

DRYWALL STAINING

FINAL REPORT

NOTE: DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE:

DÉCOLORATION DES PLAQUES DE PLÂTRE: RAPPORT FINAL

DRYWALL STAINING

**PREPARED BY: INSTITUTE FOR RESEARCH AND CONSTRUCTION
NATIONAL RESEARCH COUNCIL**

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DISCLAIMER

This study was conducted for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretations and recommendations are those of the consultant and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

TABLE OF CONTENTS

List of Tables	iii
List of Figures	iv
Executive Summary	v
Glossary of Selected Terms	vi
I. INTRODUCTION	1
II. CONDITION SURVEY OF AFFECTED HOUSES	3
III. ON SITE SAMPLING	3
IV. EXPERIMENTAL	4
IV.1 Physical Analysis	4
IV.2 Biological Analysis	4
IV.3 Chemical Analysis	4
IV.4 Investigation of the Staining Reaction	9
IV.5 Simulation of the Staining	10
IV.6 Methods of Stain Removal and Prevention of Restaining	13
V. RESULTS AND DISCUSSION	15
VI. CONCLUSIONS	35
VII. RECOMMENDATIONS	37
VIII. REFERENCES	38

List of Tables

Table 1	Occurrence of mildew on paint chips tested.
Table 2	ICP scan of the paint scraping for the presence of metal ions.
Table 3	Highest concentration metal ions and their sulfide salt colour.
Table 4	Levels of mercury detected in the various components of the drywall using AA.

List of Figures

- Figure 1** Stained drywall specimen collected from Calgary home used for chemical analysis.
- Figure 2** Stained drywall specimen showing the various layers of the drywall system.
- Figure 3** Spot test specimen showing lack of solubility of the stain to organic solvents.
- Figure 4** A drywall specimen showing the different jointing compounds used in the lab simulation.
- Figure 5** Diagram illustrating the various application and component combinations in the lab simulation.
- Figure 6** Accelerated stain generation specimen board showing PMA loaded jointing compound plugs after staining has occurred.
- Figure 7** Difference in absorption spectra between the methylene chloride extracts of paint chip from house affected with stain and unused flat latex paint.
- Figure 8** Difference in absorption spectra between the methylene chloride extracts of jointing compound from stain affected house, old (1988) and new (1990) material.
- Figure 9** Absorption spectra of methylene chloride extracts of two organic additives, phenyl mercury acetate and benzyl butyl phthalate, commonly used in jointing compounds.
- Figure 10** Cross section of drywall system showing concentrations of elemental mercury present (*ppm*).
- Figure 11** Dithizone complex TLC Plate showing the presence of PMA in the old (1988) and absent in the new (1990) jointing compounds.
- Figure 12** Dithizone complex TLC results from various stained and reference extracts.
- Figure 13** Schematic representation of the dithizone complex Thin Layer Chromatography Gel Plate.
- Figure 14** Vials containing mercury sulfide, (left vial) and bleach dissolved mercury sulfide (right vial).
- Figure 15** Extract spot plates II and III prior to exposure.
- Figure 16** Plate I showing the simulation of the stain after exposure.
- Figure 17** Plate II after exposure to UV irradiation only.
- Figure 18** Plate III after exposure to hydrogen sulfide only.
- Figure 19** The effect of light on the reaction of phenyl mercury acetate and sodium sulfide.

EXECUTIVE SUMMARY

A problem of delayed and recurring localized discolouration (staining) of finished drywall surfaces has been investigated. Biological and physicochemical methods used in the investigation, showed that the stain was chemical in nature. Various factors involved in the staining were investigated including: UV radiation (from natural or artificial sources), humidity, temperature, airborne contaminants, life style of the occupants, as well as paint application techniques. Laboratory simulation experiments were carried out to investigate the stain causing mechanism. These experiments, in conjunction with a chemical analysis of the stain, have shown the direct cause of staining to be due to the interaction of labile constituents in the jointing compound with chemical constituents in the air. Specifically, the reaction of mercury, the breakdown product generated from fungicides contained in the jointing compound, with atmospheric hydrogen sulphide (H_2S) to produce a black insoluble salt.

The primary factors contributing to the origin of the stain have been identified as the following:

- i. the presence of the fungicide, phenol mercuric acetate (PMA), in the jointing compound;
- ii. UV radiation in the form of lighting;
- iii. the concentration of H_2S present in the air;
- iv. level of humidity in the house;
- v. permeability of the paint;
- vi. moisture trapped in the wall during painting.

Methods of stain removal and prevention of the recurrence of the stain include bleach washing and re-coating with low permeability paints. An essential aspect in the prevention of staining is the provision of sufficient time for the initial paint coat to dry before applying a final coat.

Glossary of Selected Scientific Terms

aliquot	equal portions of , e.g., an extract
complexed	an intricate combination of various chemical components
elute	to remove an adsorbed material by means of a solvent
labile	unstable; having a tendency toward chemical modification
spotted	to make a spot causing a stain
supernatant	material floating on the surface of, e.g., a solvent

I. INTRODUCTION

A stain is generally described as any discolouration occurring on any exposed surface. It may be caused by a mildew, a textural problem, or due to a chemical residue. Here, it pertains to a discolouration occurring on a painted drywall surface. The problems of staining in paint are well documented [3,7-11,27]. Several workers have identified the following as direct causes for the discolouration:

- i. the reaction of hydrogen sulphide (H_2S) with lead based compounds present in pigments used in the paint [11];
- ii. the growth and proliferation of fungal colonies on the surface of painted wood [27].

The present staining problem applies to painted drywall, particularly those which occur along the joints of the drywall boards. Discolouration usually appears within a few months of occupancy of a new home. Previous work [7,8,11] has shown that stains can develop due to the reaction between heavy metals used in paint products and hydrogen sulphide present in the atmosphere of homes. Furthermore, the rate of discolouration was shown to be dependent on the humidity of the location. It has also been demonstrated that the stain could be removed with a bleach solution but is regenerated on exposure to sulphide solution [12]. In these instances, staining was attributable to a chemical rather than a biological cause.

The most recent occurrence of this phenomena was detected in western Canada [22,24] where there was widespread discolouration on walls of recently constructed homes. The problem was first recorded in 1987 in several houses in Alberta and British Columbia [5] and continued reports of discolouration were noted for the next two years. The problem was investigated by Gray [5] and Shirtcliffe [24] and an evaluation of the possible causes was made. However, the actual cause or nature of the stain was not ascertained.

Pugh [22] correlated the results of this work and summarized the status regarding research into drywall staining. Based on the recommendations offered in Pugh's report, a three part survey was undertaken to address particular issues dealing with the frequency of occurrence of drywall staining in Alberta. The three separate surveys are:

1. General Contractors and Developers Survey.
2. Sub-contractors and Tradesmen Survey.
3. Home Owners or Occupants Survey.

The results of the survey were tabulated and a computer data base was established [28]. Several conclusions were drawn from this survey:

- i. moisture appears to be a carrier or is involved in the reaction;
- ii. areas of high humidity and limited ventilation during construction and occupancy are often affected;
- iii. the inadequate sealing characteristics of the paint may contribute to the problem;
- iv. lightweight muds and latex based paints were predominantly used and may contribute to the problem;
- v. the occurrence of drywall discolouration appears to have decreased over the past six to ten months;
- vi. the major concern of the contractors is the most suitable method of repair.

The present study was commissioned by CHBA in 1990. The objectives of this investigation are given below:

- i. identify the stain causing agent.
- ii. determine the mechanism of staining.
- iii. determine factors which initiate the development of the stain.
- iv. ascertain remedial measures to remove the stain.
- v. determine methods of preventing the development of the stain.

The background for this study was drawn from reports and surveys previously mentioned above. Initial investigation consisted of a site visit and sampling of material from affected houses. Two approaches to the investigation were taken :

- i. biological analysis;
- ii chemical and physical analysis.

A preliminary investigation indicated some contribution by biological factors. However, further work showed that the stain was more chemical or physical in nature. The general approach in identifying the stain causing component was to elute the stain from selected samples and identify the materials in the solvents used in the elution. Subsequently, the stain causing potential of the various chemicals was identified. Laboratory scale simulation was carried out to investigate the stain causing mechanisms and to elucidate the factors affecting its origin and generation. Stain removal and stain prevention methods were also determined.

II. CONDITION SURVEY OF AFFECTED HOUSES

The survey and site visits, including the on site sampling, focused on the areas most affected by the staining: i.e., Calgary and Edmonton.

In Calgary, the stains were predominantly on the walls, although stains on the ceiling were also seen. The stain coincided with the location of the drywall joint and occurred in a two to three inch wide band on either side of a drywall joint. It was most intense in the center of the joint and faded out to a less intense stain at the edge of the band. In this respect, stain intensity appeared to be a function of the jointing compound thickness which thins out from the center of the joint towards the edge. The location of certain nail or screw heads appeared as dark spots where the nail had been covered with jointing compound. Stains were more intense in bathrooms. They were also identified in living rooms, bedrooms and hallways. In all cases, a flat latex paint had been used on the walls and the off-white colour of the paint made the dark coloured stains even more noticeable. Stains were first noticed four to six months after completion of construction and in several cases the application of jointing compound and paint was completed in late fall or early spring.

In Edmonton, stains were mainly identified on the ceiling, and they too coincided with the drywall joints. Both butt and bevel joints were affected. Affected areas included bedrooms as well as the living room. The intensity of the stain was uniform in a four to five inch band running along the joint. Although the staining was more uniform it was less intense than the stains investigated in Calgary. It was noted that no staining occurred in the bathroom of the Edmonton home. This is in contrast with the extent of staining found in bathrooms in Calgary. In the former instance, a semigloss alkyd based paint had been used whereas in the latter case, a latex based paint was used to coat the bathroom walls.

III. ON SITE SAMPLING

Samples of drywall on which stains had occurred as well as control samples were taken from three houses in Calgary and one house in Edmonton. In each of the four houses, two samples were collected: One board which showed the most intense stain and another, which contained no stain, was used as a control. Boards were cut from the wall to produce specimens approximately four feet by two feet, with the joint running through the center of the long direction of the board. Specimens were wrapped in aluminum foil, sealed in a polyethylene bag and placed in an insulated container and shipped to the NRC-IRC laboratories in Ottawa.

IV. EXPERIMENTAL

Biological and physicochemical techniques were used in the assessment and isolation of the possible causes of the stain.

IV.1 Physical Analysis

Optical and electron microscopy techniques were used to study the surfaces of two drywall specimens (one stained, the other free of any visible stain) obtained from boards sampled from homes in Alberta. The specimens were cut across the joint of the drywall board. In addition, paint chips peeled from the surface were also examined.

IV.2 Biological Analysis

Paint chip samples (stained and non-stained) were placed on petri plates containing a nutrient agar and incubated at room temperature for fourteen days. Positive test cultures were inspected using a stereo binocular microscope.

IV.3 Chemical Analysis

IV.3 (a) General Sampling Procedures

Specimens of approximate dimensions 34 cm x 17 cm, obtained from the master bathroom of an affected house, were used for the analysis. On one specimen, half of the joint was more substantially stained than the other. A typical drywall specimen is shown in Figure 1 after samples had been taken. Since the history of each side of this joint would be expected to be similar, the less stained side provided an ideal reference for chemical comparison with the stained side. The drywall specimen, shown in Figure 1, was marked along the seam between the stained area and less stained (reference) area.

Six strips, 2 cm wide, and perpendicular to the seam, were marked with a knife across the width of the sample. Two parallel lines, 5 cm from the seam on each side, were then marked, giving six areas of 10 cm² for the stained area, and six areas of 10 cm² for the reference area. Each of four layers in a given area was sampled, giving a total of 48 samples. The layers from top to bottom consisted of:

- i. paint;
- ii. compound between paint and paper tape;
- iii. paper tape;
- iv. compound between tape and dry wall surface.

The stained drywall was of the water resistant "blue board" variety, characteristically bevelled toward the edge. The edge of the drywall below the reference area was cut (non-factory formed edge) from regular drywall and was therefore not bevelled. The layer of compound below the stained area was thicker due to the bevelled edge. Figure 2 shows the different layers in the joint from which the samples were obtained.

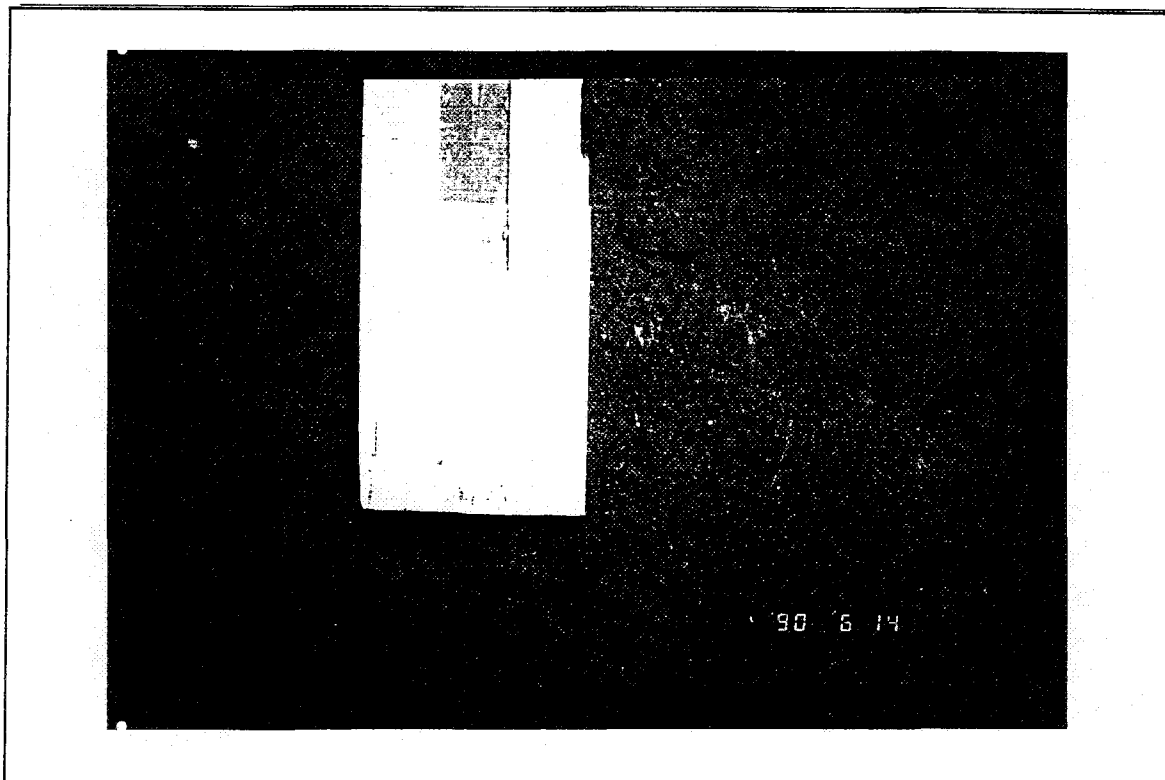


Figure 1. Stained drywall specimen collected from Calgary home used for chemical analysis.

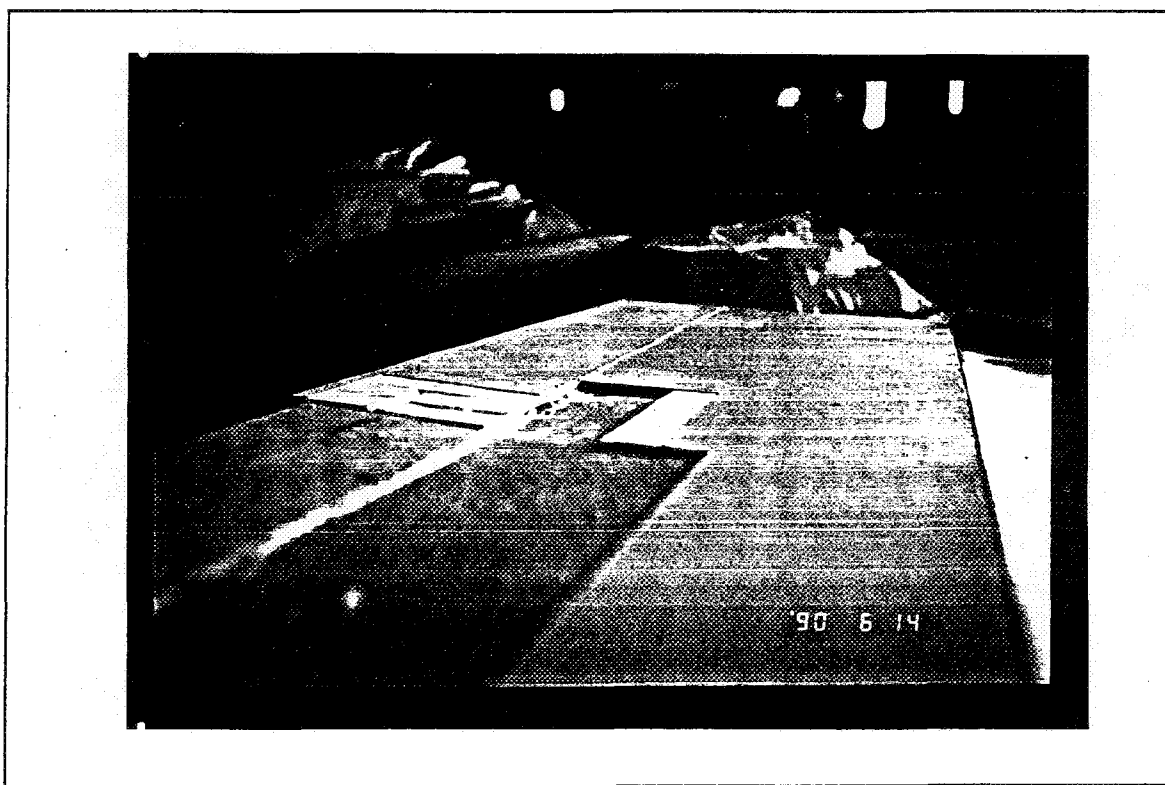


Figure 2. Stained drywall specimen showing the various layers of the drywall system.

Additional larger samples (4 cm x 5 cm) from the stained and reference areas were collected, in the same manner as described above, for subsequent chemical analysis.

Samples of the building products used in drywall installation included:

- i. white latex sealer;
- ii. white flat latex paint;
- iii. lightweight drywall jointing compound;
of two types: "old" compound, produced in 1988 (Sept.), and "new"
compound, produced in 1990 (March).

The paint and primer were applied with a clean brush to a measured area of a clean glass plate, dried, scraped, weighed and retained as original paint specimens. Samples of drywall jointing compound from two different batches were treated similarly following application with a spatula at a thickness comparable to that observed in the drywall seam (1-3 mm) of the field sample.

IV.3 (b) Instrumentation

Instrumentation included: a Hewlett-Packard 8451A Diode Array spectrophotometer with a 9133 data storage unit used for UV/Visible measurements and a 5995 Gas Chromatograph/Mass Spectrometer for trials to quantify the thermally labile organomercuric compound.

Inductively Coupled Plasma Discharge (ICP) apparatus with metal ion analyzer and an Atomic Absorption (AA) Photospectrometer fitted with a mercury analysis bulb, were used to determine the presence of metal atoms and mercury concentrations.

Thin-layer chromatography (TLC) accessories consisting of plates (0.25 mm thick) composed of either silica gel or aluminum oxide on glass, with and without fluorescent indicator in three sizes (2.5 x 7.5 cm, 5 x 20 cm and 20 x 20 cm) were used. Developing chambers, sprayers, recovery tubes and filters with a medium porosity fritted disc, templates and micropipettes were also used for TLC work.

IV.3 (c) Analytical Procedures

1. Solubility Spot Test

The surface of the stained wall was spot tested with organic solvents ranging from non-polar pentane (polarity index 0), through methylene chloride and acetone, to the more polar (6-6.6) acetonitrile and methanol. The section of the surface was also rinsed with distilled water (polarity index 10). Small volumes of the various solvents were applied directly on the stained areas. Visual inspection was used to detect stain solubility (see Figure 3).

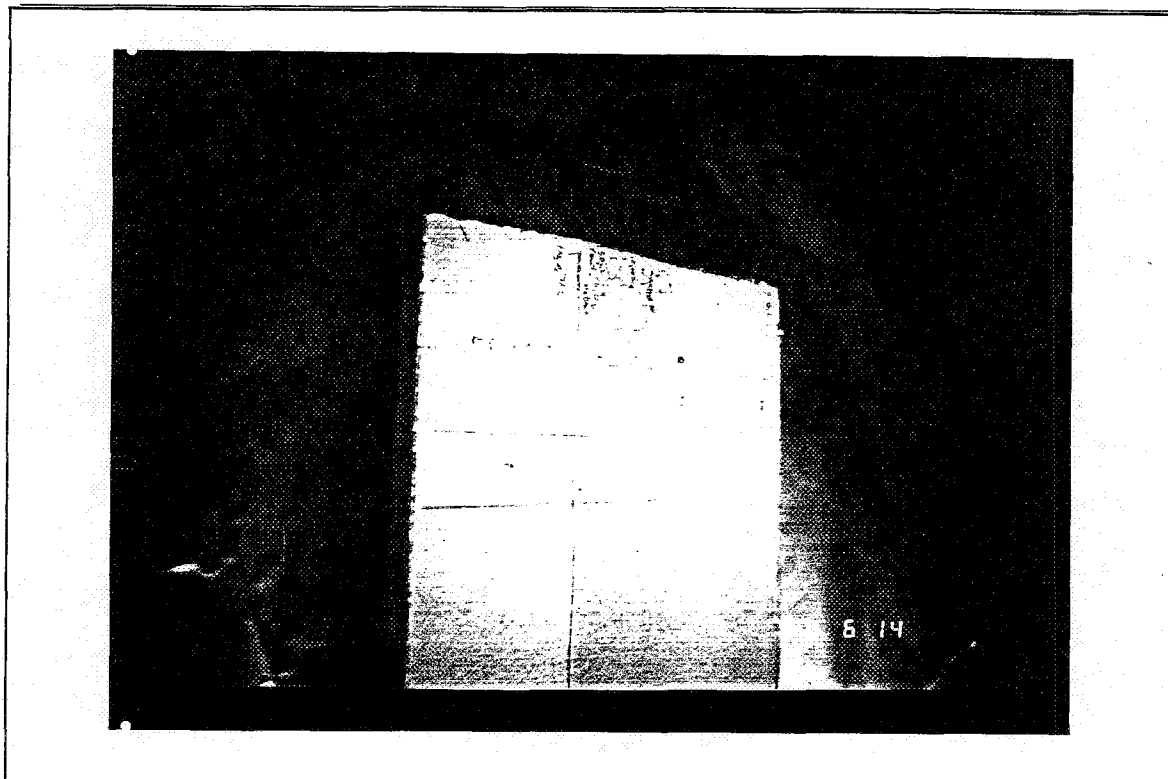


Figure 3. Spot test specimen showing lack of solubility of the stain to organic solvents.

2. Extraction

Special care was used to separate and remove the various layers of the stained drywall samples. The paint skin was cut into pieces and lifted from the underlying joint compound. The compound layer was scraped and pulverized, and the paper tape was removed as a single piece wherever possible.

Each layer removed from the reference and stained areas was weighed and extracted with four 3.5 ml portions of solvent. The insolubles were removed from the extracts by decantation and/or filtration through medium or fine pore glass frit filters. Extracts were pooled and evaporated to dryness at room temperature under a fume hood, reconstituted with 3 ml of the same solvent and stored in glass vials with teflon lined caps.

3. Ultra Violet/Visible Spectra

Extracts and pure reference solvents were pipetted into 1 cm pathlength quartz cuvettes. The range chosen was from 200 to 550 nm or from the UV cut-off of the solvent to 550 nm. Differential spectra of the extracts were generated by subtraction of the pure solvent spectrum from the extract spectrum. Extracts were removed from the cuvettes by rinsing and placed in vials for subsequent analysis.

4. Inductively Coupled Plasma Discharge(ICP) and Atomic Absorption(AA)

Inductively Coupled Plasma Discharge (ICP) and mercury determination by cold vapour Atomic Absorption (AA) were used for determination of the presence of metallic ions. An ICP (17 metal) scan was first performed on the drywall compound scraped from the drywall seam. The various layers from both the stained and reference areas were then analyzed for mercury. Samples of unused paint, primer and the two batches of joint compound were also used for mercury analysis.

5. Gas Chromatograph(GC)/Mass Spectroscopy(MS) Quantifying of PMA

GC/MS methods were attempted to detect and quantify phenyl mercuric acetate (PMA) from the extracts [2,3]. Preliminary attempts failed and even the PMA standards were not detected. A further literature search confirmed that the GC technique is not suitable for PMA analysis due to the thermal instability of organomercury compounds [4].

6. Thin Layer Chromatography(TLC)

Direct Screening

Extracts recovered from UV-Visible absorption measurements were evaporated to dryness and reconstituted with 1 ml of the original solvent. Aliquots (1, 2, 5 μ l or multiples thereof) of the extracts were directly applied to small TLC plates and developed in various solvents together with phthalate and PMA solutions. Methylene chloride was found to separate the components of the extracts satisfactorily. A UV light was used to make the separated organic components visible.

Separation of Organic and Inorganic Mercury

The method given in reference [18] was used to separate organic and inorganic mercury compounds. The extracts and standards were applied on a large (20 x 20 cm) silica-gel nonfluorescent plate and developed with a mixture of methylene chloride, acetone, and nitric acid (5:4:1 by volume). The developed plates were then exposed to either iodine vapour or hydrogen sulphide to make the separated components visible.

Separation of Complexed Metals

Aliquots (100 μ l) of the extracts were added to 100 μ l portions of dithizone reagent (0.1% w/v dithizone in methanol) and immediately spotted on small (20 cm x 20 cm) silica gel plates [15-17]. Several solvents and solvent combinations with variable polarity were used to determine the optimal conditions for the separation of complexed components [19,20,25,30]. A mixture of methylene chloride and hexane (1:1 by volume) was satisfactory. A solution of PMA treated with dithizone was applied to the gel plates

along with the samples and became visible as a reddish spot with an R_f value of 0.16. Other standards used were saturated aqueous solutions of HgSO_4 , HgS_2 , HgCl_2 , HgS and MgCO_3 , as well as solutions of CaCl_2 and SrCl_2 .

The separated complexes obtained from the developed plates were unstable and faded with time. However, spraying the developed plate with a thiourea solution (0.1% w/v in methanol) effectively stabilized the plate and prevented further fading.

7. Formation of Mercuric Sulphide

Dry sodium sulphide was added to a saturated solution of mercuric chloride (HgCl_2) prepared from distilled water. The precipitated mercuric sulphide was filtered and washed with distilled water. A large portion of the precipitate was re-suspended in 2.5 ml of distilled water, and 5 ml of bleach was added to this suspension to investigate the effects of the reaction between bleach and the staining salt.

IV.4 Investigation of the Staining Reaction

Four to five grams of material from the old and new batches of unused drywall compound were applied to a glass plate. Following a period of drying at ambient temperature, both types of drywall compound were scraped from the plates and suspended in 15 ml of methanol. The supernatant extract was separated from the solids by decantation and evaporated to dryness with a gentle stream of ultra high purity argon. The extracts were then reconstituted with enough methanol to bring both extracts to a normalized value of 3.5 g of original dry compound per ml of final solution.

Aliquots of these solutions were applied on a fluorescent silica gel plate in increments from 1 to 50 μl . Corresponding volumes of two PMA solutions (0.1 and 1.0 mg per ml of methanol) were also applied for reference. The plate was irradiated with a UV fluorescent light in a container equipped with a quartz window and filled with hydrogen sulphide over a small quantity of water.

Two more plates were prepared as described above to help differentiate the effect of the two main variables in the staining mechanism: i.e., UV radiation and hydrogen sulphide gas. Hence, one of these plates was exposed to the UV light only, whereas the other was placed in a darkened hood, to eliminate any possible sources of radiation, and immersed in an atmosphere of hydrogen sulphide gas. To further explore the mechanism of the staining reaction, a 33 mg/ml solution of PMA in methanol and a 10% solution of sodium sulphide in water was prepared. Equal volume aliquots of the two solutions were added to each of two pyrex vials. One vial was exposed to direct sunlight and the other was kept in darkness. Aliquots from each vial were applied to neutral filter paper.

IV. 5 Simulation of the Staining-Stain generation in a Simulated Wall System

The laboratory simulation was set up to demonstrate stain generation on a simulated wall system. The intent of this work was to elucidate the manner in which the stain is formed by using compounds known to cause staining in quantities sufficient to generate a stain within a relatively short period of time. It was anticipated that the simulation would show that PMA found in the jointing compound would produce a dark stain if the conditions for stain generation are maintained. Furthermore, it was also hoped that the simulation would show how the PMA in the jointing compound diffuses through paint and reacts to form a stain on the surface of the drywall board specimen.

Two sets of variables were addressed in this study: the effects of application procedures, and the effects of environmental factors on the generation of drywall stain. An investigation of application procedures focused on the manner in which the drying time of various types of coatings, as well as the time between application of a second coat, would affect the rate and intensity of stain formation. A study of environmental factors, such as the presence of water vapour, hydrogen sulphide, and UV radiation, was initiated to determine the relative influence each of these components had on stain formation.

IV. 5 (a) The Effect of Materials and Application Procedure on Stain Generation

The initial part of this experiment investigated the susceptibility of various types of drywall compound to form stains when varying the application procedure or when applying various combinations of primer and finish to the surface of a series of drywall specimens.

Gypsum boards, on which test specimens were prepared, were cut from a sample of drywall. Eighteen 20 mm diameter holes were drilled halfway through the boards of which nine were filled with old jointing compound (produced in 1988) containing PMA and the remaining holes were filled with new jointing compound (produced in 1990) not containing PMA (Figure 4).

Manufacturers generally recommend that a drywall not be sanded for 24-48 hours to allow the jointing compound adequate time to dry and provide an appropriate surface on which a primer can be applied. It is also suggested that the finish coat not be applied until the primer has had time to dry. If a painting contractor were to dispense with paint application techniques suggested by the manufacturer, due either to time or budgetary constraints, then the entire coating operation may take considerably less time and it is supposed that the susceptibility to staining is increased in these instances.

In order to simulate these conditions, and determine their effects on stain generation, two series of boards were prepared: on half the boards, the drywall joint was finished according to the application technique recommended by the manufacturer. This

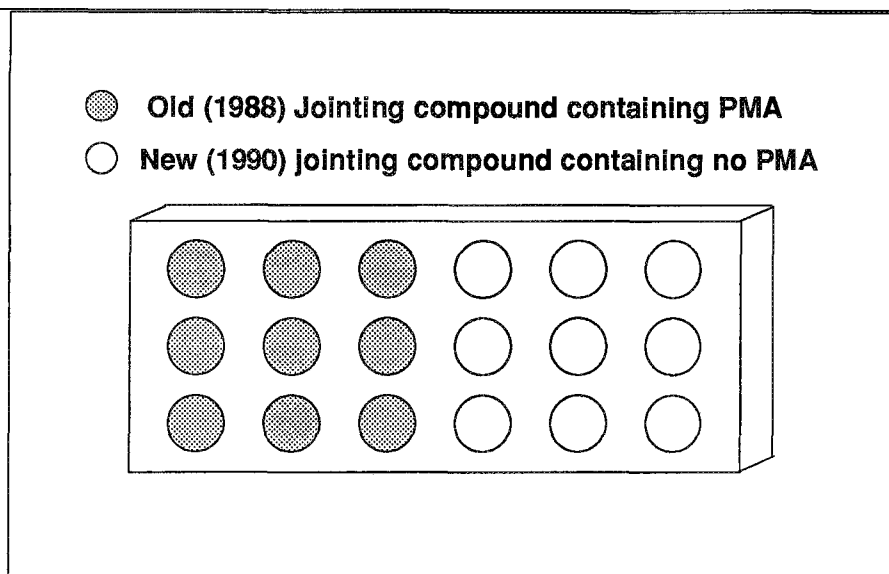


Figure 4. A drywall specimen showing the different jointing compounds used in the lab simulation.

technique, referred to as the conventional application technique, consisted of placing jointing compound in the holes, sanding the compound after it had set (24 hours), then priming the sanded surface and finally, after a 24 hour period to allow the primer to dry, applying a finish coat.

The other half of the boards were prepared according to an accelerated schedule referred to as the rapid set technique. This technique was the same as that described above for the conventional technique with the exception that the jointing compound was sanded when it was surface dry and the entire operation was completed within a four hour period.

Thus, three of the six boards were filled with joint filler, sanded, primed and painted according to that recommended by the manufacturer (XX-C). The remaining three boards were prepared within a four hour period (XX-R).

Susceptibility to stain generation, due to the type of primer or finishing coat used, was also examined. From each of the three boards, prepared according to either manufacturer's instructions or the rapid application technique, one board was primed with a latex sealer and finished with flat alkyd paint (PA-R, PA-C). A second board was primed with latex sealer and finished with flat latex paint (PL-R, PL-C) and the third board was primed and finished with flat latex paint (LL-R, LL-C). All of the test permutations are illustrated in Figure 5.

An environmental chamber was constructed to simulate the environmental conditions necessary to generate the stain, i.e. moisture, UV radiation, and hydrogen sulphide gas. The chamber was cycled between high and low humidity conditions to simulate moisture cycling. A constant flow of hydrogen sulphide was maintained in the

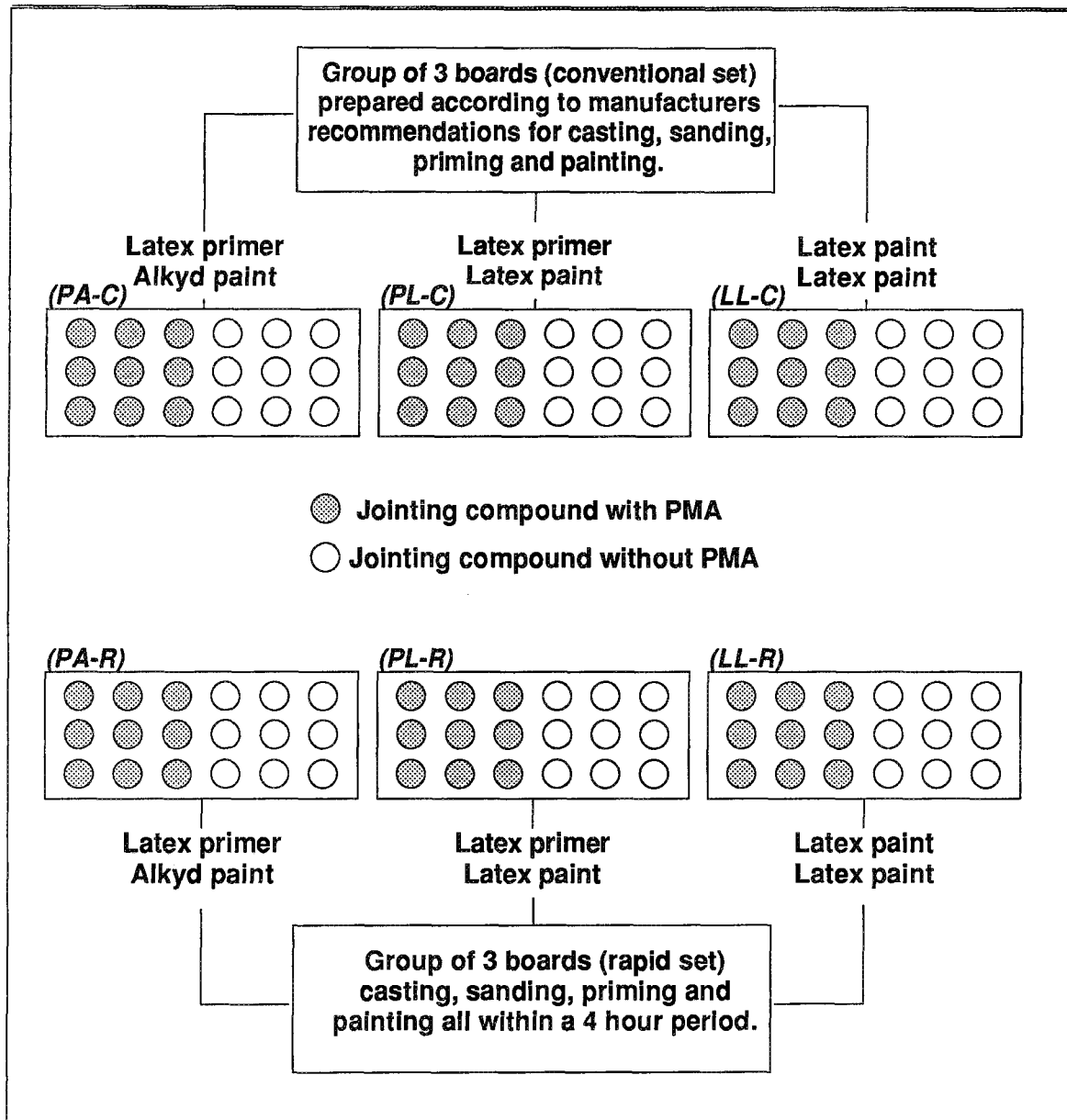


Figure 5. Diagram illustrating the various application and component combinations in the lab simulation.

chamber and the entire system was exposed to UV radiation using a series of UV fluorescent tubes (UV-340A; Q-Panel Co.).

All six boards, including those produced using the rapid application technique, were placed in the environmental chamber for two months, and exposed to the desired conditions. The specimens were monitored on a daily basis until a noticeable stain was produced. This test was repeated on a second set of six boards where the boards were allowed to surface dry 24 hours before they were exposed in the conditioning chamber.

IV.5 (b) The Effect of Environmental Conditions on Stain Generation

The relative importance of environmental factors which were suspected of contributing to the development of stains on drywall joints was investigated in this portion of the study. Two sets of six boards were prepared in which the first set was exposed to UV radiation and an atmosphere saturated with water vapour. The second set was subjected to an atmosphere containing both hydrogen sulphide and water vapour (no UV radiation).

Subsequently, a third set of four boards was prepared to determine the importance of moisture on stain generation. This set of boards was prepared in a similar manner as described below in section IV.6. Two of the four boards were wetted with a fine mist twice a week while the other two boards were left surface dry. All four boards were placed in the environmental chamber after 24 hours of initial drying and conditioned for two months.

IV.6 Methods of Stain Removal and Prevention of Restaining

The lab simulation showed that only faint stains would develop within a two month conditioning period. In order to investigate methods by which stains could be removed or prevented in a timely manner, the process of stain generation was accelerated by artificially loading a jointing compound with PMA. Although this material was not identical to the jointing compound known to produce stains in Alberta, it was surmised that if a treatment to eliminate stains could be found for those stains generated using this method, then a successful treatment for a less intense but naturally occurring stain would also be found. The method of enhanced stain generation, using samples having higher concentrations of PMA, is described below:

Enhanced Stain Generation Technique

One gram of PMA was added to 99 g of jointing compound to make a 1% (1000 ppm) artificially loaded sample of jointing compound. Six 20 mm holes were drilled half way through each of four gypsum boards, and filled with the artificially loaded jointing compound. These joints were then sanded, primed and painted with flat latex paint, in a four hour period. The specimens were still wet when placed into the environmental chamber.

A second set of four boards was produced in like manner, but in this instance, the boards were allowed to dry for 24 hours prior to being placed into the environmental chamber. These boards were also conditioned for two months. The specimens were monitored on a daily basis. (An example of these specimens is shown in Figure 6).

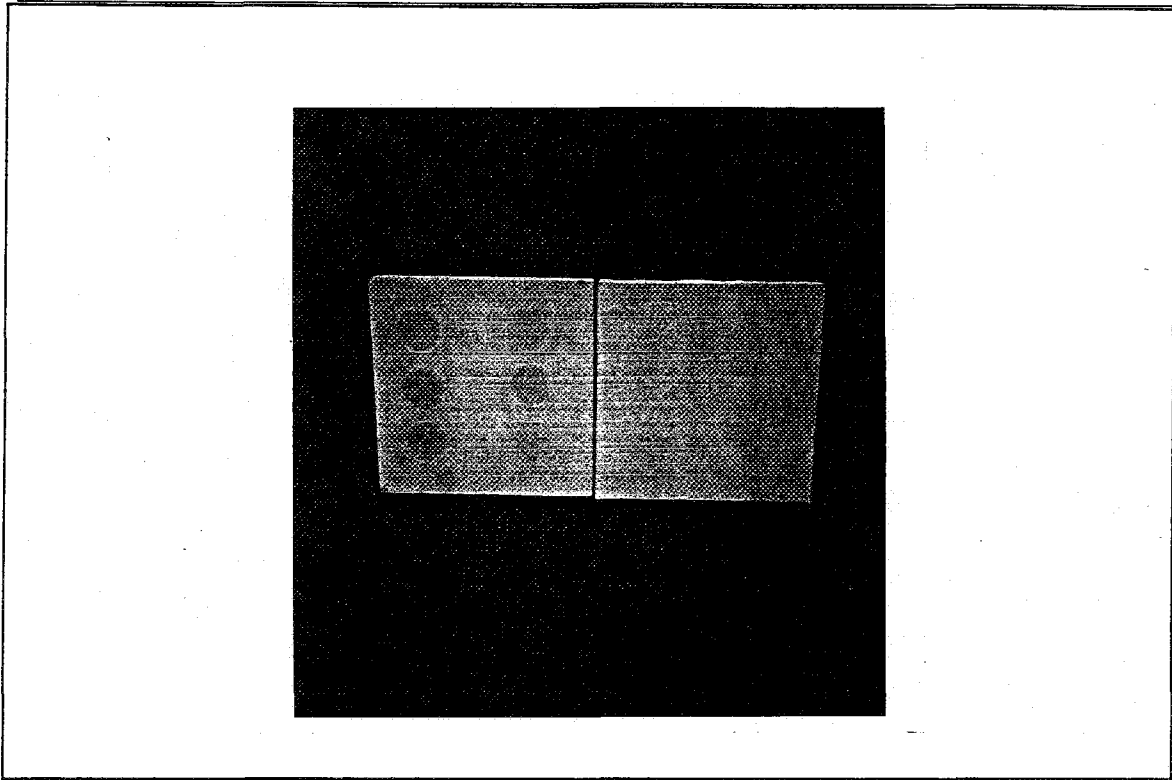


Figure 6. Specimen board showing PMA loaded jointing compound plugs after staining has occurred (left board showing stain, right board repainted with latex paint).

After two months of conditioning, certain boards were sufficiently stained to conduct test designed to evaluate stain removal options. On each of the four stained boards, three (3) stain areas were bleach washed, and the remaining three (3) areas were left untreated. These specimens were then repainted as follows:

- one board was painted with flat latex paint;
- another was primed with latex sealer followed by a flat latex paint*;
- one board was painted with flat alkyd paint;
- the final board was left with the bleach wash on half the board only.

These boards were then re-exposed to the stain generating conditions for two more months.

* 24 hours drying time was allowed between paint applications to ensure that the previous coat was completely dry.

V. RESULTS AND DISCUSSION

V.1 Visual Observations of Samples from Affected Houses

During on site sampling it was observed that staining was confined to the joints between drywall boards containing the jointing compound. Thicker applications of joint compound had an increased level of staining, and staining sometimes occurred in the area covering nail heads. A higher frequency of staining was associated with high humidity locations, such as bathrooms and kitchens. However, staining was not confined to these locations. No unusual environmental factors which might cause the stains nor any unusual workmanship factors which could have contributed to the problem was observed.

V.2 Physical Analysis

Examination of the drywall surface or paint chip surface using a stereo binocular and scanning electron microscope showed no physical anomaly which might cause the staining.

V.3 Biological Analysis

Preliminary biological investigations of the four stain smears and four non stain smears on nutrient agar plates gave the following results. Two plates, onto which stained specimens were placed, grew mildew cultures. The other two plates did not develop mildew. The mildew on the two positive plates was a grey mildew which was identified as *Aspergillus niger*. All four non stain area plates were negative for fungal growth.

Since this initial assessment of the stain was inconclusive, a more detailed evaluation was undertaken to further investigate the possibility that fungus or fungal spores might be the cause of the stain. The same technique was used to isolate fungus, but a larger sample was used. Stained and non-stained paint chips from a number of houses were used to broaden the sample size. Results are given in Table 1 below.

Table 1. Occurrence of Mildew on Paint Chips

Location	Stain/Plate	Non-stain/Plate
House 1a.	+ -	+ -
House 1b.	+ -	+ -
House 2.	+ -	+ -
House 3.	- -	- -
House 4.	- -	- -
Control	- -	- -

Note: + represents a positive test for mildew growth.

Three plates from stained boards showed the presence of mildew and seven boards showed no growth. Also, three of the ten plates from the non-stained boards were positive for mildew growth. The control plates, where no paint chip was placed, were both negative. At least four different mildew species developed and only one resembled the *Aspergillus niger* found in the first series of plates.

Since the probability of finding mildew is the same on either the stained or the non-stained paint chips, the results indicate that mildew was not directly linked to the presence of the stain.

V.4 Chemical Analysis

V.4 (a) Solubility

The results of the solubility spot testing on the upper segment of the drywall are shown in Figure 3. The area wetted by solvent was circled in pencil and observed during and after evaporation of the solvent. Except for the leaching of the paint pigment by methylene chloride, no visual improvement or change in the appearance of the stain was observed. Hence, the stain is not highly soluble in any of the solvents used in this test.

V.4 (b) UV-Visible Spectrometry

UV-Visible spectrometry was used to check for differences in the chemical composition between the stained and reference samples. Extracts from each of the four layers on each side of the joint (stained and reference side) were prepared in six solvents, and the differential absorption spectra of the resulting 48 extracts were obtained. In some cases, the presence of suspended inorganic solids slightly elevated the absorption baseline due to light scattering. After correction for this baseline elevation, such that the integrity of the measurements was not compromised, no significant differences were observed between the differential absorption spectra of the stained and reference extracts.

If the compound responsible for the staining were soluble in any of the solvents used, a significant difference in the visible region between the corresponding specimens from the stained and reference (relatively unstained) side should be seen. No such effect was observed for the paint layer, the underlying joint compound or the joint tape. This evidence, along with the lack of solubility in organic solvents shown in the spot test, strongly suggested that the stain producing compound belongs to the group of insoluble inorganic compounds. Some of the heavy (transition) metal salts are insoluble, highly coloured, and have often been implicated in paint discolouration [11,12,29].

Significant differences were, however, observed between the absorption spectra of extracts of unused finishing materials and samples from the test specimen of drywall. Figure 7 shows the difference in absorption spectra between the methylene chloride extracts of the field sampled paint and the supplied new paint. Differences in the visible absorption portion (230 - 550 nm) of the spectra were observed. A new peak appeared at about 260 nm in samples of the newly supplied sample of paint relative to the paint scraped from the drywall. It can also be noted that the peak appearing around 325 nm is more pronounced in the unused paint sample.

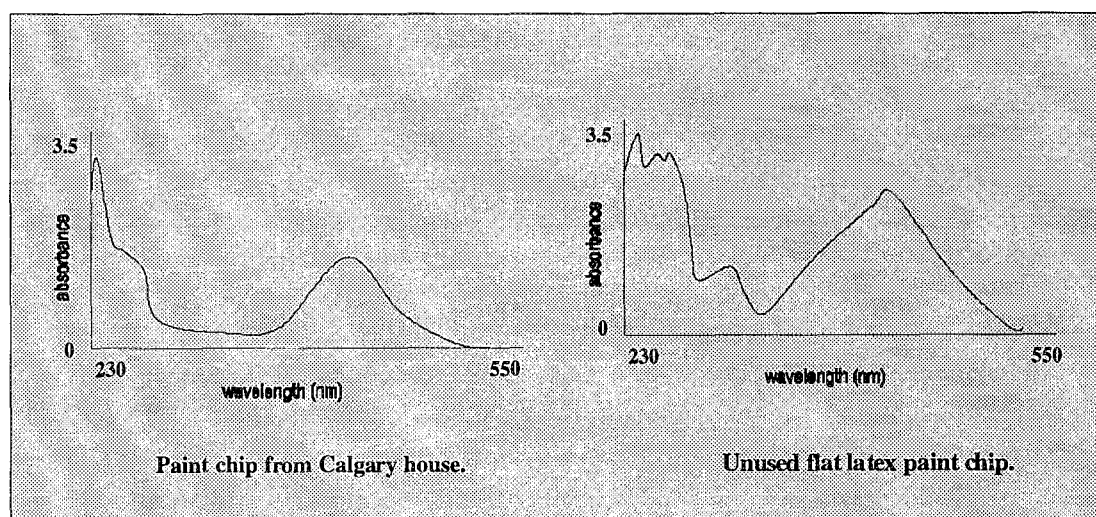


Figure 7. Difference in absorption spectra between the methylene chloride extracts of paint chip from house affected with stain and unused flat latex paint.

A similar difference was observed when comparing the spectra of the new unused joint compound with either the old unused joint compound or the joint compound from the drywall test specimen. The differential absorption spectra of these extracts are presented in Figure 8. It can be noted that the absorption spectra from the extracts of the old unused joint compound closely matches that of the joint compound sampled from the drywall.

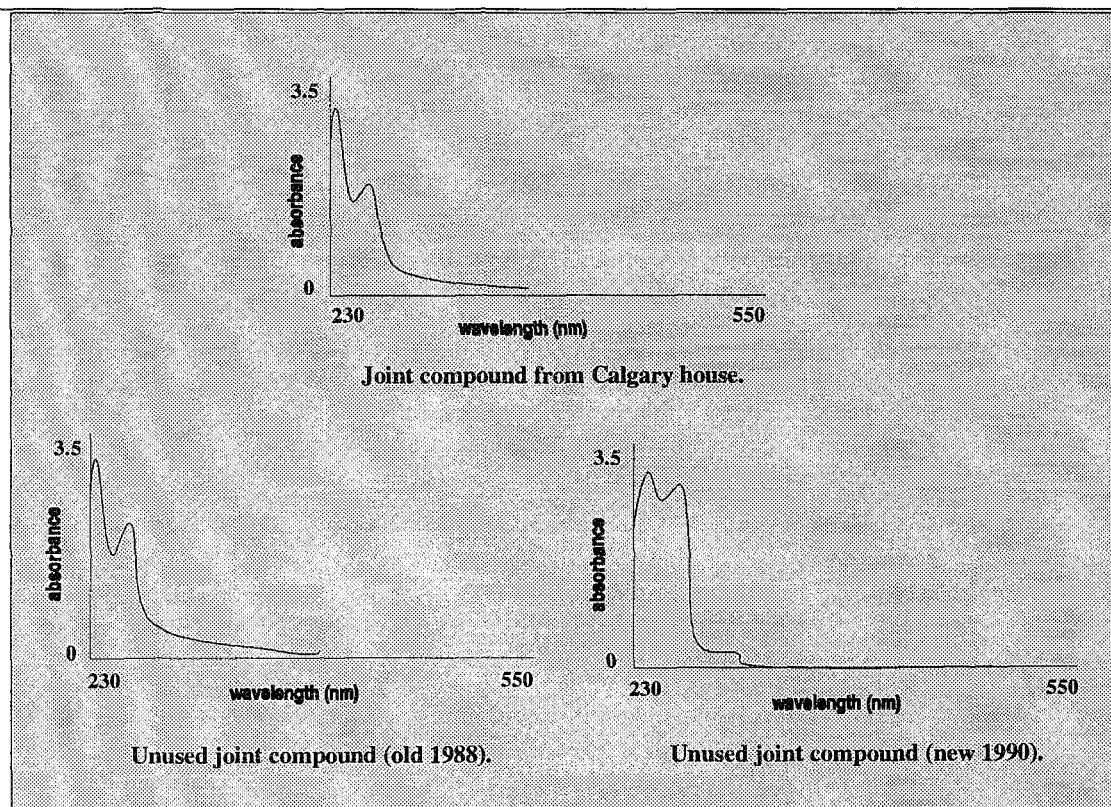


Figure 8. Difference in absorption spectra between the methylene chloride extracts of jointing compound from stain affected house, old (1988) and new (1990) material.

The spectra described above may be compared to the differential absorption spectra of two organic additives, i.e. PMA and phthalates. These additives are commonly found in paints and jointing compound and the absorption spectra are presented in Figure 9. The new peaks that appear in the spectra of the samples of new unused joint compound and paint do not correspond to the absorption of PMA and phthalates. The possible implications of these observations may be that these materials are not incorporated into the new formulation of these products.

Phenol mercuric acetate (PMA) is a fungicidal agent which is commonly added to drywall jointing compound to prevent or retard the growth of fungus. PMA has been used in paint in the same manner and for the same effect. The reason PMA was initially a desirable fungicide was its ability to diffuse freely through wet paint and concentrate on the setting surface of the paint, making it a viable fungicide even when used in low concentrations. This semi-soluble additive is used to protect the new stock of the jointing compound from biological attack. When applied to a drywall surface the PMA migrates to the surface as the jointing compound sets. In this way it protects the jointing compound from mildews and bacteria at the exposed surface. Once the jointing compound is thoroughly dried, the PMA exists as a dry residue on the surface of the joint.

Due to the increased awareness of the dangers of heavy metal based compounds, the use of construction materials containing these products has been greatly reduced over the past few years. In Canada, this trend culminated (in August of 1989) with the unilateral elimination of all mercury based compounds in paint.

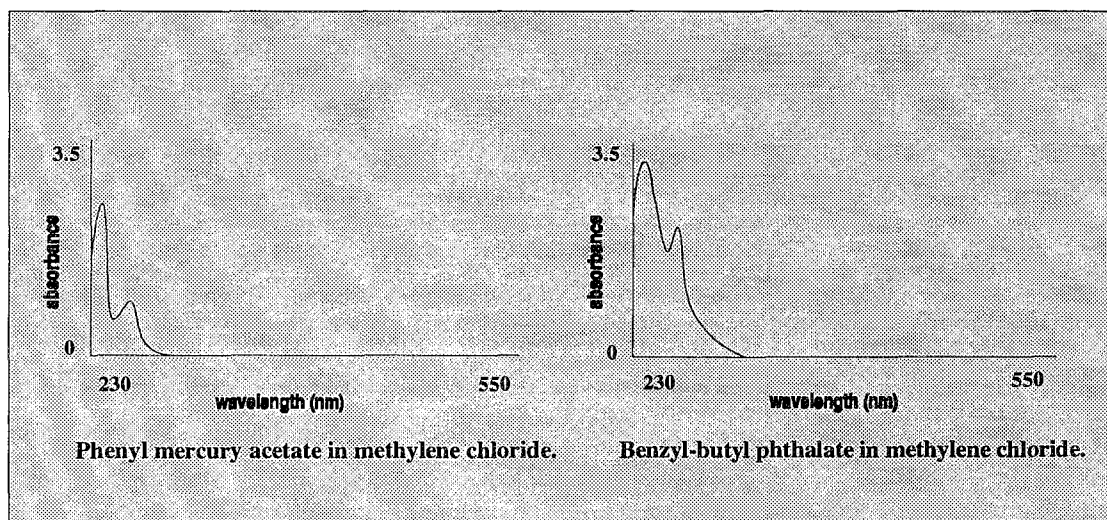


Figure 9. Absorption spectra of methylene chloride extracts of two organic additives, phenyl mercuric acetate and benzyl butyl phthalate, commonly used in jointing compounds.

V.4 (c) *Metal Analysis*

Based on the above observations and references from literature, a sample of the joint compound below the tape on the stained side of the drywall sample was screened for the presence of metals. Inductively coupled plasma (ICP) screening revealed the presence of three metals at elevated concentrations. The metals present in the jointing compound are given in Table 2.

Table 2			
ICP Scan Of The Paint Scraping for Presence of Metal Ions.			
Metal ion	concentration (ppm)	Metal ion	concentration (ppm)
Li	14	Sr	107
Be	10.3	Y	4.9
B	<2	Zr	10.4
Sc	0.9	Mo	<1
V	<0.5	Ag	0.5
Cr	<1	Cd	<1
Co	<1	Sn	<10
Ni	<1	Sb	<5
Cu	3.1	Ba	43
Zn	10.1	W	<10
As	<3	Hg	64.8
Se	<20	Pb	<2

Of the elements present in the sample of jointing compound only barium (**Ba**) and mercury (**Hg**) have the ability to produce highly coloured salts. Table 3 is a summary of the metals present in the jointing compound, their respective concentrations as determined by ICP, together with the corresponding colour of their sulphide salts [6].

Table 3 Highest Concentration Metal Ions and Their Sulphide Salt Colour		
Metal ion	concentration (ppm)	colour as sulphide salt
Lithium (Li)	14	white to yellow
Beryllium (Be)	10.3	colourless
Zinc (Zn)	10.1	colourless
Selenium (Se)	<20	yellow to red to brown
Strontium (Sr)	107	colourless to pale red
Zirconium (Zr)	10.4	gray
Barium (Ba)	43	yellow to red to green
Mercury (Hg)	64.8	black

Barium is common in dolomite, which is a major component of jointing compound filler. However, the unknown stain is grey to black and since barium sulphide is a salt having a yellowish or red colour, it was not considered as an agent which causes staining. The possibility of mercury being involved in the staining was thus further investigated.

The various layers from the stained and reference samples, as well as samples of the new materials were analyzed for mercury by cold vapour atomic absorption (AA). It should be noted that this method of analysis does not differentiate between sources of mercury (organic or inorganic) and measures total mercury concentration only.

The results of the AA analysis to detect the presence of mercury are given in Table 4. Figure 10 is a schematic depicting a cross-sectional view of the drywall in combination with the results obtained from the AA analysis.

Table 4 Levels Of Mercury Detected In The Various Components Of The Drywall Using AA			
Component of drywall	Mercury level (ppm)	Component of drywall	Mercury level (ppm)
Paint surface (heavily stained board)	131.0	Paint surface (lightly stained board)	64.0
Joint compound above tape (heavily stained board)	43.3	Joint compound above tape (lightly stained board)	50.4
Joint compound below tape (heavily stained board)	64.8	Joint compound below tape (lightly stained board)	49.7
Unused joint compound (old 1988)	70.3	Unused latex paint	0.9
Unused joint compound (new 1990)	0.23	Unused latex primer	0.22

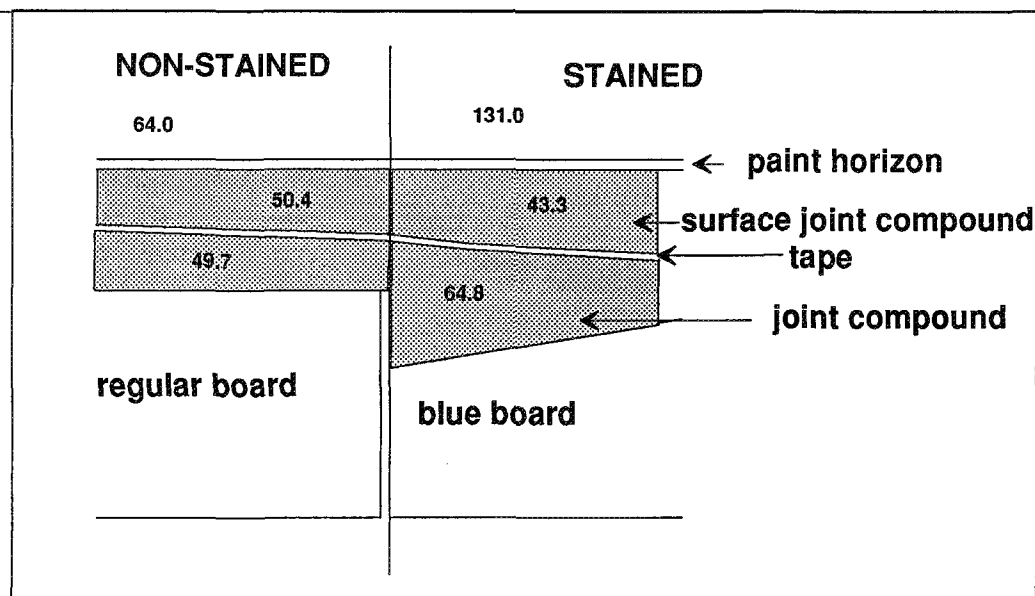


Figure 10. Cross section of drywall system showing concentrations of elemental mercury present (ppm) in various portions of the wall..

A high concentration of mercury was found in the stained paint chips and the underlying joint compound in both the stained and the reference drywall samples. However, the stained paint layer had more than twice the level of mercury compared to the reference paint layer, or any of the other layers. This result indicated that mercury may be involved in the staining. Of interest is the fact that only trace levels of mercury were found in the samples of unused paint, primer and new (1990) joint compound, whereas elevated concentrations were found in the old (1988) sample of unused jointing compound. Discussions with the formulator of the jointing compound producer, revealed that a mercury containing organic (organomercuric) compound, phenyl mercuric acetate (PMA), had previously been used as a fungicide.

V.4 (d) Thin Layer Chromatography (TLC)

1. Screening Experiments

Screening for chemical differences between the stained and reference extracts using TLC was performed to substantiate the results obtained from UV-Visible spectroscopy. Extracts were directly spotted on TLC plates along with PMA and phthalate standards. Methylene chloride was found to be an adequate solvent for development of the plates. The bands were visible as dark spots under fluorescent light, and in some of the samples, a distinct smudge from trace substances (polymeric type) was seen at low R_f values (R_f denotes the travel of the spot in a given time). The pigment from the paint extracts appeared to be quite mobile moving along with the solvent front. The PMA, at the concentrations used in this experiment (0.1 and 1.0 mg/ml), was not visible on the plate. As was previously determined in experiments using UV-Vis

absorption spectra, no significant difference was found between the stained and reference extracts.

2. Separation of Organic and Inorganic Mercury

Since the organometallic compound, PMA, was identified as the source of the stain, and the inorganic compound, mercuric sulphide, was suspected as the actual stain causing compound, an effort was therefore made to separate organic and inorganic mercury [18]. However, due to the low solubility of uncomplexed inorganic mercury salts, in both water and organic solvents, and the difficulty in enhancing the intensity of the stain, further work at separation was discontinued.

3. Separation of Complexed Metals by Thin Layer Chromatography (TLC)

Separation of inorganic and organic mercury compounds was then attempted using a TLC separation of dithizone complexed extracts. However, the low solubility of the inorganic mercury salt (mercuric sulphide) in both water and organic solvent prevented appreciable concentration of complexed metal compounds from being formed.

TLC of the organomercury-dithizone complex was used to verify the results determined by ICP screening for metallic ions. Figure 11 shows the results obtained from the extracts of samples of the old and new unused joint compound using the TLC technique. PMA is the standard and dithizone alone is used as the control. Dithizone complexed PMA appears as a reddish spot about mid-way up the slide. Clearly, it can be seen that no PMA is detected in the new sample of unused joint compound, but does appear in the older sample of unused joint compound. This corresponds to the results obtained previously which indicated the presence of mercury in the old compound. The yellow brown spot that appears in the top left corner is a decomposition product of an aged dithizone solution. Since this product had a relatively high value of R_f (i.e. is quite mobile) it did not interfere with the TLC method.

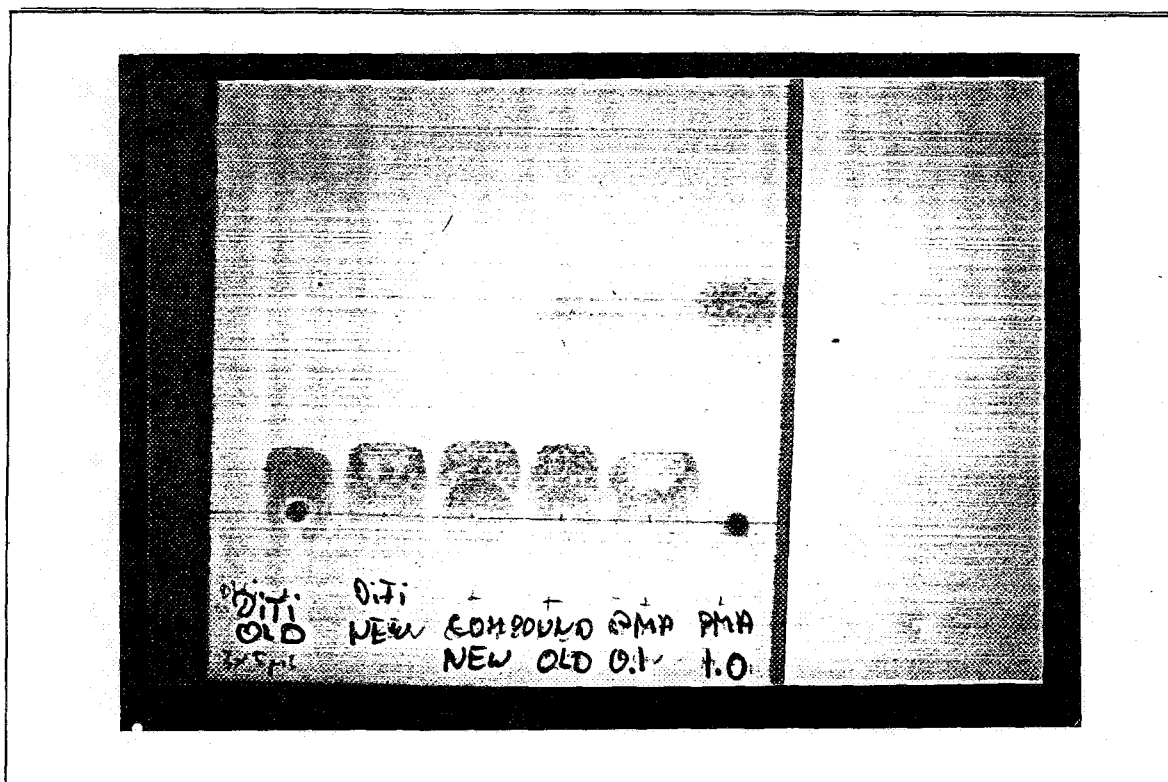


Figure 11. Dithizone complex TLC Plate showing the presence of PMA in the old (1988) but not the new (1990) jointing compounds.

Figure 12 shows an example of the TLC results of the dithizone complexes from various stained and reference extracts. Numbers 1 to 4 are from the stained side of the drywall sample. They are the water extracts of the paint, the compound above the tape, the tape and the compound below tape, respectively. Numbers 5 to 8 are the corresponding water extracts from the reference side. Numbers 1, 2, 5 and 6, on the far right side of the TLC, are dithizone complexed methylene chloride extracts. Numbers 1 and 2 are from the paint and compound above the tape on the stained side. Numbers 5 and 6 are from the paint and compound above the tape, on the reference side. The last spot on the right is representative of a solution having an abnormally high concentration of PMA and should be ignored. This TLC plate is represented schematically in Figure 13 to emphasize the presence of PMA in the various extracts.

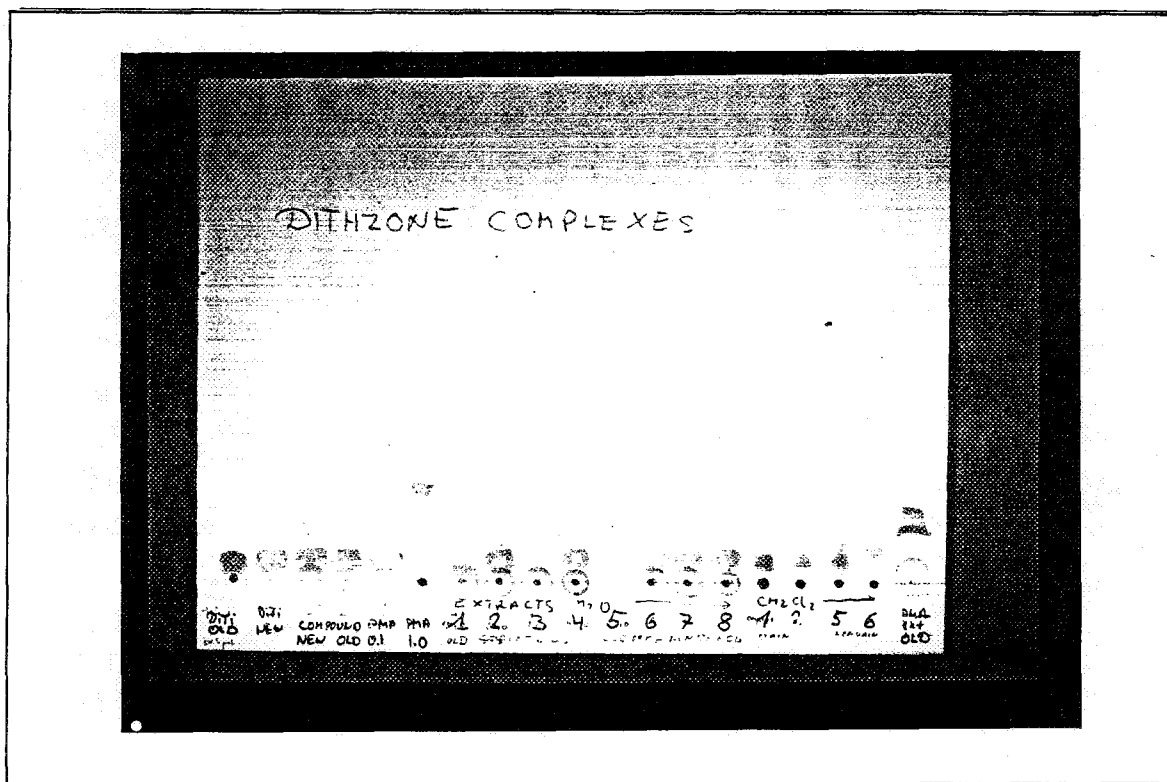


Figure 12. Dithizone complex TLC results from various stained and reference extracts.

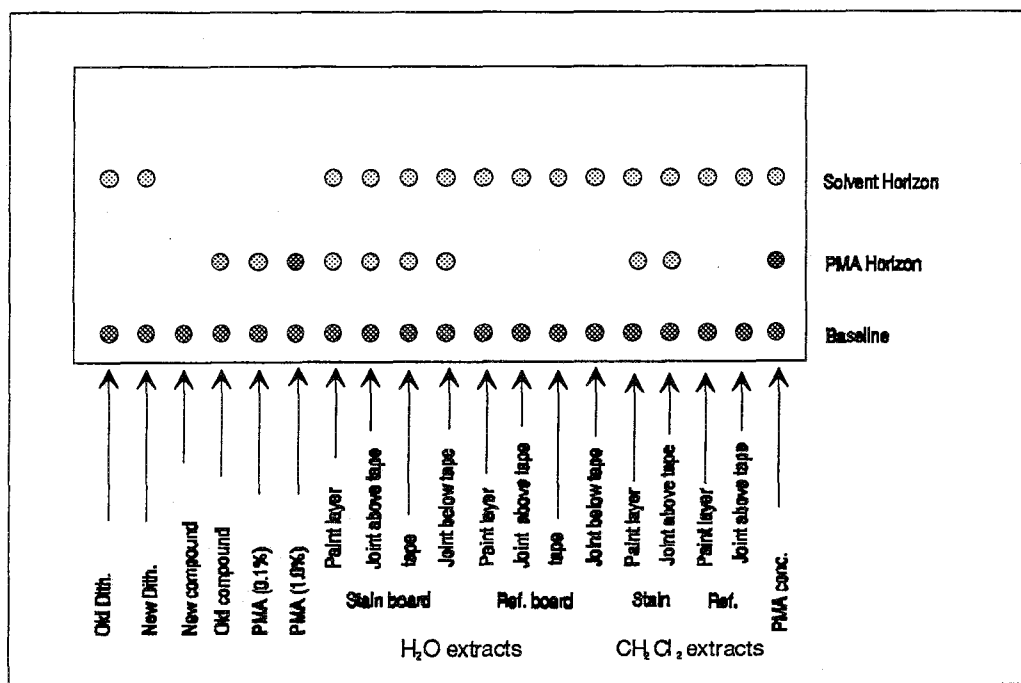


Figure 13. Schematic representation of the dithizone complex Thin Layer Chromatography Gel Plate.

Based on these results it is shown that no significant qualitative difference between the stained and reference extracts was observed. The result from this TLC plate is representative of all the results obtained using this method.

All extracts from the drywall sample, gave only a very weak spots due to organic mercury (PMA) which does not show up very well in the photograph. Comparison of the total mercury results and complexed mercuries TLC results of the used and unused old joint compound in Figure 12 and 13, shows that the total mercury concentration in these two compounds was similar. However, the results from the TLC indicate that the PMA concentration is much higher in the unused sample of old jointing compound than that in the jointing compound sampled from the drywall (as evidenced by the less intense TLC spot). This suggests that the major form of mercury in the joint compound sampled from the drywall must be inorganic in nature, and it also gives some indication of the instability of PMA.

4. Investigation of the Staining Reaction

The difference in mercury levels between the more and less intensely stained drywall surfaces does not conclusively prove that the fungicide (PMA) in the jointing compound is the cause of the staining problem. All soluble compounds (including PMA and phthalates) could be expected to concentrate on the surface when evaporation of the solvent occurs, as the jointing compound or paint dries. An elevated concentration of mercury on the stained surface, relative to the reference surface, does, however, indicate that PMA may be involved.

If PMA was involved, does a realistic mechanism exist by which the presence of colourless PMA (in the range of concentrations found) on the paint surface leads to a stain? The work presented in this report as well as the information obtained from previous work affords a plausible mechanism [11,12,29]. Since PMA is colourless, it must undergo physical or chemical processes in order to be involved in the staining. The reported UV photo-decomposition of PMA yields about 0.3 units [31], which indicates that PMA photo-decomposes quite easily to inorganic forms. Several researchers have reported mercuric sulphide staining of paints [11,12,29]. Hydrogen sulphide is a common air contaminant and would provide a common source of sulphide in the development of a stain. Mercuric sulphide, which is black, is visible even when present in very low concentrations.

The investigation of the mechanism provide the following information. Reaction of ionic (inorganic) mercury and sulphide forms the black stain. This is shown when an aqueous solution of mercuric chloride (a clear solution) was added to a solution of sodium sulphide (which is also colourless). The insoluble black precipitate of mercuric sulphide formed is seen in the left vial of Figure 14. Bleach (5 ml) was added to an aliquot (2.5 ml) containing the heavy black precipitate and the precipitate disappeared. The result was again a colourless solution shown in the right vial of Figure 14. This correlates well with field tests where the drywall stain was shown to be soluble with a bleach wash [28].



Figure 14. Vials containing mercury sulphide, (left vial) and bleach dissolved mercury sulphide (right vial).

The above results supports the involvement of PMA in the staining process. However, the concentration range used in the above simulation was well above that which was found on the drywall surface. To simulate the staining under more representative conditions, a lab scale experiment was designed, and a chamber was constructed that would provide both hydrogen sulphide and UV light exposure (see Experimental, section IV.5).

The results obtained from the TLC, UV/Visible and AA experiments can be summarized as follows:

Three TLC silica gel plates were spotted with methanol extracts from the old (1988) and new (1990) jointing compound (along with PMA standards) in increasing volumes. The investigation of the two important variables involved in the reaction mechanism was done using three plates which had spots of jointing compound extracts exposed to different exposure conditions.

- | | |
|-----------|---|
| Plate I | was exposed to both UV radiation and hydrogen sulphide. |
| Plate II | was exposed to UV radiation only. |
| Plate III | was exposed to hydrogen sulphide under a darkened hood. |

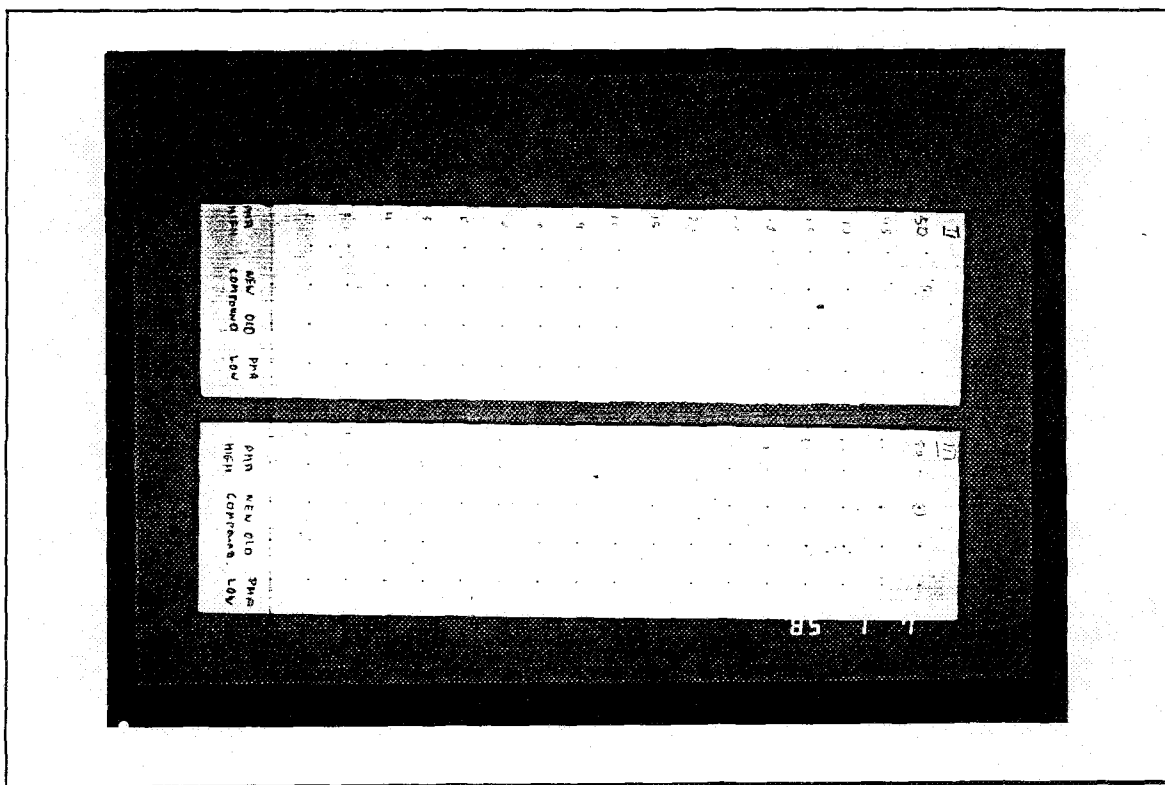


Figure 15. Extract spot plates II and III prior to exposure.

Figure 15 shows the plates prior to exposure to the reaction conditions. Figures 16, 17, and 18 show the plates after exposure. The results indicate that both UV and hydrogen sulphide are important factors influencing both the rate of formation and the intensity of the stain.

A significant stain is observed from the extract of the old (1988) jointing compound compared to the more recent (1990) drywall compound. This correlates with the results from AA mercury analysis in which only negligible traces were found in the new unused joint compound (Table 4), whereas 70 ppm of mercury were found in the old jointing compound. Larger volumes of applied extract increased the stain intensity.

Plate I, after simultaneous exposure to UV light and hydrogen sulphide, developed staining in less than one hour, and is shown in Figure 16.

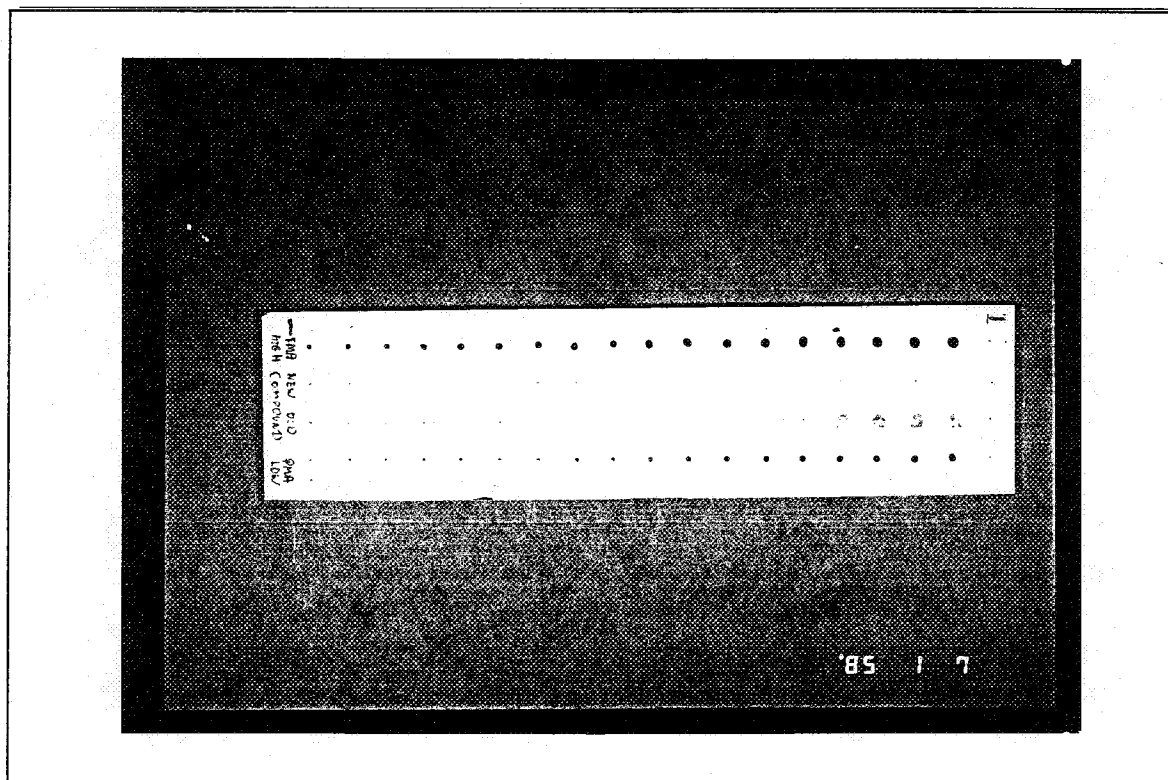


Figure 16. Plate I showing the simulation of the stain after exposure.

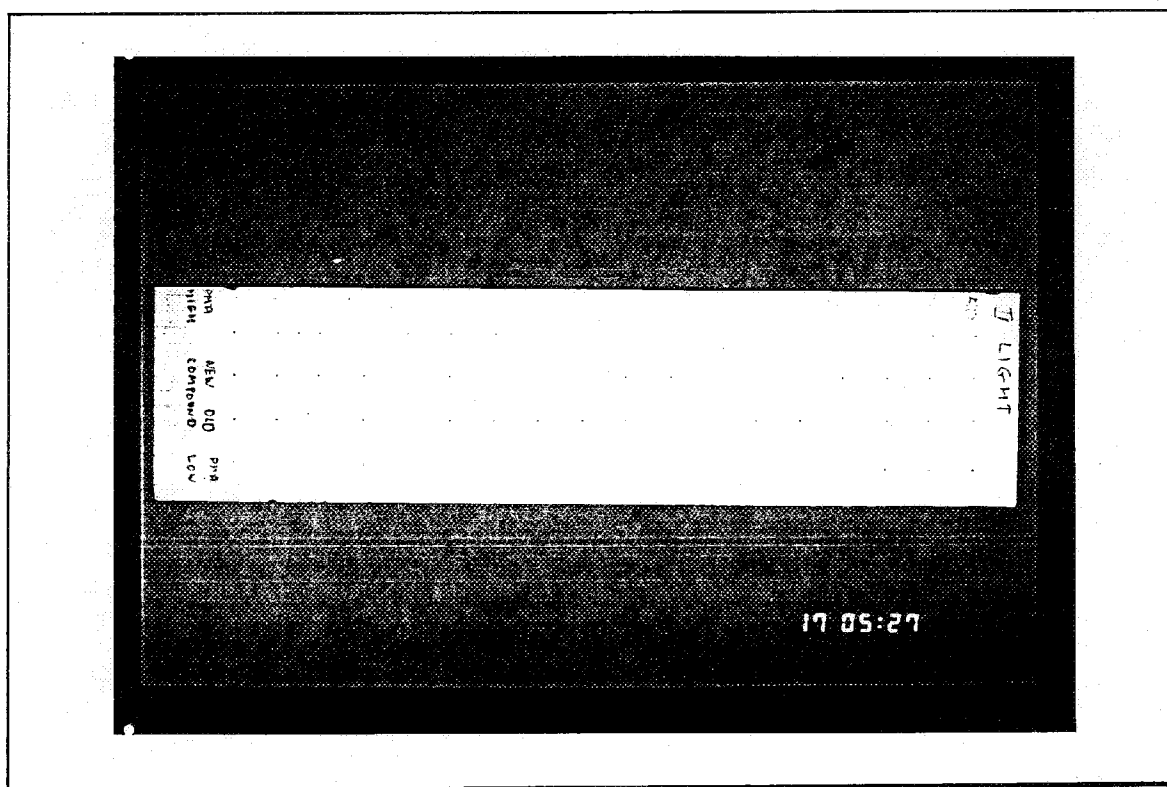


Figure 17. Plate II after exposure to UV irradiation only.

Plate II which was exposed to UV radiation only, did not form a stain, although photo-decomposition had converted the organic mercury in the PMA into the inorganic form (Figure 17).

Plate III, exposed to hydrogen sulphide only, formed a stain thus indicating that hydrogen sulphide is one of the chief factors involved in stain formation. However, it can be seen that the stain intensity was less than that seen in Plate I which was exposed simultaneously to UV radiation and hydrogen sulphide (Figure 18) indicating the synergistic effects brought about by their combined action.

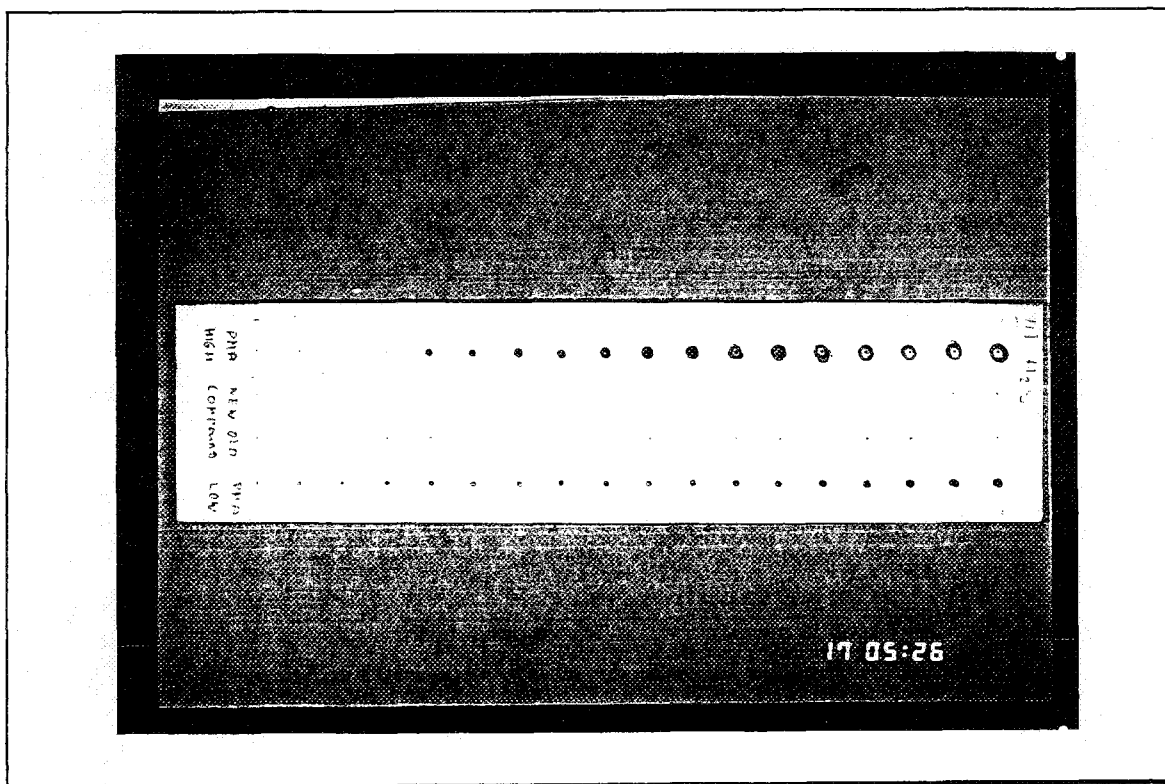


Figure 18. Plate III after exposure to hydrogen sulphide only.

Results of the UV/Visible absorption spectra (Figure 8) and AA mercury analysis (Table 4) show a close resemblance to the old (1988) drywall compound and the compound actually used in the construction of the affected house. The mercury level found by AA in the old (1988) jointing compound specimen (70 ppm) corresponds to a PMA to compound concentration of $117.5 \mu\text{g/g}$. Assuming that the PMA was not decomposed during storage, application of the joint compound to the glass plate in the laboratory or drying, and that it was quantitatively extracted, the concentration of mercury in the final preparation should be $117.5 \mu\text{g/g} \times 3.5 \text{ g/ml} = 411.25 \mu\text{g/ml}$, which corresponds to approximately $410 \mu\text{g/ml}$ of PMA.

The role of photodecomposition was investigated using two solutions of PMA jointing compound in methanol. One was irradiated while the other was kept in darkness. Figure 19 shows the results obtained when aliquots from each were applied to ashless neutral filter paper. The vivid staining produced by the solutions exposed to UV radiation compared to that kept in darkness clearly shows that light is an important factor in stain formation.

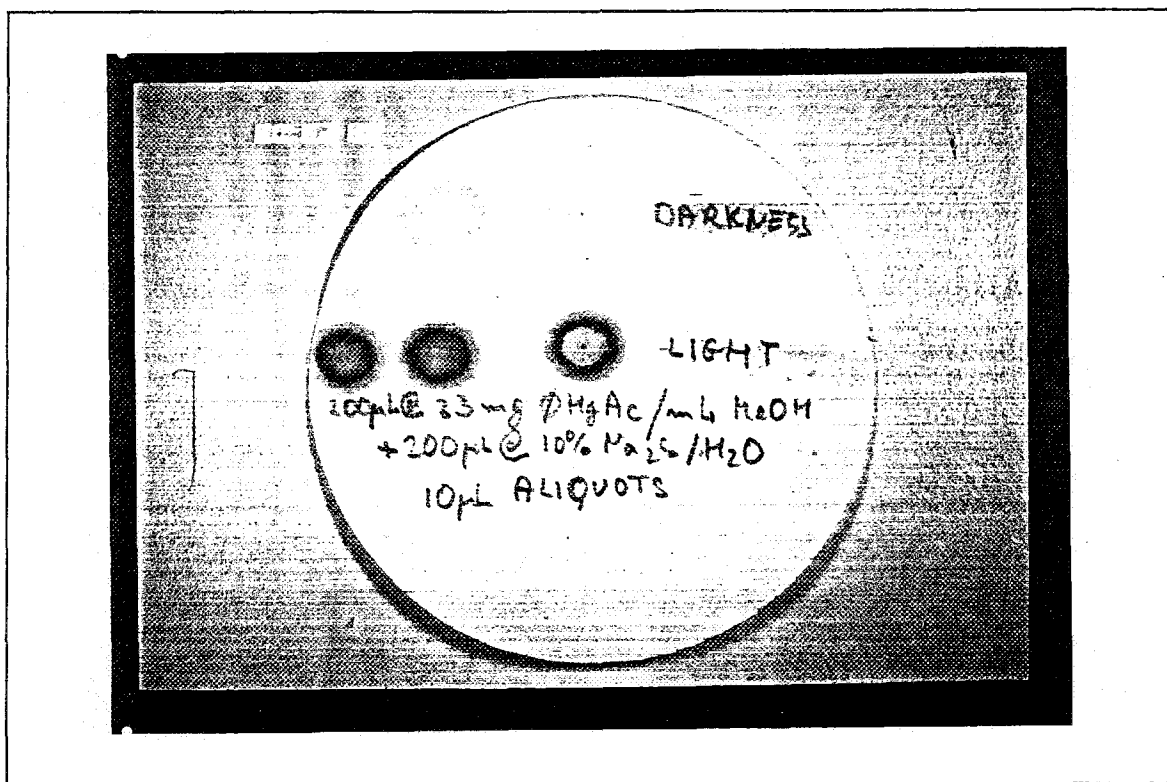


Figure 19. The effect of light on the reaction of Phenyl mercury acetate and sodium sulphide.

It is difficult to compare the intensity of staining observed on the drywall sample to the stains generated in the laboratory, in the simulation, or to that caused by the extracts of pure PMA standards. The white background of the silica gel used in the lab experiments produced a marked contrast to the stain and allows it to be readily distinguished in comparison with the reduced contrast afforded by the textured and yellowish surface of a typical drywall surface. Furthermore, the lower concentration of mercury on the surface of the drywall produced a weaker stain.

V.5 Simulation of the Staining

V.5 (a) *The Effect of Materials and Application Techniques on Stain Generation*

Within a few hours of exposure one board (PA-R) developed a light stain over the holes filled with the jointing compound containing PMA (old compound). A second board (LL-R) developed light stains over the jointing compound containing PMA within two days of initial exposure. Whereas stains on the first board (PA-R) did not darken over the next two months, on the second board (LL-R) stains darkened progressively over the same period. However the stains in this latter case never attained the intensity of those found on the first board. None of the other boards stained.

Stains generated on the board finished with an alkyd based finish coat was not typical to the type of stain found in Alberta homes. The rapid application technique contributed to the formation of stains since a similar board prepared using the conventional technique did not stain. In this instance, the PMA present in the jointing compound reacted immediately with hydrogen sulphide present in the conditioning chamber. This board (PA-R) was seemingly the most susceptible to staining since the combination of latex sealer and alkyd finish coat took longer to dry than the other coating combinations. This allowed the PMA to be exposed to factors causing staining for a longer period of time thus contributing to the intensity of staining present on these boards. The nature of stains found on the LL-R board were similar to those found in Alberta homes. It intensified with time, and appeared as a grey shadow on the surface of the paint over the jointing compound.

Results observed from those boards permitted to surface dry 24 hours prior to being exposed to UV radiation and hydrogen sulphide indicated that only the LL-R board produced stains over the jointing compound containing PMA. This suggests that stains will not form when a sealer is used to prime the surface and that the use of low permeability coatings, such as the flat latex paints used to both prime and finish the drywall, increases the susceptibility of the drywall surface to generate stains.

V.5 (b) *The Effect of Environmental Influences on Stain Generation*

A set of six boards was conditioned in the presence of UV radiation and moisture without the presence of hydrogen sulphide. After two months of exposure, this set of gypsum boards began to disintegrate, however, the paint surface remained intact. There was no evidence of staining on any of the jointing compound plugs. This result confirms that stains can not be generated in an atmosphere void of hydrogen sulphide.

A second set of six boards showed no evidence of staining after two months exposure to H₂S in the absence of UV radiation. Results from the investigation of the staining reaction (section V.4(d), p. 25) indicated that staining should, however, occur

when PMA is exposed to H_2S only in the absence of a source of UV radiation. In this instance it is supposed that the stain would have eventually develop in the absence of radiation had the experiment been continued.

A third set of four boards exposed to UV light, H_2S and humidity (which was varied by spraying half the boards with a fine mist twice per week to simulate a wetting cycle) showed that the intensity of the stains on the wetted boards was greater than the non-wetted boards. The results indicate that when hydrogen sulphide and light are both present stains will develop and furthermore, moisture cycling enhances the development of the stains.

V.6 Methods of Stain Removal and Elimination

In order to accelerate the stain generation so that methods of stain removal and prevention could be studied, it was necessary to develop a method whereby stained drywall specimens could be produced within a reasonable period of time. This series of tests was conducted on artificially loaded jointing compound and is described below:

Results from those boards placed in the environmental chamber while still in a surface wet condition showed that the surfaces immediately developed intense black stains upon exposure to the atmosphere present in the chamber. Consequently these specimens were unsuitable for use in this study because the nature of the staining was not characteristic of the naturally occurring stains observed in homes in Alberta.

The second set of boards, which were placed in the exposure chamber after initial surface drying, showed moderate staining after two months of exposure in the environmental chamber. This series of boards was used to evaluate the effectiveness of various remedial actions which would block a stain. Each of the four stained boards were treated and repainted in a manner previously described in section IV.6 (p. 14), and which is presented below:

Each board had six jointing compound plugs; half were bleach washed with a 5% bleach solution and half were not bleached.

- i. board primed with latex primer and repainted with latex paint;
- ii. board painted with latex paint only;
- iii. board painted with alkyd paint only;
- iv. board not repainted.

Results from this study reveal that in all cases where a bleach treatment was used, it alone eliminated the stain, prior to repainting the specimens. Furthermore, each paint treatment was also successful in blocking the stain present on either the bleach washed or the non-bleached halves of the board.

The results of stain removal after two months of conditioning in the environmental chamber are summarised below:

- After 60 days of exposure to stain generating conditions, no evidence of a reoccurrence of staining was evident for the boards coated with:
 - i. latex primer and repainted with latex paint;
 - ii. flat latex paint only;
 - iii. flat alkyd paint only.
- The board bleach washed only did show evidence of staining. The bleached boards were slightly stained and those areas which were left untreated had evidently more intense staining than treated areas.

Based on these results, it is apparent that although bleach washing initially dissolves the stain, bleach washing alone is not sufficient to prevent staining. Furthermore, it appears that several repainting options are available. However, the importance the drying time between applications, as demonstrated from tests used to evaluate application techniques, must be taken into consideration.

Mechanism of Stain Generation on Drywall

Based on results obtained from both the chemical analysis and the stain simulation experiments the following is an attempt to characterise the mechanism of stain generation on drywalls.

PMA migration to the surface occurs as follows: As the joint compound dries, the water soluble chemicals from the jointing compound migrate toward and are deposited on the drywall surface. The application of a latex primer wets the jointing compound, re-dissolving the chemicals previously deposited on the surface of the joint compound [21]. As the primer dries, the water soluble chemicals again migrate towards the surface of the primer. The same mechanism repeats when further coats of latex paint are applied, leaving behind a certain portion of the water soluble chemicals on the paint surface. Thicker applications of joint compound lead to an increased concentration of chemicals at the drywall surface.

Latex paints, which have a high permeability in comparison to alkyd or other oil-based paints, allow moisture to diffuse relatively easily through the paint. When such a paint is used in locations where a jointing compound which contains PMA has also been used, there is a greater likelihood that staining will occur. Furthermore, a humid environment prolongs the drying time and increases the propensity of the drywall to stain.

Understanding the mechanisms of stain generation has enabled the development of methods to eliminate the existing stain and to prevent its reoccurrence. The best method for eliminating the stain is to seal the stained wall with either a latex sealer or an

alkyd based paint (other paints have similar hiding characteristics may also be used, e.g. an acrylic emulsion stain blocker). All these coatings have a greater resistance to moisture permeability when compared with the less expensive flat latex interior wall paint [12]. These paints help to seal the stain and prevent the moisture from penetrating the wall and drawing new PMA to the surface.

In the case of a less intense stain, a latex sealer covers the stain and will prevent it from reoccurring. A latex paint on top of this will give the desired finish to the wall. A bleach wash (5% by volume) prior to painting reduces the intensity of the stain and in more intense stains, bleaching prior to sealing is advised. When a bleach wash is used a thorough rinsing of the wall should also be made to remove as much of the free mercury based compounds and bleach as possible. The latter course of action is recommended for rooms where humidity and moisture condensation are not common (e.g. bedrooms, living rooms, hallways).

In rooms where higher levels of humidity are a problem (e.g. bathrooms, kitchens), it is important to seal the surface of the wall to prevent moisture from penetrating the wall and transporting more PMA to the surface. A latex sealer should be used followed by a low permeability finishing coat. A bleach wash and water rinsing prior to painting are optional, depending on the intensity of the stain.

VI. CONCLUSIONS

- Neither physical nor biological phenomena were found to contribute to staining.
- The grey to grey-black stain found along the joint line of drywall in houses in western Canada for the past five years, has been identified as the black salt, mercuric sulphide (HgS).
- Chemical analysis showed that the mercuric sulphide salt was formed by the photochemical decomposition of the phenyl mercuric acetate (PMA), a commonly used fungicide for paint and jointing compounds and a chemical reaction between the heavy metal in PMA and atmospheric hydrogen sulphide.
- The simulation of the stain and study of the staining reaction showed that mercuric sulphide is a black pigment which is stable. It is possible to generate mercuric sulphide from PMA and H_2S in the presence of UV radiation or direct sunlight. In the absence of H_2S the PMA did not form mercuric sulphide. The mercuric sulphide salt is soluble in a 5% bleach solution.
- The factors which influence the intensity of the stain are: the concentration of PMA in the jointing compound, the concentration of hydrogen sulphide present in the air, the humidity of the affected area, the permeability of the paint used, and the drying time allowed between the application of the jointing compound and the paint layers.
- Lab simulation experiments showed that PMA migrates to the surface of the paint, where in the presence of UV radiation, it breaks down, and reacts with hydrogen sulphide. It also showed that wet paint in contact with wet or damp jointing compound causes PMA to be leached to the surface of the drywall.
- The probability of staining in a specific area is governed by the concentration of atmospheric H_2S and exposure to UV radiation.
- The schedule of the application of various layers of the drywall system is an important influencing factor on the generation of stains.
- The fungicide, PMA, is brought to the surface by wet and dry cycles. Breathable paints, such as latex paints, permit the ready transport of moisture to and from the PMA containing joint compound.
- Several options are available to eliminate the stains which may occur in existing homes. The appropriate action will depend on the cost, the severity of the stain, and the conditions under which each individual stain developed.

- Bleach washing does dissolve the mercuric sulphide and fade the stain, but with time and given the right conditions the stain recurs. Low permeability paints effectively sealed the PMA into the system, but proper drying time between the first and subsequent paint coats is essential.
- To prevent this staining problem from occurring in new construction, paints and joint compounds containing mercury-based fungicides should be avoided.
- A bleach wash (5% by volume) reduces the intensity of the stain enabling ready coverage by a paint. Bleaching of the stain prior to painting is particularly useful in covering intense stains..
- Coating a stained wall with an impermeable paint encases the mercuric sulphide and the remaining PMA preventing further reaction with H_2S present in the
- A latex sealer covers a light stain and prevents it from reoccurring.

VII. RECOMMENDATIONS

The following list of items is suggested as remedial and preventive actions:

1. Stains may be washed with a 5 - 10 % bleach solution (depending on the intensity of the stain). On a wall where severe staining has occurred more than one bleach wash may be necessary. However, the washed surface should be allowed to dry 24 hours before any further treatment is undertaken. Washing will slowly dissolve the stain; no scrubbing is necessary. It should be followed by a thorough rinsing of the wall with water and a sponge to remove the bleach. The stain may reoccur if the surface is not sealed after the bleaching operation. Therefore, this activity should be followed by sealing the surface using an appropriate paint.
2. After the wall has been washed allow the surface to dry completely (24 hours). Paint the wall with a latex sealer. Allow the sealer to dry 24 hours and then apply a second coat of paint. The type of paint used in this second coat will depend on whether or not the affected wall is located in an area of high humidity. This is discussed below.
3. In rooms where high humidity levels are present (e.g. bathroom, kitchen) an alkyd paint should be used as a finish coat. All other conditions permit the use of either a latex or alkyd based finish coat. If the level of humidity in the affected room is in doubt, then an alkyd paint should be used as a finish coat.

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