THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

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Seepage Control with Plastic Membranes

A Literature Survey and Annotated Bibliography

by

J. R. Burton and T. R. Fietz

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SEEPAGE CONTROL WITH PLASTIC MEMBRANES - A LITERATURE SURVEY AND ANNOTATED BIBLIOGRAPHY.

by

J. R. Burton and T. R. Fietz.

A Report to the Water Research Foundation of Australia, Limited.

January 1962.

PREFACE

This is the first of a series of reports to the Water Research Foundation of Australia on an investigation into the use of plastic films for seepage control in farm dams and small reservoirs.

This research programme was commenced early in 1957 and was substantially completed in 1961. Some handling tests and long-term durability trials are continuing.

The investigation was supported by grants from the Water Research Foundation of Australia, which were made possible through the generosity of Imperial Chemical Industries of Australia and New Zealand Limited. It was initiated by Professor J. P. Baxter, Vice-Chancellor of the University of New South Wales.

This literature survey was assisted by officers of I. C. I. A. N. Z. Ltd. and Moulded Products (A'sia) Ltd., who made certain company publications available.

Laboratory studies in connection with the plastic membrane research programme were made at the Water Research Laboratory, Manly Vale, N. S. W. The programme was under the direction of Mr. J. R. Burton of the Laboratory Research staff. He was assisted in this literature survey by Mr. T. R. Fietz, who was then a Research Fellow at the laboratory.

H. R. Vallentine
Assoc. Professor of Civil Engineering
Officer in Charge of the Water
Research Laboratory.

22nd January, 1962.

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SEEPAGE CONTROL WITH PLASTIC MEMBRANES - A LITERATURE SURVEY AND ANNOTATED BIBLIOGRAPHY.

Part 1. LITERATURE SURVEY.

1. INTRODUCTION.

During the past decade a keen interest in the conservation of water has developed amongst Australian landholders. This interest is evidenced by the widespread use of water held in farm storages for the supplemental irrigation of pastures and fodder crops, and has been stimulated by the enthusiasm of men like H. J. Geddes and P. A. Yeomans, who have achieved notable results through intensive water conservation practices.

Because of this new water consciousness farm dams and tanks are being constructed in ever-increasing numbers. The adoption of supplemental irrigation, with its heavy water requirements, has brought about a significant increase in the size of the average farm dam, whilst damsites which have hitherto been passed over as unsuitable are now being exploited in the endeavour to conserve as much water as possible. The design and construction of these new storages may present appreciable engineering problems, and farm dam building is rapidly assuming such importance as to merit the serious attention of the engineering profession.

An engineering problem frequently encountered is that of reservoir leakage. All earth embankments must, by their nature, allow the passage of seeping waters, but good design and construction and careful selection of materials enable this flow to be restricted within safe limits. Dam foundations and reservoir floors are normally selected so that percolation losses are relatively insignificant. In farm pond construction, however, it is often desirable that reservoirs be built in locations where careful material selection is not possible and where the reservoir floor may be extremely porous. In such cases an economical method of seepage control is essential to the successful functioning of the storage.

Many methods are available for the control of seepage losses. Such techniques as concrete slab or gunite linings, bituminous sprays or coatings, stabilisation with cements, bitumens or trace chemicals, pre-fabricated lining membranes, compacted earths or clays and the use of bentonites or sediments, all of which are employed in the treatment of irrigation channels, have been adapted from time to time to the sealing of small reservoirs. Farm storages however, differ in their requirements from irrigation channels; in particular, economic conditions are such that low material cost and simplicity of installation are primary considerations.

In the early 1950's the plastics industry began to make available large quantities of plastic film materials which, possessing desirable chemical, mechanical and waterproofing properties, offered interesting possibilities as lining materials for farm storages. Limited experience in the United States with experimental liner installations indicated that polyethelene and polyvinyl chloride films in particular, might have valuable application in this regard.

At the beginning of 1957 the Water Research Foundation of Australia, supported by grants from Imperial Chemical Industries of Australia and New Zealand Limited, financed a project at the School of Civil Engineering of the University of New South Wales under the title of "the sealing of small earth dams by the use of plastic membranes". With the support of the Foundation this project continued until 1961. The object of the project was to examine the feasibility of this method of seepage control under Australian conditions.

This report surveys the literature on seepage control with plastic membranes and outlines the particular problems which appeared most to merit treatment in the University of New South Wales programme. Subsequent reports discuss research progress in detail.

2. A SURVEY OF PLASTIC LINER APPLICATIONS

2.1 Early United States Experiments.

The available literature on plastic liner applications is extremely limited. The earliest liner experiments appear to have been undertaken in 1954; little or nothing appears in the literature before 1956. Research reports are few, the bulk of the literature comprising newspaper items, popularised articles or sales promotion brochures. No reports of the long-term behaviour of field liners have yet been published.

The earliest liner experiments, and the most detailed continuing studies of liner behaviour, were conducted by Dr. C.W. Lauritzen and Dr. F. Haws of the Agricultural Research Service, U.S.D.A., at Utah Agricultural Experiment Station, Logan, Utah. Their studies, which commenced in 1954 (Lauritzen, et al: 1956) comprised laboratory and field investigations of the suitability of polythelene (PE) and polyvinyl chloride (PVC) films.

Lauritzen and Haws measured biological deterioration root and sprout penetration and outdoor weather ageing. They showed that both materials were resistant to rot and to the penetration of roots and shoots. Two years of outdoor weathering indicated that polythene could be expected to have a reasonable service life, provided that a black pigmented formulation was used, but that PVC deteriorated rapidly. Permeability and rupture tests showed that the films could withstand heads of 30 p.s.i. on an angular gravel base.

Anticipating that the plastics would generally be used as buried membranes, Lauritzen and Haws studied the effects of dumping cover material onto films of varying thickness. It was found that light-gauge polythene films were particularly susceptible to damage and it was recommended that a 3" cover of sand be spread over the membrane before placing cover material. PVC, on the other hand, was particularly resistant to mechanical damage. Tests to determine the steepest slopes on which cover could be expected to remain in place, showed that in still water with a rapid drawdown the steepest slopes allowable were $2\frac{3}{4}$ to 1 for PE and $2\frac{1}{2}$ to 1 for PVC. It was also shown that filling the pond with water prior to dumping the cover material could greatly reduce mechanical damage.

In 1954 and 1955 eight small test ponds were excavated at Logan and lined with polythene or PVC in 4 and 8 mil gauges. These ponds were 40 feet square at the top with 2 to 1 side slopes and an overall depth of about 5 feet. Seepage measurements indicated extremely low seepage losses, the greatest loss occurring in the 4 mil exposed PE liner, which suffered a great deal of puncturing and holing. A buried 8 mil PE liner also showed high losses, the result of handling damage during installation.

In 1955 two farm ponds in Canada were lined with buried 8 mil polythene liners, and early in 1956 a pond at Emery, Utah, was lined with an 8 mil buried olive green PVC membrane. Limited seepage measurements indicated very low initial seepage losses.

The general conclusions reached by Lauritzen and Haws were that polythene was the most suitable material, because of its greater outdoor durability, and that it should be used as a buried liner, preferably in 8 mil gauge. They cautioned that extreme care was necessary in handling and installation, and suggested that problems of field fabrication and a tendency to fail along film folds had yet to be overcome. There was however, an implication that if a durable PVC film could be developed it would have advantage over PE because of its excellent resistance to mechanical damage and the ease with which it can be fabricated.

In 1954 V. H. Scott, at the Davis campus of the University of California, commenced an investigation into the feasibility of prefabricated liners for small irrigation ditches. Amongst the materials tested were black polythene in 8, 6, and $1\frac{1}{2}$ mil gauges, 4 mil clear PVC and 8 mil and 4 mil white PVC. The plastic membranes were all used as exposed liners in ditches having a wetted perimeter ranging from 4 to 6 feet and with side slopes of $1\frac{1}{2}$ to 1. The conditions were therefore not typical of the usual farm dam situation, but the results obtained are relevant to this study.

The results after two years' investigation (Scott 1956) tended to confirm Lauritzen's conclusions regarding the superiority of polythene. The vinyl films deteriorated rapidly, the 4 mil materials being useless before the end of the first season. The heavier gauge polythene liners were still in good condition after two years, although small holes developed above the waterline and an effective repair technique could not be found. It should be pointed out, however, that white and clear PVC's have never been recommended for prolonged outdoor use, and more recently developed outdoor PVC formulations could have been expected to have given a much better performance. Scott reported that the $1\frac{1}{2}$ mil black PE became useless after the first season, due to extensive holing.

Scott also reported that exposed liners gave much better seepage control than buried liners. The reasons for this are not clear, and it should be emphasised that there were no buried plastic membranes for a direct comparison with the exposed plastics. There is an implication, however, that the exposed liner might have advantages other than its lower cost and ease of installation: simple location of punctures, easier maintenance and freedom from damage by roots and burrowing animals are possible factors.

Other early American experiments have been reported from time to time but no details have been published. An exception is the work at Clemson College, S.C., where a PVC liner was installed in 1956 (Anon: Popular Mechanics, 1956). In 1958 this liner was reported to be in good condition. (personal communication).

2. 2. Australian Experiments

The first liner experiment in Australia was the sealing of the municipal reservoir at Ouyen, Victoria, with a polythene membrane in 1955. At that time this was the largest plastic-lined reservoir in the world (Anon: Plastic Sphere, 1956).

The Charlton reservoir was constructed for town water supply use in the 1920's but had never been used for this purpose because of very high seepage losses. It was lined with polythene in 1955 in an attempt to provide a leakproof tank for C.S.I.R.O. experiments with cetyl alchol anti-evaporant.

The circular reservoir was lined with an 8 mil. black polythene membrane buried under 6 inches of soil. Sealing of the polythene strips was accomplished in the field using a pressure sensitive adhesive. Because of the nature of the adhesive and the inadequacy of the sealing techniques employed considerable seepage losses were experienced, and the project proved unsuitable for evaporation suppression experiments. It did, however, provide a reasonable measure of seepage control where none had existed before, and the buried liner material is today in a reasonably satisfactory condition.

The difficulties of sealing the narrow widths of polythene available in Australia discouraged further experiment until 1957. In that year a continuous factory heat-weld process was developed by Plastalon Ltd., of Melbourne, and the prefabrication of large liners became possible.

In 1957 a small excavated tank in an orchard at Red Hill, Victoria, was lined with 4 mil polythene prefabricated by the Plastalon process (Anon: ICIANZ Circle, 1957). The liner was not buried, principally because the side slopes of the tank were far too steep to support a soil cover. Initial performance indicated that a high degree of seepage control had been achieved. At an early stage, however, wind damage occurred and the liner was later abondoned.

A major project some months later was the lining of a large reservoir at Ouyen, Victoria, again in conjunction with evaporation suppression experiments conducted by C.S.I.R.O. This reservoir, a specially constructed tank 600 feet long, 80 feet wide and 10 feet deep, was lined with a 4 mil black polythene membrane prefabricated by the Plastalon process in two pieces which were later heat-welded in the field (Anon: Australasian Irrigator, 1957). The membrane was not buried. Early seepage measurements conducted by the C.S.I.R.O. officers indicated that a very high degree of seepage control had been achieved. Wind damage soon occurred, however, and a year after the installation of the liner it was observed by the writer to be extensively torn and holed above the waterline as a result of wind action.

The first plastic liner in N.S.W. was installed in a small circular reservoir at North Richmond in July 1958. This again was a black polythene liner, heat welded in one piece by the Plastalon process (Anon: Pix, 1958). The sealing operation was filmed by the writer, and detailed measurements of seepage and observations of liner deterioration were made by the University of New South Wales. Faulty sealing around an outlet pipe led to heavy seepage losses in this liner, and high winds produced rapid deterioration of the material. Four months after its installation the membrane was completely destroyed by high winds.

Several other tanks were reportedly lined during 1958-59 but details of these have not been published. The spectacular failure of the North Richmond tank has effectively deterred any further large scale development of polythene dam liners.

The performance of some Australian liners, and a review of the research being conducted at the University of New South Wales, were discussed by the writer early in 1960 (Burton: 1960)

This report pointed out that the major factor causing deterioration of plastic liners in Australia had been wind damage, and suggested ways in which this form of damage might be controlled. It was also pointed out that the high cost of polythene in Australia made this method of seepage control uneconomical as compared with the other methods available, such as soil stabilisation. A major factor in the cost of polythene membranes was the extensive sealing necessary on the 6 foot wide strips then available, and it was suggested that if manufacturers could reduce overall costs and produce a much wider material then polythene might compare favourably with other seepage control techniques.

In 1958 (Coulls, 1958) a section of PVC liner was installed in an irrigation canal in Victoria. Early reports indicated that the performance of this liner was satisfactory. This is the first and only known PVC dam or channel liner in Australia.

No other technical data on plastic dam or channel liners have been reported in Australia. A series of research reports outlining progress at the University of New South Wales are being published concurrently with this paper. Details of these reports are as follows -

Properties of plastic film for data lining - Report No. 53.

Field studies of plastic dam liners - Report No. 54.

Laboratory studies on plastic dam liners - Report No. 55.

Design and installation of plastic dam liners - Report No. 56.

Reports of plastic liner installations in other parts of the British Commonwealth have been received; these include Great Britain (Brown , 1955), Canada (Lauritzen er al, 1956; Irwin, 1957), New Zealand and India. Brief details of the installation procedures only have been given, and information about the performance of these liners is not available.

2. 3. Recent Developments.

Since 1957 little detailed information on plastic liner research has been published.

Irwin (1957) reported some plastic liner installations in Canade which used PVC membranes. His technical data are based on the earlier work of Lauritzen et al (1956).

Hickey (1957) reported an investigation conducted by the U.S. Bureau of Reclamation to determine the feasibility of using plastic materials for dam lining. Films tested included polythene and PVC, together with a cellulose acetate butyrate and a variety of laminated plastic materials.

Burying tests in moist soil over a period of 10 years indicated that the straight plastics, particularly PE and PVC , were extremely resistant to biological attack, whilst materials which incorporated fibres in a plastic limanate deteriorated rapidly. Some limited outdoor exposure testing again indicated the suitability of PE and PVC. Other tests included pressure cell tests to determine the resistance of the films to puncturing and high hydrostatic pressures, and some limited trial linings. It was concluded that PE and PVC, in gauges of 8 mil and heavier, were suitable for use as buried liners.

Corry and Scott (1958) made a further report on the canal liner experiments at the University of California, Davis. In particular, they discussed experiences with field applications of $1\frac{1}{2}$, 4 and 8 mil black polythene ditch liners.

It was reported that all gauges of film tested suffered a great deal of mechanical damage from animals and humans, and that the lightest material was penetrated by some grasses. There were no direct reports of wind damage, but billowing of the light gauge material was mentioned and it was stated that installation was impossible in winds of 15 m.p.h. or more. In general, except for the $1\frac{1}{2}$ mil material, good seepage control was achieved and a life of three seasons was obtained. The improved hydraulic characteristics of the lined ditch sections allowed a reduction in cross-section and an increase in bed slope.

Anderson (1960) reported on advanced liner installations in Utah which employed buried PVC membranes. These liners were installed in the balancing reservoirs on an irrigation system; they were carefully engineered and constructed and were not typical of farm dams or ponds. The liners were prefabricated from an 8 mil PVC using a lapped solvent weld, the three or four prefabricated sections used in each reservoir being jointed in the field with solvent seams. The reservoirs had a side batter of 3 to 1 and where necessary a sand cushion was employed. After installation and careful stretching to remove wrinkles the liners were covered with a fine sand-clay mixture, dumped from cranes with concrete buckets and with the maximum drop restricted to 1 foot.

Finally a 6 inch layer of cobble rip-rap was placed in the same manner. Excellent performance was reported, and when the writer visited one of these installations in 1961 it appeared to be in first-class condition.

It might be noted that PVC was used on these projects in preference to polythene because of its greater resistance to mechanical damage during the covering operation. At the time of installation (1959) polythene film was somewhat cheaper than PVC; the quoted cost of the liner in place was 47.5 cents per square yard. The fact that the PVC film was obtainable in 60 foot widths greatly reduced the amount of fabrication necessary.

Lauritzen (1961) also reported on these Utah installations and discussed the general techniques of liner design and installation for similar storage reservoirs. He recommended the use of either PVC or polythene in gauges of 8 mil with sand and gravel cover. In the same paper he suggested some other uses of polythene, such as the lining of leaking concrete service reservoirs and the storing of stock water in large plastic bags to eliminate both seepage and evaporation losses.

Edminster and staff (1961) in a recent report on the general application of plastics in agricultural engineering infer that plastic dam liners have been used extensively in the United States. It is known, from personal communication with Dr. Lauritzen and Dr. Scott and travelling in the western United States, that small polythene lined ponds are in everyday use in Utah and California. Edminster and Staff suggest that there are yet many problems to be overcome, particularly as regards the life of the plastic materials and the relative economy of this form of seepage control. Corry and Scott (1958) have given a semi-arbitrary basis for determining the economic feasibility of a plastic ditch liner.

Some interesting applications of polythene liners have been made in Southern California by the University of California and Mr. Paul Ames, an Indio consultant. Ames uses 6 mil black PE in the form of a partly exposed liner with the seams buried, the seal being made with a pressure-sensitive adhesive tape and wide (60 feet) stock being used. Good performance is claimed for these liners.

Dr. Haws of Utah State University has informed the writer that the research programme at that University is essentially completed, and that PVC is generally recommended because of its flexibility, ease of sealing and resistance to mechanical damage. Utah farmers, on the other hand, prefer to use polythene, because of its lower cost. It is generally used in small tanks where a single width of film can be used and sealing is not necessary.

In general it might be stated that plastic membranes are more likely to be used in the U. S. A. than in Australia because the materials are available in much wider sheets and at lower relative cost. (i. e., cost relative to alternative sealing methods and value of water saved). In addition there have been no published reports of serious wind damage on any U. S. liner installations.

2. 4 Properties of the Membrane Materials

When the University of New South Wales research programme commenced in 1957 only two likely plastic films were commercially available in Australia; these were polyehelene and polyvinyl chloride. At that time successful outdoor vinyl formulations were still experimental and it was considered that the available vinyls would be unsuitable, because of possible plasticiser leaching. At the outset, therefore, the research programme was concerned almost entirely with polythene film. Field problems with polythene, notably the possibilities of wind damage in relatively stiff, exposed polythene liners and the difficulties of burying polythene without puncturing the membrane, together with the development of Australian-made outdoor vinyls, have now brought PVC into consideration.

A summary of many papers concerned with the properties of plastic films, and particularly with polythene, is given in Section B of Part 2 to this report. It has been impossible, with the limited resources available, to make any attempt at a comprehensive survey of the vast literature on plastics.

Excellent introductions to plastics technology for engineers have been written by Adams (1956), Cousens and Yarsley (1956), Dumond (1955), Kinney (1957) and Simonds et al (1955).

The most comprehensive reference on polythene has been written by Raff and Allison (1956). This text discusses most of the problems of strength, mechanical properties and deterioration involved in plastic dam liner research and include over 1100 useful references.

A major problem with polythene liners is the expected durability of the material. The oxidative ageing of polythene has been discussed by Biggs and Hawkins (1953). Outdoor exposure tests incorporating carbon black to inhibit ultra-violet oxidation have been reported by I. C. I. (1949, 1952). Outdoor exposure tests on a variety of plastics have been reported by Yustein et al (1951, 1954). Many attempts have been made to develop accelerated weathering testing devices; one such apparatus has been developed by Wallder et al (1950). Other investigators, notably Reinhart (1952, 1956, 1958), have maintained that accelerated exposure tests have little value in assessing the possible life of plastic materials.

The mechanical properties of plastics have been discussed in detail by Kinney (1957), Simonds (1955) and others. Of particular interest in exposed dam liners is the high-temperature stress-strain behaviour of polythene. An introduction to this topic is given by Raff and Allison.

The resistance of plastic membranes to attack by micro-organisms, insects and rodents is of considerable importance in field applications. Hueck (1960) has given an excellent review of this topic.

3. RESEARCH PROBLEMS

A survey of available literature provides a basis for further research. From the foregoing pages, the following topics appear to merit investigation. Progress at the University of New South Wales under these topics is reported in the subsequent reports in this series.

3.1 Plastic Materials.

a. What materials other than PE and PVC might be suitable?
b. What is the true expected life of PE and PVC?
c. How do the properties of membrane materials alter with time, particularly in a farm dam environment?

3.2 Fabrication and Handling.

a. Is field sealing or prefabrication to be preferred?
b. What simplified and cheaper sealing methods are available or can be developed?
c. Is tight sealing really necessary?
d. How can cover materials be applied without damaging the membrane material?
e. Which cover materials are most suitable?
f. What are the steepest slopes on which cover materials will remain stable under the action of waves or heavy rainfall?

3.3 Weathering and Durability

a. What is the life of exposed polythene under Australian conditions?
b. What is the life of PVC under Australian conditions?
c. How can wind damage be controlled on exposed liners?
d. Apart from ultra-violet oxidation, how does the high temperature induced by strong sunlight on black plastic materials affect the strength and durability of the materials?
e. How can attack by birds and rodents by controlled?
f. How can attack by yabbies and termites be controlled?
g. How can plant penetration be controlled?

SEEPAGE CONTROL WITH PLASTIC MEMBRANES - A LITERATURE SURVEY AND ANNOTATED BIBLIOGRAPHY.

PART 2.

AN ANNOTATED BIBLIOGRAPHY ON THE CONTROL OF SEEPAGE WITH PLASTIC MEMBRANES.

This bibliography is divided into four sections, as follows:-

Section A: Dam and canal liner applications of plastic film.

Section B: Properties of plastic films.

Section C: Standard specifications and testing procedures.

Section D: Measurement of seepage losses.

SECTION A: DAM AND CANAL LINER APPLICATIONS OF PLASTIC FILM

A. 1 Anon.

Bigger cut in water losses likely.
Stock and Land. October 30, 1957.

Newspaper article describing liner installation at Ouyen, Vic.

A. 2 Anon.

Canal linings and methods of reducing costs.
U.S. Bureau of Reclamation. Pamphlet, 69 pp. 1951.

Discusses techniques developed during Bureau's lower cost canal lining programme. Brief mention of plastic liners, no data or references.

A. 3 Anon.

Film on the farm.
Modern Plastics, 34, 1; September, 1956. p. 112.

Discusses current research in agricultural uses of polythene and PVC. Includes such applications as mulches, silage covers, greenhouses. Brief mention of canal and dam liner applications, refers to work at Clemson and Utah State. No specific data.

A. 4 Anon.

Huge plastic parpaulin lines pond to prevent water seepage.
Popular Mechanics; November, 1956, p. 170.

Brief item, illustrated, about pond sealing at Clemson College, Clemson, S.C. Area of pond ½ acre. Heat sealed vinyl membrane used.

A. 5 Anon.

Plastic dam lining tests at Ouyen, Victoria.
Australasian Irrigator, December, 1957. pp. 13-14.

Describes installation of 4 mil polythene liner at Ouyen, Victoria, in November, 1957. Prefabricated heat-sealed liner, made in two sections heat sealed in the field. Exposed liner with 3" sand cushion. Liner dimensions 650' x 120' for tank 600' x 80' x 10' deep. Tank to be used by C.S.I.R.O. for evaporation suppression experiments.

A. 6 Anon.

Plastic pond liners.
Gering Plastics, New Jersey. Bulletin No. GP-30.

Illustrated brochure describing polythene lining operation in S. California. Field seal with pressure-sensitive tape employed.

A. 7 Anon.

Polythene film improves on nature.
Plastics Sphere, 5, 4:1956. pp. 14-15.

Gives details, with illustrations, of the sealing of the dam at Charlton, Victoria, in 1955. 8 mil black polythene liner, on sand cushion, buried, sealed in the field with adhesive.

A. 8 Anon.

"Visqueen" enters battle of water vs. sun.
ICIANZ Circle. November 15, 1957.

Brief newspaper article describing sealing of Ouyen and Red Hill tanks in Victoria. Illustrated.

A. 9 Anon.

"Visqueen" film for temporary water storage.
British Visqueen Limited. Typed report. December 1956.

Describes in detail the procedures adopted in making the first polythene liner installations in England in 1955.

A. 10 Anon.

"What is it?"
Pix Magazine, August 16, 1958.

Pictorial report on lining of Horrex dam at North Richmond, New South Wales. Text ludicrously inaccurate, but excellent photographs of lining operation.

A. 11 Anderson, J. R.

Vinyl film liner for earth-fill reservoirs.
Civil Engineering; 30, 6; June 1960.

A. 11 (cont'd.)

Describes lining of three irrigation equalisation storage reservoirs in Utah with 8 mil vinyl film in 1959.

All reservoirs had interior batters of 3 to 1 with 2 inch sand cushion provided where necessary. Membrane material was 8 mil black vinyl. This available at time of installation in 61 foot wide strips; prefabricated by Union Carbide using solvent lap sealing into large sections. Largest reservoir used four such sections approximately 300 feet by 60 feet. Field seals made with solvent using 6 inch lap joint.

Sections accordion-folded and installed by men wearing gloves. Film was stretched to avoid wrinkling. Fine cover of sand with clay binder applied in 6 inch layer using concrete buckets and cranes, max. drop distance 1 foot. Fine cover then hand raked and levelled. Protective rip rap comprising 6 inch layer of 3/4 inch to 3 inch cobbles then placed in same manner. Cost of liner in place reported as 47.5 cents per square yard (1959).

Early performance indicated no seepage loss. 25 year life anticipated.

(Note: The largest of these installations was observed by Mr. Burton in September 1961. It was in excellent condition).

A. 12 Burton, J. R.

Polythene membrane as a dam liner.
Australasian Irrigator, <u>3</u>, 3; February 1958

Briefly outlines plastic membrane research programme at University of New South Wales.

A. 13 Burton, J. R.

Sealing farm dams with polythene.
Power Farming, March 1960.

Describes Australian research in plastic membrane seepage control. Discusses wind damage in some detail and makes economic comparison with other sealing methods used in Australia.

A. 14 Corry, J. A. and Scott, V. H.

Plastic film for lining irrigation ditches.
Internal report, University of California, Davis. 1958.

Reports on University of California's research programme in use of plastic ditch liners; specifically, refers to experiences with $1\frac{1}{2}$, 4 and 8 mil black polythene. Discusses seepage reduction measurements, vegetation control, water control (use of smaller cross-section), installation and handling, and mechanical and animal damage.

Three seasons use obtained with 4 and 8 mil material. Some penetration of lighter materials by nutgrass. Much animal and human damage in some cases. Cost benefit analyses made for each installation and a simple basis for establishing economic feasibility of a liner put forward.

A. 15 Coulls, B. H.

Australia's first plastic channel lining.
Australasian Irrigator, November 1958, pp. 17-18.

Describes installation of 4 mil PVC channel liner at Donald, Victoria, in February, 1958. Heat welded fabrication, 6" prepared soil bed, 12" soil cover spread with blade mounted on tractor and smoothed by hand. Reported in good condition after 6 months.

A. 16 Edminster, T. W. and Staff, C. E.

Plastics in soil and water conservation.
Agric. Engineering, 42, 4, 5; April, May 1961.

General paper describing experiences with such applications as pipes, irrigation tubing, mole liners, rice levees, irrigation borders, dams and siphons, canal and pond liners, watershed covers, mulches. No specific data. Some useful suggestions re liner application. Some references.

A. 17 Hickey, M. E.

Evaluation of plastic films as canal lining materials - interim report.
U. S. Bureau of Recalmation, Division of Engineering Laboratories: Laboratory Report No. B-25, July 1957.

Discusses interim results of tests to determine suitability of various plastic films for canal lining. Films tested included polythene, polyvinyl chloride, cellulose acetate butyrate, and a variety of plastic-coated fibres and glasses.

Tests included 10 year burying tests to check biological deterioration, pressure cell tests, outdoor exposure tests and limited trial canal linings. Interim conclusions are that polythene and PVC films suitable as buried liners in gauges of 8 mil or heavier.

A. 18 Holtan, H. N.

Holding water in farm ponds.
U.S.D.A. S.C.S. TP 93 (1950).

Summary of another paper in Agric. Engr. (March 1950). No mention of plastic liners.

A. 19 Holtan, H. N.

Sealing farm ponds.
Agric. Engrg. 31, 3 (March 1950) p. 125.

Excellent paper about pond sealing with bentonites and compacted clays. No mention of plastic materials.

A. 20 Irwin, R. W.

Plastic liners for water storage reservoirs.
Mun. Utilities Magazine; 95, 9 (Sept. 1957)

Canadian paper. Plastic films have been used as lining materials in large excavated reservoirs for agricultural use; properly formulated and pigmented films have good resistance to weathering, and several years durability can be expected; in Alberta and Saskatchewan storage reservoirs have been lined with polythene film.

A. 21 Lauritzen, C. W., Haws, F. W. and Humpherys, A. S.

Plastic film for controlling seepage losses in farm reservoirs.
Bulletin 391, Utah State Agricultural College; July 1956.

Research publication outlining results of two years field and laboratory testing of polythene, vinyl and other plastic films. Tests included lining of field ponds and farm reservoirs, and measurements of biological deterioration, weathering, root and sprout penetration, rupture under hydrostatic heads, mechanical damage, cushioning effect of water, stable slopes for cover material, seepage from lined reservoirs.

Test results might be summarised as follows:

Rot tests - PE and PVC highly resistant to rotting in moist soil.

Exposure - Black PE showed no deterioration after two years, but clear PE and all PVC deteriorated rapidly.

Root and sprout penetration - generally resistant; some penetration of PVC by quackgrass.

Rupture - all films withstood heads up to 30 p. s. i. on gravel base.

Mechanical damage - tests involved dumping sand and gravel on materials from various heights. PE found much more susceptible to damage than PVC, required 3" sand cushion both over and under film. Some tests dropping cover through water; one foot depth water effectively protected all films; recommendation that ponds be filled before cover applied.

Slope stability - Tests carried out in still water. Maximum slope at which sand stable on PE was 2 3/ 4:1, on PVC was $2\frac{1}{2}$:1.

Test ponds - 8 small test ponds 40' x 40' and 5' deep were lined with various materials, 4 buried, 4 exposed liners. Floors raked, 3" sand cushions. Seepage measurements indicated very low losses. 4 mil PE gave poorest results, developed many small holes and breaks.

Farm dam liners - 3 field liners installed in farm dams at Emery, Utah, Outlook, Canada and Vauxhall, Canada. All buried liners; Emery 8 mil PVC and Canadian dams 8 mil PE. Seepage measurements not completed, indication that losses very low. Some troubles on PE liners with weak seams and tendency to fail along folds in material.

Authors recommend use of PE, because of high outdoor durability, as a buried membrane; stress need for extreme care in installation, propose further research on this subject. Implication is that PVC would be a better material if outdoor durability could be improved, because of its resistance to mechanical damage and ease of fabrication.

A. 22 Lauritzen, C. W.

Ways to control losses from seepage.
"Water", U.S. Dept. Agriculture Yrbk., 1955; pp. 311-320.

General semi-technical discussion of problems of seepage in canals and reservoirs. Outlines factors influencing seepage losses, discusses methods of seepage measurement. Describes seepage control techniques, including earth linings, concrete linings, asphaltic linings and buried membranes, bentonite, plastic films and butyl rubber.

No specific data on plastics applications.

A. 23 Lauritzen, C. W.

Plastic films for water storage.
American Water Works Assocn. Journal. 53:2 (Feb. 1961) pp. 135-140.

Discusses use of polythene and PVC membranes for canal and reservoir linings.

Polythene apparently considered superior because of lower cost (in U.S.A.) and appreciably better weathering characteristics.

Claims that exposed polythene reservoir liners are satisfactory if reservoir fenced and kept at least partly full. Vinyl on the other hand reported to deteriorate in the region above water level after 2-3 years and covering considered necessary.

3:1 batters considered necessary to prevent sliding of cover material. Berms recommended in deep reservoirs. Sub-grade should be sterilised. If it contains coarse material or sharp stones, use of fine cushion material recommended, particularly with polythene. Cover should be 6 inches fine material followed by 6 inches gravel. 8 mil gauge recommended for both plastics.

Brief description given of four reservoirs in N. Utah lined with 8 mil vinyl. These linings reported to have been in satisfactory operation for 6 years.

Other suggested uses include lining of leaky concrete service reservoirs and use of large plastic bag lining which controls both seepage and evaporation losses.

A. 24 Scott, V. H.

Prefabricated Linings for irrigation ditches.
Agric. Engrg. 37, 2; Feb. 1956. p. 113.

Results of 2 years field and laboratory testing with prefabricated liners for small irrigation ditches. Materials tested included various asphalt-impregnated fibres and paper laminates, also plastic films. Some buried films, some exposed: all plastic membranes were exposed. Plastics used were black PE and both clear and white PVC.

PVC broke down rapidly; black PE was in satisfactory condition after 2 years. However, some holing in PE, and satisfactory sealing of the holes not achieved.

General conclusion that exposed liners gave better all-round performance and economy. Note, however, that the buried liners were all asphaltic, so that no direct comparison between plastic liners in exposed and covered situations was possible.

SECTION B: PROPERTIES OF PLASTIC FILMS

B. 1 Adams, C. H.

Plastics - engineering materials.
A. S. C. E. Proc. Sep. 1072: October 1956
also in Modern Plastics 33; July 1956. p. 127.

Discusses use of plastics as engineering materials, comparing properties with those of steel and wood. No specific matter on films or weathering, but material on strength, creep etc. of some interest in membrane applications.

B. 2 Aggarwal, S. L. and Sweeting, O. J.

Polyethelene: preparation, structure and properties.
Chemical Reviews, 57, 4; Aug. 1957.

Extensive review of currently available knowledge on polythene.

B. 3 Anon.

"Alkathene" brand of polythene.
Imperial Chemical Industries Ltd., 1954. 59 pp.

Discusses in some detail the properties, manufacture and use of polythene. Includes chapters on history and discovery, chemical, mechanical, electrical and thermal properties, oxidation of polythene, ranges of "Alkathene" available, and techniques for handling and using the material in its various forms. Useful references.

Contains data on tensile strength behaviour and stress/ strain curves for material at various temperatures.

B. 4 Anon.

Black polythene for weather resistance.
Modern Plastics; 34; June 1957. p. 302.
(Abstract only)

Briefly describes new DuPont polythene film, "Alathon 5F", a black formulation designed specifically for arduous outdoor conditions.

The material being used as the black surface in solar stills. Claimed that life expectancy in most climates is 2 to 4 years.

B.5 Anon.
Description and comparison of some plastic films. Moulded Products (A'asia) Ltd., Technical Service Bulletin No. 13 (Issued approx. 1957).

Compares properties of the more important packaging films available in 1957. Most suitable for water conservation use appear to be polythene, PVC, pliofilm, polyvinylidene chloride (Saran - not available in Australia). Major properties tabulated for comparison purposes.

B.6 Anon.
Further notes on the weathering of "Alkathene". I.C.I. Ltd., Plastics Division; Technical Note No. I.S. 311. June 1952.

Further results of exposure tests conducted in England and India. Tests confirm that at least 2 pc. carbon black required. 3 years satisfactory life recorded in India.

Also indicates that in hot countries temperature of exposed black PE may reach 70 deg. C. at which temperature thermal oxidation may be serious. Addition of 0.2 pc. "Nonoxol" A.W. required to inhibit this.

Paper then discusses methods for incorporating carbon black in polythene.

B.7 Anon.
Longer life for polythene.
Chem. and Engrg. News; Sept. 16, 1957.

Describes anti-oxidants developed by Bell Telephone Laboratories to give black polythene greater outdoor stability.

B.8 Anon.
New jobs for sprayed-on plastics.
Modern Plastics, 31, 2; Oct. 1953.

Reviews developments in spraying of plastics. Vinyls most advanced. Technique employs emulsion of vinyl resin combined with volatile solvents. When sprayed with ordinary spray gun solvents evaporate leaving tough, durable covering. For large openings or gaps a webbing agent used.

Have been used for sealing walls, roof etc: reported in good condition after 10 years. Some cost data.

B.9 Anon.
"Nyathene" film and lay-flat tubing. Moulded Products (A'asia) Ltd.; Technical Service Bulletin No. 3, March 1955.

Briefly summarises physical and chemical properties of polythene film ("Nyathene" is registered name used by Moulded Products for polythene materials).

B. 10 Anon.

Outdoor exposure comparison between black polythene film and vinyl film.
Gering Plastics; Tech. Data Bulletin TD-4.

Brief note re outdoor exposure on adjacent film specimens in S. California. After 4 years PE intact, PVC badly deteriorated.

B. 11 Anon.

Properties and chemical resistance of polythene.
Moulded Products (A'asia) Ltd;
Technical Service Bulletin No. 4 (issued 1956).

Summarises, with test values, data on mechanical, electrical, thermal and chemical properties of polythene.

B. 12 Anon.

The weathering of "Alkathene".
I. C. I. Ltd., Plastics Division; I. S. No. 204, Aug. 1949.

Presents results of 4 years testing of "Alkathene" (I. C. I. trade name for polythene products). Discusses in some detail the mechanism of UV oxidation, and gives preliminary results of short-term (England 3 years, India 1 year) exposure tests with various pigmentations. Available evidence shows carbon black to be an effective inhibitor of UV breakdown. At least 2 pc. well dispersed carbon black of average particle size less than 25 millimicrons required.

B. 13 Anon.

Polyethelene grabs the spotlight.
Modern Plastics: 33, 1; Sept. 1955 and 33, 2; Oct. 1955.

Describes use of low pressure polythene and reviews growth of polythene industry. Some mention of application of polythene film as an irrigation ditch liner.

Suggestion that low pressure film may be usable in thinner gauges than high pressure material in lining applications.

B. 14 Biggs, B. S. and Hawkins, W. L.

Oxidative ageing of polyethelene.
Modern Plastics: 31, 1; Sept. 1953.

Discussion of photo-oxidation process which takes place when polythene exposed to light. Describes control obtained by use of pigments, particularly carbon black.

Suggests that outdoor exposure racks only effects way to determine film life, but recommends carbon arc accelerated weathering machine (vide Wallder et al, 1950) for evaluation of pigments and inhibitors.

B.15 Couzens, E.G. and Yarsley, V.E.

"Plastics in the Service of Man"
Pelican Books; No. A. 272. 1956.

Deals with chemistry, manufacture, properties and applications of all the major plastics. Good introductory reference.

B.16 Dietz, D.H.G.

Plastics - new and promising building materials.
Civil Engineering: 26, 3; March 1956. p. 44.

Deals with possibilities of plastics as building materials, principally for structural applications. No reference to seepage control.

Some discussion of weathering. Suggests that pigmented vinyls may have a life of 10 - 15 years.

B.17 Dumond, T.C. (ed.)

"Engineering Materials Manual"
Reinhold Publishing Co., New York.
p. 241 - Plastics Primer for Engineers.

Excellent introduction to plastics.

B.18 Gouza, J.J. and Bartoe, W.F.

Weathering of plastics.
Modern Plastics; 33; May 1956. p. 157

Discusses a procedure for studying deterioration and creep deformation of plastics subject to stress during outdoor exposure. Data cited to show possible failure of laboratory simulated laboratory tests to predict outdoor service characteristics.

Concerned only with rigid transparent plastics subject to constant loading, but of some application to stressed and heated exposed membranes. Good reference list on weathering.

B. 19 Henderson, W. F.

Polyethelene.
Canadian Chemical Processing, March 1954.

Summarises general properties of polyethelene film. Some mention of ditch liner applications.

B. 20 Kinney, G. F.

"Engineering properties and applications of plastics".
Wiley, N. York. 1957.

Modern discussion of plastics from engineering viewpoint, with particular reference to engineering properties.

B. 21 Kresser, T. O. J.

"Polyethelene"
Reinhold Publishing Corp., New York. 1957.

Concerned primarily with applications of polythene. Includes chapters on general properties, chemistry, manufacture and processing, application of films, castings, mouldings, pipe, etc.

No specific data on dam lining applications.

B. 22 Hueck, H. J.

Biological deterioration of plastics.
Plastics, October 1960. p. 419.

Discusses research undertaken to determine possibilities of attack on plastics by micro-organisms, insects and rodents.

PE and PVC generally resistant to microbiological deterioration. Plasticisers in PVC may, however, be attacked and for specific applications resistant plasticisers should be used.

Insects may attack many plastics, including PE and PVC. Many common species such as weevils, carpet beetles, cockroaches and termites may attack PE and PVC. Insecticides such as pyrethrum and DDT will protect material.

Rodents may also attack PE and PVC. Repellants such as CEFRO and TMTD show promise.

Note, that insects and rodents do not normally feed on these materials, but penetrate them in search for food or if they form a barrier.

A number of useful references included.

B. 23 Raff, R. A. V. and Allison, J. B.

"Polyethelene"
Interscience Publishers, New York.
Volume IX of "High Polymers" series. 551 pp. 1956.

Exhaustive technical text. Chapters on historical development, manufacture and polymerisation of ethylene, chemistry of polythene and modified polythenes, molecular structure, chemical, physical and other properties, analysis and testing, processing, handling and application of polythenes. Includes 1152 references.

Valuable data on physical and chemical properties, UV oxidation and weathering, testing procedures, welding, adhesives, etc. No specific data or references on dam lining applications.

B. 24 Reinhart, F. W.

Conditioning and weathering of adhesives and plastics.
A. S. T. M. Symposium on Plastics Testing - Present and Future; 1952;
Special Technical Publication No. 132.

First part of paper discusses conditioning procedures involved in standard plastic tests.

Latter part discusses accelerated weathering and service testing. Points out that accelerated weathering testing is in an unsatisfactory state, due to serious lack of correlation between accelerated tests and field behaviour of material on exposure. Discusses reasons for this and concludes that hopes of good correlation are extremely remote.

B. 25 Reinhart, F. W.

Degradation of plastics.
Soc. Plastics Engrs. News, 4, 3; Sept. 1958.

Discusses current accelerated weathering tests. Analyses weather variations in U.S. and shows how difficult to simulate these in laboratory. Discusses shortcomings of equipment currently in use. Suggests a new approach based on understanding of chemical processes involved in degradation. Implies that accelerated weathering tests of little or no value in assessing suitability of films for use as dam liners.

B. 26 Reinhart, F. W. and Mutchler, M. K.

Fluorescent sunlamps in laboratory ageing tests for plastics.
A. S. T. M. Bulletin No. 212; Feb. 1956. p. 45.

Discusses improved UV radiation source for accelerated weathering tests. Suggests gives better correlation with outdoor conditions than sunlamps in current use.

B. 27 Simonds, H. R., Weith, A. J. and Bigelow, M. H.

"Handbook of Plastics"
D. Van Nostrand Company, N. Jersey; 2nd Ed., 1955 (1511 pp.)

Comprehensive handbook on chemistry, properties, manufacture and application of plastics. No specific reference to seepage control applications.

B. 28 Slone, M. C. and Reinhart, F. W.

Properties of plastic films.
Modern Plastics: 31, 10; June 1954

Properties of 168 samples of commercially available (in U. S. A.) plastic films were tested. Included polythene and PVC. Useful comparison of materials, but data not specifically applicable to Australian-made materials.

B. 29 Thor, W. B. and Goldman, M.

Polyethelene as a food film.
Modern Packaging: 37, 9; May 1954.

Concerned mainly with thin transparent polythene films suitable for food packaging.

Gives useful data on effects of temperature on tensile strength, elongation, tear strength and puncture resistance.

Gives data on effects of ageing on tensile strength, tear strength and elongation.

B. 30 Wallder, Clarke, de Coste and Howard.

Weathering studies on polythene.
Ind. and Eng. Chem., 42, II; Nov. 1950. p. 230.

Discusses mechanism of U. V. oxidation and describes a carbon-arc accelerated weathering apparatus. Claims good correlation with outdoor tests, states that on basis of accelerated studies a life of 20 years is predicted for polythene.

B. 31 Yustein, S. E., Winans, R. R. and Stark, H. J.

Outdoor weather ageing of plastics under various climatological conditions.
A. S. T. M. Bulletin 173; April 1951. p. 31.

Describes outdoor weathering programme conducted by U. S. Navy and U. S. Army. Exposure stations located in Panama, New Mexico, New York, Canada, Alaska. A variety of materials tested; no polythene, but a vinyl copolymer (83 pc. vinyl chloride) included.

Some material of interest concerning exposure racks and proposed test criteria. No attempt made to correlate with accelerated tests.

B. 32 Yustein, S. E., Winans, R. R. and Stark, H. J.

Three years' outdoor weather ageing of plastics under various climatological conditions.
A. S. T. M. Bulletin 196; Feb. 1954. p. 29.

Follows a previous paper (A. S. T. M. Bulletin 173) in reporting three years of outdoor testing. General discussion, no numerical data presented.

Vinyl copolymer showed greatest deterioration at Panama and New Mexico (White Sands). Most marked changes in coloration; only small decrease in strength reported. Interesting discussion on environmental factors in weathering, suggesting that in some cases local environment exerts much greater influence than climate in causing deterioration.

Useful suggestions for further exposure programmes.

SECTION C: STANDARD SPECIFICATIONS AND TESTING PROCEDURES

C.1 A.S.T.M. Standards on Plastics, 1957.

American Society for Testing Materials, Feb. 1957.

Lengthy publication giving standard specifications and detailed testing procedures.

C.2 Australian Standard for Polyethelene Film.

Standards Association of Australia; A.S. No. K.120 - 1961.

Standard specification, including standard test procedures.

C.3 Australian Standard for PVC Film.

Standards Association of Australia; A.S. No. K.124-1961.

Standard specification, including Standard test procedures.

C.4 Methods of Testing Plastics

Standards Association of Australia. A.S. No. K.94 - 1960

Part 1 - 1960:- Effect of temperature
Part 2 - 1960:- Electrical properties
Part 3 - 1960:- Mechanical properties.

SECTION D: MEASUREMENT OF SEEPAGE LOSSES.

D. 1 Rasmussen, W. W., and Lauritzen, C. W.

Measuring seepage from irrigation canals.
Agric. Engrg. 34, 5; May 1953. p. 326

Discusses seepage measurement procedures, with particular reference to use of seepage meters.

D. 2 Robinson, A. R., and Rohwer, C.

Measurement of canal seepage.
Trans. A. S. C. E. 122; 1957. p. 342

Excellent discussion of relative merits of various methods of seepage measurement and factors affecting seepage losses.

D. 3 Rowher, C., and Van Pelt Stout, O.

Seepage losses from irrigation canals.
Colorado Ag. Expt. Sta. Tech. Bull. 38. March 1948.

Good discussion of factors affecting seepage and methods of seepage measurement.