# A case study of the yellowing of an inkjet print by Tracey Emin

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## Abstract

The Paper and Photograph Conservation Department at Tate has been investigating the damage of an inkjet print by Tracey Emin, after a bright yellow discolouration developed around the white borders of the print during an international touring loan. This prompted an inquiry into the cause of the yellowing, the possible solutions, and research into the wider problem of inkjet yellowing in cultural heritage collections. The following questions were posed as part of the investigation; Why did this print yellow – and what is the solution? Could this yellowing happen to other inkjet prints – and what is the solution?

In the case of the Tracey Emin print, a reaction between antioxidants and nitrogen dioxide has been identified as the most likely cause of yellowing. This paper will outline the steps taken to investigate the yellowing, including a review of the literature, testimonials from experts in the conservation field and comparison with a sister print held by The National Portrait Gallery, London. Tate's approach to the print will be discussed, including treatment options, the potential reprinting of the artwork, and the preventive measures put in place to protect other inkjet prints in the collection. The paper will also touch on other cases of inkjet yellowing, and the wider issue of the preservation of inkjet materials within cultural heritage institutions.

**Keywords:** inkjet, porous inkjet, inkjet yellowing, photograph conservation, preservation

## Introduction

*The last thing I said to you was don't leave me here II*, is an inkjet print by Tracey Emin. The artwork was printed in 2000 on a cotton-fibre paper with a porous inkjet coating. Tate acquired the print in 2002 and according to our conservation records, it arrived in pristine condition, float mounted onto white museum board, and framed in an acrylic box frame. The print has been on display several times throughout our history of ownership and has remained in the original frame for both storage and display. Investigation into damage of the Tracey Emin print began in 2020 whilst the print was being prepared for an international touring loan. The print had developed a bright yellow discolouration around the white borders of the image whilst previously on loan in 2018 - the print had been on display for approximately 13 months when the discolouration was first noted. The print was removed from the frame on return from loan and has been stored in the conservation studio since then.

It was important that the yellowing of this print was investigated, and a solution found, not only so that the upcoming loan could go ahead, but from a conservation perspective it was vital that the cause of yellowing was understood, so that such damage could be prevented in the future.

Figure 1 - *The last thing I said to you was don't leave me here II*, Tracey Emin, 2000.

## History and Deterioration of Inkjet Prints

Inkjet technology has been used to create fine art prints since the 1990s, and from the very beginning there have been concerns over the longevity of these prints. The first inkjet printers used dye-based inks which turned out to be extremely vulnerable to light and moisture (Benson, 2008 and Wilhelm, 2013), so from the mid-1990s, the industry sought to produce more stable pigment-based inks (Jürgens, 2009). The newer pigment-based inks had greater light, pollution, and environmental stability, with many predicted to offer greater permanence levels than traditional analogue colour photographic prints (Wilhelm, 2006). The inkjet supports however are still vulnerable to deterioration; inkjet coatings can crack from incorrect handling and environmental fluctuations, and some inkjet papers can yellow if exposed to pollutants (Jürgens, 2009).

Permanence testing of inkjet materials is routinely carried out by manufacturers, independent research institutes and independent companies. This has helped towards predicting the stability of inkjet prints somewhat. The effects of light, heat, humidity, pollutants and housing materials on the stability of inkjet prints have all been tested (Jürgens, 2009). This data can help cultural institutions to preserve inkjet materials in their collections as they inform decisions on light exposure, storage conditions, and appropriate enclosure materials. Predicting the permanence of inkjet prints is complicated however, as there are countless different ink sets and inkjet papers available on the market, and testing has revealed a huge disparity between permanence levels across different inkjet materials. As an example, light fading tests carried out by Wilhelm Imaging Research have shown that total fading of inkjet colourants can occur anywhere between 1 and 150 years of display, depending on the type of ink set and media used (Glynne, 2001). The vast range of inkjet materials, and in turn the large difference in their permanence levels, makes the preservation of inkjet prints a difficult task for cultural heritage institutions.

## Yellowing of Inkjet Prints

*Literature Review*

The first step in this research was to undertake a review of the literature to understand why inkjet prints yellow. It is important to note that the yellowing of inkjet papers as discussed here, specifically relates to yellowing of the coatings applied to inkjet papers, which is different from the natural yellowing of the paper supports themselves which occurs over time. The

literature points to a host of different reasons why yellowing can develop, including; light exposure (Venosa et al, 2011; Venosa et al, 2016; Fischer et al, 2019), increased heat and humidity (Bugner et al, 2004; Bugner et al, 2005), degradation of optical brightening agents within the inkjet paper (Comstock and McCarthy, 2008; Reber et al, 2007), pollutants such as ozone and nitrogen dioxide (Burge et al, 2010; Burge et al, 2011; Fischer et al, 2019; Gordeladze et al, 2012; Kanazawa et al, 2004; Moeller, 2007), inappropriate housing materials (Mizen and Mayhew, 2001; Wilhelm, 2003), and absorption of antioxidants from plastic materials (Mizen and Mayhew, 2001; Wilhelm, 2003). It has also been reported that yellowing may not develop straight away after exposure to a damaging influence, but may develop sometime after, so the cause of yellowing may not be immediately obvious (Gordeladze et al, 2012). Certain types of inkjet papers are more susceptible to yellowing than others – the porous coating on some inkjet papers can readily absorb pollutants from the surroundings which can lead to yellowing (Gordeladze et al, 2012; Fischer et al, 2019; Moeller et al, 2007).

*Inkjet Media*

To understand why certain types of inkjet supports or 'media' may be more susceptible to this yellowing than others, it is important to understand their material structure. All kinds of different papers can be used as the base for inkjet media. Early fine art inkjet prints were often printed on uncoated papers, but since the 1990s, coatings, or ink receiving layers (IRLs), have been applied so that the inks are better received onto the substrate, creating a sharper and more stable image (Fischer et al, 2019; Jürgens, 2009). The two main types of IRL are porous and swellable; porous coatings are made up of fine mineral particles, often silica or alumina, in a binder of polyvinyl alcohol. The small gaps between the mineral particles create a surface of tiny pores which absorb liquid from the ink, leaving the pigment or dye particles close to the surface (Fischer et al, 2019; Jürgens, 2009). Swellable coatings are made from polymers which swell and absorb the inks, sealing the colourants into the IRL upon drying (Fischer et al, 2019; Jürgens, 2009). Both porous and swellable coatings can be added to many different paper supports, such as fine art papers, and also resin coated papers like those used for traditional analogue photography (DP3, 2022). The advantage of porous IRL's is that they quickly draw in liquid from the ink allowing for an instantly dry print, as opposed to swellable coatings which can take up to several hours to dry (DP3, 2022; Fischer et al, 2019; Jürgens, 2009). This open structure leaves porous inkjet papers vulnerable however, as pollutants from the surroundings are easily drawn into the coating layer which can initiate yellowing as well as deterioration of the inks (Fischer et al, 2019; Jürgens, 2009). The majority of inkjet papers sold for fine art purposes are now manufactured with porous coatings rather than swellable, due to the fact that they dry instantly (DP3, 2022; Moeller et al, 2007).

*Impact on the Heritage Sector*

The yellowing of inkjet prints is potentially a big problem for the cultural heritage sector, specifically the museums and institutions tasked with preserving them. A 2008 survey on the deterioration of digital prints within cultural heritage institutions, found the majority of institutions had seen deterioration of their digital print collection, and 30% of institutions had experienced paper yellowing – a large percentage considering that digital printing, including inkjet printing, is a very recent technology (Burge and Nishimura, 2008). Not only is this yellowing a common problem, but there are many potential causes, which makes this damage difficult to predict and therefore difficult to prevent. What's more, inkjet prints are being increasingly acquired by cultural institutions as the popularity for the technology grows amongst artists and photographers (Burge and Nishimura, 2008) and we know the majority of fine art inkjet papers now have porous coatings, which means the problem of inkjet yellowing could become more prevalent in collections in the future.

*Conservation Testimonials*

Contact with other photograph conservators in the field, from both the public and private sector, revealed that their experiences with the yellowing of inkjet papers largely corroborates what has been written in the literature. Conservators reported yellowing of inkjet papers after exposure to light – this was both sunlight which contains high levels of UV light, and museum lighting conditions with low light levels and no UV content. In the latter case, the yellowing was not immediately obvious, but occurred after the print had been stored in the dark for some time. This delayed staining of inkjet papers has also been demonstrated in accelerated light ageing tests (Wilhelm, 2003). Non archival housing and framing materials as well as pollutants from storage materials and the environment were also thought to be the cause of yellowing in some cases – it was commented that matt coated porous inkjet papers were more susceptible to this than others. One conservator reported that they had successfully removed yellow staining from the white border of an inkjet print by exposing the borders to indirect sunlight for just a few days, but warned that this staining could return if the print was subsequently stored in the dark. Tests by Wilhelm have demonstrated that this staining can indeed be bleached by light, and then return during dark storage (Wilhelm, 2003).

These testimonials from conservators speak to the commonality of the problem of yellowing, and its complexity. In many cases, it was impossible to say exactly what had caused the yellowing of an individual print - 'real' inkjet prints in collections may be exposed to many damaging factors throughout their lifetime, from mounting and framing materials to storage and display conditions, all of which influence how the print will age – and yellow. Unlike the scientific investigations outlined in the literature review, where variables are carefully controlled and measured, it might be difficult to say for certain why an inkjet print has yellowed in a real-life scenario.

## Why did the Tracey Emin Print Yellow?

Considering the literature, testimonials, and the specific circumstances surrounding this print, it seems there could be several possible explanations for the yellowing. Light could have been a factor as the print had been on display for 13 months when discolouration was first noted. The paper contains OBA's which could have degraded upon exposure to light or pollutants. The paper also has a porous coating, which could have drawn in pollutants and led to discolouration. However, the specific pattern of yellowing suggests that something in contact or close proximity to the print, such as the frame or mounting materials, caused the yellowing. The pattern of yellowing can be described as follows;

- Yellowing is solely on the white border – it has not extended into the printed image area (fig. 2)
- The yellowing does not cover the entire white border but is concentrated to a specific 'band' of discolouration around the border
- There are rectangular areas within the 'band' of discolouration which have not discoloured – these areas correspond directly to where Japanese paper hinges and adhesive have been applied to the verso, which has protected the recto from discolouring in these areas
- The verso of the print is still in pristine condition and has not discoloured at all (fig.3) – this suggests that it is the ink receiving layer that is yellowed, rather than the paper support itself

The frame construction was analysed in detail to investigate whether this could have caused the yellowing. Removal of some of the mountboard within the frame allowed us to see more clearly the mounting and framing materials. Figure 4 details the frame structure, which consists of an oil board backboard to which a wooden subframe and central corrugated board support was attached. A sheet of white mount board was attached to the wooden subframe using double sided adhesive film, and the print was hinged onto this mountboard. The acrylic box cover was screwed into the subframe, and the frame was not sealed at the back.

If we compare the frame construction with the pattern of yellowing, it is obvious that the area of staining directly corresponds to where the wooden subframe and adhesive film sat under the print whilst it was in storage and on display (Figures 5 and 6). But could these materials have led to discolouration?

*Wooden Subframe*

Wood is known to off-gas and emit acids which can lead to deterioration and yellowing of cellulosic materials such as paper (Grzywacz, 2006), however the back of the paper, which was in closer proximity to the wooden subframe, has not discoloured, only the ink receiving layer has been affected. We know that pollutants are readily absorbed by porous inkjet papers, so it is possible that acids off-gassed by the wooden subframe could have been absorbed by the coating and led to yellowing of the IRL.

*Double sided adhesive film*

This type of film usually consists of a clear plastic carrier sandwiched between two layers of acrylic adhesive (Down et al, 2013). These films tend to have good ageing properties, and there is no sign of deterioration of the carrier or adhesive in this case. Several articles have expressed concern however, that antioxidants found in plastic materials could cause yellowing in inkjet prints (Afirm Group, 2021; Mizen and Mayhew, 2001; Wilhelm, 2003). The antioxidant, butylated hydroxytoluene (BHT), has been implicated as the cause – BHT is a phenolic antioxidant added to plastics and adhesives, like those found in tapes, to prevent ageing (Afirm Group, 2021; O'Loughlin and Stiber, 1992). Phenolic antioxidants are the most widely used antioxidants (Mills and White, 1987; O'Loughlin and Stiber, 1992). BHT is known to be highly volatile and can easily transfer into other absorbent materials, and when it reacts with nitrogen dioxide in the environment, highly coloured quinoid structures are formed. This is known as phenolic yellowing, which is said to be bright yellow in colour and can happen extremely quickly (Afirm Group, 2021; O'Loughlin and Stiber, 1992). Much of the research surrounding phenolic yellowing has been conducted by the textile industry as it affects fabrics that have been stored in plastic bags containing phenolic antioxidants (Afirm Group, 2021; Bangee et al, 1995). Some manufacturers of porous fine art inkjet papers have also warned of this phenomenon – a technical data sheet of a Somerset Fine Art Inkjet Paper with a porous coating, states that;

*"Coated papers can react to organic solvents, plasticisers, and antioxidants. These products could be contained in tapes, plastic bags, dry mounting film and could cause discolouration of the print."* (St Cuthberts Mill, 2022).

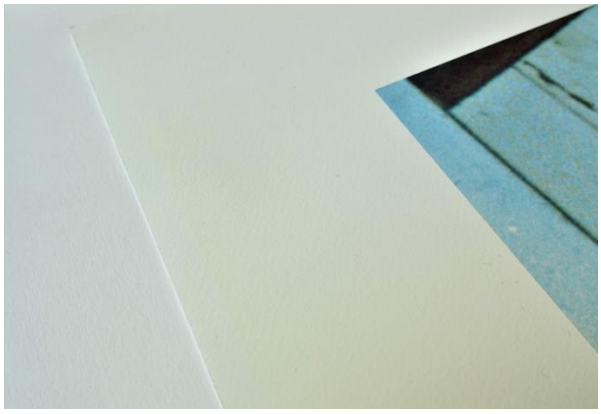
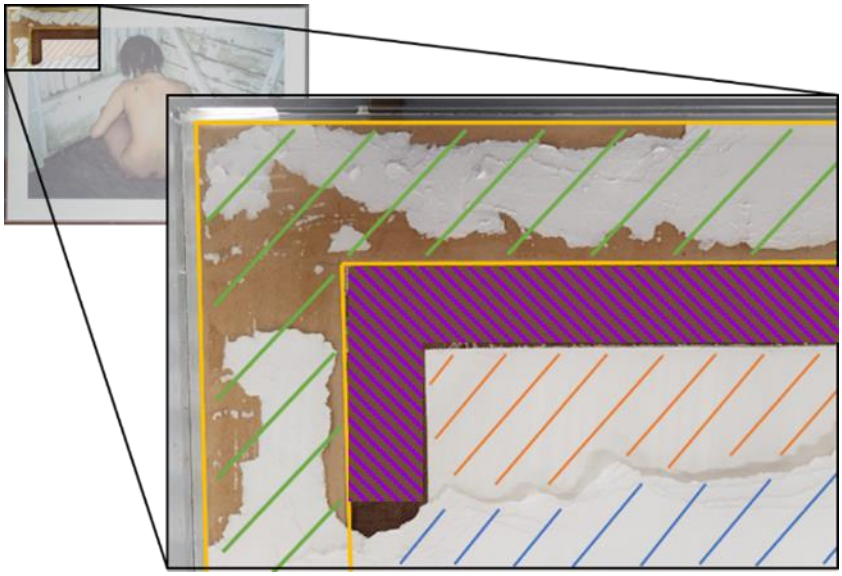


Fig. 2 – Detail of yellowing on white border

Fig. 3 – Verso of print



| Key | |
|---|---|
| | Oil board backboard |
| | Wooden Subframe |
| | Double Sided adhesive film |
| | Corrugated board |
| | Mount board |

Fig. 4 – Detail of internal frame construction

Fig. 5 – Yellow rectangles outline the area of discolouration on the white border

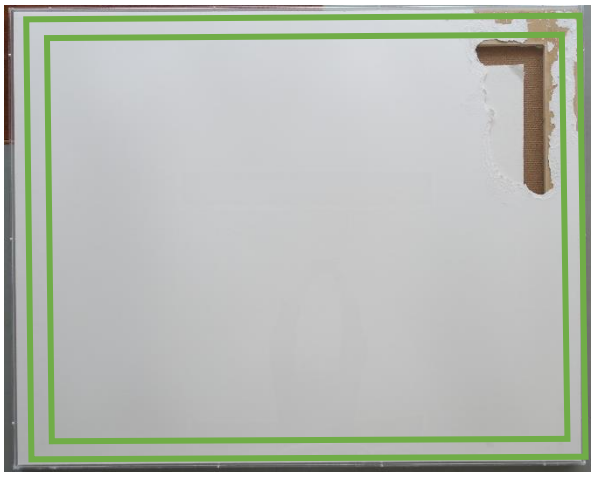


Fig. 6 – Green rectangles outline the area where the wooden subframe and adhesive film sat within the frame

It is the writer's opinion that discolouration in this print was most likely caused by absorption of antioxidants from the plastic film. The position and pattern of discolouration corresponds directly to where the adhesive film sat under the print, the adhesive film is a likely source of BHT or another phenolic antioxidant, and the porous inkjet paper would have readily absorbed volatile antioxidants from the adhesive film. According to the literature, nitrogen dioxide would have to be present for the phenolic yellowing reaction to occur - nitrogen dioxide is a common pollutant in museum environments (Blades et al, 2000) and as the back of the frame was not sealed, nitrogen dioxide could have easily entered the frame and interacted with the antioxidants to form yellow compounds.

Of course, it is possible that other factors have contributed to this yellowing, for example pollutants and acids from the wooden subframe, light exposure, or degradation of OBA's within the paper, but antioxidants reacting with nitrogen dioxide seems to be the primary cause of yellowing in this case.

*Sister Print*

Our hypothesis was reinforced after visiting The National Portrait Gallery (NPG), London, to see the sister print of Tate's print. The NPG print was printed in the same year and on the same paper as Tate's, and it has also been on display several times since it was acquired in 2000, however it is still in pristine condition with no yellowing of the white border. The NPG print had been framed in a more traditional way however, with a wooden frame which had been fully sealed at the back. This reiterated our theory that it was the mounting and framing materials which caused the yellowing in Tate's print.

**What is the solution?**

The print cannot be displayed as the yellow staining is distracting and disrupts the aesthetics of the artwork. Although the simplest solution would be to cover the staining with a window mount, this would contradict the intended display specifications for the print, which is for it to be float mounted with the white borders visible. Therefore, other options had to be explored.

*Treatment*

The only known treatment for the removal of yellow staining from an inkjet print is light bleaching. Removal of the yellow staining would restore aesthetic harmony to the artwork and the image itself could be covered during bleaching to protect it from light exposure. However, the literature and conservator testimonials suggest that staining could return after light bleaching, and to the writer's knowledge, there has been no research on the long-term effects of light bleaching on inkjet papers. At this time, it is not considered a safe treatment for this artwork.

*Reprinting*

Aside from conservation treatment, the only way of reinstating the aesthetics of the artwork would be to reprint. A lot has been written in recent years about the practice and ethics of reprinting as a preservation strategy for photographic artworks (Marchesi, 2017; von Waldthausen, 2017). In certain cases, institutions are opting to reprint photographic works which are too damaged to be displayed. Tate has a Replication Advisory Group who guide decisions on the replication of artworks in the collection, and they have recently supported a research project with artist Rineke Dijkstra to reprint three faded chromogenic prints as inkjet prints. Reprinting seems to be the most appropriate option for the Emin print at present, and

this is the likely route that Tate will take, as we cannot guarantee that any conservation treatment will permanently and safely remove the yellow staining on this print.

**Could this yellowing happen to other inkjet prints?**

The literature and testimonials from other conservators tell us that the yellowing of inkjet prints is a common problem. Worryingly, aside from the Emin print, the Paper and Photograph Conservation Department at Tate have witnessed several other cases of inkjet yellowing during the short time that research on the Tracey Emin print has been undertaken.

The first case was a set of thirteen inkjet prints that were sent to Tate for condition checking prior to acquisition – they arrived as pictured (figure 7) sandwiched between sheets of cardboard which had been secured with brown parcel tape. Yellow discolouration had developed on the white border of each print, corresponding directly to where the brown tape had been placed around the cardboard package (figure 8). In a similar scenario, a single inkjet print arrived at Tate, again for condition checking prior to acquisition. This arrived as pictured (figure 9) packaged in a cardboard folder using paper photo corners secured with masking tape. Yellow discolouration had developed on the print directly under where the masking tape had been placed (figure 10) – this was despite several layers of paper acting as a barrier between the masking tape and the print surface. In both scenarios, it is clear that tape has caused the discolouration, and it did not have to be in direct contact with the print surface, but close proximity within the packaging was enough for yellowing to develop. The last case is a set of inkjet prints by Sammy Baloji that Tate have recently acquired (figure 11). As part of the making process, the artist has applied an unknown adhesive to the verso of each print (figure 12). When Tate acquired these works, they all exhibited bright yellow discolouration on the printed side which corresponds to where adhesive has been applied on the verso (figure 13). In this case it was not tape, but adhesive which seems to have caused the yellowing. It is also important to note that these prints have previously been displayed pinned directly to a gallery wall, unmounted and unframed, meaning that pollutants could have interacted with the prints surface at some point.

What these examples have in common, including the Emin print, is that they are all printed on porous inkjet paper, and tape and adhesive seems to be the primary cause of yellowing. In the case of the Emin and Baloji prints, pollutants and light exposure could have also been a factor.

It is clear that yellowing of inkjet prints is happening in our collection right now. But what is the solution?

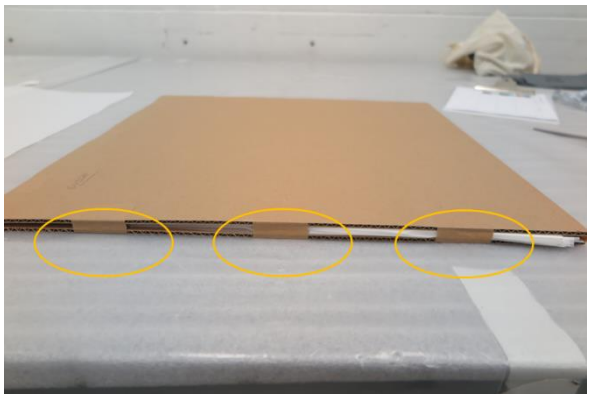


Fig. 7 – 13 inkjet prints arrived in cardboard packaging secured with brown tape around the edges

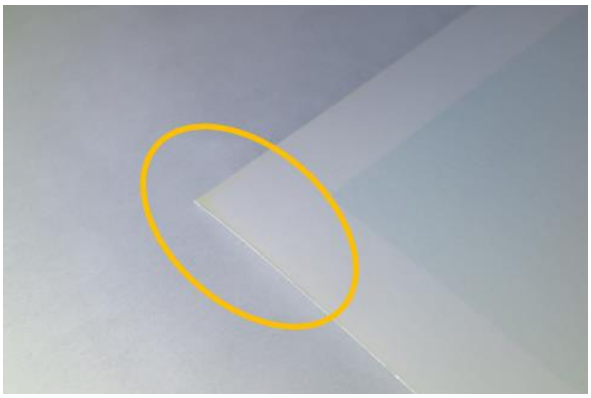


Fig. 8 – Yellow discolouration on one inkejet print corresponding to where tape had been applied on the carboard packaging

Fig. 9 – Single injet print secured into a card folder using paper photo corners and masking tape

Fig. 10 – Area of yellow discolouration across one corner of the inkjet print where masking tape had sat above in the packaging



Fig. 11 (left) – Inkjet print by Sammy Baloji
Fig. 12 (right) – Adhesive applied to the verso of print

Fig. 13 – Detail of yellow discolouration on printed side of a Sammy Baloju inkjet print

## What is the solution?

*Steps at Tate*

The Paper and Photograph Conservation Department have taken several steps so far to try and prevent the yellowing of inkjet prints in the collection. We have revised our packing guidelines for inkjet prints arriving at Tate, which includes the following recommendations:

- No tapes or adhesives should be adjacent to inkjet prints in the packaging
- Any loose inkjet prints should be housed in polyester sleeves to protect them from other packaging materials - polyester is considered a safe plastic for use with inkjet prints (Image Permanence Institute, 2014; Jürgens, 2009) and will provide a barrier from pollutants or other materials within the packing which could lead to yellowing
- Packages should be properly sealed with polythene to prevent pollutants from entering

The department would also like to review our current mounting and framing practices for inkjet prints. As an example, we often mount photographic prints, including inkjet prints, using paper photo corners secured with Filmoplast P90 archival tape. So far, we have not seen any problems with the tape when used with inkjet prints, but like many tapes and adhesives, the exact material composition of the tape, and whether it contains antioxidants for example, is not known. We have seen how sensitive inkjet prints can be to tapes and adhesives, so it is important to know that the materials we are using are appropriate and will not induce yellowing.

We also intend to test light bleaching as a treatment option for yellowed inkjet prints – we plan to carry out microfade testing on the yellow staining of the Emin print to see if it is indeed fugitive to light, so that we can explore the benefits and drawbacks of this as a treatment.

## Conclusion

The yellowing of fine art inkjet prints is a known problem in the conservation field, but there are limited published case studies detailing real-life scenarios of this damage. It is hoped that by sharing the experiences of one institution and specific instances of inkjet yellowing, this research will make a positive contribution to the field and aid in our understanding of inkjet deterioration.

Throughout this research, the question of why the Tracey Emin print yellowed has been answered - most likely a reaction between antioxidants absorbed into the porous inkjet paper, in combination with nitrogen dioxide from the environment. A solution has also been found - in this case it is likely that the work will be reprinted. Hopefully, this research has also highlighted the complexity of inkjet yellowing in cultural heritage collections, namely because the diversity of inkjet materials and the many possible causes of yellowing, makes it difficult to predict and prevent this yellowing. Further instances of inkjet yellowing within our institution has prompted a reassessment of our own practices as a conservation department and has emphasised the need for due care and attention for the specific preservation needs of inkjet materials. We cannot assume that the appropriate practices and standards applied to analogue photographic prints, are also appropriate for inkjet prints.

There is fantastic research being undertaken in the cultural heritage field surrounding the deterioration and preservation of inkjet prints in heritage collections, as we have seen in the literature referenced above. Through continued research and collaboration, institutions, and individuals responsible for the care of inkjet materials will be increasingly equipped to deal with their complex preservation needs.

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