Salvador Muñoz-Viñas*, Victoria Vivancos-Ramón and Pascual Ruiz-Segura

The Influence of Temperature on the Application of Cyclododecane in Paper Conservation

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Abstract: In paper conservation, cyclododecane (CDD) is commonly used to waterproof water-sensitive inks and paints. In order to apply CDD over thin lines (such as those of drawings or signatures), conservators often use *kistkas*. While being a useful, convenient tool, the *kistka* does not always allow for a precise application of CDD. In this study, the influence of the CDD temperature on its tendency to spread through the paper-fibre web and its ability to waterproof water-sensitive materials were assessed. CDD was applied on four types of paper that were considered to be representative. During the tests, the temperature of a regular *kistka* was precisely controlled through an open-loop phase-control AC regulator. The test series showed that at a temperature of approximately 70 °C, CDD is very easy to apply precisely, yet its waterproofing effects are not very good; at approximately 90 °C, CDD is excellent at waterproofing, but is very difficult to apply precisely. While the ideal temperature may vary depending on the technical requirements of the artefact, it is important to stress that a variation of as little as 5 °C has a relevant influence on the applicability and waterproofing efficiency of melted CDD.

Keywords: cyclododecane, waterproofing, application techniques, aqueous treatment, paper conservation

***Corresponding author: Salvador Muñoz-Viñas,** Facultad de Bellas Artes, Universitat Politècnica de València, Camino de Vera, 14, 46022 Valencia, Spain, E-mail: smunoz@crbc.upv.es
Victoria Vivancos-Ramón, Facultad de Bellas Artes, Universitat Politècnica de València, Camino de Vera, 14, 46022 Valencia, Spain, E-mail: vivanco@crbc.upv.es
Pascual Ruiz-Segura, Art Museums of Estonia, Weizenbergi 34/Valge 1, 10127 Tallinn, Estonia, E-mail: pascual-ruiz.segura@ekm.ee

1 Introduction

Cyclododecane (CDD) is an alicyclic, saturated pure hydrocarbon, or a cycloalkane. As such, its molecule is a ring made up of carbon atoms linked together and two hydrogen atoms per carbon atom. Its empiric formula is $C_{12}H_{24}$ (Figure 1). Its CAS number is 294-62-2.

In the conservation world, CDD is commonly distributed as spray or as white granules. The granules look and feel somewhat like paraffin. It is highly hydrophobic, and melts at around 60 °C. It can also be easily dissolved in many non-polar solvents, such as xylene or white spirit; acetone can also dissolve it, but at a much slower pace. Its paramount property is its ability to slowly sublimate at room temperature. This is what led Hans Michael Hangleiter, who discovered the material's possibilities in conservation in 1995, to describe it as a "volatile binder" (Hangleiter, Jägers and Jägers 1995). Since its introduction in conservation, cyclododecane has become increasingly popular and a welcomed addition to the conservators' arsenal of materials.

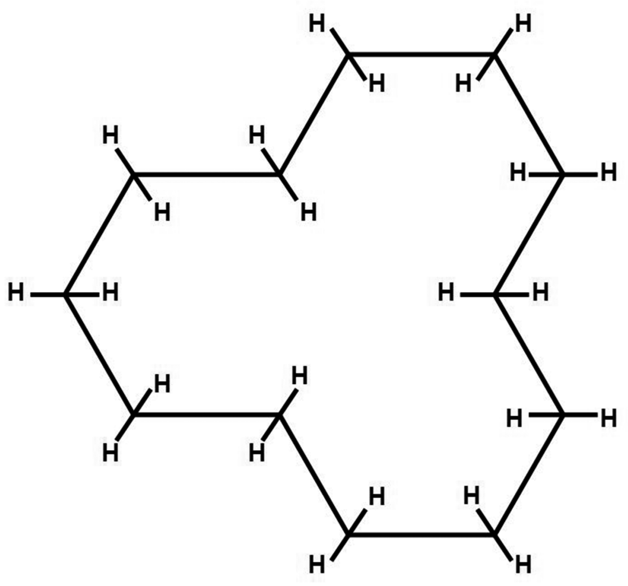

Figure 1: The chemical structure of cyclododecane consists of a ring of 12 carbon atoms.

2 CDD in paper conservation

Cyclododecane was tested in a number of conservation applications for the treatment of very different heritage objects, such as easel and mural paintings, archaeological objects or sculptures (Rowes and Rozeik 2008). In paper conservation, CDD was commonly used as a temporary barrier for water-sensitive materials during aqueous treatment. The possibilities of CDD as a temporary water-proofing material for paper-based artefacts were realized quite early (Brückle et al. 1999; Bandow 1999; Wimmer and Haberditzl 1999; Blüher, Haberditzl, and Wimmer 1999), and were subsequently recognized by different authors (see, e. g., Chevalier 2001; Scharff and Nielsen 2003; Muñoz-Viñas 2007), and by a number of practicing conservators worldwide.

When CDD was introduced into the field of paper conservation, it seemed like it might represent an excellent alternative to Paraloid B72 as a water-proofing material. It can be applied either as a solution or as a melt, or as a combination of the two (it may be brushed as a solution and then melt *in situ* with a heated spatula); given its non-polar nature, it repels water without being affected by it in any way; and, crucially, it is one of the most reversible materials available: CDD sublimates from the sheet at room temperature, without any intervention from the conservator, and without any known risk for the artefact.

Unfortunately, things are not that simple. If applied as a solution, cyclododecane tends to crystallize when the solvent evaporates, forming a network of crystals that allows liquids to pass. The density of the network is affected by the evaporation rate of the solvent and may therefore be controlled to some extent by selecting the most appropriate solvent (Hangleiter 2000). However, in practice no solution of cyclododecane will produce a good waterproofing layer. As a consequence, melted cyclododecane is often preferred.

Melted cyclododecane can be applied by different means: for instance, brushes, batik balls, heated syringes or a *kistka* have been used to this end (Rowe and Rozeik 2008). The latter is a tool used in Ukraine and other countries in Eastern Europe in the traditional craft of decorating Easter eggs. It is used in order to “draw” thin lines of melted wax over the eggs, and, in essence, it consists of a handle with a small, funnel-shaped tip. The wax is put into the heated funnel, where it melts and flows down the hole (Figure 2). In traditional *kistkas*, the wax was melted by heat of a flame; modern *kistkas*, however, are heated by an electrical heating element, which is much more convenient. Furthermore, modern *kistkas* usually have replaceable funnel-shaped tips of different thicknesses (Figure 3): the operator selects the funnel tip with the most appropriate orifice, and controls the application of the wax. The *kistka* provides a greater level of convenience than other techniques do. As a consequence, it has become a widespread tool among paper conservators using cyclododecane (see, e. g., Nichols and Mustalish 2002; Brown and Davidson 2010; Rowe and Rozeik 2008).

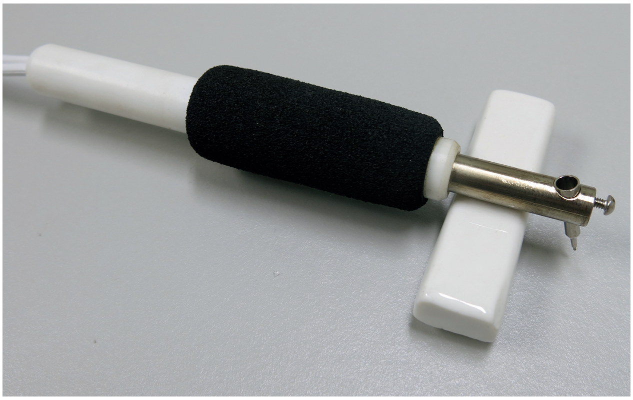

Figure 2: The electric *kistka* used in our experiments is a fairly typical model. The rod protruding from the black foam handle supports the small, funnel-shaped tip. By loosening the retaining screw, different tips may be substituted. Each tip allows the wax (or the CDD) to flow at a different rate.

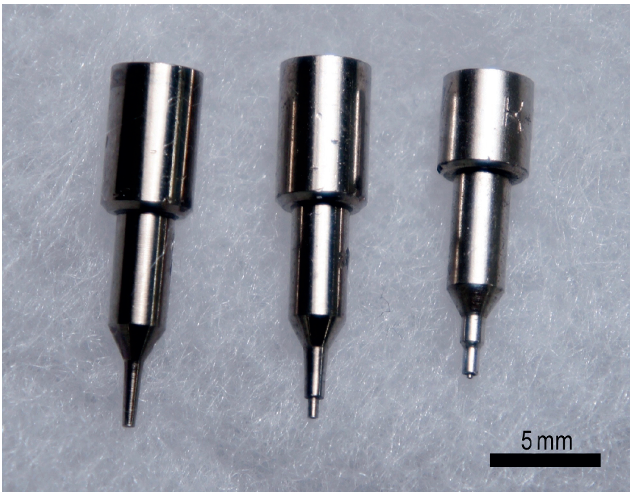

Figure 3: The tips used in the experiments. Following the manufacturer's nomenclature, the tips are, from left to right, tip #2, tip #1, and tip #00. The diameters of the tip holes are, respectively, 0.45 mm, 0.33 mm and 0.19 mm.

3 Factors influencing the application of cyclododecane

The *kistka* offers a convenient way for applying melted CDD onto small areas in a rather controlled manner. This may not be a requirement in many conservation fields; for instance, when temporarily protecting a large archaeological object before transport, or when waterproofing some areas of a mural painting in the ceiling of a church, the conservator may not need a great degree of precision. However, in paper conservation, CDD is often used to waterproof very small surfaces, such as the ink of a stamp or a signature. It is in these cases that the *kistka* becomes a highly valuable tool, allowing for a degree of precision that would otherwise be impossible to achieve. In this regard, it is important to note that many paper artefacts are expected to be seen at close range or even held by the observer, which means that the conservator must be extremely precise when applying melted CDD: if the CDD does not cover the inked surface exactly, the ink might bleed or be otherwise affected by water; if the CDD covers part of the uninked paper, then some parts of the uninked paper might end up being affected by water and others might not – usually resulting in a halo around the lines.

The required degree of precision, however, may not be easy to achieve, even with a *kistka*. The melting point of CDD lies between 58 °C to 61 °C. Indeed, the granules of CDD used in our experiments start melting at around 60 °C. In practice, however, melting CDD at this temperature does not make it usable for waterproofing: the CDD cools and solidifies too fast to be conveniently applied to the paper surface, let alone to impregnate it. If applied at this temperature, the result is, at best, a dotted, irregular line, useless for waterproofing purposes.

To be successfully applied, CDD needs to be heated to a higher degree – but how much higher is “a higher degree”? When supplied 220 volts AC, the *kistka* used in this study (shown in Figure 2; see Appendix for technical details) heats the funnel tip to 90 °C. At this temperature, CDD flows very well, and the granules of CDD melt readily as soon as they are inserted into the funnel. When the point of the funnel is put into contact with the paper, the surface tension of the melted CDD is surpassed, and the CDD flows out of the funnel and spreads over and into the paper, until it cools and solidifies. The whole process, from the application of the CDD to its solidifying, takes approximately one second. Because of both the free, fast flow of the melted CDD and the heterogeneous nature of the paper, the edges that can be produced are not fully straight, but rather irregular and imprecise. As shown in Figures 4, 5 and 6, the CDD can spread far too much through the paper, producing lines of up to 5 mm thick – far too thick in many cases. Even if using a very thin (0.19 mm in diameter) tip, the thinnest lines of CDD that can be achieved with the *kistka* at 90 °C on typical papers are ca. 1 mm thick.

Some of the factors that determine the spread of the CDD within the paper can be controlled by the conservator. For instance, the conservator can choose from among different *kistka* tips – usually, the one with the smaller hole will provide a greater degree of control. Also, the conservator can control the speed at which the *kistka* is moved and the pressure exerted on the paper: the greater the speed and the lighter pressure, the less amount of CDD will flow onto a given point. The amount of CDD put into the funnel can also have an influence

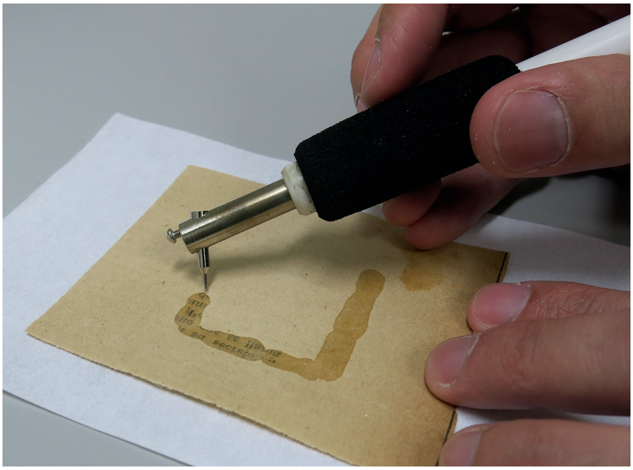

Figure 4: Melted CDD can spread through the paper in a way that is hard to control, thus producing thick lines that are inadequate for waterproofing thin lines or intricate shapes.

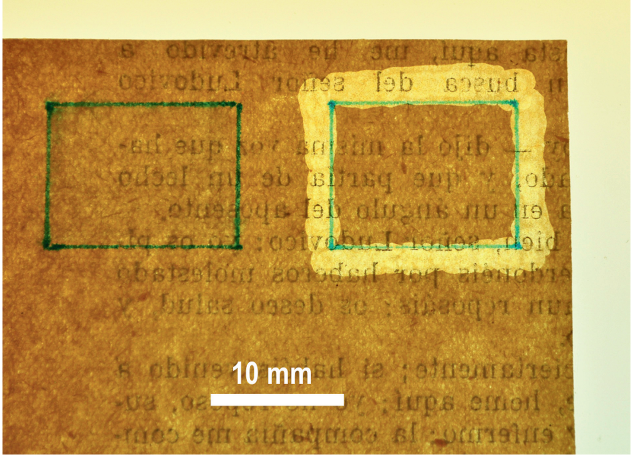

Figure 5: In this sample (illuminated in transmitted light for clarity), CDD has been applied in order to cover the marker lines while trying to adjust it to the inner edges of the 10 mm by 15 mm rectangle and leaving its interior uncovered. However, because of the fast spreading of the melted CDD through the paper, it was not possible to accurately follow the shape. Fluctuations of up to 1 mm are common when applying CDD at 90 °C.

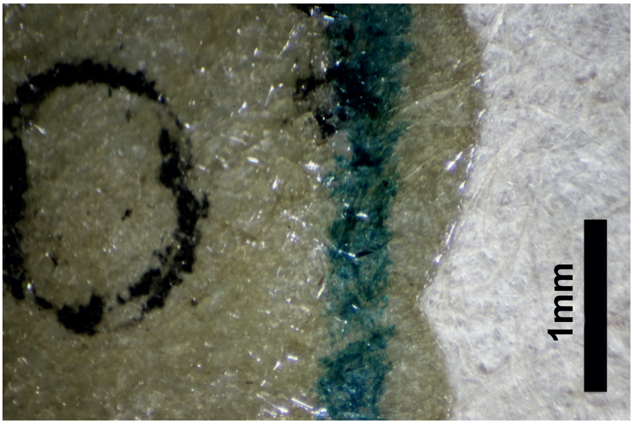

Figure 6: A detail showing the fluctuations to be expected when working on paper D (see Table 1) with a *kistka* at 90 °C. Even if applied with utmost care, CDD spreads beyond the intended area.

on the flow rate: because of its own weight, the more CDD there is in the funnel, the faster it will flow down into the paper.

However, the physical features of paper-based heritage objects may make an unwanted, unpredictable impact on the behaviour of melted CDD. These features include the total porosity of the paper, its pore distribution, the type of sizing, the degree of sizing, its degree of surface calendering, the chemical alterations the paper has undergone, etc. In real-life practice, these factors cannot be chosen, or even accurately assessed by the conservator, and furthermore, it would be naïve to expect these factors to remain constant and homogeneous along every point of the surface of the paper. Other factors related to the inks or paint layers that are to be waterproofed (type of inks, thickness of the layer(s), penetration within the paper fibre web, elasticity of the layer, resistance to heat, etc.) may also have an impact on the application of CDD (and on the final outcome of the operation) that is difficult to foresee.

The temperature at which CDD is melted is another factor that may play a role in the successful application of CDD. This factor is often ignored, and, in many cases, taken as a given. In this paper its relevance will be assessed through a set of experiments.

4 Temperature control

In order to verify the real-life impact of the CDD's melting temperature on this technique, a set of experiments was set up in which CDD was melted in the *kistka* at different temperatures. This required a custom modification of our *kistka*. Most electric *kistkas* provide no way of controlling the temperature: a pre-set amount of power is delivered to the heating element in the *kistka*; thus, the funnel tip is heated to a temperature that, in normal working circumstances, is most adequate for melting the wax used for the decoration of Easter eggs. It must be noted, however, that the actual temperature of the tip is not just dependant on heat from the element alone, but is also affected to a lesser extent by the temperature of the environment, the available ventilation and other factors, including the dissipation induced by the wax (or the CDD) itself, as shown below.

In order to be able to study the influence of the temperature on the application of CDD, a system for controlling the temperature of the *kistka* was needed. After some trial-and-error tests and consultation, an open-loop phase-control AC regulator was found to be an adequate retro-fit system. This type of regulator does not actually control the temperature of the tip, but rather the power provided to the heating element – which, along with the factors mentioned above, determines the actual temperature of the tip.

While it is not the goal of this paper to discuss the intricacies of electrical power regulation, it may be interesting to note that the type of regulator used to control the *kistka* proved to be relevant. For our experiments, several types of regulators were tried and rejected because they did not always provide the same amount of energy when the potentiometer was turned to a given point, thus resulting in an unreliable operation: given the low wattage of the kistka, small variations in the trigger angle of the regulators produced very large variations in the final temperature of the *kistka*, making it extremely time-consuming to precisely set a temperature. On the contrary, the open-loop phase-control AC regulator selected for our experiments (a relatively simple design built for teaching purposes at the Electronics Engineering School of the Universitat Politècnica de València) proved capable of controlling the temperature of the *kistka* to a practical accuracy greater than ±1 °C in a convenient, efficient way.

In order to monitor the actual temperature of the *kistka*, a K-type thermocouple was attached to the metal rod holding the funnel by means of a Teflon™ strip, 10 mm away from the tip. In turn, the thermocouple was connected to a V&A MY-64 digital multimeter.

It must be noted that the temperature of the *kistka* may be affected by being in contact with heat dissipating materials. This is to be expected for low-wattage appliances such as the *kistka* used in this study. Because of this, it was expected that adding solid CDD at room temperature to the tip of the *kistka* could also significantly lower its temperature. However, this was not the case. Figure 7 shows the temperature variation when 15 mg of solid CDD are put in contact with the tip of

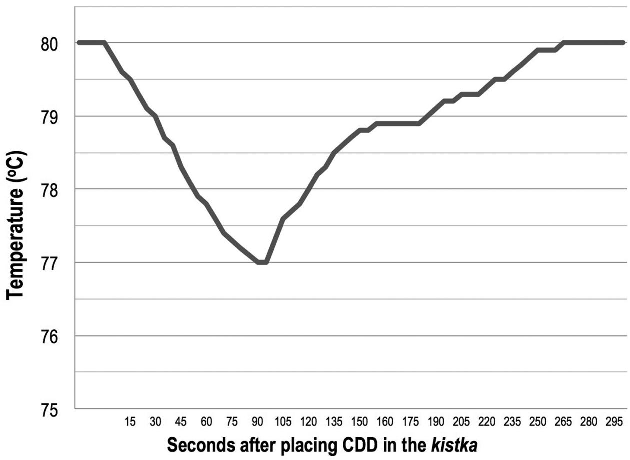

Figure 7: Variation of the temperature after 15 mg of CDD are put into the *kistka*'s tip. The initial working temperature is 80 °C. After inserting the CDD granules, the tip of the *kistka* cools down, as the evaporation of the CDD takes up heat from the *kistka*. The inverted apex of the curve signals the moment when all of the CDD evaporated: since heat is no longer taken up by the CDD, the tip can reach the original, preset temperature.

the *kistka* – which is representative of real-life working practice. As it can be seen, the *kistka* cools at a rate of approximately 1 °C every 30 seconds. After roughly 90 seconds, all of the CDD has sublimated from the *kistka*, so that it does not take up heat any longer, and the *kistka* starts recovering the preset temperature. In real-life practice, however, the CDD does not just sublimate from the *kistka*, but is also applied to the paper, so the funnel typically becomes empty within ca. 30 seconds. As a consequence, in common practice, the preset temperature is lowered by 1–1.5 °C only when the funnel is loaded with CDD. In summary, the granules of CDD do affect the temperature of the *kistka*, but, as the experiments described below demonstrate, this is barely enough to affect the flow and behaviour of melted CDD.

5 Experimental

Once the temperature-controlled *kistka* was ready, a set of experiments was carried out. The goal was to assess the precision at which the CDD could be applied at different temperatures, and the influence of the temperature of the *kistka* on both the visually perceivable impregnation of the paper and on its actual waterproofing efficiency. The experiments involved the application of melted CDD with a *kistka* in real-life circumstances, i. e., by "drawing" the line by hand. The *kistka* was pulled at an average speed of approximately 5 mm per second, though this could not be accurately measured each time, as it cannot be measured in real-life work. The lines were drawn with tips of 0.45 mm (tip #2), 0.33 mm (tip #1) and 0.19 mm (tip #00), and at different temperatures (65 °C, 70 °C, 80 °C, 85 °C and 90 °C). In order to assess the influence the paper substrate might have on the results, the lines were drawn on four types of new and naturally aged papers that were considered to be representative. These were identified as papers A, B, C and D. All of them were moderately sized and weighed 60–100 g/m^2. The only paper showing an easily noticeable difference between both sides was paper type A; in this case, melted CDD was always applied on the smoother, more calendered side. Papers B and D were made of mechanical wood pulp, and paper D was printed with black ink; the other two papers were made from lignin-free, chemical wood pulp (see Table 1). Four sets of 60 different samples combining four paper types, three different *kistka* tips and five application temperatures were prepared and assessed.

Table 1: Types of paper used in the experiments.

	Paper type A	**Paper type B**	**Paper type C**	**Paper type D**
	Calendered paper	**Recycled wood pulp paper**	**Inkjet paper**	**Newsprint paper**
New or aged	New	New	New	c. 60 years old
Weight	80 g/m^2	90 g/m^2	80 g/m^2	50 g/m^2
Avg. thickness	0.07 mm	0.12 mm	0.08 mm	0.06 mm
Texture	Smooth	Slightly rough	Smooth	Slightly rough
Colour	White	Cool light grey	White	Light beige
Fibre	Chemical wood pulp	Recycled mechanical wood pulp	Chemical wood pulp	Mechanical wood pulp
Notes	One side is more thoroughly calendered than the other.	Low-cost paper, sold in rolls	Low-cost, generic paper for inkjet printing and writing	Low-quality, printed paper from the 1950s

5.1 Precision vs. temperature

The samples were examined under incident light with a digital stereomicroscope. The thicknesses of the CDD lines were measured at three different semi-random points (no measurements were taken at the beginning of the line, which were consistently thicker), and then averaged. Four values were obtained for

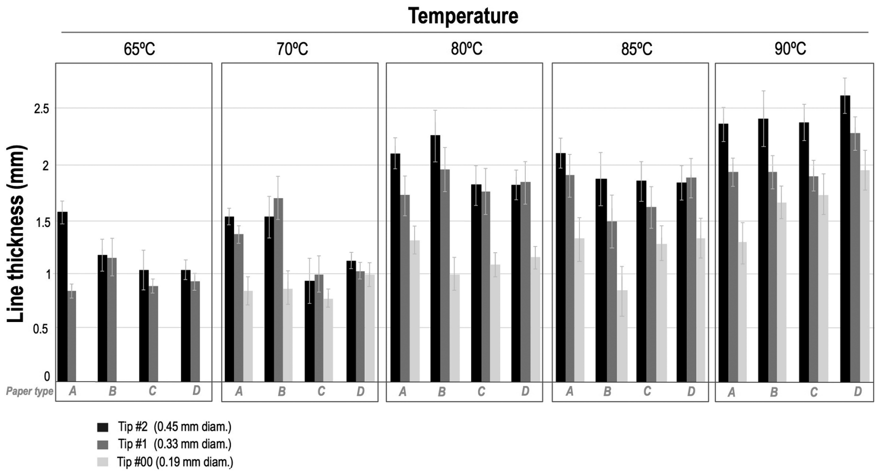

Figure 8: Influence of temperature on the thickness of lines of melted CDD drawn with the *kistka*. Each column represents the average thickness obtained in four types drawn on a particular type of paper, at five different temperatures and with three different tips. Error bars represent standard deviation.

each combination of paper type, *kistka* tip and *kistka* temperature; these values were in turn averaged. The results are summarized in Figure 8.

As can be seen, the standard deviation is remarkably small. Both the tips and the temperature had a consistent influence on the thickness of the resulting lines. Expectably, the thinner the funnel hole, the thinner the resulting lines were and therefore, the more controllable the spreading of the CDD. In this regard, it must be noted that heating the tip #00 at 65 °C did not allow for a convenient application of CDD, as it solidified immediately after leaving the funnel, which resulted in intermittent, inconsistent lines. However, a slightly higher temperature (70 °C) did allow for the application of much more precise lines with all tips. At a temperature of 80 °C, the lines became much thicker and harder to control, as the additional heat made the CDD remain liquid for a longer time, allowing for its diffusion through the capillary network of paper fibres. At 90 °C, the standard, pre-set temperature of the *kistka* at 220 volts AC, the resulting lines reached a thickness of up to 2 mm with the thinnest tip, and of 2.5 mm with the thickest tip.

5.2 Impregnation vs. temperature

Temperature also had an important effect on the ability of CDD to impregnate paper. As the CDD moves out of the heated *kistka*, it starts losing heat; when it cools down to ca. 60 °C, it solidifies within the paper-fibre web. The ability of the CDD to impregnate the paper-fibre web thus crucially depends on the time it takes for it to cool past its melting point: the longer it takes, the more easily (and the farther) it will travel through the paper – or, in other words, the better it will impregnate the paper. In turn, the time it takes for the melted CDD to solidify depends on its initial temperature: the higher the temperature, the longer it will take for it to cool to a solid state.

Successful impregnation of the paper by CDD implies that the CDD replaces the air between and within the fibres of the paper. This can be easily checked by observing the paper in transmitted light: as the CDD's refraction index is closer to that of cellulose than it is to that of the air, the substitution of CDD for air in the paper sheet means that the light is less scattered and reflected than it was before. The result is easily noticeable: the more impregnated the paper gets, the more transparent it becomes (see Figure 9). This is a simple, reliable method of assessing the thorough impregnation of paper with CDD. Most importantly, this method can be easily replicated by the conservator in regular working conditions. In fact, this is a good reason why it may be helpful to apply CDD on a light table. In our experiment, each line was visually examined and assigned a value on a five-step scale, ranging from 0 (no noticeable impregnation) to 4 (full apparent impregnation). Four values were obtained for each combination of paper type, *kistka* tip and *kistka* temperature. The average of these four values is presented in Figure 10.

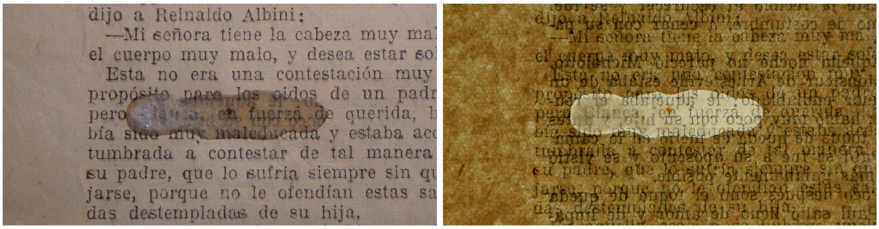

Figure 9: A side-by-side comparison of a paper that has been impregnated with CDD, seen under reflected light and under transmitted light. The high degree of transparency indicates that the CDD has thoroughly impregnated the paper.

The temperature had a noticeable impact on the penetration of melted CDD into the paper fibre web. At 65 °C and 70 °C, no penetration could be observed, while at 80 °C, CDD started to impregnate the paper. If the tip of the *kistka* was heated to 85 °C or 90 °C, the CDD thoroughly impregnated the papers.

In this case, the size of the *kistka* tip had some influence on the degree of impregnation achieved in each case: as can be seen in the graphs, the thinner tips favoured a slightly greater penetration than their thicker counterparts. A likely explanation for this phenomenon could be that the thinner tips remain on each spot for an imperceptibly longer time, thus providing a marginally larger amount of

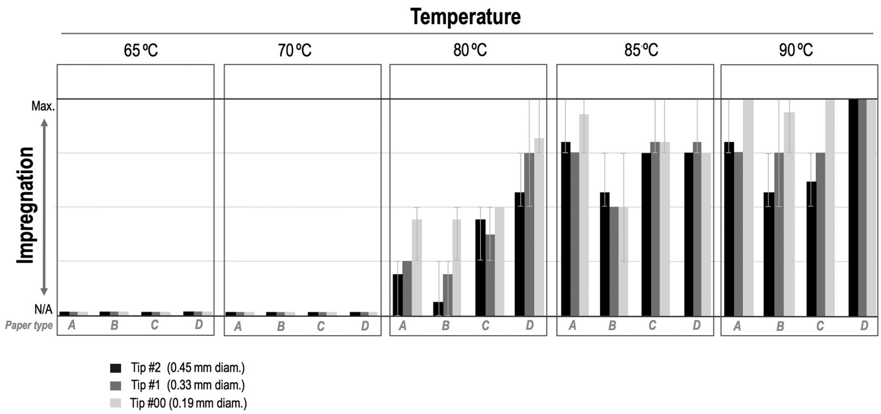

Figure 10: Influence of the temperature on the degree of impregnation of paper samples with melted CDD. The degree of impregnation was estimated through visual inspection of the samples under transmitted light. Each sample was assigned an integer value ranging from 0 (no impregnation) through 4 (full impregnation). Each column represents the average value obtained from the examination of four different samples of a particular type of paper, applied at a particular temperature and with three different *kistka* tips. Error bars represent the range of values.

heat, which in turn contributes to keeping the CDD melted for a slightly longer amount of time.

5.3 Waterproofing efficiency vs. temperature

The heating temperature proved relevant for enhancing precision when applying melted CDD while also maintaining its impregnating power, though its actual waterproofing efficiency when applied this way also had to be assessed, as this usually represents the ultimate goal of the application of CDD.

For these experiments, several sheets of the four types of papers were cut into samples of 12 × 12 cm. Then, a number of straight lines of a thickness of approximately 0.5 mm were drawn onto the samples, perpendicularly to the MD of the paper, with a Stabilo™ point 88 marker. Afterwards, the left half of each line was covered with a line of melted CDD, drawn by hand. As in the previous experiment, the lines were applied with different *kistka* tips at 65 °C, 70 °C, 80 °C, 85 °C and 90 °C. The samples were then immersed in tap water at room temperature (22–24 °C) for 20 minutes. After the immersion, the samples were blotted and allowed to air dry (see Figure 11). The stability of the ink in the left half of each line was visually assessed, and assigned a value on a five-step scale, ranging from 0 (no perceived waterproofing) to 4 (no perceived alteration). The experiment was repeated four times. The averaged results are summarized in Figure 12.

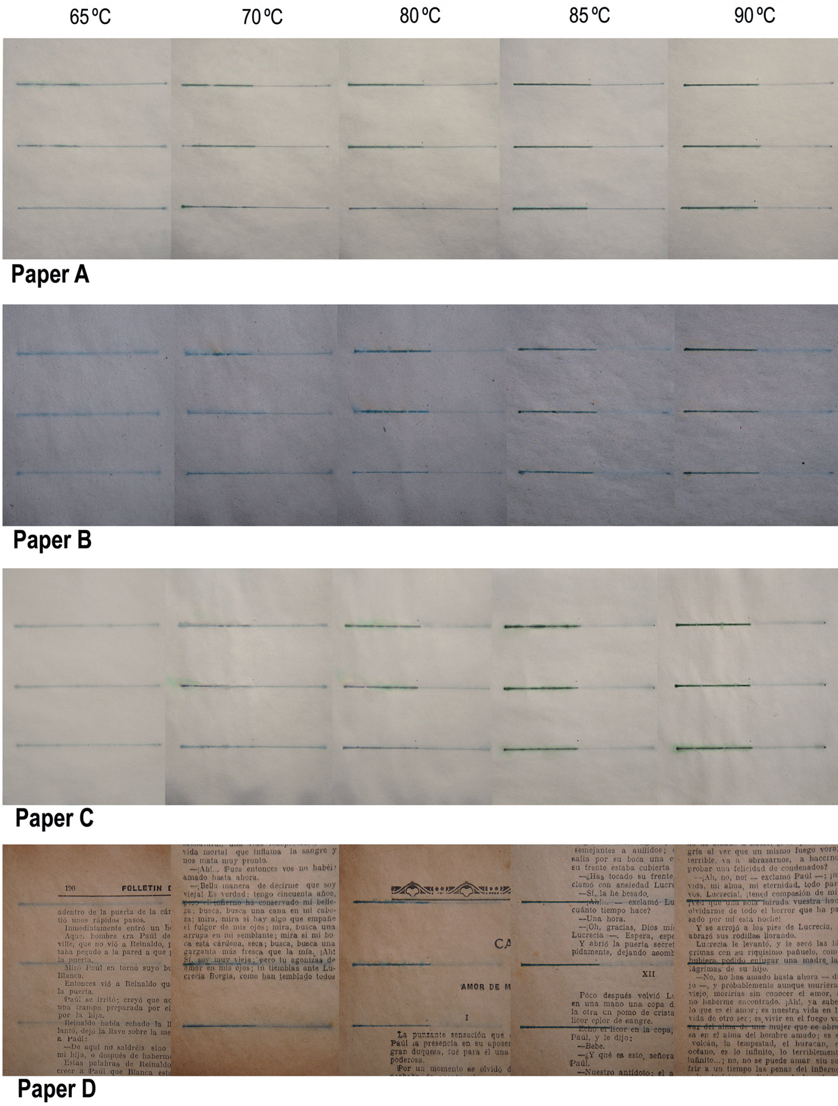

Figure 11: A side-by-side comparison of the waterproofing efficiency of CDD applied at five different temperatures on the four types papers used in our experiments. For this experiment, three lines of 60 mm in length were drawn on paper samples of each paper type with highly water-soluble ink. After this, the left halves of the lines were waterproofed with CDD applied with tip #1 at different temperatures. The samples were then immersed in tap water for 20 minutes, and then allowed to dry. The figure shows that the right halves of the lines were almost completely dissolved away, while the left halves were more or less affected depending on the temperature of application. As a general rule, the higher the temperature, the greater the waterproofing efficiency.

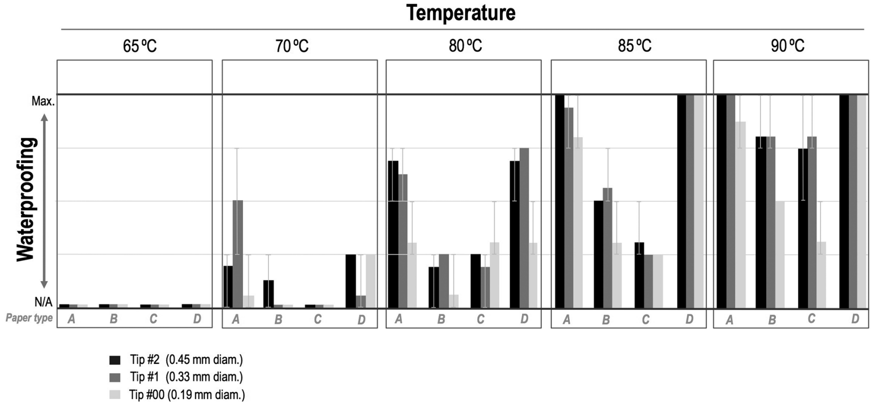

Figure 12: Influence of the application temperature on the waterproofing efficiency of CDD applied onto highly water-soluble inks and then washed for 20 minutes. The efficiency of the waterproofing was estimated through visual inspection of the samples. Each sample was visually examined and assigned an integer value ranging from 0 (no perceived waterproofing) through 4 (no perceivable alteration). Each column represents the average result of four tests carried on samples of a particular type of paper, with CDD applied at five different temperatures and with three different *kistka* tips. Error bars represent the range of values. Note that the finer tip (tip #00) could not be applied at 65 °C.

In all cases, the uncovered parts of the lines dissolved, leaving only a faint trace of colour. However, the stability of the part of the lines that had been covered with melted CDD varied greatly. A direct correlation between the temperature of application of the CDD and its waterproofing efficiency could be shown: in nearly all cases, the better waterproofing efficiency of the CDD layers was directly proportional to the application temperature.

In order to better interpret these results, it must be born in mind that the samples used in our experiments represent a worst-case scenario when it comes to ink solubility: the marker was chosen because its ink is readily soluble in water. Furthermore, in our experiments the samples were immersed in water for 20 minutes. In real life, the paper could be washed using less invasive methods, such as float-washing or capillary washing, and, if the paper was immersed, the duration of the treatment would probably be shorter: if the melted CDD can prevent the inks in the samples from dissolving, it is reasonable to assume that it will work in many real-life situations, in which the solubility of the inks may have decreased over time, and in which more cautious washing techniques may be applied.

6 Discussion

These experiments prove that the precision at which CDD can be applied with a *kistka* is greatly influenced by the temperature. At higher temperatures, CDD migrates through the paper fibre web until it cools down and becomes solid. Since the paper fibre web is never regular, the spreading of the CDD is both unpredictable and uncontrollable, so it is hard to precisely apply melted CDD over exactly any given shape: in papers such as those used in our experiments, fluctuations of 1 mm may be expectable at 90 °C (the pre-set temperature of the *kistka*). The precision, however, dramatically increases as the temperature of application is diminished. At lower temperatures, the CDD cools (and thus solidifies) faster, thus spreading less through the paper. This results in a much more controllable and precise application. Precision, therefore, is inversely proportional to the temperature at which the CDD is applied.

On the other hand, the experiments show that the impregnation and the waterproofing efficiency of melted CDD increase with the temperature: at 65 °C, CDD fails to effectively prevent the ink from bleeding, but the waterproofing efficiency increases with the temperature. As discussed above, this happens because the higher the temperature in the *kistka*, the longer the CDD remains liquid within the paper pores, and the further (and deeper) it is allowed to migrate. Thus, the warmer the CDD, the better it can encapsulate water-sensitive materials – and the better it can prevent them from being affected by water. Therefore, waterproofing efficiency is directly proportional to the temperature of the *kistka*.

The size of the tip also had an influence in this regard, since the thinner tips provided somewhat less effective waterproofing in some cases. The type of paper also had an influence, as some types of paper allowed for better waterproofing than others. Since the nature of the treated paper cannot be altered by the conservator, this is a reminder that, just as is the case with many other conservation techniques, the application of melted CDD under similar conditions may produce different results when applied to different artefacts.

7 Conclusions

When using the *kistka*, the conservator can control the way the *kistka* is used (the speed at which it moves and the pressure exerted on the paper) and the size of the funnel at the tip (the smaller it is, the slower the application and the greater the degree of precision achievable). However, in this study we show that the temperature of the *kistka*, and thus that of the melted CDD, can also have a paramount influence on both the level of precision and on the degree of waterproofing achievable. In summary, the higher the temperature, the better the waterproofing effect of the CDD, and the less precisely the CDD can be applied.

A conservator wishing to improve his or her results with the *kistka* may greatly benefit from implementing a system to control the temperature of the funnel. Such a control system will allow the conservator to experiment with different temperatures in order to find the one which best suits the conservator's preferences and the work being treated, i. e, the temperature that represents the best compromise between precision and waterproofing efficiency.

It might be worth mentioning that in our personal experience, a narrow temperature window exists at which CDD flows from the *kistka* at an adequate rate for most needs. In our case, this temperature window spans from 83 °C to 85 °C. At this range of temperatures, and with a thin tip of 0.19 mm, CDD lines of approximately 0.5 mm thickness can be easily drawn on most papers, while still obtaining good waterproofing. In the opinion of the authors of this paper, applying melted CDD in this way requires no special skill, as the movement is very intuitive and closely replicates the gesture of drawing with a marker or a similar pen.

However, it has to be stressed that this must not be taken as a "magic number" that will be adequate under all circumstances. What needs to be stressed is that temperature does play a crucial role when it comes to successfully applying melted CDD with a *kistka*, and that a variation of as few as 5 °C can make a noticeable difference: conservators need to be aware that the temperature of the *kistka* is an important factor when it comes to successfully apply melted CDD.

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Suppliers and technical data

Kistka.
Supplied by www.bestpysanky.com
Item id: EKKITAS220
Operating voltage: 220 V AC
Preset temperature: 93 °C

Kistka tips.
Supplied by www.bestpysanky.com
Items id: tip #00, tip #1, tip #2

Cyclododecane.
Supplied by CTS Srl.
Technical data:
Melting point: 58–61 °C
Boiling point: 247 °C
Specific weight: 0.82 kg/dm^3

Zusammenfassung

Der Einfluss der Temperatur beim Auftrag von Cyclododekan als Schmelze

In der Papierrestaurierung wird Cyclododekan üblicherweise eingesetzt, um wasserempfindliche Tinten oder Farben temporär wasserunempfindlich zu machen. Cyclododekan wird dabei auf dünnen Linien (wie etwa Zeichnungen oder Signaturen) oft mit Hilfe sogenannter Kistkas aufgetragen. Kistkas, die in Osteuropa zum Verzieren von Ostereiern mit Wachs verwendet werden, sind ein hilfreiches und praktisches Werkzeug, gewährleisten aber nicht immer eine präzise Applikation von Cyclododekan. In dieser Studie wurde getestet, wie die Temperatur das Eindringverhalten von Cyclododekan in das Papiervlies und seine schützende Wirkung auf wasserempfindliche Medien beeinflusst.

Cyclododekan wurde auf vier verschiedene, repräsentative Papiere aufgetragen. Die Temperatur einer gewöhnlichen Kistka wurde durch einen offenen, phasengesteuerten Wechselspannungsregler kontrolliert. Dabei konnte festgestellt werden, dass Cyclododekan bei einer Temperatur von ca. 70 °C zwar sehr präzise aufgetragen werden kann, allerdings dringt es nicht ausreichend in das Papiervlies ein, um wasserempfindlichen Medien ausreichend zu schützen. Bei einer Temperatur von ca. 90 °C können zwar die Medien ausreichend wasserunempfindlich gemacht werden, aber das Cyclodekan kann nicht präzise aufgetragen werden. Während also die ideale Temperatur beim Auftrag von Cyclododekan je nach den Gegebenheiten des Objekts variieren kann, ist es wichtig zu wissen, dass Unterschiede von nur 5 °C einen maßgeblichen Einfluss auf das Eindringvermögen und damit die Schutzwirkung von geschmolzenem Cyclododekan haben können.

Résumé

Influence de la température d’application du cyclododécane dans la conservation du papier

Le cyclododécane (CDD) a prouvé son utilité dans de nombreux scénarios de conservation-restauration: il s’agit d’un alcane qui ressemble à la paraffine et se comporte de la même façon à l’exception du fait qu’il se sublime à température ambiante. Dans la restauration du papier, le CDD est couramment utilisé pour rendre étanche des matériaux sensibles à l’eau, rendant ainsi certains traitements possibles. Afin d’appliquer le CDD sur des lignes fines (comme celles de dessins ou de signatures), les restaurateurs utilisent souvent un kistka, outil traditionnel ukrainien utilisé pour dessiner de fines lignes de cire fondue. Bien qu’étant un outil pratique et utile, le kistka ne permet pas toujours une application précise de CDD. Lors de l’application de CDD sur un matériau sensible à l’eau sur un objet papier, le restaurateur peut contrôler certains facteurs comme la vitesse à laquelle le CDD est déposé sur le papier et la taille

du petit trou en entonnoir du kistka. Cependant d'autres facteurs tels que les caractéristiques de l'objet papier lui-même et la température de travail prédéterminée du kistka sont pris tels quels. Dans cette étude, l'influence de la température à laquelle le CDD est chauffé, sa tendance à se propager à travers le réseau de fibres de papier ainsi que sa capacité à rendre efficacement étanche les matériaux graphiques sensibles à l'eau ont été évalués. Comme les expériences le prouvent, le CDD est très facile à appliquer de façon précise à une température d'environ 70 °C, mais ses effets d'étanchéité ne sont alors pas très bons; à environ 90 °C, le CDD provoque une excellente étanchéité mais est très difficile à appliquer de façon précise. Alors que la température idéale peut varier selon les conditions techniques de l'artefact, il est important de souligner qu'une variation de seulement 5 °C a une influence significative sur les modalités d'application et sur l'efficacité d'imperméabilisation du CDD fondu.

Authors

Dr. Salvador Muñoz Viñas is a paper conservation Professor at the Universitat Politècnica de València, Spain. Over the course of his career, he has worked as a conservator at the Historical Library of the Universitat de València, as a Visiting Scholar at Harvard University and as a Distinguished Visiting Professor at New York University. He is the author of several books and articles on technical aspects of paper conservation and on the theoretical tenets of heritage conservation.

Dr. Victoria Vivancos-Ramón is a paintings conservation Professor at the Universitat Politècnica de València, Spain. Currently, she is in charge of the Art Collections of the Universitat Politècnica de València. Dr. Vivancos-Ramón is an expert in panel painting conservation, and has carried out research on new conservation techniques and materials. She is the author of a number of papers and books on paintings conservation, including *La conservación y restauración de Pintura de caballete* (Madrid: Tecnos, 2007).

Pascual Ruiz-Segura is a paper conservator at the Art Museum of Estonia. He holds a Master's Degree in Heritage Conservation from the Universitat Politècnica de València. Over the course of his career, he has worked at the Instituto Valenciano de Conservación y Restauración, at the National Library of Ireland, at the Instituto Universitario de Restauración del Patrimonio of the Universitat Politècnica de València, and at the National Archives of Estonia.