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Improved Performance Standards for Polyethylene Sheet Vapour Barriers

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ABSTRACT

Moisture is transported into cavities by two principal mechanisms, vapour diffusion and air movement. The latter is considered to be the most significant factor but vapour diffusion control should not be ignored. It is now more important than ever to design and construct effective vapour diffusion control systems. Newer buildings are operating at higher indoor humidities and exterior walls and ceilings contain higher levels of insulation.

Vapour barriers reduce the transport of water vapour across an outer wall section. Polyethylene film has evolved as a preferred vapour barrier material. Physical damage to the film and long term film degradation affects the rate of moisture vapour flow. Severe exterior wall damage may result from high moisture levels in a cavity. As diffusion is a slow process this damage may not be apparent for many years.

Canada Mortgage and Housing Corporation led a survey of 15 houses to determine vapour barrier integrity. Film degradation and physical failure were observed. Survey findings suggested that the great majority of film installations lasted more than 15 years. Some of the oldest installations demonstrated no signs of degradation at all. 8 out of all samples collected were deemed to have failed within 5 years. Characteristics inviting premature degradation were "manufactured into" some of the film and were not a function of service environment. Upgraded standards for polyethylene film were recommended.

The degradation of some polyethylene film has not invited any major building disasters. Its function as a vapour diffusion control material is usually backed up by painted wall board. Thus additional vapour resistance protection remains in place from the properties of the materials adjacent to the polyethylene film.

A new Canadian standard has been issued, incorporating a requirement which should make major improvements to the expected life of polyethlene film. A testing procedure has been included to ensure that the improvements specified have been instituted. The test is one that could readily be used by materials evaluation personnel. A new method of predicting service life from accelerated testing is possible. This method of predicting service life has the potential to be very useful. Further research is required to confirm its conclusions. Film conforming to the new standard should survive in excess of 40 years. Absolute assurance of adequate life cannot be given without further research. Testing agencies must now establish a standards enforcement routine.

INTRODUCTION

This paper presents the findings from two research projects related to the deterioration of polyethylene film used as vapour barrier* in Canadian housing. As a consequence of the findings from these studies the industry and standards writing bodies responded to remedy the problem. Their related standard writing activities are discussed. Delivery of reliable future film product is now expectd.
A method of estimating polyethylene film life is presented here also.

BACKGROUND

Building scientists have long been aware that moisture can be transported into outer wall cavities by two principal mechanisms, vapour diffusion and air leakage, infiltrating or exfiltrating. While air leakage is now considered to be the most significant moisture transport mechanism, vapour diffusion must not be ignored.

In the past, code authorities believed they were covering-off the requirements for preventing moisture movement by diffusion, by calling for a vapour barrier inboard of the insulation. In Canada, the code defined the materials as Type I and Type II. Materials to satisfy the code were lumped together. For instance, foil/paper combinations 3ft. wide were grouped with polyethylene film 9 ft. wide to form Type I. Most builders commonly used "2mil poly". This thickness was adequate to limit vapour diffusion but could not be relied upon to provide adequate strength if it had to resist air movement.

With the trend to more energy efficient homes, attempts were made to achieve energy conservation by reducing the amount of air-flow across outer walls. One way to achieve this reduction was to utilize the polyethylene film as an air barrier as well as a vapour barrier.

Polyethylene film first appeared in the Canadian west in the early 1950's as a ceiling vapour barrier replacing the asphalt-kraft and wax-kraft papers used under loose fill attic insulations. Polyethylene film was also used throughout the midwest USA and central and eastern Canada as ground cover material in crawl spaces from the mid 1950s. During the 1960s it was used in electrically heated houses which became widespread at that time. It was used primarily in the ceiling until the 1970's when it was moved into broad service in walls. Even then, it was viewed as a second "insurance" vapour barrier over the asphalt-kraft vapour barrier affixed to the insulation batts.

In retrospect, almost all vapour barriers installed before the late 1970s served a nebulous function; due to the dominance of moisture transfer through air movement across outer walls. The installation of any vapour barrier material, including polyethylene, typically covered only the air leaks and gaps that the drywall also covered. The main gaps (structural junctions, electrical outlets) are covered by neither. The drywall and trim act as the interior air barrier as much, or more so, than does the separate vapour barrier. Furthermore, the vapour blocking property of the interior finish is often quite adequate. Thus the presence of a vapour barrier is largely not required in preventing air leakage. In retrospect therefore, it is quite possible that the separate vapour barrier could disappear from the majority of houses built before the late 1970s and neither the occupants, indoor air, water vapour, structure, nor the heating bill would be appreciably affected.

Since the late 1970s, however, circumstances have arisen giving increasing concern for the life of the vapour barrier. Integrity of any vapour barrier and of any air/vapour barrier is now becoming critical to the useful life of the house itself.

In the case of electrically heated or "flueless" houses in general (and in certain components of other houses, such as cathedral ceilings), even the drywall itself or the typically discontinuous polyethylene film are sometimes failing to prevent house-component moisture damage.

The typical new "low energy" houses operate in a flueless mode much of the time. They often depend on mechanical ventilation to ensure satisfactory air quality and help control humidity, and they depend also on continuous polyethylene air/vapour barriers to prevent exfiltration condensation damage.

In summary, polyethylene failure in itself will rarely lead to deterioration of the majority of houses already built. However, the potential for deterioration exists in a few thousand new "low energy" houses and other older, essentially flueless houses. Because the performance of much, or most, of our future stock will depend on continuous and durable vapour barriers and on structurally supported air barriers; the use of polyethylene film as an appropriate air barrier material is yet to be determined and investigations to determine its durability for this function are also appropriate at this time.

* ASTM and ASHRAE documents now refer to "vapour retarder."

DISCUSSION

While other Canadian papers are examining the air barrier issue (Ref. 1), this paper examines the data from studies relating to the thermal aspects of polyethylene film longevity and describes investigations and findings, all directed to ensuring reasonable life expectancy in that film for vapour barrier purposes.

In 1981, in Stockholm Sweden, it was observed that polyethylene vapour barrier in a number of 10 year old houses, was failing by way of brittle cracks. As a result of this observation, the Swedish Association of Plastics Manufacturers issued an industry standard that required vapour barrier film to contain antioxidants and ultra-violet light stabilizers adequate to assure a 6-month life at 100°c; a time-temperature combination chosen by that country's building science community as likely to identify durable film.

In 1983, Canada Mortgage and Housing Corporation started to receive sporadic reports of brittle failure of vapour barrier film. In order to obtain a better definition of the problem, Canada Mortgage and Housing Corporation commissioned research to investigate the issue, through field studies and analysis of other available data.

FIELD STUDIES

In one research project, commissioned by CMHC, film samples were obtained from 28 different locations in Canada. These samples were subdivided into the following sets:

		Number
1.	Samples from houses systematically inspected	15
2.	Samples of new film obtained from manufacturers and distributors	6
3.	Deteriorated specimens submitted by others. (Usually brittle or broken)	7
		28

In some of the houses in the first group, multiple samples were taken to see if the deterioration was affected by different temperature exposures. For example, in the case of attic samples, a typical sampling would involve film from above light fixtures with "controls" from other parts of the attic. These samples were visually inspected and classified for thickness and appearance. Tensile testing was carried out to determine the remaining amount of elongation to rupture on the non-brittle samples. (Ref. 2).

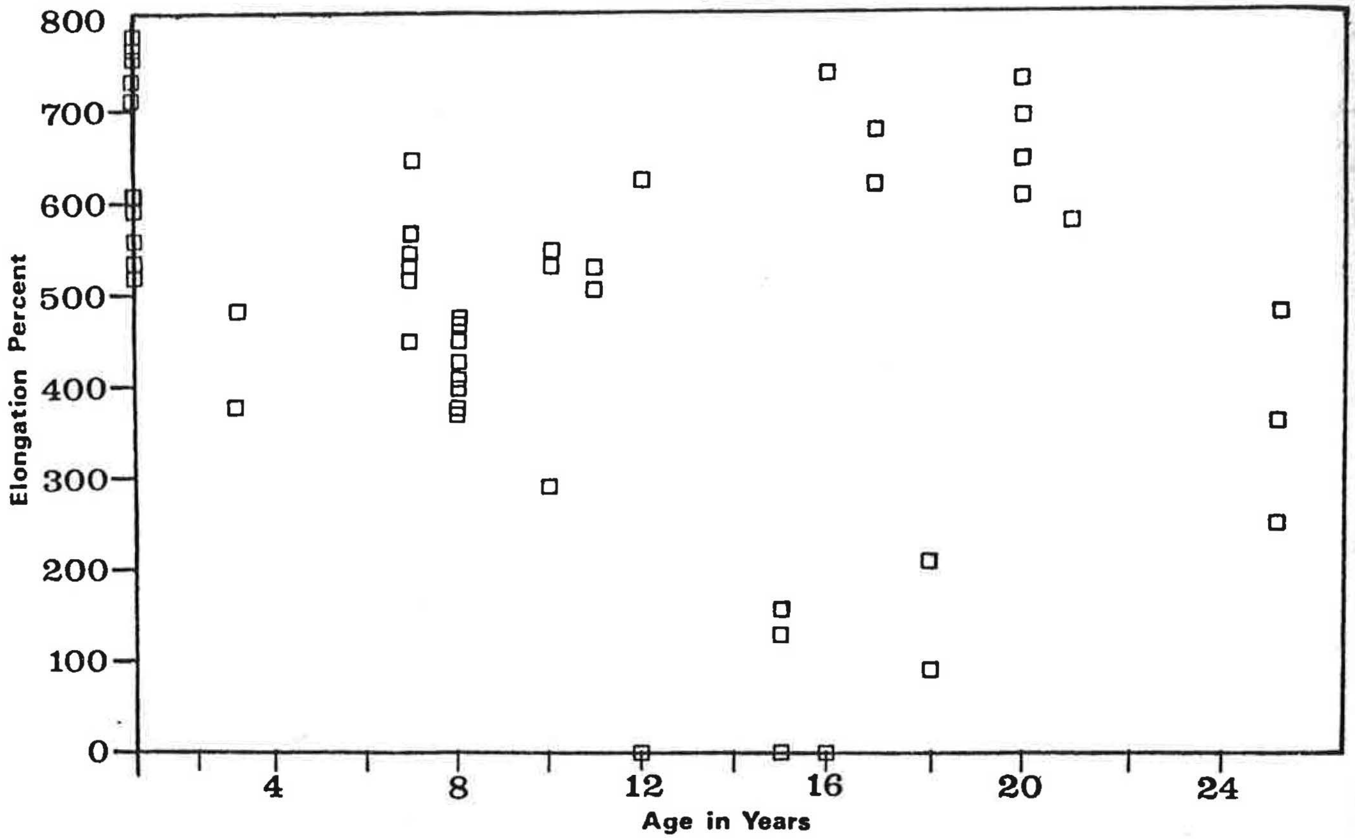
Results The physical tensile results are presented graphically in Fig. 1. It will be seen that there is a tremendous variation in the rates of degradation. Some samples showed no sign of physical degradation after a life of 20 years or more, others have failed completely in as little as 12 years. Only two of the deliberately sampled films (15 and 18 years old) showed degradation that would be cause for real concern.

The five cases where total failure had occurred (Fig. 2) were from Group 3 and were submitted by volunteers who had observed the failures independent of the study. It is impossible to estimate the statistical frequency of this type of failure however. What was quite interesting is that most of these films exhibited brittle zones running parallel to the film machine direction. Within an inch or so of the brittle zone the film was tough and apparently unaffected. Furthermore, the brittle zones exhibited the normal chemical (carbonyls) formation when examined by infra-red spectroscopy. In the tough zone nearby, carbonyls could not be detected easily. This evidence suggested that the degradation was induced by the film extrusion process.

A practical relationship between the exhibited brittle failure and the presence of carbonyls can be made. It is well known that a good method of such identification is with the use of a carbonyl index derived through an infra-red scan.

An attempt was made to correlate degradation with field service temperature. This was not observed, in fact, samples taken from above light fixtures showed nominally higher elongation than samples from other parts of the attic.

Figure 1. MAXIMUM ELONGATION BEFORE TENSILE FAILURE
Field Samples



<u>Significance of Field Study Results</u> The field study data suggested that a minority of current commercial vapour barrier films have inadequate durability to last the life of the house. Current standards for vapour barrier have no requirements to measure potential degradation characteristics. The Canadian General Standards Board (CGSB) and the Society of Plastic Industries (SPI) undertook a review of the current vapour barrier standard to determine whether requirements should be added to ensure reasonable performance of the film over time. The empirical justification for the new standard, which emerged, was based on accelerated testing of commercial films. This testing had been avoided by the film industry in the past and data are not generally available.

Findings from a second research project, commissioned by CMHC (Ref.3), showed it was possible to analyze data obtained from studies on polyethylene at elevated temperatures and applications, other than film for construction purposes, and permit tentative conclusions to be made, regarding longevity of polyethylene film. These findings, analyses and conclusions are presented here.

Figure 2. PHOTOGRAPHS OF FAILED FILM

Fig.2a

During rehabilitation of a 12 year old Bedford, Nova Scotia home, the owner found "4 mil" polyethylene film which had totally deteriorated. The film is thought not to have been exposed to extreme light or heat.

Fig.2b

During rehabilitation of a 16 year old Ottawa, Ontario home, the owner found tough, "6 mil" polyethylene film with distinct failure "seams".

It is suggested that the cause of this failure was a long-time (15 min) retention of the molten polyethylene, within the extruder barrel or die, during processing at elevated temperatures (250°c).

REVIEW OF AVAILABLE DATA ON OXIDATIVE DEGRADATION OF POLYETHYLENE

This section considers the hazards of estimating service life from accelerated testing data. Most studies of polyethylene degradation, as a result of oxidation, have been carried out at temperatures in the range of 100-200°c in order to accelerate the oxidation process. Under these conditions, polyethylene will have a life expectation ranging from one minute at 200°c, to one year at 100°c. At normal service temperatures polyethylene oxidizes too slowly to allow practical measurement to be made. It was thought desirable therefore to develop tests in the higher temperature range so that testing time is not too long.

To be useful, accelerated aging methods must be able to estimate how longevity, at higher temperatures, relates to longevity under normal service conditions.

Traditionally, the Arrhenius equation has been used for extrapolation from accelerated testing data. The Arrhenius equation can be written in the form:

$$\ln L - \ln Lo = \frac{E}{R}\left(\frac{1}{T} - \frac{1}{To}\right) \qquad (1)$$

Where L = life at temperatures T (°K)
Lo = life at a standard temperature To (°K)
E = Activation energy
R = Universal gas constant

Bell Laboratories (5) have shown that for polyethylene on copper wire, significant deviations from the Arrhenius equation do occur and that service life can easily be over-estimated by a factor of ten or more.

Some of the data published by Bell have been re-analyzed. Fig. 3 shows the data plotted in the traditional Arrhenius way and Fig. 4 shows the same data plotted to conform with Equation (2) where B is derived as a consequence of these studies and where L, Lo, To and T have the same meaning as in Equation (1).

$$\ln L - \ln Lo = B\,\frac{(To - T)}{10} \qquad (2)$$

It will be seen that Equation (2) goes a long way towards eliminating the curvature imposed by the use of Equation (1).

Similarly, some data published by Emanuel et al (6) shows the life of a polyethylene film varying with temperatures in the range of 40-200°c. Emanuel measures life by oxygen uptake, characterized by an absorption of 0.02 moles of oxygen per kilogram of polyethylene. He also presents data that suggests the time to brittle failure is four times that of initial oxygen uptake. Emanuel's data are shown in Fig. 5 plotted according to Arrhenius (Equation 1) and are also replotted in Fig. 6 (Equation 2). The empirically derived Equation (2) is thought to give a superior representation of the results. The data also show that the application of Equation (1) to the high temperature data would severely overestimate life at ambient conditions in some resins.

APPLICATION OF EXTRAPOLATION METHODS TO COMMERCIAL POLYETHYLENE FILM

The Ontario Research Foundation has generated some unpublished data on the thermal stability of a number of commercial films. They have measured oxygen induction times at 180°c and 190°c using differential scanning calorimetry. On the same samples, they have monitored the appearance of carbonyl groups at 100°c. These data have been separately extrapolated to 30°c using Equation (1) and (2). Equation (1) gives an average life of 1,000 years (9 different film samples), Equation (2) gives an average life of 30 years. The latter is in reasonable agreement with the actual field life of polyethylene film. The quality of this agreement is probably fortuitous but it perhaps adds to the confidence that might be placed in Equation (2).

RELEVANCE OF THIS RESEARCH TO PRODUCT DEVELOPMENT EFFORTS

When developing competing products it has been the practice to compare different formulations at convenient fixed temperatures. This approach simplifies the estimations of longevity. Implicit in this approach is the assumption that time-temperatures curves for differing formulations are roughly parallel. A broader review of published and unpublished data shows that this is not the case and the temperature sensitivity factor "B", shown in Equation (2), is much more dominant in determining life at ambient conditions. The data reviewed suggests that it should be possible to develop two different formulations having the same life at 100°c but their lives at 30°c could vary by a factor of 10 or more.

Figure 3. DEGRADATION OF PE INSULATION

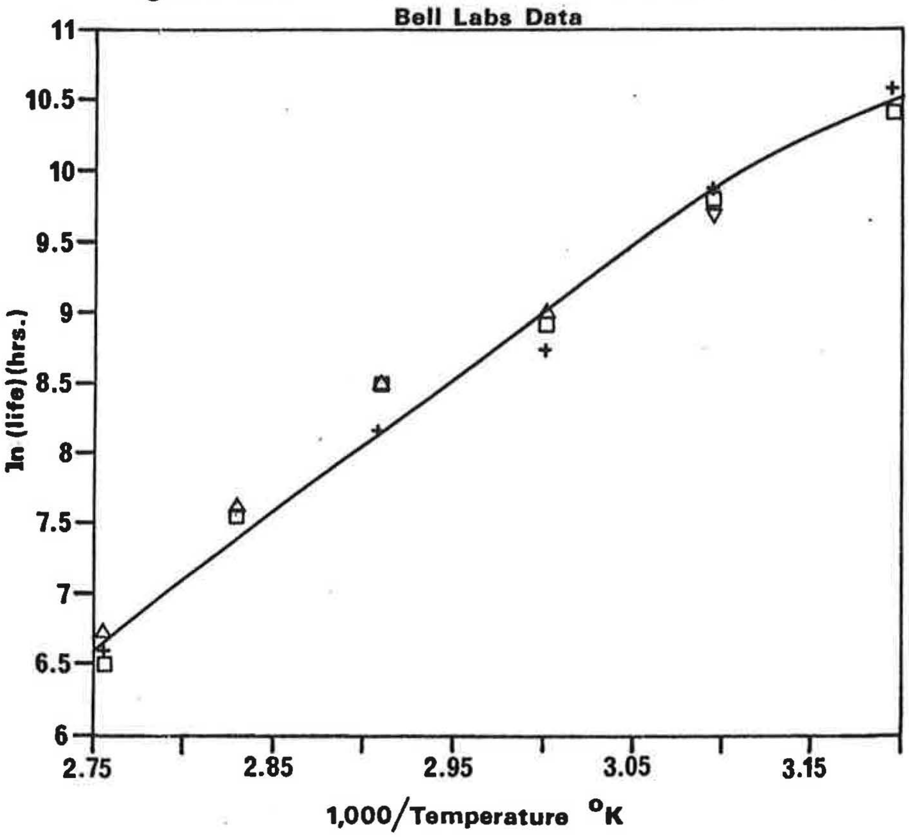


Figure 4. DEGRADATION OF PE INSULATION

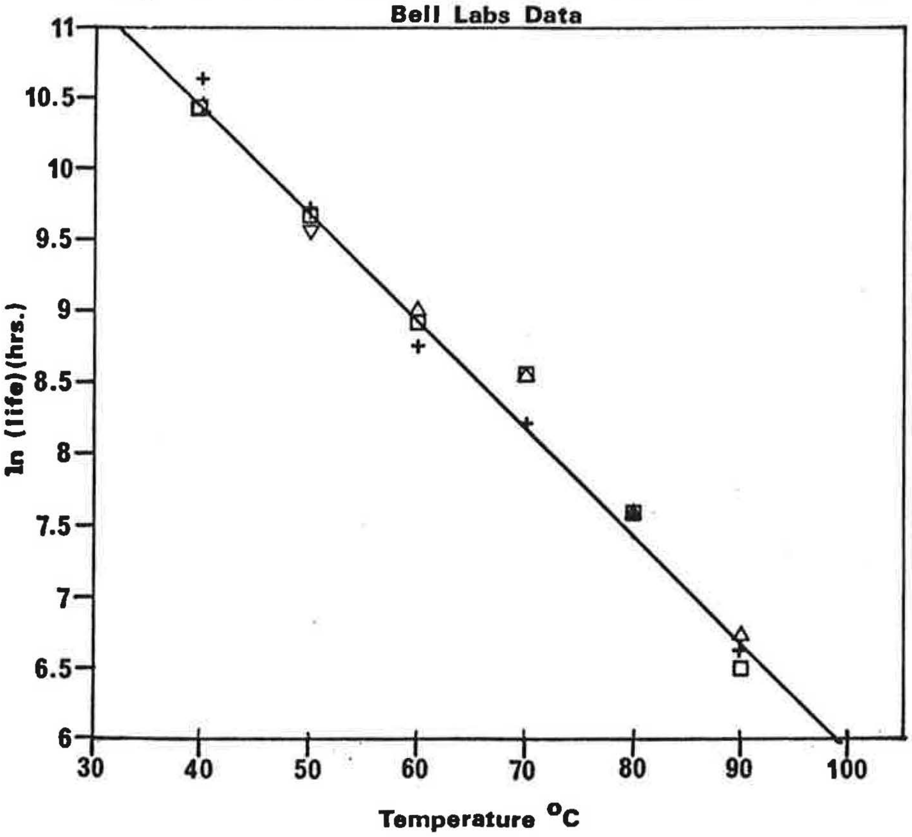


Figure 5. LIFE OF POLYETHYLENE
Data of N.M. Emanuel et al

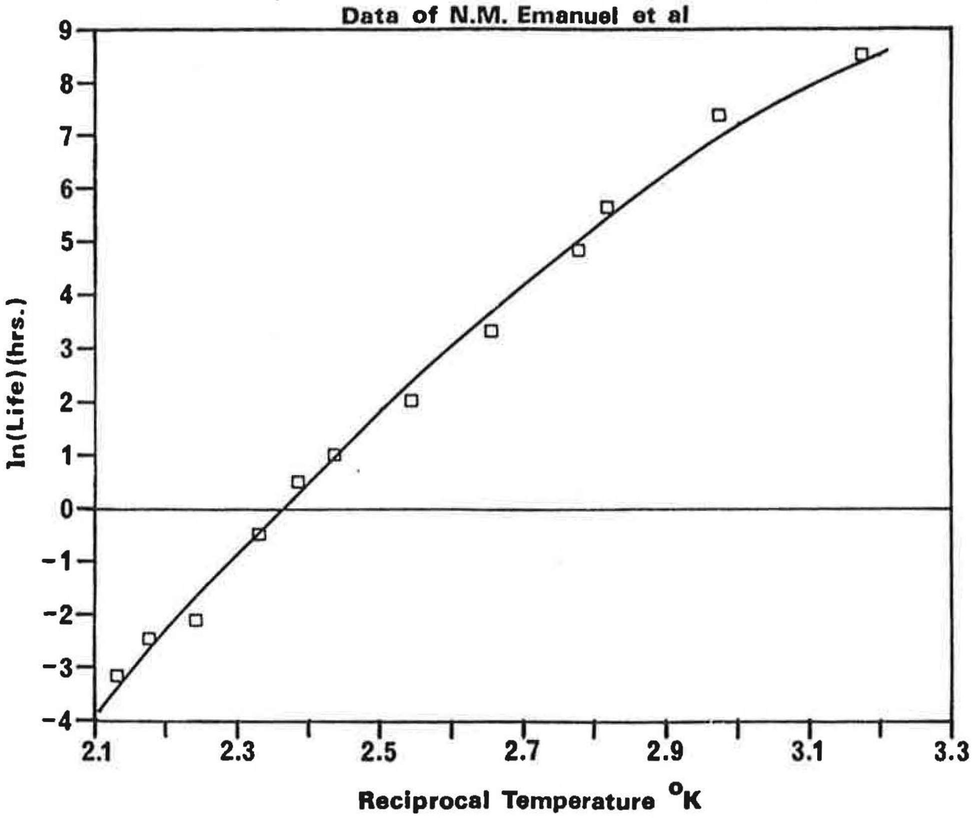
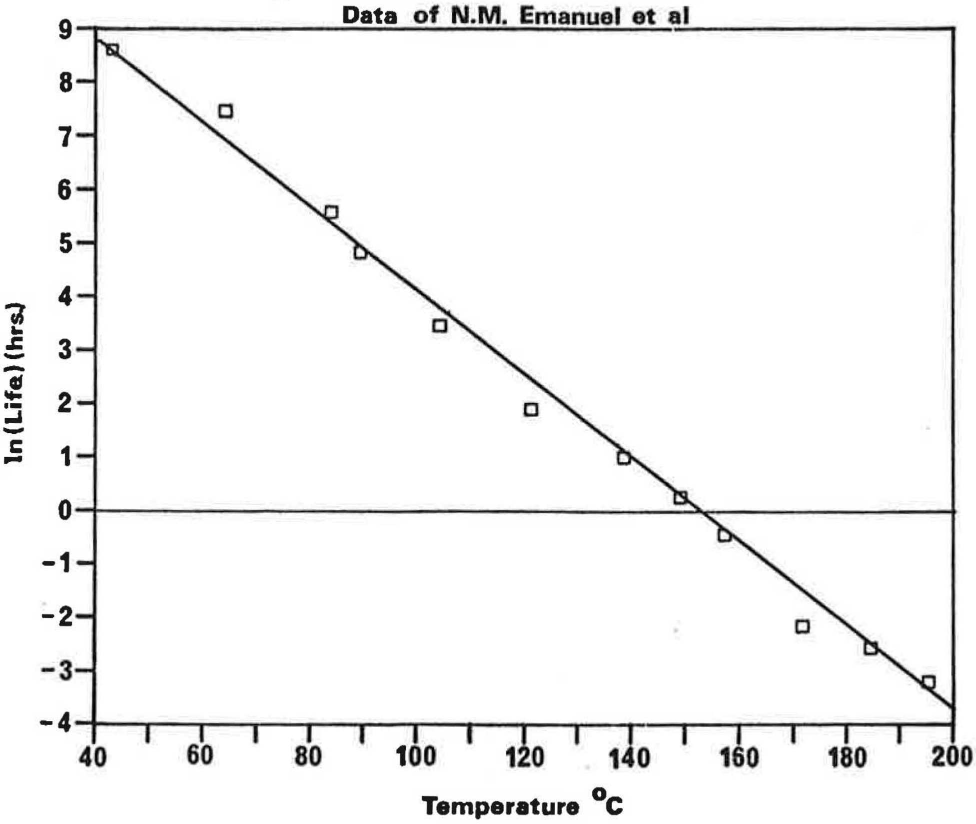


Figure 6. LIFE OF POLYETHYLENE
Data of N.M. Emanuel et al



CONCLUSIONS

Some current commercial vapour barrier films cannot be guaranteed to survive for the life of the buildings in which they are installed.

Popularly used methods to extrapolate accelerated testing data, will severely over-estimate the life of film at ambient conditions.

Improved extrapolation techniques are needed. One evaluation technique has been developed and needs further research to confirm its validity.

Product development that ignores the relationship of test temperature to temperature in service, will probably not provide realistic estimates of longevity.

SPI AND CGSB RESPONSE

As a result of these studies a Committee of the Society of Plastics Industry (SPI) was formed to make recommendations to the relevant standard writing body, Canadian General Standards Board (CGSB) on changes to its vapour barrier standard.

In June '85, the SPI recommendations were presented to the CGSB Committee on Moisture and Vapour Control. This committee accepted the recommendations in principle and agreed to incorporate the recommendations into the proposed standard and submit them to a letter ballot of members.

Highlights of these changes are:

Outdoor Weathering Resistance The previous standard made no reference to this feature.

One of the requirements in the proposed new Canadian standard follows the Scandinavian example and requires protection of the unpackaged film to survive at least three months' outdoor exposure as implied by weatherometer testing. In addition, the product must be packaged with ultra-violet-resistant material to avoid exposure in the distribution system.

Resin Properties Another change is to prohibit the use of reclaim or recycled resin. While there is no direct evidence that the use of reclaim affects the durability of polyethylene, there is ample indirect evidence that it will promote uncertainty in the reliability of the film product.

The proposed standard also requires the melt index and resin density to fall within restricted limits. This is intended to ensure general toughness and provide a reasonable range of handling characteristics.

Tensile Strength and Elongation Film durability in the new standard is being addressed through requirements for thickness control, impact testing and thermal stability. These measures are non-existent in the existing standard. The minimum thickness has been set at a value triple that of current practice.

Thickness Most existing vapour barrier film is nominal "2 mil." In practice this may range from 35 microns (1.4 mils) to 45 microns (1.8 mils). While providing adequate performance as a vapour barrier, these films have limited ability to withstand any mechanical abuse. The recommended new standard calls for an average thickness of 150 microns and a minimum spot thickness of 120 microns, making it tough as a vapour barrier and much more appropriate as an air barrier (Ref. 1).

Impact Strength The puncture resistance of films can be assessed in a large number of ways. Dart Impact strength is a commonly used assessment and has, in general, reflected field performance. The inclusion of a 300 gram Dart Impact requirement in the new standard, provides assurance of tougher behaviour.

Thermal Stability Observation of thermal oxidation of polyethylene film, in existing buildings, was the principal reason for SPI's comprehensive review and recommendations for change to the earlier CGSB standard. High level assurance of oxidative resistance can be provided only if accelerated testing is carried out over a period of one year or more. Although no known short-term test can provide absolute assurance of the durability of any polymer system, such tests are the only practicable way, at present, to estimate probable longevity.

The ASTM test for oxidative induction time (OIT) was chosen by SPI as a method for estimating the thermal stability of film. In this test, a small sample of polyethylene film is heated at a constant chosen temperature (here 190°c) in nitrogen and the atmosphere then switched to oxygen. The character of the oxidation is such that no discernible chemical reaction occurs during an induction time. This quiescent period is followed by an accelerating reaction within the resin which is easily detected by sensitive themocouples that measure the temperature of the sample undergoing an exothermic reaction.

The use of the OIT is perhaps the most contentious issue in the SPI proposed revisions to the standard. Even though OIT test at 190°c may have little relevance to performance at 10-40°c, no other tests method exists for evaluating longevity at the normal range of service temperature. (It must be remembered, however, that the needs of the industry dictate certain requirements: first, that the test does not take too long; and, second, that it can be used to ensure that the specification is being honoured.) There was consensus among SPI participants that all future vapour barrier films should be adequately stabilized with an appropriate antioxidant. The OIT test is a well-established method to verify this.

The proposed standard requires an OIT of 30 min. at 190°c. This time to oxygen induction is approximately 10 times better than the OIT given by current commercial industrial films, which are essentially unstabilized.

Film Marking (Identification) The new standard has been written so that the source of film must be easily identified in the as-applied condition.

Packaging Packaging requirements to provide protection from ultra-violet radiation are covered under "Outdoor Weathering Resistance".

ENFORCEMENT

It is a relatively simple technical procedure to raise the existing standards of polyethylene films. This activity however, may meet some commercial resistance since the market is under intense competition, which has led to under-gauging and the use of reclaim resin. The majority of Canadian film producers have agreed to support a new, higher quality standard.

The new CGSB standard for vapour barriers is now in the process of being letter balloted. CGSB have been requested by the plastics industry to institute a certification program which will provide the building industry with an assurance that they can buy a product that consistently meets or exceeds the standard.

Successful manufacturers will be licensed to use the CGSB Certification Mark on this film product. These products will be identified by a conformance number and listed and published in a Manufacturers Certification Program list, which is available to buyers and consumers. It is hoped that this certification program will influence all manufacturers to conform to the new standard.

The new standard will be designated as CAN/CGSB 51,34-M87 Polyethylene, Vapour Barrier, Sheet.

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