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Evaluation of Emissions from Simulated Commercial Meat Wrapping Operations Using PVC Wrap

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Meatwrapper's asthma is an elusive health problem with a suspected relationship to exposure to emissions from polyvinyl chloride (PVC) film cut with a hot wire. A study was conducted to determine how the type of wrap cutter (wire or rod) and its temperature affected the emissions from a simulated occupational wrapping process. The cutting temperatures covered the same range as was measured in Boston retail food stores. A commercial wrapping machine and samples of commercial PVC meat and produce wraps were used. Seventy five percent of the particulate from the hot wire was respirable, and the quantity of emissions was a strong function of the film tension and cutting technique. Particulate emissions did not increase steadily with increasing wire temperature, but plateaued or declined at high temperatures. Particulate emissions from the rod cutter were very low at low temperatures, but exceeded those of the wire at temperatures above 200 °C. The particulate was 100% dioctyl adipate (DOA, the plasticizer in the wrap) with wire temperatures below 200 °C, and was approximately 80% DOA for temperatures above this. Gaseous HCl was not detected in emissions from a hot wire operated below 150 °C, but HCl emissions increased rapidly to a plateau for temperatures above 200 °C. Approximately 20% of the HCl produced at temperatures above 200 °C was associated with the particulate, which appeared to act as a carrier and transport the HCl through water filled impingers. Field tests are needed to determine if particulate produced in the workplace may also behave as a carrier for HCl.

Introduction

Polyvinyl chloride (PVC) film is widely used to wrap commercial products for retail sales, such as meat and produce. The wrap protects the product while allowing customers to inspect its qualities. The simplest and easiest way to cut the film is to draw it across a hot wire, which melts the film so it can be pulled apart. This process produces emissions when small amounts of PVC stick to the wire and are pyrolyzed. Laboratory and field studies have shown that thermal decomposition of PVC film produces particulate from the film's plasticizer (dioctyl adipate, DOA, or dioctyl phthalate, DOP), and gaseous emissions containing principally hydrogen chloride (HCl).[1,2]

Beginning in the early 1970s, there were a number of case reports claiming occupational respiratory disease associated with emissions from wrap cutting.[3,5] Most reported an asthma-like syndrome which has been named "meat-wrappers' asthma". However, the precise nature of this disease has remained elusive, and some investigators have concluded that it may not be a single entity.[4,5]

As a result of the concern about emissions from the hot wire cutter, the industry developed a new type of cutter, the "cool rod", which had a larger thermal mass than the wire so it could effectively cut the wrap at lower temperatures.[6] A thermostat was added to control the temperature and keep it low. Preliminary field surveys by the Harvard School of Public Health (HSPH) showed that both types of cutters were widely used in meat and produce departments, and that both had a broad range of operating temperatures.

Because of the uncertain nature of the health problem, a five year prospective epidemiological study of retail food workers has been undertaken by HSPH to try to determine if there is a relationship between respiratory effects and the exposures of retail food workers.

The objectives of the HSPH environmental evaluations were to characterize the nature of the retail food worker exposures to air contaminants, and to identify groups of workers with qualitatively and quantitatively different exposures so that the epidemiological evaluations could be performed to determine if the exposure groups had significantly different risks of respiratory effects.

Previous studies have shown that the amount of particulate and HCl emissions appeared to be related to cutter temperatures, and that the rod cutter has much lower levels of emissions than the wire.[2,6] However, these studies did not relate the amount and composition of emissions to the cutter temperature in sufficient detail to be able to predict exposures from the operating temperature. They also did not evaluate the effect of work practices on the amount of emissions.

Although our main interest was the workroom exposures of retail food workers, we studied the emissions from the wrap cutting process in the laboratory for several reasons. First, a large number of experiments could be performed under carefully controlled conditions. Second, the emissions could be collected from the source without concern about the disruption that might be caused to work activities in a retail store. Finally, work activities and localized air movement vary considerably from day to day in retail stores which would add large variability to the observations and substantially increase the numbers of samples that must be

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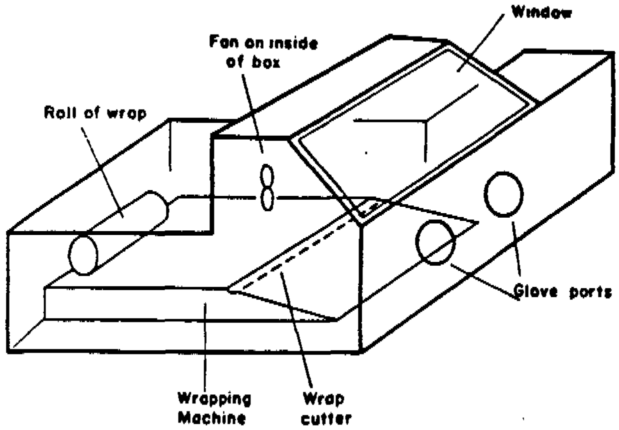

Figure 1 — Diagram of glove box with wrapping machine and sampling apparatus.

collected to characterize a given relationship between emissions and cutting conditions. Therefore, particulate emissions from the hot cutter were collected and concentrated within a glovebox, and the HCl emissions were collected with a glass hood. These procedures may cause artifacts because the emissions stay concentrated for a longer time than they would in a work environment. These possibilities will be discussed in the interpretation of the results.

Our results confirmed earlier findings by some investigators. and contradicted others. There were four important new findings: (1) particulate emissions are not linearly related to wire or rod temperature, but plateau or fall off above critical cutter temperatures; (2) the rod cutter can be a major source of emissions when operated at temperatures above 165 °C (330 °F); (3) cutting technique and film tension are important. and poor technique can produce substantially higher emissions than good technique; and (4) the HCl emissions followed the particulate levels, except there were no detectable HCl emissions below a wire temperature of 150 °C.

Methods

A standard meat wrapping machine (Heat Sealing Equipment Mfg. Co., Model 624, Cleveland, OH), with the sealing pad disconnected, was installed in a specially constructed glovebox (see Figure 1). The machine was placed with the cutter at the front of the box so that the operator could simulate normal cutting operations while the box was sealed and all emissions were collected within the box. The cutting machine had interchangeable hot wire or "cool" rod cutters. The temperature of the wire cutter was adjustable by varying the voltage across the wire. Because of the low mass of the hot wire it is likely that the wire temperatures were somewhat underestimated. The cool rod was a Film Cutter Model AT 1000 (Borden Co., North Andover, MA) the temperature of which could be adjusted by an internal potentiometer or an external voltage controller (for low temperatures). Temperatures were measured with an Omegatemp low mass, electronic thermometer (Omega Engineering Inc., Stamford, CT). The relative humidity inside the box was measured with a psychrometer (Psychron Model 566, Bendix Corp., Environmental Science Division, Baltimore, MD).

Several types of measurements were made of airborne particulate. Total particulate mass was collected on a 1.0 μm pore size, 37 mm. Teflon membrane filter in closed face cassettes operated at 1.7 Lpm. Respirable particulate was collected with a 1.0 μm pore size Teflon filter preceded by a 10 mm. nylon cyclone operated at 1.7 Lpm. Particulate number-size distributions were measured with a Laser Optical Particle Spectrometer, Model CSASP-100 (Particle Measurement Systems, Boulder, CO).

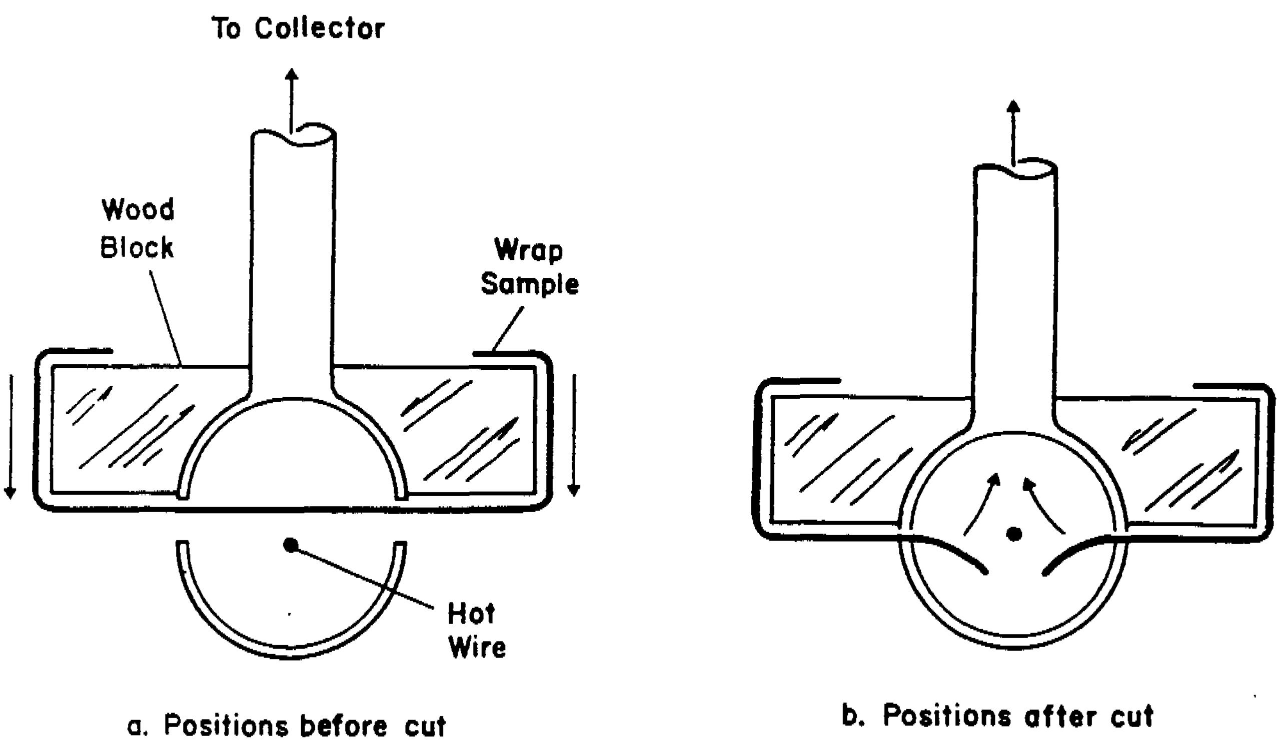

Figure 2 — Diagram of the glass hood for collecting the emissions from wire cutting.

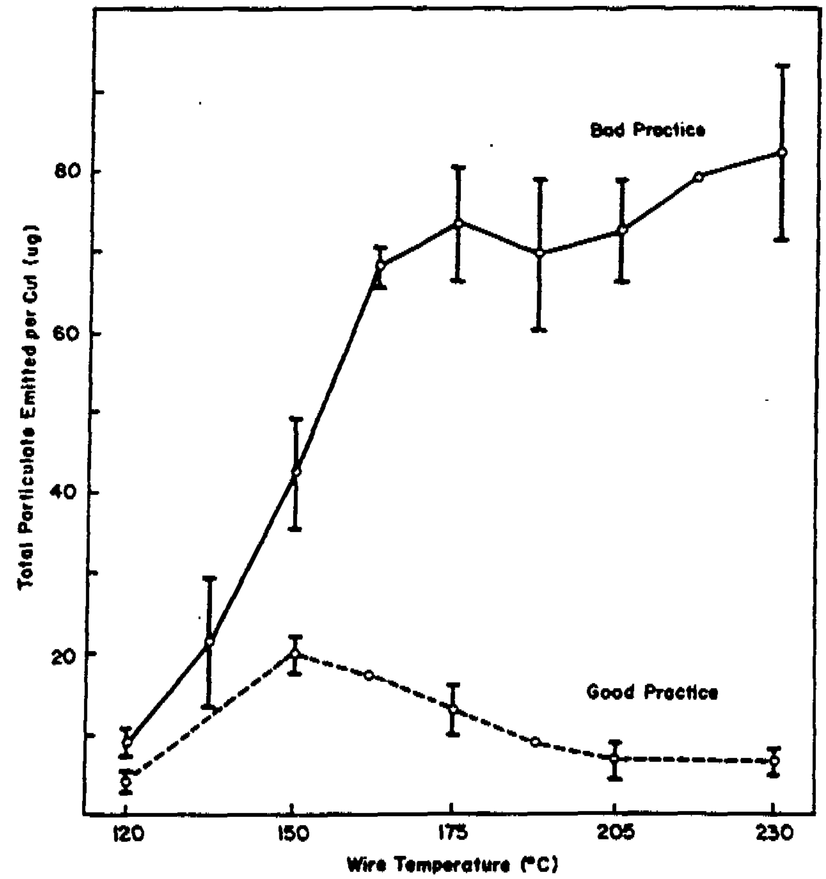

Figure 3 — Total particulate emissions as a function of wire temperature and cutting technique.

The following experimental procedure was followed:

1. the interior of the glove box was flushed with a large flow rate of filtered air for ten minutes;
2. the wire or rod cutter was set to the desired temperature,
3. the box was sealed and 30-180 cuts were made with the cutting technique selected;
4. the sampling devices were run for 20 minutes; and
5. the relative humidity was measured inside the box.

Two types of cutting techniques were used: "good practice", quick movement across the cutter while maintaining a high tension on the film; and "poor practice", laying the film on the cutter with little or no tension on the film so the cut is slow and the separation is caused by the weight of the film pulling away from the cutter. If relative humidities higher then ambient were to be studied, then a pan filled with distilled water was heated and/or boiled inside the box to saturate the air, then the pan was taken out and equilibrium established. The wire or rod was cleaned of carbonized deposits with steel wool before each experiment, and as soon as cutting was completed.

Triplicate samples of the aerosol produced at 150, 177, 204 and 232 °C by "bad practice" hot wire cutting were analyzed for di(2-ethylhexyl) adipate (DOA). DOA was extracted from the samples with methanol and the extract was analyzed by gas chromatography using a 3 mm. I.D., 1.6 m., 3% SE-30 column and a flame ionization detector. Separate studies demonstrated 100 percent recovery of DOA from spiked Teflon filters.

Air concentrations of HCl were measured by sampling in 10 mL of water in a midget impinger and analyzing the resultant solution colorimetrically by the mercuric thiocyanate method.[7] Initially, measurements were made on air samples collected in the glove box studies of aerosol emissions. However, the concentrations were unreasonably low, so the experiments were repeated using a glass hood that could directly collect emissions from the hot wire (see Figure 2). A sample of the meat wrap was wound around the wooden block holding the top half of the hood and then pressed down on the hot wire and the bottom half of the hood. Air was drawn in the open ends of the hood, sweeping the emissions into the sampling train. Three impingers, each containing 10 mL of water, were connected in series to the glass hood and operated at 2.0 Lpm. An in-line filter (47 mm glass fiber) was used to remove aerosol emissions before the gases entered the pump. In one set of experiments the filter was placed ahead of the impingers to remove the aerosol before the gases passed through the impingers. Between tests the apparatus was disassembled and cleaned with methanol and distilled water and air dried. Air sample blanks were collected without cutting to verify that the apparatus was clean. The cutting technique in the glass hood experiments was a "poor practice" type because the film only had enough tension to pull the cut ends apart from the wire a few millimeters.

Results

Hot wire and rod cutters produced particulate emissions during cutting of PVC wrap at all operating temperatures, 135-220 °C. The particle number-size distribution measured with the Laser Particle Spectrometer was independent of cutting temperature and had a logarithmic-normal distribution with geometric mean of 2.1 to 2.3 μm, and a geometric standard deviation of 3.8. Based on this size distribution, 75 percent of the particulate mass should be in particles less than 5 μm in diameter. This estimate was consistent with the measured fraction of respirable particulate mass (the ratio between respirable mass sample and total mass sample), an average of 86 percent, although the respirable mass was usually a larger fraction of the total than estimated from the number-size distribution.

Relative humidity did not affect the particle concentration from the hot wire or its size distribution over the range of temperatures.

Particulate emissions from the hot wire were strongly related to cutting technique and wire temperature. Figure 3 compares emissions resulting from "good" and "poor" practice as a function of wire temperature. Neither technique showed a uniform tendency for emissions to increase with wire temperature: good practice emissions declined above a wire temperature of 150 °C, and bad practice emissions plateaued above 170 °C.

Good practice cutting technique required: 1) quick downward contact with the hot wire, drawing the film down to form at least a 30° angle with the plane of the film from the roll; and 2) strong film tension to quickly pull the cut ends of the film away from the wire when it softened from the heat. Under these conditions, the film cut more quickly as the temperature of the wire increased. At temperatures under 150 °C, a small amount of clear deposit remained on the wire after 60 or more cuts. At temperatures above 170 °C, fine strands of char accumulated on the wire after about 60 cuts and in some cases reduced the cutting efficiency of the wire by insulating the film from the wire's heat.

Cutting with "poor" practice occurs if the film separates because of its own weight and loss of mechanical strength from the heat. At temperatures above 150 °C, substantial visible emissions were apparent with each cut, which,

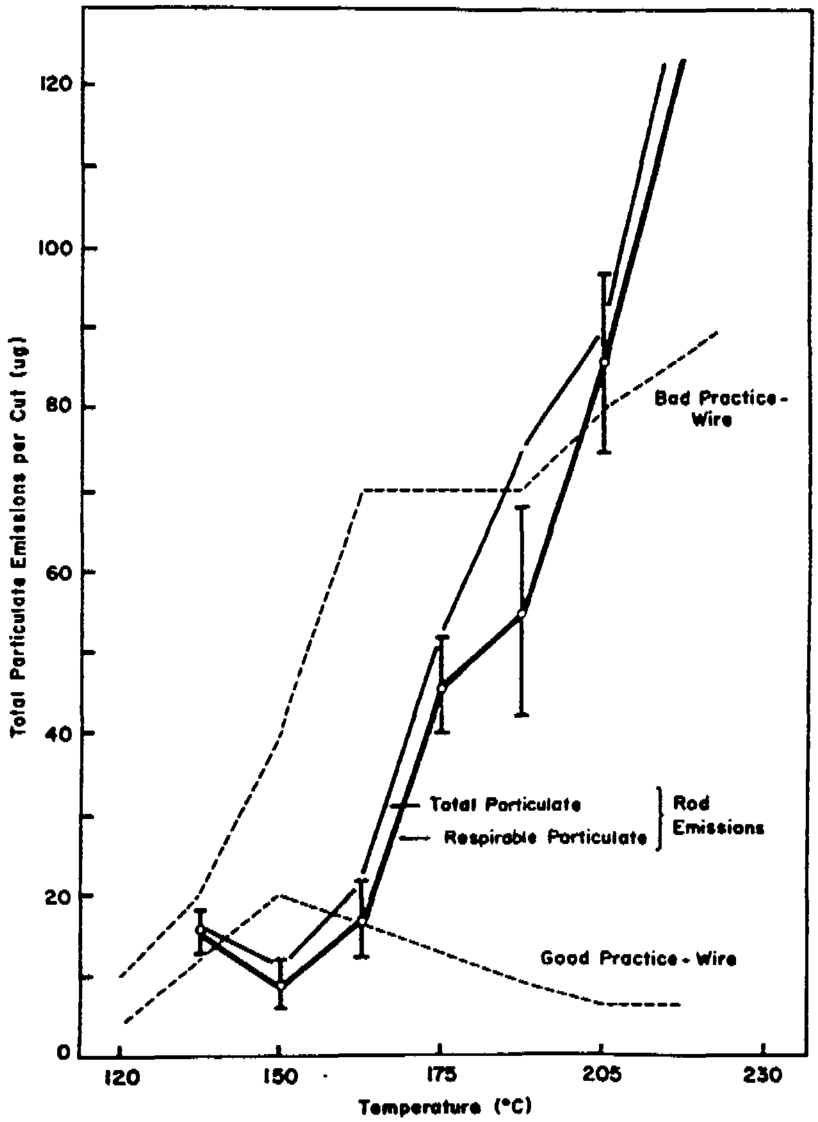

Figure 4 — Total and respirable particulate emissions as a function of temperature.

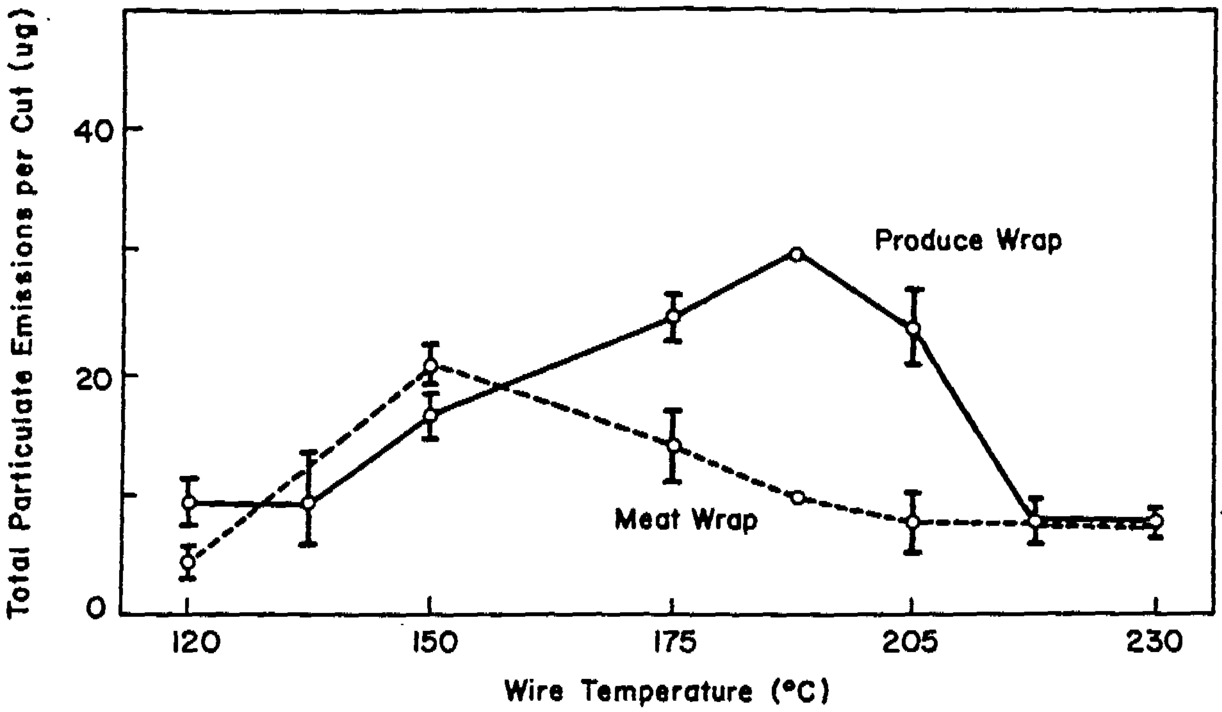

Figure 5 — Total particulate emissions as a function of temperature and type of wrap film.

because of accumulated deposits of film on the wire, become a continuous emission after several cuts. Substantial deposits of char accumulated at temperatures above 170 °C. At higher temperatures, the poor practice technique produced s[illegible] to ten times as much particulate as the good practice technique.

Emissions from the rod cutter were not sensitive to operator technique and had the relationship with temperature shown in Figure 4. For rod temperatures 135-165 °C, the rod emitted particulate at a rate less than or equal to that of good practice wire cutting. At temperatures above 165 °C, emissions of particulate increased sharply until at 210 °C they exceeded those of the "poor" practice hot wire technique. At high temperatures — above 165 °C — the film parted on edges of the strip in contact with the rod leaving a 2-4 mm wide deposit along the length of the rod. Successive cuts added to the deposit, which became a continuous source of emissions. When the temperature of the rod was increased above 165 °C, the amount of non-respirable particulate (>5 μm in diameter) stayed approximately constant at 0.01 mg/cut, even though the respirable fraction increased by seven fold. Rod temperatures as high as 195 °C have been observed in the stores.

The relationship between particulate emissions and temperature for hot wire cutting with the good practice technique was affected by the composition of the film. Figure 5 shows a comparison of particulate emissions from the meat wrap and produce wrap. These films differ in their composition primarily their type of plasticizer: DOA in the meat wrap and dioctyl phthalate (DOP) in the produce wrap. The peak of particulate emissions occurred at a much higher temperature for the produce wrap (190 °C) than the meat wrap (150 °C). These temperatures do not correspond to any known physical property of the wrap films, such as softening temperature.

Analyses of the aerosol from the hot wire cutting showed that the aerosol was 100% DOA (107.6% average with a standard deviation of 10.8) at cutting temperatures below 232 °C. At 232 °C, the DOA accounted for 79.2% with a standard deviation of 8.6, which was significantly less than 100% ($p > 0.05$).

The relationship between the HCl emissions and wire temperature is shown in Fiure 6. The total HCl emissions per film cut were very small at 150 °C but increased rapidly up to 204 °C and then apparently plateaued at approximately 45 μg/cut, similar to the particulate emissions.

The relative quantities of HCl collected among the three impingers showed that an interaction took place between the HCl and the aerosol. Experiments showed that a single impinger would collect 99% or more of gas phase HCl if the aerosol were removed with a filter. When the aerosol was present, 4 to 13% of the HCl penetrated into the second impinger as shown in Figure 6. The amount collected by the second impinger increased with the wire temperature. Thus, there appeared to be an interaction between the HCl and the aerosol that carried HCl through the first impinger. Analyses of the aerosol produced at 202 °C and 232 °C suggested that there may also have been some adsorption on the aerosol because a significant amount of chloride (15% of the total emitted) was extractable from the particulate (see Figure 6). This change in particulate composition was also apparent in the DOA analyses, which showed that the particulate formed at 232 °C was only 79% DOA whereas at lower temperatures it was 100% DOA.

Discussion

These studies clearly show that cutter type and operating temperature are critical determinants of the quantity and composition of emissions from wrap cutting. They also show that the operator's technique on the hot wire cutters is very important in determining exposure. An unanticipated result was the finding that the rod emissions could exceed those of the wire at the high temperatures that have been observed in the stores.

The tension on the film from the wrapping machine was also important for obtaining good practice results. If it was insufficient, the film would not retract from the wire and "poor" practice cuts would result in spite of the operator's attempts to do otherwise. In practice, it was difficult to make a large number of cuts with good technique; approximately one in ten cuts was not sharp and would leave a deposit, unless the operator was very careful. The technician was able to achieve large numbers of good technique cuts by much practice and careful attention during the procedure.

Particulate emissions increased with temperature for both the wire and rod cutters as a result of pyrolysis of bits of the film deposited on the cutter. The emissions from the hot wire plateaued at temperatures above 150 °C, probably because of the limited capacity of the wire to hold molten PVC. The rod had a larger surface area and could hold larger deposits. At temperatures above 165 °C, deposits collected on the rod after several cuts formed a source of continual emissions which was observed to smoke for some time after the cutting had stopped. The data presented in the "Results" section do not include this extended emission because the rod was wiped clean once the desired number of cuts had been completed, so the emissions measured represent a lower boundary of the levels that might be seen in the meat wrapping environment.

The glass hood experiments demonstrated that hot wire cutting of wrap did not generate significant levels of HCl until the wire temperature exceeded 160 °C. The experiments also showed that the aerosol formed at hgher temperatures may act as a carrier of HCl enabling it to pass through impingers that would collect 99% if it were present as a gas only. Passage through the first impinger apparently released some loosely held HCl because the relative fraction of HCl collected by the second impinger was substantially higher than the first impinger. Ten to fifteen percent of HCl was apparently bound to the aerosol because it was carried through three impingers and collected on the glass fiber filter at the end of the sampling train, even though the third impinger showed little or no HCl.

The DOA analyses of the aerosol also showed that the composition of the aerosol changed with increasing temperature. Above 200 °C approximately 20% of the aerosol was something other than DOA. This was consistent with the HCl experiments which showed that above 200 °C, 5 to 7 μg/cut of particulate chloride were present but this does not account for all of the non-DOA aerosol. It is likely that the remainder of the aerosol was carbonized PVC fragments, because significant amounts of char were formed on the wire at these temperatures, but not at lower temperatures. This carbonized material would also be a reasonable carrier for HCl.

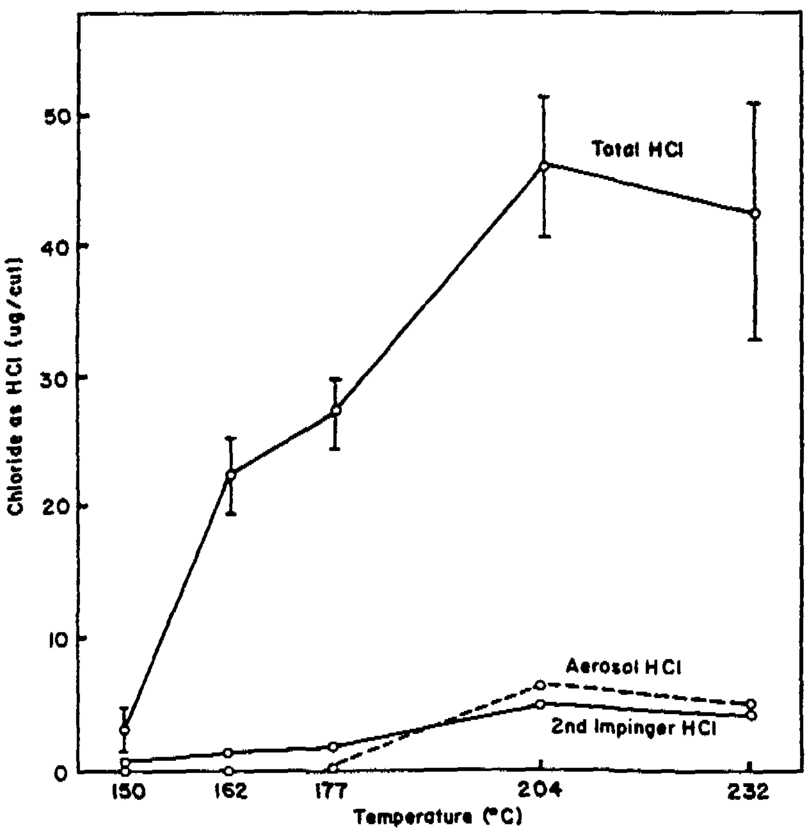

Figure 6 — Emissions of total chloride (as HCl), aerosol chloride and chloride collected in the second impinger as a function of temperature.

Stone and co-workers observed that the carbonaceous soot from burning torches of mixed PVC and polyethylene plastics had both loosely and tightly bound forms of HCl.[8] They found 19 mg/g of HCl that could be easily stripped from the aerosol with a nitrogen purge, and 27 mg/g of HCl was tightly bound to the aerosol. It was not reported if any of the tightly bound HCl could be removed from the soot by water extraction. Their findings were reasonably consistent with our observation that part of the HCl was carried into the second impinger by the aerosol, while another part was extractable from the aerosol that passes through all the impingers.

These findings are potentially very important because they imply that the aerosol may act as a carrier for the HCl to transport it deep into the lungs of the exposed workers, whereas if the same exposure were all gas phase HCl it would be removed by moist upper airways. However, the conditions of the laboratory experiment do not duplicate the exposures received by workers, because the concentrated emissions from the hot wire were immediately captured by the hood and passed through the collection system. This may have produced an artificial situation that is not present in the work environment because normally the emissions are diluted by mixing with room air as soon as they leave the wire. The increased contact time and high concentration conditions in the laboratory may have enhanced the interaction between the HCl and the aerosol. Field experiments are planned to determine if aerosol produced under high temperature cutting has a significant HCl content when it reaches the worker's breathing zone.

Our findings compared quite well with those of Boettner and Ball, if we presume that their smoky and clean cuts were equivalent to our bad and good practice cutting techniques.[9] Their HCl and DOA values were both significantly higher than ours: HCl was 50% higher, and DOA was 100% higher. This was probably the result of better recovery of emissions in their experiments, and wall losses in our experiments. We both observed that approximately seven times more DOA was emitted by smoky cuts than clean cuts. Our observations that HCl was negligible at 150 °C confirms Boettner and Ball's determination that no HCl was produced at 135 °C. They did not measure the composition of the aerosol so no comparison was permitted with our observation of absorbed HCl on the aerosol. Our emission concentrations were more reproducible than theirs, *i.e.*, had smaller ranges under a given set of conditions. This may have been a result of our closer control of cutter temperature and film tension during cutting, although there was no direct evidence to support this.

Another relevant study was performed by Van Houten and coworkers, who looked at "worse case" emissions from a wire cutter under a variety of temperatures.[2] The wire temperature was measured with a thermistor, which we have found may substantially underestimate the temperature if the sensor is too large relative to the wire (they did not report the size of the sensor). They found that total particulate emissions increased with temperature, but they did not observe any tendency for the amounts of emissions to plateau at higher temperatures. However, they did observe the HCl concentrations plateaued at 171 to 182 °C, and were very slight at 132 °C and below. This general behavior of both HCl and, to some extent, total particulate emissions, was consistent with our findings, although the temperatures at which they occurred for Van Houten *et al.*, were 20 °C lower than ours. They also found that the particulate was 100 percent DOA; it ranged from 50 percent at 82 °C up to 92 percent at 132 °C, but there was no clear trend and no standard deviations were present to show the precision of the measurement.

The wrap film appears to decompose at lower temperatures on the hot wire and rod than expected from bulk PVC studies. Boettner and co-workers presented data on powder samples of PVC polymers and showed that dehydrochlorination does not begin to appear on differential thermal analyses until 240 °C.[10] Apparently, thin deposits of PVC on a wire or rod behave differently than small samples of powder. We observed the formation of char at temperatures above 170 °C for both rod and wire cutters, which suggest pyrolysis of the film. The HCl measurements suggest that significant dehydrochlorination of the film deposited on the wire or rod begins at 160 °C. However, the PVC does not appear to have been completely decomposed at temperatures within the normal range of the cutters. If the dehydrochlorination were complete, then the ratio of HCl to DOA in the emissions would be approximately 1:1 because the film contains approximately 30 percent DOA and 30 percent chlorine by weight. Based on our data at 205 °C and 230 °C, it appears that approximately 50 percent of the potential HCl yield was released. The data from Boettner and Ball suggest only 10 to 15 percent of the HCl was released at approximately 215 °C, but this is not certain because they did not present paired HCl and DOA data from analyses of emissions and their wire temperatures apparently were not as closely controlled as ours.[9]

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