# Improved Performance Standards for Polyethylene Sheet Vapour Barriers

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BTECC SYMPOSIUM

# Guidelines for Air Infiltration, Ventilation and Moisture Transfer

Fort Worth Texas
December 2-4, 1986

## 1. INTRODUCTION

This paper presents the findings from two specific 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 interested industry and standards writing bodies responded. Their related standard writing activities are discussed. Delivery of reliable future film product is now expected.

A method of estimating polyethylene film life is presented here also.

A limited review is given also of the Canadian government's housing agency activities, particularly in relation to technical research projects.

## 2. ROLE OF CANADA MORTGAGE AND HOUSING CORPORATION

Canada Mortgage and Housing Corporation (CMHC), the federal government's housing agency, is responsible for administering the National Housing Act (NHA). Its mission is "to promote the construction of new houses, the repair and modernization of existing houses, and the improvement of housing and living conditions". In addition, CMHC and the NHA have been used to further such government objectives as economic growth, job creation, and energy conservation.

Under the terms of the NHA, the Corporation is authorized, on the government's behalf, to establish a system of mortgage loan insurance: to acquire lands for public purposes; and to assist Canadians, mainly by the provision of loans and contributions, in gaining access to suitable accommodation, whether as homeowners, tenants or members of cooperative organizations, and in improving existing dwellings and the quality of their community environment. It also has a general mandate to improve the quality of housing and community planning through research, development, materials evaluation and the dissemination of useful information, and to act as a policy advisor to the government.

Within the Research Division at CMHC, performance of some existing building materials and building systems have been recently reviewed; particularly as a sequal to energy conservation measures. In addition, and where required, division personnel have encouraged industry trade groups and standards writing authorities to upgrade their requirements, so that the quality of housing is improved, without dramatic increases in first time costs and ongoing or operating costs for housing.

The following case study shows how, with changing technical demands being placed on one building product, quality improvement of that product has been achieved, through the use of field derived data, laboratory data and theoretically derived longevity concepts being reflected in a revised standard.

Quite separate from the Research Division, CMHC has another technical staff group called Materials Evaluation. The role of Materials Evaluation staff is to ensure that the performance of materials which get incorporated into a structure, financed by CMHC, will last at least as long as the amortization period of the mortgage. As a consequence of their activities, the homebuilder is able to buy a product that he feels is reliable if it has been evaluated by CMHC. Although CMHC's lending and mortgage insurance activity directly affects no more than 30% of the Canadian housing market, its numbered evaluation reports, are sought by building product suppliers wishing to reach all Canadian housing markets.

The basic criterion of evaluation is conformance to applicable Canadian standards as published by standards writing organizations accredited by the Standards Council of Canada, (Ref. 1). This document was presented by G.L. Walt in April 1986 to the WOBO meeting in New Zealand.

## 3. PROBLEM IDENTIFICATION

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 polyethelene film 9 ft. wide to form Type I. The code was unclear as to thickness for these vapour barriers. Commercial choices for most builders were reduced to "2mil poly". From a theoretical vapour diffusion point of view this thickness was adequate. However, the basic toughness of a 2mil film precluded its use as an air barrier.

With the movement 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, as an air barrier, the polyethylene film that had evolved as the material of choice for vapour barriers.

Polyethylene film first appeared in the Canadian west in the early 1950s as a ceiling vapour barrier replacing the asphalt-kraft and wax-kraft papers used under loose fill attic insultations. Polyethylene subsequently gained attention throughout the midwest USA and central and eastern Canada as an outstanding ground cover material in the "heated crawl space" affordable houses which emerged in the mid 1950s to early 1960s. During the 1960s it made further inroads in the east when it was brought into wider use when electrically heated houses gained popularity. In these houses it was used primarily in the ceiling until the 1970s 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 serve a nebulous function. 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, 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. Vapour barrier and air/vapour barrier integrity 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 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 is also appropriate at this time.

While other Canadian papers are examining the air barrier issue (Ref. 2), 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.

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.

## 4. 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. | Houses deliberately entered and inspected | 15 |
| 2. | Samples of brand new film obtained from manufacturers and distributors | 6 |
| 3. | Samples submitted by volunteers, who observed the film to be in an unusual state (usually brittle or broken down) | 7 |
| | | 28 |

In some of the houses deliberately sampled, multiple samples were taken in order to detect variations in degradation rate. 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 appearance, tensile testing was carried out on the non-brittle samples (Ref. 3), and film gauge was measured.

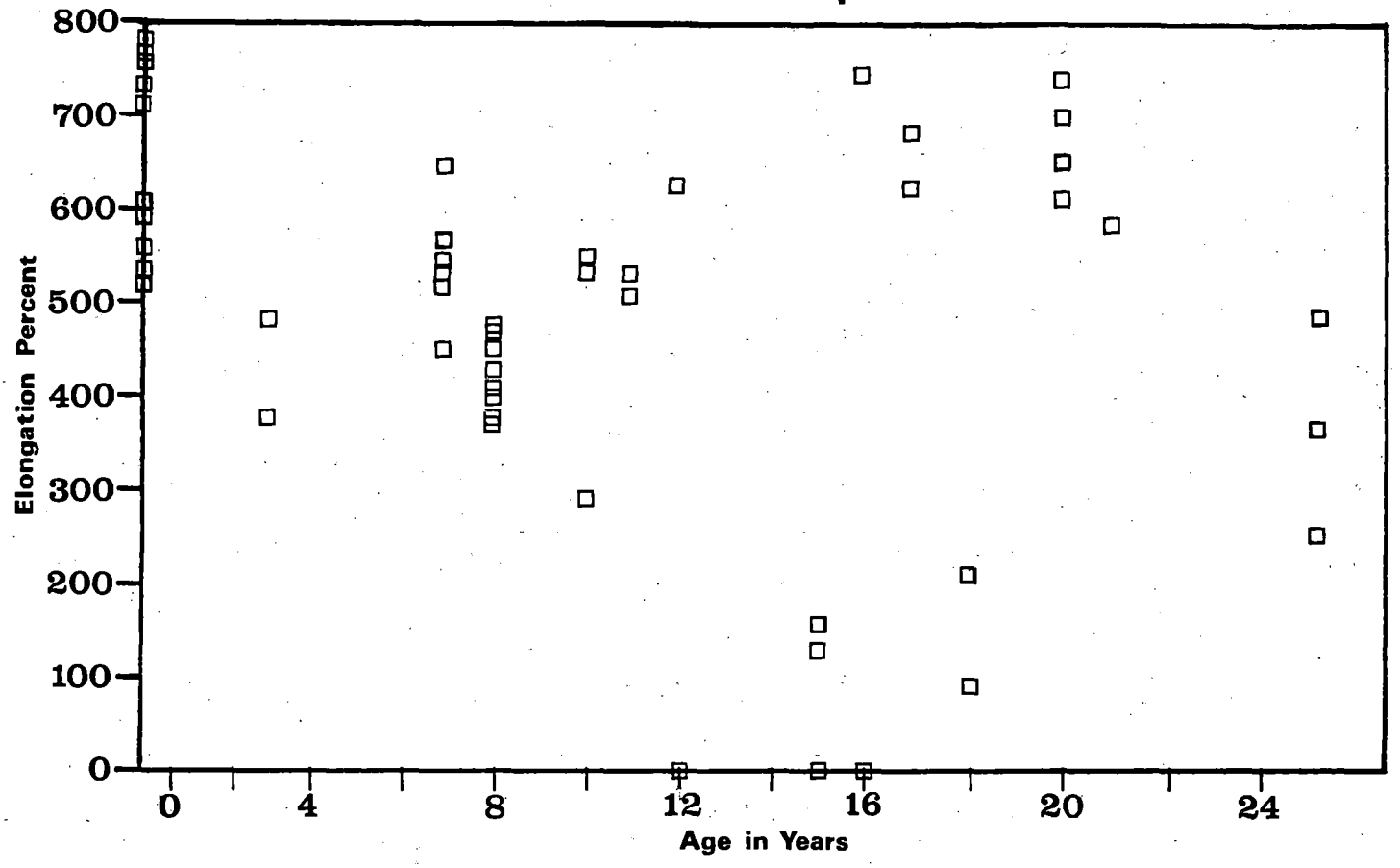
### Results

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.

There were five cases where total failure had occurred (Fig. 2). These examples were all submitted by the volunteers who had observed the failures independent of the study. It is impossible to estimate the statistical frequency of this type of occurrence due to the random sources of the failed film. 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. 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 thermal instability was induced by the film extrusion process.

An attempt was made to correlate degradation with field service temperature. Conceptually, such a correlation should exist, but in this study it could not be observed. For example, samples taken from above light fixtures showed nominally higher elongation than samples from other parts of the attic. No significance can be attached to this perverse result.

**Figure 1. ELONGATION VERSUS AGE**
**Field Samples**




Significance of Field Study Results

The field study data suggested that a minority of current commercial vapour barrier films have inadequate durability to last the life of their supporting structure. Such a finding required a review of the existing standards. The Canadian General Standards Board (CGSB) together with the Society of Plastic Industries (SPI) undertook such a review. 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. 4), showed it was possible to analyze data obtained from polyethylene kinetic studies and polyethylene 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

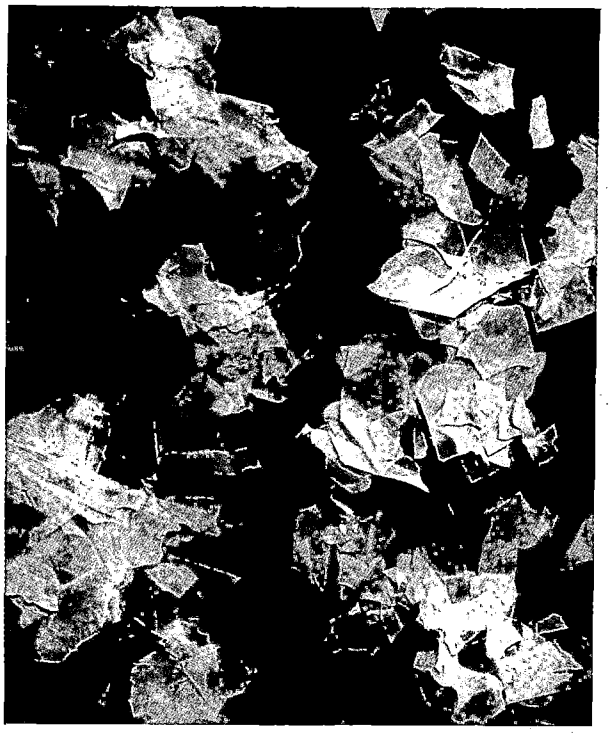


Fig. 2a During rehabilitation of a 12 year old Bedford, Nova Scotia home, the owner found "4 mil" polyethylene film which had totally deteriorated. The film is thought not to have been exposed to extreme light or heat.

Fig. 2b During rehabilitation of a 16 year old Ottawa, Ontario home, the owner found tough, "6 mil" polyethylene film with distinct failure "seams". Unnecessary extruder hang-up is suggested for inducing this failure mechanism.

## 5. REVIEW OF AVAILABLE DATA ON OXIDATIVE DEGRATION OF POLYETHYLENE

Most oxidative degradation studies, on polyethylene, have been carried out at temperatures in the range of 100-200°C. Under these conditions, polyethylene will have a life ranging from one minute at 200°C to one year at 100°C. It is thought desirable therefore to develop tests in this temperature range so that testing time is not too long.

To be really useful, methods must also be developed to extrapolate to ambient conditions the life data at elevated temperatures.

Traditionally, the Arrhenius equation has been used for extrapolation from accelerated testing. 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 temperture To (°K)
E = Activation energy
R = Universal gas constant

While this is a powerful tool, Bell Laboratories have shown that for polyethylene on copper wire, significant deviations from the Arrhenius equation do occur. If these deviations are not recognized, polyethylene product 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 the equation:

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

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 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 that time to brittle failure is four times that of initial oxygen uptake. Emanuel's data are show in Fig. 5 plotted according to Arrhenius (Equation 1) and also replotted in Fig. 6 (Equation 2). Once again Equation (2) gives 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.

**Figure 3. DEGRADATION OF PE INSULATION**

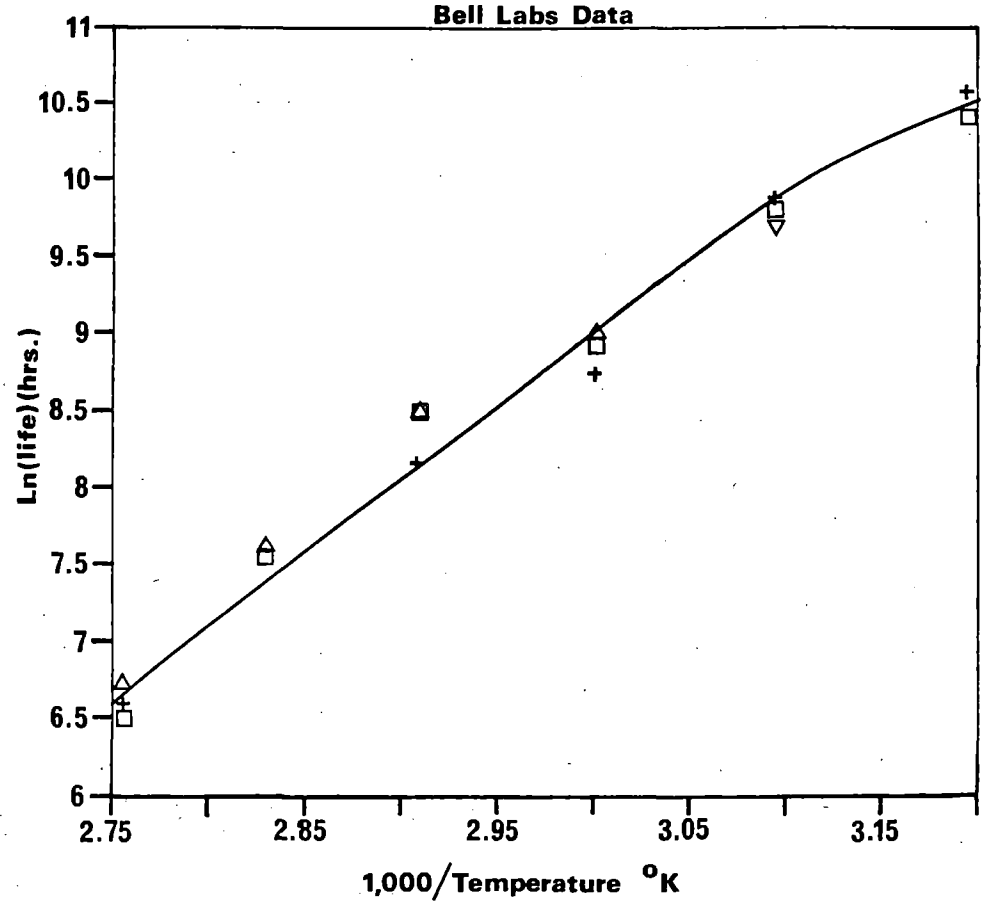



**Figure 4. DEGRADATION OF PE INSULATION**

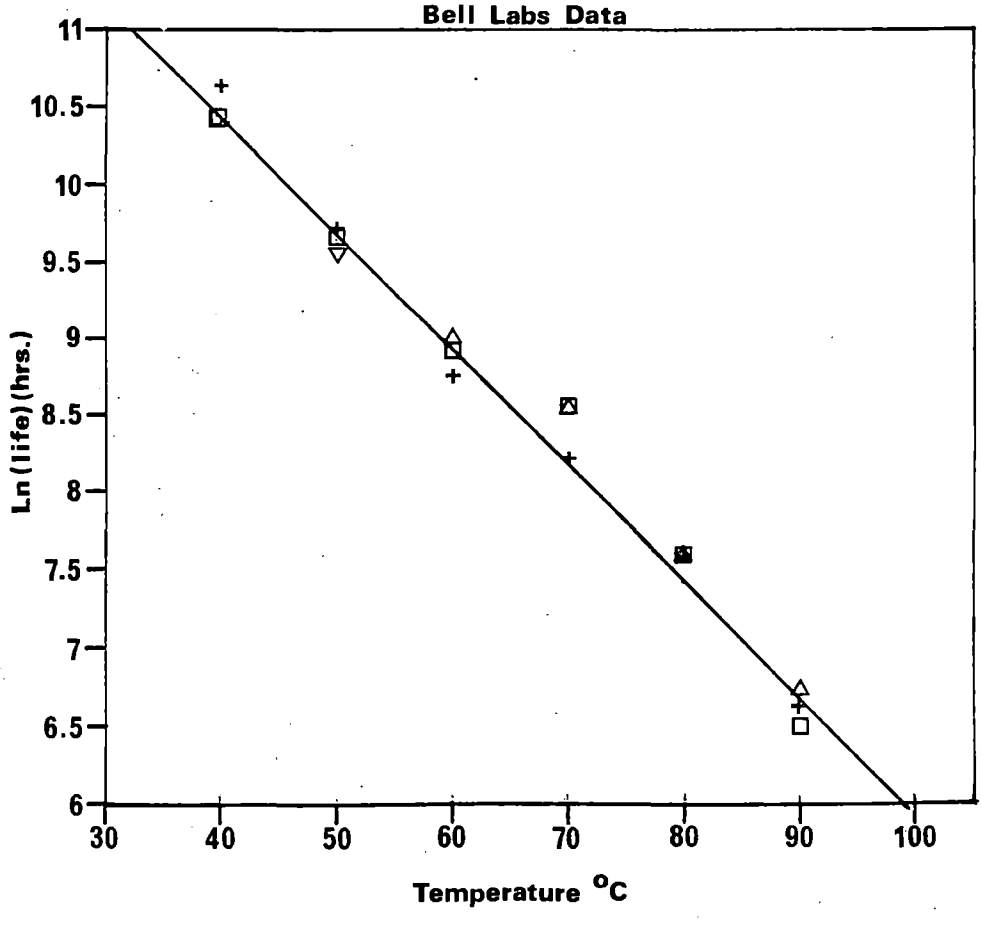


**Figure 5. LIFE OF POLYETHYLENE**

Data of N.M. Emanuel et al

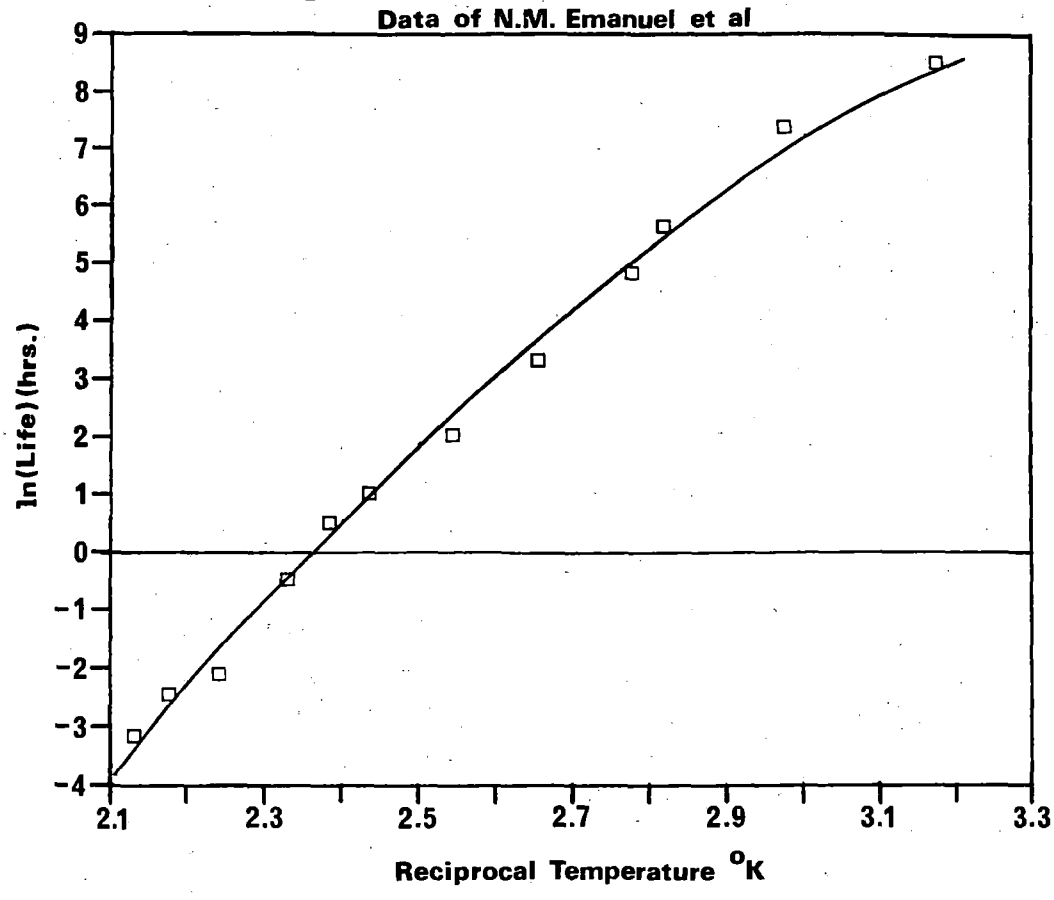
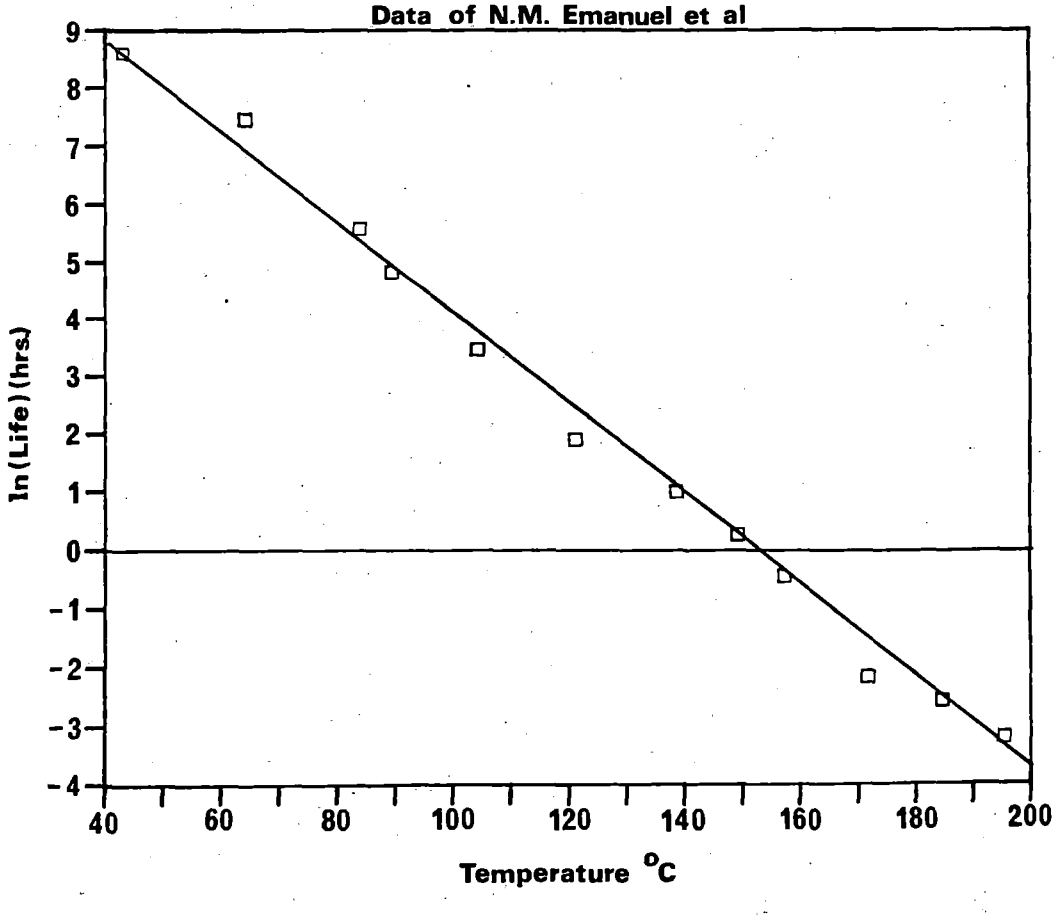



**Figure 6. LIFE OF POLYETHYLENE**

Data of N.M. Emanuel et al



## 6. 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 Equations (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 excellent agreement with the actual field life of polyethylene film. The quality of this agreement is probably fortuitous but it certainly adds to the confidence that can be placed in Equation (2).

## 7. RELEVANCE OF THIS RESEARCH TO PRODUCT DEVELOPMENT EFFORTS

Development of improved formulations have tended to compare competing formulations at convenient fixed temperatures. This simple approach has no doubt been inspired by the tedium of studying more than one temperature and the impossibility of obtaining timely results with testing being carried out at temperatures below 100°C. 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.

## 8. 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 technique are needed. One evaluation technique has been developed and needs further research to confirm its validity.

Product development that ignores temperature sensitivity, will likely produce inferior service life in polyethylene films.

## 9. SPI AND CGSB RESPONSE

As a result of CMHC's findings, a Society of Plastics Industry (SPI) committee was formed to make recommendations to the relevant standard writing body, Canadian General Standards Board (CGSB) on changes to its

vapour barrier standard. It reviewed the old standard clause by clause. Extensive attention was given to the issue of thermal stability. The results of the committee's deliberations were presented to a wide audience of industry representatives and to CMHC, CGSB and to the Dept. of Energy Mines and Resources, at a meeting in March '85.

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 draft them according to its own standards and submit them to a letter ballot of members.

Highlights of these changes are:

Test Methods

A number of evaluative tests have been added to the new standard. Appropriate ASTM designations have been specified.

Outdoor Weathering Resistance

The previous standard made no reference to this feature. The proposed new Canadian standard follows the Scanadivian 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. These measures should protect the product in all conditions other than those that could be described as extremely abusive.

Resin Properties

The most significant change is to prohibit the use of reclaim (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 restricts the melt index and density of the resin to less than 1.5, and 0.905 to 0.930, respectively. The joint use of these two factors will ensure general toughness and provide a reasonable range of handling characteristics.

Tensile Strength and Elongation

In the new standard, reliance for film durability has been transferred to gauge control, impact testing and thermal stability. These measures are non-existent in the previous standard. Gauge has been set at a value triple that of current practice.

Thickness

Most existing vapour barrier film is "2 mil." It is industry practice to run as low as 35 microns (1.4 mils) and film is rarely found above 45 microns (1.8 mils). While providing adequate performance as a vapour barrier, these films have limited physical durability when subjected to 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 adaptable to air barrier needs (Ref. 2).

Impact Strength

The field durability 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 specification provides assurance of tougher behaviour.

Thermal Stability

Observation of thermal oxidation of polyethylene film in existing buildings was the "raison d'être" of SPI's comprehensive review and recommendations for change to the earlier CGSB specification. High level assurance of oxidative resistance can be provided only if accelerated tesing is carried out over a period of one year or more. No known short-term test can provide absolute assurance of the durability of any polymer system. However, a short-term test was the only practicable route to satisfy requirements of CMHC and SPI.

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 the 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. Critics will argue that OIT at 190°C can, under some circumstances, have little relevance to field performance at 10-40°C. It must be remembered, however, that the needs of the field 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 also that all future vapour barrier films should be adequately stabilized with an appropriate antioxidant. The OIT test is a well-established method for indicating the presence of antioxidants.

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. The significance of this improvement was discussed in more detail in Section 5 which considered the opportunities and hazards of extrapolating accelerated testing to field conditions.

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

The packaging requirements have been upgraded to require protection from ultra-violet radiation.

## 10. ENFORCEMENT

It is a relatively simple matter, from a technical point of view, to raise the existing standards of the polyethylene films now used as vapour barriers and likely to be used as air/vapour barrier materials. Raising standards from the commercial and regulatory point of view is not easy. The vapour barrier film market had suffered from intense competition. The chief competitive weapons being under-gauging and the use of reclaim resin. While the majority of Canadian film producers have agreed to support a new higher quality standard, the response of a minority of producers is not known.

The new standard has been presented to the Canadian General Standards Board on Air Moisture and Vapour Control and is now in the process of letter balloting. 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 as a purchasing source document for buyers and consumers. In this way it is hoped that product liability considerations will be accounted for when this most import home construction component is chosen by builders and installers.

The new standard is called Polyethylene Vapour Barrier Sheet CAN/CGSB 51.35-M.

Ref. (1) Development and Application of the Codes and Standards for Canadian Housing. G. Walt, Canada Mortgage and Housing Corporation, April 1986.

(2) Building Practice Note. BPN54, The Difference Between a Vapour Barrier and an Air Barrier, by R.L. Quiroutte. Institute of Research in Construction, National Research Council, Canada.

(3) Field Investigation of Service Life Characteristics of Polyethylene AIR/VAPOUR Barrier. By Scanada Consultants and Plastecnics. For CMHC, April 1984.

(4) The Long Termn Service Life of Polyethylene Film at Ambient Conditions. By Plastecnics. For CMHC, July 1985.

(5) Canadian General Standards Board, Polyethylene Vapour Barrier Sheet, CAN/CGSB 51.35-M.