut to size and stretched on the working-size frame before it was prepared for the artist's use. In this case, preparatory size and ground layers only cover to the front edges of the picture area, but do not extend onto the tacking margins that were folded over the sides of the stretching frame. If primary cusping occurs on one side, two opposite sides, or not at all, the painting's support was primed on a larger priming frame and the support cut from the larger primed canvas. In this case the preparatory size and ground layers coat the tacking margins of the picture support too. If a painting's angle map reveals primary cusping on one or two opposite sides, that painting's support was cut from the edge(s) of the sheet and a painting that weave matches in that direction should also show cusping.

The absence of primary cusping implies the support did not originate from the sides of the sheet.

Van Gogh repeatedly requested ten, occasionally five, meters of canvas, corresponding to a whole or a half-length length (warp direction) of a commercially primed roll that usually measured about 2.10 m wide (weft). [4] The largest weave match clique we have found among van Gogh paintings in our database contains 44 paintings, while spreading across a little over 2 meters in weft, must encompass more than 13 meters of canvas in the warp direction, much larger than what van Gogh ordered. Figure 2 shows five aligned paintings from this clique. Furthermore, ground analysis of a subset of paintings in this clique reveals at least two different ground compositions, which coincides to the paintings' chronology (paintings having the same ground have similar dates). Clearly, weave matches don't necessarily imply roll matches. Exploring the practices of commercial priming firms reveals that canvas rolls were cut from a much longer sheet we term a *bolt*. [5] Common practice in manufacturing artist-grade canvas was to produce 100 m or 200 m long bolts, which were shipped to a commercial priming company as an accordion-style stack, probably because a stack can be more efficiently shipped than a large roll. The company would cut each bolt into rolls, making each a little more than 10m long, and prime each separately.

What follows is a description of one company's sizing and priming procedure that fits with our findings on van Gogh's works, though variations on this method are known to have existed during his period .[6] A priming frame is depicted in Figure 3. The short ends of the cloth were folded and nailed to upright bars. One bar was affixed to the end of the priming frame and then the other bar attached to the other end of the frame, stretching the canvas taut in the process. The top of the canvas was then pushed onto a set of spikes protruding from the frame. A set of hooks inserted through the canvas's bottom edge and then laced with a length of rope to the frame that stretches the canvas vertically. The nail/hook system stretches the canvas in the weft direction, which has the effect of creating cusping in the warp threads (fig. 3). The intervals between the fixed spikes at the top were typically shorter and more consistent than that between the hooks inserted each time by hand along the bottom. Consequently, cusping should differ along these edges. [6] Because the canvas ends are nailed to the *sides* of the end bars and the primer does not extend to the tack locations, one should not expect cusping in the weft direction. [7] After the primer has been applied and has dried, the canvas is removed from the frame and rolled onto a rod for shipping to the client. If the firm had a good customer that repeatedly asked for rolls of the same grade of primed canvas, it would hold them in reserve, shipping them upon request.

CONCLUSIONS

The weave pattern introduced by slight manufacturing variations can be used to search for warp- and weft-direction weave matches. In our experience, warp-direction weave matches are very sharp and well defined; weft-direction matches are generally much more vague and ill defined (Hendriks et al. 2010).

For commercially primed canvas from van Gogh's era, when one finds a warp-direction weave match among a set of paintings, the best that can be claimed is a *bolt* match, not necessarily a roll match .[8] Since ten to twenty rolls comprise a bolt, bolt matches by themselves say little about the timing of warp-matched paintings. Other considerations must be brought to bear to assign paintings to the same roll, which would suggest a close temporal relationship.

Paintings having a weft-thread match must come from the same roll. Unfortunately, it is difficult to find such matches. Longer lengths of canvas must overlap than required for warp-direction weave matches.

The build-up and composition of the sizing and ground layers for paintings from the same roll must be the same for commercially primed canvas. Priming firms used a variety of grounds, but only one type was used on a roll. Of course, different rolls could have the same ground, but if warp-matched pre-primed paintings have different grounds, they must have come from different rolls. These differences further point to different rolls within the same match clique.

Van Gogh's correspondences describing paintings he executed at about the same time can help localize paintings to a roll.

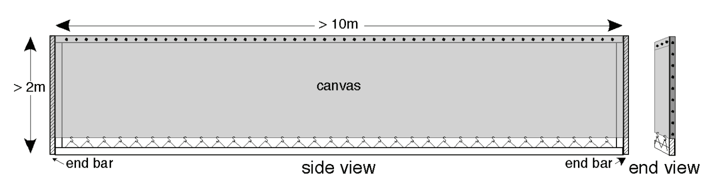


Figure 3. Schematic representation of a commercial priming frame. The black dots represent spikes. Note that the bottom edge is stretched with a hook-and-lace mechanism.

However, it is not always possible to identify the pictures mentioned with certainty, as in the case of some of his repetitions or serial versions of the same theme. For example, there are five *La Berceuse* paintings, six *Postman Roulin* paintings, and seven *Sunflower* paintings, all painted during his time in Arles. [9]

We are working to determine other criteria so that paintings can be located on a canvas roll rather than a bolt, which would provide further insight into the artist's process.

ENDNOTES

1. Van Gogh preferred 5 or 10m rolls of "ordinaire"-grade canvas obtained from the Paris colorman Tasset et L'Hôte.
2. By convention, the threads along the long direction of a canvas roll are the warp threads and the short-direction threads running across a roll the weft threads.
3. We must make sure that the x-ray-wide thread counts agree sufficiently because two deviation maps could agree even though the average thread count subtracted from the weave maps to produce them do not agree. In fact, we have found that such false agreements do occur.
4. For example, see letters 593, 629, 631, 680, 687, 689, 691, 699, 758, 777, 800, 808, 823 and 863, 874 from February 2, 1888 to May 21, 1890 (Jansen et al. 2009). Occasionally, other lengths were ordered (one time 20m but not from Tasset) and van Gogh made use of local canvas suppliers.
5. The authors are indebted to Philippe Huyvaert, President of nv Claessens sa, for devoting his time for a tour of his operations and answering our questions about his manufacturing practices. The company is exceptional for its knowledge and skills concerning traditional hand methods of preparing artist canvas, which it still practices there today.
6. These findings agree with what we see in the angle maps of van Gogh's paintings on Tasset et L'Hôte canvas, suggesting that the canvas was indeed stretched in a manner similar to this hook-and-lace system on an upright priming frame and them primed. An alternative commercial practice was to simply nail the four canvas edges at consistent intervals to the sides of a priming frame that had been laid flat on trestles for applying sizing and ground layers. This procedure is used today by the French Company Lefranc Bourgeios (Bomford 1990, 48).
7. We have found strong weft-thread cusping for two paintings that aligned in weft. Cusping strength, as measured by the size of the thread angle deviation, was much larger than the warp thread cusping introduced by the priming frame. Philippe Huyvaert informed us that cusping occurs in the canvas weaving process due to the initial slackness in the tension of the wound bobbin. Its presence indicates the beginning of a bolt.
8. We do not know if looms produced bolts having similar manufacturing variations in the warp direction.
9. The *Sunflower* paintings differ sufficiently in composition that determining which one is being referred to in a letter can be at least partially, if not uniquely, deduced.

ACKNOWLEDGEMENTS

The authors are indebted to Philippe Huyvaert, President of nv Claessens sa, for allowing us to visit his commercial priming facility and extensive discussions. We thank Luuk van der Loeff, conservator for the Kröller-Müller Museum, for allowing us to use F386 (KM 108.951) and F617 (KM 101.173) in our examples. The van Gogh Museum provided F659, F671 and F770 for this study.

REFERENCES

Bomford, D., J. Kirby, J. Leighton and A. Roy. 1990. *Art in the Making: Impressionism*, National Gallery London.

de la Faille, J.-B. 1970. *The Works of Vincent van Gogh: His Paintings and Drawings*, Meulenhoff, Amsterdam.

Hendriks, E., D.H. Johnson and C.R. Johnson, Jr. 2010. Interpreting Canvas Weave Matches, Submitted to *Art Matters.*

Jansen, L., Luijten, H. and Bakker, N., eds, 2009. *The Letters: The Complete Illustrated and Annotated Edition*, Vol. 5: Saint Remy-de-Provence - Auvers-sur-Oise, 1889–1890, Mercatorfonds.

Johnson, D.H., C.R. Johnson, Jr., A.G. Klein, W.A. Sethares, H. Lee and E . Hendriks. 2009. A thread counting algorithm for art forensics. *DSP Workshop*, Marco Island, Florida.

Johnson, D.H., L. Sun, C.R. Johnson, Jr. and E. Hendriks. 2010. Matching canvas weave patterns from processing x-ray images of master paintings. Poster VMSP-P2.8, *ICASSP*,

Dallas, van de Wetering, E. 1997. *Rembrandt: The Painter at Work*, Amsterdam University Press, Amsterdam.

AUTHORS' INFORMATION

Don H. Johnson
J.S. Abercrombie Professor Emeritus
Department of Electrical and Computer Engineering

Rice University
Houston, Texas

Ella Hendriks
Conservation Department
van Gogh Museum
Amsterdam, Netherlands

Muriel Geldof
Netherlands Institute for Cultural Heritage
Amsterdam, Netherlands

C. Richard Johnson, Jr.
Geoffrey S. M. Hedrick Senior Professor of Engineering
School of Electrical & Computer Engineering
Cornell University
Ithaca, New York

JOHN K. DELANEY, JASON G. ZEIBEL, ROY T. LITTLETON, MATHIEU THOURY, MICHAEL PALMER, KATHRYN MORALES, AND E. RENÉ DE LA RIE

Visible and Infrared Imaging Spectroscopy of Paintings: Pigment Mapping and Improved Infrared Reflectography

ABSTRACT

Imaging spectroscopy, the collection of images in narrow spectral bands, has been developed for remote sensing of the Earth utilizing reflectance or luminescence. In this talk, the authors presented findings on the use of imaging spectroscopy to identify and map artist pigments as well as to improve the visualization of preparatory sketches. Two novel hyperspectral cameras, one operating from the visible to near-infrared (VNIR) and the other in the shortwave infrared (SWIR), have been used to collect diffuse reflectance spectral image cubes on a variety of paintings. The resulting image cubes (VNIR 420 to 970 nm, 240 bands, and SWIR 950 to 1700 nm, 85 bands) were calibrated to reflectance and the resulting spectra compared with results from a fiber spectrometer (350 to 2500 nm). In addition, a calibrated luminescence multispectral camera (600 to 950 nm, 8 bands) was used to obtain luminescence spectral image cubes after exciting the painting materials in the blue. False color reflectograms, obtained from the SWIR hyperspectral images, of extensively reworked paintings such as Picasso's *The Tragedy* (1903) are found to give improved visualization of these changes. Spectral image processing on the VNIR and SWIR image cubes are found to be useful in identifying the primary pigments. Kubelka-Munk theory was used on some of the data to determine the composition of the mixtures. For example, the primary pigments and their distribution in Picasso's *Harlequin Musicians* (1924) and *Peonies* (1901) were determined and compared with X-ray fluorescence data. The results show that inclusion of the NIR and SWIR reflectance along with the luminescence provides for a more robust ability to assignment of pigments than using visible spectroscopy alone.

AUTHORS' INFORMATION:

John K. Delaney
Scientific Research Department
National Gallery of Art

Jason G. Zeibel
U.S. Army Night Vision & Electronic Sensors Directorate

Roy T. Littleton
U.S. Army Night Vision & Electronic Sensors Directorate

Mathieu Thoury
Scientific Research Department
National Gallery of Art

Michael Palmer
Scientific Research Department
National Gallery of Art

Kathryn Morales
Scientific Research Department
National Gallery of Art

E. René de la Rie
Scientific Research Department
National Gallery of Art

ANNA VILA AND MARGARET MACDONALD

Historical and Analytical Literature Review on Driers Used in Late 19th and Early 20th Century Paint Formulations

ABSTRACT

Historically, certain pigments were noted to have a drying effect on drying oils and were frequently added as an ingredient in artist paints. Artists' recipes in the mid-eighteenth century called for compounds containing lead, zinc, copper, and manganese to be mixed in to aid in drying time. By the nineteenth century, colormen sold products known as driers containing premixed oil and driers in bladders and, later, metallic tubes. [1]

These early recipes led the way to manufactured artists' tube paint and house paint in the late-nineteenth and early-twentieth centuries, of interest in the present paper. To identify and address the evolution of paint formulations manufactured in this period, this presentation will carry out an exploration of the incorporated driers. Therefore, the aim is to identify and catalog compounds, such as metallic soaps (metallic fatty acid salts), which were employed commercially as driers in late-nineteenth and early-twentieth century oil paint. Paint manuals, notebooks from paint factories, and ancient and contemporary paint catalogues have been collected and will be presented. In addition, a technical study has been undertaken to analyze driers in paint samples from this period. Identification of driers could aid in the differentiation of artists' tube paint from house paint and individual manufacturers and play an important role in understanding the materials for the conservation field.

This work arose out of on-going research on paint driers and will be restricted to oil paint and painting manuals from the end of the nineteenth and the first half of the twentieth century with consideration of characterization methods and conservation strategies.

ENDNOTES

1. Carlyle, L., *The Artist's Assistant: Oil Painting Instruction Manuals and Handbooks in Britain, 1800-1900, With Reference to Selected Eighteenth-Century Sources.* London: Archetype Publications Ltd., 2001.

AUTHOR'S INFORMATION

Anna Vila
Art Institute of Chicago
Conservation Department
111 South Michigan Avenue
Chicago, Il 60603-6404
(312) 443-3335
E-mail: Annave@gmail.com

Margaret MacDonald

Studio Tips: Bench Cookies

Bench Cookies are non-slip discs made for wood working. They are advertised for uses such as sanding and router work. The textured soft rubber on each side of a hard plastic disc creates two non-slip surfaces designed to hold a piece of wood in place, hands-free, while being worked on.

We found them quite by accident in a Rockler wood workers supply store and immediately thought they could also be very useful for varnishing paintings when it is desirable to varnish flat, as with a small panel.

For varnishing a solid flat painting four cookies are placed under the painting, one at each corner. The panel stays in place held only by the friction of the rubber pads. Substantial pressure and vigorous brushing cause no slipping.

A larger painting or a panel with a weak join might require more cookies for extra support. A warped panel or stretcher may need a lift in one corner.

You can find them on the Rockler web site along with Rockler stores and product outlets.
ROCKLER Woodworking and Hardware. Advertised at $11.99 for set of 4.
Find a ROCKLER outlet near you via their website.http://www.rockler.com

AUTHOR'S INFORMATION

Laurent Sozzani
Senior paintings restorer
Rijksmuseum Amsterdam

Studio Tips: Wall Mounted Easel

Space Saving Wall Mounted Easel
This is a MABEF easel mounted directly to the wall. Wall mounting eliminates the floor space normally necessary for the base.

The easel base has been removed and the easel is bolted in place onto the wall. It isn't as versatile as a rolling easel but there are others for that. The easel pictured is Mabef model M/02, a double design, made to hold large paintings. Its location is set-up for larger paintings, paintings up to 7 X 7 feet in a rather small room. It is also wide enough to hold two independent paintings side by side. The bolts holding it to the wall go through the wall into a closet.

http://www.mabef.it for a distributor near you.

AUTHOR'S INFORMATION

Laurent Sozzani
Senior paintings restorer
Rijksmuseum Amsterdam